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Comparative study on structural modification of *Ceiba pentandra* for oil sorption and palm oil mill effluent treatment

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ABSTRACT

The performance of raw *Ceiba pentandra* (L.) Gaertn (raw kapok fibers (RKF)) for oil sorption and palm oil mill effluent (POME) treatment was compared with structurally modified kapok (NaOH-treated (SKF) and surface-modified kapok fiber (SMKF)) and bentonite clay. Based on FTIR, kapok wax functional group at 1726/cm was not detected in SKF rendering higher hydrophilicity. The reduction in peak intensity at 473 and 523/cm upon HCl treatment of bentonite, suggests the cleavage of Si–O–Al bond layer and Si–O–Mg (Fe) bonds. For filtration under gravity at 0.08 g/cm^3, SKF showed high POME sorption of 82 g/g, but lower diesel sorption of 23 g/g. With HCl-treated bentonite, POME sorption at 69 g/g was only slightly higher than diesel sorption of 60 g/g. However, RKF and raw bentonite achieved higher removal efficiency of biological oxygen demand, chemical oxygen demand (COD), total organic carbon, and total nitrogen at 74–98% and 72–94%, respectively, than with SKF at 66–80%, and HCl-treated bentonite at 64–80%. In batch mode, SMKF at 0.08 g/cm^3 showed the highest oil sorption capacity of 56.7 g/g for Crude Palm Oil (CPO) and 33.7 g/g for diesel. Under continuous mode with 4000 mg/l CPO in water, 99% of COD removal was achieved at all packing densities and flow rates, regardless of kapok packing material. The dynamic oil retention was 96–99% for CPO and 99–100% for diesel at all packing densities. RKF and SMKF can both be suitable sorbent materials for CPO and diesel sorption, and for POME treatment.

Keywords: Ceiba pentandra; Bentonite; Palm oil mill effluent; Diesel; Residual oil

1. Introduction

Over the last few decades, there has been a growing concern on indiscriminate discharge of oil-containing industrial wastewater into the ecosystem. These include the increase in palm oil wastes from palm oil industries [1], and the high risk of petroleum product contamination from approximately 10 million tonnes of petroleum and derivatives used daily across the globe [2]. Palm oil industry produces huge amount of wastewater known as palm oil mill effluent (POME). For 16.3 million tonnes of palm oil production, about 2.5–3.5 tonnes of POME being generated from every tonne of crude palm oil (CPO) [3,4]. POME contains

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oil in the emulsified form and a high concentration of natural surfactants such as phospholipids and glycolipids for which treatment poses a real problem due to its high stability [4–6].

One of the common POME treatment methods is ponding system, which is used by more than 85% of palm oil mills in Malaysia [7]. Non-biological methods have been reported for the treatment of mill effluent [8] such as adsorption [4,9], coagulation [5], air floatation [10], and membrane filtration [11]. Different oil sorbent materials from organic [2,12], inorganic minerals [13], and organic synthetic fibers [14] have been explored and these include chitosan [5], bentonite/organoclay [15], zeolite [16], and superhydrophobic sponges [17]. However, the utilization of agricultural products such as barley straw [6], raw bagasse [18], rice husks [19], oil palm [20], and *Ceiba pentandra* [2,21–24] has gained increasing attention due to its biodegradability and low cost. *C. pentandra* (L.) Gaertn (Kapok) is effective natural oil sorbent with high sorption and retention capacities, structural stability, and high reusability [2,21]. To increase the efficiency and effectiveness of the raw kapok fiber, chemical and surface modification can be applied [17,23]. Carbonization and activation of raw bagasse [18], and acetylation of rice husk [19] have proved successful to improve the sorption capacity of pollutants.

In this study, physicochemical and oil sorption characteristics of raw kapok fibers (RKF) and structurally modified Kapok (SKF and surface-modified kapok fiber (SMKF)) were compared with bentonite clay and HCl-treated bentonite for sorption of diesel and CPO and for POME treatment. The performance was compared based on the effects of packing density and flow rate on oil sorption capacity and the dynamic oil retention in the batch and continuous mode.

2. Materials and methods

2.1. Materials

POME was collected from Palm Oil Mill, FELCRA Nasaruddin, Bota, Perak, Malaysia. POME sample was placed in a cold room at 4˚C for 24 h. POME suspended solid particles were filtered and the liquid fractions were used for experimental study.

RKF were obtained from Bota Kanan, Perak, Malaysia. The visible dust particles were removed manually. The fibers were dried in an oven at 70˚C until moisture content was less than 1%.

Bentonite clay (R&M Chemicals, USA) was brownish powder with wet sieve of 0.2 μm. Diesel oil (PETRONAS D2, PETRONAS Sdn. Bhd.) and CPO (FELCRA Nasaruddin Oil Palm Mill) were used as experimental oils.

2.2. Preparation of chemically treated Kapok and Bentonite clay

RKFs were cut into small pieces by using blender and were further chemically treated without sieving. For NaOH-treated kapok fibers (SKF), 5 g of RKF was soaked into 1% NaOH and placed in water bath for 48 h at 20 ± 2˚C. The fibers were removed and washed with distilled water containing 1% acetic acid to neutralize the excess NaOH and rinsed with distilled water. The treated fiber was then dried in an oven and placed in a desiccator before use.

The SMKF was prepared by using modified method [23]. RKF was placed in 400 mL of NaCl solution (0.5 wt%) and the pH was adjusted to pH 4.5. The sample was kept on a shaker at 700 rpm, 80˚C for 1 h. The treated-fiber was washed with distilled water until neutral pH and dried in an oven at 70˚C. Tetratethylorthosilicate (4 wt%), 2 mL sodium dodecyl benzene sulfonate (1.2 mmol/L), and distilled water made up to 500 mL were mixed and stirred for 1 h at room temperature. The treated-fibers were then added and again stirred for 20 min, followed by slow addition of ammonia solution (1.8 wt%) and further stirred for 1 h. The SMKFs were filtered and washed with methanol several times, and cured in an oven at 120˚C.

Five gram of Bentonite clay powder was treated with 50 mL of 5% HCl for 24 h, continuously stirred with magnetic stirrer. The treated clay was filtered and washed until the filtrate became neutral. Samples were dried at 70˚C in drying oven for 24 h and placed in desiccators.

2.3. Morphological and chemical characterization

The morphology of the Kapok and Bentonite clay was studied by using scanning electron microscopy (SEM, LEO 1430P VPSEM). Before SEM observation, all samples were fixed on aluminum stub sand coated with gold. The SEM images were recorded at 15 kV of incident source beam.

Infrared spectra were analyzed by using FTIR spectrophotometer (Perkin–Elmer, USA). Separately, Kapok fiber and Bentonite clay of 2 mg weight was mixed with 200 mg of KBr and compressed into a pellet by using a Punch press. Two scans were carried out at 500 until 3000/cm wavelength, at a resolution of 400/cm.

2.4. POME, CPO, and diesel sorption

2.4.1. Batch mode

The effect of packing density on fibers sorption capacity and retention time was based on ASTM standard method [25]. Loosed-form RKF, SKF, or SMKF was packed inside an 87.5 cm^3 wire-mesh basket at different packing densities of 0.02, 0.04, 0.06, and 0.08 g/cm^3 and immersed inside 400 mL filtered raw POME, CPO, and diesel oil bath in 500 mL glass beaker (Pyrex, Germany) for 30 min until it reached equilibrium. The test cells were then lifted and the tested oil was allowed to drip out. The transient weight of filtered raw POME, CPO, and diesel bath was recorded until constant weight. The experiments were carried out in triplicate. The sorption capacity was calculated as follows:

$$\text{Sorption capacity} = \frac{S_i - S_f}{S_A} \tag{1}$$

where S_i = weight of oil before sorption inside the beaker (g); S_f = weight of oil inside the beaker at 1 min dripping (g); S_A = dry weight of kapok (g).

The percentage of dynamic oil retention was calculated as follows:

$$\text{Dynamic oil retention (\%)} = \frac{W_i}{W_{t=1}} \times 100 \tag{2}$$

where $W_{t=1}$ = weight of oil bath (g) at 1 min dripping, W_i = weight of oil bath (g) at t min dripping, i = 2, 3, 4, …

2.4.2. Packed-column

For comparison of kapok and clay, POME and diesel filtrations under gravity were investigated using 10–20 mL syringe as a packed-column. Filter paper (Whatman No. 1) was placed inside the syringe to separate out clay powder from the POME and diesel. Dried raw and HCl-treated clays were ground to no specific sieve sizes before packing. The initial weight of the column at packing densities of 0.02, 0.04, 0.06, and 0.08 g/cm^3, and the final weight after POME and diesel filtration were recorded. Ten mL of POME or diesel oil was added to the column and left until constant weight for complete sorption after 4 h. The experimental procedures were repeated in triplicates and the results were calculated based on mean values.

For comparison of RKF, SKF, and SMKF, an acrylic column measuring 2 cm in diameter and 15 cm in length was used as a packed-column. Experimental setup was as reported before [21]. CPO and diesel were used as residual oil at initial concentration of 4000 mg/L in water, at pH 4–7, based on the oil and grease content in POME [4], and tested at upward flow rates of 0.5 and 1.5 L/h. The kapok fibers sorption performances were analyzed by analyzing the pH and the chemical oxygen demand (COD) changes before and after treatment.

2.5. Chemical analyses of POME

Biological oxygen demand (BOD) was analyzed using Standard Methods by HACH (HACH, USA). COD measurement was carried out using spectrophotometer DR 5000, according to 8000-Reactor Digestion Methods (HACH) [26]. Total organic carbon (TOC) and Total nitrogen (TN) were analyzed using TOC Analyzer (TOC-VCSH SHIMADZU, Japan). pH of POME was measured by using Mettler Toledo-320 pH probe. Removal efficiencies of BOD, COD, TN, and TOC were calculated using the following equation.

$$\text{Removal efficiency (\%)} = \frac{C_i - C_f}{C_i} \times 100 \tag{3}$$

where C_i and C_f, respectively, are the initial and final concentrations (mg/L).

3. Results and discussion

3.1. Morphological characterization

RKF has been shown as cylindrical networks, arranged in parallel fashion or across each other, giving fluffy and soft texture, while SKF is shown to have the tubular structure collapsed with total disappearance of air entrapment, turning into a hardened, dark color fibers [2]. Fig. 1(a) and (b) shows the morphology of RKF and SKF single fiber where the cylindrical structure of RKF can be clearly seen while that of SKF showed the collapse of hollow structure. The surface appearances of SMKF (Fig. 1(c)) were rough with subtle textures and wrinkles with whitish elements on the surface possibly due to the presence of silica nanoparticles. However, the overall internal hollow lumen network remained intact [26].

The bentonite clay morphology (Fig. 1(d) and (e)) suggests a multi-layer structure with inter-layer micro-spacing that could act as small channel for oil and water. However, HCl-treated clay showed a denser and more compact structure suggesting that the micro-spacing had collapsed. Al–Si interlinks in clay microstructure may react with the acid, forming the respective chlorides and then get dissolved [27].

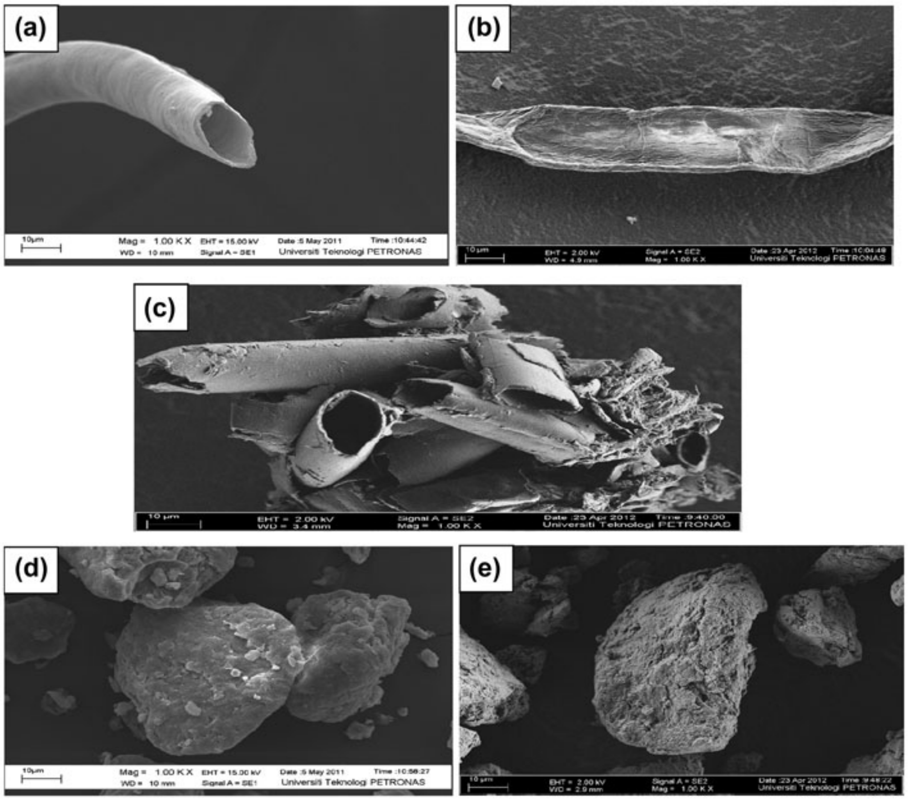

Fig. 1. SEM micrograph of (a) RKF, (b) SKF, (c) SMKF, (e) Raw bentonite, and (f) HCl-treated bentonite.

3.2. Chemical characterization

Fig. 2 shows the FTIR spectra of all tested kapok and clay materials, and Table 1 summarizes the important peaks of RKF, SKF, and SMKF. Comparing RKF with SKF (Fig. 2(a) and (b)), there is no detection of peak intensity at 1,726/cm for the carbonyl (C=O) stretching vibrations of the acetyl and uronic ester groups, suggesting the removal of pectin, hemicelluloses, or the ester linkage of the carboxylic group of ferulic and p-coumaric acids of lignin or hemicellulose in the raw fibers. Moreover, the vibration peak at 1,366/cm in RKF indicates the presence of bending vibration of C–H and C–O bond in the polysaccharide aromatic rings of lignin. The absence of these two peaks—1,726 and 1,366/cm, in SKF and SMKF suggest more exposed OH groups and CH_2, with the removal of lignin, hemicelluloses, and waxes [2,23,26]. The lignin and hemicellulose peaks at 1,366/cm in RKF, has appeared as 1,316/cm peak in SKF for OH deformation or CH_2 wagging to further support the suggestion on the exposed cellulose-lignin surface [2,23]. The asymmetric and symmetric stretching vibrations of CH_2 and CH_3 were observed at 2,913 and 2,889/cm, respectively, in RKF and SMKF. The peaks at 1,029–1,030/cm were the characteristic of anhydroglucose chains.

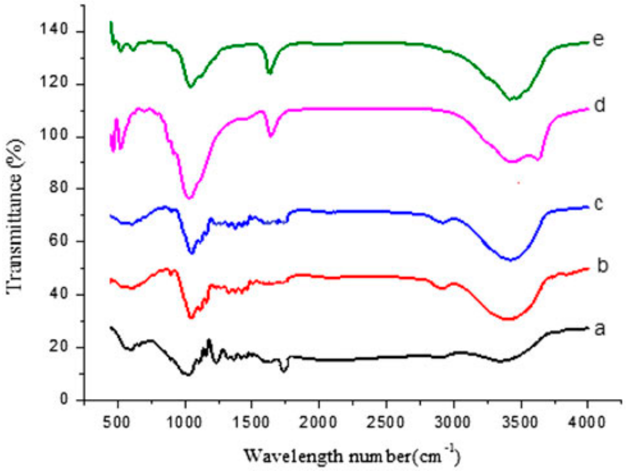

Fig. 2. FTIR spectra of (a) RKF, (b) SKF, (c) SMKF, (d) Raw bentonite, and (e) HCl-treated bentonite.

FTIR spectrum of SMKF (Fig. 2(c)) indicates the silica characteristic peak at 473/cm with the possibility of silica particles formed on the surface of kapok fiber. The bands at 1,098–1,123/cm in SMKF may suggest that the Si–O–Si particles overlapping with the C–O

Table 1
FTIR spectral peaks(/cm) of RKF, SKF, and SMK

RKF	SKF	SMKF	Bond type/Assignment [2,23,26,28]
3,340	3,332.8	3,312.5	OH stretching
2,913	2,906.6	2,889	CH stretching of CH_2 and CH_3 groups
1,726	–	–	Carbonyl C=O stretching of ester
1,643	–	–	H–O–H of absorbed water
1,604	1,590	1,598.9	C=C stretching
1,508	–	1,505.7	C–H bending of aromatic group
1,418	1,418.9	1,402.8	OH and CH_2 bending
1,366	–	–	C–H bond in –O(C=O)–CH_3 group
1,330	–	–	CH_3 bending or OH in-plane bending
–	1,316	–	OH deformation and/or CH_2 wagging
1,232	–	1,278.9	C–O stretching of acetyl group
1,155	1,158.8	1,123.8	C–O–C anti-symmetric bridge stretching in cellulose and hemicellulose
1,030	1,029	1,098	Anhydroglucose unit
669	–	–	β-glucosidic linkages between the sugar units in hemicelluloses and celluloses
601	579	–	OH out-of-plane bending and/or atmospheric CO_2 (deformation vibration) contamination-OH
–	–	473	Symmetric stretching vibration of Si–O–Si

stretching vibration of cellulose in fiber, with reduced OH numbers [26]. The outer surface of hollow cylindrical core and the lumen network has the protecting and stiff outer layer, or the cuticle [2,23,28]. The waxy layer and the air entrapped within the lumen network contribute towards kapok oleophilic property and tensile structure [2,28]. The alkaline treatment had caused the collapse of the hollow tube with the removal of the plant wax resulting in more hydrophilic surface exposed in SKF [2], while the silica particles deposition increases hydrophobicity of SMKF.

Raw and HCl-treated clay FTIR spectra in (Fig. 2(d) and (e)) shows peaks at 3,415 and 1,638/cm which describe the inter layer water. The peak intensity at 1,053/cm shows the twisting and deformation of Si–O–Si bond [27] whereas the peak intensity at 616/cm for HCl-treated clay corresponds to Si–O bonds. The reduction in peak intensity at 471 and 523/cm suggests the cleavage of Si–O–Al bond layer and Si–O–Mg (Fe) bonds. The Mg, Al, and Fe ions may be released from octahedron bentonite structure and SiO_2 is formed. Dehydration and dehydroxylation can shift the peak to higher intensity due to the shortening in bond length and compression of clay layer [29]. The bentonite treatment with HCl therefore causes the reorganization of aggregate, and the compactness of the structure reduces interlayer spaces as compared to raw bentonite.

3.3. Effects of packing density on POME and diesel sorption

Fig. 3 shows that by increasing kapok and bentonite density, the POME and diesel sorption capacity were increased. For filtration under gravity at 0.08 g/cm^3, SKF showed higher POME sorption of 82 g/g, but lower diesel sorption of 23 g/g than RKF. The packing density higher than 0.08/g/cm^3 showed lower amount of sorption (results not shown) as the lower interspatial distances and compactness within the kapok and bentonite packed-columns had prevented smooth flow of tested oils. At the initial stage of diesel oil sorption onto the kapok surface, the hydrophobic interactions and the Vander Waals forces could play important role between the oils and waxy surface coating [2]. However, the reduced waxy surface in SKF has improved the affinity for POME which has 95–96% water content [30,31].

With HCl-treated bentonite, POME sorption at 69 g/g was only slightly higher than diesel sorption of 60 g/g (Fig. 3(b)). The diesel sorption was two-fold higher than that obtained with kapok. Bentonite has layered structure which contributes towards porosity. Al-metal present in bentonite belongs to electron deficient group with electronic configuration ns^2, np^1 resulting in the co-ordination properties towards oxygen containing functional group (R-COOH, R-CO-R, R-OH, R-COOR) [29]. The HCl treatment increases the compactness and at high packing density, the compactness may reduce the inter-layer spacing and porosity with Al-layer in tight sandwich between two Si-layers. Bentonite packed-column may provide higher arrangement of Si–Al–Si layers and inter-layer distances that POME and diesel oil could flow through and held between the layers [32]. This study showed that both sorption methods are convenient, inexpensive, and green. Kapok fibers and bentonite clay could be structurally modified and derivatized

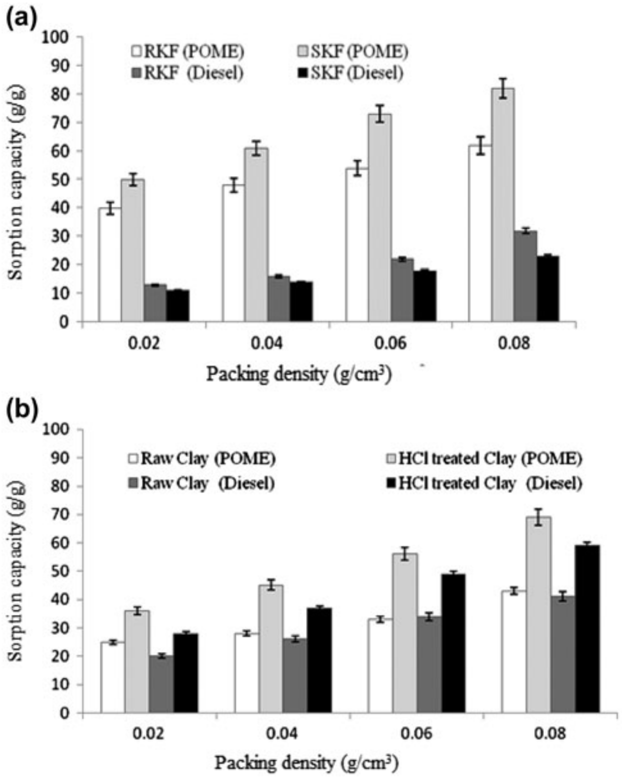

Fig. 3. Sorption capacities of (a) RKF/SKF, (b) raw/HCl-treated bentonite, for POME and diesel at room temperature and pressure in packed-column under gravity.

into potential products for environmental and health applications.

3.4. POME treatment

Table 2 shows the comparison of physicochemical characteristics of POME from various studies. Table 3 shows the physicochemical characterization of POME after the kapok and bentonite treatment. At 0.08 g/cm^3, the highest removal efficiency of COD, BOD, TOC, and TN was 98, 97, 94, and 78%, respectively, achieved with RKF. These were comparable to previously reported values [4]. With raw bentonite at 0.08 g/cm^3, the COD, BOD, TOC, and TN removal was 92, 93, 91, and 77%, respectively. Both SKF and HCl-treated bentonite achieved lower efficiency of POME treatment. The removal of waxy layer in the former and the compactness in the latter may not assist removal of organic compounds present in POME, but only filter out the solid residues under the influences of gravity. The functional groups present in RKF and raw bentonite, on the other hand, may be more effective to capture and filter the more complex organic chemical structures.

3.5. Comparison of RKF, SKF, and SMKF

Fig. 4 shows the POME and diesel sorption capacities of RKF, SKF, and SMKF in batch process. Increase in packing density increases the sorption capacities to around 10–20 g/g. The highest sorption capacity of CPO was achieved at 0.08 g/cm^3 with SMKF at 56.7 g/g, followed by RKF at 51.2 g/g and SKF at 49 g/g. The diesel sorption capacity was 33.7, 31.3, and 20.1 g/g, respectively, which were comparable to the values reported earlier [2]. SMKF however has exhibited higher sorption capacities than RKF, suggesting its potential as oil sorbent for oil floating on water to prevent the dispersion of spilled oil. The high oil sorption capacity could possibly due to the surface roughness within nanometer size magnitude with the presence of silica particles while retaining the lumen network to hold oil within the fiber assembly [28]. The opposite is true with regards to the dynamic oil retention (Fig. 5). More than 99% of diesel was retained regardless of packing materials, while 0.1 g/cm^3 packing retained more than 98% CPO regardless of the materials used. The diesel oil reached equilibrium faster than CPO due to the difference in the viscosity where the less viscous oil reaches the equilibrium faster [2,20].

The performance of RKF, SKF, and SMKF (results not shown) was also evaluated in a continuous upward flow of residual oil (4,000 mg/L CPO in water at pH 4.7) at 0.5 and 1.5 L/h into the assembly of 0.04, 0.06, and 0.08 g cm^3 densities, using a peristaltic pump. The COD before treatment was measured at 111 mg/L. After treatment, 99% of COD was removed and the pH of 6–6.9 was recorded in all effluent, regardless of materials, packing densities, and flow rates. The low levels of COD and near neutral pH suggest that the upward flow through a packed-column is effective in reducing the organic content. The low flow rate allows sufficient time for the oil to make contact with the surface of the kapok fiber and be absorbed into the fiber. The entrapment of the residual oil in the kapok fiber assembly could be observed, with clear effluent collected from the top of the column. The strategy was able to reduce the acid value in the oil emulsion, giving the pH value to almost neutral with almost complete COD removal.

The selection of packing materials will be determined not only by the scale and the economics consideration, but the types and nature of pollutants to be treated. Although both RKF and SMKF showed higher sorption for both CPO and diesel at 0.08 g/cm^3 in batch mode, and SKF had shown higher POME sorption for filtration under gravity at all densities, both RKF and raw bentonite had exhibited superiority in POME treatment. In fact, raw bentonite can be

Table 2
Physicochemical characteristics of raw POME

*Parameters	[1]	[31]	[33]	This study
pH	4.7	4.5–5.2	3.4–5.2	4.5–5
Chemical oxygen demand (COD)	50,000	61,994	16,000–100,000	51,000 ± 282
Biological oxygen demand (BOD)	25,000	27,766	10,000–44,000	27,000 ± 60
Total organic carbon (TOC)	5,370	–	–	5,580 ± 43
Total nitrogen (TN)	750	–	80–1,400	580 ± 2.3
Total suspended solids (TSS)	18,000	7,860	5,000–54,000	19,000 ± 255
Oil and grease	4,000	–	150–18,000	4,200 ± 28

*All units are in mg/L except for pH.

Table 3
Physicochemical characterization of POME after treatment with RKF/SKF and raw/HCl-treated bentonite

	*Removal efficiency (%)															
	RKF (g/cm^3)				SKF (g/cm^3)				Raw bentonite (g/cm^3)				HCl-treated bentonite (g/cm^3)			
Parameters	0.02	0.04	0.06	0.08	0.02	0.04	0.06	0.08	0.02	0.04	0.06	0.08	0.02	0.04	0.06	0.08
pH	7 ± 0.4	7.5 ± 0.2	7.6 ± 0.1	8 ± 0.7	7 ± 0.6	7.5 ± 1.0	7.6 ± 0.8	8 ± 0.5	6 ± 0.5	6.5 ± 0.7	7 ± 0.1	7.5 ± 0.4	5 ± 0.7	6 ± 0.9	7 ± 0.8	7.5 ± 1.6
BOD	93 ± 0.3	94 ± 0.6	95 ± 0.4	97 ± 0.5	76 ± 0.2	77 ± 0.5	78 ± 0.6	80 ± 0.3	90 ± 0.2	91 ± 0.2	92 ± 0.5	93 ± 0.3	78 ± 0.2	76 ± 0.3	77 ± 0.3	79 ± 1.0
COD	94 ± 0.4	95 ± 1.0	96 ± 0.3	98 ± 0.5	70 ± 0.4	72 ± 0.4	74 ± 0.7	76 ± 0.2	91 ± 0.7	92 ± 0.8	93 ± 0.2	92 ± 0.1	79 ± 0.3	71 ± 0.7	73 ± 0.4	75 ± 0.4
TOC	90 ± 0.6	91 ± 0.6	92 ± 0.1	94 ± 0.7	66 ± 0.5	67 ± 0.2	69 ± 2.3	70 ± 0.7	93 ± 0.5	94 ± 1.5	82 ± 0.2	91 ± 0.2	64 ± 1.2	64 ± 0.6	70 ± 0.6	71 ± 0.2
TN	74 ± 1.1	75 ± 0.6	76 ± 0.7	78 ± 0.7	74 ± 0.6	76 ± 0.8	79 ± 0.7	78 ± 0.0	72 ± 0.1	76 ± 0.1	78 ± 0.6	77 ± 0.1	79 ± 0.6	73 ± 0.2	80 ± 0.3	74 ± 0.6

*Removal efficiency (%) is for all parameters except for pH.

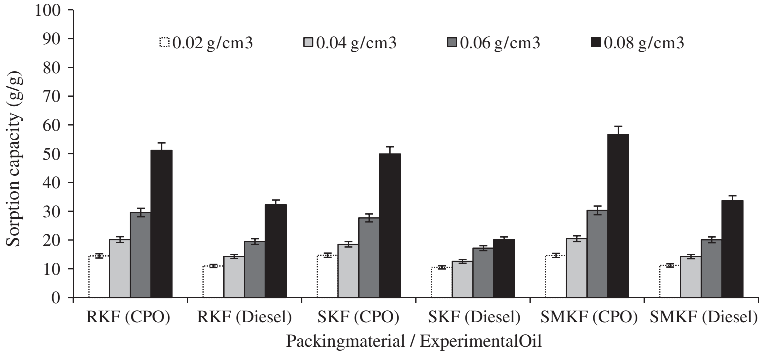

Fig. 4. Sorption capacities of RKF, SKF, and SMKF for CPO and diesel at room temperature and pressure in batch mode.

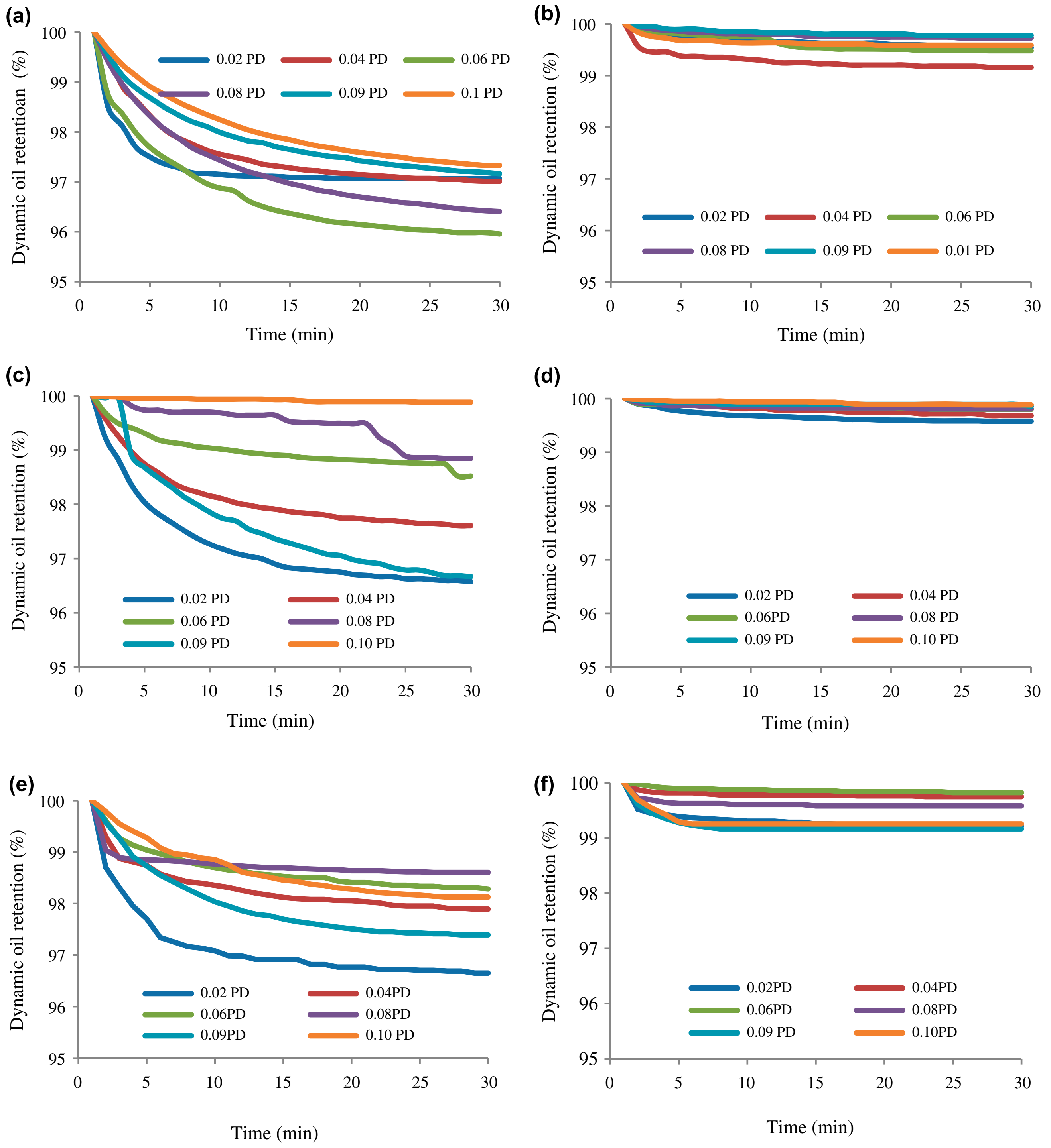

Fig. 5. Dynamic oil retention of ((a) and (b)) RKF, ((c) and (d)) SKF, ((e) and (f)) SMKF, respectively, for CPO and diesel, at room temperature and pressure in batch mode.

effective for POME and diesel sorption, and the HCl treatment could further enhance the sorption. The effluent treatment through kapok packed-column can be improved by upward continuous flow at low flow rate. Low packing density may result in higher oil sorption, while the higher packing density may improve oil retention. The more compact configuration of kapok assembly may make it harder for the oil to be absorbed but once absorbed, may find it harder to get out. The interactions based on van der Waals forces between the oils and the wax on the kapok fiber initiate the absorption mechanism of oil into the hollow lumen. The alkalization changes the fine structure of kapok fiber where the hollow lumen to store the oils disappears partially or completely with the collapse of the tubular structure. The higher oil sorption capacity of SMKF as compared to RKF may prove that the incorporation of the silica nanoparticles on the surface of the fiber, not only results in rougher surface, but also reduces the surface energy to enhance the oil affinity through capillary effect [23,28].

4. Conclusions

Kapok fibers, bentonite clays, and the modified structures were compared for their effectiveness on oil sorption and POME treatment. SKF showed the collapse of hollow structure, while the HCl-treated bentonite clay became denser and more compact. SMKF however retained the lumen network structure with rough surface with the deposition of silica nanoparticles. FTIR spectra suggested that the kapok wax functional group at 1,726/cm was completely removed upon NaOH treatment, while SMKF showed the overlapping peaks at 1,098–1,123/cm attributable to Si–O–Si bands, incorporated into cellulosic fibers. The reduction in peak intensity at 471 and 523/cm upon HCl treatment of bentonite suggests the cleavage of Si–O–Al bond layer and Si–O–Mg (Fe) bonds. SKF showed high POME sorption at 82 g/g, but lower diesel sorption at 23 g/g, while HCl-treated clay had both high POME sorption at 69 g/g and diesel at 60 g/g. POME treatment with RKF at 0.08 g/cm^3 achieved the highest removal efficiency of COD, BOD, TOC, and TN at 98, 97, 94, and 78%, respectively. SMKF achieved the highest CPO sorption at 56.7 g/g but the effluent treatment can be improved via upward continuous flow at low flow rate, regardless of kapok packing material.

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