Engineering Heritage Journal / Galeri Warisan Kejuruteraan 1(1) (2017) 49-54

ISSN:XXXX

Contents List available at RAZI Publishing

Engineering Heritage Journal / Galeri Warisan Kejuruteraan

Journal Homepage: http://www.razipublishing.com/journals/galeri-warisan-kejuruteraan-gwk/

Phytoremediation Potential of Palm Oil Mill Effluent by Constructed Wetland Treatment

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ARTICLEDETAILS

Article history:

Received 12 September 2016

Accepted 20 December 2016

Available online 10 January 2017

Keywords:

Phytoremediation, Palm oil mill effluent (POME), Constructed Wetland (CW), Aquatic Plants

ABSTRACT

Phytoremediation are emerged technology among the environmentalist as the green technology and environmental friendly approach in the domestic, agricultural and industrial wastewater treatment. This method had shown their potential in reducing organics, solids, nutrients and trace metal concentration. Due to their potential in removing pollutant and improving the water quality, this technology had been used in industrial wastewater and effluent treatment such as aquacultures effluent, leachate and palm oil mill effluent (POME). Various species of aquatic plants such as water hyacinth and water lettuce had been utilized in the phytoremediation treatment and they demonstrate a pollutant removal with higher percentage in the wastewater like POME. Thus, this paper will review the phytoremediation potential of the constructed wetland (CW) treatment systems and their essential component in the POME treatment.

1.0 Introduction

Palm oil industry has become the major agro-industries commodity in Malaysia since the last four decades. Malaysia is the second largest producer of palm oil in the world. In Malaysia, the plantation areas had cover about five million hectares in 2011 with 426 palm oil mills [1]. On average, 1 tonne of crude palm oil production requires 5-7 tonne of water and more than 50% of the water will be discharged as palm oil mill effluent (POME) [2]. POME containing high organics and suspended solid that needs to treat properly before discharged to the water bodies such as rivers to prevent water pollution that can destroying aquatic flora and fauna thus sustaining the environment. Various treatment methods had been tested in POME treatment such as pond treatment, anaerobic treatment, aerobic treatment, physicochemical treatment and latest using membrane separation [3]. These treatment technologies generally had their advantages and limitations.

The phytoremediation term is a combination of *Phyto* (meaning plant) from Greek word and *remedium* (meaning correct or remove an evil) from Latin. The phytoremediation concept was introduced by Chaney (1983). The phytoremediation is the green technology approach and environmental friendly approach with the use of green plants, soil and the associated microorganism in reducing the pollutant. This technology were relatively recent technology in the research study since the last two decades (1990 onwards) with relatively low capital, operational and maintenance cost compared to other remediation option in the wastewater treatment [4], [5].

Constructed Wetland (CW) or also known as Artificial Wetland are the one of phytoremediation techniques that can effectively remove pollutant in water and wastewater [6]. CWs treatment systems promotes the sustainable approach along with the sustainable environment with utilize the functions of macrophytes and soil media in the domestic, municipal, agricultural and industrial water and wastewater treatment [7]. Besides, CW also promotes biodiversity where involvement of soil, water and plant in one systems. The aquatic plants have shown their enormous ability to absorb pollutants from aquatic environment by various mechanisms as reported by various researchers. The selections of suitable plants species are the main important aspect in the constructed wetland systems.

The concept of phytoremediation thereby will be applying in the CW treatment systems to treat and reducing pollutant in POME. This review thus focuses on the mechanism, types of aquatic plants and operational design of phytoremediation in the CWs systems for further applications.

2.0 Palm Oil Mill Effluent (POME)

POME were combination from three principle sources which are produced from sterilizer condensate, separator sludge and hydrocyclone wastewater in a ratio of 9:15:1, respectively[8]. Fresh POME are hot (80-90°C), acidic (pH 4-5), dark brown in color, have foul smell, contains high organics (biological oxygen demand (BOD) and chemical oxygen demand (COD)) content, high suspended solid (SS) and oil and grease [3]. Details on the characteristics of POME and other industrial effluent were tabulated in Table 1. As compared to other effluent, it clearly shows that POME has highest BOD, COD and SS. The characteristics of POME may varies depending on age of fruits, batches, climate, season, condition of the cropping process, and factory standard [8]. Estimated about 30% of the BOD load [9] and 50% of total SS load [8] contributes from POME to the aquatic environment. Therefore, this effluent should be treated and purified before being discharged into the environment to avoid serious environment degradation. The discharge must comply with the Malaysian Department of Environment (DOE) standard for Palm Oil Mill Effluent Discharge Standard as listed in Table 2. The palm oil industry therefore faces big challenges to comply with the standard and protect the environment to ensure the sustainable development.

Table 1: Concentration of major pollutant in industrial wastewater and effluent

Type of wastewater	BOD_5	COD	SS	TKN	NH_4-N	Reference
POME	10,250 - 43,750 **	15,000-100,000	5000 - 54,000	*180 - 1,400	4-80	[1]
Rubber Mill Effluent	1,500-7,000	3,500-14,000	200-700	*200 - 1,800		[10]
Rice Mill Wastewater	6,900	18,600	49,140	*3,100		[11]
Sugar Mill Wastewater	1,700-6,600	2,300-8,000	5,000			[12]

Landfill leachate (young age landfill)	10,000 – 20,000	>10,000	200-2,000			[13]
Aquacultures Industries (Fish processing)	40–78,000	325–90,000	15–10,000	77–3000	1–860	[14]

*TN
**BOD_3= The samples of BOD analysis is incubated at 30°C for 3 days
All units in mg/L

Table 2: Discharge Standard for Palm Oil Mill Effluent

Parameter	Unit	
Temperature	°C	45
pH	-	4-9
BOD_3 at 30°C	mg/L	100
Suspended Solids	mg/L	400
COD	mg/L	-
Oil and Grease	mg/L	50
Ammoniacal Nitrogen	mg/L	100

Several treatment processes have been studied in the POME treatment such as aerobic and anaerobic digestion and treatment, physicochemical treatment like floatation, coagulation, centrifugation, adsorption and membrane filtration, but the main issue are the practical and economics aspects[3], [8]. The high organics content with colloidal character of POME difficult the treatment process. The most common practice for POME treatment is by anaerobic-aerobic pond [15] and/or open digesting tank systems [16] whereby the anaerobic removed partial of organic matter before further treat by aerobic process. Furthermore, the pond treatment systems (90-120 days) also required large area, long retention time emitted biogas such as methane, carbon dioxide and hydrogen sulphide[17]. The open tank digester are now converted to closed tank systems or high rate bioreactors to enable biogas collection and recovery [18].

While for physicochemical treatments, none of the treatment methods could be applied alone in the palm oil mill due to very large amount of coagulant and adsorbent required thus make the treatment uneconomical and unfeasible. For example, coagulation, flocculation and adsorption treatment could be combined with polishing step treatment like membrane treatment and constructed wetland treatment to achieve a good effluent quality. Adsorption process is efficient for the removal of colour, organic matter and suspended solid from waste effluent. Activated carbon are the widely used adsorbent due to their excellent adsorption capabilities [19]. However, its high initial cost and the need of regeneration systems make it less economic viability as adsorbent. Taking these criteria, the searches of low cost adsorbent from industrial by-product and agricultural waste origin have been a highlight by many researchers. Such example are fly ash, waste slurry, red mud, sawdust, rice husk, and sludge [20]. The membrane filtration process offering a good quality of treated POME but needed a pre-treatment due to fouling effect caused by high concentration of colloidal particles. Furthermore the high cost of installation and maintenance are the main bottleneck in the system, and no locally membrane fabricator [21].

Current trend of wastewater treatment were based on promotion of environmental sound biotechnology in order to attain a sustainable development [8]. Therefore, phytoremediation technology in offers the great potential of contaminant such as removal with low initial and operation cost.

3.0 Phytoremediation in the Constructed Wetland

Constructed wetland (CW) treatment is an engineered wastewater treatment system that designed and constructed to utilize natural processes and remove pollutants from contaminated water [22]. Furthermore, the CW treatment always been chosen due to low operation of operation and maintenance cost compared to the other treatment alternatives. The CWs were catch attention as reported by various researchers in treatment of domestic sewage, agricultural effluent, industrial effluent, landfill leachates, aquacultures effluent and runoff [23]. The CW systems shows better organics and suspended solid removal in the wastewater treatment [23]. The major mechanism of CWs for wastewater treatment is the interaction among substrate (media), plants and microorganisms through a series of physical, chemical and biological process [24]. The subsequent section will discussed more about the mechanism of phytoremediation in the constructed wetland systems and the major component in the CW systems: substrate and wetland plants.

There are two types of CW according to their hydrology: free water surface flow (FWS) and sub-surface flow (SSF) wetlands. In SSF systems, they are further divide into horizontal flow (HF) and vertical flow (VF) CWs according to their flow directions [25]. A combination of two or more CW systems or also known as hybrid CWs also introduces to enhance the treatment performance [26]. In recent years, intensified CWs were introduced to improve the treatment performance such as baffled flow CWs, step feeding CWs, towery CWs, artificial aerated CWs and circular flow corridor CWs [27]. The baffled flow CW had been designed to improve the nutrients removal through their baffled wall that allow the water moves up and down flows [28]. The design enhance the water pathway travel time by forcing the wastewater up and down flow and passed through aerobic zone (upper layer), anoxic zone (middle layer), and anaerobic zone (lower layer) [29]. Figure 1 summarized the type of CWs in wastewater treatment.

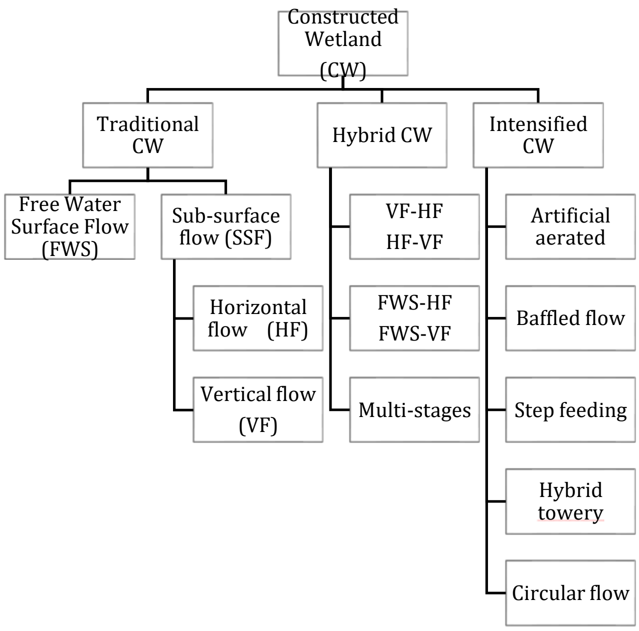

Figure 1: Type of Constructed Wetland in Wastewater Treatment

3.1 Mechanism

Phytoremediation in CWs have been successfully used to remove metal and organics contaminant. The systems are combining the physical, chemical and biological process to remove pollutant in wastewater. The main mechanisms involves in the treatment includes phytoaccumulation, phytodegradation, phytovolatilization, phytofiltration, rhizodegradation and phytodesalination [30].

For trace and heavy metal metal contaminations, plants uptake the contaminant through phythoaccumulation, filtering metal from water on the root systems (phytofiltration) and stabilize the sites by evapotranspiration of water by phytovolatilization while for organics contaminants, the degradation of organic chemical in the rhizosphere by the release of enzymes, root exudates and the build-up organic carbon in soil (phytodegradation and rhizodegradation).

3.2 Aquatic plants

Phytoremediation were claimed as attractive biological treatment method for wastewater due to the use of green plants[31]. Plants provide a subtrate (roots, stems and leaves) for microorganisms that can breakdown the organic pollutant and uptake the nutrients and the trace metals in the wastewater. Wetland plants are the key factor influence the water quality in the constructed wetland systems. The selections of suitable plant species are essential in the implementation of phytoremediation [6]. Suitable plant species used should have high uptake of both organic and inorganic pollutants, fast grow rate, tolerance in polluted water, adaptable to the climate and easily controlled in dispersion [31], [32]. In addition, the efficiency of phytoremediation treatment also depends on the plant species and their characteristics, interaction of their root zone, medium and wastewater properties and the environmental condition [30]. The key roles during implementation of phytoremediation are the rate of photosynthetic activity and the plant growth during the pollutant removal process [6]. Plant age can influence the ability of plants to uptake the contaminant where young roots will grow faster and have higher nutrient uptake rates than older roots.

Aquatic macrophytes are suitable for wastewater because of their fast growth and large biomass and also their capabilities to uptake the pollutant in the contaminate water [33]. Due to their positive role in contaminant removal in CWs, species selection always is an important consideration. Aquatic macrophytes are classified to four types: emergent plants, floating leaves plants, submerge plants and free floating plants[34]. Different vegetation species have different capabilities for nutrient uptake and heavy metal accumulations, as well as function and bacterial communities involved in the contaminant removal process [35]. The plants that able to accumulate and extract pollutant are called hyperaccumulator plants. Most common aquatic hyperaccumulator species includes water hyacinth (*Eichhornia crassipes*), duckweed (*Lemna minor*), water fern (*Azolla sp.*), water spinach (*Ipomoea sp.*), water lettuce (*Pistia stratiotes*), *Cyperus spp.*, vetiver grass (*Chrysopogon zizanioides*) and bulrush (*Typha spp. and Scirpus sp.*).

Various and different aquatic plants especially the indigenous plant species such as *Cyperus sp., Scirpus sp., Canna sp.*, as emergent plants and *Azolla sp., Ipomea sp.* as floating plants can be investigate for their potential in the pollutant removal in POME treatment. *Cyperus alternifolius* were found as the best in phosphorus removal and tolerate to unfavourable condition and easy propagation [36]. *Cyperus alternifolius* also had been effectively used in the olive mill effluent treatment with high COD and phosphate removal [37]. *Scirpus sp.* (bulrush) is perennial herbs that grow in large colonies. *Scirpus grossus* had been used in diesel contaminated wastewater by Al-Baldawi, Abdullah, Anuar, Suja, & Mushrifah, (2015) and were suggested as a promising solution for oil based contaminated wastewater[38]. Studies by Cui *et al.*, (2015) shows *Canna indica* plant had removed about 50% of nitrogen and 90% of phosphorus in septic tank effluent [28]. Azolla or also known as water fern is a small floating plant and can be find in paddy field and water canal. *Azolla sp.* were proved had capacity to removed toxic contaminant in wastewater such as arsenic, mercury, cadmium and nickel as literate by Sood, Uniyal, Prasanna, 2012)[39]. *Azolla* also have fast growth rate and high biomass production make it suitable plant for phytoremediation of industrial wastewater. While for water spinach or *Ipomea aquatica*, they had been uses in Arsenic, cadmium, zuprum and zinc removal[40]. *I. aquatic*a can be growth and easily found at the contaminated water bodies of domestic and industrial effluent.

3.3 Role of substrate

Substrate plays a great role in the contaminant removal in the CW treatment especially in SSF CWs because its provide suitable growing medium for plant and allow successful movement of wastewater [41]. Substrates are able to remove pollutants from wastewater by ion exchange, adsorption and precipitation. Substrates also provide the surface for microbial attachment. Substrate or media always utilize as phosphorus removal from wastewater.

The selection of substrate are depend on their hydraulic permeability and absorption capacity [34]. The adsorption capacity may influence by content of the substrates, hydraulic and pollutant loading. Poor hydraulic conductivity will result clogging in the system, low adsorption capacity thus decreasing the effectiveness in pollutant removal. Clogged substrates are the biggest concern in the CW systems and can reduce oxygen infiltration in the growth media and failed the treatment. The clogged problems may come from solids accumulation and oil-grease in the industrial wastewater.

The common substrate in the CW systems may come from natural materials (eg. gravel, sand, clay, zeolite, limestone, bentonite), industrial by-product and agricultural waste (eg. rice husk ash, oil palm ash, slag, fly ash, coal cinder) and artificial products (eg. activated carbon, compost, calcium silicate hydrate). Gravel is regularly used substrate in the CWs systems as growing medium and provide attached growth for biomass with low sorption and precipitation capacities [42]. Industrial by-product and agricultural waste with high sorption capacity could be further explored for their potential in industrial wastewater treatment.

The combination of substrates layers can also applied in the CWs systems. Tee, Lim, Seng, & Nawi, (2012) combined rice husk and gravel media in domestic wastewater CW treatment with excellent removal of TON while Cui *et al.*, (2015) combined the used of gravel, cinder, rubble, blast furnace slag, and fine sand in the CW systems with higher removal of NH_4-N and TP[28], [29]. Thus promotes the other combination of substrate layers with higher porosity will provide aerobic condition in the CW systems and limiting denitrification.

4.0 POME Phytoremediations

The phytoremediation technology has been studied to treat industrial wastewater: mixed industrial effluent [43], petroleum effluent [38], . This section only will focus on POME phytoremediation technology. Table 3 listed the previous research on phytoremediation of POME. Most of them use floating plant using different aquatic plant species such as water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*), and vetiver grass in their POME phytoremediation treatment either with diluted samples or pre-treated samples. The main problem associated with industrial effluent samples like POME due to high organics and suspended solid contents in the raw POME samples. This high colloidal POME may clogged the substrate surface of water and require pre-treatment to reduce the suspended solid and oil and grease before directly fed into the treatment systems. Therefore, phytoremediation technology always been used as a polishing method of treatment especially in POME treatment.

There are very limited published researches in this area with limited number of plants used. Most used plants are water hyacinth and water lettuce class as floating aquatic plants. This may due to their properties that easy to growth and able to treat the pollutant effectively [6]. However the survival and growth of plant were not discussed in detail. The potential of emergent plant were seen have a prospective to be explored since the used of Vetiver grass had shown their great pollutant removal effect in POME treatment. Therefore, the uses of other types of emergent plants still further probabilities to be explored and study in POME treatment with consider their capabilities in pollutant removal, survival and their tolerance in the effluent.

None of the researcher listed, studies the nutrients uptake by plants and their biomass accumulation. The phytoaccumulation as one of aspects in phytoremediation are important to understand the mechanism of water quality improvement via nutrients accumulation in plants. The plant nutrients content can be analysing for their total nitrogen and total phosphorus concentration by acid digestion method. Furthermore, the growth of plant also can be observed for their height and weight of plants.

Table 3: Summary of Phytoremediation of Industrial Effluent POME

No	Author/ Year	Type of Waste water	Methodology	Type of Plant used	HRT	% Removal
1	[44]	Anaerobic pond (POME)	Two stage phytoremediation	*Eichornia crassipes, Nymphae sp., Spirulina*	3-8 days	*Eichornia crassipes* COD: 50% N: 88% P: 64%
2	[45]	Anaerobic pond (POME)	Two stage phytoremediation	*Pistia Stratiotes, Spirulina sp.*	1-5 days	COD: 39.1-59.66% N: 17.73 -30.78% P: 6.14 - 18.46%
3	[46]	Final discharge POME	Phytoremediation using single plant	*Pistia stratoites, Leersia oryzoides, Ludwigia peploides*	Not stated	*Pistia statoites* BOD_5: 93% COD:30 % NH_3-N:82% *Lersia oryzoides* BOD_5: 90% COD: 27% NH_3-N: 80% *Ludwigia peploide* BOD_5: 93% COD: 20% NH_3-N: 80%
4	[47]	Raw POME	Coagulation pre-treatment	*Eichornia crassipes*	Batch 6 week treatment	BOD: 50% COD: 50%
5	[48]	Anaerobic treated pond	Hydroponic treatment	*Vetiveria zizanioides*	Batch 5 weeks	BOD:90 % (low concentration) :60% (high concentration), COD: 94% (low concentration) :39% (high concentration)
6	[49]	POME	Two stage phytoremediation	*Lemna minor, Clamidomonas*	Not stated	COD : 25.41% NO_3-N: 75%, NH_3-N: 93.70% PO_4-P: 70.47%.

5.0 Conclusion and Future studies

The phytoremediation treatment technology had shown their potential in reducing pollutant in the POME. However, there is still lack of report of the integration of phytoremediation technology in the constructed wetland treatment. The diversity of aquatic plants in POME treatment and industrial wastewater treatment should be further explored. Some recommendations within this area need to further investigate.

1. Using various and different aquatic plants especially the indigenous plant species such as *Cyperus* sp., *Scirpus* sp., *Canna lilies*, as emergent plants and *Azolla* sp., *Ipomea* sp. as floating plants.
2. Assess the plant uptake of nutrients by the plant species and studying their mechanism of uptake.
3. Measure the plant growth in along the treatments.
4. Utilize the use of Constructed Wetland that promotes biodiversity approach and complete biosystems for wastewater treatment.
5. Using raw POME and introduce the pre-treatment in the systems to reduce organics and suspended solids particles.

6.0 Acknowledgement

The authors acknowledge the USM, UniMAP and Ministry of Higher Education for the facilities and support throughout the research period.

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