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CAKE FILTRATION FOR SUSPENDED SOLIDS REMOVAL IN DIGESTATE FROM ANAEROBIC DIGESTED PALM OIL MILL EFFLUENT (POME)

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ABSTRACT

Oil palm industry contributes significantly to the economic growth in Malaysia. At the same time, it generates a huge amount of palm oil mill effluent (POME) which contains valuable resources for energy, water and nutrients recovery. Currently, it has been used as feed for anaerobic biogas reactor to produce methane, a renewable energy source. The effluent discharged from the anaerobic digester, known as digestate, still contains abundant water and nutrients for recovery. However, the presence of suspended solids in digestate hinders the downstream water and nutrients recovery processes. Cake filtration process that has been successfully employed in water industry to remove suspended solids appears to be an attractive option for the removal of suspended solids in digestate. This paper investigates the performance of cake filtration process in removing suspended solids in digestate. Various types of filter aid such as perlite, diatomaceous earth (DE), bleaching earth (BE), powdered activated carbon (PAC), and boiler ash (BA) are used in this study. The amount of filter aid used as precoat and body feed was also varied (with ratio 1:1 from 1.0 g to 3.0 g) in the process. The effectiveness of cake filtration process was evaluated based on the quality of filtered digestate and the filtration flux. Overall, the particle size and size distribution of filter aids have huge influence on the cake filtration process. Turbidity removal above 90 % can be achieved regardless the type and amount of filter aids used. Due to the presence of plenty fine pores (as shown by FESEM image) on perlite particles and its narrow particle size distribution, the permeation of water was the highest flux (1 ml/cm².min) and retention of suspended solids also was among the highest compared to other filter aids. This study shows that cake filtration process has the potential to be used to remove suspended solids in digestate so that the nutrient and water can be recovered in the following downstream process.

KEYWORDS

Palm oil mill effluent (POME), anaerobic digestate, cake filtration, filter aids, turbidity and suspended solids removal.

1. INTRODUCTION

Oil palm industry is one of the major agriculture sectors which contributes 5-6 % to Malaysia's Gross Domestic Product (GDP) [1]. Currently, Malaysia accounts for 39 % of world palm oil production and 44 % of world exports [2]. Associated with the huge production of crude palm oil, large volume of colloidal wastewater known as palm oil mill effluent (POME) is produced. POME contains high amount of biochemical oxygen demand (BOD), chemical oxygen demand (COD) and it is rich in nutrients and degradable organic matter which make it a highly polluting wastewater [3,4]. Currently, the most conventional POME treatment practices in Malaysia since 1982 are anaerobic and facultative pond systems due to their low cost. However, many palm oil mills nowadays have started to adopt anaerobic digester tank system to treat POME and at the same time to recover methane biogas which is one attractive renewable energy source [5]. Even though anaerobic digestion manages to reduce COD and BOD, the anaerobic treated digestate still contains abundant nutrients and water that could be recovered and reused in palm oil plantation [6]. In order to realize these targets, the suspended solids inside the digestate have to be removed so that the downstream water and nutrient recovery processes can be conducted smoothly.

Cake filtration is a suspended solids removal process which has been widely used either as a primary separation step to recover biomass solids or as a final step to remove fine particulate matters in bioprocessing industry [7]. It utilizes filter aids which form a cake layer on the mesh support (filter medium) to retain suspended solids in the solution [8]. Filter aids are particulate or fiber materials that can be used as a precoat

or body feed or combination of both to enhance the filtration flux and particles removal efficiency of the filtration operation. As a precoat, filter aids form a dense yet porous and highly permeable cake layer on the filter medium to protect it from clogging and consequently improving the separation efficiency. For body feed application, filter aids are mixed with the water to-be-treated to increase suspended solids cake porosity and decrease cake compactibility so as to facilitate better filtration flux [9]. This reduces filtration time and energy consumption due to high filter-cake permeability [10]. The main solid by-product of the process is the filter cake; a spongy, amorphous and dark color substance (due to the retention of organic suspended solids) with high moisture content. The use of filter cake as fertilizer or soil amendment is widely accepted and is practiced in agriculture industry. Filter cake prevents soil erosion, crusting and cracking. It improves drainage and promotes the natural growth of bacteria and microorganisms [11].

To date, there is no report on the use of cake filtration to remove suspended solids in POME. Hence, this study aims to investigate the performance of cake filtration process to remove the suspended solids in POME digestate. The performance of cake filtration using different types and amount of filter aids was evaluated by the quality of the filtered digestate and the filtration flux.

2. MATERIALS AND METHODS

2.1 Materials

Digestate POME was collected from closed-type anaerobic digester system at Sime Darby East Palm Oil Mill, Carey Island, Malaysia. The digestate was preserved at temperature less than 4 °C to avoid biodegradation in the sample due to microbial action [4]. The digestate was then thawed at room temperature before being used for experiment. The characteristics of digestate POME was analyzed and listed in Table 1.

Table 1: Characteristics of digestate POME from anaerobic digester system

Parameters	Digestate POME
pH	7.8
COD (mg/L)	2570
Total suspended solid (mg/L)	1620
Turbidity (NTU)	472
Nitrogen (mg/L)	251
Phosphorus (mg/L)	118

In these tests, the filter aids used were perlite supplied by Dr. Mueller AG SEA Regional Office, Malaysia, diatomaceous earth (DE) purchased from DEFG, Malaysia, bleaching earth (BE) supplied by Taiko Bleaching Earth Sdn Bhd, Malaysia and powdered activated carbon (PAC) purchased by R&M chemicals. Boiler ash (BA) was the incinerated solid waste from palm oil mill and then milled using ball mill system at 30 rpm. The milled boiler ash was then sieved to 25 µm.

2.2 Cake Filtration Process

The cake filtration process was performed in a laboratory scale Nutsche filter (Figure 1) driven by compressed air. The filtration area was 0.001 m². The filter medium (Figure 1) used is a woven cloth with PVDF monofilament weft. The diameter measurement is 46 mm with porometer value 10 µm. The filter medium acted as a support for the cake layer to form on top of it. Both Nutsche filter and filter medium was supplied by Dr. Mueller AG SEA Regional Office, Malaysia. This experiment was conducted under constant pressure (2 bar) condition. Ratio for precoat and body feed is 1:1 for each test. Moreover, mass of each type of filter aids as precoat and body feed was varied from 1 g – 3 g. The filter aids to be used as precoat was mixed with 200ml of ultra-pure water to form filter aid slurry before being recirculated through the filter medium. Pressure from the compressed air will force the filter aid slurry to pass through the filter medium, in which the filter aids will be retained by the filter medium and formed a cake layer that works as the filter layer. Then, the same filter aids were mixed with 200 ml of digestate as the body feed prior pouring the digestate slurry into the filter. Filtration flux (q) was measured to determine the permeability of the cake filtration process from Eq. 1 based on Darcy's law [9]. The suspended solids removal efficiency was determined by measuring the turbidity and total suspended solids (TSS) of the filtered digestate.

$$q = \frac{V}{At} \text{----- Equation (1)}$$

where V is volume of filtered digestate (m³), A is filtration area (m²), and t is filtration time (hr).



Figure 1: Laboratory scale Nutsche filter (left) and filter medium (right)

2.3 Analytical Methods

COD, nitrogen, and phosphorus content of the digestate were determined using Hach COD low range reagent (Cat no.: 2125815), Hach Nessler reagent kit (Cat no.: 2119449), Hach phosphate low range reagent (Cat no.: 2106069), respectively according to the manufacturer's instruction. The measurement of each reading was determined by using Hach DR 3900 spectrophotometer. pH was measured by Hanna Instruments HI 2550. The digestate and filtered digestate were measured for its turbidity by using Hach 2100 AN Turbidimeter. TSS content was measured by oven-dried 10ml of digestate and filtered digestate through cellulose nitrate membrane filters (Whatman pore size 0.45µm, Cat no.: 7184-004) at 105°C. The particle size analysis was conducted for all types of filter aids by using Malvern Mastersizer Hydro 2000MU. Furthermore, high-resolution image of each filter aids was also captured by using FESEM Supra 55VP.

3. RESULTS AND DISCUSSION

3.1 Turbidity Removal Efficiency

The impact of the types and amount of filter aids used on the turbidity removal is given in Table 2 and Figure 2. The turbidity removal was observed to increase slightly as the mass of filter aids increased. This observation was also supported with the decreasing amount of TSS remains in the filtered digestate as shown in Figure 3. Generally, with the presence of more filter aids as precoat, the cake layer formed on the filter support became thicker and it exerted better retention for the suspended solids. This finding can be explained by referring to the particle size distribution (Table 3 and Figure 4) and morphology via FESEM images (Figure 5) of the filter aids.

Table 2: Turbidity of filtered digestate at different types and amount of filter aids

Filter aids	Turbidity (NTU)		
	1 g	2 g	3 g
Perlite	21.8	17.1	13.9
DE	21.3	18.4	17.4
BE	48.4	33.5	27.1
PAC	17.0	13.6	10.2
BA	48.2	44.6	41.9

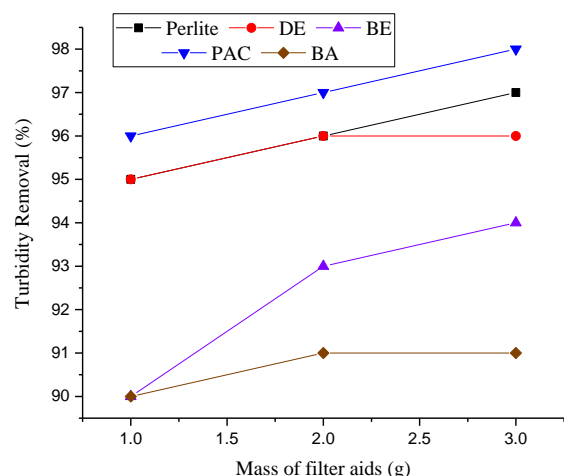


Figure 2: Turbidity removal efficiency at different type and mass of filter aids

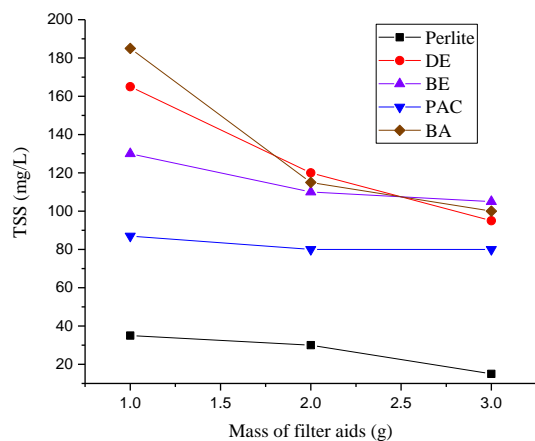


Figure 3: TSS content in the filtered digestate at different type and mass of filter aids

Overall, PAC shows the highest turbidity removal at 96-98 %, followed by perlite (95-97 %), DE (95-96 %), BE (90-94 %) and BA (90-91 %). Particle

size distribution plays an important role to turbidity removal efficiency. In accordance with the turbidity removal is the decline in TSS remains, where the final TSS concentration of perlite is the lowest, lesser than 40 ppm. The variance for turbidity and TSS removal efficiencies could be attributed to filter aids characteristics. One particularly interesting observation was the lower TSS removal of PAC compared to its high turbidity removal. This could be due to PAC has the adsorption capability that could capture very fine or dissolved organic substances [12]. The removal of these substances was reflected by lower turbidity reading due to less transmitted light scattered away from its original direction when it hits the particles in the water column [13]. Hence, the TSS remains in filtered digestate would be the more accurate performance indicator for PAC.

Table 3: Particle size distributions of the filter aids

Filter aids	D ₁₀ (μm)	D ₅₀ (μm)	D ₉₀ (μm)
Perlite	4.96	15.79	46.85
DE	2.59	10.06	26.51
BE	3.38	25.59	70.06
PAC	3.70	28.60	168.66
BA	5.95	26.68	65.48

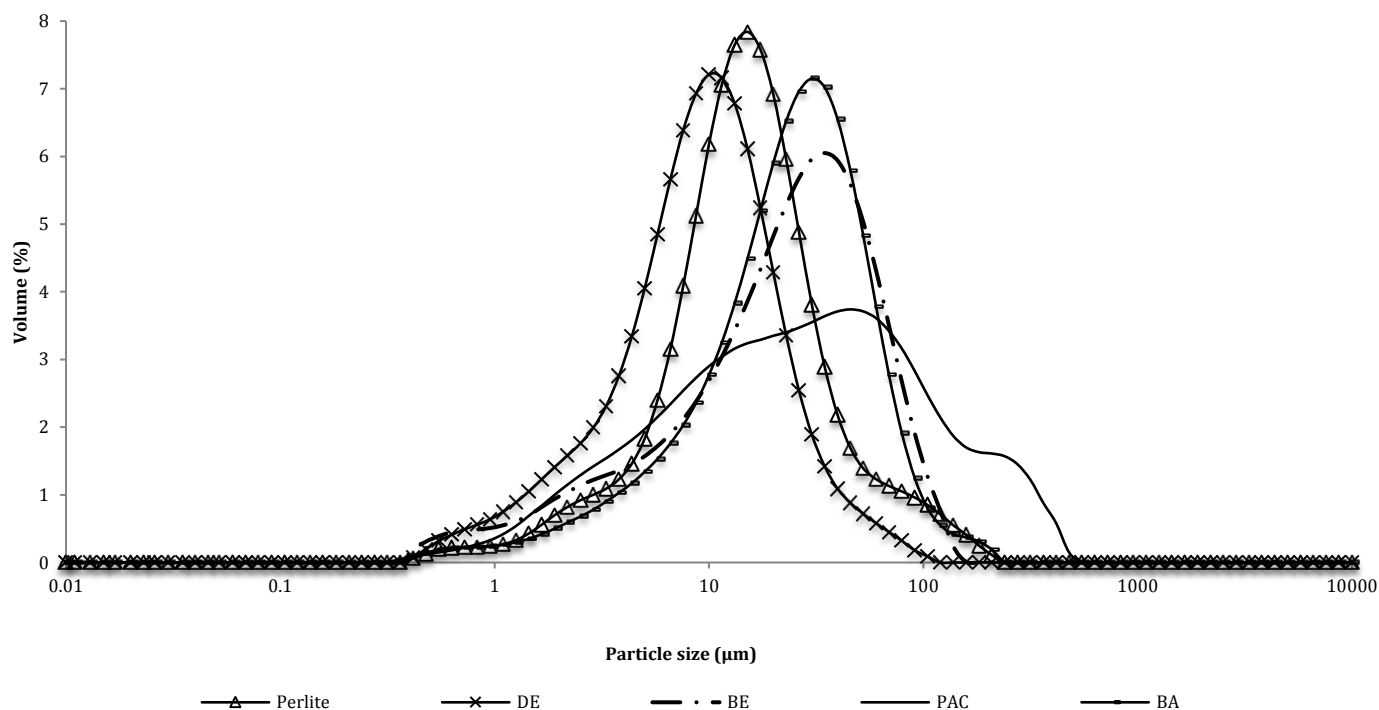


Figure 4: Particle size distribution curve of the filter aids

By referring to Table 3 and Figure 4, it could be observed that the particle size distribution varies for each filter aids. It was postulated that the broader size distribution and higher percentage of finer particles produced a less permeable filter bed for fluid flow and resulted in higher detainment of suspended solids [14]. For instance, the particle size of PAC was broadly distributed from 3.7 μm to 168.7 μm. The presence of larger portion of smaller size PAC would be able to fill up the gaps among larger PAC particles, which effectively clog the space for solids permeation. Eventually, the turbidity removal efficiency was highest for PAC. Even though BE and BA has narrower range of particle size, it could be seen from Figure 4 that the distribution of particles has been shifted to smaller size. This resulted in the formation of uneven cake layer, which probably possessed loophole for the permeation of particles and rendered the filtration process less efficient. On the other hand, the narrow and even particle size distribution of perlite and DE enabled the formation of homogenous cake layer that could consistently retain the suspended

solids.

Apart from the particle size of filter aids and its size distribution, the morphological structure of filter aids also has considerable impact on the removal of suspended solids. It could be seen from Fig. 4 that among the entire filter aids, perlite is the most porous and it contains finest pores on the surface. This characteristic facilitated the retention of suspended solids, as supported by the low TSS and turbidity of the filtered digestate. DE possesses similar structure as perlite but due to its larger pore size, the retention of suspended solids is slightly lower than perlite. Surface inspection on PAC shows that the number of pores is much lesser compared to perlite and DE. This further supported the claim that the adsorption property of PAC actually captured the dissolved organic substance and resulted in lower turbidity reading. In addition, the presence of much lesser pores also hindered the permeation of suspended solids, which can be explained by the lower TSS value compared to DE.

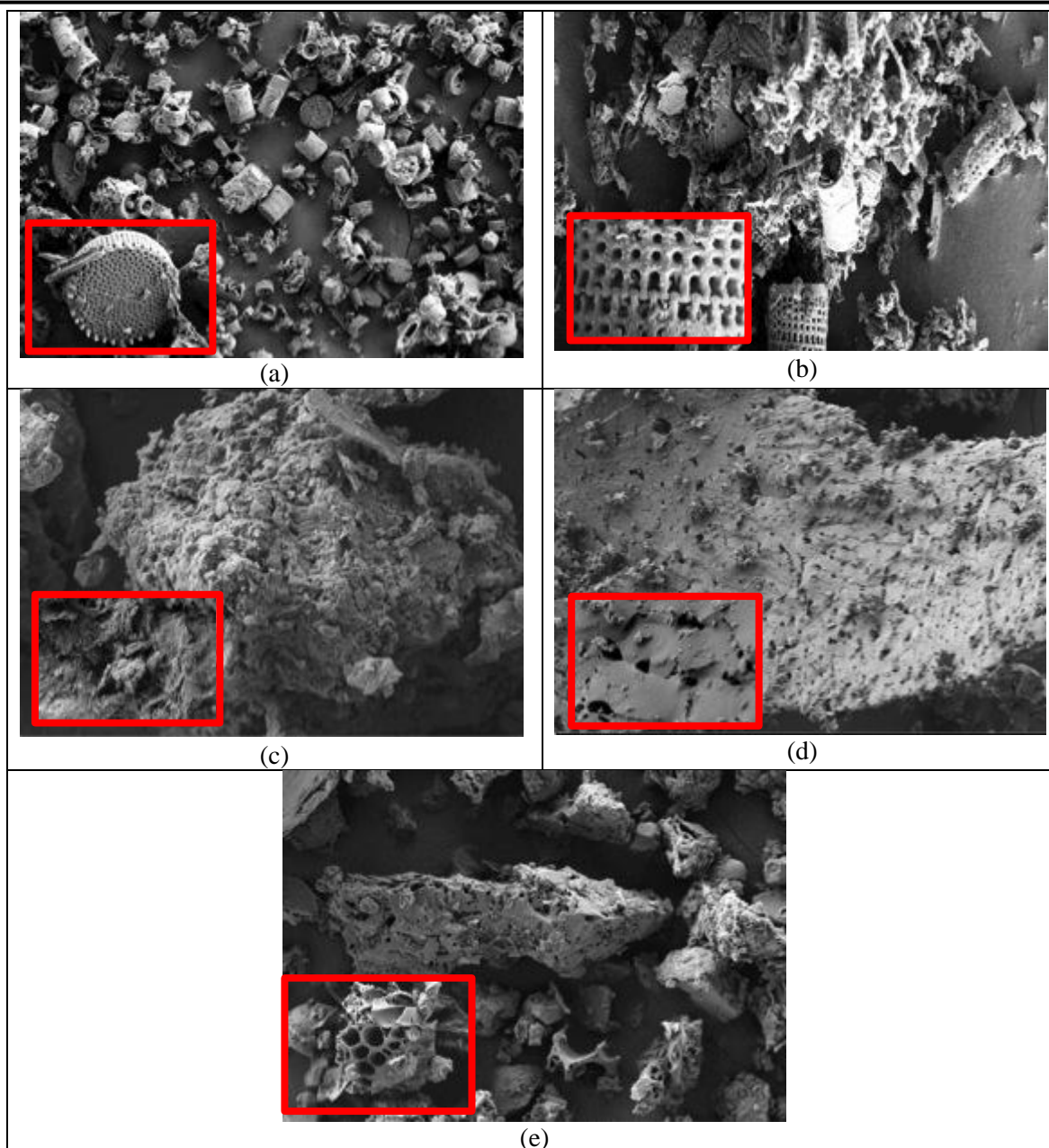


Figure 5: FESEM images of different type of filter aids at magnification 1k (larger image) and 10k (inset)
(a) perlite (b) DE (c) BE (d) PAC (e) BA

On the other hand, BE and BA did not show obvious pores on the surface. Figure 5(e) indicates that some of the BA particles are spongy and contains large pore structure [15]. The presence of such structure might responsible to the permeation of suspended solids through the filter aids cake layer and result in low turbidity removal. The absence of pores on BE surface could be an indication that the retention of suspended solids is mostly due to the gaps formed between the particles. As observed in Figure 2, the turbidity removal increased with the amount of BE used, which supports the postulation made about the retention mechanism, as more BE will reduce the gaps between the filter aids particles and thus hinder the permeation of suspended solids.

3.2 Filtration Flux

As observed in the previous section, the improvement of turbidity removal was only around 5% - 10% when the mass of filter aids was increased. Thus, 1 g of filter aids used as precoat and body feed was selected for filtration flux assessment. Filtration flux of each filter aids is displayed in Fig. 6. It can be seen that during the initial stage of filtration, the flux drops considerably especially for filter aids with higher initial flux. Flux of perlite was around 1 ml/cm².min initially and decreased by 50 % after 5 minutes of filtration period. The initial flux decline for the rest of the filter aids was slightly less drastic compared to perlite. As shown in the previous section, perlite possesses considerable number of fine pores compared to the other filter aids. This morphological structure enabled more water to pass through the cake layer easily and eventually resulted in higher flux. However, higher flux will bring more suspended solids to the surface of

the cake layer and quickly accumulated on it. Consequently, the resistance for water permeation will increase and therefore decreasing the flux in a short period of time. This phenomenon is similar with the membrane fouling study reported by some researcher [16]. The higher initial membrane flux induced stronger permeation drag, which brought more particles to the membrane surface and resulted in the quick buildup of foulant layer on the membrane. Subsequently, the membrane flux decline was the sharper for membrane with higher initial flux.

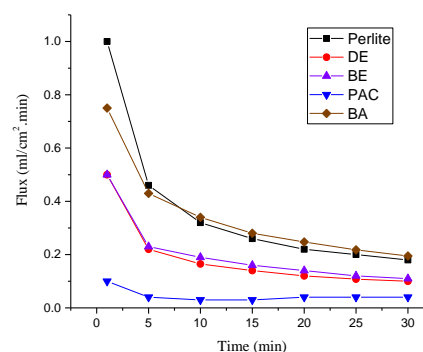


Figure 6: Filtration flux of different type of filter aids

The milder flux decline following on could be due to the slow deposition of suspended solids on the cake layer. As the cake layer composed of suspended solids grew thicker and more compact with time, the cake resistance would increase and hinder the water permeation [17]. Overall, the retained suspended solids covered up the filter aids cake layer and hindered the water permeation whereby digestate can only pass through the unblocked gaps and pore areas [15]. Similar finding has been reported

in a study where the flow rate of beer residues filtration decreased due to the pores and spaces of cake filled with the beer residues [14].

The filtration flux data offered valuable information to strengthen the postulation made in the previous section. As shown in Table 3, the size of PAC particles ranged widely from 3.7 μm to 168.7 μm . This caused the smaller size PAC to fill up the gaps between larger PAC particles. Subsequently, a compact cake layer was formed in which not only it exerted a high resistance to water permeation but also contributed to high retention of suspended solids. This might explain why PAC removed a huge amount of turbidity and at the same time recorded low filtration flux. On the other hand, BA which has irregular shape and hollow-structure (Figure 5 (e)) facilitated the permeation of suspended solids and water due to the presence of larger gaps in the filter aids cake layer.

4. CONCLUSION

Cake filtration achieved a fairly high turbidity and TSS removal (> 90 %) regardless of the type of filter aids. The turbidity and TSS removal rates increased slightly with the amount of filter aids used. Perlite and DE with smaller pores and narrow particle size distribution recorded better removal rate compared to irregular shape BA and BE. On the other hand, PAC possessed considerably high turbidity removal, which could be attributed to its adsorptive property. However, the presence of small size particles which filled up the gaps between the coarse size PAC resulted in low water permeation. Perlite, which was porous and had narrow size distribution to form even cake layer facilitated the permeation of water. Consequently, its flux was the highest compared to the rest. This study showed that cake filtration process could be used to remove the suspended solids in the digestate before being sent for downstream process for nutrient and water recovery. The solid waste can be used in the production of compost as to reduce the usage of chemical fertilizer in agriculture industry. It was found out that the characteristics of the filter aids; particle size and size distribution have significant impact on the performance (suspended solids removal and filtration flux) of cake filtration process. Thus, further work is required to understand the mechanism of cake layer formation from the filter aids, to optimize the cake filtration process for digestate treatment and to conduct economic assessment for the feasibility of this application in industrial scale.

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REFERENCES

- [1] DSMP. 2017. Department of Statistics Malaysia Official Portal. [Online]. Available: https://www.dosm.gov.my/v1/index.php?r=column/cthemByCat&cat=72&bul_id=T2Z3NkhLSFk2VjZ5dkdUL1JQUGs4dz09&menu_id=Z0VTZGU1UHBT1VJMFJpaXRRR0xpdz09. [Accessed: 31-May-2017].
- [2] MPOC. 2017. Malaysian Palm Oil Council. [Online]. Available: http://www.mpoc.org.my/Malaysian_Palm_Oil_Industry.aspx. [Accessed: 31-May-2017].
- [3] Ahmad, A.L., Sumathi, S., Hameed, B.H. 2006. Coagulation of residue oil and suspended solid in palm oil mill effluent by chitosan, alum and PAC. *Chemical Engineering Journal*, 118 (1), 99–105.
- [4] Chan, Y.J., Chong, M.F., Law, C. L. 2010. Biological treatment of anaerobically digested palm oil mill effluent (POME) using a Lab-Scale Sequencing Batch Reactor (SBR). *Journal of Environmental Management*, 91 (8), 1738–1746.
- [5] King, L.S., Yu, L.C. 2013. A Retrofitted Palm Oil Mill Effluent Treatment System for Tapping Biogas. *European International Journal of Science and Technology*, 2 (2), 106–114.
- [6] Lee, K.T., Ofori-Boateng, C. 2013. Sustainability of Biofuel Production from Oil Palm Biomass - Keat Teong Lee, Cynthia Ofori-Boateng - Google Books. Penang, Malaysia: Springer.
- [7] Suh, C.W., Kim, S.E., Lee, E.K. 1997. Effects of filter additives on cake filtration performance. *Korean Journal of Chemical Engineering*, 14 (4), 241–244.
- [8] Tien, C., Bai, R., Ramarao, B.V. 1997. Analysis of cake growth in cake filtration: Effect of fine particle retention. *AIChE Journal*, 43 (1), 33–44.
- [9] Du, L., Chen, X., Li, W., Zhu, Q. 2011. A study on enhancement of filtration process with filter aids diatomaceous earth and wood pulp cellulose. *Chinese Journal of Chemical Engineering*, 19 (5), 792–798.
- [10] Kuhn, M., Briesen, H. 2015. Dosage of Filter Aids in the Case of Pure Surface Filtration – An Optimal Control Approach, 37 (6), Elsevier.
- [11] Ochoa George, P.A., Eras, J.J.C., Gutierrez, A.S., Hens, L., Vandecasteele, C. 2010. Residue from Sugarcane Juice Filtration (Filter Cake): Energy Use at the Sugar Factory. *Waste and Biomass Valorization*, 1 (4), 407–413.
- [12] Malik, R., Ramteke, D.S., Wate, S.R. 2007. Adsorption of malachite green on groundnut shell waste based powdered activated carbon. *Waste Management*, 27 (9), 1129–1138.
- [13] Omar, A.F., MatJafri, M.Z. 2009. Turbidimeter design and analysis: A review on optical fiber sensors for the measurement of water turbidity. *Sensors*, 9 (10), 8311–8335.
- [14] Ediz, N., Bentli, I., Tatar, I. 2010. Improvement in filtration characteristics of diatomite by calcination. *International Journal of Mineral Processing*, 94 (3–4), 129–134.
- [15] Indran, V.P. 2014. An accelerated route of glycerol carbonate formation from glycerol using waste boiler ash as catalyst. *RSC Adv.*, 4 (48), 25257.
- [16] Ang, W.L., Mohammad, A.W., Teow, Y.H., Benamor, A., Hilal, N. 2015. Hybrid chitosan/FeCl₃ coagulation–membrane processes: Performance evaluation and membrane fouling study in removing natural organic matter. *Separation and Purification Technology*, 152, 23–31.
- [17] Chang, S.Y., Toledo, R.T., Science, F., Lillard, H. S., Russell, R.B. 1987. Clarification and Decontamination of Poultry Chiller Water for Recycling, 1100–1108.

