IJE available online at www.ije-pyc.org
INDONESIAN JOURNAL OF ENERGY

Facing Indonesia’s Future Energy with Bacterio-Algal Fuel Cells

Intan Subadri[1]*, Adhi Satriyatama[1], Ignatius D. M. Budi[1]

[1]*Chemical Engineering Department, Faculty of Industrial Technology, Institut Teknologi Bandung, Jalan Ganesha No. 10, Bandung 40132, Indonesia*

Received 3 July 2020; Accepted 11 August 2020
Available online 31 August 2020

Abstract. The energy crisis has become a global issue that has plagued almost all parts of the world. MFCs (Microbial Fuel Cells) is an alternative technology because of its ability to convert waste into electrical energy. The bacterio-algal fuel cell (BAFCs) is kind of an effort for increasing the economic value and carbon capture capability of MFCs. In this case, algae used as a catholyte and organic substrate containing anode-reducing exoelectrogenic bacteria acted as anolyte. This research will examine the potential of algae in BAFCs as an alternative energy for Indonesia's future. By photosynthesis reaction, bacterio-algal fuel cells are operated in a self-sustaining cycle. It can be configured in single, dual chambers, and triple chambers. The performance of bacterio-algal fuel cells is strongly influenced by the bacterial and algae species in each compartment. Factors involved in bacterial-algal fuel cells are also analyzed and assessed: electrode materials, membrane, carbon sources, and algae pretreatment, including the operational parameter, such as pH and temperature. Bacterio-algal fuel cells are recommended to be used to convert algae into electricity by scaling-up and integrating the devices. Organic substrate could be obtained from municipal wastewater. Algae as by-product could be harvested and converted into certain products. Algal Fuel Cell is the solution to produce electricity and reduce CO_2 pollution at the same time. Also, an algal fuel cell is potential for sustainable use in the future. By integrating the algal fuel cell in the factory that produces high-concentrated wastewater, the fuel cell can purify the wastewater so that it is safe to be drained to the environment and also can make an integrated electricity production for the whole factory. Some ways to improve the power production are proposed to improve the power generation from BAFCs since this technology offers clean, affordable, sustainable energy, and in-line with SDGs.

Keywords: bacteria, algae, microbial fuel cells, renewable energy

1. Introduction

In recent years, the energy crisis has become a global issue that has plagued almost all parts of the world. Massive utilization of petroleum or other fossil fuels still dominating worldwide energy consumption, that is equal to 50.66% (Dudley, 2018). Indonesia is also facing a huge dependency on fossil fuels, reaching 91% (Suharyati et al., 2019). In addition, the widespread use of fossil fuels also increases the concentration of CO_2 in the atmosphere, causing global warming (Doney & Schimel, 2007). This makes the development of research currently leading to renewable energy that is environmentally friendly.

MFCs (Microbial Fuel Cell) is an alternative technology because of its ability to convert waste into electrical energy (Lovely, 2008). One of the elaborations of MFCs is bacterio-algal fuel cells (BAFCs). In general, MFCs consists of two compartments separated by membrane with an external circuit connecting the anode and cathode. Based on the type of catholyte, MFCs can be divided into 1) abiotic catholyte, such as $KMnO_4$ and 2) biotic catholyte, such as algae and cyanobacteria (Rismani et al., 2008). The bacterio-algal fuel cell is a kind of effort for increasing the economic value and carbon capture capability of MFCs. In this case, algae used as a catholyte and organic substrate containing anode-reducing exoelectrogenic bacteria acted as anolyte. This research will examine the potential of algae in

---

*Corresponding author
E-mail address: intansubadri@gmail.com

BAFCs as an alternative for Indonesia's future energy, supporting 23% of renewable energy sources program in 2025.

2. Bacterio-Algal Microbial Fuel Cells

2.1 Reaction Mechanisms

Bacterio-algal microbial fuel cells are operated when the organic substrate on the anolyte is oxidized by bacteria. Oxygen is then produced by algae in the catholyte. In this case, oxygen acts as an electron acceptor, which is by reducing CO_2 and producing water through the mechanism of photosynthesis. The chemical reaction equation in the cathodic chamber is explained in equations (1), (2), and (3).

Light reaction (Photosynthesis)

$$6CO_2 + 12H^+ + 12e^- + \rightarrow C_6H_{12}O_6 + 3O_2 \qquad (1)$$

Dark reaction (Calvin cycle)

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \qquad (2)$$

Cathodic reaction

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \qquad (3)$$

Algae growth in the cathodic chamber occurs in a self-sustaining cycle. Overtime, the formation of biofilms on electrodes and chamber surfaces can also occur due to algal growth. The formed biofilm could act as both an electron acceptor and be penetrated in the algal cell body (Lin et al., 2013). In addition, the effect of dissolved oxygen on algal biofilms has an important role in the performance of bacterio-algal microbial fuel cells (Wang et al., 2013).

2.2 Bacterio-Algal Microbial Fuel Cell Configurations

In general, configurations in bacterio-algal fuel cells consist of three types, which are (1) single chamber, (2) dual chambers, and (3) three chambers. Further illustration explained in Figure 1 below.

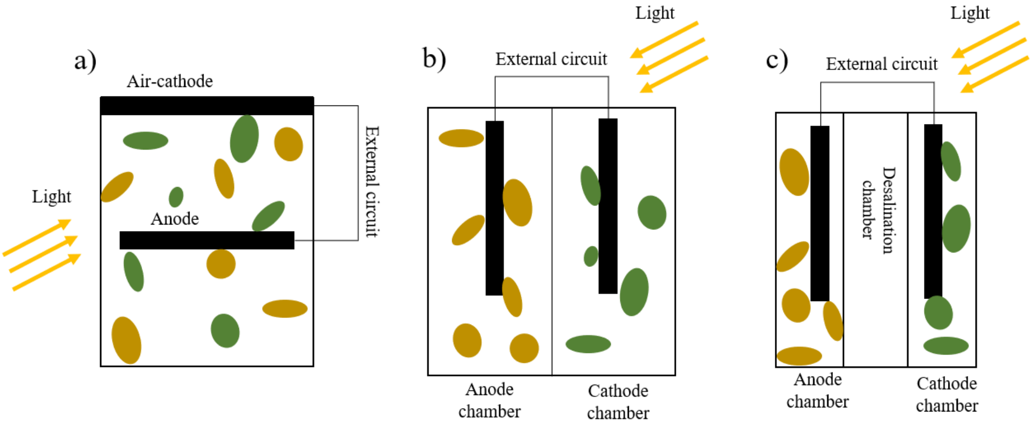

Figure 1. BAFCs configuration (a) single chamber, (b) dual chamber, and (c) triple chambers.

In a single chamber model, algae and bacteria are grown together in one chamber. The main characteristics of a single chamber are cathodes are directly exposed to water (air-cathode), membrane-less, easy to operate, and cost effective in scaling up. Single chamber is relatively easier to operate on a laboratory scale compared to other types.

In dual chamber type, algae and bacteria are separated by a membrane in two compartments. In order to accommodate photosynthesis, light source is placed on the algal side. The performance of this configuration is strongly influenced by membrane crossover and internal resistance.

In triple chambers technology, a compartment containing saline solution is placed between the anode chamber and the cathode chamber. The compartment functions as a desalination process, where cations move towards the cathode and anions move towards the anode. The presence of a salt solution is known to reduce electricity production compared to dual chambers (Kokabian et al., 2013; Saba et al., 2015).

2.3 Electricity Production

The performance of bacterio-algal fuel cells is strongly influenced by the bacterial and algae species in each compartment. Table 1 below explains the effect of bacterial and algae species on electricity generated with dual-chamber type compartments.

Table 1. Power output from various anodic and cathodic contents.

Cathodic contents (algal)	Anodic contents	Power output (mW/m^2)	References
Blue green algae	Anaerobic wastewater sludge	114	Yuan et al., 2011
Chlorella vulgaris	Activated sludge	13.5	Campo et al., 2013
Desmodesmus sp.	Synthetic wastewater	99	Wu et al., 2014
Mix algal culture	Municipal wastewater	11.5	Lobato et al., 2013
Chlamydomonas reinhardtii	*Geobacter sulferreducens*	41	Nishio et al., 2013
Scenedismus obliquus	Activated sludge	1,780	Rashid et al., 2013
Laminaria saccharina	Wastewater microbial consortium	118	Gadhamsetty et al., 2013
Chlorella vulgaris	Domestic wastewater	5,200	Wang et al., 2010

3. Factors involved in Bacterio-Algal Microbial Fuel Cells

3.1 Electrode Materials

Anodes in BAFCs are used to conduct electricity caused by bacterial activity that forms biofilms. Carbon-based anode is a material that is often used due to its good chemical, better conductivity than other materials, low prices, and supports the formation of biofilms properties. Various carbon-derivative materials, such as carbon felt, graphite felt, and carbon paper have been widely used as electrode materials as seen in Table 2.

Table 2. Power density of various anode-cathode materials in BAFCs.

Anode	Cathode	Power density (mW/m^2)	References
Carbon felt	Fe-N-C	2,437±55	Pan et al., 2016
Graphite plates	Graphite plates	1,771	Kaewkannetra et al., 2011
Porous carbon	Air cathode	1,606	Chen et al., 2015
Carbon felt	CoO@N-AC	1,650±36	Huang et al., 2017
Carbon fiber felt	Carbon paper with Pt catalyst	1,015	Wang et al., 2009
3D GA/Pt	Pt sheet	1,460	Zhao et al., 2015
MWCNT/SnO_2/GCE	Pt rod	1,421	Mehdinia et al., 2014
N-doped graphene	Carbon cloth	1,008	Kirubaharan et al., 2015

In addition, the material used as a BAFCs chamber varies from polymers to ceramics. The use of specific types of material has not yet demonstrated its effect on BAFCs performance. As an electrode connector, copper wire tends to be widely used because of its advantages in thermal and electrical conductivity and good mechanical properties (Kakarla et al., 2014; Li et al., 2013). Corrosion resistance also supports the use of copper as an electrode connecting cable material (Harper et al., 1994).

3.2 Membrane

In BAFCs, the membrane acted as an ion-transfer and separator between positive and negative electrodes. Membranes can also prevent crossovers between anodes and cathode chambers due to effluent, CO_2, and oxygen (Ho et al., 2013; Li et al., 2011). Different types of membranes for proton conductivity are explained in Table 3. Nafion® is the most widely used membrane type because of the high conductivity of protons.

Table 3. Various membrane materials and its properties for BAFCs.

Membrane	Thickness (μm)	Proton conductivity ($S\ cm^{-1}$)	Water uptake (%)	References
PVA-Nafion-borosilicate (MPN)	167	0.07	105	Tiwari et al., 2016
Sulfonated-oxy-polybenzimidazole	20-30	0.0783	29	Singha et al., 2016
Sulfonated PEEK	180 (±20)	0.00163	15.85	Venkatesan et al., 2015
SPSEBS	180	0.382	164	Ayyaru et al., 2012

3.3 Carbon Sources

Electricity production in BAFCs is generally influenced by the oxidation-reduction reaction at the anode chamber. Several carbon sources for organic substrate are reported to have been commonly used, such as glucose (Wang et al., 2010), formate and acetate (Nishio et al., 2013). Other carbon sources that can be used are LB medium (Walter et al., 2013), GSMM (Gadhamsetty et al., 2013), *Scenedesmus* algae

(Cu et al., 2014), GM Medium (Kakarla et al., 2014), fruit industry waste (Campos et al., 2006), and synthetic wastewater (Wu et al., 2014).

3.4 Algae Pretreatment

Algae is a large group of species that has chlorophyll to do a photosynthesis process in its cell. There are some types of algae, unicellular or multicellular, microscopic, or macroscopic, freshwater algae or saltwater algae. Because of the capability to do photosynthesis, algae can absorb the CO_2 in environment naturally and convert it into carbohydrates and oxygen. In fact, algae reduce CO_2 and produces about 75% of the global oxygen (Safi et al., 2014)

Microalgae is a subgroup of algae that has microscopic structure. The use of microalgae in Microbial Fuel Cell is more beneficial than the microalgae since microalgae needs smaller space to grow. There are some species of microalgae that can be used for microbial fuel cells, depending on their function, power density, and characteristics. Table 4 shows the various type of microalgae and its function, power density, and characteristics.

Based on the power density and characteristics that have been shown above, this research uses *Chlorella vulgaris* since it has capability to absorb the harmful substances in the wastewater and produce high power density. The isolation of the *Chlorella* is carried out in the natural habitat of each species. *Chlorella vulgaris* can be found in freshwater, or in rich-soil medium; the form of the *Chlorella vulgaris* is shown in Figure 2. Then, the isolated *Chlorella* is cultivated in supportive conditions: rich in nutrients, sufficient of CO_2 and sunlight (Castiglioni et al., 2017). The taxonomy classification and the biomolecule composition of *Chlorella vulgaris* is mentioned in Table 5 and Table 6.

The microalgae are placed in a Photobioreactor (PBr), containing the imitating natural habitat of the algae. The culture medium composed of 2.78 mg/L of $FeSO_4.7H_2O$; 19.78 mg/L of $MnCl_2.4H_2O$ and 37.22 mg/L of $Na_2EDTA.2H_2O$. The carbon and nitrogen provided by: 1.14 mg/L of glucose, 1.14 mg/L of fructose and 1.08 mg L−1 of sucrose; 23.55 mg/L of sodium nitrate, 18.31 mg/L of ammonium sulphate and 8.32 mg/L of urea (Castiglioni et al., 2017). When the colony has been formed, the medium is changed with the wastewater that will be used in the fuel cell. The mixture in the flask or the photobioreactor is centrifuged in 120 rpm for 3 days under the light sun, 25 ^oC.

Table 4. Microalgae and its function, power density, and characteristics (Shukla and Kumar, 2018).

Algae	Function	Power density	Characteristics
Dunaliella tertiolecta	Substrate	0.015 W/m^2	Abundant in hypersaline environments, quite difficult to be cultivated
Scenedesmus sp.	Substrate	0.102 W/m^2	Live in colony, non-motile, fresh-water algae, good at absorbing ammonia and phosphorus substances.
Chlorella pyrenoidosa	Assisting cathode	0.0302 W/m^2	Widely used for pharmaceutical industry
Chlorella vulgaris	Substrate and assisting cathode	0.187 W/m^2	Absorb ammonia and phosphor, high protein, easy to be cultivated
Microcystis aeruginosa	Assisting cathode	0.058 W/m^3	Freshwater algae, can form harmful algal bloom
Arthrospira maxima	Substrate	0.01 W/m^3	Characterized as Spirulina, used for food supplement

Table 5. Classification of *Chlorella vulgaris* by ITIS Taxonomy.

Kingdom	Plantae
Phylum	Chlorophyta
Class	Trebuxiophyceae
Order	Chlorellales
Family	Clorellaceae
Genus	*Chlorella*
Species	*C. vulgaris*

Figure 2. *Chlorella vulgaris* under microscope (Anonymous, phytocode.net).

Table 6. Biomolecules composition of the *Chlorella Vulgaris* (Safi et al., 2014).

Biomolecules	Content (% dry weight)
Protein	42-58
Lipid	5-40
Carbohydrate	12-55
Pigment(chlorophyll)	1-2
Vitamin	rest

When the number of the microalgae reaches about 300 mg/L, the *Chlorella* colony can be harvested by doing a 3,000-rpm centrifugation for 5 minutes. To ensure that the nutrient is sufficient for the microalgae, the addition of a high-concentrated suspension mixture is needed. The suspension contains 100 g/L NH_4Cl, 4 g/L $MgSO_4.7H_2O$, $CaCl_2.2H_2O$ dan 5 ml phosphate solution (288 g/l K_2HPO_4, 144 g/l KH_2PO_4) (Xu et al., 2015). Then, the algae are transferred into the cathode chamber of the fuel cell.

4. Life Cycle Assessment

At the beginning of the BAFCs operation, the voltage produced by BAFCs is not high enough. This indicates that the Electricity-Producing Organism (EPM) or the bacteria could produce the electricity, however, the bacteria still try to adapt with the new environment. This lag-phase happens for about 5 days (Campo et al., 2013), then continued by the exponential electricity production. After 30 days of operation, the system will reach steady-state condition. This condition happens if the nutrients for microalgae and bacteria have been decreasing and the condition does not support EPM to produce more electricity.

The physics and chemistry parameters that affect the condition of the microorganism are pH, temperature, conductivity, redox reaction, COD removal, and the microorganism concentration itself (Campo et al., 2013). However, pH and temperature have the greatest impact on the fuel cell. Consequently, intensive observation must be carried periodically to know the algae and bacteria condition inside the Microbial Fuel Cell. Figure 3 shows the evolution of pH in cathode during the operation time. If the pH lies out of the normal range for the fuel cell, it will disturb the performance of the fuel cell. If there is a lot of CO_2 in the cathode, CO_2 can assimilate with the water and form carbonate acid, and the pH will go down. Therefore, the addition of a buffer is needed during the BAFCs operation.

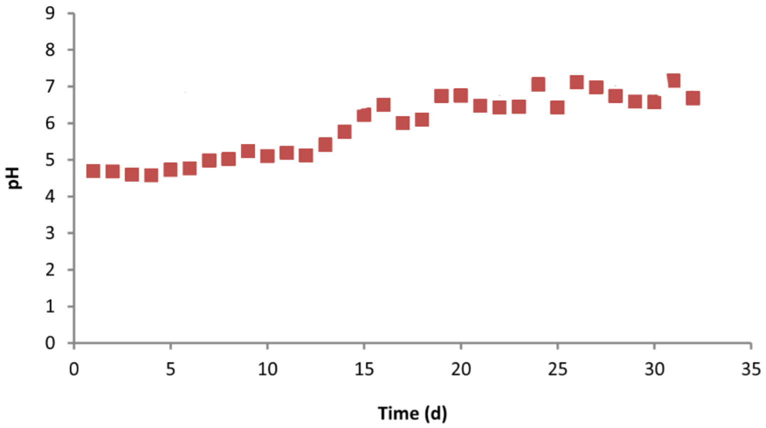

Figure 3. Evolution of pH in cathode during the operation of the BAFCs (Campo et al., 2013).

Based on the graph above, the starter pH lies between 4-5 because of the high concentration of CO_2. During the process, algae consumes the CO_2 and converts it into carbohydrate, and the pH rises. After about 16 days of operation, the pH is close to the normal pH and the production of electricity in the fuel cell increases.

5. Operational Parameter

5.1 pH

BAFCs need neutral pH (typically 6–8) in both anode and cathode chamber, which is the optimal condition for metabolic activity of anaerobic microbes. Any imbalance in the concentration of electrons, protons or oxygen leads to pH gradient and reduces the electricity production by disturbing the physiological reactions within the cell. The movement of electrons to anode results in the increased proton concentration in anodic chamber, leading to low pH condition. The physical and chemical environments (pH, protons, and type of anion) in BAFCs affect the thermodynamics and the kinetics of the oxygen reduction. By Nernst equation, the cathode potential ideally shows 0.81 V at pH 7.0, but in practice the values are always lower than the theoretical value due to mixed potential effects and to the presence of contaminating species. Addition of buffers like carbonate, phosphate, borax, carbon dioxide, saline catholyte, zwitter ionic buffers such as MES (2[N-morpholino] ethane sulfonate), help in maintaining the pH (Marcus et al., 2011). Carbonate is a low-cost and effective pH buffer for large-scale applications (Fan et.al., 2007). However, the advantages of zwitter ionic buffers are associated with their non-toxicity, non-interference with biochemical reactions and slightly higher pKa (6–8) than the solution pH (Nam et al., 2010).

5.2 Temperature

High operating temperatures are considered beneficial to fuel cell performance in terms of biochemical reaction kinetics, mass transfer rate and reduced internal resistance resulting in high current densities and columbic efficiency. An operating temperature of 35 °C is reported to be optimum, although, it may vary with the organism used in the fuel cell. The maximum power density (193.8 mW m^{-3}) was observed at 30 °C, which remained constant with further increase in temperature (Tang et al., 2012). Similar observation was reported for double chambered BAFCs, where a temperature of 35 °C exhibited stable and high-power output over a long period (Wei et al., 2013).

6. Process Recommendation

6.1 Scaling up Bacterio-Algal Microbial Fuel Cells

As discussed above, bacterio-algal microbial fuel cells are suggested to be used to convert algae into electricity; the flowchart of the system is described in Figure 4. Dual-chamber configuration with Nafion® membrane separator was used in this design. The anode chamber conditions are anaerobic, prepared by gas purging with nitrogen, while the cathode chamber is aerobic (open-air). Graphite felt is used as anode and cathode material because it has the best performance. Glucose used as a carbon source in the organic substrate. The fuel cell operating conditions are carried out at atmospheric pressure and temperature. Outdoor conditions are intended to get a supply of light intensity for algae growth. The operating parameters used, such as COD removal, DO, pH, and CO_2 concentration were analyzed to determine the optimum operating time.

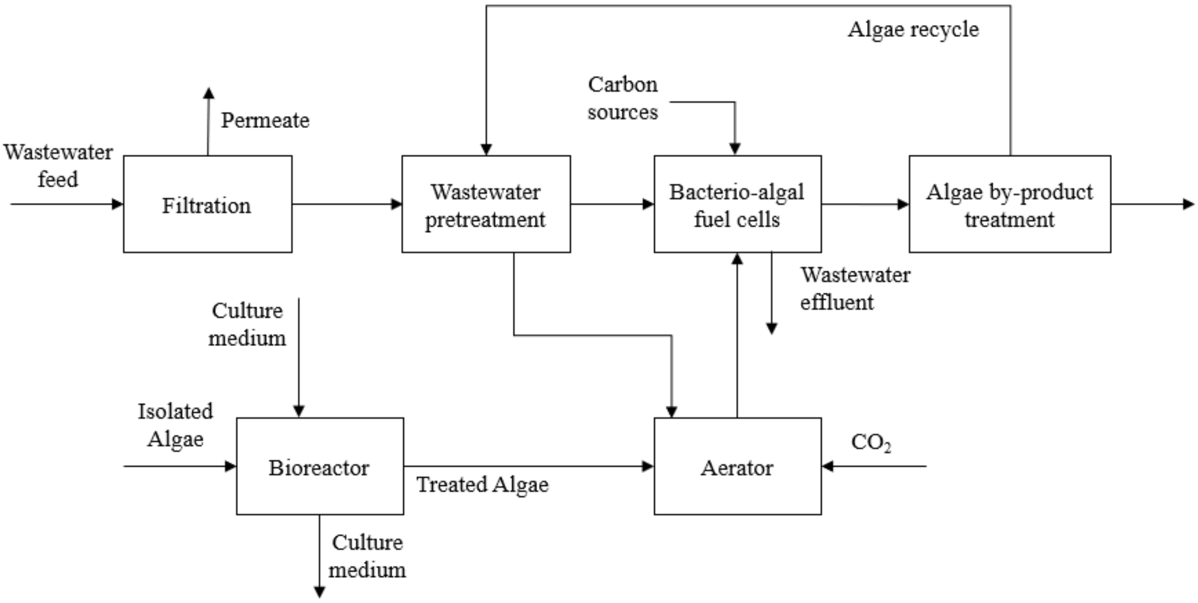

Figure 4. Block flow diagram of scaled-up bacterio-algal microbial fuel cells.

BAFCs units were constructed consisting of stacks as described in Figure 5. A single module can consist of up to three to four BAFC stacks. The chamber materials were built using polycarbonate. Fischer et al., 2018 studied about scaling up the BAFCs in pilot concept. Maximum power point tracking was combined with power storage to charge a polymer lithium battery of 3.7 V. It was designed to manage up to 12 BAFCs units at a time.

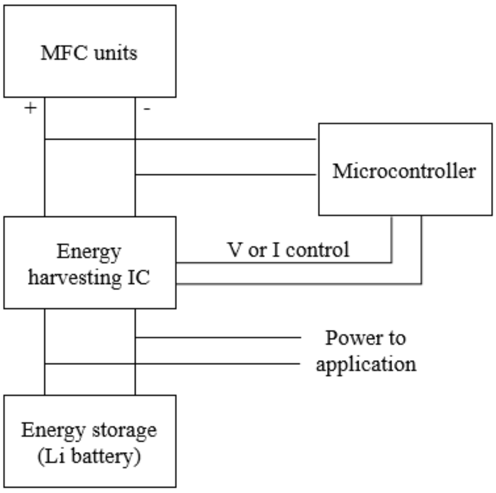

Figure 5. Principle scheme for power management integrated with BAFCs unit.

6.2 Wastewater Pretreatment

Municipal wastewater used as organic substrate. Municipal or domestic wastewater contains feedstock and multitude of pollutants, so it can be used for electricity generation (Ren et al., 2016). Municipal use also has side effects in saving sewage treatment plants which spend 50% of total management investment. On the other hand, municipal waste contains a relatively high organic substrate, which is around 66% (Ting & Lee, 2007). Several studies have shown the performance of BAFCs with municipal wastewater organic substrates as appeared in Table 7.

Table 7. Various BAFCs performance using municipal wastewater.

Configuration	Performance/result	References
Air-cathode	The maximum power density was 10,000 mW/m^2, average COD removal 71%.	You et al., 2006
Two-chamber	Removal efficiency COD was 30% and the maximum power density was 25 mW/m^2	Rodrigo et al., 2007
Air-cathode	The highest power density was 420 mW/m^2 (series flow), COD was reduced by 44%	Choi and Ahn, 2013
SEA MFCs and SPA MFCs	SEA BAFC produced 328 mW/m^2 and SPA BAFC 282 mW/m^2. Total COD removal ranged from 62% to 94% (SEA BAFC) and 81% to 93% (SPA BAFC)	Ahn et al., 2014
Stackable horizontal MFCs	The maximum power density was 116 mW with removal efficiency of COD 79%	Feng et al., 2014

6.3 Current Status in Indonesia

The problem of environmental pollution in Indonesia shows symptoms that are quite serious, especially water pollution. The cause of pollution is not only due to industrial wastewater but also domestic wastewater which is getting bigger and bigger according to population development. Government efforts in overcoming these problems have been carried out as described in Table 8, including the issuance of laws and regulations both from the government and from ministries as well as others.

Table 8. The Current Strategies Used by Indonesian Government in Dealing with Wastewater.

Strategy	Description	References
Onsite treatment	Waste treated directly in the units e.g. biofilter aerobic or anaerobic	JICA, 1990
Selective offsite treatment	Centralized waste management if the carrying capacity of the river is appropriate	Said, 2008
Aggressive off site treatment	Centralized waste management if the carrying capacity of the river has exceeded the limit	Said, 2008

6.4 Algae by-product treatment

Microalgae that is used for the fuel cell needs to be replaced periodically since the long-term growth of microalgae could cause microalgae biofouling. Biofouling happens when organic foulants (extracellular polymeric substances) aggregate on the surface of the membrane. This biofouling can reduce the fuel cell performance since it obstructs the CO_2 and sunlight to get through the whole fuel cell, thus the power density will be decreased. *Chlorella vulgaris* that has been used in the BAFCs, has higher lipid and carbohydrate content, and could be harvested. *Chlorella v.* has 22-27% of lipid (dry weight), consists of mainly linoleic acid (C18:2), palmitic acid (C16:0), 7,10-hexadecaduenoic acid (C16:2), linolenic acid (C18:3), stearic acid, 11-octadecenoic acid (C18:1), palmitoleic acid (C16:1), 7,10,13-hexadecatrienoic acid (C16:3), arachidic acid (C20:0), trans-13-octadecenoic acid (C18:1), hexacosanoic acid (C26:0), myristic acid (C14:0), tetracosanoic acid (C24:0), pentacosanoic acid (C25:0) (Ling et al., 2019). The lipid content consists of long chain fatty acid that is suitable for biodiesel production. Nevertheless, some of the fatty acids are considered as vital fatty acids for the human body, so the *Chlorella v.* also can be used for food supplement production.

Algal-based biodiesel is made in a closed-loop cycle, with the main process are extraction and transesterification (Shukla & Kumar, 2018). The past fuel-cell-microalgae contains carbohydrate, lipid, and other organic substances that can be constructed into biodiesel. The extraction of microalgae can separate lipids and other substances by crushing the *Chlorella*'s cell wall. There are some oil-extraction methods: Folch method, Bligh and Dyer Method, superior solvent extraction method, however the oil extraction cost is still uneconomical, and many technologies are developed to create a low-cost extraction process. Around 75% of the total lipid can be extracted (Kumar et al., 2015). The rest of the extraction process contains water and organic substances. Water can be reused as the algal-culture medium. The protein can be packed into a food supplement, while the carbohydrate can be transformed into CH_4 or biogas by pyrolyzing the algae.

Microalgae transesterification is conducted with a catalyst such as sodium hydroxide, mixed with methanol as the solvent. The final products are biodiesel and glycerol. The mixture is refined to remove the glycerol. Biodiesel is then transferred into factories or other machinery companies that need it (Shukla & Kumar, 2018).

Besides being a beneficial organism for producing energy, *Chlorella sp.* also contains essential protein and fatty acids for the human body, such as omega 3, vitamin A, riboflavin, iron, magnesium, and zinc (Safi et al., 2014). The algae are converted into food supplements so that humans can easily digest them. Algal-based food supplement has been developed recently and widely used for medical treatment, especially to heal internal organ diseases.

The rest of the composition in microalgae waste mainly contains a high level of sugar that can be converted into bioethanol by a fermentation process. Common yeast such as *Saccharomyces cerevisiae* is used to break down the sugar chain and form bioethanol. Nitrogen gas is fixed into the fermenter to speed up the process. The fermentation process produces ethanol, acetate, hydrogen, and carbon dioxide. The carbon dioxide is transferred into the fuel cell to be the substance of photosynthesis.

The remaining carbohydrate in the algae also can be recycled to be the culture medium of the bacteria. The algae are transferred into the anodic chamber and the bacteria will consume the nutrients, leaving the death algae in the bottom of the chamber. The death algae are carried out regularly so that it will not disturb the bacteria performance.

7. Impacts

Bacterio-algal Microbial Fuel Cell is the solution to produce electricity and reduce CO_2 pollution at the same time. Also, a bacterio-algal fuel cell is potential for sustainable use in the future. By integrating the algal fuel cell in the factory that produces high-concentrated wastewater, the fuel cell can purify the wastewater so that it is safe to be drained to the environment and also can make an integrated electricity production for the whole factory.

BAFC concept also decreases the possibility of blooming algae in the river. When the wastewater is just drained to the river without any treatment, it still contains a lot of nutrients that can promote the over-blooming algae. This phenomenon is harmful to the living creatures below the surface and it can also affect the human life.

Using microalgae to produce electricity is aligned with the Sustainable Development Goals (SDGs), especially number 7 and 13. SDG number 7 talks about affordable and clean energy, while SDG number 13 discusses climate action. Bacterio-algal microbial fuel cell can make the world cleaner and fulfill the electricity needs around the world.

Access to affordable, reliable, and sustainable energy is crucial to achieve other SDGs. Energy access still varies widely across countries and needs to be solved by technological approach. The primary energy supply in Indonesia is still mainly based on fossil fuels like oil, gas, and carbon. In 2018, 38.81% of Indonesian energy consumption was based on oil, 19.67% on natural gas and 32.97% on coal. Renewable energy, particularly hydro and geothermal have a share of 8.55%. Indonesia also has a comparatively low overall rate of electrification for a middle-income country. As much as 20% of the population representing 50 million people does not have access to electricity. Around 50% of unelectrified people in Indonesia are living in already electrified areas and would need grid densification programs. The other half is living in non-electrified villages, which are mostly found in remote rural areas.

Increasing greenhouse gas emissions are driving climate change. In 2017, greenhouse gas concentrations reached new highs, with globally averaged mole fractions of CO_2 at 405.5 parts per million (ppm), up from 400.1 ppm in 2015, and at 146% of pre-industrial levels. Carbon dioxide (CO_2) emissions in Indonesia have increased in recent years. In 2018, the amount of CO_2 emissions reached 543 million tons, an increase of 5.2% from the previous year. In this context, both problems could be solved with bacterio-algal microbial fuel cells in terms of gaining clean energy without leaving climate action.

8. Suggestion and Conclusion

The alternative way to extract energy from algae has been studied by researchers. Algal microbial fuel cells were developed to use live algae as electron donor and extract energy directly from live algae to generate electricity. Previous studies have already indicated that not every microorganism could be used in the anode to generate electricity because of electrochemical inactivity (Chang et.al., 2015). Therefore, the power generation of BAFC was significantly influenced by the type of microorganism community at the anode (Lesnik & Liu, 2014). Eukaryotic cells as electron donor could be used in BAFC. When algae in normal culture conditions were placed in the anode, it would not generate electricity in BAFC even if it produces electron. The reason behind it is due to algae photosynthesis occurrence. In photosynthesis, oxygen would be produced as a by-product. Electron that leaked out from cells during the metabolism would be tied. It was the reason why the electric current generation in algal BAFC decreased with increase in light intensity at the anode. Research also shows that by using algae that had been genetically modified to reduce the number of electrons they lose during photosynthesis could give a power density of 0.5 W/m^2, which is five times better than the ordinary design (Saar et al., 2018). Indonesia has a great potency to utilize algae in BAFC system due to its abundant availability, such as *Chlorella vulgaris* (Purkan et al., 2019).

Future development to modify the equipment with better electrode materials and larger anode volume might improve the power production as well as its economic study. In addition, re-circulating the anodic algae with fresh algae might help to improve the survival of algae and general electricity production time. There is a large potential for the development of algal based cathode BAFC systems for wastewater treatment as stated in the model proposed. At present, the infrastructure of wastewater treatment systems provides an opportunity to evaluate large scale operation of algal based biofilm technologies, integrating waste remediation and biomass production. On the other hand, biomass is a good choice for electricity generation and algae are one of the most available sources of biomass. BAFC has gained significant attention as a power source in biological environments as it offers a clean, affordable, sustainable energy, and in-line with SDGs.

Referencess

Ahn, Y., Hatzell, M. C., Zhang, F., & Logan, B. E. (2014). Different electrode configurations to optimize performance of multi-electrode microbial fuel cells for generating power or treating domestic wastewater. *Journal of Power Sources*, *249*, 440-445.

Anonymous. (2008). *Green Micro Algae Chlorella vulgaris*. Phytocode.net. Retrieved from: http://phytocode.net/phytoglossary/green-micro-algae-chlorella-vulgaris/.

Ayyaru, S., Letchoumanane, P., Dharmalingam, S., & Stanislaus, A. R. (2012). Performance of sulfonated polystyrene–ethylene–butylene–polystyrene membrane in microbial fuel cell for bioelectricity production. *Journal of Power Sources*, *217*, 204-208.

Campo, G. A. D., Cañizares, P., Rodrigo, M. A., Fernández, F. J., & Lobato, J. (2013). Microbial fuel cell with an algae-assisted cathode: A preliminary assessment. *Journal of Power Sources*, *242*, 638–645.

Campos-Martin, J. M., Blanco-Brieva, G., & Fierro, J. L. (2006). Hydrogen peroxide synthesis: an outlook beyond the anthraquinone process. *Angewandte Chemie International Edition*, *45*(42), 6962-6984.

Castiglioni, G. L., da Silva, A. F., Santos, M. V., Freitas, F. F., & de Souza Nogueira, I. (2018). Isolation, identification and development of culture medium in the production of Chlorella vulgaris. *International Journal of Environmental Studies*, *75*(2), 321-333.

Chen, X., Cui, D., Wang, X., Wang, X., & Li, W. (2015). Porous carbon with defined pore size as anode of microbial fuel cell. *Biosensors and Bioelectronics*, *69*, 135-141.

Choi, J., & Ahn, Y. (2013). Continuous electricity generation in stacked air cathode microbial fuel cell treating domestic wastewater. *Journal of Environmental Management*, *130*, 146-152.

Doney, S. C., & Schimel, D. S. (2007). Carbon and climate system coupling on timescales from the Precambrian to the Anthropocene. *Annu. Rev. Environ. Resour.*, *32*, 31-66.

Dudley, B. (2018). BP energy outlook. *Report–BP Energy Economics: London, UK, 9.*

Fan, M., Zhang, W., Sun, J., Chen, L., Li, P., Chen, Y., Zhu, S., & Shen, S. (2017). Different modified multi-walled carbon nanotube–based anodes to improve the performance of microbial fuel cells. *International Journal of Hydrogen Energy*, *42*(36), 22786-22795.

Fan, Y., Hu, H., & Liu, H. (2007). Sustainable power generation in microbial fuel cells using bicarbonate buffer and proton transfer mechanisms. *Environmental Science & Technology*, *41*(23), 8154-8158.

Feng, Y., He, W., Liu, J., Wang, X., Qu, Y., & Ren, N. (2014). A horizontal plug flow and stackable pilot microbial fuel cell for municipal wastewater treatment. *Bioresource Technology*, *156*, 132-138.

Fischer, F., Bastian, C., Happe, M., Mabillard, E., & Schmidt, N. (2011). Microbial fuel cell enables phosphate recovery from digested sewage sludge as struvite. *Bioresource Technology*, *102*(10), 5824-5830.

Gadhamshetty, V., Belanger, D., Gardiner, C. J., Cummings, A., & Hynes, A. (2013). Evaluation of Laminaria-based microbial fuel cells (LbMs) for electricity production. *Bioresource Technology*, *127*, 378-385.

Harper, C. A., & Sampson, R. M. (1994) *Electronic materials and process handbook.* New York: McGraw Hill

Ho, N. A. D., Babel, S., & Kurisu, F. (2017). Bio-electrochemical reactors using AMI-7001S and CMI-7000S membranes as separators for silver recovery and power generation. *Bioresource Technology*, *244*, 1006-1014.

Huang, Q., Zhou, P., Yang, H., Zhu, L., & Wu, H. (2017). CoO nanosheets in situ grown on nitrogen-doped activated carbon as an effective cathodic electrocatalyst for oxygen reduction reaction in microbial fuel cells. *Electrochimica Acta*, *232*, 339-347.

JICA. (1990). *The study on urban drainage and waste water disposal project in the city of Jakarta*, JICA (Japan International Cooperation Agency).

Kaewkannetra, P., Chiwes, W., & Chiu, T. Y. (2011). Treatment of cassava mill wastewater and production of electricity through microbial fuel cell technology. *Fuel*, *90*(8), 2746-2750. https://doi.org/10.1016/j.fuel.2011.03.031

Kakarla, R., & Min, B. (2014). Photoautotrophic microalgae Scenedesmus obliquus attached on a cathode as oxygen producers for microbial fuel cell (MFC) operation. *International Journal of Hydrogen Energy*, *39*(19), 10275-10283.

Kirubaharan, C. J., Santhakumar, K., Senthilkumar, N., & Jang, J. H. (2015). Nitrogen doped graphene sheets as metal free anode catalysts for the high performance microbial fuel cells. *International Journal of Hydrogen Energy*, *40*(38), 13061-13070.

Kokabian, B., & Gude, V. G. (2013). Photosynthetic microbial desalination cells (PMDCs) for clean energy, water and biomass production. *Environmental Science: Processes & Impacts*, *15*(12), 2178-2185.

Lesnik, K. L., & Liu, H. (2014). Establishing a core microbiome in acetate-fed microbial fuel cells. *Applied Microbiology and Biotechnology*, *98*(9), 4187-4196.

Li, W. W., Sheng, G. P., Liu, X. W., & Yu, H. Q. (2011). Recent advances in the separators for microbial fuel cells. *Bioresource Technology*, *102*(1), 244-252.

Li, X. M., Cheng, K. Y., & Wong, J. W. (2013). Bioelectricity production from food waste leachate using microbial fuel cells: Effect of NaCl and pH. *Bioresource Technology*, *149*, 452-458.

Lin, C. C., Wei, C. H., Chen, C. I., Shieh, C. J., & Liu, Y. C. (2013). Characteristics of the photosynthesis microbial fuel cell with a Spirulina platensis biofilm. *Bioresource Technology*, *135*, 640-643.

Ling, J., Xu, Y., Lu, C., Lai, W., Xie, G., Zheng, L., ... & Li, G. (2019). Enhancing stability of microalgae biocathode by a partially submerged carbon cloth electrode for bioenergy production from wastewater. *Energies*, *12*(17), 3229.

Lobato, J., del Campo, A. G., Fernández, F. J., Cañizares, P., & Rodrigo, M. A. (2013). Lagooning microbial fuel cells: a first approach by coupling electricity-producing microorganisms and algae. *Applied Energy*, *110*, 220-226.

Lovley, D. R. (2008). The microbe electric: conversion of organic matter to electricity. *Current Opinion in Biotechnology*, *19*(6), 564-571.

Marcus, A. K., Torres, C. I., & Rittmann, B. E. (2011). Analysis of a microbial electrochemical cell using the proton condition in biofilm (PCBIOFILM) model. *Bioresource Technology*, *102*(1), 253-262.

Mehdinia, A., Ziaei, E., & Jabbari, A. (2014). Multi-walled carbon nanotube/SnO2 nanocomposite: a novel anode material for microbial fuel cells. *Electrochimica Acta*, *130*, 512-518.

Nam, J. Y., Kim, H. W., Lim, K. H., Shin, H. S., & Logan, B. E. (2010). Variation of power generation at different buffer types and conductivities in single chamber microbial fuel cells. *Biosensors and Bioelectronics*, *25*(5), 1155-1159.

Nishio, K., Hashimoto, K., & Watanabe, K. (2013). Light/electricity conversion by defined cocultures of Chlamydomonas and Geobacter. *Journal of Bioscience and Bioengineering*, *115*(4), 412-417.

Pan, Y., Mo, X., Li, K., Pu, L., Liu, D., & Yang, T. (2016). Ironenitrogene activated carbon as cathode catalyst to improve the power generation of single-chamber air-cath-ode microbial fuel cells. *Bioresource Technology*, *206*, 285-289. https://doi.org/10.1016/j.biortech.2016.01.112

Poon, Karen., Xu, Chang., Choir, Martin M. F., & Wang, Ruihua. Using live algae at the anode of a microbial fuel cell to generate electricity. *Environmental Science and Pollution Research*. *22*, (20), 15621-15635.

Ranjith Kumar, R., Hanumantha Rao, P., & Arumugam, M. (2015). Lipid extraction methods from microalgae: a comprehensive review. *Frontiers in Energy Research*, *2*, 61.

Rashid, N., Cui, Y. F., Rehman, M. S. U., & Han, J. I. (2013). Enhanced electricity generation by using algae biomass and activated sludge in microbial fuel cell. *Science of the Total Environment*, *456*, 91-94.

Ren, L. X., He, L., Lu, H. W., & Chen, Y .Z. (2016). Monte Carlo-based interval transformation analysis for multi-criteria decision analysis of groundwater management strategies under uncertain naphthalene concentrations and health risks. *Journal Hydrology*, *539*, 468–477.

Rismani-Yazdi, H., Sarah, C. M., Christy, A. D., & Tuovinen, O.H. (2008). Cathodic limitations in microbial fuel cells: An overview. *Journal of Power Sources*, *180*(2), 683–694.

Rodrigo, M. A., Cañizares, P., Lobato, J., Paz, R., Sáez, C., & Linares, J. J. (2007). Production of electricity from the treatment of urban waste water using a microbial fuel cell. *Journal Power Sources*, *169*, 198–204.

Saba, B., & Christy, A. D. (2015). C*omparison of biological catholyte to chemical catholyte in microbial desalination cells.* In : Proceedings of annual international meeting of American Society of Agricultural and Biological Engineers (ASABE). July, 26–29, New Orleans Louisiana, USA.

Safi, C., Zebib, B., Merah, O., Pontalier, P., & Vaca-Garcia, C. (2014). Morphology, composition, production, processing and applications of *Chlorella vulgaris*: A review. *Renewable and Sustainable Energy Reviews*, *35*, 265-278.

Said, N.I. (2008). *Pengolahan Air Limbah Domestik di DKI Jakarta*. PTL-BPPT. Bab 8-170.

Shukla, M., & Kumar, S. (2018). Algal growth in photosynthetic algal microbial fuel cell and its subsequent utilization for biofuels. *Renewable and Sustainable Energy Reviews*, *82*, 402-414.

Singha, S., Jana, T., Modestra, J.A., Kumar, A.N., & Mohan, S.V. (2016). Highly efficient sulfonated polybenzimidazole as a proton exchange membrane for microbial fuel cells. *Journal Power Sources*, *317*, 143-152

Suharyati., Pambudi, S. H., Wibowo, J. L., & Pratiwi, N. I. (2019). *Indonesia energy outlook 2019.* Sekretaris Jenderal Dewan Energi Nasional.

Tang, Y. L., He, Y. T., Yu, P. F., Sun, H., & Fu, J. X (2012). Effect of temperature on electricity generation of single-chamber microbial fuel cells with proton exchange membrane. *Advanced Materials Research*, 393–395,1169–1172.

Ting, C. H., & Lee, D. J., (2007). Production of hydrogen and methane from wastewater sludge using anaerobic fermentation. *International Journal Hydrogen Energy*, *32*(6), 677–682.

Tiwari, B. R., Noori, M. T., & Ghangrekar, M. M. (2016). A novel low cost polyvinyl alcohol-Nafion-borosilicate membrane separator for microbial fuel cell. *Materials Chemistry and Physics*, *182*, 86-93.

Venkatesan, P. N., & Dharmalingam, S. (2015). Development of cation exchange resin-polymer electrolyte membranes for microbial fuel cell application. *Journal of Materials Science*, *50*(19), 6302-6312.

Walter, X. A., Greenman, J., & Ieropoulos, I. A. (2013). Oxygenic phototrophic biofilms for improved cathode performance in microbial fuel cells. *Algal Research*, *2*, 183–187

Wang, Y. K., Sheng, G. P., Shi, B. J., Li, W. W., & Yu, H. Q. (2013). A novel electrochemical membrane bioreactor as a potential net energy producer for sustainable wastewater treatment. *Scientific Reports-UK*, *3*(1), 1-6.

Wang, X., Cheng, S., Feng, Y., Merrill, M. D., Saito, T., & Logan, B. E. (2009). Use of carbon mesh anodes and the effect of different pretreatment methods on power production in microbial fuel cells. *Environmental science Technology*, *43*(17), 6870-6874.

Wang, X., Feng, Y., Liu, J., Lee, H., Li, C., Li, N., & Ren, N. (2010). Sequestration of CO2 discharged from anode by algal cathode in microbial carbon capture cells (MCCs). *Biosensors and Bioelectronics*, *25*(12), 2639-2643.

Wei, L., Han, H., & Shen, J. (2013). Effects of temperature and ferrous sulfate concentrations on the performance of microbial fuel cell. *International Journal of Hydrogen Energy*, *38*(25), 11110-11116.

Wu, Y. C., Wanga, Z., Zheng, Y., Xiao, Y., Yang, Z., & Zhao, F. (2014). Light intensity affects the performance of photo microbial fuel cells with Desmodesmus sp. A8 as cathodic microorganism. *Applied Energy*, *116*, 86–90.

Xu, C., Poon, K., Choi, M. M., & Wang, R. (2015). Using live algae at the anode of a microbial fuel cell to generate electricity. *Environmental Science and Pollution Research*, *22*(20), 15621-15635.

You, S. J., Zhao, Q. L., Jiang, J. Q., & Zhang, J. N. (2006). Treatment of domestic wastewater with simultaneous electricity generation in microbial fuel cell under continuous operation. *Chemical and Biochemical Engineering Quarterly*, *20*, 407–412.

Yuan, Y., Chena, Q., Zhoua, S., Zhuanga, L., & Hu, P. (2011). Bioelectricity generation and microcystins removal in a blue-green algae powered microbial fuel cell. *Journal of Hazardous Matter*, *187*, 591–595

Zhao, S., Li, Y., Yin, H., Liu, Z., Luan, E., Zhao, F., Tang, Z., & Liu, S. (2015). Three-dimensional graphene/Pt nanoparticle composites as freestanding anode for enhancing performance of microbial fuel cells. *Science Advances*, *1*(10).