Performance of Oil Palm Frond Fiber as Filtration Material in Palm Oil Mill Effluent Treatment

Man Djun Lee\textsuperscript{1,*}, Nur Fathin Amirah Mohamad\textsuperscript{2}, Norhasmillah Abu Hassan\textsuperscript{2} and Pui San Lee\textsuperscript{2}

\textsuperscript{1}Department of Mechanical Engineering, Faculty of Engineering and Science, Curtin University Malaysia, CDT 250, 98009, Miri, Sarawak, Malaysia
\textsuperscript{2}School of Engineering and Technology, University College of Technology Sarawak, 1, Jalan Universiti, 96000 Sibu, Sarawak, Malaysia

*Email: mandjun89@gmail.com

Abstract. Over the years, oil palm waste management has always been a severe issue for the palm oil industry. The growing demand for palm oil contributes to the rapid raising of biomass waste and effluent discharge. This study aims to use oil palm frond fibre (OPF) as media filter material to treat wastewater generated by the palm oil mill itself; known as palm oil mill effluent (POME). POME contains high chemical oxygen demand (COD) and is highly acidic, which is very harmful to the environment if discharged directly to the watercourse without proper treatment. OPF fibre is selected due to its fascinating properties such as high cellulase content, readily available, biodegradable and non-toxic. Several arrays of experiments are conducted to assess the effectiveness of OPF in POME pollutants removal. The parameters to determine the performance of pollutant reduction of this study are COD, biochemical oxygen demand (BOD), total suspended solids (TSS), and pH. OPF filters are arranged in a different ratio, particle size and even paired with other filter media materials, such as activated carbon and sand to determine the best treatment result. Findings indicate that the OPF filter with a ratio of 4:3:3 fine, medium and coarse fibres yield the best results, which are 26.44% BOD removal, 55.21% COD removal, 98% TSS removal and pH of 5.77. The findings show that the OPF filter is significant in treating POME. OPF as filtration material could be a sustainable means in wastewater treatment since it is biodegradable and readily available in oil palm plantation as agricultural waste. The outcome of this study contributes to waste management and wastewater treatment. For future studies, OPF could be coupled with other treatment methods to achieve higher treatment performance to contribute to environmental sustainability.

1. Introduction
The oil palm mill industry is one of the biggest industries that contribute significantly to the pollution of water. The usage of wastewater from such extensive facilities is considered advantageous for reducing freshwater usage, decreasing the cost of replacement choice for water supply, and thus helping to reduce freshwater usage consumption because the water used can be treated and reused. Oil palm is Malaysia’s most famous asset which has helped shape the country’s outline of agriculture and economy. Agriculture in Malaysia accounts for 11 percent of its Gross National Income (GNI). A large amount of biomass product is created each year during the process of producing this net worth, including the production of palm oil, rubber, and rice. Since Malaysia is the second-largest producer of crude palm oil in the world,
this produces the highest number of biomass, valued at 80 million tons of dry oil per year, which has immense commercial potential. [1]

Based on the Foreign Agriculture Service’s Commodity Intelligence Report, Malaysia’s palm oil industry has progressed rapidly in recent years. In December 2012, Malaysia had an oil palm plantation of 5.08 million hectares, increased by 11.8 percent compared to 2008 and accounted for the world exports of 44 percent and 39 percent of the world’s total palm oil production [2]. In 2012, Malaysia had produced 18.79 million tons of crude palm oil (CPO). In the current scenario, however, Malaysia’s oil palm industry had produced around 70 million tons of biomass residue [3]. The palm tree’s excess of available raw materials contains about 90 percent of biomass waste and only about 10 percent of crude. In 1998 around 90 million tons of production of oil palm fruit was recorded. However, the empty fruit bunch (EFB), shell, and fibre were the mill residues that contribute to 45 percent of the number. This immense value of the production of CPOs and the presence of oil palm waste has contributed to a significant problem of disposal, thus causing a negative impact. The critical waste management standards are to limit and recycle the waste, and to recover as much energy as possible. In this way, it is desirable for both environmental and economic reasons to boost energy recovery from waste. For example, the final residue, such as ash can be either used or disposed of as fertiliser [4]). The residue of oil palm biomass has been extensively researched as a substitute of raw material for the processing of biofuel, paper-making pulp, wood production and bio-based chemicals applications. The alternative conversion technologies such as direct combustion, gasification, pyrolysis, liquefaction, fermentation, and anaerobic digestion can help maximise the recovery of energy (Wu et al., 2017). In this aspect, this study aims to use oil palm frond fibre (OPF) as media filter material to treat wastewater generated by the palm oil mill itself known as palm oil mill effluent (POME). This study could help to lessen the biomass residue that is produced from the palm oil plantation and to use the biomass residue as an effective method for the water treatment process. This can lead to minimising the environmental impact of biomass waste and assessing the opportunity for future applications of oil palm fibre.

2. Materials and Methods
The research methodology of this study is comprised of 3 phases which are shown in Figure 1. This study starts with a literature review. The Scientific publication related to the properties and characteristics of oil palm frond fibre (OPFF) and POME is reviewed. The outcome of the literature review will be used to determine the particle size of OPFF as a filtration material for POME treatment. In the next phase, a series of experiments are carried out in laboratories to determine the effectiveness of OPFF with different layout of media filter by using POME from the same source. The result of the wastewater is determined based on chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), pH and colour tests. The results are then analysed and discussed in the last phase of work. Main findings of this study are analysed and validated by comparing with previous studies in the field.
2.1 Characterisation of Oil Palm Frond Fibres
The OPFF samples were obtained from a local oil palm plantation located in Sibu, Sarawak, Malaysia. The samples are shredded into three different sizes: fine, medium, and coarse. The processed samples are shown in Figure 2. Some of the physical properties of OPFF are listed in Table 1.

![Various sizes of oil palm frond fibres](image)

**Figure 2.** Various sizes of oil palm frond fibres.

| Fibre Length (mm) | Fibre Diameter (μm) | Density (g/cm³) | Fibre Angle (°) |
|-------------------|---------------------|-----------------|-----------------|
| OPFF              | 0.59 – 1.59         | 11-19.7         | 8.20-11.66      | 40               |

**Table 1.** Physical properties of oil palm frond fibres [5].
The samples of different sizes are placed inside the filter tube based on different settings and ratios. The performance of OPFF is compared with other filter media as well: sand, zeolite and activated carbon which is shown in Figure 3.

![Other common media filter materials.](image)

Figure 3. Other common media filter materials.

The configurations of five different settings of media filter tubes are shown in Figure 4. The details about each setting are shown below:

- **T1**: The mixture of OPFF of all sizes together but with a ratio of 1:1:1
- **T2**: The organised layer of OPFF starting from fine, medium and coarse with a ratio of 1:1:1
- **T3**: Only contain layers of medium (50%) and coarse fibre (50%)
- **T4**: Multi-layer filter that contains sand, zeolite, and activated carbon only with a ratio of 1:1:1
- **T5**: Multi-layer of filter that contains sand (25%), zeolite (25%), activated carbon (25%) and OPFF coarse fibre (25%)

![Media filter with different settings.](image)

Figure 4. Media filter with different settings.

2.2 Palm Oil Mill Effluent

The wastewater samples were collected from one of the local palm oil mills operating in Sibu, Sarawak, Malaysia. The POME samples are being characterised by conducting experiments to determine the BOD, COD, TSS, pH, and of raw and treated samples. The samples are collected one-off to prevent contamination and fluctuation of results due to climate and other uncertainties. These could potentially contribute to the bias in this study. All POME samples are being treated in room temperature. The general characteristics of POME are shown in Table 2.

![Table 2. Characteristics of POME [6].](image)

| Characteristics | Range          |
|-----------------|----------------|
| pH              | 3.5 - 5.2      |
| Colour          | Brownish       |
| BOD (mg/L)      | 10 000 - 44 000|
| COD (mg/L)      | 16 000 - 100 000|
| TSS (mg/L)      | 5 000 - 54 000 |
2.3 Biochemical Oxygen Demand

BOD test of this study is following the Standard Procedure 5210 B: 5-Day BOD Test [7]. Dissolved oxygen (DO) was measured by YSI 5000 dissolved oxygen meter. The method started with the filling of a specified sized airtight bottle with a diluted and seeded sample to overflowing and incubating it at the specified temperature for 5 d. DO is measured initially and after incubation, and the BOD reading is computed from the difference between initial and final DO. Because the initial DO is determined shortly after the dilution is made, all oxygen uptake occurring after this measurement is included in the BOD measurement. The measurement of BOD is shown in Equation (1).

\[
\text{BOD (mg/L)} = \frac{(D_1 - D_2) - (s)V_s}{p}
\]

where \( D_1 = \) DO of diluted sample immediately after preparation, mg/L; \( D_2 = \) DO of diluted sample after 5 d incubation at 20°C, mg/L; \( S = \) oxygen uptake of seed, DO/mL seed suspension added per bottle (\( S = 0 \) if Samples are not seeded); \( V_s = \) volume of seed in the respective test bottle, mL; \( P = \) decimal volumetric fraction of sample used; \( 1/P = \) dilution factor.

2.4 Chemical Oxygen Demand

The COD of the POME samples before and after the treatment was measured following the APHA method for examination of water and wastewater using HACH reagent. The degree of the sample oxidation can be influenced by digestion time, the intensity of the reagent and concentration of the sample COD. COD was measured using the HACH Method 8000 with a HACH digestion solution with a range of 20-1500 mg/l before and after the experiment. The samples are heated with sulfuric acid and potassium dichromate; a potent oxidising agent, for 2 hours at 150 degrees Celsius in DRB200 reactor. At 620 nm, colourimetric COD assessment was conducted using a DR 6000 HACH spectrophotometer (HACH, 2013).

2.5 Total Suspended Solid

TSS was measured in compliance with Standard Methods Section 2540 D before and after the procedure, with total solids dried at 103°C to 105 °C. The filtered and unfiltered wastewater samples are evaporated in a weighted dish and dried in an oven at 103 ° C to 105 ° C to constant weight. The change in filter weight measures the cumulative suspended solids. When the suspended material clogs the filter and prolongs filtration, the filter diameter may have to be expanded, or the sample volume can be reduced. The discrepancy between estimated dissolved solids and total solids is determined to get the estimated suspended solids value (APHA, 2012). TSS calculation is shown in Equation (2).

\[
\text{TSS (mg/L)} = \frac{(\alpha-\beta) \times 1000}{\text{sample volume, mL}}
\]

2.6 pH

pH was measured with pH meter HACH HQ11D Portable pH meter with Gel pH Electrode. The pH measurement range is from 1 to 14 pH, and the pH meter was calibrated with pH 4.0, 7.0 and 10.0 buffers [8]. Several trials are recorded to obtain the average value and to make sure the consistency in the result value. The electrode is cleaned with distilled water before taking the next measurement or every time the wastewater sample is changed.

2.7 Colour

The colour of the POME sample is shown in Figure 5. The colour of this study is collected and compared visually using photographs taken with a white background. This test is not significant in this study as total colour removal using OPFF is not possible. The OPFF media filter would change any plain watercolour to the yellowish colour shown in Figure 6. Therefore, the results are only being compared visually to provide a general view of colour removal using OPFF.
3. Results and Discussion

3.1. pH Treatment Performance

The pH of the untreated and treated POME samples are shown in Table 3. It was found that T2 media filter able to reduce the acidity of POME from 3.94 to 5.77, which comply to the minimum discharge standard of pH 5.5 set by Department of Environment (DOE) Malaysia [9]. Findings indicate that OPFF alone with three different sizes can neutralise the acidic content of POME to fulfil minimum discharge requirement, which is significant to the palm oil mills. The configuration of fibres based on different sizes of fibres plays an essential role in neutralising the acidity of POME samples as proved by results obtained from T1, T2 and T3. On the other hand, sand, zeolite and activated carbon can neutralise acidic of POME as well but not as significant as OPFF as indicate by result shown in T4 and T5.
Table 3. pH of treated POME samples.

| Sample | Untreated | T1  | T2  | T3  | T4  | T5  |
|--------|-----------|-----|-----|-----|-----|-----|
| pH Value | 3.94 | 5.29 | 5.77** | 4.73 | 4.87 | 4.92 |

**compliance to minimum discharge standard based on Department of Environment Malaysia of pH 5.5.

3.2 Colour Removal Performance

The colour of the untreated and treated POME samples are shown in Figure 7. The colour in POME samples is usually due to the presence of metals, rust, organic acids, microbiological matter and other industrial wastes. By visually comparing the results in Figure 7, it was found that the colour of the T2 sample is the clearest compared to others. This result further supports the previous findings of pH in which configuration and different sizes of OPFF have significant roles to play in neutralising acid and colour removal. The result shows that the T3 setting is not significant in colour removal. Treated POME colour result from filter media T1, T4 and T5 shows that POME colour is being removed as well but not as significant as T2. However, the natural occurring yellowish colour from fibre contributes to the colour of the solution, and therefore total removal of colour is not possible. Even though results are compared visually, but it is believed that T2 media filter is significant in colour removal compared to other settings.

![Figure 7. Colour of POME samples.](image)

3.3 BOD, COD and TSS Removal Performance
The results for BOD, COD and TSS removal are shown in Figure 8. It was found that OPFF is significant in BOD, COD and TSS removal as reflected in T1 and T2 results. With proper configurations, T2 media filter yield the best result in BOD, COD and TSS removal percentage, which are 26.44%, 55.21% and 98% respectively. As for BOD removal percentage result shown in T3 exhibits negative result. In this situation, the oxygen consumption rate of the sample T3 reaches its rate of replenishment. This implies that the BOD level is greater than the BOD value of the untreated POME, consequently contributed to the negative result. The high value indicates the intense level of microbial pollution in the wastewater. The reason for high BOD levels is due to the presence of nitrates and phosphates in a body of water which contributes to the increase of organic waste in the water [10]. Although the wastewater for T3 is being filtered, however, the small sediments are still able to pass through quickly because of the size of the fibre that is not dense enough.

Findings from this study show that the removal rate of COD depends on the presence of fine size fibre inside the filter. The results of T4 and T5 also have confirmed these findings with the presence of fine fibres in the filtration media, which contribute to increasing the removal percentage of COD. However, the present of sand, zeolite and activated carbon did not demonstrate excellent performance compared to the filter media containing just the fibre.

Most media filter (T1, T2, T4 and T5) exhibit excellent TSS removal in POME treatment, with removal percentage higher than 90%, only T3 shows TSS removal percentage of 84%. This shows that TSS removal depends on the fine fibre in OPFF filter. As expected, sand, zeolite, and activated carbons are excellent in TSS removal; as these are common materials being used as media filter materials. However, OPFF media filter exhibits much better performance in TSS as shown in T2 with 98% removal percentage.

All these findings indicate that T2 media filter is better media filter than sand, zeolite and activated carbon for BOD, COD and TSS removal in POME treatment. The overall treatment performance of OPFF depends heavily on the presence of fine OPFF in media filter, as shown in all T2 treatment results.

4. Conclusion and Recommendation
The present study was designed to determine the performance of OPFF as a filtration material for POME treatment. The contribution of this study is twofold: agricultural waste management and wastewater
treatment for the oil palm industry. Findings from this study indicate that OPFF is indeed significant in POME treatment, especially in neutralising the acidic environment, colour, BOD, COD and TSS removal. The best performance for OPFF is in T2 settings with fine, medium and coarse fibres in equal ratio yielded pH treatment result of 5.77, which complies minimum discharge limit set by the Malaysian Department of Environment. As for colour removal, T2 gives the best visual result of the clear yellowish solution, which is similar to the natural occurring colour of OPFF.

Moreover, T2 media filter exhibits the best performance in BOD, COD and TSS removal of 26.44%, 55.21% and 98% respectively. The outcome of this study would contribute to achieving environmental sustainability. This study provides an opportunity for the oil palm plantation in agricultural waste management issue related to OPF and increases the value of OPFF. Since OPFF is readily available and the media filter is easy to produce, the palm oil mill could produce this filter and treat POME with relatively lower cost now. For future study, it is recommended that the scale of this filter be increase to treat a larger volume of wastewater which could ultimately contribute to sustainable palm oil production and reduce the negative perception of public towards oil palm products.

Acknowledgments
Authors acknowledge the support received from Curtin University Malaysia and University College of Technology Sarawak.

References
[1] Ong T, President V and Innovation S 2012 National Biomass Strategy 2020: New Wealth Creation for the Palm Oil Industry Agensi Inov. Malaysia
[2] USDA 2012 Malaysia: Stagnating Palm Oil Yields Impede Growth United States Dep. Agric. - Foreign Agric. Serv.
[3] Shuit S H, Tan K T, Lee K T and Kamaruddin A H 2009 Oil palm biomass as a sustainable energy source: A Malaysian case study Energy 34 1225-35.
[4] United Nations Development Programme 2007 Malaysia Generating Renewable Energy from Oil Palm Wastes
[5] Sukiran M A, Abnisa F, Wan Daud W M A, Abu Bakar N and Loh S K 2017 A review of torrefaction of oil palm solid wastes for biofuel production Energy Convers. Manag. 149 101–20
[6] Lee M D, Lee P S and Chong K H 2020 Treatment performance of palm oil mill effluent by utilizing chitosan and ferric chloride coupled with activated carbon and ultrasound bath Desalin. Water Treat. 174 136–42
[7] APHA 2017 APHA 5210B: 5-Day BOD Test
[8] HACH 2013 Water Analysis Guide (United States: HACH Company)
[9] Parthasarathy S, Mohammed R R, Fong C M, Gomes R L and Manickam S 2016 A novel hybrid approach of activated carbon and ultrasound cavitation for the intensification of palm oil mill effluent (POME) polishing J. Clean. Prod. 112 1218–26
[10] Bello M M and Abdul Raman A A 2017 Trend and current practices of palm oil mill effluent polishing: Application of advanced oxidation processes and their future perspectives J. Environ. Manage. 198 170–82