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Comparative Study on single and double chambered Microbial Fuel Cell

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Abstract

The COD reduction efficiency and voltage generation were considered to evaluate the performance of the fabricated single and double chamber microbial fuel cell (SMFC and DMFC) using carbon cloth as electrode. In SMFC, pH was found above 7, whereas in case of DMFC, it was observed in the range of 4.88 to 5.91. Maximum chemical oxygen demand (COD) removal efficiencies of 67.8% and 68.9% were obtained in SMFC and DMFC. A total suspended solid (TSS) was reduce upto 62% in SMFC and 33.5% of total dissolved solids (TDS) in DMFC. Maximum power was obtained was 34.9 mW and 82.6 mW in SMFC and DMFC respectively

Introduction

Due to a growing global population, domestic and industrial energy demands are on the rise. According to the International Energy Agency (IEA), power demand is expected to rise up to 18 billion tonne oil equivalent by 2035 from a current demand of 12 billion tonne oil equivalent (Chu and Majumdar, 2012). The increase in the global energy demand every year and the over-consumption of nonrenewable sources of energy has led to the identification and use of renewable and cost effective sources of energy (Daniel et al., 2009). Non-renewable energy sources are depleting and renewable energy sources are not properly utilized (Chaturvedi and Verma, 2016). Microorganisms have proven to be promising agents for electricity generation. The potential of microbial fuel cell as an alternative source of energy has been studied extensively (Shukla et al., 2004). This wastewater mainly comprises of waste generated from the residential housing societies and industries. It has contained dissolved organic as well as inorganic matters which acted as substrate for the microbial growth and the substrate conversion reactions led to the generation of electricity (Daniel et al., 2009). An idea developed by British botanist Potter in 1911 was to produce electricity using microbes that oxidize organic molecules (Potter, 1911). Since then, MFCs have attracted special attention from researchers, representing a promising solution for energy generation. MFCs treat water in addition to generating energy by consuming organic pollutants from the wastewater. The concept discovered by Potter in 1911 was not well appreciated until 1999 (Potter, 1911), when it was shown that bacteria can transfer electrons externally to electrodes (Kim et al., 1999). During the last decade, this technology has been developed in a practical way for electricity generation along with wastewater treatment (Min and Logan (2004); Rabaey et al., 2005).

A wide variety of substrates have been employed in MFC by the researchers and substrates influence the integral composition of the bacterial community in the anode biofilm. Many studies have been performed, which have utilized wastewaters from different sources such as potato-producing industries (Rabaey et al. 2005b), and meat packing industry (Heilmann and Logan 2006), Beer brewery wastewater (Wen et al. 2009), Chocolate industry wastewater (Patil et al. 2009), Domestic wastewater (Wang et al. 2009), Protein-rich wastewater (Liu et al. 2009b), Starch processing wastewater (Lu et al. 2009), Food-industry wastes (Quezada et al. 2010), Vegetable based waste (Mohanakrishna et al. 2010), Food waste (Choi et al. 2011), Slaughterhouse wastewater (Katuri et al. 2012) and cow urine (Javalkar and Alam, 2013). During development of this technology, low molecular weight substrates were employed as substrates, i.e., carbohydrates (Chaudhuri and Lovley 2003), organic acids (Bond and Lovley 2005), alcohols (Kim et al. 2007) and inorganic compounds (Rabaey et al. 2006). In addition, complex carbon sources present in wastewaters from different sources were also tested for bioenergy production (Liu et al. 2004). A MFC converts the chemical energy into electrical energy without any combustion and substrate is oxidized by microorganisms. Conventionally, MFCs consist of an anode and a cathode separated by proton exchange membrane (PEM). The bacterial biofilm produced at anode acts as catalyst to convert the chemical energy of the organic molecule into electrons while the oxygen gets reduced to form water at cathode (Watanabe, 2008; Zhou et al., 2013). The selection of the proper electrode material is crucial for the performance of MFCs in terms of bacterial adhesion, electron transfer and electrochemical efficiency. There are many studies to scale up the power production using different carbon-based materials such as carbon felt (Kim et al., 2002), carbon paper (Kim et al., 2008), carbon fiber as well as carbon nanotube-based composites. The anode material significantly impacts the biofilm formation and the electron transfer between the microorganism and the electron acceptor. Various materials used in an MFC including carbon rods, carbon fiber, stainless steel mesh (Dumas et al., 2007), carbon cloth (Ishii et al., 2008).

Materials and methods

Construction materials for MFC

Acrylic pipe (ID: 6.5 cm) and Nafion-117 (Sigma Aldrich) proton exchange membrane (PEM) was used for making MFC. Carbon cloth was selected as electrodes material for anode and cathode.

Designing and fabrication

Single chamber microbial fuel cell (SMFC): The cathode was exposed directly to the air and PEM was placed before the cathode. Anode was apart 2cm from PEM and working volume was 180ml. Carbon cloth electrode was connected with copper wire to make the circuit complete. Wax was used to prevent any leakage and the chambers were kept air tight during the entire incubation period.

Double chamber microbial fuel cell (SMFC): Two chambers were physically separated by a cation exchange membrane. Both anode and cathode chamber were closed with the help of plastic caps and pressed tightly together with the help of four nuts and bolts assembly. Each chamber (ID: 6.5cm, L: 5.0cm) has capacity of 180 ml. The anode chamber was kept oxygen free for anaerobic breakdown process. Two circular electrodes (anode and cathode) were made from carbon cloth and placed 2cm apart from the PEM position. The surface area of each electrode was 56.54 cm^2. The anodic chamber contained wastewater. The cathodic chamber contained distilled water (pH=7). Both chambers have provided inlet and outlet port for feeding and taking samples from MFC. All raw and treated wastewater samples were carried out in triplicates.

MFCs were complete acclimatize with anaerobically digested sludge for one week, which was collected from biogas plant. The mix culture of microbes was used for present study i.e. heterotopic microbes were already present in biogas digested sludge. The pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Volatile Suspended Solids (VSS) and Total COD of was measured according to APHA, 2005. MFCs were fed substrate (10 ml) on alternate days. Aquarium air pump was used to supply air externally to the cathode chamber in DMFC. The cell voltage was recorded regularly after one hour period using digital multimeter (Mastech MAS830L, India).

Results and Discussion

Microbial fuel cells for wastewater treatment are closely related to anaerobic process. Today anaerobic process is well formulated technology for wastewater treatment. In the present study, Both SMFC and DMFC were tested in batch mode at room temperature (34.7±2.6^{o}C). A comparative study was carried out in order to find out the performances of both MFCs in terms of voltage generation and reduction of total COD during the study. The physio-chemical parameters of raw wastewater and treated effluent are given in table 1.

Table 1: Profile of raw wastewater

Parameters	pH	COD	TSS	TSS	VSS
Value	4.57	34800	4980	5020	350

Note: units for all parameters in mg/l, except pH

Effect of solids

The maximum removal of TSS was noticed in SMFC. The percent removals of TSS were observed 62% and 59% in SMFC and DMFC respectively. This may be due to sufficient amount of substrate was available to microbes as a result increased the population of microbes in both the MFCs. During the study it found that the TSS concentration was decreased with time in both the MFCs. The decline of TSS might be due to hydrolysis of substrate in wastewater. Prasad et al., (2015) has also reported that the concentration of TSS was decreased in DMFC in his study.

Initially, TDS contents were increased 24.5% and 2% up to day 6^{th} and 2^{nd}, respectively in SMFC and DMFC. After that TDS were decreased in both the MFCs. The maximum TDS removal was observed 28.1% and 33.5%, respectively in SMFC and DMFC. The results indicated that SMFC removes less TDS. The results indicated that DMFC has better efficiency for removal of TDS. The VSS concentration in both the MFCs was increased with time. The biomass concentration was increased 49% and 41% in SMFC and DMFC respectively. The growth of microbes was observed faster in SMFC and this may be due to other microbe species present in anodic chamber along with the electron-transfer bacteria.

Effect of Process parameters

pH

The feeding substrate pH was maintained in range of 6-7 during entire study. The pH variation was observed in both single and double chamber MFC. In single chamber MFC, with addition of substrate, the pH was increased continuously. The minimum and maximum pH was noticed on day second and day 14^{th} respectively, with minor fluctuation in pH. The pH was detected on last day was 7.93. Due to addition of substrate, rate of reaction may increase and this may be due to production of OH ions. Therefore, the pH of anode chamber increased. This may indicates that in anodic chamber, neutral pH is required for growth of microbes. The similar pattern was also noticed by He et al, 2008 in his study. In double chamber MFC, the pH was decreased up to 6 days. The pH was slowly increased after 6^{th} day. The pH was detected on last day was 5.91. Rozendal et al., 2006 reported that the strength of other positive charge species (Na^{+}, K^{+}, NH^{4+}, Ca^{2+}, and Mg^{2+}) are normally 10^{5} times more than the positive charge protons and positive charge cation species other than protons were responsible for the transport of positive charge through the membrane in the cathode chamber as a result decreased in pH in anode chamber. But later on the transfer of cations process was slow down which resulted in continuous increased of pH in anode chamber. This may be due to accumulation of cations strength in the cathode chambers.

Chemical Oxygen Demand (COD)

The wastewater treatment capability was estimated in terms of COD removal using SMFC and DMFC. The variation in COD removal using carbon cloth as cathodes with time at room temperature is shown in Figure 1. The maximum COD removal was observed 67.82% and 68.97% respectively at 20th day, whereas minimum COD removal was noticed 36.54% on day 8th and 27.34% on day 12th for SMFC and DMFC, respectively (Figure 1). The results showed that both the MFCs have potential for removal of COD and SMFC has better efficiency as compared to DMFC for COD removal. Liu et al., (2004) reported the performance of SMFC using domestic wastewater and removal efficiency of COD was in the range of 50-70%. The generated voltage varied with COD reduction or removal but maximum voltage was not recorded on highest COD reduction or removal. The maximum voltage was noticed at highest concentration of substrate by other researchers.

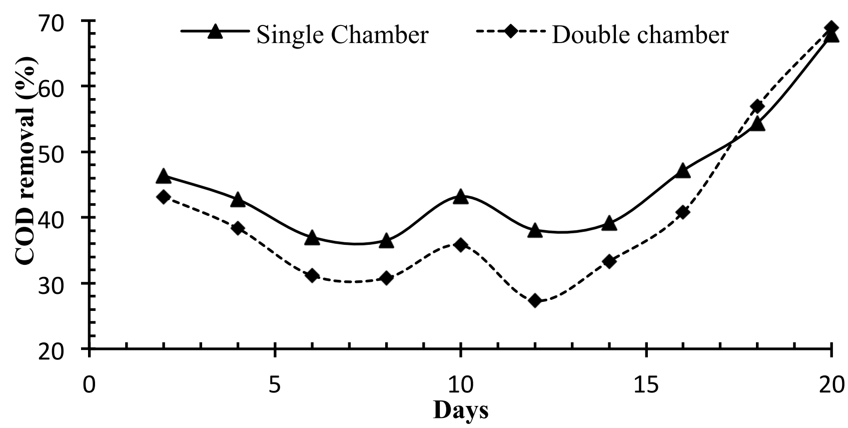

Figure 1 Percentage removal of COD

The maximum voltage was observed at 47% and 43% reduction of COD for SMFC and DMFC respectively (Figure 2). The generation of low voltage may be due to the major portion of COD (Substrate) was consumed by other microbes (sulphate reducing bacteria and methanogens) present in anodic chamber, in lieu of the electron producing bacteria, which might also affect performance of MFCs and same was also reported by Rabaey and Rozendal 2010.

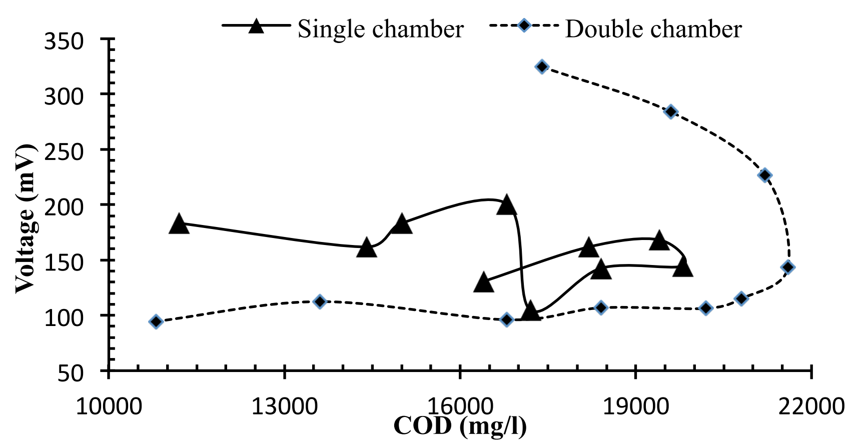

Figure 2 Effect of COD in voltage generation

Voltage, Current and Power Output

No linear relationship between current and day in SMFC. After day 3rd, current was increased up to day 5th. Afterward it was decreased up to day 9th then current increased slightly up to day 10th, then decreased up to day 12th. After 12th day, the current was reaches maximum on 15th day. There were fluctuations in current up to termination of experiment. As far as power is concerned, it was noticed that the similar pattern like current was observed. The maximum power of 34.97mW was observed on day 15th of experiment.

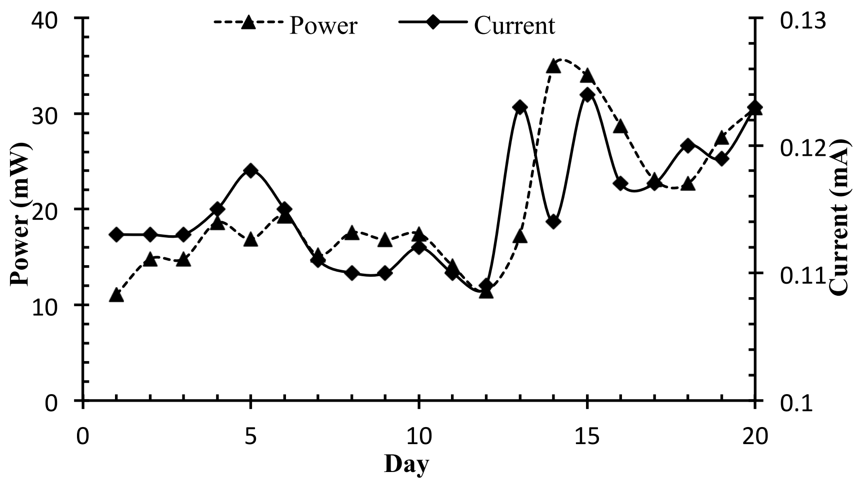

Figure 3 Power out in single chamber MFC

In DMFC, the current was increased from 1st day up to 3rd day. Afterward it was decreased up to 4th day. After addition of substrate on 4th day, the current was increased up to 6th day then it was decreased up to 17th day with minor fluctuations and after 17th day, it was increased and then decreased up to last day of experiment. In case of power, it was increased upto 3rd day. Afterward, it was decreased. On the addition of substrate, there was further increase in power on 6th day. Afterward there was decrease in power with minute fluctuations up to 17th day. Power was increased on 18th day then it was decreased up to last day of experiment. The maximum power of 82.65mW was observed on 3rd day of experiment.

In SMFC, the power was measured to be increased with the time but in DMFC, the power was decreased as compared to initial time period of study (Figure 3). The decrease in pH of anodic chamber of DMFC indicating that the ongoing biochemical reactions in the MFC have not been working properly, which resulted in decreased voltage in MFC (Belafi-Bako et al., 2014).

The power output of DMFC was comparatively higher than single chambered MFC though the generation of biomass in SMFC was more (Figure 4). This may be due the difference in the internal resistance of MFCs. The higher internal resistance in the SMFC is because of the constraint of proton exchange due to high salts and other chemicals presented in the wastewater or because of thicker bio-film development in the MFC and lower down performance of MFC (Choi and Ahn, 2014). The production of electricity from MFC is mainly related with biomass formation (Li et al., 2015).

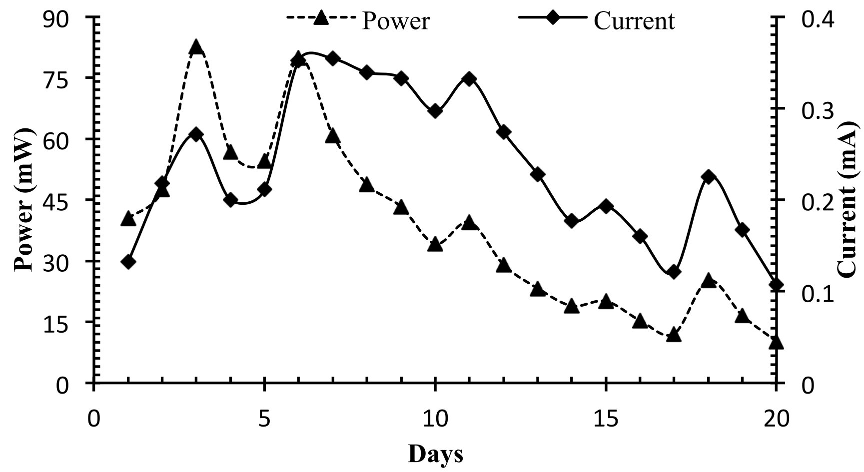

Figure.4 Power out in double chamber MFC

Today, the wastewater management is big challenges before all nations of the world. In India, about 80% of water pollution caused due to domestic wastewater. The present study was carried out for the comparison of different structured MFCs i.e. single and double chambered MFC in terms of COD reduction and generation of electricity. From the study it was found that SMFC is more efficient than DMFC. The COD removal efficiency (67.8%) was more in SMFC when it was compared with DMFC. The constant pH (7.05-8.1) was observed in SMFC with minor variation and useful for growth of microbes. The total suspended solid removal efficiency was observed as 62% for SMFC and 59% DMFC. The voltage generation has showed different pattern in both MFCs. In SMFC, the voltage was increased with the time, whereas it was decreased in DMFC. The High power (82.65mW) was calculated in DMFC and 34.97mW power was calculated in SMFC. In future, MFC could be a best alternative for the treatment of domestic wastewater by microbial fuel cell can be an efficient and cost-effective source of electricity generation.

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Author's contribution: Dr. Jitendra Pal (Assistant Professor) has planned project methodology and final editing of menuscipt and also corresponding author and Naveen Kumar. (Project fellow) has meticulously carried out the experiments and worte the menuscript.

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