INTRODUCTION
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Energy is the major backbone for the growth of an economy and its survivor. The use of fossil fuels, especially oil and gas, in recent years have accelerated in a number of countries due to its newly emerging economies and its economies in transition which have triggered a global energy crisis. A variety of non-conventional energy resources are currently exploited to meet power needs. But some of these have severe drawbacks: wood and cow-dung for burning stoves, for instance, have been linked to respiratory diseases which are thought to cause 484,000 deaths per year in South East Asia (Logan, 2008). Also it is found that the usage of fossil fuels result in the emission of carbon dioxide, which again poses a threat to the environment and a principal cause of global warming. As such, alternative energy source is urgently required. There is a great need for clean, reliable primary sources of power but above all, which are affordable. Renewable bioenergy is viewed as one of the ways to alleviate the global warming crisis. Major efforts are being devoted to developing alternative electricity production methods.

Microbial Fuel Cells (MFCs) technology that convert the energy stored in chemical bonds in organic compounds to electrical energy achieved through the catalytic reactions by microorganisms has generated considerable interests among academic researchers in recent years (Allen and Benetto, 1993; Gil et al., 2003) which may be the answer for improving and optimizing global energy usage. New electricity production from renewable resources without a net carbon dioxide emission is much desired (Lovely, 2006). MFCs can be the next generation of fuel and thus play an important role in energy conservation and alternate fuel utilization. There are different aspects of MFCs as well as different types of fuel cells. MFCs can be used for different purposes such as electricity generation, biohydrogen production and waste water treatment.

MFC concept was demonstrated by Potter, 1911 where Escherichia coli and Saccharomyces sp. were used to generate electricity using platinum electrodes. But the major work began only in later years (Allen and Benetto, 1993). The breakthrough in MFCs occurred in 1999 when it was recognized that mediators did not need to be added (Kim et al., 1999). Bacteria are small sized microorganisms that can utilize a variety of substrates for their respiration. In the respiration process they produce electrons that can be mediated onto the surface of an anode with the help of some chemical or natural mediators. In this experiment
natural mediators i.e. sex pili are used as biological nano wires for electron mediation at the anode. These electrons are then allowed to pass through an external circuit to a cathode where they are taken up by some electron acceptors, in this case oxygen, to form water.

MFC, as the name itself indicates, utilizes microorganisms or enzymes as the biocatalysts to catalyze the oxidation of organic and inorganic matter and generate current out of it (Bond et al., 2002). The bacteria in the substrate produce electrons which are deposited on the negative terminal, i.e., the anode and then they are transferred through a cation exchange membrane to the cathode. The protons migrate to the cathode and combine with the electron and a catholyte, a chemical such as oxygen, which is reduced at the cathode surface. The electrodes are linked by a conducting material with a resistor. Electric current generation is made possible by keeping microbes separated from oxygen or any other end terminal acceptor other than the anode and this requires an anaerobic anodic chamber. The potential between the two electrodes generate electricity. The microorganisms release the electrons by degrading the organic matter and makes energy for the cell in the form of ATP. The electrons are accepted by the terminal electron acceptor (TEA) at the cathode such as nitrate, sulfate, oxygen etc. and get reduced (Logan, 2008). The current produced by the MFC is typically calculated by monitoring the drop across the resistor using a voltmeter or a multimeter.

The reaction taking place at the anode and the cathode chambers can be depicted as below:

Using acetate as the substrate,

**Anodic reaction:** \( \text{CH}_3\text{COO}^- + 2\text{H}_2\text{O} \rightarrow 2\text{CO}_2 + 7\text{H}^+ + 8\text{e}^- \) \(\text{------------------- (1)}\)

**Cathodic reaction:** \( \text{O}_2 + 4\text{e}^- + 4\text{H}^+ \rightarrow 2\text{H}_2\text{O} \) \(\text{------------------------------- (2)}\)

The direct oxidation of microbial hydrogen shows a number of potential advantages. Thus, it does not require the separation and purification of the gas for its subsequent conversion in conventional fuel cells.

MFC can be of two types: Single chambered or a double chambered microbial fuel cell. In double-chamber MFCs, liquids in the anode and cathode chambers are separated by a proton
exchange membrane (PEM) or salt bridge so as to create a potential difference between them. Organics are injected into the anode chamber under anaerobic conditions, while oxygen (or any other oxidant, e.g., ferricyanide) is supplied to the cathode chamber. Many types of double-chamber MFCs have been reported so far (Allen and Benetto, 1993). In contrast, when a membrane-type cathode is used, a single-chamber MFC can be constructed and no membrane is required. But however, the removal of the PEM increases oxygen transfer into the anode chamber, which is responsible for low electron and energy recoveries in MFCs. Additionally, high concentrations of hydrogen gas in the absence of oxygen in a single chamber MEC favours the growth of methanogens which can lower hydrogen recoveries and contaminate the gas with methane. Therefore, as is the case in membrane-less MFCs, a single chamber MEC lacking a membrane suffers from low overall efficiency and hence dual chambered MFCs are more advantageous (Hoogers, 2003).

Many microorganisms have the capability of transferring the electrons derived from the metabolism of the various substrates such as glucose, acetate, lactose, sucrose, molasses etc. Microorganisms can transfer electrons to the anode electrode in three ways: (1) exogeneous mediators (mediators external to the cell) such as potassium ferricyanide, thionine, or neutral red; (2) using mediators produced by the bacteria and by direct transfer of electrons from respiratory enzymes (i.e., cytochromes) to the electrode (Bond and Lovely, 2003). Marine sediment, soil, wastewater, fresh water sediment and activated sludge are all rich sources for these microorganisms (Niessen et al., 2006; Zhang et al., 2007; Masih et al., 2011). Many microorganisms have been employed to generate electricity using various organic compounds as their substrates. For instance, Actinobacillus succinogenes, Enterobacter aerogene, Enterobacter cloacae (Maish et al., 2012a) Pseudomonas aeruginosa, Gluconobacter oxydans, Lactobacillus plantarum can feed on glucose and produce electricity out of it. Enterobacter aerogene and Enterobacter cloacae can use wide range of organic compounds such as sucrose and sodium acetate (Masih et al., 2012a).

There are also several microorganisms reported which can transfer electrons across the membrane to cathode. These microorganisms are stable and have high columbic efficiency. Shewanella putrefaciens (Kim et al., 2002), Geobacteraceae sulferreducens (Bond and Lovely, 2003), Rhodoferax ferrireducens (Chaudhuri and Lovely, 2003) and Geobacter metallireducens (Min et al., 2005) are all effective and form film on the anode surface and
transfer electrons directly to electrode. Bacteria gain metabolic energy by transferring electrons from an electron donor, such as glucose, sucrose and sodium acetate (Masih et al., 2012b) to an electron acceptor, such as oxygen. In a microbial fuel cell (MFC), bacteria do not directly transfer their produced electrons to their characteristic terminal electron acceptor but these electrons are diverted towards an electrode (anode). The electrons are subsequently conducted over a resistance or power user towards a cathode and thus, bacterial energy is directly converted to electrical energy. To close the circuit, protons migrate through a proton exchange membrane from anode to cathode.

MFC technologies are a promising and yet completely different approach to wastewater treatment as the treatment process can become a method of capturing energy in the form of electricity or hydrogen gas, rather than a drain on electrical energy. The high energy requirement of conventional sewage treatment systems are demanding for the alternative treatment technology which will be cost effective and require less energy for its efficient operation (Logan, 2008). In the past two decades, high rate anaerobic processes are finding increasing application for the treatment of domestic as well as industrial wastewaters. The major advantages these systems offer over conventional aerobic treatment are no energy requirement for oxygen supply, less sludge production, and recovery of methane gas. While treating sewage, particularly in small capacity treatment plant recovery of methane may not be attractive, because most of the methane produced in the reactor is lost through effluent of the reactor. The methane concentration of about 16 mg/L (equivalent COD 64 mg/L) is expected in the effluent of the reactor due to high partial pressure of methane gas inside the reactor. Hence, while treating low strength wastewater major fraction of the methane gas may be lost through effluents, reducing the energy recovery.

In addition, due to global environmental concerns and energy insecurity, there is emergent interest to find out sustainable and clean energy source with minimal or zero use of hydrocarbons. Electricity can be produced in different types of power plant systems, batteries or fuel cells. Bacteria can be used to catalyze the conversion of organic matter into electricity. Fuel cells that use bacteria are classified as two different types: bio fuel cells that generate electricity from the addition of artificial electron shuttles (mediators) and microbial fuel cells (MFCs) that do not require the addition of mediator. Unlike a battery, a fuel cell does not store energy. Instead, it converts energy from one form to another (much like an engine) and will continue to
operate as long as fuel is fed to it. However, unlike internal combustion generators, fuel cells convert chemical energy directly into electricity without an intermediate conversion into mechanical power. Fuel cells, if used for wastewater treatment, can provide clean energy for people, apart from effective treatment of wastewater. The benefits of using fuel cells include: clean, safe, quiet performance; high energy efficiency; low emissions; and ease in operating.

In 2004, the link between electricity using MFCs and wastewater treatment was clearly forged when it was demonstrated that domestic wastewater could be treated to practical levels while simultaneously generating electricity.

The operational and functional advantages of MFCs are:

1) MFCs use organic waste matter as fuels and readily available microbes as catalysts.

2) MFCs do not require highly regulated distribution systems like the ones needed for Hydrogen Fuel Cells.

3) MFCs have high conversion efficiency as compared to Enzymatic Fuel Cells, in harvesting up to 90% of the electrons from the bacterial electron transport system.

MFC technology represents a multi-disciplinary approach to the quest for alternate sources of energy. It symbolizes the confluence of the chemical, physical and life sciences and is a meeting point of basic and applied research. Since clean water and stable sources of electricity are two major needs that must be addressed in the developing world. Conventional resources are polluting and finite, and therefore not ideal avenues to pursue. The high energy requirement of conventional sewage treatment systems are demanding for the alternative treatment technology which will be cost effective and require less energy for its efficient operation.

The possibility of direct conversion of organic material in wastewater to bioelectricity is exciting since it emphases bioremediation potential of the microbial fuel cell technology (Masih et al., 2011) and with continuous improvements in microbial fuel cell, it may be possible to increase power generation rates and lower their production and operating cost. Thus, the combination of wastewater treatment along with electricity production may help in saving of millions of rupees as a cost of wastewater treatment at present and may give an effective and cheap alternate energy source with new trend of energy. One of the greatest advantages of MFCs over hydrogen and methanol fuel cells is that a diverse range of organic materials can be used as fuels (Devasahayam and Masih, 2012). Also in wastewater treatment they produce much less excess sludge than conventional methods of treating wastewater. In future work can be done in
this field to develop this technology to enlighten the entire world by maintaining green environment.

The present study was conducted with the following objectives:

1. To Design a dual chambered aerated mediator less MFC assembly to generate electricity and study remediation efficiency.

2. To compare generated electricity and coulombic efficiency using different pure bacterial cultures such as *Enterobacter aerogene, Enterobacter cloacae* and *E.coli*.

3. To compare electrical conductance and remediation efficiency of inland water, waste water and textile waste water samples.