Chapter 8
Microbial Fuel Cell Research Using Animal Waste: A Feebly-Explored Area to Others

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8.1 Introduction

A fuel cell is an electrochemical cell that converts chemical energy from the fuel supplied to it into electricity, through an electrochemical reaction of hydrogen fuel with oxygen or another oxidizing agent. In contrast to batteries, fuel cells need a constant supply of fuel in order to continue the electrochemical reaction that generates electricity. Batteries produce electricity only from the chemicals already present in them while fuel cells can produce electricity continuously for as long as fuel and oxygen are supplied. Fuel cells are also similar to batteries in that they have an anode, a cathode and an electrolyte.

Many researchers in the field of biology and environmental technology have always demonstrated the potentiality of microbial fuel cell (MFC) technology. Annually, huge volumes of waste are produced from industries, animals and agricultural field. Microbial fuel cell has an ability to convert the waste food materials to energetic form. The MFCs fed with food waste (FWs) are affected by organic loading rate.

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Higher amounts of food waste are mainly produced from our own domestic and from commercial cookeries. Approximately 60 million loads of FWs are generated per year in China alone and have exceeded 1.0 thousand tons in Beijing and Shanghai of China (Yan et al. 2012). The 34 million tons of FWs that were generated in the USA in 2010 was reported by the US Environmental Protection Agency (EPA) of which only less than 3% were recycled. The rest of the obtained FWs were thrown away. These FWs are considered as one of the valuable resources and tend to process higher energy, corrosion and ubiquity. Therefore, the problem produced by these FWs has been a demanding field of research due to the awareness on environmental conservation and energy revival (Goud et al. 2011).

In current years, researchers simultaneously attain waste treatment and energy creation of anaerobic digestion of FWs (Zhang et al. 2012). Microbial fuel cell (MFC) is used as an important and promising technique for anaerobic waste treatment in which bacteria are used as a catalyst and the bacteria help in generating bioelectricity from organic wastes (Min et al. 2005). The open access energies also innovated that bacteria has an ability to produce electricity from waste and renewable sources. Recently, bacteria named *Geobacter sulfurreducens* KN400 have the capacity to produce high electric current and were considered as the most important innovation for the year 2009 as announced by Time Magazine. Through this it was finalized that anaerobic digestion was found to be beneficial for the environment and also for treating the commercial waste (Levis and Barlaz 2011). Up to our knowledge, the communication between the microbes in MFCs fed with FWs is uncertain.

The animal wastewater discharged in the environment should be avoided to prevent (Suzuki et al. 2002) water contamination and odour issues (Luo et al. 2002). The water pollution is the major cause nowadays. The presence of higher concentration of nitrate and phosphate in wastewater confers to water pollution through eutrophication of surface water (Luo et al. 2002; Ra et al. 2000).

The present chapter discusses microbial fuel cells (MFCs) using different waste including animal waste and their application as an affordable and reliable anaerobic treatment technology. It has also discussed how rumen waste has bestowed its part for the energy production.

8.1.1 Microbial Fuel Cells in Waste Management

Microbial fuel cells (MFCs) have been proved experimentally that it has an ability to produce electricity (Oliveira et al. 2013; Poggi-Varaldo et al. 2014). Whereas in recent research, it has been proved that organic bioenergy is obtained from biofuels, biodiesel from algae, hydrogen from microbial electrolysis cells and electricity from MFCs. The current and power density (PD) can be affected by operational conditions, such as pH, temperature, substrate concentration, organic loading rate, hydraulic retention time (HRT), microorganisms' activity, parallel or serial connection and static magnetic field (Akman et al. 2013; Jadhav and Ghangrekar 2009; Jafary et al. 2013; Li et al. 2011).

In order to enhance the PD from MFCs, various nano-engineered electrode materials, electrode architectures and cost-effective electrodes have been considered (Gadhamshetty and Koratkar 2012; Kumar et al. 2013; Lefebvre et al. 2013)**.** MFCs have an ability to convert biomass to electricity while leaving the anaerobic macerate to be used as soil improvement, etc. MFCs treatment has an ability to produce electricity from wastewater or biological waste products by converting the waste products to soil reformation. The antagonistic electron acceptor produced by them may be detrimental in the wastewater or biological waste treatment (Chiu et al. 2016).

The coupling of MFC with electricity results in the degradation of organic compounds, solid and liquid wastes. The waste management in MFC attains vital results in the removal of COD and power output. MFC never wanted a chemical catalyst or a temperature. The author confirms that MFC to waste treatment is much more reliable, and it has shown positive results from the last 20 years (Nastro et al. 2013). As most of the researchers perceive that MFC is a system which is efficient enough to convert the organic biodegradable substances to chemical energy into electrical energy, the first METs (microbial electrochemical technologies) was detected. METs are technologies which gain various energy and resources from the wastewater which had various subsystems, targeted to various objectives, and they also include MFCs (Logan and Rabaey 2012). Mainly, MFC has been studied for treating civil and industrial wastewater with a gain of feasible energy that could balance waste treatment cost (Puig et al. 2011; Capodaglio et al. 2013; Cercado-Quezada et al. 2010). Urban wastewater is generally said to have more than nine times of energy than the energy produced from wastewater treatment processes (WWTPs) (Shizas and Bagley, 2004). Recovery of that segment of energy will reduce the cost of both economical and environmental waste. Practical application of MFC in WWTPs construction is considered to be a fluctuated system because of low voltage and low power density (Kaur et al. 2014; Capodaglio et al. 2015). The achievement of MFC is found to be increasing depending upon the OLR (organic loading rate), pH, HRT and electricity resistance (Aelterman et al. 2008; Ieropoulos et al. 2010; Molognoni et al. 2016).

8.2 Energy Production from Various Sources

The fuel in an MFC varies depending on various factors such as the nature of the microorganism that is being used, the amount of energy to be produced by the MFC, the cost of the fuel that is being used and so on. The sources of MFC have been depicted in Fig. 8.1. Some commonly used fuels are:

1. Sewage sludge (Jiang et al. 2009; Zhang et al. 2012)
2. Domestic waste (Fornero et al. 2010)

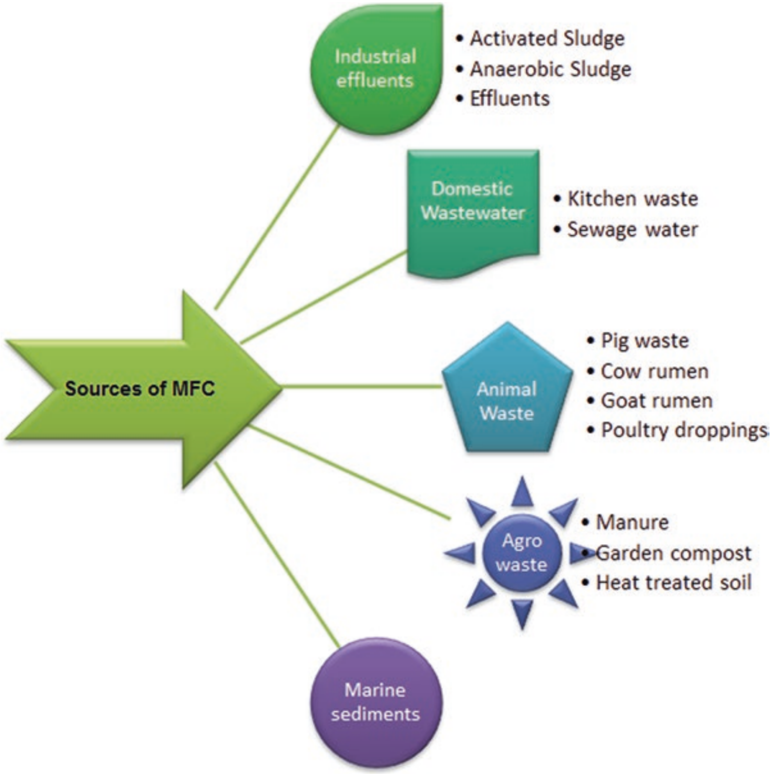

Fig. 8.1 Sources of MFC

3. Industrial waste (Angenent et al. 2004; Wang et al. 2008)
4. Animal waste (Min et al. 2005; Yokoyama et al. 2006; Kim et al., 2008b)
5. Marine sediments (Dumas et al. 2007; Donovan et al. 2011)

8.2.1 Sewage Sludge

Industrial and urban areas are said to pollute the water. There are tremendous wastewater plants which produce huge quantity of sludge per year. Many countries are involved in the production of sludge. In USA, 7.6 million tons of sludge were recovered in the year 2005, and this rate is expected to increase to 8.2 million tons by 2010 (Lee et al. 2005). In the year 2005, EU produced 8.2 million tons of sludge, and China produced approximately 1 million tons of sludge in the same year (Strünkmann et al. 2006). This kind of sludge can be disposed only when it undergoes a proper treatment under appropriate conditions (Burke et al. 2003; Cusido et al. 2003). The sludge treatment is quite expensive, and China still carries out with sludge treatment which costs 25–60% of the total expense.

Biological fuel cell is one of the promising and innovative technologies to solve this issue. When compared to conventional fuel cells, the biological fuels cells have a mild reaction temperature like ambient temperature, normal pressure and neutral pH. The authors Rodrigo et al. studied that the generated power density was found to be in organic matters but not on the wastewater flow. The maximum power density obtained in the system is 25 mW m^{-2}. The presence of oxygen occurred in both anodic chamber and cathodic chamber. The oxygen in cathodic chamber is found to be low. A couple reaction takes place between oxidation-reduction and COD oxidation in anodic chamber. The removal of 0.25% of COD was obtained during the generation of electricity. Occasionally, the anodic chamber worsens the MFC performance because of the presence of oxygen. For a better performance of MFC, the algal growth should be controlled. His work concluded that from wastewater, he was able to generate electricity by means of biological cultures (Rodrigo et al. 2007).

Later, the anaerobic digestion method was identified for sewage sludge treatment because it consumes very less amount of energy, generated very limited amount of solids and requires less nutrition and recovery of energy from biogas. During anaerobic digestion, the sewage sludge maintains its stability by converting the organic matter into biogas (Hwang et al. 2004). There are two anaerobic digestion processes, mesophilic and thermophilic processes. Mesophilic process requires a long retention time, whereas thermophilic needs less retention time and desires to have extreme heating (Zupancic and Ros 2003). The biogas produced from the digested sludge is now considered as bioenergy source.

MFC can convert organic substances into electricity. The organic compounds are simple carbohydrates such as glucose, acetate and butyrate (Liu and Logan, 2004) and complex organic wastes that include swine waste, domestic waste and sludge waste which produce maximum electricity through MFC (Scott and Murano 2007).

8.2.2 Domestic Waste

Domestic wastewater is treated in wastewater treatment plants which produce large amounts of excess sludge. The treatment and disposal of this sludge are becoming more and more of a challenge due to economic, environmental and regulatory considerations (Wei et al. 2003; Aelterman et al. 2006).

In this situation, MFCs that use exoelectrogenic bacteria to produce electricity while also treating the domestic wastewater become attractive options. The electricity produced can be cycled back to the same wastewater treatment plant. The other property of MFCs that make them attractive as wastewater treatment plants is that they are carbon neutral. MFCs oxidize organic matter which releases recently fixed carbon back into the atmosphere (Lovley 2006). Because MFC-based wastewater treatment plants can be installed far from existing treatment plant networks, such decentralized wastewater treatment can also be financially attractive (Wilderer and Schreff 2000).

One of the goals of present studies is to make MFCs net electricity producers. The high energy content of domestic wastewater provides the possibility of higher energy production. Cusick et al. (2010) examined the procedures and processes that can lead to higher energy production using MFCs where the fuel/substrate is domestic wastewater or wastewater from winery. But all domestic wastewater treatments produce nitrogen which needs to be treated. Especially, for decentralized treatment plants that use MFCs, the processing of nitrogen is an issue that still needs an optimal solution that is financially viable.

In another study, the wastewater treatments at two different temperatures using batch as well as continuous flow systems were examined. The treatment was dependent upon the calculation of the removal of COD, power generation, recovery of energy and removal of nitrogen. These are the certain factors which determined the potentiality of MFC to produce power and reduce the solid production from the treatment systems compared to aerobic conventional process. Under mesophilic conditions and continuous flow, the highest power density achieved was 422 mW/m^2 and 12.8 W/m^3 at an organic loading rate of 54 g COD/L-d, and the COD removal was only 25.8%. Energy recovery was obtained by proper operational conditions of flow mode, temperature HRT and organic loading (Ahn and Logan 2010).

However, in recent years, researchers have been using single-chambered MFCs. Adeniran et al. (2016) designed a sandwich domestic wastewater-fed dual-chambered microbial fuel cell for the generation of energy and wastewater treatment. The power density generated by MFC seems to increase COD of domestic wastewater. When the COD was 3400 mg L^{-1} at a current density of 0.054 mA cm^{-2}, the maximum power density was 251 mW m^{-2} and external resistance of 200 Ω. These records were declined when they used 91% diluted wastewater. The domestic wastewater reduces cost, and it might be the bright future for large-scale industries (Adeniran et al. 2016).

There are many studies carried on treating long-term operation of MFCs. In a municipal wastewater treatment facility, two 4 L microbial fuel cells (MFCs) were installed on primary effluent for more than 400 days. Nearly 65–70% of COD at hydraulic retention time of 11 h were removed by both the MFCs, and it reduced about 50% of the solids. Some fluctuation occurred like discharge of anode for 1–3 days or different HRTs. The groundwork analysis of production of energy and consumption indicates that the two MFCs can hypothetically achieve energy consumption, and positive energy balance can be reduced by using large tubing connectors. By denitrifying MFC, the MFC system enhances the removal of total nitrogen from 27.1% to 76.2%. However, the production of energy gradually declines because of the conception of organic substances in the denitrifying MFC. Establishing a carbon balance discloses that sulphate reduction was found to be a major scavenger and methane production plays a very minimal role in the distribution of electrons. These results determine the technical capability of MFC technology, and the advantages are recovery of energy from waste, low conception of energy and low production of sludge (Zhang and He 2013).

8.2.2.1 Kitchen and Bamboo Waste

Moqsud et al. (2014) studied the generation of bioelectricity through kitchen waste and bamboo waste by a microbial fuel cell (MFC) method. The beneficial nutriments like nitrogen, phosphorus and potassium (NPK) were determined to use them as soil amendments. By using both kitchen and bamboo wastes, one-chambered MFC was used for the generation of bioelectricity. The room temperature is maintained for 25 °C for approximately 45 days, and the data logger was recorded. The voltage generation of kitchen and bamboo waste showed different peaks. In kitchen waste, the voltage was found be more in the initial stage and then reached to a peak of 620 mV, whereas the bamboo's waste reached the voltage of 540 mV. This result concluded that MFC shows productive and environment-friendly results for organic waste management which is very useful for less unaware countries and can contribute safe electricity from organic waste materials.

Five two-chambered MFCs were connected to the MFC stack which was further incorporated into the sink pipe connected with the kitchen wastewater treatment. The performance of the MFC stack functioning with real and artificial wastewater was reviewed. Practically, the voltage was checked at different flow rate and temperature. The results detected were with an average open circuit voltage of 3.44 ± 0.02 V, a coulombic efficiency of 78.2 ± 3.6% and a peak power of 45.74 ± 1.39 mW. The performance of MFC is agitated by a process called the flushing process. The MFC stack can be operated by flushing the substrate at 50 °C, and beyond that, irreversible performance corrosion was observed. The suggested MFC stack is likely to function as a potential power source for light and low power devices, specifically in off-grid rural areas (Yang et al. 2016).

Apart from wastewater, solid organic waste has also been looked into as a possible substrate/fuel for commercial production of electricity. Solid food waste from commercial kitchens is anaerobically digested by bacteria, and this kind of anaerobic digestion has been concluded to be the most environmentally beneficial treatment option for commercial FWs (Levis and Barlaz 2011). Now, studies are considering to not only treat the solid food waste but also research on how to use the microbes that digest the food waste as part of viable microbial fuel cells.

8.2.3 Industrial Waste

Of the large variety of industrial waste products, the waste from organic matter and organic matter-related products is the most promising candidate to be used as substrate/fuel for MFCs. Organic matter is used as a substrate by an innumerable variety of microorganisms, and using some of these microorganisms as electrogenic bacteria is only a matter of research.

Some of the industries whose wastewaters are used for electricity generation include brewery/winery, chocolate making, food processing, meat packing and paper recycling industries. In the case of industrial waste, the primary purpose is to reduce the cost of treating the wastewater so that the water itself becomes recycled. The resultant electricity is considered more a bonus rather than a useful commodity that can be commercialized.

8.2.3.1 Winery Wastewater

One of the reasons for this being that enough research has not been done to make electricity generation from the treatment of industrial wastewaters treatment commercially viable. For example, Cusick et al. (2010) compared the amount of electricity generated by using winery wastewater versus domestic wastewater and found that winery wastewater is a better substrate for MFCs while domestic wastewater processing are better processed by so-called microbial electrolysis cells (MECs) which need a supplemental voltage supply in order to function.

8.2.3.2 Brewery Wastewater

The need for energy has increased worldwide. Researchers have also focused on the production of electricity and MFC modelling from beer brewery wastewater. According to Wen et al. (2009), a single air cathode MFC was constructed in which carbon fibre was used as anode and brewery wastewater allowed to dilute is then used as substrate. The open circuit voltage displayed by the MFC is 0.578 V, and the maximum powered density was found to be 9.52 W/m^2 (264 mW/m^2). Kinetic loss and transport loss are the most important factors which manipulates the implementation of MFC. There are also many other factors which decrease these losses, for example, increase in reactant concentration, retaining much effective and cheaper electrode catalysts, retaining irregular electrode, increase in reaction temperature, improvement of flow structure and many more.

8.2.3.3 Food Industry

There are large amount of fats and oils used in food industries. These comprise of organic compounds and vegetable oils. The organic compounds include fatty acid, glycerine, waxes and hydrocarbons. A considerable amount of compounds are discharged as waste. Many investigations have been undergone in food waste industries, and it was recorded that nearly 500,000 tons per year of cooking oil is wasted in Japan.

Large amounts of fats and oils are discharged into wastewater from food industries. In a recent study the researcher estimated the risk of using MFC for the generation of electricity from wastewater containing vegetable oils. Single-chambered MFCs were used and were furnished with artificially created wastewater-bearing soybean oil, removed oil and examination of electric output at many different terms. It was also found that MFC functioning can be upgraded by inoculation of oil-contaminated soil; enhancing wastewater with emulsifier and graphite-coated anode with carbon nanotubes resulting in 2 Wm^{-2} power output. The bacterium "*Burkholderia*" that helps in degrading oil in oil-contaminated soil and anode biofilms was detected by means of PCR amplification of 16 S rRNA fragment. Through these results, it has been concluded that MFCs can be used for energy recovery from food industrials wastewater containing oils and fats (Hamamoto et al. 2016).

8.2.3.4 Potato-Processing Wastewater

MFCs appear as a new chance to deal with organic waste (Logan and Regan 2006; Rabaey and Verstraete 2005). The MFCs play an important role in the potato-processing industries, which undergo certain sequences that include the production of methane as the anaerobic one. In most countries, potato processing plays an important role. The wastewater compost mainly consists of debris and chipping of potato peeling. In order to reduce the organic materials from the waste, both aerobic (Lasik et al. 2010) and anaerobic way of processing has been done (Linke 2006). The researcher investigates the possibility of methanogenesis with many new technologies of MFCs. They have also studied the production of electrified biofilms from real anaerobic sludge and renovation of potato-processing wastewater into electricity. The MFCs had an ability to process the wastewater with prohibitive amount of COD removal but with low energetic conversion productivity. The methanogenesis helps to improvise conversion productivity and gradually degrades the organic matter from the final collected effluent. The author described the production of methanogenesis and a removal of electricity from better quality COD as optimal achievement.

8.2.3.5 Dairy Industry

MFC is the bioreactor which has an ability to convert chemical energy to electrical energy in an anaerobic condition with the help of catalytic reacting microorganism (Du et al. 2007). In MFCs the substrate of cheese whey from dairy industry has been tried out (Antonopoulo et al. 2010; Nasirahmadi and Safekordi 2011; Kassongo and Togo 2010; Dalvi et al. 2011). During the cheesemaking process, the precipitation and removal of milk casein ostracize liquid fraction which is called cheese whey which has a significant amount of carbohydrates, lactose, protein, lactic acid, fat and salt (Gelegenis et al. 2007).

According to Tremouli et al. (2013), MFC produced electricity from different organic loads of sterilized cheese whey. The investigation was further carried on two-chambered MFC. The enactment of the cell was detected at the highest concentration of the pretreated cheese whey (6.7 g COD/L) corresponding to the maximum power density of about 46 mW/m^2. For comparative reasons, the experiment was carried out using glucose (0.35 g COD/L). In this study, the open circuit impedance of MFC varied virtually to the same magnitude on both ohmic resistance between anode and cathode in the complete polarization resistance. This overpotential of ohmic resistance is the main purpose for the energy loss in two-chambered MFC.

A country like India has always raised the need of processing milk, and people and the mechanization have activated the latest trend of relocation of rural people to urban areas for employment. In such countries, process of milk is approximately 94.6 million tons every year. 2–2.5 L of wastewater is produced for every litre of milk (Ramasamy et al. 2004). Therefore, a large amount of dairy wastewater is wasted without utilizing it and contaminated the environment when released without treatment. The power production of a two-chambered MFC with dairy wastewater was employed with two different metabolism: aerobic and anaerobic. The initial COD concentration was 1600 mg/L and pH 7 was maintained in the anode chamber. Comparatively, anaerobic metabolism favoured the MFC performance by producing better columbic efficiency. Conversely, high power production was evident in MFC with aerobic metabolism. (Elakkiya and Matheswaran 2013).

In another study, the author reported the fabrication of novel annular single-chambered microbial fuel cells (ASCMFC) with spiral anode. Anode has a graphite coating with stainless steel. Dairy wastewater with organic matter was used as a substrate. By operating ASCMFC for 450 h, the outcome indicates a high open circuit voltage of about 810 mV. The maximum power density obtained was 20.2 W/m^3, and 91% of COD removal was achieved. Thus, he proved that ASCMFC is a promising alternative to predictable MFCs for wastewater treatment and power generation (Mardanpour et al. 2012).

8.2.4 Animal Waste

A large volume of wastewater has been produced annually from industries and agricultures. For example, in each year, the USA generates approximately 5.8×10^7 tons of animal manures (Dentel et al. 2004). The animal waste should be treated in order to protect the environment from getting polluted and to avoid water contamination and odour problem (Luo et al. 2002). Many treatment techniques are there in order remove organic and inorganic compounds from water. Now, MFC plays an important role in the treatment of wastewater by generating electricity directly from marine sediments, anaerobically digested sludge domestic and food wastewater.

8.2.4.1 Slaughterhouse Wastewater

Though slaughterhouse wastewater is classified as industrial waste, the high concentration of contaminants such as fats, blood, manure and other organic compounds make slaughterhouse wastewater a strong pollutant of the environment in general and a major degrader of aquatic ecosystems, in particular. The same contaminants that make slaughterhouse wastewater a strong pollutant also make it a high-strength wastewater – the fats, blood, manure and other organic compounds are all biodegradable organic compounds that can be broken down by bacterial treatment. For instance, more than 30,000 m^3/day of slaughterhouse wastewater is produced in Ireland alone.

Katuri et al. (2012) studied direct electricity production from slaughterhouse wastewater using MFCs. The conclusion was that the generation of electricity from slaughterhouse wastewater using two-chambered MFCs is feasible and should be considered for large-scale application. Deepika et al. (2015) investigated the usage of goat rumen fluid as an MFC substrate/fuel for the production of bioelectricity. The rumen fluid is normally drained from the slaughterhouses and has no use. By using MFCs to produce electricity using rumen fluid, this fluid instead can serve a useful purpose instead of being discharged to pollute the environment.

In another study done by Oladejo et al. (2015), poultry droppings were used as a substrate/fuel for an MFC arrangement to determine if electricity can be produced from such a system. They demonstrated energy production from poultry droppings, but further research is needed to establish the feasibility of such a system. As with other systems, the electricity generation is dependent on the concentration of the substrate (poultry droppings), and these act as a limiting factor generating a sustainable power supply.

8.2.4.2 Swine Wastewater Treatment

Swine and wastewater treatment and control of odour are important constituents for ecological animal production. Harsh systems of heifer industry require to control the swine wastewater and odour (Zahn et al. 1997). The researcher carried out anaerobic treatment which can generate methane gas, but ammonia and other odour stuffs are not completely removed. Whereas aerobic treatment of animal wastewater is bit costly and do not produce any useful products, so it was found that anaerobic treatment can be energy demanding (Kim et al. 2004; Chen et al. 2004).

The removal of several distinctive aliphatic and aromatic hydrocarbon, phenolic compounds and indoles is known to contribute to nuisance chemical odours from swine wastewater. The chemical removals were compared with the MFC operated in an open circuit mode and with a sealed reactor over the same period of time. Single-chambered MFCs were used to reduce ten chemicals which created the odours by 99.76% and acetate, butyrate and propionate, the three volatile organic acids, by >99%. The MFC seems to produce 228 mW/m^2, and approximately 84% of organic compounds were removed in 260 h. These results showed that it is possible to accelerate the odour removal using MFCs, though at the same time removing the organic compounds and electricity production (Kim et al. 2008a).

Bioelectrochemical systems (BES) are operated in MFC or MEC (microbial electrolysis cell) mode, when the electricity is produced or supply of energy to non-spontaneous reaction can be combined to anaerobic digestion in order to expand its implementation and effluent quality (Hamelers et al. 2010). These systems are considered as one of the most effective systems for the combinations of wastewater treatments to the productions of chemical matters and energy carriers (Pant et al. 2012).

The raw and anaerobically digested pig slurry was inspected in batch say in two-chambered BES run in MFC and MEC mode. Recovery of nitrogen, cation transport, COD and microbial population evolution were evaluated. The anaerobic digestion-MEC integrated system achieved utmost of 60% in 48 h removal of COD, while the maximum removal of ammonium was achieved in MFC mode fed with digested pig slurry in 24 h. High pH in MEC mode could favour recovery of ammonium in a successive shedding and absorption process. *Thermoplasmatales* is favourable to acetotrophic *Methanosaetaceae* and has hydrogenotrophic and methylotrophic methanogen phylotypes while the known family of exoelectrogenic bacteria *Desulfuromonadaceae* was developed under MEC mode. These results show that intermingling of anaerobic digestion in BES seems to be an interesting substitution for the treatment of complex substrates. Recovery of ammonia can be used in the future as a fertilizer (Cerrillo et al. 2016).

8.2.5 Agrowaste Industries

The innovative hypothesis of circular economy claims many fresh scientific approaches for energy and resource regain. Agro-food industries yield great amounts of organic materials as a secondary stream and waste (Fava et al. 2013). Four sets of membrane-less single-chambered MFC were operated in a parallel form for more than 100 days and were immunized with anaerobic sludge from biogas production plant and fed with different organic substrates regularly. The substrates are kitchen waste, cheese whey from dairy industries, fish residual oil and pulpy waste of citrus fruits. All MFCs were able to produce electricity, and biodegradation rates were accomplished. Radical decrease of biodegradation proficiency in sequential batch cycle corresponded to weakening peaks of MFC potentials. The pH drop below 6.5 will affect the biodegradation and anodic exoelectrogenic activity. The bioreactor with complex organic matter delays electric signal and COD degradation. Low current was produced by anodic and cathodic polarization curves. Here, the author explains the electrical signal produced by MFCs during anaerobic biodegradation of four unusual types of agro-industrial residual materials of significance in Mediterranean agro-food sectors (Colombo et al. 2017).

8.2.6 Marine Sediments

MFC is also considered as a novel energy harvesting technology which provides reliability and power conception for a long time and has a strong lifetime of sensor and communication hardware. Ten years ago, MFC was organized in marine sediments (Reimers et al. 2001). In 2007, these MFCS were first established to feasible power sources for undersea sensors and communication systems (Tender et al. 2008). The progress of Trophos Energy which is positioned in these aquatic systems and made in the development of BMFC (benthic microbial fuel cells) technologies and further steps are taken into consideration for power generation. BMFC is a novel form of energy harvesting for marine environment. After a lot of experimentation, it was proved that Trophos Energy has developed novel BMFC that expands a generation of power density. Merging of BMFCs with Trophos offers robust and long-term power generations for various marine applications. The author clearly explains about the importance of BMFC systems as power sources for marine networks (Guzman et al. 2010).

8.3 Rumen Waste in MFC

8.3.1 Rumen Fluid as a Cheap Energy Source

Microbial fuel cell studies have been dealt with different wastewater from treatment plants to generate bioelectricity where there are various parameters to be maintained in a particular limit. However, there are very less reports in using animal waste in MFC research. In the rumen ecosystem, a wide range of bacterial community habitats with different temperature gradients shows complex metabolic function, such as physical, physiological and environmental factors. Ruminants feed on various cellulosic materials with different composition which leads to acquiring different microbial consortia. These microbes breakdown the feed into volatile fatty acids (VFAs): acetic acid, propionic acid and butyric acid.

Rumen microbial fuel cells (RMFCs) are a favourable technology for viable production of green energy and fibre waste treatment. The ruminal chamber of these animals possesses abundant microbes, consisting of bacteria, fungi and protozoa. The microorganisms residing inside the rumen produce active enzymes to commendably degrade the complex ingested plant material under anaerobic conditions (Hobson and Stewart 1997).

8.3.1.1 Pros and Cons of Using Animal Waste

Animal waste is generated at places such as slaughterhouses and meat factories, and so it is easier to procure. Since it is more uniform in composition than plant waste, it can also be studied more easily. In places where more meat is consumed, animal waste will be cheaper to obtain than plant waste. The fermentation of ruminants is usually complemented by the production of electrons and protons. This has made a pavement for the electricity production (Offner and Sauvant 2006).

Recent studies have confirmed that addition of plant fibres (Zang et al. 2010) and purified cellulose (Rismani-Yazdi et al. 2007) could be transformed into bioelectricity by rumen microbes in the anodic chamber without the aid of any external mediators. Thus, usage of rumen waste in MFC would definitely solve the piling of agricultural waste in an indirect manner.

The problem with using animal waste is the timeframe of the microbes that ingest the cellulose present in the rumen fluid. Since it is a complex carbohydrate, assimilation is quite tough and takes a longer time. One other problem is that animal rights, which already don't want animals to be used as food, will oppose the usage of animals and animal products for energy production.

8.4 Conclusion

The energy source has become so important, and its running out day by day is quite noticeable. In order to overcome this problem, renewable and environmental friendly sources are used as alternative tools. The microbial ecology of electrochemically active bacterial population is insufficient. The ecophysiology and microbial association within MFCs are just about to be explored. MFCs incorporated with microbial community are a major compound to be studied. Since the microbial colonies release electrons which helps in the generation of electricity are affected by some parameters such as MFCs types and substrate. The changes in microbial ecology occur based on the type of sources used in the anode chamber. For additional exhibition, the MFC technology is crucial to examine the long-term performance and firmness of large-sized MFCs with actual wastewater.

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