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Influence of Particle Size and Pressure Drop in Cake Filtration Process on Removal of Suspended Solids in Anaerobically Digested Palm Oil Mill Effluent

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ABSTRACT

Palm oil mill effluent (POME) poses a great threat to the environment. However, it contains valuable resources such as energy, water and nutrients that could be recovered for sustainable development. Currently, anaerobic digester has been employed to recover the energy potential in POME. However, the presence of suspended solids in the digestate hinders the downstream nutrients recovery process. In that light, cake filtration process appears to be an attractive option for the removal of suspended solids in the digestate. Hence, this paper studied the performance of cake filtration in removing suspended solids at different pressure condition and particle size of perlite. The effectiveness of cake filtration process was evaluated based on the quality of filtrate (turbidity and total suspended solids (TSS)) and filtration flux. In this study, perlites of different particle size distribution (FP3, FW6, FW20, and FW50) were used as both precoat and body feed. The amount of precoat and body feed were chosen as 1 g each. The filtration process was carried out at different pressure condition (2 - 5 bars). It was found that perlite with the finest particle size (FP3) achieved up to 90% of turbidity and TSS removal due to the formation of more compact cake filtration layer. On the other hand, larger perlite FW50 recorded lowest removal efficiency due to its porous cake layer, though this resulted in higher filtration flux. Generally, an increase in pressure resulted in higher flux but at the same time led to drastic initial flux decline due to the quick cover up of filtration voids. The outcomes from this study show that it is wise to consider the effect of particle size distribution and pressure drop in order to achieve high clarity of filtrate as well as high filtration flux.

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NOMENCLATURE

B	Turbidity/TSS before	α_{av}	Specific cake resistance (m/kg)
C	Turbidity/TSS after	μ	Filtrate viscosity (Pa.s)
q	Filtration flux (m/hr)	ΔP	Pressure drop (Pa)
V	Digestate volume (m^3)	c	Solid concentration (kg/m^3)
A	Filtration area (m^2)	R_m	Filter medium resistance (m^{-1})
t	Filtration time (hr)		

1. INTRODUCTION

Palm oil industry in Malaysia is growing rapidly over the years and is currently ranked as the second largest palm oil producer in the world. Around 20-23% of crude palm oil (CPO) can be produced from 1 ton of fresh fruit bunch (FFB) [1]. Concurrently, with the large production of CPO, a voluminous amount of water was used to extract oil from the FFB, resulting of about 2.5 m^3 palm oil mill effluent (POME) per tonne of crude oil processed discharged to the watercourse [2]. Raw POME is considered as highly polluting wastewater due

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to its high content of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) contents at 25000 mg/L and 50000 mg/L, respectively [1, 3 - 5]. Moreover, the dissolved organic matter in POME contributes a huge risk to the water resources [6]. Therefore, in view of high organic strength in POME, Malaysia is identified as one of the country producing the largest pollution load in rivers throughout the country [7].

However, the high organic contents in POME appear to be a promising source for renewable energy source by generating methane gas via anaerobic digestion [8]. Therefore, most of the palm oil mills nowadays have shifted from conventional open ponding treatment to closed-type anaerobic digester tank in order to recover the methane gas [9]. Moreover, the discharged digestate from the digester tank contains abundance of nutrients that is worth recovery to be reused in the plantation. Nonetheless, the presence of large suspended solids in the digestate disrupts the downstream treatment process. In that light, pretreatments prior to downstream treatment is important in order to remove suspended solid without involving high cost material and generating secondary waste.

Cake filtration is widely employed throughout the years in chemical and process industry [10]. It is acknowledged to be significantly more cost-effective than thermal dewatering for the removal of liquid from the retained filter cake [11]. In cake filtration, the liquid suspension to be treated is passed through a filter medium under pressure force, which allows the flow of the suspension. Hereafter, a cake layer will be formed due to the suspended solids retained on the filter medium [12]. However, an increase in cake resistance due to the growth and formation of cake layer on the filter medium is a major shortcoming in the cake filtration process [10]. Some effluent or wastewater in the industry is found to be highly viscous, colloidal, stable, deformable or highly compactible and very difficult to be filtered with the formation of highly resistant cake. For such cases, addition of filter aid, is needed to enhance the filtration [13].

Filter aids are chemically inert and porous materials that produce cake layer of high permeabilities and nearly zero compressibility [14]. The porous cake layer controls flow and removes contaminants by trapping the suspended solids and prevents them from blinding the filter medium. There are two main methods to form a cake layer using the filter aid. The first is to form a precoating layer of filter aid on the filter medium. This will prevent solids from blocking the filter medium and further avoiding medium fouling to occur. The second is to mix the filter aid with the filtrate liquid (as body feed) to form a porous cake layer that will increase the filtration rate. Commonly used filter aid includes diatomite, perlite, cellulose and asbestos [14, 15].

Perlite is an amorphous volcanic alumina–silicate rock with relatively high water content (2–5% w/w). Perlite ore consists mostly of SiO_2 , Al_2O_3, and lesser amounts of several metal oxides (sodium, potassium, iron, calcium, and magnesium) [16]. Perlite will bond to each other to form a porous cake layer on the filter medium during the precoating stage to achieve rapid filtration due to the large numbers of tiny and connective pores [15]. Due to its low density after being processed, and relatively low price, many commercial applications for perlite have been developed, including the removal of hazardous metals, dye pollutions, particulates from exhaust gases, medicine and bioprocessing and also food and beverage industry [17].

There are two major factors that need to be considered when adopting cake filtration as the treatment process, namely, particle size of filter aid and the operating pressure. Particle size of the chosen filter aid is mostly considered in previous study in order to achieve high performance of filtration cycle [13, 18, 19]. It was reported that filter aid with higher amount of fine particle size resulted in lower flow rate and turbidity [19]. On the other hand, pressure drop provides the driving force, in which water will be pressurized to flow through the filter medium. Pressure has an influence on the particle arrangement during the cake formation and compression stages. Typically, filter cakes are more or less compressible, which in practice means that an increase in the filtration pressure causes an increase in filtration flux and at the same time results in reduction of cake porosity due to compression [20]. This might lead to two consequences, better removal efficiency of suspended solids or increase resistance towards the flow.

Hence, the influence of filter aid particle size and operating pressure on the treatment process has to be conducted comprehensively to achieve optimal performance in terms of suspended solids removal and filtration flux. This study for the first time employed cake filtration with perlite as the filter aid to remove the suspended solids in anaerobically digested POME. The influence of different particle size of perlite filter aid and pressure drop on the suspended solids removal efficiency and filtration flux were systematically investigated in this study.

2. MATERIALS AND METHODS

Samples of anaerobically digested POME were collected from a closed-type anaerobic digester system at Sime Darby East Palm Oil Mill, Carey Island, Malaysia. The samples were then kept at temperature less than 4°C, such condition preserved its main composition from any apparent effects [21]. The required sample was then thawed at room temperature prior to conduct the experiment. In this study, perlites at different particle size were tested with median size ranging from 15 μm to 50 μm. The perlite (FP3, FW6, FW20, FW50) was supplied by Dr. Mueller AG SEA Regional Office, Malaysia.

2. 1. Cake Filtration Process A laboratory scale Nutsche filter with a filter area of 0.001 m^2 was used to perform cake filtration process. The filter medium used is a woven cloth with polyvinylidene fluoride (PVDF) monofilament weft with diameter and porometer value of 46 mm and 10 μm, respectively. 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.

All filtration processes were performed with the same parameter of 200 ml volume of anaerobically digested POME with turbidity and total suspended solids (TSS) values were measured as 1303 NTU and 3530 mg/L, respectively. The amount of chosen perlite as precoat and body feed was 1 g each. Perlite was first mixed with 200 ml of ultra pure water as precoat and recirculated through the filter medium. The slurry will pass through the filter medium with pressure from the compressed air. Consequently, a cake layer will be formed due to the particles from the slurry retained on the filter medium. Then, the same perlite was mixed with 200 ml of the anaerobically digested POME as the body feed prior to pouring into the filter. This experiment was conducted under different pressure condition from 2 - 5 bars.

After completion of each test, turbidity and total suspended solids removal Equation (1), and filtration flux Equation (2) were measured; where B is turbidity (NTU) or TSS (mg/L) before filtration, C is turbidity (NTU) or TSS (mg/L) after filtration.

Filtration flux (q) was measured to determine the permeability of the cake filtration process from Equation (2) based on Darcy's law [13], where V is volume of filtered digestate (m^3), A is filtration area (m^2), and t is filtration time (h).

Mathematical modelling of cake filtration was fitted based on Hermia's model. This model has been applied to explain the fouling mechanism encountered in membrane filtration process. One of the mechanisms is cake filtration, which describes the formation of foulant layer formed on top of the membrane and blocks the permeation of flux and impurities [22]. This model was used to prove the formation of cake layer on the filter aid. The fitting was done using Equation (3), where q_0 is the initial flux and k_{cf} is the constant for cake filtration.

The specific cake resistance used to measure the total resistance of the cake layer towards the filtrate flow rate per unit mass of filter cake solids [23] is shown as in Equation (4), where V is volume of filtered digestate (m^3), t is filtration time (h), μ is filtrate viscosity (Pa.s), A is filtration area (m^2), ΔP is pressure drop (Pa), c is solid concentration (filter aids and suspended solids in filtrate) (kg/m^3), R_m is filter medium resistance (m^{-1}), and α_{av} is specific cake resistance (m/kg). R_m and α_{av} can be obtained from the intercept and slope of t/V vs V plot, respectively.

$$Turbidity\ or\ TSS\ removal\,(\%) = \frac{B - C}{B} \times 100 \quad (1)$$

$$q = \frac{V}{At} \quad (2)$$

$$\frac{1}{q^2} = \frac{1}{q_0^2} + k_{cf}t \quad (3)$$

$$\frac{t}{V} = \frac{\mu\alpha_{av}c}{2A^2\Delta P}V + \frac{\mu R_m}{A\Delta P} \quad (4)$$

2. 2. Analytical Methods The turbidity and TSS of the samples before and after filtration was determined using Hach 2100 AN Turbidimeter and HACH method 8006 using Hach DR 3900 spectrophotometer, respectively according to the manufacturer's instruction. The particle size analysis for different types of perlite was conducted using Malvern Mastersizer Hydro 2000MU. High-resolution image of each filter aids was also captured using FESEM Supra 55VP.

3. RESULTS AND DISCUSSION

3. 1. Characterization of Perlite Figure 1 shows the particle size distribution of the perlite used in this study. It was observed that FP3 has the narrowest particle size distribution, with the mean particle size d_{50} of 15.85 μm (as shown in Table 1). The mean particle size of the other perlite are 23.61 μm (FW6), 31.29 μm (FW20) and 54.07 μm (FW50). In accordance with the particle size, the order of the specific surface area is in descending with FP3 perlite recorded the highest surface area due to its finest particle size.

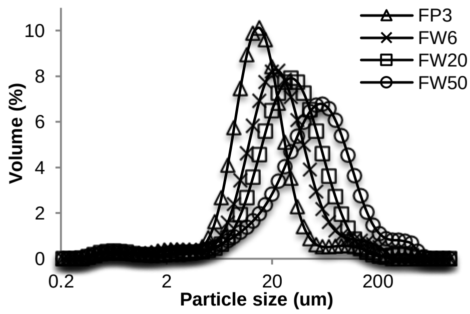

Figure 1. Particle size distribution curve of different types of perlites

TABLE 1. Physical properties of different types of perlites

Perlite	Particle size distribution			Specific surface area (m^2/g)
	d_{10} (μm)	d_{50} (μm)	d_{90} (μm)	
FP3	7.43	15.85	34.30	0.52
FW6	9.27	23.61	62.85	0.12
FW20	11.42	31.29	75.50	0.08
FW50	13.44	54.07	149.53	0.04

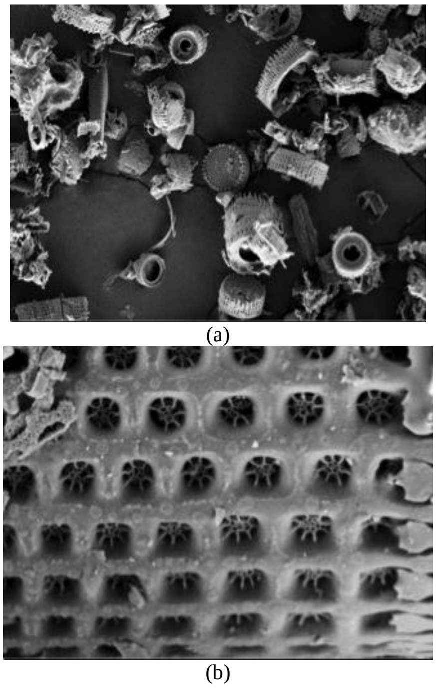

Figure 2. FESEM images of perlite at magnification 1k (a) and 10k (b)

It can also be seen from Figure 1 that as the mean particle size is getting larger, the particle size range is more broadly distributed. The particle size and the size distribution of perlite will play an important role in forming filtration cake layer with different compactibility which eventually will influence the filtration flux and retention of the suspended solids.

Examination from FESEM images show that the shape of perlite has a combination of spherical and elongated oval shape (Figure 2 (a)). It could also be seen from Figure 2 (b) that plenty of small pores are present on the surface of perlite. It is due to the presence of these fine pores that enables the suspended solids in digestate effluent to be retained while allowing the liquid digestate to flow through during the filtration process.

3. 2. Turbidity And TSS Removal The turbidity (Figure 3) and TSS removal (Figure 4) of the filtered digestate decreased with increase in particle size regardless the pressure drops. By referring to Table 1 and Figure 1, it could be observed that the particle size varies for each perlites used. It was found that the finest particle size (FP3) has the highest turbidity (90-92%) and TSS (86-87%) removal while the largest particle size (FW50) shows the lowest turbidity (79-80%) and TSS (67-75%) removal. Therefore, it was postulated that finer size of perlite formed more compact cake layer, which resulted in two consequences; better retention of suspended particles and lower water permeation. Figure 5 shows the typical cake layer formed in cake filtration process. The bottom layer is the precoat layer consisting of perlite while the top layer is the retained suspended solids layer.

Kinnarinen et al. [20] stated that in practical filtration applications, the mechanism of cake formation is affected by the particle size, which influences the filtration flow rate and the deposition of the particles in the cake. They reported that cake layer formed by larger particle size is more porous. Thus, the porous cake layer enabled the suspended solids to pass through the cake layer and resulted in low removal efficiency, which is in agreement with the finding of this study.

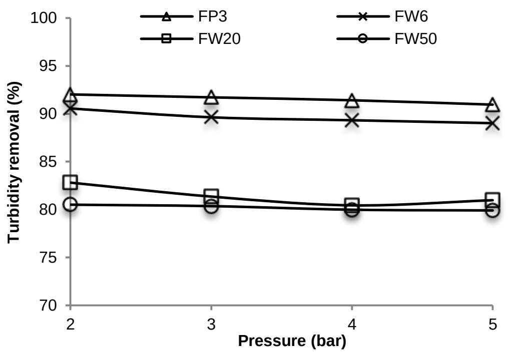

Figure 3. Effect of different pressure using different types of perlite on turbidity removal

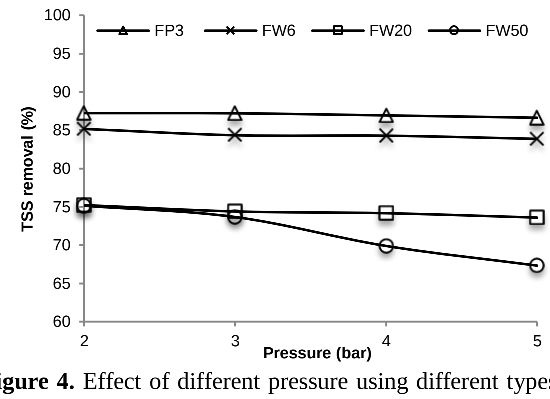

Figure 4. Effect of different pressure using different types of perlite on TSS removal

Figure 5. Typical cake layer formed in cake filtration process

From Figure 3, it was also discovered that doubling the particle size from FP3 will decrease the turbidity removal around 10-15%. This is mainly due to the limitation of bridging mechanism between the suspended solids to be captured on the cake layer [24]. Furthermore, high turbidity present in the filtered digestate with larger particle size of perlite such as FW20 and FW50 can be explained by the large number of small particles that had flowed through the porous channel within the filter medium. As shown in Figure 1, FW20 and FW50 have larger particle size and the size is broadly distributed up to 70-150 µm. This resulted in the build-up of less compact cake layer which facilitated the formation of larger channel in the cake layer. Eventualy, suspended solids will permeate through the cake layer via those channels.

The mild decline in turbidity and TSS removal with pressure observed for all perlite could be attributed to the stronger force exerted on the digestate effluent. With stronger driving force due to higher pressure, the POME will be forcefully pushed through the cake layer. Along with this impact, some suspended solid will bleed through the cake layer too, which explain the decline in retention performance with the rise of pressure. It is especially noticeable that TSS removal of FW50 drastically dropped with increase of the pressure shown in Figure 4. This phenomenon indicated that the increase in pressure drops exerted stronger force to push the POME through the cake layer of FW50 (more channels due to irregular and larger particle size) and thus caused the bleeding of small particles to the filtrate side [13].

3. 3. Filtration Flux

The relation between different particle size and filtration flux is displayed accordingly to the pressure drop, 2 bars (Figure 6), 3 bars (Figure 7), 4 bars (Figure 8) and 5 bars (Figure 9). The curve trend for each figure is similar with the filtration flux increased with the particle size and pressure drop. The high filtration flux observed for larger size of perlite was due to the presence of more porous voids in the cake layer during the cake formation and filtration stages. On the other hand, finer filter aids such as FP3 and FW6 formed a more compact cake layer that exerted larger resistance to the flow of POME. Consequently, the recorded filtration flux was lower as well [18].

FW20 and FW50 show the highest flux during the initial stage before dropping considerably around 50% regardless the pressure drops. The initial flux of both perlites at 60 ml was similar which could be attributed to the comparable gaps between the perlites in the cake layer. This postulation was supported by the similar TSS removal at 2 bars (Figure 4), indicating the gaps between the perlites particles in the cake layer were roughly the same.

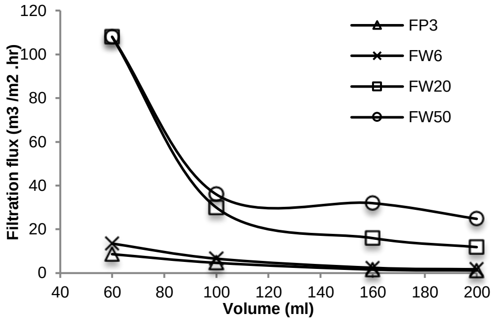

Figure 6. Effect of different type of perlite to the filtration flux at 2 bars

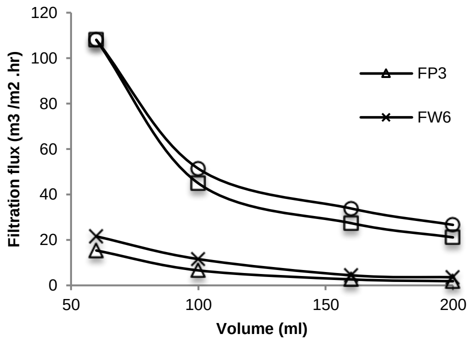

Figure 7. Effect of different type of perlite to the filtration flux at 3 bars

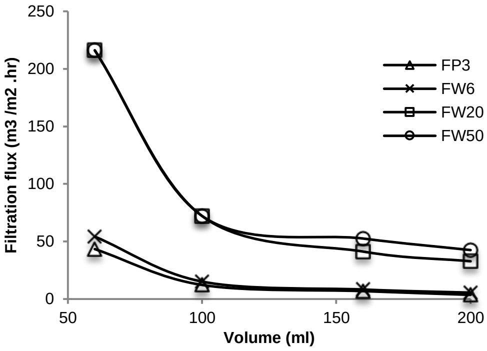

Figure 8. Effect of different type of perlite to the filtration flux at 4 bars

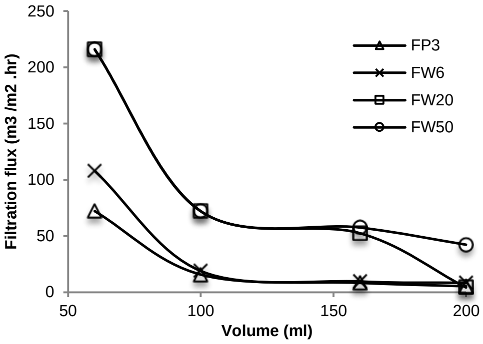

Figure 9. Effect of different type of perlite to the filtration flux at 5 bars

Often the high initial flux will bring more fine suspended solids to pass through the cake layer and result in bleeding of suspended particles (lower suspended solids retention). This proves the reason why the turbidity and TSS removal is lower for FW20 and FW50 as mentioned in previous section. Some of those suspended solids would be trapped inside the cake channel and clog the water permeation path. In addition, this initial condition also led to the quick deposition of larger suspended solids on the surface of perlite cake layer. The retention of larger suspended solids will form a new cake layer on top of the perlite. Consequently, both the clogging of porous channel and the formation of new cake layer will effectively reduce the initial filtration flux. Thus, in order to minimize this phenomena, Reynolds et. al (2011) suggested to slowly increase the operating pressure so that high overall filtration flux can be achieved due to the formation of more open structure (less compact) cake layer.

On the other hand, it was spotted that the filtration flux doubled when the pressure drop reached 4 bars and above for all perlites. Hence, it was denoted that the filtration flux increased with the pressure drop. High initial flux observed in all perlites is due to the available gaps in the formation of cake layer along with the pressure drop that drives the filtrate to flow through the medium. Eventually, the gaps is reduced due to the cover up of cake layer with suspended solids and resulted to steady state flux.

TABLE 2. Fitting of experimental data to Hermia's cake filtration model

Perlite	R^2 value			
	2 bars	3 bars	4 bars	5 bars
FP3	0.9914	0.9883	0.9656	0.9813
FW6	0.9885	0.9947	0.9860	0.9926
FW20	0.9871	0.9966	0.9986	0.9957
FW50	0.9144	0.9981	0.9942	0.9893

Furthermore, the reduction in filtration flux as the digestate is filtered throughout the filtration cycle is due to the compression of the cake layer as more suspended solids were retained on the cake layer [18]. The build-up of cake layer will increase the cake resistance toward the water flow, thus result in the decline of filtration flux with time.

In order to verify that cake layer was responsible for the observed filtration flux and impurities removal, Hermia's cake filtration model was fitted with the experimental data as according to Equation (3). Table 2 shows the corresponding correlation coefficients (R^2) for each type of perlite and filtration pressure. It can be seen that all the scenarios fitted well with the cake filtration model, with most of the R^2 values approaching 1. Hence, it can be concluded that the suspended solids formed a cake layer on the filter aids and retained the residual suspended solids from passing through the cake layer as well as affected the filtration flux.

Overall, it was found out that the pressure drop has no significant impact on the suspended solids removal for all size of perlite. In addition, the steady filtration flux recorded for each perlite also did not vary much with pressure drop. Therefore, the operating pressure of 2 bars is selected as the optimal pressure drop for this study. Perlite FW6 was deemed as the optimal size to remove suspended solids in POME due to its considerable better removal rate compared to FW20 and FW50 whereas its flux was slightly higher than FP3. The steady flux of FW6 was 1.66 m3/m2.hr, which is within the normal flux range commonly employed in industry (as informed by the cake filtration supplier).

3.4. Cake Resistance From previous section, it was observed that the filtration flux is inversely correlated to suspended solids removal. This observation can be linked to the specific cake resistance of the filter cake, be it the perlite cake layer or the cake layer formed by the retained suspended solids. The linear equation represented by Equation (4) is the conventional method to determine specific cake resistant for constant pressure filtration [11].

The following linear plot is displayed according to the different types of perlite; FP3 (Figure 10), FW6 (Figure 11), FW20 (Figure 12) and FW50 (Figure 13). From those figures, it was observed that all the plots will have intercepted the time over volume axis at a very minimal value. The low interception on the time over volume axis indicates that the perlite filter medium exerted a minimal resistance to the flow of digestate effluent. Therefore, the cake resistance calculated in this study could be fully attributed to the cake formed by the retained suspended solids. Figure 14 illustrates the logarithmic plot of cake resistance against pressure drop by using the slope of linear relationship plotted in Figures 10-13.

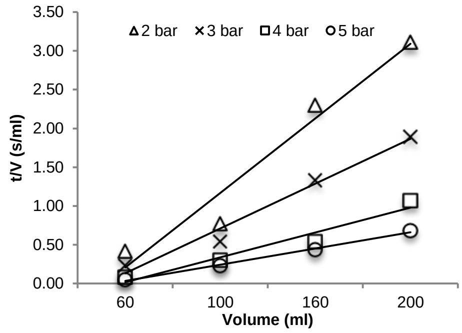

Figure 10. t/v vs V linear plot for FP3

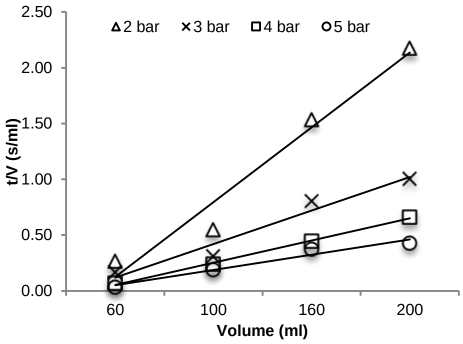

Figure 11. t/v vs V linear plot for FW6

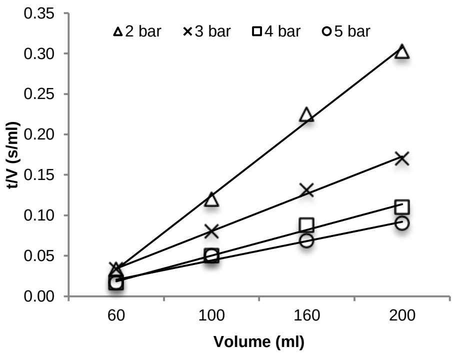

Figure 12. t/v vs V linear plot for FW20

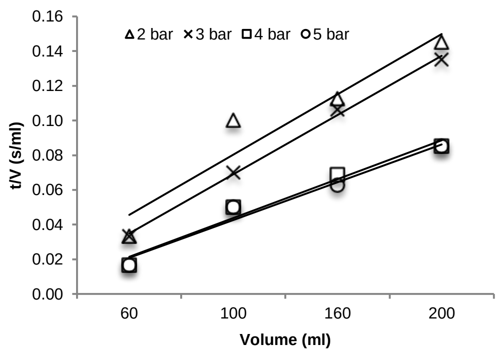

Figure 13. t/v vs V linear plot for FW50

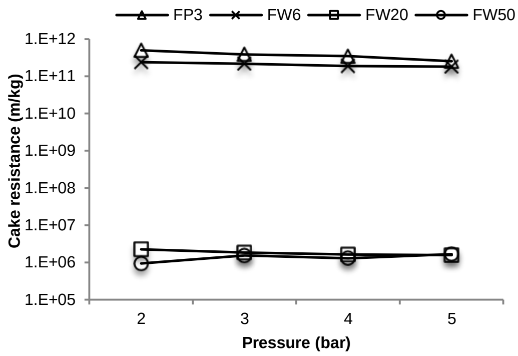

Figure 14. Logarithmic plot of cake resistance against pressure drop

The cake resistance remained roughly the same regardless of operating pressure, indicating the operating pressure did not have strong impact on the cake resistance. It is noticeable that FP3 and FW6 recorded a relatively high cake resistance compared to FW20 and FW50. As discussed in the previous section, both FP3 and FW6 could retain considerable amount of suspended solids due to the finer perlite size.

The accumulated of large amount of retained suspended solids will form another cake layer on top of the perlite cake layer. The build-up of this cake layer will decrease the filtration flux with time due to the increase of cake resistance [11]. Eventually, the cake resistance of FP3 and FW6 was a few magnitudes higher than FW20 and FW50. This cake resistance results correlated well with the observed and recorded suspended solids removal and filtration flux performance.

4. CONCLUDING REMARKS

This study shows that particle size and pressure drop contribute to the performance of cake filtration in terms of quality and filtration flux. Increased in particle size will decrease the quality of filtered digestate, but increase the filtration flux. This is because the cake layer formed from large particle size is more porous, enabled the filtrate to flow through along with the small particles of suspended solids and resulted in high turbidity in the supernatant yet with higher flux. The results from cake resistance supported the postulation made about the correlation between the particle size of perlite with suspended solids removal and filtration flux. With the build-up of thicker suspended solids cake layer, the increase of cake resistance will reduce the filtration flux. Perlite FW6 was believed to be the optimal size to remove suspended solids in anaerobically digested POME. Although FP3 has smaller particle size and higher removal efficiency, FW6 recorded better filtration flux and its associated suspended solids removal efficiency was at par with FP3. Therefore, FW6 was considered as the optimal size of perlite as filter aid for further work in removing suspended solids in POME treatment prior to downstream nutrient and water recovery processes.

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6. REFERENCES

1. Hadiyanto, H., Christwardana, M. and Soetrisnanto, D., “Phytoremediations of palm oil mill effluent (POME) by using aquatic plants and microalge for biomass production”, ***International Journal of Engineering - Transaction C: Aspects***, Vol. 27, No. 12, (2014), 1809–1814.
2. Yeoh, G., “A technical and economic analysis of heat and power generation from biomethanation of palm oil mill effluent”, ***International Energy Journal***, Vol. 6, No. 1, (2004), 63–79.
3. Bukhari, N. A., Ngatiman, M., Soh, K. L. and Choo, Y. M., “Characteristics of palm oil mill effluent (POME) in an anaerobic biogas digester”, ***Asian Joournal of Microbiology, Biotechnology & Environmental Sciences***, Vol. 16, No. 1, (2014), 225–231.
4. Zhang, Y., Yan, L., Qiao, X., Chi, L., Niu, X., Mei, Z. and Zhang, Z., “Integration of biological method and membrane technology in treating palm oil mill effluent”, ***Journal of Environmental Sciences***, Vol. 20, No. 5, (2008), 558–564.
5. Ahmad, A. L., Sumathi, S. and Hameed, B. H., “Coagulation of residue oil and suspended solid in palm oil mill effluent by chitosan, alum and PAC”, ***Chemical Engineering Journal***, Vol. 118, No. 1–2, (2006), 99–105.
6. Ebrahimi, A., Asadi, M. and Najafpour, G. D., “Dairy wastewater treatment using three-stage rotating biological contactor (NRBC)”, ***International Journal of Engineering - Transaction B: Application***, Vol. 22, No. 2, (2009), 107-114.
7. Wu, Y.T, Mohammad, A. W., Jahim, J. M. and Anuar, N., “A holistic approach to managing palm oil mill effluent (POME): biotechnological advances in the sustainable reuse of POME”, ***Biotechnology Advance***, Vol. 27, No. 1, (2009), 40–52.
8. Chin, M. J., Poh, P. E., Tey, B. T., Chan, E. S. and Chin, K. L., “Biogas from palm oil mill effluent (POME): opportunities and challenges from Malaysia’s perspective”, ***Renewable and Sustainable Energy Reviews***, Vol. 26, (2013), 717–726.
9. King, L. S. and Yu, L. C., “A retrofitted palm oil mill effluent treatment system for tapping biogas”, ***European International Journal of Science and Technology***, Vol. 2, (2013), 106–114.
10. Iritani, E., Katagiri, N. and Kanetake, S., “Determination of cake filtration characteristics of dilute suspension of bentonite from various filtration tests”, ***Separation and Purification Technology***, Vol. 92, (2012), 143–151.
11. Mahdi, F. M. and Holdich, R. G., “Chemical engineering research and design laboratory cake filtration testing using constant rate”, ***Chemical Engineering Research and Design***, Vol. 91, No. 6, (2012), 1145–1154.
12. Tien, C. and Bai, R., “An assessment of the conventional cake filtration theory”, ***Chemical Engineering Science***, Vol. 58, No. 7, (2003), 1323–1336.
13. Du, L., Chen, X., Li, W. and Zhu, Q., “A study on enhancement of filtration process with filter aids diatomaceous earth and wood pulp cellulose”, ***Chinese Journal of Chemical Engineering***, Vol. 19, No. 5, (2011), 792–798.
14. Chen, W., “Optimization of sludge dewatering through pretreatment, equipment selection, and testing”, ***Drying Technology***, Vol. 31, No. 2, (2013), 193–201.
15. Wu, C., Li, Z., Su, X., Jia, Y. and Lu, X., “Novel ultrafiltration membrane fouling control method with *in-situ* filter aid of perlite particles”, ***Desalination and Water Treatment***, Vol. 57, No. 12, (2016), 5365–5375.
16. Maxim, L. D., Niebo, R. and McConnell, E. E., “Perlite toxicology and epidemiology – a review”, ***Inhalation Toxicology***, Vol. 26, No. 5, (2014), 259–270.
17. Petrović, D. V., Mitrović, Č. B., Trišovic, N. R. and Golubović, Z. Z., “On the particles size distributions of diatomaceous earth and perlite granulations” ***Journal of Mechanical Engineering***, Vol. 57, No. 11, (2011), 843–850.
18. Braun, F., Hildebrand, N., Wilkinson, S., Back, W., Krottenthaler, M. and Becker, T., “Large-scale study on beer filtration with combined filter aid additions to cellulose fibres”, ***Journal of the Institute of Brewing***, Vol. 117, No. 3, (2011), 314–328.
19. Ediz, N., Bentli, I. and Tatar, I., “Improvement in filtration characteristics of diatomite by calcination”, ***International Journal of Mineral Processing*,** Vol. 94, No. 3–4, (2010), 129–134.
20. Kinnarinen, T., Tuunila, R., Huhtanen, M., Häkkinen, A., Kejik, P. and Sverak, T., “Wet grinding of $CaCO_3$ with a stirred media mill: Influence of obtained particle size distributions on pressure filtration properties”, ***Powder Technology***, Vol. 273, (2015), 54–61,
21. Zinatizadeh, A. A. L., Mohamed, A. R ., Mashitah, M. D., Abdullah, A. Z. and Najafpour, G., “Pretreated palm oil mill effluent (POME) digestion in an up-flow anaerobic sludge fixed film bioreactor: a comparative study”, ***International Journal of Engineering - Transaction B: Application***, Vol. 19, No. 1, (2006), 1-9.
22. Aryanti, N., Wardhani, D. H., and Supandi, S., “Flux profiles and mathematical modeling of fouling mechanism for ultrafiltration of konjac glucomannan”, *Scientific Study and Research Chemistry and Chemical Engineering Biotechnology, Food Industry*, Vol. 17, No. 2, (2016), 125–137.
23. Chang, S. Y., Toledo, R. T., Science, F., Lillard, H. S. and Russell, R. B., “Clarification and decontamination of poultry chiller water for recycling”, ***Poultry Science***, Vol. 68, (1987), 1100–1108.
24. Wakeman, R., “The influence of particle properties on filtration”, ***Separation and Purification Technology,*** Vol. 58, (2007), 234–241.

Influence of Particle Size and Pressure Drop in Cake Filtration Process on Removal of Suspended Solids in Anaerobically Digested Palm Oil Mill Effluent

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چکیده

فاضلاب صنایع روغن پالم (POME) تهدید بزرگی برای محیط زیست به شمار می آید. با این حال، این نوع فاضلاب حاوی منابع ارزشمندی مانند انرژی، آب و مواد مغذی است که می تواند برای توسعه پایدار مورد بازیافت قرار گیرند. در حال حاضر، هضم بی‌هوازی برای بازیافت انرژی موجود ذخیره شده در فاضلاب روغن پالم مورد استفاده قرار می گیرد . با این حال، حضور مواد جامد معلق در فاضلاب هضم شده مانع بازیافت مواد مغذی توسط صنایع پایین‌دستی می شود. با در نظر گرفتن این نکته، فرایند فیلتراسیون کیک گزینه مناسبی برای حذف مواد جامد معلق در فاضلاب هضم شده به نظر می رسد. از این رو، در این مقاله عملکرد کیک فیلتر در حذف مواد جامد معلق در فشار های مختلف و اندازه مختلف ذرات پرلایت مورد بررسی قرار گرفت. اثربخشی فرایند تصفیه کیک بر اساس کیفیت فیلتراسیون (کدورت و مواد جامد معلق کل TSS)و شار فیلتراسیون بررسی شده است. در این مطالعه پرلیت با اندازه ذره های مختلف (FP3، FW6، FW20وFW50) به صورت بادی فید و فیلتراسیون پری-کت مورد استفاده قرار گرفتند. مقدار بادی فید و پری-کت 1 گرم انتخاب شد. فرایند تصفیه در فشار های مختلف (2تا5 بار) انجام شد. نتایج بدست امده نشان داد که پرلیت با کوچکترین اندازه ذرات (FP3) به علت تشکیل لایه فیلتراسیون کیک متراکم تر موفق به حذف کدورت ومواد جامد معلق تا ۹۰ درصد شدند. از سوی دیگر، پرلیت با اندازه ذرات بزرگتر FW50 کمترین راندمان حذف رابه علت تشکیل لایه کیک متخلخل نشان دادند، هرچند تشکیل لایه کیک متخلخل موجب افزایش شار فیلتراسیون می شود. به طور کلی، افزایش فشار موجب افزایش شار شد، اما در عین حال باعث کاهش شدید شار اصلی به دلیل پوشش سریع حفره های تصفیه شده است. نتایج حاصل از این تحقیق نشان می دهد که در نظر داشتن اثر توزیع اندازه ذرات و افت فشار برای دستیابی به فیلتراسیون با کیفیت و همچنین شار بالا، اهمیت دارد.

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