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Phytoremediation of POME Using Water Lettuce and Duckweed

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ABSTRACT

Phytoremediation is a broadly studied emerging technology, using various plants to remediate contaminants from wastewater by extraction, containment or destruction method which also known as eco-friendly and cost-effective techniques compared to conventional processes. The huge increased of palm oil production industry has become major environmental concern but not much have been said about the negative effects. Three major waste streams in processing palm oil were gaseous (pollutant gases), liquid (palm oil mill effluent, POME) and solid (palm press fibre, chaff, palm kernel shell and empty fruit bunch). The aim of this study was to determine the potential of water lettuce (Pistia Stratiotes) and duckweed (Lemna Minor) in removing contaminants in POME. Seven water quality parameters based on Sewage and Industrial Effluent Discharge Standards were selected in this study like pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (NH3-N), Iron (Fe) and Zinc (Zn). POME sample were placed in 3 basins for 28 days; (Basin 1 – control, Basin 2 – duckweed, Basin 3 – water lettuce), and each basin were tested with different retention time. The results showed that both studied plants have positive results as phytoremediation agent was effective in removing contaminants of POME. To achieve optimal contaminant reduction, incorporating a combination of phytoremediation and other complementary treatment would be beneficial before POME release into waterways.

Keywords:
Phytoremediation; Palm Oil Mill Effluent (POME); Water Lettuce; Duckweed

1. Introduction

Malaysia is the second largest producer of palm oil in the world since the last four decades [1]. Rapid expansion of palm oil industry produced palm oil mill effluent (POME) as by which contents high volume and various forms of solid and liquid waste substances poses significant threat to environment and aquatic ecosystems [2]. In Malaysia, POME has been identified as the main sources of water pollution due to high concentration of biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N) and heavy metal [3]. Thus, remediation of POME is a

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must before it released to the environment. Generally, the release of physicochemical treated POME into the rivers still does not meet the standard and contains high COD and suspended solid [4].

Phytoremediation is the green technology approach and environmentally friendly approach by direct use of green plants with or and associated microorganisms to clean up contaminated water, soils or sediments [5]. Phytoremediation is a new, cost effective, aesthetically pleasing, and low-cost suitable solution for many environmental problems across the world [6-8]. Various researchers have proven that the aquatic plants have ability to absorbs or remove pollutants from aquatic environment by various mechanisms such as heavy metals, pesticides, organic compounds, toxic aromatic pollutants and acid mine drainage [9-11]. High uptake of both organic and inorganic pollutants grow well in polluted water and easily controlled spreading dispersion are the characteristics of plant suitability to be used as phytoremediation agent [3]. Furthermore, the selected plant also should grow fast in a range of different conditions and harvest easily [12,13].

Phytoremediation can be divided into phytoextraction, phytodegradation, phytostabilization, phytovolatilization and rhizofiltration [14]. The advantages of Phytoremediation are low cost, the plant can easily monitor, possibility of recovery or reuse of valuable metals and least harmful method because using natural materials. Phytoremediation also have limitations like limited to certain surface area or depth occupied by the roots, slow growth and low biomass required for long duration of remediation, the survival of plants is affected by the toxicity of the pollutants and bioaccumulation of contaminants which can pass into food chain [15].

Pistia Stratiotes commonly called water lettuce (WL) or water cabbage because of its superficial resemblance to the green leafy vegetables but not edible [16]. WL is a floating perennial plant which floats on the surface of the water, and its roots hanging submerged beneath floating leaves [17]. WL leaves are densely covered with fine hairs that prevent wetting of the actual leaf surface and trap air so the plant has increased buoyancy to float easily [16]. WL grows abundantly in summer months with sunny days and high temperatures and can proliferate into 7 or 8 new individuals in 10 days [18]. WL has been widely used to mitigate pollutants from contaminated water [19]. WL root system and stolons act as filters, trapping suspended matters and providing a surface for the adhesion and the proliferation of microorganisms. WL then absorb biodegradation products and are constantly eliminated from the system by regular harvest of part of the crop generated [20].

Duckweed *(Lemna Minor)* also known as water lentils or water meal is a rapid growing plant is found in ecosystem on every continent except Antarctica. Duckweed (DW) are world's smallest and simplest flowering, free-floating, aquatic green plants commonly found in lentic or slowly moving water bodies [21]. With the right light and nutrient levels, DW can withstand a wide range of pH levels and temperatures, and under optimal conditions, it can double its mass in 2-4 days [22]. DW have been utilized for food, pharmaceutical, phytoremediation, and other industrial applications [23-26]. DW has been proven widely in removing nutrients or accumulate metals, radionuclides and other pollutants in their tissue from contaminated waters [27-30].

2. Methodology

This study was carried out to observe how aquatic plants in nature respond to the reduction of contaminants by using the phytoremediation method. For this study, two aquatic plants (WL and DW) were chosen to compare which plant is better at reducing contaminants in POME sample.

(a) (b)

Fig. 1. (a) Water Lettuce (*Pistia Stratiotes)*, (b) Duckweed (*Lemna Minor)*

POME sample was collected from Palm Oil Mill in Teluk Intan while for WL and DW were collected at drainage system nearby Politeknik Sultan Idris Shah (PSIS). Seven water quality parameters based on Sewage and Industrial Effluent Discharge Standards were selected in this study like pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (NH_3-N), Iron (Fe) and Zinc (Zn). The POME sample then placed in 3 basins for 28 days (Basin 1 – control (C) sample of POME without any plants, Basin 2 – POME sample placed with DW and Basin 3 – POME placed with WL). All POME samples were collected for testing with 4 different hydraulic retention time (HRT) which namely 7, 14, 21 and 28 days left to react with WL and DW. All of the analyses methods in testing the water sample will be according to procedures of Standard Methods for the Examination of Water and Wastewater [31].

3. Results

Average POME sample during sampling indicates that the overall values of the parameters does not meet effluent standards that has been set out in the Environmental Quality (Sewage and Industrial Effluent) Regulations 1979. The results of the study showed that the average pH was 7.92 DO 1.19 mg/L, BOD 6.77 mg/L, COD 4250 mg/L, NH_3-N 230 mg/L, Fe 3.04 mg/L and Zn 0.24 mg/L as shown in Table 1. Referring to Table 1, POME sample need to be treated to make sure the nearby surrounding environment in good condition and comply with the standard.

Table 1
The value of 7 parameters (pH, DO, BOD, COD, NH_3-N, Fe and Zn)

Parameters (mg/L)	POME (Initial)	Sewage Industrial Effluent Standard	
		Standard A	Standard B
pH	7.92	6.0 - 9.0	5.5 - 9.0
DO	1.19	-	-
BOD	6.77	20.00	50.00
COD	4250.00	60.00	100.00
NH_3-N	230.00	-	-
Fe	3.04	1.00	5.00
Zn	0.24	2.00	2.00

Table 2
POME conditions after phytoremediation

Test (mg/L)	POME (Initial)	Control				WL				DW			
		7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days	7 days	14 days	21 days	28 days
pH	7.92	8.8	8.91	8.63	8.91	8.62	8.85	8.57	8.89	8.23	8.04	8.45	8.94
DO	1.19	1.03	2.01	2.76	5.17	0.4	0.95	3	3.46	0.47	0.82	0.98	1.46
BOD	6.77	6.24	3.75	7.94	4.88	6.05	3.44	6.46	3.95	5.12	4.01	6.98	3.65
COD	4250	4230	972	750	1020	1855	878	652	855	1716	643	560	628
NH_3-N	230	60	39	3	14	144	48	0	11	100	84	36	47
Fe	3.04	0.38	0.11	0.54	0.60	0.41	1.74	0.78	0.89	0.29	1.34	0.11	1.44
Zn	0.24	0.04	0.02	0	0.14	0.03	0	0	0.05	0.02	0.02	0	0.04

Table 2 shows the summary of the capabilities of phytoremediation method by using WL and DW in treating POME sample. All of the parameters giving positive result, simple and affordable technique in POME treatment. Past studies also revealed that both plant species (WL and DW) have the ability to absorb, store or remove contaminants actively in polluted environments.

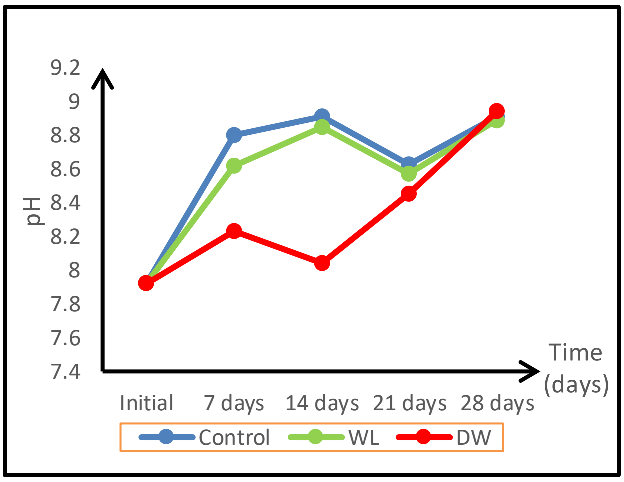

Fig. 2. pH Vs Time (days)

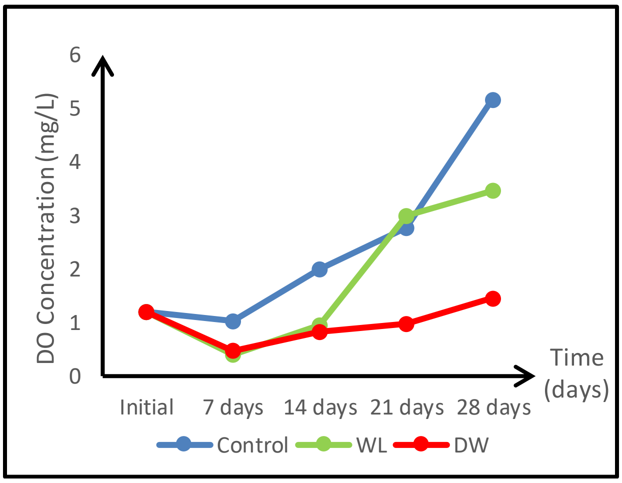

Fig. 3. DO (mg/L) Vs Time (days)

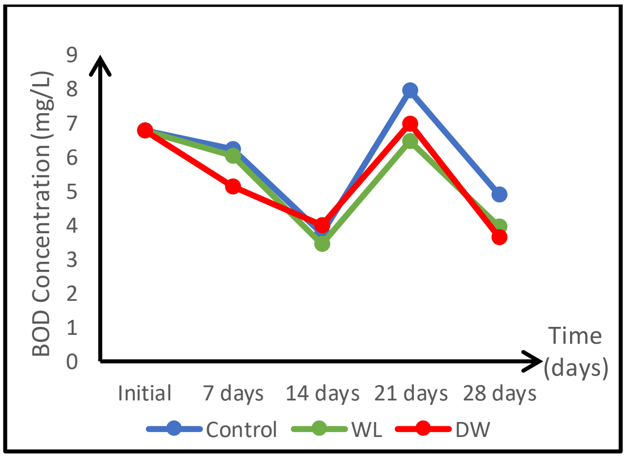

Fig. 4. BOD (mg/L) Vs Time (days)

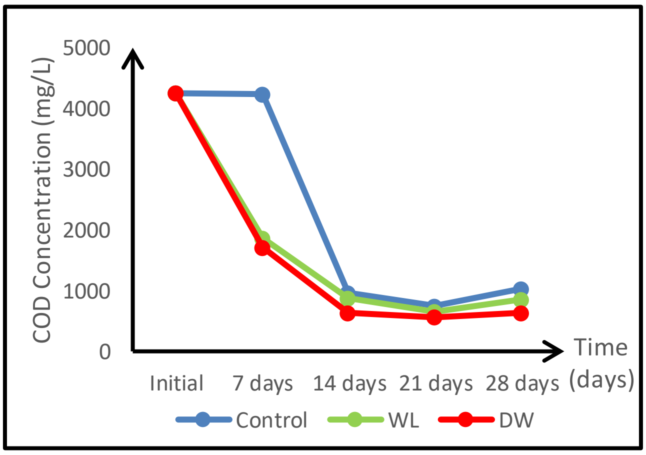

Fig. 5. COD (mg/L) Vs Time (days)

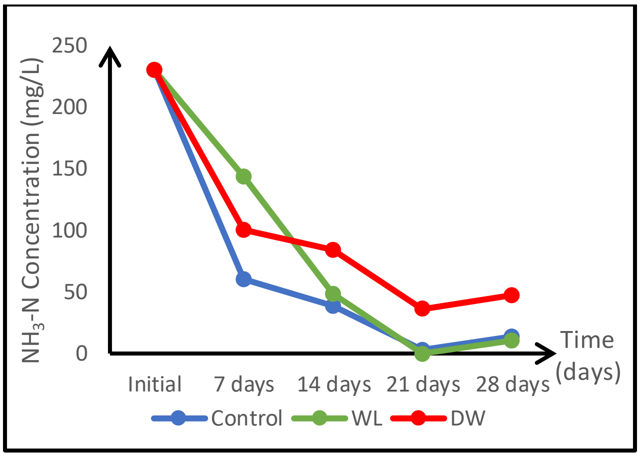

Fig. 6. NH_3-N (mg/L) Vs Time (days)

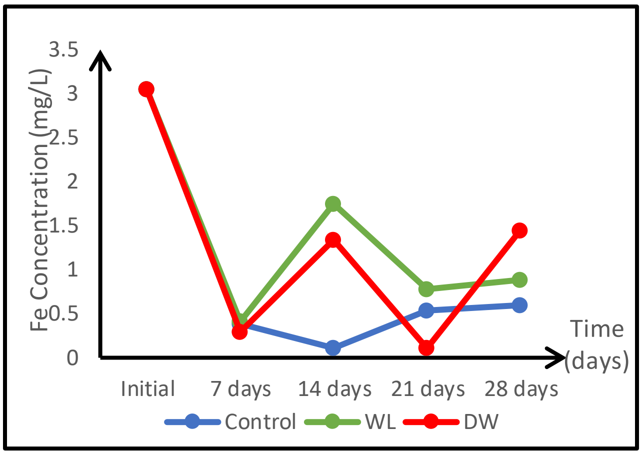

Fig. 7. Fe (mg/L) Vs Time (days)

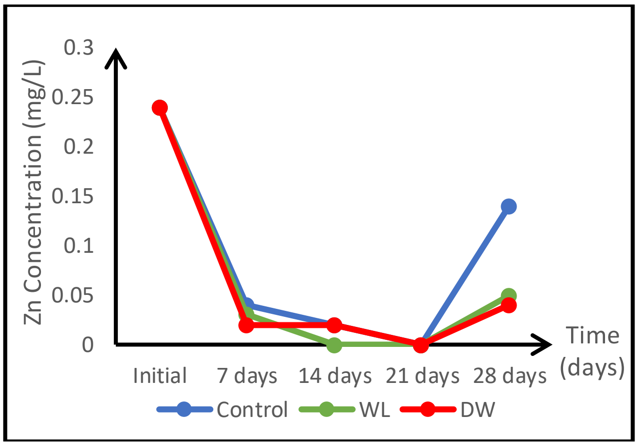

Fig. 8. Zn (mg/L) Vs Time (days)

Table 3
Comparison of initial POME and after phytoremediation with Sewage and Industrial Effluent Standard

Parameters (mg/L)	Sewage Industrial Effluent Standard		POME (Initial)	WL (28 days)	DW (28 days)
	Standard A	Standard B			
pH	6.0 - 9.0	5.5 - 9.0	7.92	8.89	8.94
DO	-	-	1.19	3.46	1.46
BOD	20.00	50.00	6.77	3.95	3.65
COD	60.00	100.00	4250	855	628
NH_3-N	-	-	230	11	47
Fe	1.00	5.00	3.042	0.89	1.44
Zn	2.00	2.00	0.24	0.05	0.04

Figure 2 showed gradual increment in pH in both samples could be resulted from the photosynthetic activities of periphyton and phytoplankton communities or algae which depleted dissolved carbon dioxide from the water and raised the water pH. The pH increments also resulting from higher presence of dissolved minerals like calcium and magnesium in the water sample. Although the pH value increase but it is still in the standard range for sewage industrial effluent.

The purpose of BOD test is to measure the potential of POME and other waters to deplete the oxygen level of receiving waters. BOD measures the amount of oxygen required (used up, depleted, consumed and assimilated) by the microorganism as they assimilate various organic and inorganic materials in water. This is an important parameter to assess the pollution of surface waters and ground waters where contamination occurred due to disposal of domestic and industrial effluents. DO and BOD results are inversely proportional to each other, when DO levels are high, BOD levels decrease because the oxygen that is available in the water is being consumed by the bacteria and also can be seen in Figure 3. The high value of BOD could be attributed to the high quantities of heavy metals, inorganic salts, oil, grease and others contribute largely towards high BOD demand. Referring to Figure 4, BOD result for WL and DW increased significantly on day 21 because most of the plant placed in the basin began to decay and compete with other organisms that requires oxygen to decompose. BOD result continued to decrease after that, by replacing new plant in both basins for WL and DW.

The COD determination is a measure of oxygen equivalent of portion of the organic matter that in a sample that is susceptible to oxidation by a strong chemical oxidant. Figure 5 showed that by placing WL and DW in POME sample gave drastic decreased in the value of COD. WL able to remove 80% of COD in POME while DW 85%. If longer retention time given, the better declination result of COD can be seen. By referring to Figure 6, high amount of NH_3-N in POME have removed by both plants which 95% and 80% removal for WL and DW respectively. NH_3-N values is important to take care off because NH_3-N is actually nutrient that can promote in algae growth and brings other parameters to increase like BOD and COD.

According to Figure 7, after 28 days of sampling, WL effectively remove Fe in POME sample until can be classified into standard A while DW slightly more than 1 mg/L and was classified into standard B. However, both phytoremediation agent reacts positively in reducing Fe in POME. Figure 8 also proved that WL and DW have huge potential in reducing Zn in POME until 21 days which happened to have the same situation with BOD. When the plants decay, Zn that have been stored or absorbed from POME were returned back to the water sample that makes the Zn values increased in POME sample after 21 days.

Table 3 revealed that all of the 7 parameter results clearly gave positive effect of phytoremediation process in treating and improve the quality of POME and also comply with the sewage and industrial effluent standards. Throughout for the 28 days of sampling both plants have its own ability in POME treatment, where WL gave better results in increasing DO level and reducing NH_3-N and Fe concentrations in POME compared to DW. DW showed better pollutants reduction in BOD, COD and Zn concentration compared to WL results in POME treatment.

4. Conclusions

The study showed that POME sample does not meet the parameters values of effluent standards that have been set out in Environmental Quality (Sewage and Industrial Effluent) Regulations 1979.

This project has proven that POME sample responded well in removing pollutants from the sample by using water lettuce *(Pistia Stratiotes) and duckweed (Lemna Minor)*. All 7 parameters tested showed that WL and DW abilities as phytoremediation agent. WL and DW capabilities in contaminants removal depend on different factors like climate, contaminants concentrations, temperature, pH, moisture and nutrients [19, 9].

For the success of this technology, identification of plant species having high biomass production, maintenance control (remove the decay plant) and microbial and chemical additives usage can be used to enhance phytoremediation process [32, 33, 18]. Besides that, phytoremediation avoids excavation and transport of polluted media thus reducing the spreading the contaminant and has potential to treat more than one type of pollutant [34]. Phytoremediation process can be improved by extending hydraulic retention time, replace the new plants in the basin when there was sign of decay detected and scoop out algae and decomposed plants/ materials from the water surface. This action can help in improving phytoremediation workability in removing pollutants from POME sample. The aquatic plant that used WL and DW must rinsed thoroughly to avoid POME condition become more worst caused by the origin of the plant. Phytoremediation method were highly recommended for POME and wastewater treatment.

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