Treatment and decolourisation of treated palm oil mill effluent (POME) using oil palm trunk-derived activated carbon as adsorbent

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Abstract. Palm oil mill effluent (POME) has become a serious problem for the oil palm industries because of its high organic contents and other contaminant formation that results in dark colour, turbid and unpleasant odour. In the conventional treatment of POME used in Malaysia, treated POME can still pollute receiving water bodies as colour is one of the major contaminants that is not completely removed. Adsorption is a promising technique for addressing this problem, with a large range of adsorbents to choose from. It works by adhering the pollutants on to the high porous surface area of adsorbent. However, the high cost of coal-based AC that is commonly used can be the limiting factor for its wider application in palm oil industry. Therefore, this work looks into resource recovery (i.e., use of waste stream) from plantation as precursor of AC synthesis to treat its own waste from the palm oil mill. Hence, the suitability of oil palm trunk (OPT) as feedstock for AC application in POME colour removal in the mill is investigated. Experimental run at the as-synthesis OPT-derived AC was performed for validation via POME adsorption test. The result shows that the OPT-derived AC produced can remove the organic pollutants and colour of POME at the dosage of 15% w/v within 48 hours.

1. Introduction

Malaysia has been ranked as the second largest palm oil producer in the world, thus it is unquestionable that palm oil industry has significant contribution to the economy in Malaysia. However, this will also result in massive amount of waste being produced during the palm oil milling process (i.e., POME) and in the oil palm plantation (i.e., oil palm trunk (OPT) and oil palm frond (OPF)). POME is a brown oily wastewater that contain approximately 95–96% water, 0.6–0.7% oil and 4–5% total solids including 2–4% suspended solids. Existence of colour in POME hinders the photosynthetic process of aquatic beings and has toxic impact.

Due to the biologically stable pigments present in POME, therefore typical techniques used like biological degradation is inadequate to get rid of the remaining colour and organic compounds from wastewater. As a result, further treatment is required to remove the colour and improve the quality of the POME before it is release into the receiving water bodies. Till date, there are various methods used for reduction of POME colour. Anaerobic digestion has been used commonly by majority palm oil mills for POME treatment [1]. More than 85% of palm oil mills in
Malaysia have adopted the ponding system for the treatment of POME [2] while the others has chosen the open digesting tank method [3]. These aforementioned techniques are known as conventional POME treatment method because it implies lower capital and operating cost but requires long retention time (i.e., 1-2 months) and large treatment areas [4]. Coagulation-flocculation method is also commonly applied for the treatment of POME [5] but is restricted for high-soluble compounds. Thus, the use of low-cost adsorbents for decolourisation of wastewater via adsorption process have received much attention. Adsorption is a favourable method for the removal of impurities and colour and has potential application for the treatment of real industrial wastewater. However, commercially available AC are deemed to be expensive [6]. This is because non-renewable and relatively costly are used as the starting material like coal, which is unwarranted in pollution control applications. Thus, in recent years, this matter has driven an increasing research interest in the synthesis of AC using starting materials that are renewable and cheaper which are mostly industrial and agricultural waste, particularly for purpose regarding wastewater treatment.

Potential strategies to reduce the environmental pollution created by palm oil mill industry (i.e., POME) is by utilising its own waste from the plantation and turn it into adsorbents (i.e., AC). Hence, this project proposes to tackle both waste and pollution issue from the palm oil sector using its waste stream. There is limited information regarding the production of AC from OPT despite of its great potential of being the AC precursor due to its high carbon content of around 35-44% and a low inorganic mineral content of around 2-4%. Consequently, OPT is chosen to be investigated on the performance of POME colour reduction in order to fill this knowledge gap. Based on literature, there is only one journal paper by [7] uses OPT as the AC precursor. It uses both physical and chemical activation synthesis method to produce AC with relatively high surface area of 1884 m² g⁻¹, which is considered a remarkable result.

In this study, efficiencies of OPT-derived AC for the removal of colour, and COD from the treated POME were investigated. Chemical Oxygen Demand (COD) is a common parameter used for evaluating the quality water or wastewater. COD chemical evaluation determines the total amount of all chemicals contained in the liquid, including organic and inorganic materials. It is defined as the equivalent amount of oxygen consumed to the chemical oxidation of organic matter by strong oxidant. The oxidation of matters for polluted water is done using the strong oxidizing agents like potassium dichromate (K₂Cr₂O₇), whereas for clean water it is conducted using potassium permanganate (KMnO₄) [8]. Water with high COD value has higher chances of causing harm to the environment and the living organisms. The POME COD level arises from the compounds stored in oil palms and the processes to generate palm oil. Generally, raw POME has very high COD value of approximately 50,000 mg L⁻¹ [9] and about 1730 mg L⁻¹ in bio-treated POME [10]. The discharge limit for COD, based on the Malaysian Department of Environment (DOE) 1986, is 1000 mg L⁻¹ [11]. Hence, effective method is required to treat POME and major oil palm industries in Malaysia applied conventional treatment such as ponding system which involves long retaining duration and the usage of large surface area. Colour is another display of water quality that is simple to examine. The dark colour of POME derives from the palm oil mill's sterilising procedure of fresh fruit bunches. The yellowish-brown colour and strong sourish odour are due to the present of complex organic compounds in POME. The degradation of lignocellulosic components (i.e., anthocyanin, lignin, tannin, carotene pigment, polyphenol compounds, polyalcohol, and melanoidin) caused by sterilisation of fresh fruit bunches results in the creation of an oily, viscous texture and the dark brown colour of POME [12-14]. The Malaysian DOE has yet to set a standard regulation for POME colour. Nonetheless, the discharge's murky and dark brown colour raises public concerns about the low water quality.

The aim of this research was to determine whether the optimised synthesis OPT-derived AC from the previous work [15] is a potential adsorbent for the treatment and decolourisation of POME.
2. Materials and methods

2.1. Materials

The OPT used to synthesised AC was collected from an oil palm estate in Bintulu were washed with water to remove dirt from its surface and then dried in an oven at 105 °C for 1 day. Then, the dried OPT were crushed to particle size ranging from 0.3 to 1.18 mm by using a blender and sieved. Raw palm oil mill effluent (POME) was obtained from Felcra Berhad at Kota Samarahan. Then, the raw POME was filtered using filter paper with pore size of 180 μm to obtain filtered POME.

2.2. Sample preparation

The synthesis of AC from OPT was done via chemical activation with phosphoric acid as its impregnating agent. The synthesis procedure of OPT-derived AC via chemical activation was carried out corresponding to Lim et al. [16] with modification as follows: 10 g of dried OPT was mixed with 15.9 mL phosphoric acid (i.e., impregnation ratio of 2.29). To allow the sample to absorb phosphoric acid, distilled water was poured to the OPT until it was completely covered. The sample was then left at room temperature for 24 hours before being dried at 100°C for 1 day to remove excess water and allow the phosphoric acid to absorb entirely.

The resulting samples underwent semi carbonisation at 170 °C in an oven for an hour. Before the activation process, the semi-carbonized sample was allowed to cool to ambient temperature. Then, the sample was put in a muffle furnace for activation at 450 °C for 6 mins. The obtained ACs were washed with distilled water until the wash liquor conductivity level was less than 50 μS. The samples were then dried for 24 hours at 105°C in an oven. After that, the ACs were ground into a fine powder and stored for future use.

2.3. Characterisation

2.3.1. Proximate analysis. Proximate analysis is carried out to determine the physical characteristics of the resulting sample such as the moisture content (%) by mass, volatile matter content (%) by mass, ash content (%) by mass and fixed carbon content (%). It is also used to determine the suitability of OPT as the precursor for the synthesis of AC. The procedures of proximate analysis were carried out according to the [17].

2.3.2. Iodine number. Iodine number denotes the amount (i.e., in milligrams) of iodine that can be adsorbed by 1 g of AC. The purpose of this analysis is to determine the adsorption capacity of the OPT-derived AC. The AC iodine number can be regarded as a quantitative benchmark of the AC porosity, which can be used as a precise forecast of its surface area. Iodine number analysis was carried out in accordance with the standard procedure [18].

2.4. POME adsorption

Batch adsorption studies were carried out in a Memmert shaking water bath at a constant temperature of 30 °C. Around 2 g of AC (dosage of 15 % w v⁻¹ with respect to the sample volume) were added to 13.33 mL raw POME in five Erlenmeyer flasks, respectively. Controlled experiment was also conducted where 100 mL of raw POME is added into five Erlenmeyer flasks. In five consecutive days, the parameters of the treated POME (i.e., after adsorption) and degraded raw POME are measured accordingly.

3. Results and discussion

3.1. Iodine number test

The experimental response value (i.e., iodine number from experimental run) and the predicted value is 884.49 mg g⁻¹ and 937.94 mg g⁻¹ respectively. The results obtained was very close with 5.70%
difference, proving that the model can satisfactorily predict the experimental conditions. The AC prepared using the optimized variable set were then subjected to POME adsorption tests. Iodine number of AC synthesis using the optimum parameter combination has iodine number in the range of 600 to 1100 mg g⁻¹, which is suitable to be used for water treatment [19].

3.2. Proximate analysis
According to table 1, raw OPT has high volatile matter and low ash content. According to Rafatullah et al. [20], precursor of AC that possess high volatile matter content is preferred as high temperature during carbonisation and activation will cause them to be removed. Consequently, more pores will be formed within the resulting AC. The statement of the removal of volatile matters from AC precursor can be further proven by the decrease in volatile matter content while converting from OPT to AC.

Moreover, low ash content in AC precursor is more advantageous for the production of AC. This is because high ash content represents high inorganic constituents in the resulting carbon, which restricts the pore generation by blocking the pore entrance during the activation stage. Additionally, table 1 also reveals that AC synthesised from OPT fulfil the standard physical characteristics of AC. Thus, based on the proximate analysis results, it can be concluded that OPT is a suitable precursor in the production of AC.

Table 1. Proximate analysis of each sample and the standard acceptance level for AC.

| Proximate analysis            | Raw OPT | OPT-derived AC | Acceptable level for AC [21, 22] |
|------------------------------|---------|----------------|----------------------------------|
| Moisture content (%)         | 9.80    | 0.33           | 15                               |
| Volatile matter (%)          | 72.43   | 14.86          | 13 – 18                          |
| Ash (%)                      | 2.95    | 4.96           | 2 – 5                            |
| Fixed carbon content (%)     | 24.62   | 80.18          | > 72                             |

3.3. POME adsorption test
POME adsorption test was performed to determine the efficiency of OPT-derived AC in removing the organic pollutants and colour of POME. Table 2 shows the initial parameters of the raw POME and filtered POME as well as the percentage reduction of parameters due to filtration through filter paper. Hence, it can be deduced that filter paper can barely remove the organic compound and colour of POME.

Table 2. The parameters measured for raw and filtered POME.

| Parameters          | Treated POME | Filtered POME | Reduction (%) |
|---------------------|--------------|---------------|---------------|
| COD (mg L⁻¹)        | 1700         | 1600          | 6             |
| Colour (Pt Co⁻¹)    | 9200         | 5500          | 40            |
According to table 3, it can be observed that OPT-derived AC can removed most of the pollutants and colour of POME. Therefore, it can be concluded that OPT-derived AC has higher efficiency in treating POME due to its high iodine number and BET surface area. As mentioned earlier, one of the disadvantages of conventional ponding system is that it requires long retention time of approximately 1 to 2 months. Furthermore, even if the POME is biologically treated to meet the government standard discharge limit, it will still bring negative environmental impacts. As for the POME treatment through adsorption by AC, it only requires approximately 2 days to remove most of the organic pollutants and decolourise the POME based on the results obtained from this work.

Table 3. Comparison of POME adsorption test using OPT-derived AC and PKS-derived AC.

| Parameters                              | Results from This Work | Results from [23] |
|-----------------------------------------|------------------------|-------------------|
| AC precursor                            | Oil palm trunk (OPT)   | Palm kernel shell shell (PKS) |
| BET surface area (m² g⁻¹)               | 1605.7                 | 566.27            |
| Iodine number (mg g⁻¹)                  | 884.49                 | -                 |
| Dosage of AC (% W V⁻¹)                  | 15                     | 15                |
| Optimum removal in COD (%)              | 99                     | 85                |
| Optimum removal in colour (%)           | 99                     | 92                |
| Optimum removal in tannin-lignin (%)    | 99                     | 92                |
| Period treatment to reach maximum pollutant removal (days) | 2                      | 3                 |

POME treatment demands an efficient method to deal with the contemporary challenges. Till date, some palm oil mill that apply the current available treatment method, still fail to comply with the standard discharge limit set by the DOE. [24]. Thus, it is understood that the adsorption method can enhance the biological POME treatment method in a more advantageous way such as shorter retention time and smaller surface area (i.e., in terms of land used). In this study, the condition of the POME is not altered and used as it is. The colour of treated POME (i.e., dark brown) was significantly decreased, as more than 99% of its initial value was decreased, and it was observed to be colourless to the naked eye. The removal percentage of this work was 99 % via OPT-derived AC adsorption compared to the 92 % colour removal by Jalani et al. [25] after treating POME with PKS-derived AC.

After adsorption by OPT-derived AC, the COD test results indicates a 99 % decrease. The adsorption treatments employing OPT-derived AC greatly reduces the COD value to almost 0 mg L⁻¹ from the initial COD value of treated POME (i.e., 1600 mg L⁻¹). It also shows that, the reduction in COD in this work by OPT-derived AC is higher compared to that performed by Jalani et al. [25] using PKS-derived AC.

High surface area adsorbent will have high efficiency in treating POME which is the main factor that contributes to the excellent performance of OPT-derived AC in treating POME. Based on the comparison on the maximum removal of pollutants and the duration to reach the maximum pollutant
removal shown in table 3, it can be concluded that OPT-derived AC from this work not only has higher efficiency in treating POME, and also shorter duration to reach maximum pollutant removal of POME as compared to the PKS-derived AC by Jalani et al. [25].

4. Conclusion
Oil palm trunk have successfully been modified into highly porous AC with high iodine number of 884.49 mg g\(^{-1}\). Based on the proximate analysis results, it can be concluded that OPT has the potential to be the precursor of AC synthesis and the OPT-derived AC fulfils the standard physical characteristics of AC. On the other hand, the performance of OPT-derived AC on POME adsorption was significantly satisfied, specifically measuring parameters in COD, and colour removal in approximately two days with the dosage of 15 %w v\(^{-1}\). In conclusion, this research project has justified that OPT is suitable to be used to produce AC that can treat POME efficiently.

5. Practical Implication
According to the outcome of this work, the production of OPT-derived AC is favourable in large scale production of AC as this will consequently reduce the waste produced in the fill and at the same time able to treat the waste stream from the oil palm mill. Besides, conventional ponding system requires extremely large surface area of land and long retention time of about 1 to 2 months. However, these issues can be solved by using OPT-derived AC from this work as the adsorbent. POME can be treated efficiently in shorter duration which would be an advantage for the palm oil mill manufacturers to handle the substantial amount of POME being produced during the palm oil milling process.

References
[1] Tay J H 1991 Complete reclamation of oil palm wastes Resour., Conserv. Recycl. 5 383–92
[2] Ma A, Cheah S, Chow M and Yeoh B 1993 Current status of palm oil processing waste management, waste management in Malaysia: Current status and prospects for bioremediation 111–36
[3] Yacob S, Hassan M A, Shirai Y, Wakisaka M and Subash S 2005 Baseline study of methane emission from open digesting tanks of palm oil mill effluent treatment Chemosphere. 59 1575–81
[4] Abdurahman N, Rosli Y and Azhari N 2011 Development of a membrane anaerobic system (MAS) for palm oil mill effluent (POME) treatment Desalination. 266 208–12
[5] Bhatia S, Othman Z and Ahmad A L 2007 Pretreatment of palm oil mill effluent (POME) using moringa oleifera seeds as natural coagulant J. Hazard. Mater. 145 120–6
[6] Babel S and Kurniawan T A 2003 Low-cost adsorbents for heavy metals uptake from contaminated water: A review J. Hazard. Mater. 97 219–43
[7] Hussein M Z B, Rahman M B B A, Yahaya A H, Hin T-Y Y and Ahmad N 2001 Oil palm trunk as a raw material for activated carbon production J. Porous Mat. 8 327–34
[8] Ma Y, Tie Z, Zhou M, Wang N, Cao X and Xie Y 2016 Accurate determination of low-level chemical oxygen demand using a multistep chemical oxidation digestion process for treating drinking water samples Anal Methods. 8 3839–46
[9] Adeleke O A, Saphira M R, Daud Z, Ismail N, Ahsan A, Ab Aziz N A, et al 2019 Principles and mechanism of adsorption for the effective treatment of palm oil mill effluent for water reuse Nanotechnol. Water Wastewater Treat. 1–33
[10] Amosa M K 2016 Sorption of water alkalinity and hardness from high-strength wastewater on bifunctional activated carbon: Process optimization, kinetics and equilibrium studies Environ. Technol. 37 2016–39
[11] Bello M, Nourouzi M, Abdullah LC, Choong TS, Koay Y and Keshani S 2013 POME is treated for removal of color from biologically treated POME in fixed bed column: Applying wavelet neural network (WNN) J. Hazard Mater. 262 106–13
[12] Amat N A, Tan Y, Lau W, Lai G, Ong C, Mokhtar N, et al 2015 Tackling colour issue of
anaerobically-treated palm oil mill effluent using membrane technology. *J. Water Process. Eng.* **8** 221–6

[13] Mohammed R R 2013 Decolorisation of biologically treated palm oil mill effluent (POME) using adsorption technique *Int Ref J Eng Sci.* **2** 1–11

[14] Mohammed R R and Chong M F 2014 Treatment and decolorization of biologically treated palm oil mill effluent (POME) using banana peel as novel biosorbent *J. Environ. Manag.* **132** 237–49

[15] Lim A, Chew J J, Ng L H, Ismadji S, Khaerudini D S and Sunarso J 2020 Synthesis, characterization, adsorption isotherm, and kinetic study of oil palm trunk-derived activated carbon for tannin removal from aqueous solution *ACS Omega* **5** 28673–83

[16] Lim W C, Srinivasakannan C, Balasubramanian N 2010 Activation of palm shells by phosphoric acid impregnation for high yielding activated carbon *J. Anal. Appl. Pyrolysis* **88** 181–6

[17] D1762-84 A 2009 Standard test method for chemical analysis of wood charcoal. American Society for Testing and Materials, Conshohocken, PA. 2009

[18] D4607–94 A 2006 editor Standard test method for determination of iodine number of activated carbon. Standard Test Method for Determination of Iodine Number of Activated Carbon; 2006: ASTM International, West Conshohocken, PA

[19] Gupta T 2017 Carbon: the black, the gray and the transparent *Springer*

[20] Rafatullah M, Ahmad T, Ghazali A, Sulaiman O, Danish M and Hashim R 2013 Oil palm biomass as a precursor of activated carbons: A review *Crit. Rev. Environ. Sci. Technol.* **43** 1117–61

[21] Deshpande R Ultracapacitors: Future of energy storage: McGraw-Hill Education; 2014

[22] Rafatullah M, Ahmad T, Ghazali A, Sulaiman O, Danish M and Hashim R 2013 Oil palm biomass as a precursor of activated carbons: A review *Crit. Rev. Environ. Sci. Technol.* **43** 1117–61

[23] Jalani N F, Aziz A A, Wahab N A, Hassan W H W and Zainal N H 2016 Application of palm kernel shell activated carbon for the removal of pollutant and color in palm oil mill effluent treatment *J. Environ. Health Sci. Eng.* **2** 15

[24] Mohammed R R and Chong M F 2014 Treatment and decolorization of biologically treated palm oil mill effluent (POME) using banana peel as novel biosorbent *J. Environ Manage.* **132** 237–49

[25] Jalani N F, Aziz A A, Wahab N A, Hassan W H W and Zainal N H 2016 Application of palm kernel shell activated carbon for the removal of pollutant and colour in palm oil mill effluent treatment *J. Earth Environ. Health Sci.* **2** 15