An Overview of Microalgae as a Wastewater Treatment

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Abstract

There are many types of technologies used to treat wastewater from the industrial and agricultural effluents. Among them are chemical, physical and biological treatment. Research of microalgae as a solution for wastewater treatment has gained importance in recent years. It is because microalgae require inexpensive substrate which can be found vastly in wastewater, carbon dioxide and solar light. Moreover, microalgae have growth efficiency 10 ~50 times more compared to the terrestrial plant. Present review of biological treatment of wastewater by microalgae only covers municipal and agriculture related to animal manure waste. However, biological treatment by microalgae of palm oil mill effluent (POME) scarcely being reviewed. POME contains organic waste, heavy metal, ammonium, phosphorus etc. which can be assimilated by microalgae for its growth. Previous review shown, microalgae have the capacity to reduce chemical oxygen demand (COD), heavy metal and other substrate value. Addition to that, microalgae also produce biomass that can potentially be used as other product such as bio-fertilizer, animal feed etc. This review investigates several methods for culturing different strains of microalgae in wastewater.
Keywords : microalgae, wastewater, POME

1.Introduction

Water pollution has become a problem to humankind since the beginning of industrial revolution. Waste from industry and agro-industry are released to water bodies such as rivers, lakes and oceans which later interrupts the natural recycling process such as photosynthesis, respiration, nitrogen fixation, evaporation and precipitation. Therefore, wastewater treatment plays a major role today to make we live in healthy environment and ensure the security of water supply for humankind.

For the last decade Malaysia has been known as a leader in producing palm oil product. Based on statistic released from Malaysian Palm oil Board (MPOB), Malaysia controls almost 45% of total palm oil production in the world. It has been reported that production capacity of approximately 89 million tonne of fresh fruit bunch (FFB) per year and revenue generated by this industry in 2005 was US$ 7.5 billion.

Although the expansion and progress of this industry contributes to the growth and development of national wealth, but the by-product/waste generated by this industry has the potential to deteriorate the water ways and aquatic environment. The main by-product in crude palm oil production is liquid sludge waste also known as palm oil mill effluent (POME)[1]. This waste is rich in organic matter and highly polluting; for every FFB processed, 0.75 tonne of POME is generated (Department of Environmental (DOE) 1999).POME is thick brownish colloidal suspension and released unpleasant odour. This waste is rich in organic matter and highly polluting. POME is generated from 3 main process of crude oil production; sterilization, clarification and nut cracking process.

Like a palm oil mill, large-scale production of wastewater is likely to consequence of all health effect to the societies. Wastewater usually hazardous to mankind and the environment and has been made obligatory for wastewater to be treated prior to disposal into streams, lakes, seas and land surfaces. Wastewater treatment can be classified into three groups which are physical, chemical and biological treatment. Secondary treatment of domestic and industrial wastewater (e.g POME) still released large amount of phosphorus and nitrogen. Phosphorus and nitrogen play a major role for eutrophication of rivers, seas and lakes and disposal of partially treated wastewater can deteriorate freshwater resources on a global scale (Lau et al., 1997)[2].

This is global problem that can be solved by the used of microalgae which the wastewater is used as feed for the microalgal growth. The advantage is that while microalgae is removing the nutrient from the wastewater and at the same time accumulation of biomass that can be utilized for producing other by-product. The use of wide range of microalgae for treating domestic wastewater has been reported and efficiency of this method is promising[3].

Research shows that wastewater that has been exposed with microalgae shows a rapid decrease in level of metals[4], nitrates and phosphate[5] for some times. This shows the possibility of microalgae to be commercialized for tertiary wastewater treatment solution.

Recently microalgae have received a lot of exposure because of its ability to become a new source of renewable energy. Microalgae offer a great potential for exploitation especially in production of biodiesel and other product. Some of the main characteristic which set microalgae not only for the biomass production for biodiesel are that microalgae do not require agricultural land, freshwater is not essential and nutrients can be supplied by wastewater and CO_2 by combustion gas[6]. The main advantages of utilizing microalgae for wastewater treatment are high growth rates and short generation times, minimal land requirement, producing lipid content biomass which can be utilized for biodiesel production and using wastewater bodies as nutrient feed with no herbicides and pesticides.

2.0 Wastewater characteristic

Wastewater can be characterized by its physical, chemical and biological component of wastewater[7]. For example raw or treated POME mostly contains extremely high content of degradable organic matter. POME contains 95-96% of water, 4-5% of total solid, 2-4% suspended solid and 0.6-0.7% oil. POME can cause severe pollution to water bodies due to oxygen depletion and other related effects. Oil content of POME can be found in two phase which is either suspend in supernatant or float on the upper layer of the suspension. Physical, chemical and biological methods are used today to remove contaminants from wastewater. The main goal of wastewater treatment management is the protection of the environment and the public health by protecting the water bodies which provide important water resources. Table 1 shows the composition of untreated domestic wastewater levels.

Table 1, Composition of untreated wastewater, (source; Metcalf E, Eddy H. 1991)[8]

Contaminants	Unit	Concentration		
		Weak	Medium	Strong
Total solids (TS)	mgL^{-1}	350	720	1200
Total dissolved solid (TDS)	mgL^{-1}	250	500	850
Fixed	mgL^{-1}	145	300	525
Volatile	mgL^{-1}	105	200	325
Suspended solids	mgL^{-1}	100	220	350
Fixed	mgL^{-1}	20	55	75
Volatile	mgL^{-1}	80	165	275
Settleable solids	mgL^{-1}	5	10	20
BOD_5, 20˚C	mgL^{-1}	110	220	400
TOC	mgL^{-1}	80	160	290
COD	mgL^{-1}	250	500	1000
Nitrogen (total as N)	mgL^{-1}	20	40	85
Organic	mgL^{-1}	8	15	35
Free ammonia	mgL^{-1}	12	25	50
Nitrites	mgL^{-1}	0	0	0
Nitrates	mgL^{-1}	0	0	0
Phosphorus (total as P)	mgL^{-1}	4	8	15
Organic	mgL^{-1}	1	3	5
Inorganic	mgL^{-1}	3	5	10
Chlorides	mgL^{-1}	30	50	100
Sulphate	mgL^{-1}	20	30	50

Alkalinity (as $CaCO_3$)	mgL^{-1}	50	100	200
Grease	mgL^{-1}	50	100	150
Total coliforms	No/100mL	10^6-10^7	10^7-10^8	10^7-10^9
Volatile organic compound	mgL^{-1}	<100	100-400	>400

2.1 Physical characteristic

For physical characteristic there are some fields of character will be observed. The fields are wastewater temperature, the colour, and the odour release by the wastewater. Temperature of wastewater is important because it affects chemical and biological reaction in wastewater. Temperature is also very important in determination other parameters such as pH, conductivity and saturation level of gases. The colour of wastewater plays as indicator of the age of wastewater. Moreover microalgae undergo photosynthesis process which require light and therefore penetration of light is important and the colour of wastewater should be considered as the important factor in utilizing microalgae for wastewater treatment.. Odour presents in wastewater is caused by dissolved impurities cause by decaying aquatic microorganism and accumulation of gases[9].

2.2 Chemical characteristic

Combination of carbon, hydrogen, oxygen and other elements such as phosphorus, sulphate, ammonia and iron made up as an organic matter[7]. The presents of ammonia is considered as chemical evidence of organic pollution. On the other hand, sewage wastewater contains large amounts of nitrogenous matter and considered as inorganic pollution when the wastewater release to the water bodies.

2.3 Biological characteristic

Wastewater naturally holds large amount of macro and microorganism. Determining biological treatment depends on the quantity of any species of macro and micro organism and aquatic life in a receiving water bodies. Within treatment facilities, wastewater provides an ideal medium for potential microbial growth, not taking into account of being anaerobic or aerobic wastewater treatment[10].

3.0 Algal Growth

To ensure the wastewater can be treated by microalgae successfully, good algal growth and the factors that affect the growth must be determined. The growth rate of algae is influenced by physical, chemical and biological factors.

3.1 Carbon and nutrients

The need to supply mineral nutrients and other growth requirements to algae growth is essential. Algae are autotrophs which they are capable of synthesizing their own food from inorganic substances by utilizing solar energy by photosynthesize process. The most common elements for algal cell is $C_{106}h_{181}O_{45}N_{16}P$ and for optimal growth of microalgae, medium should be prepared by this proportion. Vonshak (1986) summarised the requirement of nutrient for algal growth as follow; (i) the total salt content, (ii) cell composition in terms of the major ionic components i.e. K^+, Mg^{2+}, Na^+, $Ca2^+$, SO_4^- or HCO_3^-,(iii) the nitrogen source especially nitrate, (iv) carbon source either CO_2 or HCO_3^-, (v) pH , (vi) trace elements and some chelating agent i.e. EDTA, (vii) vitamins[11].

3.1.1 Carbon

The supply of inorganic carbon such as CO_2 and HCO_3- is essential for high rates autotrophic algal production[12]. Microalgae is different to the land plants, which atmospheric CO_2 alone cannot satisfy the property of microalgae which is C-requirements of high yielding autotrophic algal systems. Diffusion rates for CO_2 from the atmosphere into open ponds can at most sustain productivities around $10g(dw)m^{-2}d^{-1}$. Rates as high as $70g(dw)m^{-2}d^{-1}$ have been reported giving carbon shortfall of about $30g\ C\ m^{-2}d^{-1}$ (assuming a 50% C content of the biomass) (Lee at al., 1995)[14]. The CO_2-H_2CO_3-HCO_3—CO_32- system is the most important buffer generally present in freshwaters and it is the best method available to control and maintain specific pH levels that are optimal for algal cultivation.

CO_2 is provided by the buffer system of bicarbonate-carbonate for photosynthesis according to the following reactions;

$2HCO_3^- \longleftrightarrow CO_3^{2-} + H_2O + CO_2$
$HCO_3^- \longleftrightarrow CO_2 + OH^-$
$CO_3^{2-} + H_2O \longleftrightarrow CO_2 + 2OH^-$

These reactions occur during photosynthetic CO_2 fixation. Gradual rise of pH is because of OH^- accumulation in the growth solution. Richmond and Grobbelaar 1986, reported that has been a high pH level as high as 11 in high algal production with no additional CO_2 has been supplied[15]. The most convenient method of pH control is by CO_2 sparging into the culture media. In photosynthesis, microalgae assimilate inorganic carbon by utilizing solar energy and convert to chemical energy and oxygen (O_2) as a by-product. Later the chemical energy is used to assimilate CO_2 and convert it to sugar. CO_2 from the atmosphere can be supplied to medium culture by aeration. However, CO_2 only consist about 0.033% of gases in atmosphere and this will not much affect the growth of algal. To overcome this problem, extra carbon supply is needed and this can be accomplished by providing 1-5% CO_2[16] air enriched medium. Stoichiometric formula for photosynthesis is shown by the following reaction;

$6\ H_2O+6CO_2 + light \longleftrightarrow C_6H_{12}O_6 + 6O_2$

Besides using inorganic carbon, there is some algal species that have ability to use organic carbon for their carbon source. This heterotrophic metabolism is probably significant in waste loaded ponds which standing of algae is very high and the carbon dioxide may be exhausted. Study shows that almost 25 – 50% of the algal carbon in high rate algal pond is derived from heterotrophic utilisation of organic carbon[19]. Hetetrophic metabolism can be divided into two broad classes; (i)chemoheterothrophs (ii)photoheterotrophs[17][18]. For chemoheterotrophs case, the organic substrate is used both as the source of energy (through respiration) and carbon source, while photoheterotrophs light is the energy source.

3.1.2 Nitrogen

Nitrogen is the second most important nutrient for algal which will contribute in biomass production fields. The nitrogen content of the biomass can range to more than 10%, depending on the supply and availability of nitrogen. Mostly nitrogen is supplied as nitrate (NO_3^-) and ammonium (NH_4^+) form[19]. However, ammonia nitrogen is often preferred as the N-source for algal[19]. The assimilation of either NO_3^- or NH_4^+ is related to the pH of the growth media. When ammonia is utilized as N-source for algal growth, pH could decrease significantly during active growth because of the release of H^+ ions. On the other hands, pH could increase when nitrate is supplied as the only N-source. In addition to ammonium and nitrate, other nitrogen compounds such as urea ($CO(NH_2)_2$) and nitrite (NO_2^-) can be utilized as N-source , but the at the higher concentration, toxicity of nitrite may occur and it will inhibit the algal growth[45]. Luz Estela Gonzalez et al (1997) had studied the efficiency of ammonia uptake by *chlorella vulgaris* and *scenedesmus dimorphus* from agroindustrial wastewater and the result shows that almost 80% of NH_3 was remove after 216 hours of incubation time. Besides that, Luz Estela Gonzalez et al (1997) reported that Scenedesmus dimorphus removed significantly more NH_3 from the wastewater than chlorella vulgaris at the beginning of wastewater treatment, but after 216 hours of treatment, both microalgae strains removed the same percentage of NH_3[5]. Some cynobacteria are capable of utilising nitrogen by reduction of N_2 to NH_4^+, a process catalysed by the enzyme nitrogenase. Although this process is happened in natural ecosystems, the quantities are too low and not appropriate for large scale of algal production.

3.1.3 Phosphorus

Phosphorus is essential for growth and many cellular processes. The preferred form of phosphorus to supply to algae is orthophosphate (PO_4^{3-}). Phosphorus is often one of the most important growth limiting factors in algal biotechnology because it is easily bound to other ions such as CO_3^{2-} and iron. Borowitzka (1988) found that supply of phosphorus affect the composition of the produced biomass especially the lipid and carbohydrate content[46]. Mostert and Grobbelaar (1987) found that the phosphorus concentration in cell varied with supply concentration, from a maximum of 1170mg dry mass per mg P at a supply concentration of 0.1 mg P l^{-1} to as low as 10 mg dry mass per mg P at supplies of 5 mg P l^{-1} and greater[20]. Therefore algae cultivated in wastewater may contain large amount of phosphorus that needed.

3.1.4 Other nutrient

As stated above, besides carbon, nitrogen and phosphorus, other macro (e.g potassium, calcium[21] magnesium[22], micro-nutrients (manganese[23], molybdenum, copper iron, zinc[24], boron[25], chloride and nickel[26] and trace element is important for microalgae cultivation. Many of trace elements are important in enzyme reaction and for biosynthesis of many compound such as cobalt is essential for vitamin B_{12} production. Addition of metal chelator such as EDTA is for preventing macro and micronutrients from bonding with phosphorus which will resulting precipitation and consequently rendering them as unavailable. In addition, certain algae need special elements such as silicon, iodine and vanadium is required.

3.1.5 Heavy metal

Besides carbon, nitrogen and phosphorus, microalgae also can be grown in wastewater consisting heavy metal. Industrial process and intensive agricultural practices always result in the release of various heavy metals into environment. Heavy metals are stable and cannot be degraded and because of that, naturally uptake of heavy metals by microalgae show the potential of microalgae in the application of heavy metal bioremediation by microalgae. According to De Filippis & Pallaghy (1994), microalgae have a remarkable ability to take up and accumulate heavy metal from their surrounding[27]. Moreover, it is abundant in the natural environment. Various studies by Cho et al.(1994), Chong et al. (2000) and Wong et al (2000), shows that microalgae have the ability to sequester various metal ions such as copper, cadmium, nickel, gold and chromium[28][29]. Studied by Maria Lourdes et al. (2008) shows that in a laboratory-cultivated microalgae (*Chlorococcum* sp.) removed copper (Cu) from aqueous solution in the batch culture system. Result shows that *chlorococcum* sp. removed 43-75% of Cu with the highest removal at 10 mgL^{-1} initial solution concentration.

3.2 Physical factors for algal growth

3.2.1 Temperature

Temperature plays a major role in algal growth rate. The temperature factor may affect the biochemical reaction and eventually it may affect the biochemical composition of algae[30]. Increased temperature enhances algal growth until an optimum temperature is reached. Further increase in temperature may cause stress in algae and will affect algae growth and resulting decline in growth rate. Generally, temperature around 15-25 ˚C is the most adequate temperature for algae cultivation[28].

3.2.2 Light

Microalgae are phototrophs, which means microalgae covert light to energy. However there are some microalgae classified as heterotrops and they are able to obtain energy from organic compounds like carbon as their source of energy. Light is essential for microalgae because energy that are converted from light to chemical energy is used for photosynthesis process. When cultivated in wastewater, shading effect due to high content of particulate matter may occur and this will prevent microalgae which are not floating on the surface from getting the light for energy source. To solve this problem, turbulence is important because all cells will expose to light for at least short period, and making high productivity possible. The other way to counter this problem is by limiting the depth of culture vessel to ensure light can penetrate until the bottom of the culture vessel. According to Fontes A.G. (1987) generally, depth between 15 and 50 cm are recommended[30]. Friedman et al (1991) reported that hight light intensities tend to enhance polysaccharide production in algal cell[31]. Tredici et al (1991) also reported that spirulina platensis grown outdoors was significantly higher on sunny days than cloudy days.

3.2.3 pH

pH is also an important factor that affect the growth of microalgae. In microalgae cultivation, pH value usually increase because of the photosynthetic CO_2 assimilation. pH value will affect the availability of inorganic carbon[32]. Absorption of nitrogen by microalgae also affect the pH value of the medium. Assimilation of nitrate ions may raise the pH value. Higher pH value may cause precipitation of phosphate in the medium but this can be avoided by reducing the pH value by the process of respiration where CO_2

assimilation is not happen. Gassan Hodaifa et al (2009) studied the influence of pH on the microalgae in wastewater and the result shows that the highest growth rate of microalgae (*Scenedesmus obliquus*) when the medium at a constant pH value of 7.0[33].

4.0 Cultivation methods

There are three main groups of system for cultivation of microalgae. They are open system, closed system and immobilized system. Open system cultivation is more preferable because it is simpler to conduct and cheaper. However, open system is expose to the environmental factors such as temperature and light intensity. Closed system cultivation is more complex to conduct but it allows condition control for cultivation. The third is immobilized system where algae are trapped in a solid medium.

4.1 Open system cultivation

Open system cultivation is the more preferable due to its low cost and can be done in a large scale cultivation and it is easier to manage. More over it is more durable than large closed reactors. Open system cultivation can be carried out in natural or artificial lake and ponds. They are many types of ponds that had been designed and experimented before for the optimum cultivation of microalgae. Despite many types of open system(ponds) have been proposed before, only three major design have been developed and operated at relatively large scale. The three major design is raceway ponds, inclined system and circular ponds. For this review, we only investigate raceway pond cultivation technology because it is the most common technology used for mass cultivation of microalgae.

4.1.1 Raceway ponds

Open ponds is the most common cultivation technology for mass cultivation of microalgae because it is simpler and cost effective. In this system, water level is kept no less than 15 cm, and algae are cultured according to the optimum growth condition by supplying needed nutrient to the medium. The pond is designed in a raceway configuration, in which paddlewheel circulates and mixes the algal cell with the nutrient. The raceways are typically made from poured concrete to prevent the ground from soaking up the liquid . The fresh feed (containing nutrient including nitrogen, phosphorus and inorganic salt) is added in front of the paddle wheel and algal broth is harvested behind the paddle wheel. Although the open system is cost effective, it has some disadvantages. Among the disadvantages are it requires large land areas for a considerable biomass yield. Moreover, because this cultivation technology is carried out in the open air, the water level can be effected by from evaporation and rainfall. Besides that, biomass productivity is limited by contamination with unwanted algal species and organism that feed on algae. Studied by Lee showed that only sereal microalgae (*Dunaliella Sp, Spirulina Sp, Chlorella Sp*) species resistant to be cultured in open ponds due to severe culture condition[34].

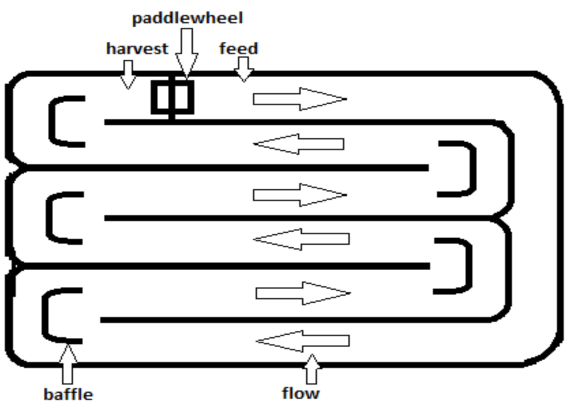

Fig 1, Schematic picture of race way pond cultivation

4.2 Closed system cultivation

Closed system cultivation is where cultivation of microalgae is done in closed and controlled environment. This cultivation method can maximize the yield of biomass and reduce the possibility of contamination during the cultivation but it is not very cost effective. The most common cultivation technology for closed system cultivation is photobioreactor(PBR). PBR is more effective compared to open system cultivation because it has better light penetration which is usually less than 30 mm, and this will boost productivity of biomass within a short period of retention time[35]. But due to its complexity to built and conduct it, PBR require much more cost and energy, plus it also requires expert to run the PBR. However, PBR is using transparent pipes for cultivation which minimize the internal shadowing effect between the algae, and the penetration of light is more efficient compare to open system cultivation. Nevertheless, light refraction may create shaded areas in the tubes, and therefore adequate turbulence is needed to provide all cells with light[36]. Tubular reactors can be constructed with several material either from rigid or soft material. PBR commonly constructed vertically or horizontally. In a vertical column reactor, aeration and agitation is performed by injection of CO_2-enriched air from the bottom of the column[37].

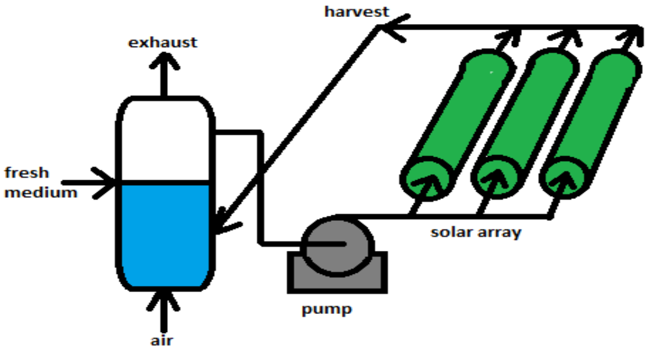

Fig 2, Schematic picture of closed system cultivation

4.3 Immobilised system cultivation

Immobilised system can be defined as the cell of the algae is trapped in a solid medium and is prevented from moving independently. This system can solve the harvesting problem[38]. To immobilise the algae, algae cells are trapped in alginate or synthetic polymer which let the substances in wastewater diffuse through the cell. The algae-medium mixture is often shaped as beads but can even cover screens or surfaces. Immobilised system have been tested for several wastewater treatment and according to Chevalier and de la Noue, 1985, entrapped algae are able to efficiently remove nitrogen and phosphorus from secondary effluent and be considered a tertiary wastewater treatment[39]. It should be noted that almost of immobilisation of algal cell have been done only in small scale in the laboratory which will hinder our knowledge of how it will perform in the large scale.

5.0 Harvesting

According to Oswald W.J (1988) algae grown in open ponds system cultivation can reach biomass levels up to 300mg dry weight per litre. Harvesting microalgae is important process for wastewater treatment because the main goal for these process is to separate other nutrient and reducing the level of BOD, COD, and heavy metal substances from the water. There are some method can be used for harvesting microalgae; filtration, sedimentation, and centrifugation. Some studies also suggested that immobilised cultivation system is more convenience in harvesting process of the microalgae. For this review, we will focus three types of harvesting microalgae; filtration, sedimentation, and centrifugation.

5.1.1 Filtration

Filtration is the most simple and cost effective harvesting method[40]. Filtration can be carried out either in small or large scale. Filtration can be done by using filter paper in laboratory scale or using coarse screening in a large scale harvesting of microalgae. Besides that, large colonial algae such as *Spirulina* can be harvested by using basic principal of filtration called microstraining. This process consist a rotating fine-mesh screen and backwash to harvest microalgae. According to Benemann J.R (1979), by using microstraining for harvesting microalgae, almost 20-fold of concentration, or higher can be achieved. According to Mohn (1980), for the filtration harvesting method, rotary vacuum and the chamber filter appears to be commonly employed type of filter in fairly large size of microalgae. The advantages of these filters are they can be used in continuous operation and useful when sterility and cantaiminant is not reviewed. However, filtration is only suitable for harvesting fairly large microalgae (e.g spirulina platensis) and not succeed to separate bacteria size microalgae like scenedesmus, dunaliella or chlorella species (Mohn, 1980).

5.1.2 Sedimentation

Sedimentation without addition any chemicals is the most common in full-scale facilities, but to facilitate sedimentation, prior flocculation is more desirable because microalgae have the tendency to float to the surface of water to catch the light. Sedimentation combined with flocculation is reported to be cost effective because of the use of gravity for biomass settling and it only use minimal power consumption[40][41]. Sedimentation cultivation method depends on the density of the microalgae.Edzwald (1993) shows that low density microalgae are found do not settle well[47]. Flocculation the final product of algae before harvesting can raise some issue because the disadvantage of the flocculation is it can cause secondary pollution. For flocculation, algae can be added with alum, $FeCl_3$, or $Ca(OH)_2$. However, there are some flocculating agent which is toxically save such as chitosan and potato starch derivatives can be used for sedimentation harvesting method[42].

5.1.3 Centrifugation

Centrifugation harvesting method can be applied to almost every type of microalgae. Centrifugation is using the same sedimentation principal but with addition with enhanced gravitational force to increase the sedimentation rate. There are some types of centrifugation harvesting method and it is depending on the particle size ranges. Tubular bowl centrifugation provides the most efficient result in harvesting but the capacity is very limited. This type of method is more preferably done in small laboratory scale. For slurries and high content of biomass (5-80% v/v), decanter bowl discharge centrifuge is more suitable[43]. However, there is some disadvantages of centrifugation which is microalgal cells structure can damage due to the exposure to high gravitational and shear forces[44].

6.0 Recommendation on the operation

Wastewater is naturally abundance in nutrient that can be used for algal growth. From all the factor that effecting algal growth and treatment efficiency, it is likely that the major factors is carbon and light. Light is the important parameter to be consider and hence in open culture the depth of culture and turbulence are major factors to obtain optimum performance. For the humid climate like Malaysia, where rain may affect the performance of wastewater treatment and algal growth, greenhouse would be recommended. By observing the properties and ability of the microalgae in the uptake of carbon, nitrogen, phosphorus and heavy metal, microalgae show a potential in wastewater treatment for various types of effluent including POME. It is recommended for starting a microalgae wastewater treatment by inoculating large variety of algae because this will create a mixture of algae where the best suited species will strive and grow faster and dominate the treatment steps. This approach requires less supervision and operation than if a particular algal is chosen to be cultivated for any purpose.

References

[1] Ahmad A.L, Ismail S, Bhatia S, (2003), Water recycling from palm oil mill effluent (POME) using membrane technology, Desalination, 157, 87-95

[2] Lau et al. (1997), Wastewater nutrients (N and P) removal by carrageenan and alginate immobilized immobilized chlorella vulgaris, environ Technol, 18, 945-951

[3] Levoie, A.,De la Noue, (1985), hyper concentrated cultures of Scenedesmus Obliquus: a new approach for wastewater biological tertiary treatment, Water Resource, 19, 1437-1442

[4] Travieso L, Canizares R.O, Borja R, Benitez F, Dominguez A.R, Dupeyron R, Valiente Y.V, (1999), Heavy Metal Removal by Microalgae, Environ Contam and Toxicol, 62, 144-151.

[5] Chevalier, P., Proulx, D., Lessard, P., Vincent, W.F. & Noue, J.D.L, (2000), Nitrogen and Phosphorus removal by high latitude mat-forming cyanobacteria for potential use in tertiary wastewater treatment, Appl Phycol, 12, 105-112

[6] Pittman, J.K., Dean , A.P. & Osundeko, O., (2010), The potential of sustainable algal biofuel production using wastewater resource, Bioresource Techn, 102, 17-25

[7] Muttamara S., (1996), Wastewater characteristic, Resource Conserv Recy, 16, 145-159

[8] Metcalf E, Eddy H. Wastewater engineering treatment disposal re-use. New York: Metcalf and Eddy; 1991.

[9] Metcalf E, Eddy H, (1987), Wastewater treatment engineering: treatment, disposal, reuse, Tata-McGraw-Hill Publishing Company Ltd

[10] Abeliovich A, (1986), Algae in wastewater oxidation ponds; (ed. Richmonds A.), Handbook of microbial mass culture, CRC Press, p331-338

[11] Vonshak A, (1986),Laboratory technique for cultivationof microalgal mass cultured (ed. Richmonds A.), p117-145.

[12] Travieso, L., Canizares, R.O, R. Borja, (1999), Heavy metal removal by microalgae, Bull Contam Toxicol, 62,144-151

[13] Chojnacka K, Marquez-Rocha, F.J, (2004), Kinetic and stoichiometric relationships of the energy and carbon metabolism in the culture of microalgae, Biotechnology, 3, 21-34

[14] Lee Y.K, Ding S.Y, Low C.S, Chang Y.C, Forday W.L & Chew P.C. (1995), Design and performance of an α-type turbular PBRfor mass cultivation of microalgae, Appl Phycol, 7, 47-51

[15] Richmond A, & Grobelaar J.U, (1986), factor effecting the output rate spirulina platensis with reference to mass culture, Biomass, 10, 253-264.

[16] Fogg G.E, (1975), Algal cultures and phytoplankton ecology, The University of Wisconsin Press.

[17] Ogbonna j.C, Yoshizawa H, & Tanaka H (2000), Treatment of high strength organic wastewater by mix culture of photosynthetic microorganism, Appl Phycol, 12, 277-284

[18] Wood B.J.B, Grimson P.H.K, German J.B, & Turner M, (1999), Photoheterotrophy in the production of phytoplankton organism, Biotechnol, 70, 175-183

[19] Kaplan D., Richmond A, Dubinsky Z & Aaronson A. (1986), Algal nutrition; Handbook of microalgal mass cultured, p147-198

[20] Mostert E.S, Grobbelaar J.U, (1987), The influence of nitrogen and phosphorus on algal growth and quality in outdoor mass cultures, Biomass,13, 219-233

[21] Piccioni R.G, Mauzerall D.c, (1979), increase effected by calcium ion in rate of oxygen evaluation from preparation of phormidium luridum, biochim Biophys Acta-Bioenerget 423, 605-609

[22] Utkilen H.C, (1982) Magnesium limited growth of the cyanobacteria Anacystis Nidulans, Gen Microbiol, 128, 1849-1862

[23] Patrick R, crum B, Coles J, (1969) Temperatures and manganese as determining factors in the presence of diatoms or blue-green floras in stream, Proc Natl Acad Sci, 64, 472-478

[24] Cavet j.S, Borrelly G.p, Robinson N.J, (2003), Zn, Cu and Co in cyanobacteria; selective control of metal availability, FEMS Microbiol Rev, 27, 165-181

[25] Bonilla I, Garcia-Gonzalez M, Mateo P, (1990), boron requirement in cyanobacteria, Plant Physiol, 94, 1554-1560

[26] Campbell P.M, Smith G.D, (1986), Transport and accumulation of nickel ions in the cyanobacteria Anabaena Cylindrica, Biochem Biophys, 244, 470-477

[27] De Filippis L.F., Pallaghy C.K. (1994). Heavy metals: sources and biological effects., Advances in Limnology. pp. 31-7

[28] Cho D, Lee S, Park S& Chug A, (1994), Studies on biosorption of heavy metals onto chlorella vulgaris, Environ Sci Health, 29, 389-409

[29] Chong A.M.Y, Wong Y.S, & Tam N.F.Y, (2000), Performance of different microalgal species in removing nickel and zinc from industrial wastewater, chemosphere, 41,251-257

[30] De la Noue J, Laliberte G & proulx D (1992), Algae and wastewater, Appl Phycol, 4, 247-254

[31] Friedman O, Dubinsky Z, Arad S, (1991) effect of light intensity on growth and polysaccharide production in red and blue-green rhodophyta unicells, bioresources Technol, 38, 105-110

[32] Azov Y,(1982), Effect of pH on inorganic carbon uptake in algal cultures, App Environ microb, 43, 1300-1306

[33] Hodaifa G,M.Eugenia Martinez & Sebastian Sanchez, (2009), influence of pH on the culture of scenedesmus obliquus in olive-mill wastewater, Biotechnol and bioprocess Eng, 14, 854-860

[34] Lee Y.K, (2001)Microalgal mass culture systemand methods; their limitation and potential, Appl Phycol,13, 307-315

[35] Borowitzka M.A, (1998) Limit to growth in wastewater treatment with algae, (ed. Y.S.

Wong, & N.F.Y. Tam), Springer Verlag, 203-226

[36] Buhrer H, (2000), Light within algal cultures; Implications from light intencities with lens, Aquat Sci, 62, 91-103

[37] Richmond A, (1990) Large scale microalgal culture and applications; in Progress in Phycological Research , Biopress Ltd, 269-330

[38] Lau, P.S., Tam, N.F.Y., Wong, Y.S., 1997. Wastewater nutrients (N and P) removal by carrageenan and alginate immobilized Chlorella vulgaris. Environ. Technol. 18, 945–951.

[39] Chevalier, P., De la Noüe, J., 1985a. Wastewater nutrient removal with microalgae immobilized in carrageenan. Enzyme Microbial. Technol. 7, 621–624.

[40] Grima E.M, Berlabi E.H, Fernandes F.G.A, Medina A.R, Christi Y, (2003), Recovery of microalgal biomass and metabolites; process options and economic, Biotecnol Adv, 20, 491-515

[41] Muno z R, Guiesse B, (2008), Algal-bacteria processes for the treatment of hazardous contaminant; a review, Water Resource, 40, 2799-2815

[42] Ravi Divakaran & V.N. Sivasakara Pillai, (2002), Flocculation of algae using chitosan, Appl Phycol, 14,419-422

[43] Mackay D (1996), Broth conditioning and clarification; downstream processof natural products, A practical handbook (ed M.S. Verral), p 11-40, John Wiley & Sons.

[44] Knuckey R.M, Brown M.r, Robert R, Frampton D.M.F,(2006), Production of microalgal concentrates by their assessment as aquaculture feeds, Aquacult Eng, 35, 300-313

[45] W. Admiraal, !977, Tolerance of estuarine benthic diatoms to high concentration of ammonia, nitrite ion, nitrate ion, and orthophosphate, Marine Biology, 43, 307-315

[46] Susan S.Kilham, Daniel A. Kreeger, Cylde E. Goulden, Scott G. Lynn, (1977), Effect of nutrient limitation on biochemical constituents of Ankistrodesmus falcatus, Freshwater Biology, 38, 591-596

[47]Edzwald J.K, 1993, Algae, bubble, coagulants, and dissolved air flotation, Water Sci. Technol, 27, 67-81