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Increasing The Efficiency of Microbial Fuel Cell With Hydrodynamic Cavitation

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Abstract –*Microbial fuel cell is a device that converts chemical energy to electrical energy by the actions of microorganisms. They are electrochemical devices functioning on metabolic abilities of microorganisms to oxidize organic substances and generate flows of electrons serving the dual purpose of waste management and energy generation. MFC works by allowing bacteria to do what they are best, oxidize and reduce the organic matter that could be easily degraded with the help of micro-organisms.*

Cavitation is phenomenon which is characterized by formation, growth and collapse of bubbles within a liquid. A flowing fluid system also gives cavitation, which is known as hydrodynamic cavitation. Generally cavitation is generated during a flowing fluid passing through a VENTURI tube or an orifice plate with a constriction, which leads to hotspot generation. There are various applications of hydrodynamic cavitation but it plays a major role in food industry and waste water treatment.

Hydrodynamic Cavitation is considered as one of the high energy demanding process for water treatment. For this study, we used a simple experimental setup to generate cavitation at a low pressure (low energy) so the digestibility by microbes is done at a higher rate in MFC system.

Using MFC in combination with HYDRODYNAMIC CAVITATION will help to increase the efficiency of charge generation by degrading the organic material which will help the micro-organisms to do their work at much faster rate. As a result using Hydrodynamic cavitation can be proved to be very helpful for industrial wastewater treatment and thus treating waste water.

The overall performance on near future of an MFC depends on Microorganism, appropriate electrode materials, suitable MFC designs, and optimizing process parameters which would accelerate commercialization of this technology in near future. And MFC with Hydrodynamic cavitation will help to evaluate these parameters and their effects.

MFC with cavitation is a great technology which can be used in the Modern World for generation of electricity and concomitant wastewater treatment.

Keywords-*Hydrodynamic Cavitation, Electricity Generation, Wastewater Treatment*

I- INTRODUCTION

Wastewater is classified into domestic wastewater and industrial wastewater. Domestic wastewater means wastewater with a measured strength less than "high-strength wastewater" and is the type of wastewater normally discharged from, or similar to that discharged from plumbing fixtures, appliances and other household devices including, but not limited to toilets, bathtubs, showers, laundry facilities, dish washing facilities, and garbage disposals. Industrial wastewater means the water or liquid carries waste from an industrial process. These wastes are sent to Fresh Water or Oceans from any process of industry, manufacture, trade or business, from the development of any natural resource, or from animal operations such as feedlots, poultry houses, or dairies. The term includes contaminated storm water and leachate from solid waste facilities. In India near about 14000 million liters per day wastewater is produced due to our domestic & industrial use. The treatment capacity of municipal corporation is nearly around 12000 million liters per day. Treatment of industrial effluents has long been a challenge for modern technologies combining high effectiveness of degradation of pollutants with low costs of the process. Hydrodynamic cavitation is effective and energy efficient method which the modern world requires. Cavitation is one such recent technique which has been found to be highly beneficial in wastewater treatment and has attracted considerable research interest.

II-MICROBIAL FUEL CELL

Microbial fuel cell (MFC) provides a new opportunity for the sustainable production of energy in the form of direct electricity from biodegradable compounds present in the wastewater achieving the simultaneous water treatment. Microbial Fuel cell is bio-electrochemical fuel cell where the anode reaction is controlled by microorganisms. The greatest value of MFC have ability of electrode associated microbes to degrade wastes and toxic chemicals.

MFC is a device that converts chemical energy to electrical energy with the aid of the catalytic reaction of microorganisms that is produced by the oxidation of organic compounds into ATP by sequential reactions in which electrons are transferred to a terminal electron acceptor to generate an electrical current. Despite their MFCs have not successfully translated into commercial applications because the demonstrate persistent performance limitations and bottlenecks associated with scaling up. Instead, micro scale MFCs have received increasing attention as a unique platform for various applications such as powering small portable electronic elements in remote locations, performing fundamental studies of microorganisms, screening bacterial strains, toxicity detection in water.

MFC is a great technology which can be used in Modern World for generation of electricity and concomitant wastewater treatment. MFC consists of an anode compartment where fuel is oxidized by bacteria which generates free electrons H30+. A membrane that separates anode and cathode and allows flow of H30+. An external circuit helps transfer of electrons from anode to cathode. In MFC, organic matter is oxidized in the anode chamber producing carbon dioxide, protons and electrons are then transferred to the anode surface. from anode, the electrons move to cathode.

III- HYDRODYNAMIC CAVITATION

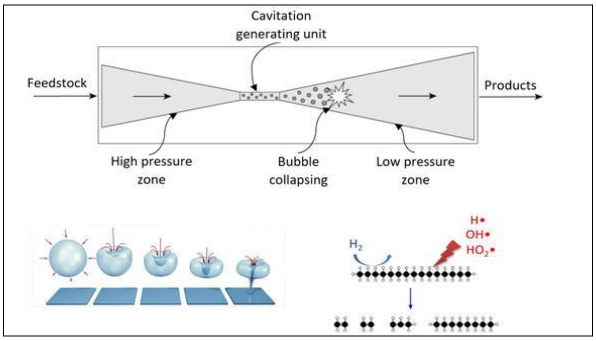
Cavitation is a phenomenon in which rapid changes of pressure in a liquid lead to the formation of small vapor-filled cavities in places where the pressure is relatively low.

When subjected to higher pressure, these cavities, called "bubbles" or "voids", collapse and can generate a shock wave that is strong very close to the bubble, but rapidly weakens as it propagates away from the bubble.

Hydrodynamic cavitation can be generated by using a constriction in the flow, such as an orifice plate, venturi or throttling a valve. According to Bernoulli’s principle, when liquid flows across a constriction, the kinetic energy of the liquid increases at the expense of the pressure energy If the decrease in pressure is sufficient to cause the pressure around the point of vena contracta to fall below the threshold pressure for cavitation (usually vapour pressure of the liquid medium being pumped at the operating temperature), vapour cavities are generated. The cavities expand in the downstream section and eventually collapse as the pressure recovers. During the passage of the liquid through the constriction, boundary layer separation and turbulence occurs and a substantial amount of energy is lost in the form of a permanent pressure drop due to local fluid turbulence.

The collapse pressure generated by the cavity can be of the order of several hundreds of bars, which is sufficiently high to rupture the biological constituents of water including the microbial cells causing its death and viability. As a result, the use of hydrodynamic cavitation as a post process to treat the secondary effluent (wastewater coming from biological treatment unit) to meet the discharge limits of PRE without the addition of chemicals.

High-intensity cavitation is needed to to ensure that microbial count is substantially reduced like in water disinfection applications.



IV- LITERATURE SURVEY

1. Microbial Fuel Cell (MFC):

MFCare devices which exploit microbial catabolic activities to generate electricity from a variety of materials, including complex organic waste and renewable biomass.

These sources provide MFCs with a great advantage over chemical fuel cells that can utilize only purified reactive fuels (e.g., hydrogen).

A developing primary application of MFCs is its use in the production of sustainable bioenergy, eg, organic waste treatment coupled with electricity generation, although further technical developments are necessary for its practical use. In this article, recent advances in MFC technologies that can become fundamentals for future practical MFC developments are summarized.

A microbial fuel cell is a device that converts chemical energy to electrical energy by the actions of micro-organisms.Results of recent studies suggest that MFCs will be of practical use in the near future and will become a preferred option among sustainable bioenergy processes.

MFC works by allowing bacteria to do what they are best, oxidize and reduce the organic matter and that would be MFC in a nutshell.

Process such as hydrodynamic cavitation combined with MFC can be an excellent choice for waste water treatment and electricity generation

Hydrodynamic cavitation is a new, advanced technology to be used in combination of MFC for the decomposition of complex compounds and for generating voltage out of by-products or wastes from domestic or industrialwastewater/effluents.

2. Hydrodynamic Cavitation:

The combination of the two computational tools are going to be used as an evaluation of the potential of hydrodynamic cavitation as an AOP.

The pressure pulses are defined by the pressure recovery and therefore the pressure rate of change, and that they correspond to the calculated data.

The temperatures reached with hydrodynamic cavitation are almost like those reached inside ultrasonic cavitation bubbles.

Therefore there's enough evidence to think about this technology a potentially efficient AOP for water treatment, with some additional difficulties, but with variety of serious advantages over the competing techniques. Cavitation as a phenomenon is characterized by a formation, growth and collapse of bubbles within a liquid.

In hydrodynamic cavitation the geometry of a system is that the reason for velocity fluctuations during a liquid flow, which may cause local drop of pressure.

Vaporous cavity can form anywhere during a flowing liquid where the local static pressure is reduced to the liquid vapour saturation pressure. The study is predicated on efficiency in degradation by using different additives in hydrodynamic cavitation.

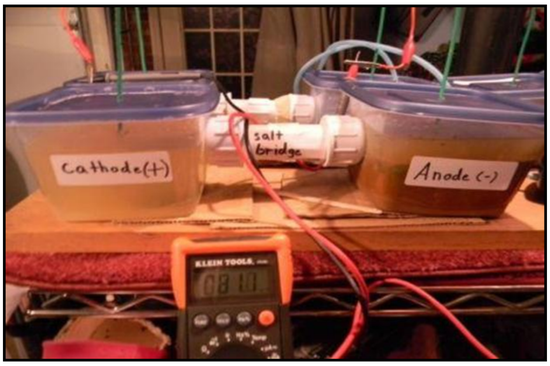
It offers new possibilities thus it is less energy demanding, has a simple construction and less operational costs in comparison with acoustic cavitation that is commonly applied today.

V- CONSTRUCTION OF MFC

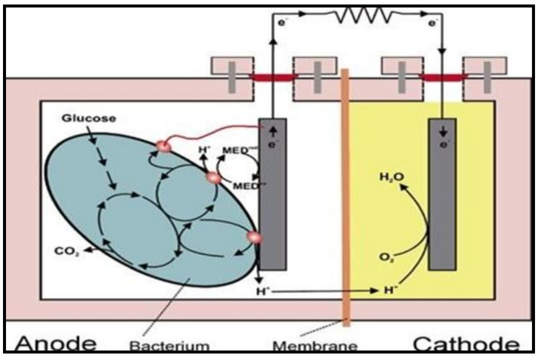
Components of MFC :

- **AnodeCompartment**: In Anode Compartment, fuel is oxidized by bacteria which generates free electrons and H3O+
- **Membrane**: Membrane separates anode and cathode and allows flow of H3O+
- **ExternalCircuit**: External Circuit helps transfer of electrons from anode to cathode.
- **Substrate**: Any organic matter used as source of energy for microorganisms (i.e. wastewater)
- **Bacteria**: Exo-Electrogene most suited for Microbial Fuel Cell applications.

Microbial Fuel Cell consists of two plastic containers connected to each other with the help of salt bridge. On the top of both the container graphite rod is connected with the help of nail or screw. Salt bridge is made by using Agar Gel.



VI- WORKING OF MICROBIAL FUEL CELL



Anode Reaction :

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

Cathode Reaction:

$$4H^+ + O_2 + 4e^- \rightarrow 2H_2O$$

Microbial Fuel Cells are electro bio chemical devices that use the metabolic activity of microorganisms to oxidize fuels generating electric current by direct or mediated electron transfer to electrodes .

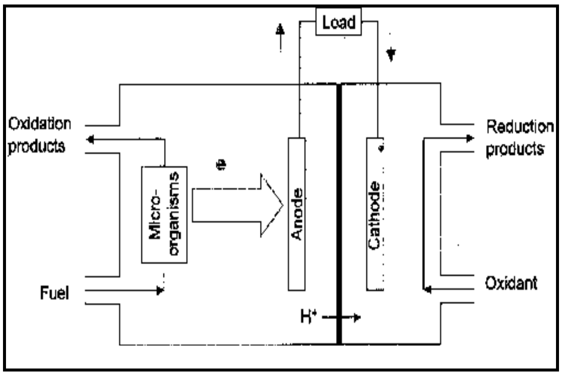
The use of microorganisms in biological fuel cells eliminates the isolation of individual enzymes, thereby providing low quality substrates for biological fuel cells. Microorganisms can be used in four ways for producing electrical energy:

(i) Microorganisms can produce electrochemically active substances through fermentation or metabolism. For the purpose of energy generation, fuels are produced in separate reactors and transported to the anode of aconventional fuel cell. Accordingly, in this configuration, the microbial bioreactor is kept separated from the fuel cell.

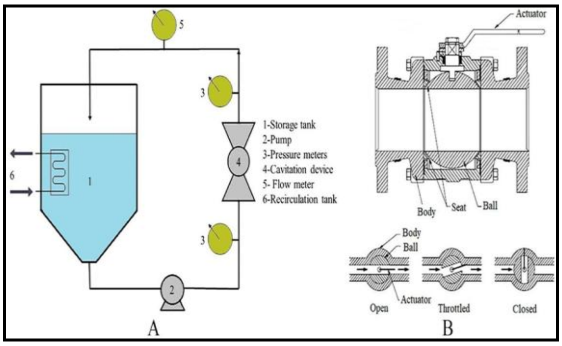
(ii) In the second configuration, the microbiological fermentation process proceeds directly in the anodic compartment of the fuel cell.

(iii) In the third configuration, electron-transfer mediators shuttle electrons between the microbial biocatalytic system and the electrode. The mediator molecules accept electrons from the biological electron transport chain of the microorganisms and transport them to the anode of the biological fuel cell.

(iv) In the fourth configuration, the metal-reducing bacterium having cytochromes in its outer membrane and the ability to communicate electrically with the electrode surface directly result in a mediator-less biological fuel cell.



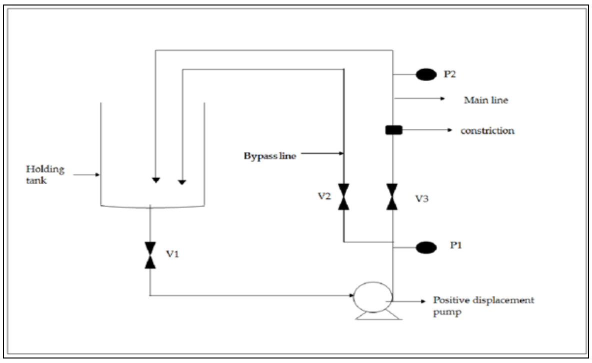
VII- CONSTRUCTION OF HYDRODYNAMIC CAVITATION



Hydrodynamic cavitation was generated using an in-house constructed unit termed the Hydrocavitator which has a feed vessel tank with maximum capacity of 25 L and operates in a re-circulation mode. Effluent from the feed tank is pumped using a triplex plunger pump (SPECK NP25) with a maximum discharge pressure of 4,500 psi and passes through an orifice unit (orifice area about 7.0×10^{-2} m^2) followed by a catalyst bed and finally back to the feed tank. An external heat exchanger unit is also provided to control the temperature in the feed vessel tank, which is necessary as cavitation results in the production of heat thereby increasing the temperature of the effluent stream.

Sr. No.	Property	Favorable Conditions
1.	Inlet pressure / Rotor Speed of equipment	Use increased pressure / rotor speed Operate below optimum value to avoid super cavitation
2.	Diameter of the construction	Carry out an optimisation for application Select higher diameter for applications which require intense cavitation. Select lower diameter with a large number of holes for applications with reduced intensity.
3.	Percentage of the free area for the flow i.e., the cross-sectional area of holes on the orifice to the total cross-sectional area of the pipe [11,21,22,23,24]	Use smaller free areas to produce high intensive cavitation.(11,21,22,23,24)

VIII- WORKING OF HYDRODYNAMIC CAVITATION



- Cavitation is the formation of vapor cavities in liquid and this takes place in three steps : expansion, refraction and explosion of the cavities. Cavitation forms and develops in a flowing liquid through zones, in which the pressure of the liquid falls below a critical value, normally close to the saturated vapor pressure at a given temperature for the liquid. value for this pressure is dependent not only on the type of liquid, but also on the amount of pollutants such as micro-particles or macro-particles, and micro-bubbles containing incompletely dissolved gases. As the liquid expands, the pressure recovers and this results in the collapse of the cavities generating the forces and increase in temperature. After moving through the cavitating liquid into regions exceeding the critical pressure, the bubbles and cavities undergo sudden implosions in time periods significantly smaller than milliseconds, thus creating a local rise in pressure in different zones of the region.

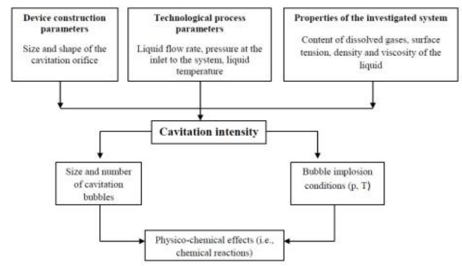


Figure 2: Main factors influencing the intensity of the cavitation process [2,5,11,20].

The first group consists of parameters such as the size and shape of the cavitation inducer and the flow chamber which determine the structural characteristics of the reactor

The second group consists of parameters which characterize the liquid medium in general: viscosity, density, surface tension and the dissolved gas contents.

The third group includes the technological process parameters; the “processing” time (the number of times which the medium passes through the cavitation region) and the interdependence between temperature and pressure of the process.

The technological effectiveness of the cavitation process depends on the cumulative effect of the above mentioned parameters. The range of the cavitation process parameters particularly the number of cavitation bubbles and their implosion conditions (i.e. pressure and temperature) is quite extensive. The magnitudes of the pressures and temperatures during bubble collapse, as well as the number of free radicals at the end of cavitation, are strongly dependent on the operating conditions and configuration of the hydrodynamic cavitation reactors.

IX- WORKING OF MICROBIAL FUEL CELL ALONG WITH HYDRODYNAMIC CAVITATION

Microbial Fuel Cells are promising for energy recovery and electricity generation from organic compounds using microbes as electro catalyst .Because of large variation in microbial metabolisms , many different organic compounds can be used as a substrate for electricity generation in MFC's .In anode compartment, organic matter is oxidized by microbial metabolism which transfers the electrons to anode . In cathode compartment, oxygen or oxidized compounds are reducedby microbial activities. With the help microbial activity on different organic compound electricity is generated in MFC's.

For example: Rice Bran is a potential source material for MFC's because of its rich nutrient and organic compounds. But it has major problem as rice bran contains cellulose, which has a crystalline structure , hence it is difficult to degrade.

To obtain an effective hydrolysis some substrates need efficient efficient pretreatment which is done by Hydrodynamic Cavitation. After Hydrodynamic Cavitation Treatment, a reduction on particle size could be seen on all the organic substrates.

This is the major advantage that cavitation successfully reduces the particle size in subsequent process. Because of large quantity of biopolymer such as cellulose should be altered therefore it can be easily digested by microbes in the MFC system.

- **To improve the digestibilityof biomass, pretreatment is the most powerful tool. Thus, we examined that the pretreatment of biomass by hydrodynamic cavitation , which has been found efficient for the pretreatment of biomass.**

X- CONCLUSION

Hydrodynamic cavitation is a new, advanced technology to be used in combination of mfc for the decomposition of complex compounds present in the sewage water and for generating voltage out of by-products or wastes from domestic or industrial wastewater/effluents. The use of hydrodynamic cavitation in environmental engineering technologies is very helpful as the waste water after treatment is been reused again in garden, other basic uses etc. . Microbial fuel cell (mfc) is a technolgy that uses an active microorganism as a biocatalyst in an anaerobic anode compartment for production of bioelectricity. However, mfc technology is not been used on a large scale because of low effeciceny of power generation as existing mfcs demonstrate low performance, have expensive core parts and materials. Rather, special applications to (i) power battery-reliant devices that consume reasonably small amounts of energy and (ii) facilitated studies of microbial behavior might be more applicable and potentially realizable. Therefore, microscale mfcs are rapidly gaining attention in a wide variety of applications such as portable power supplies, analytical study tools, energy storage devices, and toxicity biosensors. The combination of mfc and hydrodynamic cavitation can be proved to be very useful in various sectors of industries.

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