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ELECTRICITY GENERATION FROM MSW LEACHATE USING MICROBIAL FUEL CELL

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Abstract: **Rapid increase in the world population and economic development has resulted in sudden rise in the quantities of municipal solid waste generated in most developing countries. Such wastes often get disposed unscientifically in landfills and sometimes in dump-yards, with the percolating water producing undesirable waste soup generally called leachate. This leachate has several adverse impacts on environment and human health, and needs to be carefully managed and disposed. A potent use of this waste leachate is to employ it as a substrate in a microbial fuel cell. In the present work, a dual chambered microbial fuel cell was fabricated and its potential for electricity generation was explored under varying environmental conditions. The fuel cell comprised two chambers, one each for leachate and for salt solution. The environmental conditions were varied by varying either the salt concentrations or by diluting the leachate (as per dilutions expected in rainy seasons), and the electricity generation was then determined under two conditions wherein external aeration of the salt solution was carried out in one case, and was not carried out in another case. 8% NaCl was found to be the best salt option both technically and economically, with typical organic leachate generating electricity to an extent of 180 mV per 2000 ml of the leachate. In view of the extra energy requirement the aeration of salt solution was not preferred, although aeration was observed to marginally (0.1-5%) increase power generation potential of the microbial cell. The generation of electricity through the microbial fuel cell route provides a potent opportunity to use an environmentally undesirable waste product as a resource by upscaling the laboratory technology in the real world.**

Keywords *– Leachate, Electricity generation, Dual Chambered Microbial Fuel Cell, Fuel Cell Performance.*

I INTRODUCTION

In line with the increasing urbanisation trends worldwide, most of the Indian population which is still rural is also witnessing an unprecedented shift of people to cities. The population is increasing at a very fast rate which has triggered many more problems one of them being the rising quantities of municipal solid waste (MSW). The disposal of MSW is a global concern, especially in developing countries across the world, as efficient management of wastes is prevented by poverty, population growth and high urbanization rates along with ineffectual and under-funded governments. Hence, landfilling is the simplest and cost-effective method of disposing of MSW in these nations. Waste placed in landfills is subjected to either groundwater underflow or infiltration from precipitation. This percolating liquid termed as 'leachate' (which is a mix of inorganic and organic compounds) accumulates at the bottom of the landfill, and can create various impacts on soil, groundwater, human health, ecology and environment (Nagarajan et al, 2012). One of the most important issues related to the management of MSW landfill is the management of leachate. Therefore, an effort was made to use leachate in an effective way.

The current work focused at arriving at the answers to the following questions:

- Is there a way to use the rather menacing municipal solid waste leachate as a resource of economic value?
- Is microbial fuel cell an answer to the usage of the leachate as a resource?
- How do the changes in environmental conditions / system parameters affect the electricity production

from the microbial fuel cell?

- What is the electricity generation potential of this microbial fuel cell with reference to the use of organic leachate from municipal solid waste ?

II CONVENTIONAL LEACHATE MANAGEMENT AND TREATMENT

Efficient leachate management is obligatory to eliminate the landfill's potential in polluting aquifers. Conventional leachate management techniques are:

Leachate Recycling

Recycling leachate into landfills is considered as an effective method for treating leachate. It is sprayed onto the working face or is injected through an interior piping system. Recycling of leachate helps in the attenuation of leachate constituents by biological activity and other physical or chemical reactions inside the landfill. It can also increase the rate of waste biodegradation and rate of gas production. Before disposal, the leachate residue is collected and treated. This process often requires large leachate storing facilities (Krishnadas, 2009).

Leachate Evaporation

It is the simplest of leachate management techniques. Leachate is discharged into lined ponds and is subjected to evaporation.

Onsite Treatment followed by Disposal

This method involves treatment in an on-site treatment facility. Depending on the leachate characteristics a variety of treatment technologies are used. The common leachate characteristics of concern include: TDS, COD, Sulfate (SO_4^{2-}), heavy metals and major other non-specific toxic constituents. Leachate with high COD is treated anaerobically, because aerobic treatment can get very expensive. On the other hand, leachate with high sulfate concentration cannot be treated with anaerobic methods due to the production of odour. Often, landfills will pre-treat the leachate for removing some major constituents that may cause issues at WWTP i.e. wastewater treatment plant (e.g. high COD and Nutrients). Pre-treatment mainly include aeration and addition of activated carbon (Krishnadas, 2009).

The various ways of leachate treatment range from Biological processes (e.g. Sequencing Batch Reactors (SBRs) (ARRPET, 2004)), Physical Treatment Processes (which include filtration, activated carbon adsorption, pressure-driven membrane filtration processes, evaporation and reverse osmosis etc.), to Chemical Treatment Processes such as precipitation, coagulation, oxidation, reduction, ion exchange, stripping, etc.

Besides, there also exist natural leachate treatment systems which are different from conventional systems based on the source of energy that predominates.

Discharge into a Municipal Wastewater Collection System

A pressure sewer may be used to connect the collection system of landfill leachate to a wastewater collection system, when the landfill is located near to a wastewater treatment service. In other cases, leachate is stored and transported by tanker trucks to a WWTP. In majority of the circumstances, pretreatment is required to trim down the organic loading (Jambeck and Damiano, 2010).

Other than these conventional methods, one of the state-of-the-art techniques that can be used to handle landfill leachate is to use it as a substrate in microbial fuel cell. So, in the present paper, the microbial fuel cell technique is used and electricity generation is emphasized. Also, changes are made in the system parameters and their effect on the voltage generation was studied.

III LEACHATE MANAGEMENT USING A MICROBIAL FUEL CELL

A Microbial Fuel Cell (MFC) is a device in which chemical energy is converted into electrical energy through the catalytic reaction of microorganisms (Mercer, 2014). Generally, an MFC consists of two compartments: anode and cathode, which are separated by a salt bridge or a cation specific membrane. The fuel (substrate) is oxidized by microorganisms in the anode compartment, generating protons, electrons and CO_2. The protons get transferred to the cathode compartment through the salt bridge or membrane, while the transfer of electrons to the cathode compartment takes place through an external electric circuit. In the cathode compartment, both are consumed combining with oxygen to form water (Mercer, 2014).

Advantages of a Microbial Fuel Cell

The various operational and functional advantages of MFCs are cited in literature as:

- Dependence on non-renewable energy sources gets reduced.
- Hard-to-treat wastes are biodegraded.
- An unused and potentially harmful waste has been used to develop a renewable, clean source of electricity. (Frew and Christy, 2006).
- Organic waste matter is used as fuels and readily available microbes are used as catalysts.
- Highly regulated distribution systems are not required.
- They have high conversion efficiency, in harvesting up to 90% of the electrons from the bacterial electron transport system (Nicholls, 1982).

Applications of a Microbial Fuel Cell

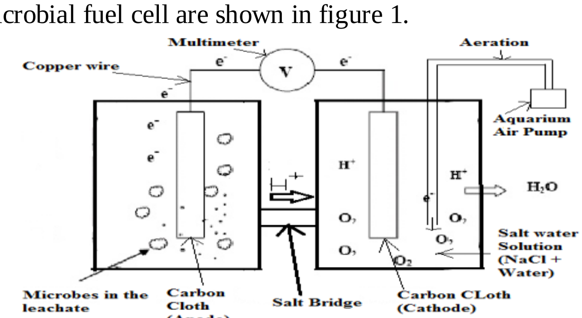
The most important use of MFC is obviously as a source of electricity in both, rural and urban sectors (Karmakar et al, 2010). MFCs can also power low power wireless systems. A study has been reported in which MFC was used to utilize the body glucose to power implanted medical devices. In the field of robotics also, there is a high usage of MFCs to maintain self-sustainable autonomous robots. MFCs produce lesser solid wastes and the generated electricity can be used for aerating the sludge, leading to formation of self-powered treatment facilities. Studies are also there on the production of bio-hydrogen at the cathode of MFCs. Also, there have been studies in which MFCs were used to produce sensors for detecting the pollutant level by measuring the voltage and if suitably modified, can be used for measuring BOD too via measurement of Columbic yields (Karmakar et al, 2010). MFCs also have potential uses in desalination, brewery and domestic wastewater treatment, hydrogen production, pollution remediation, remote sensing, and as a remote power source. Many new applications are beginning to be tested and may come into widespread use in the near future (Mercer, 2014).

Greater Hyderabad Municipal Corporation (GHMC), the urban local body which is responsible for providing civic services to the citizens of Hyderabad has modernized the existing municipal dumpsite under Public Private Partnership (PPP) with Ramky Enviro Engineers Ltd. At present, the landfill design capacity is 5500 TPD.

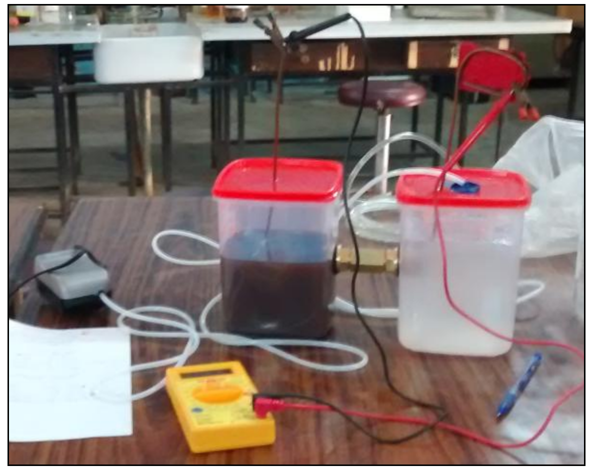
IV MATERIALS AND METHODS

Fabrication of dual chambered microbial fuel cell

MFC is a fuel cell which harnesses the naturally occurring electro-chemical processes of breaking down of food by anaerobic bacteria to generate electricity. The constructed MFC was of suspended growth type process. The source of bacteria and organic substance in the anode chamber of the cell is the leachate collected from Jawaharnagar landfill site, Hyderabad; while in the cathode chamber, an 8% salt water solution (NaCl + water) was used. The cathode chamber is aerated by an aquarium air pump. The electrodes are of carbon cloth. Copper wires are used to conduct electrons through the external circuit. The two chambers were connected by a salt bridge for the passage of positive ions. The line diagram and experimental set-up of the microbial fuel cell are shown in figure 1.



(a)

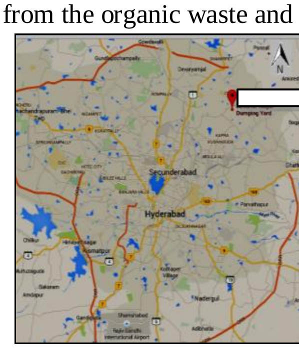


(b)

Figure 1 (a) Line diagram (b) Experimental set-up of microbial fuel cell

Source of Leachate

Fresh leachate samples were collected from the Jawaharnagar landfill site located in RangaReddy district, near Hyderabad, Telangana, India. The site is 35 km away from Hyderabad. The coordinates of selected site were +17° 30' 14.18", +78° 34' 4.94" respectively. At present, the site is spread over an area of approximately 350 acres, and receives about 4000 MT of waste from the city on a daily basis (Devi et al, 2014). The landfill site is having a proper leachate collection system, through which the leachate gets collected in tanks. Two types of leachate samples were collected, one from the organic waste and another from the inorganic waste.



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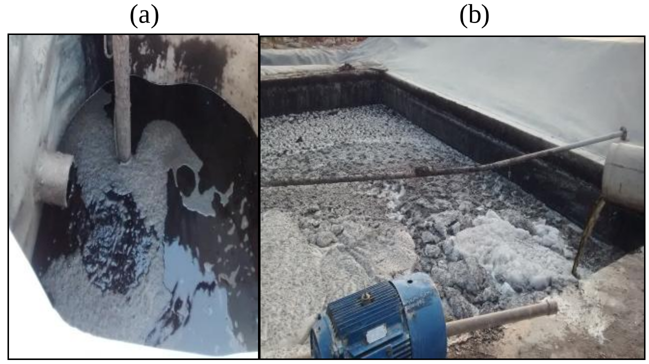

(c)

Figure 2 (a) Location (b) Landfill site view (c) Leachate collection tank, Jawaharnagar Landfill Site, Hyderabad (Source: Google Maps, 2015)

The leachate is collected in plastic bottles at the inlet point of the leachate tank at the landfill site and preserved in an ice box. The sample collection is carried out in February, 2015. The map showing general location of the site and the leachate collection tank is given in figure 2.

Physico-chemical analysis of leachate

Various tests were performed to determine the characteristics of leachate. All the tests were conducted as per "Standard Methods for the Examination of Water and Wastewater" published jointly by American Public Health Association, American Water Works Association and Water Environment Federation. The results of various tests conducted on the leachate sample in the laboratory are tabulated in table 1.

Table 1 Initial Leachate Characteristics

Parameter	Value	
	Organic Leachate	Inorganic Leachate
Acidity	27500 mg/l	10000 mg/l
Alkalinity	18000 mg/l	9000 mg/l
pH	5.42	8.53
Turbidity	16 NTU	73 NTU
BOD	32800 mg/l	15600 mg/l
COD	64000 mg/l	32000 mg/l

Variation of system parameters

The electricity generation potential of the microbial fuel cell was determined by varying the system parameters like time, salt solution concentration and leachate dilution.

V OBSERVATIONS, RESULTS AND DISCUSSIONS

The MSW leachate can serve as an economic resource. After proper treatment and processing, around 40-50% water can be produced. This water is clear, pure and can be used for drinking as well as in other applications. The MFC is a technique for the treatment of leachate and its advantages are two-fold. As electricity is generated during treatment, leachate serves as an economic resource when used in a microbial fuel cell. Fabrication of MFC is relatively cheap. Locally available raw materials can provide good options for manufacture. The maximum electricity generation potential of the fabricated MFC in the laboratory was found to be around 180 mV, though it varied with time and other parameters. The voltage generation varied with change in different cell parameters like time, leachate dilution, salt concentration and no. of weeks passed, and are explained in the text that follow.

Voltage variation with respect to time

The voltage readings per day are given in table 2. Figure 3 shows the variation in voltage generation with the passage of time. Initially, the voltage generation increases upto about three weeks, decreases sharply in the next one week and then decreases gradually afterwards.

Table 2 Daily Voltage Generation Readings

Date	Temperature (^0C)	Voltage Reading (mV)	
		Without Aeration	With Aeration
24/02/15	34	115	128.6
25/02/15	34	103.7	117.5
26/02/15	30	96.5	108.2
27/02/15	31	89.1	98.9
28/02/15	28	90.5	95.4
01/03/15	20	99.4	100.2
02/03/15	25	117.7	119.5
03/03/15	26	123.4	126.1
04/03/15	26	129.8	135.8
05/03/15	28	135.5	138.2
06/03/15	30	141.2	143.7
07/03/15	31	144.6	148.5
08/03/15	32	155.2	157.3
09/03/15	30	146.8	158.5
10/03/15	29	148	159
11/03/15	31	160.8	172.6
12/03/15	27	161.5	176.8
13/03/15	23	160.6	176.4
14/03/15	21	159.2	176.2
15/03/15	27	163.4	175.9
16/03/15	29	166.6	175.7
17/03/15	30	168	177.7
18/03/15	29	167	176.8
19/03/15	30	160	171.6
20/03/15	32	160.8	171.5
21/03/15	35	161.6	171.2
22/03/15	36	162	170.8
23/03/15	36	162.2	170
24/03/15	36	157.7	164.1
25/03/15	37	155.2	162.9
26/03/15	36	158.7	167
27/03/15	37	161.1	167.7
28/03/15	38	162.2	166.2
29/03/15	35	160.5	165.3
30/03/15	35	162.8	166.1
31/03/15	36	164.1	167.7
01/04/15	37	165.2	168.2
02/04/15	37	166.7	169.1
03/04/15	38	167.3	170.6
04/04/15	35	165.3	172.8
05/04/15	35	166.8	173.2
06/04/15	34	169	174.1
07/04/15	35	167.6	168.4
08/04/15	35	173.4	177.2
09/04/15	38	174.2	175.6
10/04/15	37	170.2	172.8

11/04/15	38	172.1	173.6
12/04/15	37	171.5	172.5
13/04/15	31	164	166.2
14/04/15	26	163	165
15/04/15	30	168.2	169
16/04/15	31	169.2	171.1
17/04/15	34	169.6	171.5
18/04/15	37	166.3	170.2
19/04/15	40	164.7	166.8
20/04/15	43	160.8	161.4
21/04/15	42	158.4	159.7
22/04/15	40	157.6	158.5
23/04/15	40	156.9	157.3
24/04/15	40	156.3	156.8

The reason for this variation is that initially, the microbes were trying to adapt to the surrounding conditions, hence less value of voltage generation is obtained. As soon as the microbes adapt to the surrounding conditions, the value of voltage generation increases. After some time (three weeks in the present case), when the food source for the microbes is finished, the value of voltage generation starts to decrease. If the voltage generation is to be increased again, the food source for the microbes is to be added in the anode chamber after three weeks in the present case.

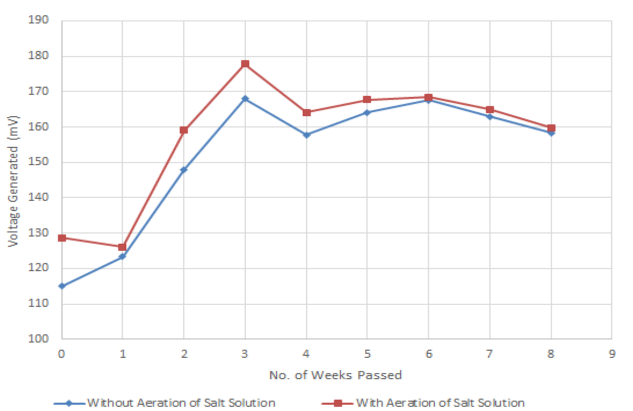

Figure 3 Graph showing the voltage generated vs time elapsed

When the daily voltage generation was recorded, the peak voltage generated was 179.2 mV with aeration and 173.4 mV without aeration, which was obtained at 44th day of recording. After that, the voltage generation started to decrease. Also, the voltage generation increases with the increase in temperature. The average voltage generated was 137.7 mV with aeration and 159.5 mV without aeration. Generally, in steady temperature condition, the leachate can produce good amount of electricity up to around 3 weeks, after which either it has to be inoculated, or changed.

Voltage variation with respect to leachate dilution

The voltage readings with respect to leachate dilution are given in table 3. The voltage readings were taken at every ten percent dilution of the leachate. The salt concentration in the solution in the cathode chamber was 8% at all the leachate dilutions.

Table 3 Voltage Readings at Different Leachate Dilutions

% Leachate Dilution	Voltage Reading (mV)	
	Without Aeration	With Aeration
100%	140.5	142.6
90%	139.6	141.3
80%	138.3	141
70%	136.8	139.9
60%	136.4	139.9
50%	129	131.8
40%	123	123.4
30%	121.6	121.8
20%	120.7	120.9
10%	119.3	119.8

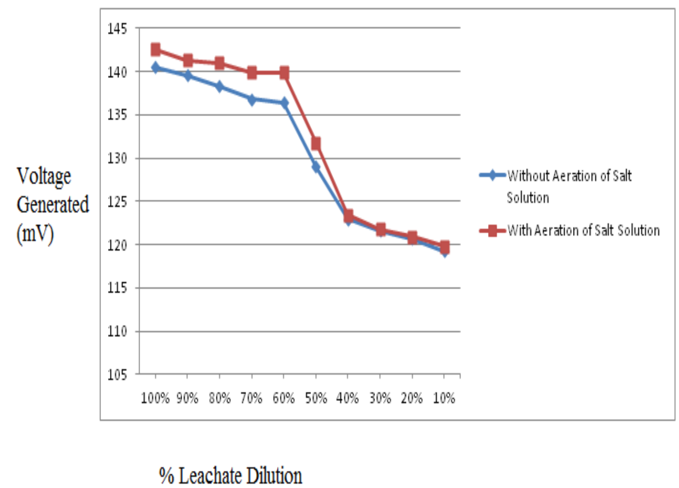

Figure 4 Graph showing the voltage generated vs % leachate dilution

Figure 4 shows the variation in voltage generation according to the percentage leachate dilution. As the figure shows, the peak voltage generated was 142.6 mV with aeration and 140.5 mV without aeration, which was obtained at 100% leachate dilution, at which point the microbial and organic content was maximum. The average voltage generation was 132.24 mV with aeration and 130.52 mV without aeration. The voltage generation decreases gradually from 100% to 60% dilution, then decreases sharply from 60% to 40% dilution and after 40% dilution, decreases gradually.

The reason for this variation in voltage generation is that when the leachate is diluted, the organic content as well as the microbial concentration gets decreased, which results in the decrease in the voltage generation. Therefore, for better electricity generation, leachate dilution should not be less than 60%.

Voltage variation with respect to salt solution concentration

The voltage readings with respect to salt solution concentration are given in table 4. The voltage readings were taken at every five percent change in salt concentration in the solution. The leachate dilution was 100% at all the salt concentrations.

Table 4 Voltage Readings at Different Salt Solution Concentrations

% Salt Solution	Voltage Reading (mV)	
	Without Aeration	**With Aeration**
5%	86.2	86.3
10%	98.3	99.4
15%	116.6	121.8
20%	135.5	136.3
25%	148	149.2
30%	157	159.4
35%	170	175.2

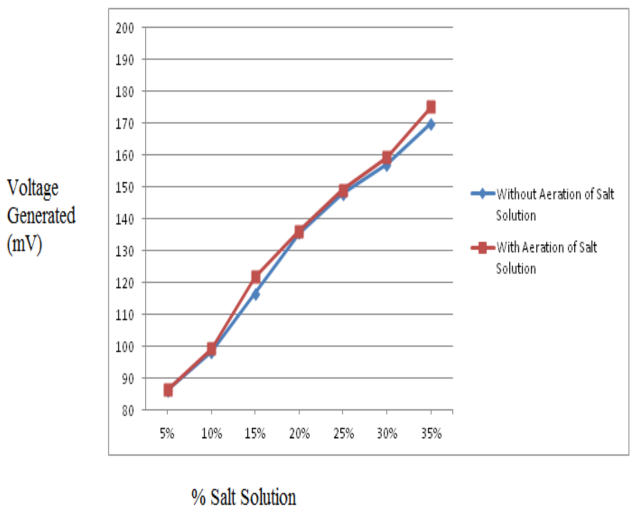

Figure 5 Graph showing the voltage generated vs % salt solution concentrations

Figure 5 shows the variation in voltage generation according to the percentage salt concentration in the solution in the cathode chamber. As the figure shows, the peak voltage generated was 175.2 mV with aeration and 170 mV without aeration, which was obtained at 35% salt solution concentration, which is the saturation point of salt dissolution. The average voltage generation was 132.5 mV with aeration and 130.2 mV without aeration. The voltage generation increases almost at a constant rate from 5% to 35% salt concentration.

The reason for this variation in voltage generation is that when the salt concentration is increased, the numbers of ions in the salt solution is also increased, thus facilitating the movement of the electrons and positive ions, due to which voltage generation is increased. Therefore, for better electricity generation, salt concentration should be as much as possible. But, the salt concentration cannot be increased more than 35% as this is the saturation point of the solution.

Final Leachate Properties

After the leachate is being utilized in the MFC, it was analyzed again to determine the physico-chemical properties. The results are presented in table 5.

Table 5 Final Leachate Characteristics

Parameter	Value	
	Organic Leachate	**Inorganic Leachate**
Acidity	7570 mg/l	900 mg/l
Alkalinity	25500 mg/l	15660 mg/l
pH	5.92	8.23
Turbidity	10 NTU	79 NTU
BOD	3590 mg/l	1290 mg/l
COD	6560 mg/l	1870 mg/l

The results showed that after the leachate was used in microbial fuel cell, there was a reduction in the organic content, which was due to the reactions taking place in the cell.

VI CONCLUSIONS

The work conducted can be summed up as the following:

- A working dual chambered microbial fuel cell was constructed from the locally available materials in the environmental engineering laboratory of MANIT, Bhopal.
- It was found that the organic leachate procured from the Jawaharnagar landfill site at Hyderabad, is able to produce electricity in microbial fuel cell whereas the inorganic leachate produced no electricity.
- It appears that if the organic content is less in the leachate, then it will tend to produce lesser or no electricity. Hence, in the present case, there was no electricity production when inorganic leachate was used. It may be noted that even the successive dilutions of organic leachate also produced lesser and lesser electricity.
- The maximum electricity generation potential of the organic leachate was about 180 mV when the salt solution (NaCl + Water) was aerated.
- The environmental conditions were varied and electricity generation potential was explored by varying NaCl concentrations and by diluting the leachate. The electricity generation was determined under two conditions wherein external aeration of the salt solution was carried out in one particular case. It was found that aerated solutions produced more electricity. But, when aeration is done, external

electric supply is required. So, in the overall study, it was found that aeration is not necessary for generating electricity in an MFC.

- The voltage generated was higher with greater NaCl concentrations, and when fully concentrated leachate was used.
- It was found that 8% NaCl was the best option both technically and economically.
- The total production of electricity from a typical dual cell MFC is 28.26 kV per 314 litre of leachate generated from municipal waste of around 5500 million tonnes per day.

It can be concluded that a dual chambered microbial fuel cell can prove to be a promising route to usage of obnoxious municipal solid waste leachate as a resource and can generate electricity that may be fed into a grid for sustainable economic benefits.

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