Effect of Gravel-Sand Substrate on Sub-Surface Flow Constructed Wetland for Palm Oil Mill Effluent Treatment

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Abstract. Constructed wetland as one of technique in phytoremediation, combined and utilized green plants, soil and microorganism in reducing the pollutants in wastewater. Plant selection and types of a substrate are among the factors that contribute to the greater performance of pollutant removal. Gravel and sand are the commonly substrate used in sub-surface constructed wetland because they have acceptability with the hydraulic condition and capable to increase the removal of pollutants in wastewater treatment. In this study, the gravel and sand combination were used to increase pollutant removal. Three (3) sets of experiments were set up as treatment of palm oil mill effluent (POME) which is POME only (PO) as control and, POME with gravel (PG), and POME with gravel-sand (PGS) bed. The POME samples were recirculated through the sub-surface flow constructed wetland for 30 days of treatment. The PGS systems contributes higher performance rather than single gravel or sand with 66% COD, 97% suspended solid, 98% turbidity, 98% ammonia-nitrogen and 99% TN removal and 74% of TP removal. Therefore, the use of gravel-sand substrate is very promising for sub-surface flow constructed wetland treatment systems for POME.

1. Introduction
Palm oil industry is one of the main commodities in Malaysia since the last decades. Malaysia was the second largest producer of palm oil in the world after Indonesia. The wastewater from palm oil processing is called palm oil mill effluent (POME). Approximately, for 1 tonne of crude palm oil, about 70% of wastewater will end up as POME. POME containing high organics and solid concentration that need to treat properly before being discharged to the water bodies such as rivers and groundwater that can cause water pollution and destroying aquatic flora and fauna.

Table 1 list the average raw POME characteristic as compared to discharge standard enforced by Department of Environmental Malaysia for crude palm oil effluent. Fresh raw POME is a thick brownish slurry with oil and colloids suspended solids. It is hot with 80–900°C and has a high biological oxygen demand (BOD) concentration. The effluent is acidic with pH around 4.5, not hazardous since no chemicals are added to in the extraction process [1].
**Table 1.** Average raw POME characteristic and Discharge Standard for Crude Palm Oil [2-3].

| Parameter               | Unit   | POME   | Standard |
|-------------------------|--------|--------|----------|
| pH                      | -      | 4.7    | 4-9      |
| BOD₃ at 30°C            | mg/L   | 25,000 | 100      |
| Suspended Solids        | mg/L   | 18,000 | 400      |
| COD                     | mg/L   | 50,000 | -        |
| Oil and Grease          | mg/L   | 4000   | 50       |
| Ammoniacal Nitrogen     | mg/L   | 35     | 100      |
| Total Nitrogen          | mg/L   | 750    | 150      |

The phytoremediation were the relatively recent technology with lower capital and operational cost as compared to other treatment option [4]. Phytoremediation refers to the use of green plants and soil to reduce the pollutant in environment by various removal mechanism. This sustainable and environmentally friendly technology catch attention in the constructed wetland treatment for industrial effluent treatment by various aquatic plants species such as water hyacinth, water lettuce, water lily, Canna, cattail, Cyperus, and many more.

Constructed wetland (CW) treatment systems as one method of phytoremediation, is a wastewater treatment system that designed and constructed to mimic processes in natural wetland systems [5]. CW systems can efficiently treat the contaminant in various sources of water and wastewater [6] such as domestic wastewater, agricultural effluent, industrial effluent, landfill leachates, aquacultures effluent and agricultural runoff [7]. The mechanism of CWs for wastewater treatment involves the interaction between substrate, plants and microbes through a chemical, physical, and biological process [8].

Generally, there are two types of CW classified according to their hydrology which are free water surface flow (FWS) and sub-surface flow (SSF) CW. In the SSF systems, they are further divides into horizontal flow (HF) and vertical flow (VF) CWs depends to their directions of water flows under the surface medium [9]. A combination of two or more CW systems or also known as hybrid CWs also introduces by several researchers to enhance the treatment performance of CW [10]. In recent years, intensified CWs were introduced in enhancing the treatment performance such as baffled flow CWs, step feeding CWs, towery CWs, artificial aerated CWs and circular flow corridor CWs [11].

The substrate is the one of essential parameter in SSF CW in particular, because it can provide medium for plant growth and path for wastewater flow. In addition, absorptions of substrate in absorbing the various pollutants in wastewater especially phosphorus also the main function of substrate. Selection of suitable substrates to use in CWs for industrial wastewater treatment is an important issue[11]. The selection is determined by the hydraulic permeability and the capacity of substrate in absorbing the pollutants. Substrates with poor hydraulic conductivity could clog the CW treatment systems, thus decreasing the removal efficiency of the system, and low adsorption by substrates could also affect the long-term removal performance of CW. Substrates can remove pollutants from wastewater by ion exchange, precipitation, adsorption, and complexation mechanisms[12].

The mixed substrates systems provide better surfaces areas for microbial or biofilm attachment, and offer a high hydraulic conductivity in CW treatment systems. According to [13], the combination of gravel and sand media substrate contributes to better pollutant removal efficiency than gravel alone. Gravel-sand bed was used as substrate in this project because of the high hydraulic conductivity and able to stabilized the retention time in SSF CW treatment systems [14]. Therefore, the combination of gravel and sand or also known as gravel-sand bed still have a great potential in treatment although they are considered conventional as constructed wetland substrate.
2. Materials and Method

2.1 Experimental Setup
The experiment was set by collection tank, constructed wetland tank and settling tank. The wetland tank was used plastic aquarium sizes with 40 cm (L), 22 cm (W) and 27 cm (H). Three (3) sets of experiments were set up name as POME with gravel (PG) and POME with gravel-sand (PGS) bed and POME only (PO) sets that served as control. Gravel-sand bed in the SSF CW tank layered with 1:1 ratio with depth of each layer set to 8 m each, with gravel at the bottom followed by sand at the top. Gravel-sand bed in the SSF CW tank arranged with 1:1 ratio. The gravel and sand were washed with tap water and dried under the sun in the greenhouse for 2-3 days before being utilized in the wetland tank. The granite gravel used was in diameter of 10-20 mm and coarse sand was used in the CW treatment tanks.

The POME samples were recirculated through the sub-surface flow constructed wetland for 30 days of treatment. The hydraulic retention time (HRT) was set to 3 days and the recirculated samples were run every 3 days. The experiment was run under rain shelter at School of Civil Engineering, Universiti Sains Malaysia (USM), Nibong Tebal, Pulau Pinang, Malaysia. The POME samples were collected from polishing pond at palm oil mill located at Nibong Tebal, Pulau Pinang. The polishing pond is the last pond before final discharge of POME treatment ponds. The water samples were taken from a polishing pond and preserved below 4°C in the cold room prior to analysis and experiment.

2.2 Analytical Procedures
The gravel-sand bed substrate was analysed for their porosity. The sand also analysed for particle size distribution curve by sieve analysis that plotted in Ms Excel using semi-log graph. A grade size distribution curve was analysed using different particle sizes D60, D30 and D10. The gradation of sand was measured using uniformity coefficient, Cu and curvature coefficient, Cc. The formula of Cu and Cc as Equation (1) and (2), respectively.

\[ C_u = \frac{D_{60}}{D_{10}} \]  
(1)

\[ C_c = \frac{D_{30}}{D_{60} \times D_{10}} \]  
(2)

The effluent was analysed for their turbidity, pH, chemical oxygen demand (COD), suspended solid (SS), ammoniacal nitrogen (NH₃-N) and total phosphorus (TP) and total nitrogen (TN). All the analysis of the POME were following the Standard Method for the Examination of Water and Wastewater, APHA. The removal efficiencies (RE) were analysed using Equation (3):

\[ RE (\%) = \frac{C_e - C_i}{C_i} \times 100 \]  
(3)

where RE (%) is the removal efficiency performance in percentage (%), \( C_e \) is the concentration of the effluent and \( C_i \) is the concentration of the influent.

All samples data was performed a statistical analysis using MS Excel using two-way ANOVA between days of treatment and types of substrate.

3. Results and Discussion

3.1 The initial concentration of POME Samples
The concentration of POME samples from the polishing pond are tabulated in Table 2. The pH, COD and SS of the effluent still in the discharge standard range of crude palm oil effluent. However, the
effluents also need further advance treatment to decrease the ammoniacal nitrogen and TN concentration to comply with crude palm oil discharge standard. The POME samples showed a significant concentration of nutrients such as nitrogen and phosphorus make them suitable in constructed wetland treatment as nutrients for plant growth and soil modification [15].

| Parameter                        | Unit | Concentration     |
|----------------------------------|------|-------------------|
| pH                               | -    | 8.25 ±0.21        |
| Turbidity                        | NTU  | 116 ± 0.7         |
| Color                            | Pt-Co| 5360 ± 113        |
| Suspended Solids                 | mg/L | 217 ± 2.8         |
| COD                              | mg/L | 833 ± 42          |
| Ammoniacal Nitrogen              | mg/L | 110 ± 22          |
| TN                               | mg/L | 153 ± 9.89        |
| TP                               | mg/L | 29.5 ± 6.01       |

**Table 2. Physicochemical Characteristic of Polishing POME Samples.**

3.2 *Gravel-Sand Bed Analysis*

The measured porosity of sand and gravel samples was 31% and 51%, respectively. The gravel porosity was higher than other research using gravel with 43% [16]. The particle size distribution analysis was shows in Figure 1. The coefficient of uniformity, C_u is equal to 1.628 that demonstrations the sand was uniformly graded while the coefficient of curvature, C_c is 0.9 that almost reached 1. That shows that the sand is well graded.

![Figure 1. Particle Size Distribution Curve of Sand.](image-url)
3.3 Pollutant Removal Efficiencies

The performance of SSF CW was measured in terms of removal efficiency for SS, turbidity, COD, color and total N and total P removal. Figure 2 shows the removal efficiency charts of PO (control) with PG and PGS. The PGS systems contributed higher performance rather than single gravel and control set with 66% COD, 97% suspended solid, 98% turbidity, 98% ammonia-nitrogen and 99% TN removal and 74% of TP removal. The COD removal is the lowest removal efficiency with 66% in PGS systems. There is a significant difference between PO, PG and PGS treatment systems (p<0.05). The most common of COD removal mechanism was through microbial degradation process, and a little contribution by sedimentation [17]. The COD removal in POME support by the microbes presence in the POME such as Micrococcus luteus, Stenotrophomonas maltophilia, Bacillus cereus and Bacillus cereus [15]. SS removal achieved 95.4% removal efficiencies. SS removal mechanism in wastewater treatment was by sedimentation and accumulation of solid particles into media pores and filtration by substrates particles [18]. The high SS removal attributed by the higher porosity and wide pore space of the gravel substrate [16].

Ammonia and TN removal shows the highest removal with 98% for ammonia and 99% of TN. There is insignificant different between the PG and PGS treatment (p>0.05). Nitrogen removal mechanism in CW was by nitrification and denitrification process. About 60–70% of TN is removed by denitrification process [19]. The high porosity of the substrates also increase oxygen inside the media thus enhance the rate of nitrification [20]. The phosphorus removal mostly related with the phosphorus adsorption by the substrate, microbial assimilation and the sedimentation [21]. There is significant different between PG and PGS with p<0.05.

![Figure 2. POME Removal Efficiencies Percentage.](image)

4. Conclusion

In this study, the effect of gravel-sand bed was analysed on the performance of polishing POME treatment. The removal efficiencies of most parameters such as SS, turbidity, ammoniacal nitrogen and total nitrogen achieved up to 97%-99% removal while 66% COD and 74% of TP removal. The treatment showed, the utilization of gravel-sand bed in SSF wetland treatment systems have significant effect in POME treatment. Substrates, such as gravel and sand, functions as supporting medium for plants in CWs and for nutrients removal (especially phosphorus) and pollutants removal. However, CW treatment systems using these substrates may be challenged with numerous problems, such clogging and low treatment performance. Thus, in future, the inspire the development of alternative substrate and low-cost substrate using agro-waste materials in CWs are recommended.
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