Research Article

Development of Microbial Fuel Cells and Electrode Designs with Waste Water Anaerobes

A. Banik, N. K. Jana, B. R. Maiti and T. K. Ghosh*

Department of Biotechnology, Heritage Institute of Technology, Kolkata, West Bengal, India.

*Corresponding Author's Email: tapanswatighosh@gmail.com

Abstract:

Two designs of microbial fuel cells have been developed. In the first type, a Single Chambered-Microbial Fuel Cell of 200ml capacity was constructed with the cathode and anode made of carbon brushes in a 'T' shaped configuration, attached in Cloth Electrode Assembly. In the second type, multiple anodes attached in a circuit, were used in developing a Multi Anode Single Chambered-Microbial Fuel Cell of 100ml capacity along with a common cathode made of graphite powder and adhesive, hardened by air drying. The generation of voltage and current was observed with both designs. Three types of substrates viz Carboxy-Methyl-Cellulose, Dextrose and Sodium Acetate were used with anaerobic micro-organisms grown from waste water. Nernst Equation have been used to calculate maximum cell voltage due to ionic reaction of sodium acetate. The main purpose of the study was to validate workability of a novel MFC design in terms of current generation and cheap materials, hence showing current generation could be increased with multiple anodes sharing a common cathode and also providing possibility for serial connectivity for increasing voltage output.

Keywords: Microbial Fuel Cell, Novel design, parallel circuit, Nernst Equation, MASC-MFC

Abbreviations:
MFC = Microbial Fuel Cell;
SC-MFC = Single Chambered MFC;
MASC-MFC = Multi Anode SC-MFC;
CEA = Cloth Electrode Assembly;
E^0 = Standard electrode potential w.r.t Hydrogen electrode;
Ecell = Total Cell Potential;

Introduction:

Power generation from MFCs (Microbial Fuel Cells) using anaerobic microbes is a novel technology with great potential for alternative energy generation and environmental remediation. Organic substances are degraded by micro-organisms through anaerobic metabolism liberating electrons and protons in a biochemical cell using anode and cathode separated by ion exchange membrane.

$$C_{12}H_{22}O_{11} + 13H_2O \rightarrow 12CO_2 + 48H^+ + 48e^-$$

The Current is generated through the flow of electrons via a complete electric circuit. In 1910, Potter had put forward the idea of production of EMF during fermentation of organic compounds by yeast. However the first known patent of MFC dates back to 1967. Since then, different researchers worked on the development of MFCs with different configurations. As for example, dual chambered cell with a proton exchange membrane or single chambered cell with anode and cathode separated by cotton cloth, may be mentioned.

Park and Zeikus(2000) developed an MFC which produced a current of 14mA with power density of 787mW/m^2 and a current density of 1.75A/m^2 with sewage sludge using Mn^{++}-graphite anode Fe^{3+}-graphite cathode separated by porcelain septum[1].

Another work by Schroder(2003) reported a current density of 15A/m^2 with a dual chambered MFC using anode coated with metallic electrocatalyst like Pt or platinized carbon cloth covered by conductive polymer[2].

The beneficial effect of increasing the cathode surface area was demonstrated by Logan(2004) validated that power production got increased when the cathode surface area was increased from 22.5cm^2 to 67.5cm^2[3]. On the other hand, work of Liu et al (2007) demonstrated that 2 layers of separation cloth/membrane fetched the optimum output[4] but replacing phosphate buffer with bicarbonate buffer at 9.9 pH increases output most[5].

The concept of stacked MFCs was advanced by Aelterman et al(2006) for generating current along with a considerable voltage output via series parallel combination[6].

Scott and Murano(2007) demonstrated the importance of electrode position in a cell for enhanced power output[7]. Besides Sarma et al(2007) also observed that overall voltage generation, power yield and substrate degradation were all dependant on Organic Loading Rate to the cell[8].

It is noteworthy to mention here that all this maximum power and current yield was obtained running the MFC in mostly continuous or fed batch mode. The list given by Huang et al(2011) on operational mode of bio-cathode of MFCs showed that electron transport is best in continuous operational mode[9].

These previous studies of MFCs as discussed above, indicate that the efficiency of operation of MFCs depends on various aspects like construction mode, operation mode, nature of electrodes, multiplicity of anodes and nature of substrates. But the primary backdrop is that they were not so economical. The objective of the present investigation, is to develop indigenous models of SC-MFC (Single Chambered MFC) in CEA (Cloth Electrode Assembly) assembly, built with simple materials, which can produce maximum power under various process conditions, viz electrode design, carbon substrate, types of chamber assembly, electrode areas and application of mediators.

Materials and Method:

In the first scheme of investigation, a SC-MFC as shown in the Figure 1 was constructed on the basis of the design given by Liu(2007)[4] (shown in Figure 2) but more in a 'T'-shaped assembly with a cell volume of 200ml using cathode and anode made of carbon brushes (7cm * 3.8cm * 8mm). The total surface area of the anode was 0.006744m^2.

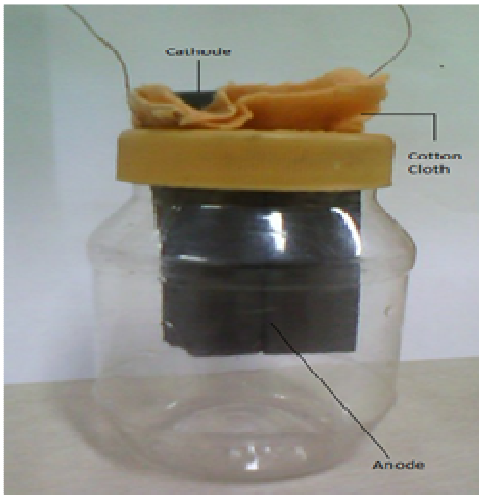

Figure 1: CEA in this study

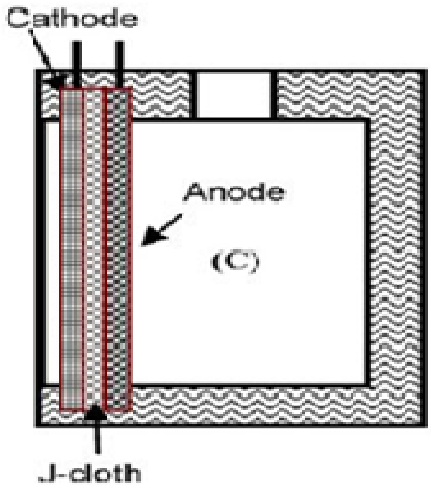

Figure 2: CEA in Hong Liu's Work

The electrodes were separated by two layers of cotton cloth as shown in Figure 3.

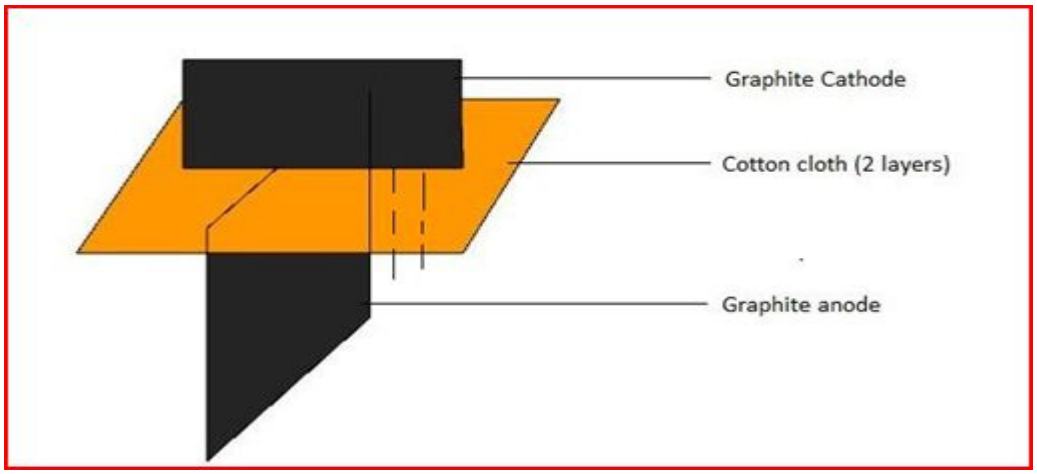

Figure 3: Schematic Diagram of Configuration Employed in 1st Phase

Various substrates used were CMC, dextrose, Na-Acetate (all of .03M conc.) and their mutual mixtures. Micro-organism introduced in the cell were anaerobic and allowed to grow inside the cell in presence of sodium carbonate buffer (.01M), potassium chloride (.005M), ammonium chloride (.011M) and yeast extract (1g/l) beside the substrate. The MFC was operated in a batch mode.
In the second scheme of experimentation, the number of anodes was increased. The orientation of anodes made of carbon brushes was shown in the Figure 4.

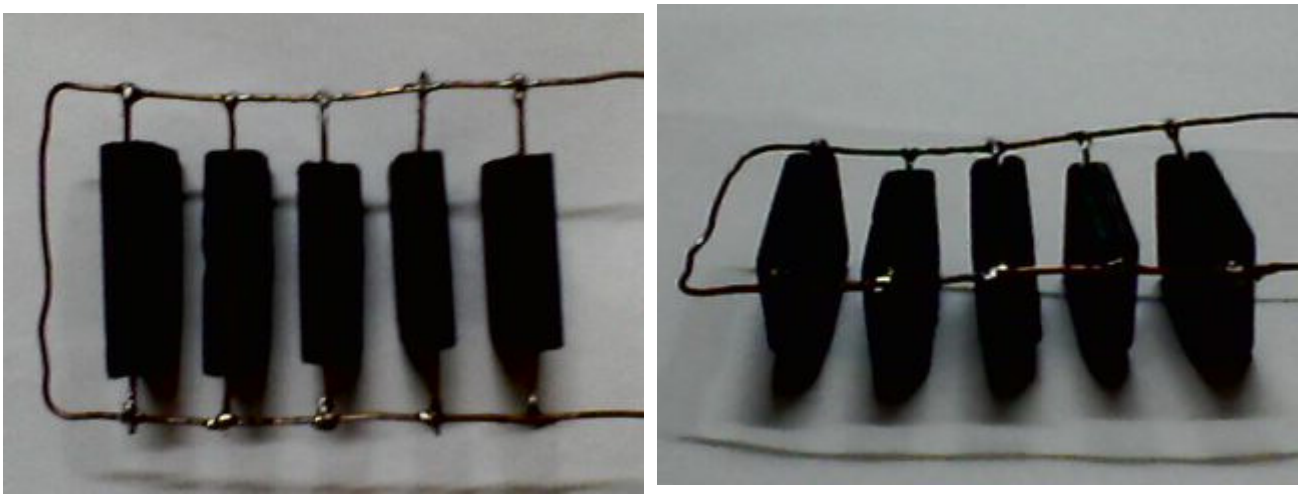

Figure 4: Orientation of graphite brushes in the circuit

The cell volume was changed now to 100ml, containing the same nutrients as used earlier in the same proportion except potassium ferricyanide mediator (10g/l) was added for facilitating electron transfer. The common cathode(C) was fabricated with graphite powder, water and adhesive, hardened by air drying. A copper wire(A) was fixed upon the graphite cathode (as shown in Figure 5) so as to orient them in a circuit(Circuit 1). These multiple anode assembled with copper wires (EE' to II'), was fully immersed in the anolyte with two terminals(BB') coming out of the anode chamber. The circuit diagram of the MASC-MFC was shown below.

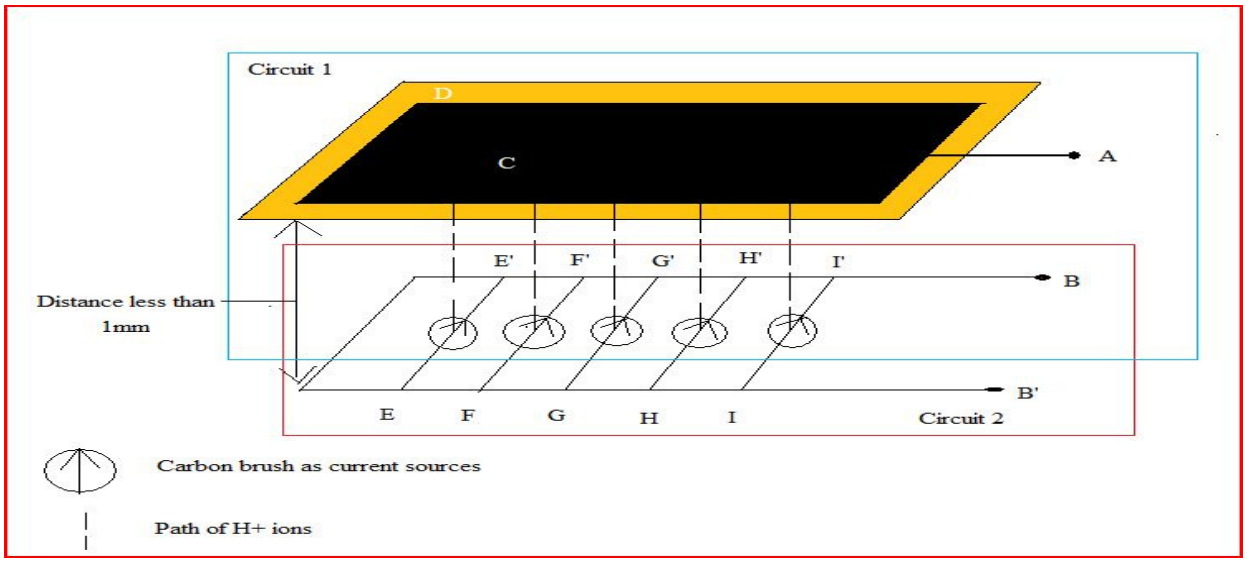

Figure 5: Schematic diagram of configuration employed in 2nd Phase

Results and Discussion:

The single chambered MFC was operated with the addition of appropriate medium constituents and anaerobic micro-organisms of waste water. The latter was cultivated in the cell in the complete absence of air. After the lapse of sufficient time, voltage and current in the MFC were measured with a digital multimeter and plotted in Figure 6 whereas the output power and current density was calculated and plotted in Figure 7.

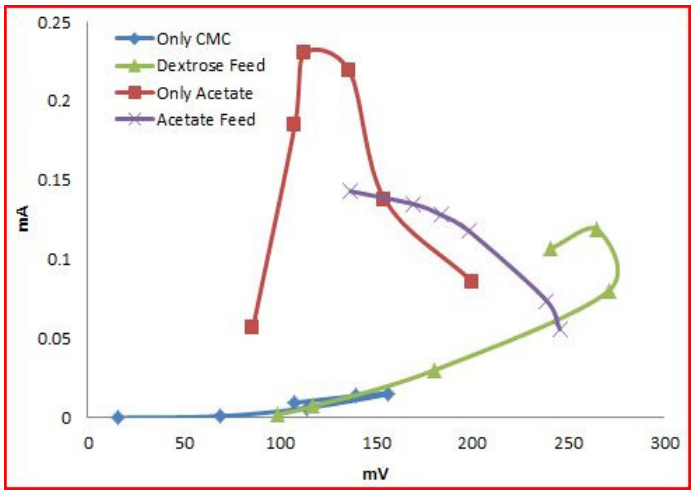

Fig 6: Voltage vs Current for all types studied

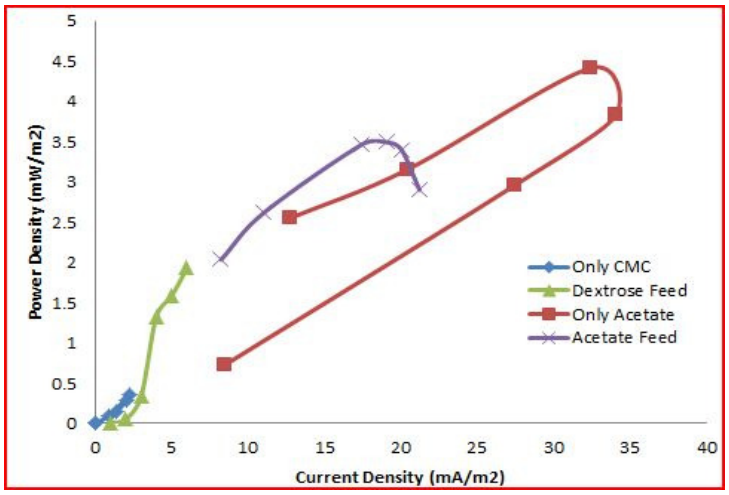

Fig 7: Power density vs Current density in 1st phase

The figure 6 indicates that the generation of current was very low with the substrate CMC, addition of dextrose (*Dextrose Feed in the graphs*) increased power production considerably compared to it whereas pure acetate as a substrate yielded highest power as well as current among all the substrate studied. Furthermore when acetate was fed to a mixed substrate of CMC and dextrose (*Acetate Feed in the graphs*), voltage increased further. But the high values could not sustain and both the voltage and current dropped to a minimum after a peak value. This may be attributed to low substrate concentration or high solution resistance. The curve in figure 7 is cyclic in nature, equivalent to cyclic voltammetry due to redox potential. With the variation of voltage and current outputs, the $O.D_{660}$ of medium was observed at an interval of 48 hours which was indicated in figures 8 & 9 respectively. Each curve showed some maximum indicating the highest growth of microorganisms.

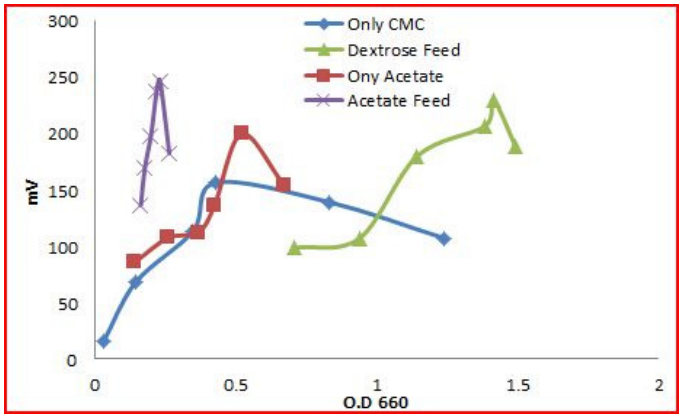

Fig 8: Variation of Voltage with $O.D_{660}$ of sample

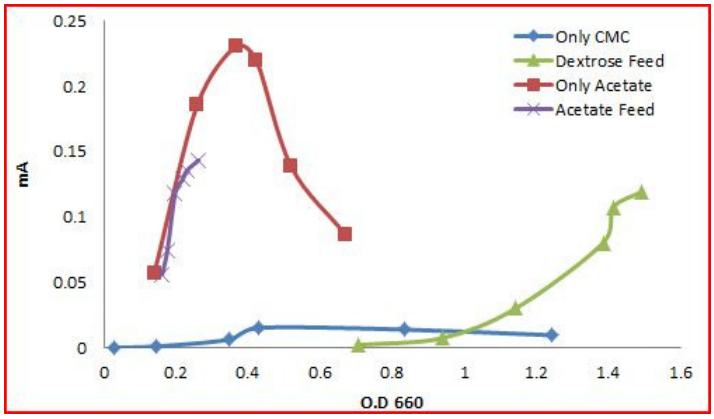

Fig 9: Variation of Current with $O.D_{660}$ of sample

The effect of pH on power density and cell mass($O.D_{660}$) were shown in figures 10 & 11 respectively with maxima and minima. An optimum pH of 9.0 was observed for acetate with respect to power output. However in most of the cases, the cell growth decreased with pH.

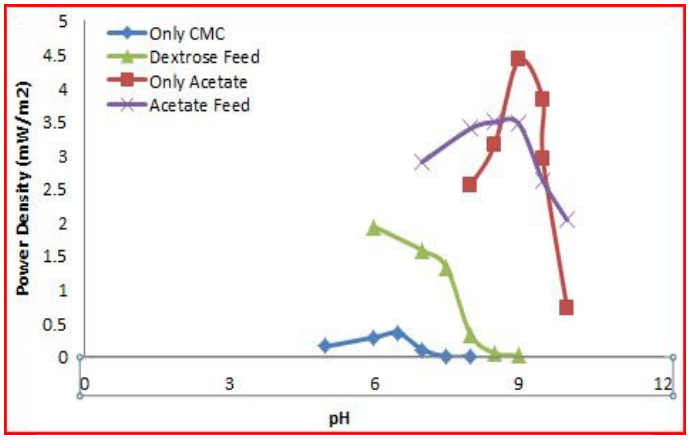

Fig 10: Power Density as a function of pH

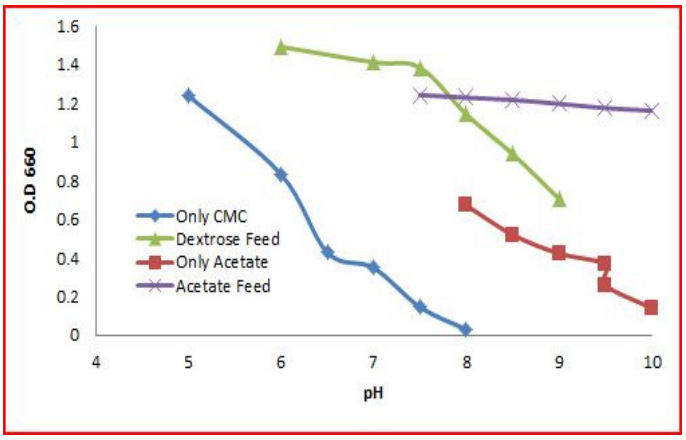

Fig 11: $O.D_{660}$ as a function of pH

The effect of time on power density and internal resistance was shown in figure 12 indicating characteristic curves for acetate and the mixed substrate only since they have given good outputs. As expected power generation was observed to be highest when internal resistance was lowest but it was only prominent in case of only acetate as substrate. Since from figure 11 it was observed that the $O.D_{660}$ of Acetate Feed don't increase much with time, the high power generation might be attributed to exponential growth of the microbes. The low value of power density at longer time might be caused by the depletion of substrate or when media lose contact with the cloth, cutting off the path of H^+.

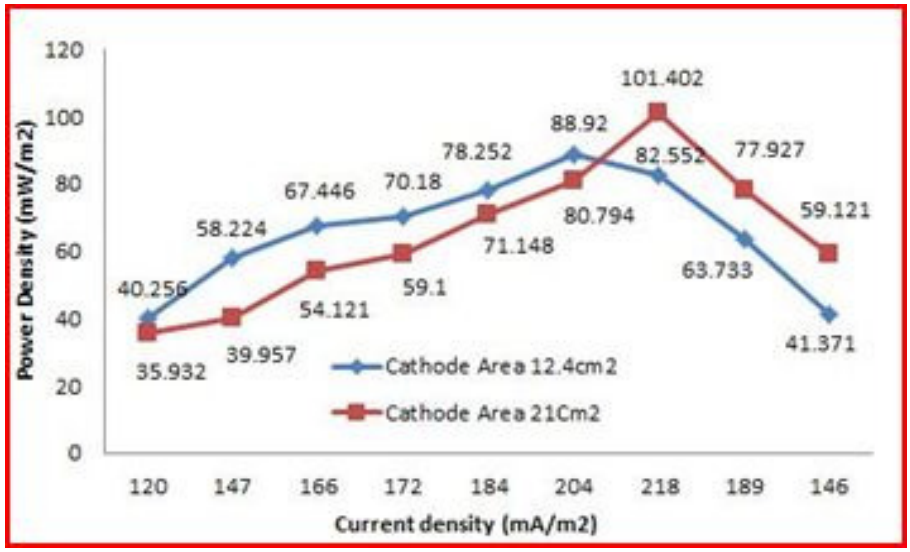

Fig 12: Variation of Power Density and Internal Resistance with time

The new configuration as shown in the Figure 5 was inspired by the parallel circuit law in case of current sources And as the graphite cathode was handmade devoid of any diffusion layer, there was ample chance of evaporation of the media through it. So readings were taken in per hour basis that were plotted in the figure 13. The increment of cathode surface area contributes in passage of more cations in the media to the cathode and thus flow of electrons in the external circuit (circuit 1) increases, which contributes in increment of current as well as voltage at the same time.

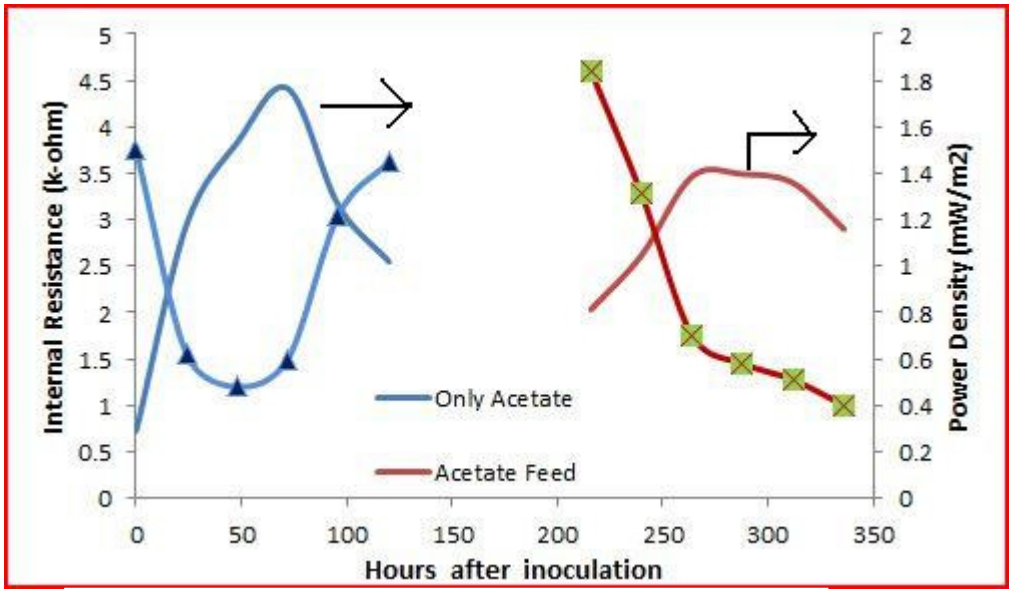

Fig 13. Power density vs Current density in MASC-MFC

The 1st scheme of experimentation validated the workability of the T shaped orientation of electrodes, thus giving the optimized result as listed in Table 1.

Table 1 listing the optimized result of 1st phase

Substrate	Sodium Acetate
Buffer	Bicarbonate
pH	9.0
$O.D_{660}$	0.423
Electrode Spacing	0.5 cms
Electrode Orientation	T-shaped
Surrounding Temperature	25^oC
Inoculum	Mixed Consortia of Wastewater

With respect to second scheme of experimentation, it was observed that voltage output was enhanced by 2.6 times compared to the SC-MFC utilised in the first phase. Furthermore, it was observed that the voltage output increased by 2.8 times when cathode area was increased by 1.69 times. Similar type of observation was also reported by Logan (2004). The maximum cell voltage of 435mV and output current of 2.01mA was recorded through multimeter. Applying Nernst equation, $E_{cell} = E^0 - (RT/nF)lnQ$ where E^0 of graphite was taken .5 V, the reaction quotient Q was calculated to be $5*10^{-9}$ at 313K with n = 10, the cell voltage was calculated to be 552mV. However, it was not possible to measure cell current by the equation of chronoamperommetry, $i = nFADC_{ox}/ \delta$, since diffusivity of ions(D) and diffusion layer thickness(δ) could not be measured with accuracy.

Conclusion:

The study proved the workability of a novel MFC design in terms of current generation. Furthermore current yield could be enhanced with multiple anodes sharing a common cathode, simultaneously providing possibility of serial connectivity for increasing voltage output. The ionic substrate, sodium acetate has been found to be the most effective substrate in this design.

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