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Effect of different filter aids used in cake filtration process on the removal of suspended solids in anaerobically digested palm oil mill effluent (POME)

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ABSTRACT

Palm oil mill effluent (POME) is a highly polluted wastewater that requires proper treatment before it can be safely discharged to the environment. Presently, the effluent is treated with a closed anaerobic digester tank which is used to entrap methane gas prior undergoing downstream treatment. The digestate discharged from the tank contains abundance of nutrients that can be potentially recovered and reused as organic fertilizer. However, the digestate contains a high amount of suspended solids that may disrupt the downstream nutrient recovery process. Therefore, this paper explores the feasibility of the cake filtration process to remove suspended solids in anaerobically digested POME. Different types of filter aids such as perlite, diatomaceous earth, bleaching earth, powdered activated carbon and boiler ash were used to investigate the filtration performance by evaluating the quality of filtered digestate (turbidity and total suspended solids), filtration flux and specific cake resistance. The amount of filter aid used as precoat and body feed was varied (with ratio 1:1) from 1.0 to 5.0 g in the process. Turbidity removal above 90% can be achieved regardless of the amount of filter aids used. It was found that perlite achieved the highest turbidity removal (99%) combined with the highest filtration flux at the end of the process (~2 m^3/m^2 h) and lower specific cake resistance (2.69 m/kg). This was due to the presence of plenty fine pores (as shown by field emission scanning electron microscope image) on perlite and its narrow particle size distribution (10–15 μm) which resulted in the formation of a homogeneous cake layer that succeeded in retaining the suspended solids. The findings from this study showed that cake filtration is a feasible treatment process to remove suspended solids in POME and thus produce filtrate of an improved grade for downstream nutrient recovery processes.

Keywords: Palm oil mill effluent (POME); Anaerobic digestate; Cake filtration; Filter aids; Turbidity and suspended solids

1. Introduction

Malaysia is the second largest palm oil producer with production of 17.32 million tonnes of crude palm oil (CPO) in year of 2016 [1]. Associated with the huge production of CPO, a large volume of colloidal wastewater known as palm oil mill effluent (POME) is produced, with an alarming ratio of three times the quantity of CPO [2]. The raw POME is acidic (pH 4–5), concentrated with dark brownish colloidal suspension and composed of 95%–96% of water, 0.6%–0.7% of oil

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and grease and 4%–5% of total solids [3]. It is categorized as a highly polluting wastewater due to its high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) content at 25,000 and 50,000 mg/L, respectively [2–4].

Currently, due to low capital and operating cost, around 85% of the mills employ the conventional treatment process, mainly known as the open ponding system which consists of anaerobic followed by aerobic ponding system [5]. In recent years, more and more palm oil mills have shifted to closed anaerobic digester tank systems to treat POME and at the same time to recover methane gas as an alternative to electricity sources [6]. This practice could potentially reduce the impact of the palm oil industry to global warming [7], as well as to produce renewable energy from methane that can substitute the conventional energy sources [8]. Although anaerobic digester managed to reduce COD and BOD contents, the discharged digestate is still rich in nutrient comprised of nitrogen, phosphorus, and potassium [9]. This issue has prompted the efforts to recover the nutrients in the treated POME as organic fertilizer to substitute the inorganic fertilizer [10–12]. This may reduce the consumption of chemical fertilizer which is less environmentally friendly compared with the organic fertilizer derived from treated POME and at the same time minimize the problem of nutrient leaching to the environment. However, the presence of suspended solids has hindered the proposed nutrient recovery plan. Hence, a pretreatment process to remove the suspended solids in the digestate is necessary prior to the downstream nutrient recovery process.

To date, the most frequently used treatment process for removing suspended solid in POME is by using coagulation–flocculation as it is economically feasible, has easy handling, and is an energy efficient treatment process [13–16]. However, the usage of aluminum sulphate, which is the most commonly used coagulant in the wastewater industry, has been criticized for producing hazardous activated sludge and the residual aluminum has been associated with Alzheimer's disease [3,15]. Some studies have recently addressed this issue by using natural coagulants such as *Moringa oleifera* seed [15], chitosan [3] and cationic organic polymer [16,17] for coagulation process. However, some drawbacks have been pointed out by Ghebremichael et al. [18] that natural coagulants, such as *M. oleifera* seed, when used in crude form the residual coagulant will impact the water quality by increasing the dissolved organic carbon. Apart from that, the use of chitosan is more expensive in some developing countries and residual acrylamide or epichlorohydrin monomers found in organic polymers are reported to have neurotoxicity and strong carcinogenic properties [18]. Hence, it is vital to find alternative treatments that manage to remove suspended solid without requiring high cost materials or creating secondary waste disposal issue.

Cake filtration has been widely used over the years to remove suspended solids in the bioprocessing industry [19]. It is acknowledged to be more cost efficient for the removal of suspended solids in the form of a retained cake layer [20]. The cake layer is formed on the filter medium by using filter aids to retain the suspended solids during the filtration process [21]. Filter aids can be used as a precoat layer by forming a highly permeable and dense cake layer on the filter medium. The precoat layer prevents the clogging of filter medium by suspended solids and eventually improves the separation efficiency. Furthermore, filter aids can also be mixed into the solution as body feed to improve filtration flux by forming a more porous and water permeable cake layer [22]. Therefore, filtration time and energy consumption can be reduced due to high filter cake permeability [23]. Filter cake, which is a spongy, amorphous and dark-coloured substance (due to the retention of organic suspended solids) of high moisture content, is the solid by-product of the process. This filter cake can be applied on the land to prevent soil erosion, improve drainage and promote the natural growth of bacteria and microorganisms. Due to these benefits, filter cake has been widely employed as fertilizer or soil amendment in the agricultural industry [24]. Unlike coagulation process, cake filtration generates green wastes, which can be safely disposed or used for other purposes.

The most commonly used filter aids in the industry are diatomaceous earth (DE), perlite, and cellulose fibres [25]. Diatomaceous earth is comprised of skeletal remains of single-cell water plants [26]. It has been found to be the most significant filter aid due to its high inner porosity. However, direct inhalation of DE can cause lung cancer due to its small crystalline particles entering the respiratory system [27]. On the other hand, perlite is made of amorphous volcanic alumina-silicate rock with 2%–5% water content [28]. Perlite has been extensively used as a substitute to DE due to its low density and low cost [29]. Perlite is an excellent filter aid in many processes due to its high silica content (more than 70%) and adsorptive feature, which makes it chemically inert in the environment [30].

Some important factors, such as operating pressure, filtration flux, specific cake resistance and particle properties play an important role in the success of cake filtration process. Most cases in laboratory testing applied constant pressure during the filtration cycle where pressure drop is applied through the cycle from the initial process until the formation of the cake layer [20]. In constant pressure filtration, the filtration rate decreases with time due to increase in cake resistance. Therefore, compressibility of the filter cake can be obtained at the end of the process by determining the dependence of specific cake resistance on pressure over the cake [31]. Apart from constant pressure testing, constant body feed concentration is also a common practice in the industry. Kuhn and Briesen [23] pointed out that higher amount of body feed should be dosed in the beginning and constantly decreased with time to assure higher retention of impurities on the cake layer. Other than that, Wakeman [32] stressed in his study that particle size is important because small particles will bleed through the filter medium during the initial stage and later accumulate on the cake layer. This will affect the specific cake resistance which can be translated into water permeability. The challenge of cake filtration is the increase of cake resistance attributed to the formation and growth of the filter cake on the top surface of the filter medium during filtration. Therefore, the determination of the specific cake resistance (α_{av}) of the filter cake is a crucial factor in the analysis of filtration operations [31].

To the best of our knowledge, cake filtration has yet to be employed in removing suspended solids in anaerobically digested POME. Hence, this study aims to investigate the performance of cake filtration process by evaluating the quality of the filtered digestate, filtration flux and specific cake resistance using different types and amount of filter aids. Filter aids used in this study were DE, perlite, bleaching earth (BE), powdered activated carbon (PAC), and boiler ash (BA). DE and perlite were chosen because both are frequently applied in the industry. On the other hand, BA and BE are two major solid wastes generated from the palm oil mill. It is of interest to investigate whether these solid wastes could be an alternative low-cost filter aids. PAC was included in the study to evaluate whether its adsorptive characteristic could help in reducing dissolved organic substances in the effluent.

2. Materials and methods

2.1. Materials

The anaerobically digested POME was collected from a closed-type anaerobic digester system at Sime Darby East Palm Oil Mill, Carey Island, Malaysia. The digestate was preserved in a cool storage at 4°C to avoid any composition changes due to microbial activity [33]. The required digestate was then thawed to room temperature (27°C) prior to perform each experiment. The characteristics of digestate POME was analyzed and listed in Table 1.

Perlite, DE, BE, and PAC used for this study were supplied and purchased from EP Minerals (USA), DEFG (Malaysia), Taiko Bleaching Earth Sdn Bhd (Malaysia), and R&M Chemicals (Malaysia), respectively. BA was the incinerated solid waste collected from the Sime Darby East Palm Oil Mill (Malaysia). A ball mill system was used to grind the particles of BA at 30 rpm for 1 h and further sieved to 25 μm with a sieve shaker.

2.2. Cake filtration process

The cake filtration process was carried out in a laboratory scale Nutsche filter (Fig. 1). This cake filtration driven by compressed air was supplied by DrM, Dr. Mueller AG, Switzerland. It has a filtration area of 0.001 m^2. The filter medium used is a woven cloth with polyvinylidene fluoride monofilament weft. The surface area and porometer value of the filter medium are 16.62 cm^2 and 10 μm, respectively. The function of filter medium was acting as a support for the cake layer to form on top of it.

This experiment was performed under constant pressure (2 bar) condition. Ratio for precoat and body feed was 1:1 for each test. Mass of each filter aids used as precoat and body feed was varied from 1 to 5 g. The filter aids used as precoat were first mixed with 200 mL of ultra-pure water. The filter aid slurry was then recirculated through the filter medium. Pressure driven from the compressed air enforced the filter aid slurry to flow through the filter medium. Due to its larger size, the particles from the filter aid slurry were retained on the filter medium. A precoat layer was then formed on top of the filter medium. Then, the same filter aids were mixed with 200 mL of the anaerobically digested POME as body feed before pouring the digestate slurry into the filter candle. The filtration process was started by pressurizing the effluent in the filter candle to pass through the cake layer formed earlier. The quality of the filtered digestate was determined by measuring the turbidity and total suspended solids (TSS) removals of the supernatant:

Table 1
Characteristics of digestate POME from anaerobic digester system

Parameters	Digestate POME
pH	7.64
COD (mg/L)	6,467
Total suspended solid (mg/L)	3,457
Turbidity (NTU[a])	1,303
Nitrogen ammonia (mg/L)	342
Phosphorus (mg/L)	242

[a]NTU is the unit of turbidity, nephelometric turbidity unit.

$$\text{Removal (\%)} = \frac{A - B}{A} \times 100 \tag{1}$$

where A is turbidity (NTU) or TSS (mg/L) before filtration, B is turbidity (NTU) or TSS (mg/L) after filtration, depending on which parameter (turbidity or TSS) to be measured.

Filtration flux (q) was measured to determine the permeability of the cake filtration process from Eq. (2) based on Darcy's law [22].

$$q = \frac{V}{At} \tag{2}$$

where V is volume of filtered digestate (m^3), A is filtration area (m^2), and t is filtration time (h).

The specific cake resistance as denoted by Eq. (3) was used to measure the total resistance of the cake layer towards the filtrate flow rate per unit mass of filter cake solids [20].

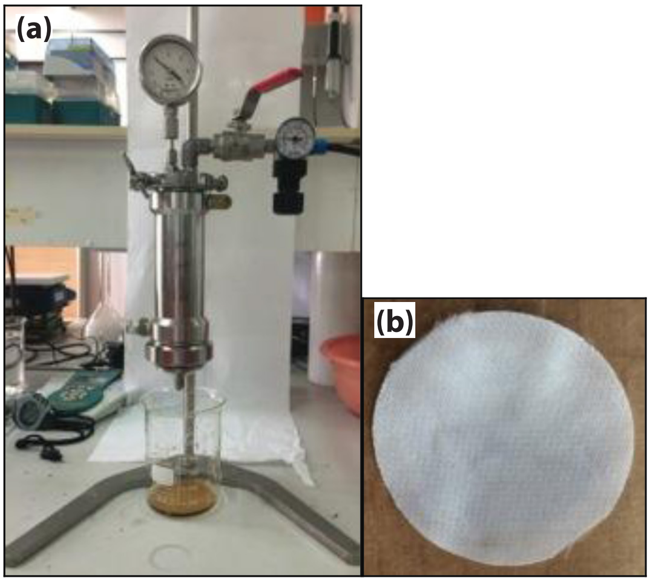

Fig. 1. Laboratory scale Nutsche filter (a) and filter medium (b).

$$\frac{t}{V} = \frac{\mu\alpha_{av} c}{2A^2\Delta P} V + \frac{\mu R_m}{A\Delta P} \tag{3}$$

where V is volume of filtered digestate (mL), t is filtration time (s), 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 versus V plot, respectively.

2.3. Analytical methods

The COD, nitrogen ammonia, phosphorus, and TSS of digestate and filtered digestate were measured according to Standard Methods for the Examination of Water and Wastewater [34]. All the reagents used for COD, nitrogen, ammonia, and phosphorus measurement were purchased from Hach, USA. For COD, nitrogen ammonia, and phosphorus measurement, the digestate and filtered digestate were diluted into the desired concentration prior further measurement. Diluted sample (2 mL) was then pipetted into a low range solution of COD reagent and further heated for 2 h in Hach DRB 200 reactor (Hach, USA) at 150°C before being sent to Hach DR 3900 spectrophotometer (Hach, USA) for COD measurement. For nitrogen ammonia measurement, 25 mL of the diluted sample was mixed with Nessler reagent before measured with Hach DR 3900 spectrophotometer. Another 10 mL of diluted sample was mixed with orthophosphate reagent for phosphorus measurement with Hach DR 3900 spectrophotometer. For TSS measurement, 10 mL of digestate and filtered digestate were filtered through a pre-weighted glass fibre filter paper (Whatman, grade GF/C) and the filter paper with the retained solids was then oven-dried for 1 h at 105°C. Then, the oven-dried filter paper was cooled in a dessicator to reduce the temperature before being measured for its weight. The difference between the weight before and after dried in oven gave the TSS value.

pH was measured using HI 2550 benchtop meter (Hanna, USA). The turbidity of the digestate and filtered digestate was measured using Hach 2100 AN Turbidimeter (Hanna, USA). The particle size analysis was conducted for all types of filter aids by using Mastersizer Hydro 2000MU (Malvern, UK). The high-resolution image of each filter aids was captured using field emission scanning electron microscope (FESEM) Supra 55VP (Zeiss, Germany) at an accelerating voltage of 3.0 kV, with magnification of 1.00k × and 10.00k ×.

3. Results and discussion

3.1. Turbidity and TSS removal efficiency

As shown in Table 2 and Fig. 2, the turbidity values of the filtrate decreased with the mass of filter aids. This observation was also supported with the increased percentage of TSS removal in the filtered digestate (Fig. 3). Such phenomenon could be attributed to the presence of more filter aids as precoat. Hence, the cake layer formed on the filter medium became thicker and provided better retention for the suspended solids.

It is noticeable that the increase of filter aids slightly improved the turbidity removal of perlite, DE, and BE when compared with PAC and BA (Fig. 2). This indicated that low dosage of perlite, DE, and BE is sufficient to remove the turbidity of the digestate up to 99%. Overall, perlite shows the highest turbidity removal at 99.4%–99.5%, followed by DE (99%–99.4%), PAC (98%–99.3%), BE (98%–98.5%) and BA (95.5%–97.5%). In comparison with the common treatment employed to remove suspended solids in anaerobically digested POME, which is coagulation–flocculation process, cake filtration provided a far better result. This is because from the previous study done by Zahrim et al. [17], coagulation–flocculation process only managed to remove TSS up to 89% in anaerobically digested POME [17].

By referring to Table 3 and Fig. 4, it can be observed that the particle size distribution varies for each filter aid. For instance, perlite and DE have finer particle size and are more narrowly distributed compared with the others. The particle size distribution of perlite and DE is in the same range, which

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

Filter aids	Turbidity (NTU)		
	1 g	3 g	5 g
Perlite	7.31	6.28	6.19
DE	10.40	9.54	6.29
BE	26.20	20.80	19.80
PAC	26.60	18.6	8.48
BA	58.90	42.20	32.10

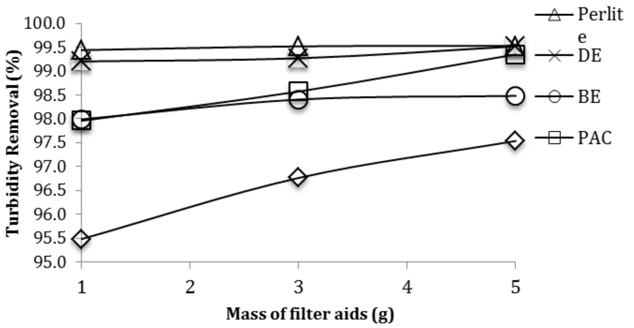

Fig. 2. Turbidity removal efficiency at different type and mass of filter aids.

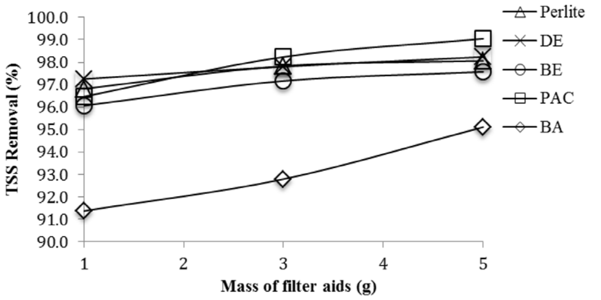

Fig. 3. TSS removal efficiency at different type and mass of filter aids.

Table 3
Particle size distributions of the filter aids

Filter aids	D_{10} (µm)	D_{50} (µm)	D_{90} (µm)
Perlite	4.96 ± 0.25	15.79 ± 0.50	46.85 ± 0.15
DE	2.59 ± 0.10	10.06 ± 0.25	26.51 ± 0.20
BE	3.38 ± 0.50	25.59 ± 0.25	70.06 ± 0.10
PAC	3.70 ± 0.10	28.60 ± 0.30	168.66 ± 0.25
BA	5.95 ± 0.50	26.68 ± 0.10	65.48 ± 0.40

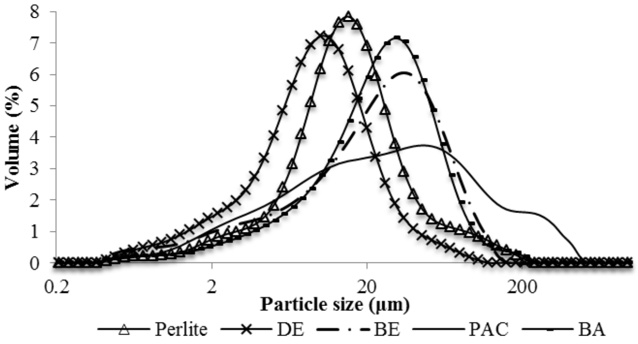

Fig. 4. Particle size distribution curves of the filter aids.

contributed to their higher turbidity removal as seen in Fig. 2. This finding is consistent with study reported by Ediz et al. [26] where the finer particles with uniform distribution could produce a less permeable filter bed that led to higher detainment of suspended solids [26]. Eventually, it enabled the formation of homogenous cake layer that consistently retained the suspended solids and gave the highest turbidity removal efficiency.

Although BE and BA have narrower particle size distributions, they have a higher percentage of particles over 60 µm. It was postulated that finer particles will fill up the gaps between the coarse particles during the formation of the cake layer [26]. Therefore, the blocking of gaps between the particles in the cake layer might contribute to the suspended solids removal for BE and BA. However, the suspended solids removal with BE as the filter media is relatively higher than for BA (Fig. 3), mainly because BE has an additional property that BA did not have, which is adsorption capacity to remove impurities [35]. This can be seen in other studies where BE had been used to remove pigmented substances in a palm oil bleaching process [36].

As for PAC, its particle size is widely distributed and comprised of large particle size up to 168.66 µm. Therefore, this resulted in the formation of uneven cake layer, with the gaps between large particles filled with finer particles. This might lead to the formation of a cake layer with high resistance due to the loss of permeation space within the cake layer [37].

Apart from particle size distribution, the morphological structure of filter aids (Fig. 5) also affects the removal of suspended solids. Perlite has many fine pores on the surface, as shown in Fig. 5(a). It is similar to the observation of perlite reported by Jahanshahi and Akhlaghinia [38] in which the surface layer was highly porous. Therefore, the fine porous structure of perlite enabled better retention of suspended solids by its high removal of TSS and turbidity in the filtered digestate. Although DE has a similar structure as perlite, the obvious difference that can be spotted from Fig. 5(b) was its larger pores which facilitated water to pass through the pores [39]. Therefore, the suspended solids retention is slightly lower than perlite.

On the other hand, PAC shows lesser pores and has a relatively smooth surface, as observed from the inset image (Fig. 5(d)). Consequently, suspended solids most probably were removed through its compact cake layer, which hindered the permeation of suspended solids. Furthermore, the presence of much smaller pores also prevents the bleeding of fine suspended solids through the cake layer. Chen et al. [40] reported that the small pores present in low amounts in PAC could easily trap the solid particles inside the pores, supporting the finding in this study for PAC high turbidity removal [40].

As illustrated in Fig. 5(e), large pores were observed on the surface layer of BA. As indicated in other study, some of the BA particles are spongy and contain large pore structure [41]. The presence of such structure might be accountable for the lower accumulation of suspended solids on the cake layer and smaller suspended particles can easily bleed through the cake layer, resulting in low turbidity removal. On the other hand, the FESEM image of BE (Fig. 5(c)) shows agglomerate of fine particles and fibrous-like structure similar to the image observed in previous literatures [42,43]. Hence, the absence of pores on BE surface could be an indication that the retention of suspended solids is mostly due to the gaps between the particles. As observed in Fig. 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 disrupt the permeation of suspended solids.

3.2. *Filtration flux*

As stated in the previous section, the improvement of turbidity removal was only around 1%–2% when the mass of filter aids was increased. Thus, 1 g of filter aids was selected to be used as precoat and body feed for filtration flux assessment. Excessive dosage of filter aid will increase the purchasing cost as well as affect the filtration flux [25]. This is supported by Du et al. [22] who have reported that excess addition of DE as filter aid produced a thicker cake layer and reduced the filtration flux due to cake resistance.

Filtration flux of each filter aid is displayed in Fig. 6. It was obvious that during the initial stage of filtration, the flux drops considerably especially for filter aids with higher initial flux. Chang et al. [37] also observed the same behaviour of flux decline during the initial stage of chiller water clarification using cake filtration. The initial flow rate was higher, followed by a declining trend due to the accumulation of suspended solids on the cake layer that rapidly reduced the cake porosity and thus the flux. Furthermore, the pores and spaces between particles were available in the early stage of filtration for the permeation of water, which explained the high flow rate during the initial stage [26].

Flux of perlite was around 7.8 m^3/m^2 h initially and decreased by 50% after 5 min of filtration period. As shown in the previous section, perlite shows a considerable number of fine pores compared with the other filter aids. This morphological structure enabled more water to pass through the cake

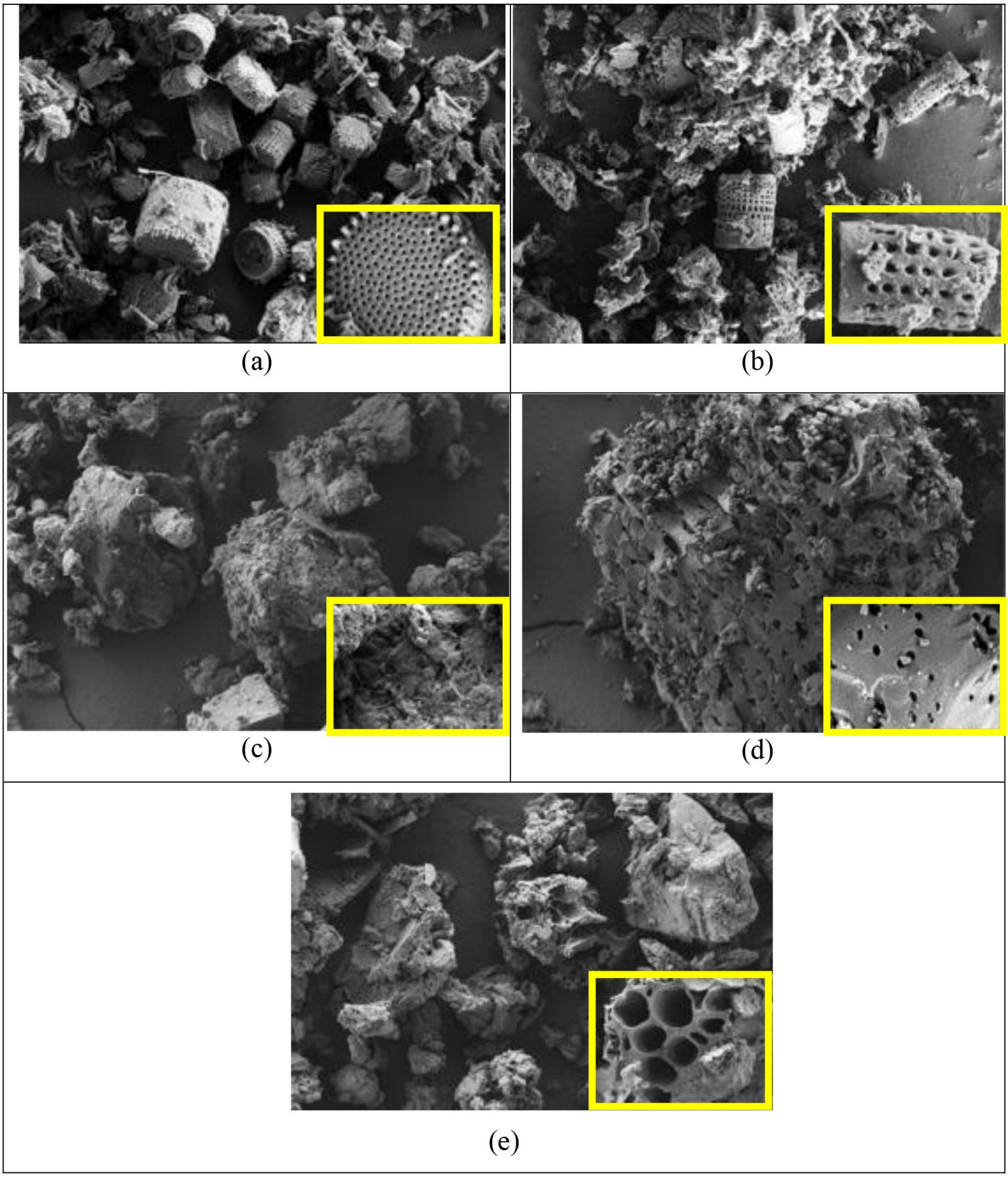

Fig. 5. FESEM images of different type of filter aids at magnification 1k (larger image) and 10k (inset): (a) perlite, (b) DE, (c) BE, (d) PAC, and (e) BA.

layer and eventually resulted in higher flux. Furthermore, the finer and narrower particle size distribution of perlite can form a compact and even cake layer that will contribute to high filtration flux. However, higher flux will bring more suspended solids to the surface of the cake layer and instantly get accumulated on it. Consequently, the resistance for water permeation will increase drastically and therefore decrease the flux in a short period. This phenomenon is similar with the membrane fouling study reported by Ang et al. [44]. 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 sharper for membrane with higher initial flux.

Although BA recorded the second highest flux after perlite, the turbidity removal is the lowest compared with the others. This is because the presence of large pores on its surface facilitated the bleeding of suspended solids and the permeation of water through the cake layer (Fig. 5(e)). Hence, this explained the reason why BA has higher flux compared with DE, PAC, and BE.

From Fig. 6 it is observed that the flux of the filter aids started to decline with time. This could be due to the slow deposition of suspended solids on the cake layer. The cake layer grew thicker and more compact with time as the cake layer retained more suspended solids which will then disrupt the permeation of water [37]. Furthermore, this phenomenon can be correlated with finer particles of filter aids which will be trapped in between the coarse particles and cause a decrease in flux by blocking the spaces for water permeation [26]. This is in agreement with a study conducted by Morgan et al. [45] who had observed that very fine particles of BE led to poor performance of flux [45].

Overall, the retained suspended solids covered up the cake layer and disrupted the water permeation rate so that it can only flow through the unblocked gaps and pore areas [15]. Similar finding has been reported by Ediz et al. [26] where the flow rate of beer residue filtration decreased due to the pores and spaces of cake filled with the beer residues.

3.3. Specific cake resistance

The specific cake resistance of different filter aids is displayed in Fig. 7 and Table 4. A best-fit line (Fig. 7) was plotted based on linear equation in Eq. (3) in order to obtain the values of the specific cake resistance. In accordance to the linear curve, the intercept is slightly above the origin, which signified a small but finite filter medium resistance present in the filtration process [20].

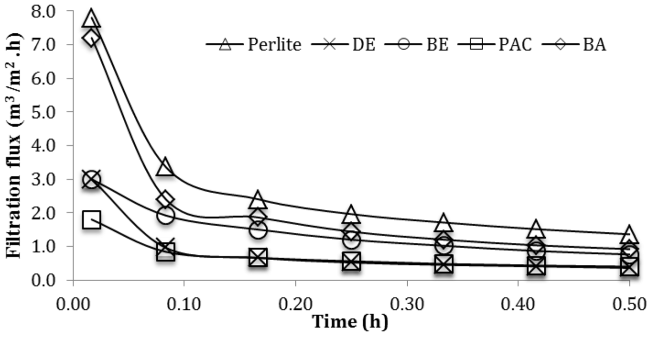

Fig. 6. Filtration flux of different type of filter aids.

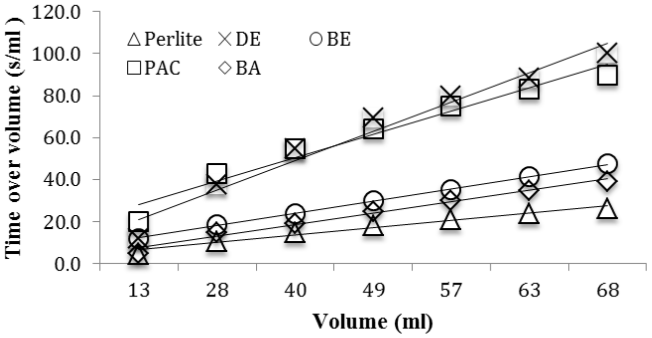

Fig. 7. Specific cake resistance curve of different type of filter aids.

Perlite yields the lowest cake resistance (195.94 m/kg) and the largest amount of filtered digestate (68 mL), which correlated with the aforementioned high filtration flux of perlite. The results indicated that lower cake resistance accompanied by lower pressure drop acted over the cake layer and led to higher filtration flux. Therefore, cake filtration process managed to run for a longer time before the flux dropped significantly. The steady flux after the initial decline could be attributed to the maximum pressure drop acting on the cake layer as the cake resistance increased. The increase in cake resistance over time was because the cake layer became thicker due to the accumulation of suspended solids [37]. The image of perlite cake layer is shown in Fig. 8.

On the other hand, lower filtration flux of DE as mentioned in previous section is due to its high cake resistance (783.15 m/kg) value. Although DE has as fine and narrow a particle size distribution as perlite, the pores observed in DE filter aid (Fig. 5(b)) are larger than perlite. Therefore, small particles of DE had the tendency to clog the cake layer and caused high resistance towards the flow rate. This can be observed by the formation of a compact and rigid cake layer due to the clogging of solids as shown in Fig. 8. Similar observation was made by Chang et al. [37] on the comparison of cake resistance between perlite and DE. The specific cake resistance of DE was much higher because the cake porosity reduced more rapidly than perlite. Similarly, the specific cake resistance for PAC was high (623.85 m/kg), indicating that the cake layer was also compact and hindered the permeation of water, as shown in previous discussion where the flux of PAC was recorded as one of the lowest. As observed in Fig. 6 and Table 4, both BA and BE have relatively higher flux and lower cake resistance compared with DE and PAC. This correlation was expected as lower resistance (more gaps in between the cake media) indicated higher water flux.

4. Conclusion

Cake filtration attained fairly high turbidity and TSS removal (>90%) regardless of the type of filter aids used. The amount of filter aid showed no significant impact on the turbidity and TSS removal rates. Perlite was found to perform the best in cake filtration process as it produced filtrate quality with 99% removal of turbidity and TSS, as well as

Table 4
Specific cake resistance of the filter aids

Filter aids	Total amount of filtered digestate (mL)	Specific cake resistance (m/kg)
Perlite	68	195.94
DE	18	783.15
BE	38	326.98
PAC	20	623.85
BA	46	306.11

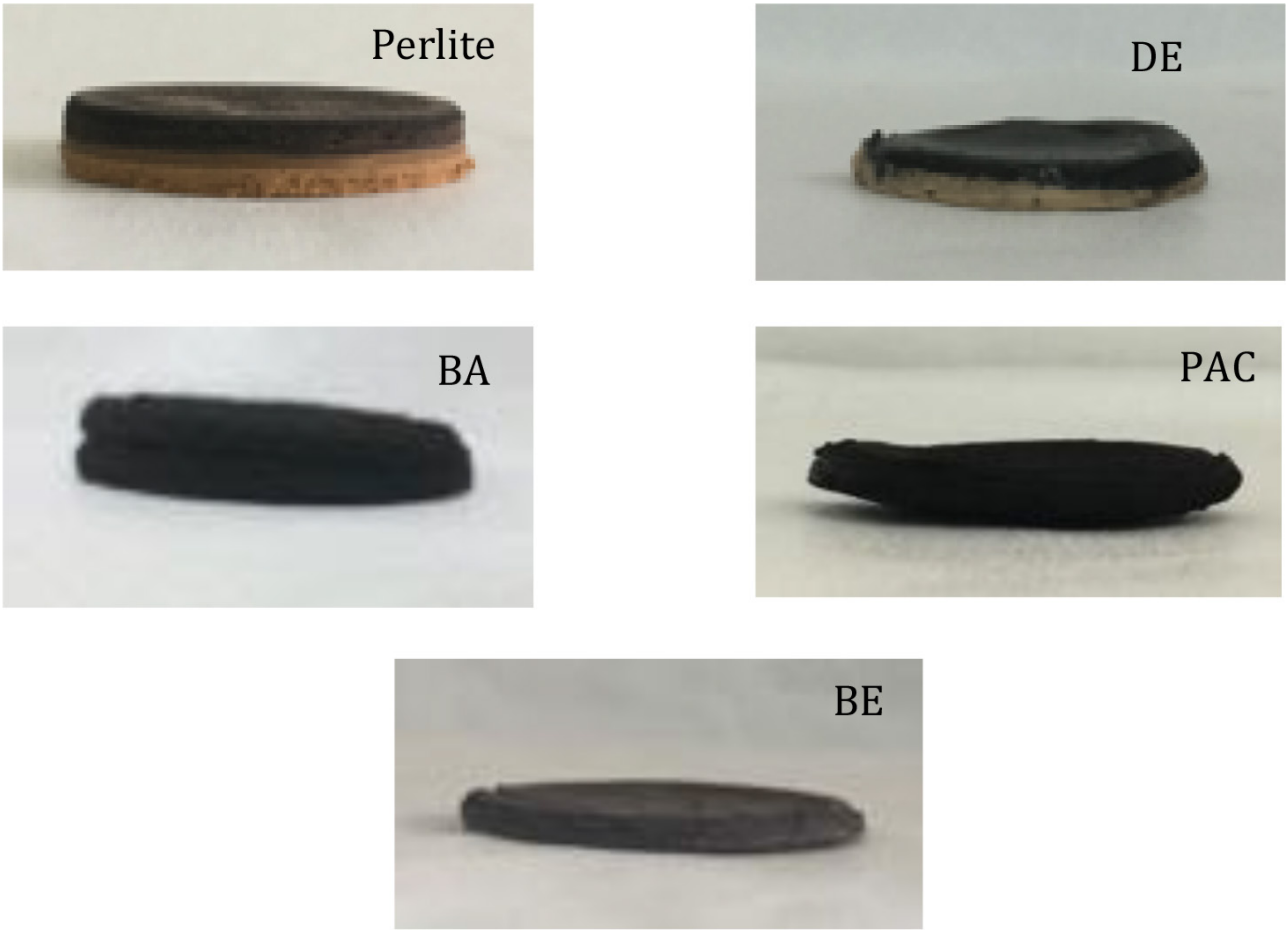

Fig. 8. Cake layer for each filter aid after filtration process at 1 g of dosage.

high filtration flux. Its porous structure and uniform particle size distribution resulted in the formation of uniform cake layer with low cake resistance (195.94 m/kg) that facilitated the permeation of water and retention of a high amount of TSS. Hence, the filtration process managed to run for a longer time without losing much of its pressure drop that drove the filtration process. This study showed that cake filtration process was capable to remove suspended solids in anaerobically digested POME prior to downstream process for nutrient and water recovery. Furthermore, cake filtration process had proven to generate better quality of treated anaerobically digested POME than coagulation–flocculation process. The suspended solids removal with cake filtration was 10% higher than the previous work done on coagulation–flocculation process. Thus, further work is required to optimize the operating conditions for the cake filtration process and to conduct economic assessment for the feasibility of this application in industrial scale.

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