



Phytoremediation of Palm Oil Mill Effluent (POME) Using Water Lettuce and Duckweed

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ABSTRACT: Phytoremediation is a widely recent studied and applied 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 (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 result as phytoremediation agents effectively in removing contaminants of POME. To achieve optimal contaminant reduction, incorporate 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]. The rapid expansion of the palm oil industry has led to the production of POME, which contains a high volume of various solid and liquid waste substances. These by-products pose a significant threat to the environment and aquatic ecosystems [2]. In Malaysia, POME has been identified as the main sources of water pollution due to high concentration of BOD, COD, NH₃-N and heavy metal [3]. Thus, remediation of POME is a 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 environmental 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 absorb 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 has 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. Materials and Methods

The POME sample was collected from Palm Oil Mill in Teluk Intan while for water lettuce and duckweed were collected at drainage system nearby Politeknik Sultan Idris Shah (PSIS). This study was carried out to observe how aquatic plants in nature respond to the reduction of contaminants by using the phytoremediation method. The analyses methods in testing the water sample will be according to procedures of Standard Methods for the Examination of Water and Wastewater [31].



Figure 1. Water lettuce (*Pistia stratiotes*) (A); Duckweed (*Lemna minor*) (B).

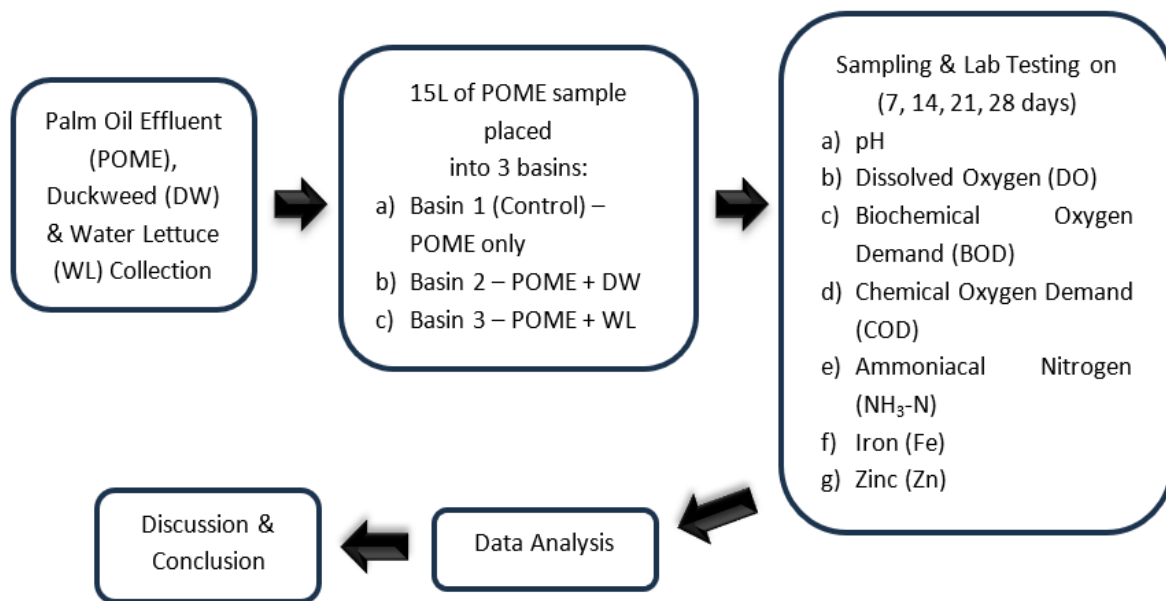


Figure 2. Phytoremediation testing of POME sample using duckweed and water lettuce.

3. Results and Discussion

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, NH₃-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 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.

Table 1. The value of 7 parameters (pH, DO, BOD, COD, NH₃-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 (days) | | | | WL (days) | | | | DW (days) | | | |
|--------------------|-------------------|----------------|------|------|------|-----------|------|------|------|-----------|------|------|------|
| | | 7 | 14 | 21 | 28 | 7 | 14 | 21 | 28 | 7 | 14 | 21 | 28 |
| 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 |

Figure 3A showed gradual increment in pH in both samples of WL and DW 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 standards from higher presence of dissolved minerals like calcium and magnesium in the water sample. Although the pH value for initial reading and after phytoremediation treatment increased but it is still in the acceptable range for sewage and industrial effluent standard. 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 3B. 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 3C, 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. The high concentration of COD in POME are caused from the accumulation of organic matter including both biodegradable and non-biodegradable substances [32]. Figure 3D, showed that by placing WL and DW in POME sample gave drastic decreased in the value of COD. WL able to removed 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 3E, high amount of NH₃-N in POME can be remove significantly in both plants which 95% and 80% removal for WL and DW respectively. NH₃-N values is important to take care off because NH₃-N is actually nutrient that can promote

in algae growth that can lead to eutrophication and brings other parameters to increase like BOD and COD. Therefore, to ensure the effectiveness of pollutants removal, it is crucial to implement a regular monitoring and harvesting schedule to prevent plant decomposition and pollutant reintroduction into POME sample after 21 days. According to Figure 3F, 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 3G 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.

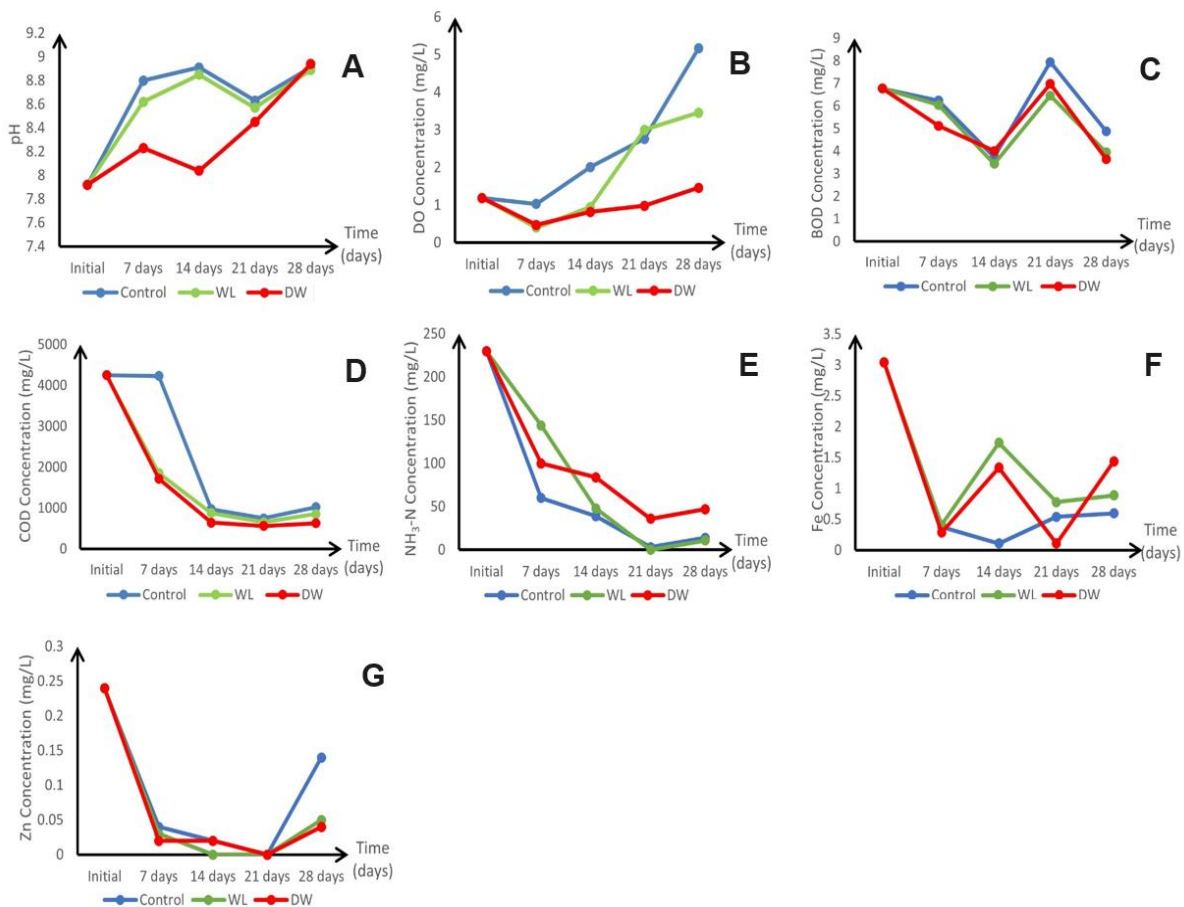


Figure 3. pH Vs Time (A), DO Vs Time (B), BOD Vs Time (C), COD Vs Time (D), NH₃-N Vs Time (E), Fe Vs Time (F), Zn Vs Time (G).

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 NH₃-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.

Table 3. Comparison of initial POME before 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 |

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. 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. 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. 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 was highly recommended for POME and wastewater treatment.

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