Potential of phytotechnology in wastewater treatments to produce alternative electrical energy: a review

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Potential of phytotechnology in wastewater treatments to produce alternative electrical energy: a review

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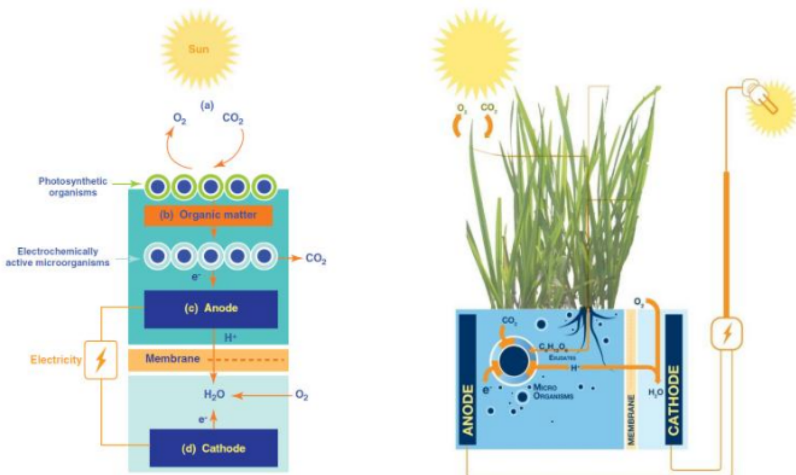
Abstract. Recently, phytotechnology has gained much attention due to its capability in treating wastewater by biological processes. Phytotechnology is the application of science and engineering to examine environmental problems and provide solutions by the direct use of plants for in situ removal or degradation of contaminants or improving environmental function and quality. This process using bacteria formed in the roots of the plant and it can be applied to treat the wastewater. In this phytotechnology process, it presents the potential for energy generation and comprehensive wastewater treatment in Microbial Fuel Cell (MFC) system, which in the process utilizes bacteria that can produce alternative electrical energy because of the activity of bacteria which can self-mediate electrons to the anode through contact between the membrane-anode. MFC are expected to be applied to energy-saving wastewater treatments (WWT). The combined of MFC and phytotechnology system have function to degrade organic compunds and remove contaminant contained in wastewater to produce bacterias that come out in the roots and then the bacterias will be used by electrodes to produce electricity. This paper will analyze the advantage and disadvantages of phytotechnology system while used to produce electrical energy by MFC system as hybrid system. Based on the existing research, show that phytotechnology has a lot of advantages. One of the advantages is promising low cost, highly efficient, and renewable energy-producing alternative to conventional wastewater treatments.

1. Introduction

The application of phytotechnologies which is a combination of science and engineering will involve the use of plants to prevent, reduce or restore wastewater that exists in the ecosystem. Plants can also be used as indicators to monitor and assess the health of ecosystems [1]. In the phytotechnology system, an in situ approach is used, so native plants are more recommended in the application of this system. In most applications, plants that are adapted to local conditions will have better chances of success than non-adapted plants [1]. Wastewater treatment must be done because it is one of the most basic sanitation needs to protect the environment and water bodies. Wastewater is complex substrates, rich in organic carbon and nutrients, as well as energy [2]. First, it provides an overview of current energy needs for wastewater treatment and potential energy recovery options followed by a comprehensive review of the principles of wastewater treatment, substrate utilization (organic removal), recent process developments, nutrient and metal removal capacities in microbial fuel cells [3]. This wastewater is treatment is carried out in the phytotechnology process with the Microbial Fuel Cell (MFC) system to produce the potential energy because of the activity of bacteria that came out from the root of the plants which can self-mediate electrons to the anode through contact between the membrane-anode. This paper will analyze the advantage and disadvantages of phytotechnology system while use for produce electrical energy by MFC system as hybrid system by reviewing journals related to phytotechnology and microbial fuel cell systems.

2. Microbial fuel cell

Microbial Fuel Cell (MFC) is a device that uses microbe as a catalyst to convert organic and inorganic substrates into electrical current. It uses living plants and bacteria to produce electricity [4]. Naturally occurring processes around plant roots are utilized in the MFC system to generate electricity directly. Organic matter is produced from sunlight and CO_2 is produced through photosynthesis by plants. 70% of this organic matter ends up in the soil as dead root, lysate, mucus, and exudate and will be oxidized by bacteria that live in the roots and surrounding areas, to release CO_2, protons and electrons. Electrons are donated by bacteria to the MFC cell anode. Anodes are combined, through an external load to the cathode. Protons released at the side of the anode move through a membrane or spacer towards the cathode. At the cathode ideally oxygen is reduced together with protons and electrons to water. MFC is a specific form of Microbial Solar Cells; system where Microbial Fuel Cells or Microbial Electrolysis Cells are solar-powered. Schematic presentation of Microbial Solar Cells and Microbial Fuel Cells using plants is shown in Figure 1 [5].



A *B*

Figure 1 Schematic overview of a Microbial Solar Cell (MSC) (A) of which the Plant-Microbial Fuel Cell (P-MFC) (B) is a specific type. In the P-MFC the photosynthetic organisms are plants.

3. Phytotechnology system

Phytotechnology system is an emerging field that implements solutions to scientific and engineering problems in the form of plants. Plants commonly used in MFCs are plants that can grow with roots flooded in water, to avoid oxygen intrusion from the air to the anode. If oxygen is available at the anode, electrons will be directly used for oxygen reduction and will be lost for electricity production. Biomass production from sunlight occurs through photosynthesis. In general, the rate of photosynthesis can range from 2.5 to 5%. The main factor of photosynthesis depends on the concentration of CO2 and the intensity of PAR light at the plant level. The intensity of PAR (Photosynthetically active radiation) is around 150 W m in Western Europe but can be 10 times higher around the equator [6].

The main principle is that plants produce rhizodepocytes which are mostly in the form of carbohydrates, then the bacteria convert the rhizodepocytes into electrical energy through MFC. But, when plants get older, rhizodeposition decreases. Hence, it can be hypothesized that power output of a PMFC declines near the end of the life cycle [5].

One combination of the MFC with ecological treatment technologies is integrating an MFC into the wetland treatment system. Researchers have reported that the plants would be able to secrete organics into soils and sediments in the form of rhizodeposits, accounting for about 40.0% of plants photosynthetic activity [3].

Rhizodepocytes are excreted by plant roots and then converted to electrons, protons and CO_2 by electrochemically active microorganisms that are around the roots. These microorganisms have been found capable of delivering these electrons to solid surfaces, such as graphite which is one of the materials most often used as electrodes, under anaerobic conditions [5]. There are other materials that can be used as an electrode in MFC system, such as : carbon felt, carbon cloth, carbon paper, glass slide coated with a layer of Cr/Au or Ti/Pt, glassy carbon, graphite foam, graphite felt, multilayer graphene coating on stainless steel electrode, graphite plate, graphene, and etc.

Table 1. Types of plants that have been used in previous studies

No	Plants	Microbes	System output	Explanation	References
1.	Ipomoea aquatic	Dye Wastewater	560 mV and 0.88 W/m^3	Using Constructed Wetland MFCs	[7]
		Anaerobic Sludge from municipal wastewater	1242 mW/m^2		[8]
2.	Spartina Anglica	Industrial Wastewater	222 mW/ m^3		[5]
3.	Arundinella Anomala	Industrial Wastewater	22 mW/ m^3		[5]
4.	Arundo Donax	Industrial Wastewater	-	Stopped after 10 weeks because of the break down in the system due to the root growth of the plant	[5]
5.	C. Indica	Tap Water	18 mW/m^2	Constructed wetland	[9]
6.	Elodea Canadensis L	Agriculture and irrigation wastewater	407 mV after 6 days using electrogenic drugs	Make plant phytomass as an energy source	[10]

4. Discussion

4.1. Advantage of phytotechnology in microbial fuel cell (MFC)

Generally, five advantages make MFCs more sustainable when implemented in wastewater treatment: (1) the direct conversion of substrate energy to electricity; (2) less excess activated sludge compared to the processes of AD and conventional aerobic activated sludge CAAS; (3) insensitive to operation environment, even at low temperatures; (4) without any gas treatment; (5) without any energy input for aeration; (6) a widespread application in locations with insufficient electrical infrastructures [11].

PMFCs with algae biocathode offer several advantages: i) the treatment and purification of urban or industrial wastewaters, ii) the growth of functional microalgae, iii) the harvesting of bioelectricity. The presence of microalgae at the bio-cathodes also makes this technology more sustainable in terms of costs, because it helps to replace the mechanical aeration methods. In addition, it reduces also the CO2 generated from bacterial metabolisms and respiration [12].

Another advantage of using MFC technology for wastewater treatment over conventional anaerobic digestion is that it can be employed for the remediation of dilute wastewater. An important advantage of an MFC is the lower cell yield compared to aerobic processes. This is caused by the reduced energy available for biomass growth as a significant part of the substrate energy is converted to electrical power. The benefit of CW-MFC system is that it takes the advantages of MFC and CW to achieve wastewater treatment and bioenergy generation concurrently [13].

Another advantage of MFC technologies is it is less dependent in comparison to other renewable energy technologies (i.e. solar and wind) upon geographical location and seasonal change [14]. The advantage of the system was that a malfunctioning unit could be easily replaced by a new one without disturbing the whole system

Moreover, cathode driven processes carry a number of advantages: cathode chambers can be altered to use environmentally friendly processes to provide strong electron acceptors in the form of pure oxygen, nitrites, nitrates and sulfates (which are other environmental pollutants that will be reduced to less toxic forms in this process); and there is no need for external chemicals for electron acceptors, which omits the need for their transport, storage, dosing and posttreatment; the dosing of the electron donor occurs in situ (if necessary, e.g. denitrification) [15]

Some benefits of using phytotechnologies compared to conventional methods of cleanup are the relatively low capital costs, high community acceptance, aesthetic and ecological value, and sustainability [16].

In terms of capital costs, many phytotechnology applications simply involve the cultivation of a plant *in situ* allowing for the conservation of important resources such as energy and water [16]. Phytotechnologies also have ancillary positive impacts on the surrounding environment, providing ecosystem services with tangible, quantifiable value for public health and social welfare [17]

Three special features (i.e. energy saving, less sludge production, and energy production) make MFCs outstanding compared with the existing technologies. It has been demonstrated that MFCs would be capable of effectively removing several contaminants.MFC technology has the ability to directly convert chemical energy into electrical energy through biological processes [18].

MFC is an environmentally friendly technology because it consumes only about 10 percent of external energy, it shows great potential for energy savings and enables energy recovery in wastewater treatment [2].

MFC are more flexible for degrading medium- and low-strength wastewaters with a relatively simple composition [18]. The integration of MFC is promising, principally no use of chemicals or, mechanically simple, environmentally friendly, and sustainable [18].

MFC has great treatment effects in terms of the removal efficiency of COD or other contaminants. The effluent COD was less than 20 mg/L with the maximum removal efficiency of COD was more than 90.0% [18]. MFC offers some energy (direct electricity generation, energy savings by anaerobic treatment because it eliminates aeration, low sludge yields, and centralized and decentralized applications); environment (water reclamation, low carbon footprint, lower sludge volume to be disposed of); economy (income through energy and value-added products - chemicals, low operating costs, eliminating downstream processes) and operational benefits (independent microorganism creation, good resistance to environmental stresses, and can receive real-time monitoring and control) [2].

4.2. Disadvantage of phytotechnology in microbial fuel cell (MFC)

The combination of energy out and operation cost of MFC has hindered their applications at practical scales. Long-term stability would be another great challenge along with the solution of energy out and capital investment [18]

Another problem is its non-functionality at low temperatures, which renders the microbial biocatalysts inactive, thus, inhibiting the bioanodes or biocathodes [19].

5. Conclusion

This paper presents an overview of the contribution of a combined system of phytotechnology and microbial fuel cells in wastewater treatment that can produce alternative electrical energy. The main scope of this review is to present an analysis of the advantages and disadvantages of MFC. This MFC system offers potential prospects in wastewater treatment that generates renewable electricity but it has problems in the form of its non-functionality at low temperatures, which renders the microbial biocatalysts inactive, thus, inhibiting the bioanodes or biocathodes. MFC shows the potential for sustainable hybrid systems to reduce the increased energy demand for wastewater treatment and environmental protection [20]. In general, there are three features in wastewater treatment using MFC, namely energy saving, less sludge production, and generating alternative electrical energy. Many studies have explored the capacity of MFC to treat different wastewater and different plant uses. It has been proven that MFC is able to eliminate multi-contaminants, such as biological wastes, heavy metals, polyalcohol, petroleum products dyes, phenol, and phenolic compounds, furan, quinolone, pyridine derivatives. To apply the development of MFC in sustainable wastewater treatment, future research must emphasize: (a) the mechanism of metabolism, electrochemically active microorganisms will contribute in choosing microorganisms of high electrochemical activity; make conductive thick biofilms and optimize operating conditions; (b) the design and architecture of the MFC reactor will immediately decide on the application of MFC in wastewater treatment. (c) The stack of MFC, voltage reversals and ionic short circuit is still a major obstacle in practical application due to the reaction of the biocatalysis electrode in the MFC; (d) development and utilization of power so that it will accelerate MFC commercial applications; (e) synergistic effect by combining with other wastewater treatment technologies to accelerate the application of MFC in wastewater treatment.

Acknowledgements

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References

[1] UNEP 2004 *Phytotechnologies, A Technical Approach in Environmental Management* (*Fresh water Management Series No. 7*). United Nations Environment Programme USA
[2] Gude V G 2016 *J. Clean Prod*. **122**. 287-307
[3] Rosenbaum M, He Z andAngenent L T 2010 *Current Opinion in Biotech* **21**. 259–264
[4] Strik D P B T B, Hamelers H V M , Snel J F H and Buisman C J N 2008 *Inter. J. En. Res*. **32.** 870 – 876
[5] Helder M 2012 *Design criteria for the Plant-Microbial Fuel Cell Electricity generation with living plants – from lab to application (*Thesis) (Wageningen University)
[6] Taiz L and Zeiger E 2006 *Plant physiology* 3rd ed. (Sunderland, Mass: Sinauer Associates)
[7] Fang z, Song H, Yu R and Li X 2016 *Ecol. Eng*. **94** 455 – 463
[8] Liu S, Song H, Li X and Yang F 2013 *Inter.J. Pho.en*. **2013**
[9] Lu L, Xing D and Ren Z J 2015 Biores. Tech. **195** 115-121
[10] Stom D I, et al 2017 *IOP Conf. Ser.: Earth Environ. Sci*. **52** 012029
[11] Palanisamy G, Kim S C, Jung H Y, Sadhasivam T, Kurkuri M D and Roh S H 2019 *J. Clean. Prod*. **221** 598-621
[12] Pandit S and Das D 2015 *Role of microalgae in microbial fuel cells* (*Algal Biorefinery: An Integrated Approach*) 1st ed., Springer International Publishing.
[13] Fang Z, Song H L, Cang N and Li X N 2013 *Biores. Tech*. **144** 165 – 171
[14] Rabaey K, Verstraete W 2005 *Trends Biotech* **23** 291 – 298
[15] Gude, V G , Kokabian B, Gadhamshetty V , 2013 *J. Microb.. Tech*. 6, 2
[16] Interstate Technology & Regulatory Council 2009 *Phytotechnology Technical and Regulatory Guidance and Decision Trees,* (*Revised*). (Interstate Technology & Regulatory Council Washington (DC)

[17] Holzman D C 2012 *Env. Health Perspect* **120 (4)** 152–157
[18] He L, Du P, Chen Y, Lu H, Cheng X, Chang B and Wang Z 2016 *Renew.and Sustain. En. Rev.* **71** 388-403
[19] David P B T B, Strik H V M, Hamelers B, Jan F H Snel and Cees J N B 2016 *Intern. J. En. Res.* **32(9**) 870 – 876
[20] Zhang Y, Liu M, Zhou M, Yang H, Liang L and Gu T 2019 *Renew. and Sustain En. Rev.* **103** 13 – 29

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