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Abstract

Microbial fuel cell (MFC) is an innovative remediation technology for waste and wastewater treatment because of its potential to degrade organic substrates and simultaneous generation of electricity. This paper briefly reviews the techniques employed in recent MFC studies and status of China's energy and water environment. According to the future development of economy and society in China, the paper discusses the application prospect of MFC from different aspects, such as field, scale, region, etc. and proposes related solution of energy and water environment problems to some extent.

Keywords

Microbial fuel cell; China; water; energy; application

INTRODUCTION

China is the developing country with the largest population in the world. The development of China has so far been unbalanced, as the East is much advanced than the West. As most development of economy was based on the cost of environment, China has realized the problem, and promoted the concept of sustainable development as a national policy. Still, approximately 56 percent of China's population lives in rural areas, where they have faced a complex array of energy and resource problems for a long time. In 21st century, with the increase of population, improvement of living standard, acceleration of urbanization process, the amount of water resource per capita decreases gradually, while the water demand is rising, contradiction between water supply and demand is becoming more significant, so water deficiency is the prominent restrictive factor of food security, economic development, social harmony, as well as ecological improvement in China.

Like most countries in the world, China is on its way searching for new renewable energy resources and technologies for environment protection. While microbial fuel cell is considered as a novel technology for wastewater treatment and energy resource, because it is based on electrochemically active microorganisms that grow by oxidizing the biodegradable material to carbon dioxide and protons, meanwhile transferring the electrons to a solid electrode (LOGAN et al, 2006). The electrons then flow through a resistor to a cathode, at which the electron acceptor is reduced. In contrast to anaerobic digestion, a MFC creates electrical current and an off-gas containing mainly carbon dioxide (RABAEY and VERSTRAETE, 2005). Obviously, concerned to some rural areas where lacking electrical infrastructures, or weak in environmental protection, microbial fuel cell has the potential for widespread application in waste treatment and also to expand the diversity of fuels used to meet the energy requirements.Microbial fuel cell undoubtedly can be used to fix some problems in China to some scale applications.

The principle of Microbial fuel cell

A microbial fuel cell (MFC) is a reactor that can convert biodegradable materials, e.g. organics present in wastewater, directly into electricity by the bio-electrochemical bacterial processes. Typical microbial fuel cells are designed with cathode and anode chambers separated by proton exchange membrane. Fuel (i.e. organic substrates) is oxidized via bio-catalysed reactions at anode onto which the electrons released during this oxidation process are transferred.. The anode is connected to the cathode via an external electrical circuit through which electrons flow to form the current. Electron acceptors are reduced at cathode by catalysts with protons arriving via the proton exchange membrane. Finally electrons, protons and oxygen react to form water at the cathode.

MFCs can not only generate electricity with simple carbohydrate as fuel, but also degrade other complex organic contaminants from wastewater. It now seems that electricity can be generated from any biodegradable material, ranging from pure compounds such as acetate, glucose, cysteine, bovine serum albumin and ethanol to complex mixtures of organic matter including domestic (human), animal, food-processing and meat-packing wastewaters.Compared to the traditional methods for treatment of wastewater, MFCs are able to operate and generate electricity effectively in ambient or at even lower temperatures, they produce less gas and less sludge and hence offer substantial cost savings for wastewater treatment. Since biofilms are ubiquitous, especially anaerobic sludge itself may serve as fuel for electricity production. The cell lysis accompanying endogenous decay of anaerobic sludge releases soluble substrates that can potentially support the regrowth of bacteria and electricity generation (HU, 2008).

The driving force of a typical MFC using glucose as substrate can be expressed through a redox reaction (GRZEBYK and POZNIAK, 2005). The chemical reactions at each electrodes are as followed:

$$C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$$

$$6O_2 + 24H^+ + 24e^- \rightarrow 12H_2O$$

MFCs have operational and functional advantages over the technologies currently used for generating energy from organic matter. First, the direct conversion of substrate energy to electricity enables high conversion efficiency (LOGAN, 2007). Second, MFCs take the advantage of general biochemical reaction, based on the function of microbial communities, without any extra energy input for aeration on the cathode. This distinguishes them from all current bio-energy processes, which results in lower operation and maintenance costs. Third, an MFC does not require gas treatment because the off-gases of MFCs are mainly carbon dioxide which does not have any useful energy content. Furthermore the redox products are usually CO_2 and H_2O, which are not considered contaminants. . Fourth, MFCs can have a huge range of resources as their fuel becuase they do not need to be high quality. Wastes are full of organic compounds most of which are degradable can be used in MFCs as fuel (RABAEY and VERSTRAETE, 2005) Fifth, MFCs have the potential for widespread application in locations lacking electrical infrastructures and also to expand the diversity of fuels we use to satisfy our energy requirements (LOGAN, 2007). For example, in the poor rural and mountainous areas in developing countries, people benefit from localized modest electricity generating facilities like

MFCs to provide light at night or access to the internet; both of which could change the education prospects of a generation of poor children

Researchers are expanding the concepts of MFC, modified MFC reactors are coming out to deal with different situations, either huge or small. The application of MFC technology is continuously developed on its way of non-membrane and non-mediator, becoming more and more feasible in its practical application, not only in the lab. One reason of these trend is because the materials are very expensive. Widespread application need to cut down the cost of MFC reactors.

Status of water and energy in China

China is the biggest developing countries with the largest population in the world. It is characterized by unbalance in distribution of population, water resources and energy. The economy is most developed in east of China which has a larger population, but less resources compared to the west. However, the disparities are also on the north-south axis, with for example the north having typically less water resources than the south. That's the reason why big projects, such as the South-to-North water diversion project and the West-to-East natural gas transmission project promoted. These are efforts to alleviate the unbalance between economical development and energy resources.

Status of water environment

The total volume of fresh water is about 2800 billion m^3; accounting for 6% of the global freshwater resources. However, the amount of water per capita is just 2300m^3,
one fourth of the world average level. This makes China one of the worst 13 countries lacking water resource per capita countries as defined by the United Nations. Besides, much of the cited freshwater is not readily available, as it comes in the form of seasonal floods and groundwater in remote areas. As such the real available fresh water is only 1100 billion m^3, around 900 m^3 per capita. Especially, water resource availability in 6 provinces and regions of North China amounts to merely 500 m^3 per capita, which is half the critical value of the United Nations (UN) standard (1,000 m^3 per capita) Comparably, Canada uses 1,600 cubic metres of water per person per year, not to mention the available water resource per capita (Canada vs. The OECD, internet, 2009).

China has serious water-deficient problem, especially in the northern areas. Most of freshwater resources are in the South, with three times more water than the North of the country. Though the water resources currently meet the demand, China is facing many water-related problems that will compromise the sustainable use of this precious resource. Such problems include: the uneven distribution of water resources in time and space; pollution; wasteage; low consumption efficiency; and aquatic ecosystem imbalance. All of these issues have resulted in a conflicting situation between the supply and availability of freshwater in recent years (Baidu-Contributors, 2009)..

According to the data from China Water Resources Bulletin 2007(*China Water Resources Bulletin 2007*, 2008), the annual usage of water amounted to 302.2 billion m3, most of which was used in agriculture (74.6%) followed by domestic and industrial consumption (12.4 and 11.0 %, respectively). Water wasteage rates also varied between different user groups greatly, industry, municipal, irrigation, and rural living cost 24%, 30%, 62%, 84% respectively. Also water pollution is an increasing threat to water resources. In 2007, wasterwater discharge of whole country was 75 billion ton, two thirds were industrial wastewater, and one third was from domestic and the third industry. Taking Yellow River as an example, industrial wastewater is the main cause of its pollution, occupied 73% of the total wastewater discharge, result in nearly 6 billion RMB loss annually, including loss of water resource value, municipal water supply, and also increasing the extra investment of wastewater treatment. And most of the industrial wastewater is full of high strengthed organics.

Status of energy
China's energy stockpile amount ranks the first class of biggest stockpile in the world. Meanwhile, however, China also ranks amongst the world's largest energy consumers. Coal plays a dominant role among the energy resources which have been explored in China, though the global energy system has transferred from coal to petrol and gas as primary energy fuels. Recently, other renewable energy resources are currently being developed, like hydropower, wind, solar, biofuel, geothermal, ocean energy. But these have still not been implemented in a large-scale. It is estimated that the usage of renewable energy may be improved from 7% at present to about 16% till 2020 (FENG, 2007). China's energy consumption is rising in accordance with its economical growth. However, the energy efficiency is still lower than developed countries, due to issues related to finance, technology, energy price and so on. China's growing coal-based energy demand has also lead to other problems such as air pollution and its associated environmental pressures. Chinese energy policy is now starting to consider such impacts and is seeking to avoid further environmental damage.

According to the Chinese National Development and Reform Commission Energy Bureau, the energy issue in rural areas is also very serious. Most villagers in West China don't have enough power and there are still more than 10 million people don't have electricity at all. Accelerating construction of off grid renewable energy sources such as solar, wind, biofuel energy can provide a suitable energy solution for such villages (WU, 2007).

MFC TECHNOLOGY POTENTIAL

Microbial fuel cell technology has the ablility to treat organic wastes whilst generating electricity. As such this technology has the potential to tackle two of China's greatest problems at once. Furthermore, MFC technology can be applied in different fields of interest to China's sustainable development. However, there are issues that need to be overcome in order for MFCs to become a viable solution.

Applications

Wastewater treatment According to the mechanism of MFC, it is obviously that MFC is a clean way to treat wastewater. It oxidizes organic matters at the anode with bacteria, and the product at the cathode is water without producing any contaminants. MFC does not need any extra energy input, also can operate in an ambient atmosphere, without location restriction at all. In current China, the water pollution is a serious problem which affects the limited water resource. Especially a lot of factories discharged a huge amount of sewage which had extremely high concentration of organic matters. MFC is undoubtedly a good option to solve it. Once the power density of MFC would have been improved much enough will make wastewater treatment into a lucrative energy business.

Bioremediation One novel application of the MFC is as a method of bioremediation, Because MFC utilizes microorganisms to return the natural environment altered by contaminants to its original condition, such as degradtion of hydrocarbons by bacteria. Remediation can include degradation of organic pollutants at the anode as well as reduction of inorganic chemicals such as nitrate or uranium at the cathode. The Sediment MFC consists of anode in the anaerobic sediment and cathode in overlying water containing dissolved oxygen. It suits river, lake and coast line where sediments are full of organic carbon and exoelectrogenic bacteria already present in them.

Also, it has been shown that MFC-based technologies could be used to remove nitrate, conversion to nitrite, even N_2 gas from water, reduced by receiving electrons from the cathode. It is known that nutrient removal is critical to treatment objectives of most wastewater treatment. Because findings on nitrogen removal show great promise for new types of nutrient removal processes for wastewater treatment, particularly if nitrogen can be removed without the need for additional post-treatment carbon sources or through water recycling. Typically, as the lake eutrophication phenomenon is highlighted recently in China, like Taihu Lake and Dianchi Lake, both are the result of water body pollution, may be capable to use MFC technology to treat and remove the nutrient.

Biosensors The current output of an MFC can be related to the type and amount of substrate being treated. Therefore MFCs can be used as biosensors to monitor quality parameters that are related to substrate characteristics, such as biochemical oxygen demand (BOD). Such a sensor may contribute into wastewater treatment plants as a monitor to test the treated wastewater's BOD concentration and calculate BOD removal rate. Compared to the conventional BOD assays, MFC BOD biosensor has the advantage of time saving. Because conventional BOD assays need 5 days at least to test the value, while BOD sensor reflects BOD value by the electricity produced by MFC in 24 hours.

It also has been suggested that the voltage output from small scale MFC can drive MEMS (microelectromechanical systems) devices, which doesn't need too much electricity. Microelectromechanical systems is the technology of the very small, and merges at the nano-scale into nanoelectromechanical systems (NEMS) and nanotechnology. MEMS are also referred to as micromachines (in Japan), or Micro Systems Technology - MST (in Europe) (Wikipedia-contributors, 2009). At the same time, products of MFC are water and carbon dioxide which won't relate to contamination and erosion to MEMS. Like micro blood glucose testing meter combined with a MFC, operates with the electricity produced by MFC using glucose in blood as fuel, while transferring into electromagnetic signals to show the information about blood glucose concentration, in order to monitor it for long time. So the similar inner bio-detection can use the MEMS combined with MFC technology, which is another prospect of MFC development in medical application (YANG et al, 2007).

Scale of Applications

Centralized wastewater treatment plant Most researchers focus on microbial fuel cell's benefits and modified it in wastewater treatment plants. The reactor of it has been suggested to scale up to treat a huge amount of wastewater. More than 40 million cubic meters of municipal wastewater was treated each day in China according to 2005 estimates. Most of this wastewater was sent to centralized facilities that consume large amounts of energy for treatment due to aeration and produce a great deal of surplus sludge. In the more developed regions in eastern China, it is possible that MFCs can be used to replace the conventional bioreactors like activated sludge (AS) or trickling filters (TF) treatment systems. The MFC is a treatment process that has been advocated to solve high energy costs and sludge treatment expenses problems of anaerobic treatment limitations (LIU et al., 2004). And thus its function will be to remove BOD in the same manner as accomplished by the AS aeration tank or the TF. With increasing of the power generation in the system, MFC may provide a new method to cut down wastewater treatment plant operating costs, making advanced wastewater treatment technology affordable by developing countries. MFC can even take a place in the discharge of industrial wastewater before it flowing into centralized treatment plants. It means pretreat industrial wastewater in a MFC bioreactor on the way to conventional treatment plants. High strengtened contaminants present in wastewater are the sufficient food source for microbial communities, result in high current output. Furthermore, it could allieve the pressure of centralized facilities in treating and save its energy cost in aeration.

Home-use MFC for wastewater treatment In the remote areas, like the western mountainous villages, it is not practical to treat wastewater in a centralized facility. This is due to the small quantities of water consumed and also because the dwellings in this are typically very sparsely distributed, making the collection system for a centralized wastewater treatment facility uneconomical. In this way, MFC can be utilized efficiently to treat domestic wastewaters on site. Though the effluent of MFC can not reach the water quality for drinking, once the organics removal rate of MFC reaches the level of making water suitable to reuse, it will decrease the frequency of pumping groundwater out of wells by villagers. It is absolutely a good way to solve water problem to some extent in these areas.

Direct current devices Based on the other main function of MFC, electricity generation, though the power density gained is not very high so far, it has proved the electricity produced by MFC is sufficient to run some little direct current devices. Little fan, flashlight are the examples of devices which could use the electrity produced by MFC. To this point, MFC has significant implications, especially for the electricity lacking areas. MFC is reliable, once it started, it can operate for quite a long time and gain continuous current. The main limitation of MFC is low power density at present, due to its high internal resistance, but it can solve with a storage battery to collect the electricity, just like the use of solar cells.

Region

As it discussed above, in well developed cities and regions, MFC's benefit of electricity production will be most probably ignored in commercialization before it improved power density output, but its utilization in wastewater treatment process will be widely applied. In addition, the landscape is profitable for using scaled up MFCs. However, in places where lacking electricity, MFC technology do give a positive aspiration for people getting energy from wastes.

Considered as a novel renewable energy resource, MFC can help to contribute into the new rural villages, because energy demand is going to be satisfied according to the rural development policy, and besides solar, geothermal, biomass energy, MFC is another alternative. Virtually all biomass energy in China is used in rural areas, where approximately 56% of the population lives, the rural sector includes rural households, agricultural activities. Utilization of MFCs could better combine with these aims, for example, heating is critical in the north, while cooking for pig feed is important in south and central areas, once MFC improved the electricity production, we'd better transfer it into thermal energy to meet the demand of these rural places.

CONCLUSIONS

Microbial fuel cell technology has a huge amount of potential and will emerge gradually an essential element for both renewable energy resource and wastewater treatment process. As the status of water and energy in China, both are very important factors for sustainable development, the idea of MFC can match these two aspects greatly. And the application of MFC technology should consider the practical situations such as in field, scale or region, in a word, adaption to local conditions. Also MFC can treat waste and wastewater, undoubtedly, it is a good alternative to solve the present serious problems in environmental protection in China. However, there are still many challenges remaining to fully exploit the maximum power production possible by MFCs. Concerns to the limited energy production, MFC is on its way of improvement, excluding saving water and energy, especially in some extreme rural areas where no electricity at all. Thus, reductions in material costs, advancements in power densities will make a wide range of MFC technologies have a bright and promising future.

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