The oil-absorbing properties of kapok fibre – a commentary

Check Shyong Quek 9, Norzita Ngadi 9 and Muhammad Abbas Ahmad Zaini a,b

aSchool of Chemical & Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia Johor Bahru, Malaysia; bCentre of Lipids Engineering & Applied Research, Ibnu-Sina Institute for Scientific & Industrial Research, Universiti Teknologi Malaysia Johor Bahru, Malaysia

ABSTRACT
This paper highlights the oil absorbing properties of natural and modified kapok fibres. The discussion is centred on the waxy layer and hydrophobic nature that translate the excellent oil retention performance of kapok fibre. A stirring had shown that the oil absorption by natural kapok could be greatly enhanced to over 200 g/g. For dispersed oil in wastewater, a depth filtering system with rotatable and taper-shaped filter column with kapok fibre was reported to recover 32.3 g/g of the oils. Several modifications to boost the performance of kapok fibre as in acetylation, solvent treatment, fibre hybridization, assembly structure and design, etc. are identified and discussed to shed some light into future prospective in oil and emulsion removal. So far, all the studies have shown that kapok fibre and its modified counterparts are promising green oil absorbents.

1. Natural kapok fibre – an overview
Kapok fibre is a natural product obtained from the fruits of silk-cotton tree. It exhibits a high oil absorption capacity owing to its high holowness and natural hydrophobic nature [1,11,12,14,15,24]. The hydrophobic–oleophilic character of the kapok fiber assembly renders a unique character for oil retention. The mechanism of oil absorption is generally attributed to the hollow lumen and surface wax of kapok fiber [29]. Oil may be retained in the internal voids of fibre trough van der Waals forces and hydrophobic interaction afforded by the wax layer [5]. The smooth wax layer also facilitates the diffusion of oil towards the internal lumen of fibre. In addition, the intermolecular forces responsible for cohesion and adhesion contribute to the capillary action especially for the large lumen. Thus, the removal mechanisms would likely include hydrophobic interaction, van der Waals forces, diffusion and capillary action. The optimum absorption capacity of raw kapok fibre by immersion for diesel oil (low viscosity) was found to be 30 g/g, vegetable oil of medium viscosity at 40 g/g and lubricating oil of high viscosity at 50 g/g [13]. For other non-polar organic solvents, they would have similar chemical properties and so the mechanisms for absorption would be the same although the performance might be different.

The surface of kapok fibre is smooth with a layer of wax, and the cross-section is oval to round with a large lumen and thin wall (ca. 8–10 µm in diameter of fibre, and ca. 0.8–1.0 µm in cell wall thickness) [6]. The smooth wax layer is responsible for its hydrophobicity, and the large lumen greatly contributes to its sorption capacity [17]. It is this hollow structure which separates kapok fibre from other natural fibres, endowing it a porosity of more than 80% [28]. The FTIR spectrum of kapok fibre has a peak at about 2900 cm−1 that could be assigned to the asymmetric and symmetric aliphatic CH2 and CH3 stretching vibrations [17]. This is linked to the presence of plant wax, which typically consists of long-chain alkanes, aldehydes, fatty acids, esters, ketones and alcohols [16].

The contact angle of kapok fibre was observed to be 138.6° with water as reported elsewhere [24,17]. The value is more than adequate to show that kapok fibre is very hydrophobic attributed to the wax layer. Nevertheless, the contact angle may vary according to the place of origin. For instance, Dong et al. [8] reported a contact angle of 151.2° with water which demonstrates the superhydrophobicity of kapok fibre from Java, Indonesia. XRD spectrum of kapok fibre shows that the crystallinity and amorphous region present in kapok fibre are 63.2% and 36.8%, respectively [17]. The high crystallinity of kapok fibre could be disrupted to form more amorphous region for oil sorption by simple treatment in water for a period of time. Wang et al. [24] reported a better sorption performance of water-treated kapok fibre although the change in surface morphology is minimal. An increase in amorphous region...
could also be brought about by the stirring method that could dramatically increase the oil sorption to as high as 200 times the amount of sorbent used [18]. The surface area of kapok fibre from BET analysis is 79.8 m²/g, while the pore volume at a relative pressure of 0.95 is 0.0101 dm³/kg [17]. The isotherm follows a type III without the knee, hence there is no detectable monolayer formation. It signifies that kapok fibre is a macroporous material as a result of weak interactions between nitrogen molecules and surface texture. Surface area can be increased by coating [26,23]. More surface area increases the interaction probabilities between oil molecules and kapok fibre. The elements in kapok fibre are 0.338% N, 45.2% C, 6.26% H, 0.105% S and 48.1% O [17]. It is equivalent to the molecular formula of cellulose, (C₆H₁₀O₅)ₙ. It signifies that kapok fibre is mainly composed of cellulose. Although cellulose is hydrophilic, kapok fibre is known for its hydrophobic character due to the surface wax [1,6].

2. Oil absorbing potentials

The application of kapok fibre in water pollution control is an attractive alternative from the viewpoints of economic and sustainability. Kapok fibre is inexpensive and abundantly available especially in tropical countries worldwide. The natural hollow fibre demonstrates fast oil absorption rate, high oil absorption capacity (oleophilicity) and low water uptake [1,11,14,15,24]. It is lightweight, which makes it easy for transportation, and possesses excellent buoyancy to facilitate retrieval. The reusability of the material can be up to 15 cycles [1,14,15], that contributes to environmental sustainability. Hence, its application to control water pollution due to oil spills is indeed a sustainable approach.

Quek et al. [18] reported that 1 g of the kapok fibre can absorb 200 g of refined palm oil used for cooking. Attempts to modify the fibre surface with attention to boost the oil absorption also have been reported in literature. It was reported that an acetylated kapok fibre exhibits a better oil absorption capacity for diesel and soybean oil [25]. Wang et al. [24] also attempted to alter the surface wax, hollow structure and crystallinity of the fiber wall matrix by solvent treatment using HCl, NaOH and NaClO₂. In a different work, kapok surface was coated with oleophilic polymer using polybutyl methacrylate and polystyrene through solution-immersion step [26]. In general, these modification strategies can offer a better performance of oil sorption ability than that of the pristine one. Therefore, modifications to improve or increase the hydrophobicity or oleophilicity, pore diffusion, capillary action in the lumen, amorphous regions, porosity and surface area would be reasonable in attempting to improve the oil absorption capacity. The improvement of oil absorption property of kapok fibre instigates more promising opportunities for the removal of oil, emulsion and other organic contaminants. Nevertheless, the economic, environment and sustainability factors should also be taken into consideration while aiming for a high oil sorption capacity through surface alterations of kapok fibre [3].

3. Surface modification and oil absorption

Kapok fibre has a hollow structure and smooth surface due to the coverage of plant wax with small orifice opening. According to Wang et al. [25], upon acetylation, kapok fibre exhibits a tiny groove on the surface with open lumen orifice. Accordingly, the smooth fibre surface may not in favour of oil adhesion as compared with the rough surface. Also, the acetylation does not cause severe collapse of the hollow lumen that is useful for oil retention by kapok fibre assembly [25].

The NaOH-treated kapok fibre displays a rough surface with wrinkles and grooves, indicating the removal of waxy layer and exposing the hydrophilic surface. The strong alkali can produce severe damage to the structure of kapok fibre, causing the collapse of hollow tube, and forming fine fibrils, shallow pit and broken hole. Generally, the coarse surface would increase the external area and improve the interaction probabilities and adhesion of oil particles. Consequently, they could easily enter the inner lumen, ensuring high oil absorption [24]. Similarly, Wang et al. [26] reported the undulant and coarse surface of polybutylmeth acrylate- and polystyrene-coated kapok fibre samples, signifying the deposition of polymers with considerable roughness on the external lumen. It can positively affect the retention of oil for a higher capacity.

Diesel and soybean oil were employed to evaluate the oil absorption capacity of acetylated kapok fibre [25]. Oil recovery from kapok adsorbent was determined by n-hexane extraction. In the study, the oil absorption capacity is in the order of, kapok fibre (diesel, 30.5 g/g; soybean oil, 47.4 g/g) < acetylated kapok fibre (diesel, 36.7 g/g; soybean oil, 52.2 g/g). The acetylation of kapok fibre makes it easier for the oil to be retained owing to a stronger intermolecular interaction between oil particles and acetyl surface groups on the fiber, and facilitates the diffusion through fiber wall to hollow lumen. The non-polar nature of acetyl groups renders the hydrophobic surface of kapok fibre. Consequently, oil is preferentially absorbed, with minimum amount of water held in the fiber. The increase in surface roughness after acetylation also leads to a better oil-locking capability. In addition, a more viscous soybean oil (67.12 mm²/s) is absorbed in a greater extent than diesel (4.15 mm²/s) because of a stronger intermolecular force to entrap oil particles in the fibre matrix [10].

The chloroform absorption capacity of kapok fibre is 40.2 g/g. Upon treatment with HCl, the capacity increases to 51.8 g/g. Similarly, NaClO₂-treated kapok
fibre displays a higher chloroform absorption capacity, with an increase amount of 30.0% [24]. The treatment using solvents can increase the surface roughness for a better oil absorption. Generally, the affinity between the hydrophobic waxy layer and oil provides small contact angle and surface tension for the penetration of oil into the lumen texture of kapok fibre [1]. The NaClO₂ treatment also enhances the amorphous region of lignocellulose, which aids the penetration of solvent. Hence, the molecular arrangement of the polymer matrix contributes to the absorption [5]. Yet, the diffusion of solvent into the fibre matrix is permissible whenever the lignocellulose chains are not too dense. In addition, the interstices of NaClO₂-treated kapok fibre can afford space for the removal of oil with low viscosity. The changes within the fibre texture stabilize the liquid bridge of kapok fibre, compensating the loss of oil absorption due to the removal of surface wax. Consequently, the oil absorption can be maintained at high level. For comparison, the waxy coating shows a more prominent attributes in the absorption of hydraulic oil, engine oil and diesel [1,14]. As it is difficult for oil with high viscosity to penetrate into the smooth fibre matrix, this may reveal that the small surface roughness becomes less relevant in the oil absorption as compared with surface wax. In the NaClO₂ treatment, however, the removal of plant wax does not affect the capacity of oil absorption [24].

According to Wang et al. [26], oil sorption capacity of kapok fibre in the absence of water for paraffin oil is 54.3 g/g. The absorption capacities of polybutylmethacrylate- and polystyrene-coated samples are 80.3 and 83.3 g/g, respectively. The surface coating using polymer is effective to yield a better oil absorption. The oil particles are adhered to the fiber surface via the van der Waals forces and intermolecular interaction [7]. The chemical compatibility between the surface coating and oil makes it easier for the oil to penetrate into the lumen and interstices [27]. Furthermore, the roughened surface after the treatment could increase the oil contacting area as well as to prevent the stripping of absorbed oil.

Dong et al. [8] demonstrated that chloroform-treated kapok fibre displays an enhanced removal performance for diesel, cooking oil, used motor oil and motor oil despite the insignificant change in oil absorbencies as compared with the raw fibre. The very low surface energy and extreme hydrophobicity of the treated kapok fibre made the oils highly penetrable into the lumen and inter-fibre pores, resulting an increased rate of absorption [1]. The chloroform treatment caused the smooth surface of the kapok fibres to be greatly roughened, with densely vertical grooves that provided more accessible surface and more driving force for oil sorption through the fibre assembly.

Kapok fibre was compared with structurally modified NaOH-treated kapok fibre and HCl-treated bentonite for oils sorption and palm oil mill effluent treatment [2]. Raw kapok fibre showed a removal of palm oil mill effluent at 82 g/g, and diesel absorption at 23 g/g. For HCl-treated bentonite, the capacities are 69 and 60 g/g, respectively. In batch mode, NaOH-treated kapok shows the oil absorption capacity of 56.7 g/g for crude palm oil and 33.7 g/g for diesel. The kapok sorbent derivatives exhibit excellent performance and are suitable for crude palm oil and diesel sorption, and for palm oil mill effluent treatment.

A recent study reported several materials and geometrical factors such as fibre type, fibre diameter, fibre surface area, porosity and blend proportion of fibres in a series of thermally-bonded, hybrid and oil-sorbent non-wovens constructed from binary and tertiary mixing of cotton, kapok, and three varieties of milkweed fibres (Asclepias Syriaca, Calotropis Procera and Calotropis Gigantea) and polypropylene fibres for oil sorption properties [19]. Calotropis Procera and Calotropis Gigantea fibres offered higher sorption than kapok and common milkweed (Asclepias Syriaca). The porosity and fibre surface area played important roles in determining the oil absorption performance [1,11,12,14,15,24]. Excellent and selective oil sorption behaviours of milkweed fibres, namely Calotropis Procera and Calotropis Gigantea blended with cotton and polypropylene fibres are documented. The maximum oil sorption capacities of the thermally-bonded nonwoven absorbent are 40.16 g/g for high-density oil and 23.00 g/g for diesel oil.

An attempt has been made to produce kapok/polypropylene needle-punched nonwoven for oil spill clean-up process [20]. The hydrophobic-oleophilic kapok fibre nonwoven has been characterized for its oil absorption and retention. The maximum oil absorption was found to be 40.80 and 29.0 g/g for high-density oil and diesel oil, respectively which is higher than the commercial polypropylene-based oil sorbent pads. Also, its retention value ranges from 0.88–1.00, making it a good substitute for synthetic sorbent. The burning test of the oil absorbed samples ended up with only less amount of ash residue confirming its suitability and eco-friendly nature.

Thilagavathi et al. [21] also investigated the oil sorption capacity of nettle fibrous assembly and needle-punched nonwoven structures of 100% nettle and a 50:50 nettle/kapok blend. The porosity of fibrous assembly greatly affected the oil sorption capacity where the presence of kapok fibre in the blended absorbent increased the oil sorption capacity and decreased the water absorption than that of 100% nettle nonwoven. This is due to the natural hydrophobic property of kapok. However, 100% kapok could not be structured into needle-punched nonwoven, and hence it has been blended with nettle. A 50/50 nettle/kapok blend structure exhibits maximum oil sorption capacity of 28.5 g/g and 22.5 g/g for high-density oil and diesel oil, respectively, that is better.
than the commercial polypropylene-based nonwoven absorbent. The presence of kapok increased the absorption capacity by 13–18% when compared to 100% nettle nonwoven.

A study by Wang et al. [22] using magnetically superhydrophobic oil sorbent was prepared by direct immobilization of Fe₃O₄ nanoparticles on the surface of kapok fibre and subsequent hydrophobic modification. The absorbent demonstrated excellent superhydrophobicity and magnetic responsivity. It exhibits high separation efficiency for oil/water mixtures and can quickly absorb floating oils on water surface via magnetic driving mechanism. Compared with raw fibre, the oil sorption capacities of the magnetic absorbent fibre for n-hexane, toluene, chloroform, paraffin oil, gasoline and diesel can increase to 70.8%, 58.5%, 96.1%, 23%, 37.3%, and 30.5%, respectively. Furthermore, the fibres can be used to continuously separate a large quantity of oil contaminants from water surface by means of vacuum pump. Importantly, the water contact angle still can reach above 143° with water after being repeatedly used several times and immersed in various oils under harsh water environments for long period of time, implying excellent recyclability and chemical durability in the oil sorption. The findings suggest that the magnetically superhydrophobic kapok fibre has the prospect of potential applications in the removal and recovery of spilled oil contaminants.

A depth filtration system with rotatable and tapered-shaped filter column with filter made of kapok fibre is designed to highly remove and recover oil from wastewater [9]. The filter is prepared by air-lying-bonding method. The oil removed is then recovered from the oil-loaded filter by rotating the filter column, and the filter can be reused for subsequent operation. The system demonstrated extremely high oil/water separation in which oil is completely retained by the filter at the first 20–100 min at a flow rate of 560 mL/min using 11,500–13,150 mg/L vegetable oil or diesel-contaminated water. A total of 47.6–176 L clean water is able to be collected after four cycles of filtration and centrifugation. The wetted filter with oil capacity of 32.31 g/g is centrifuged to recover 80–91% of the oils. The sorption capacity appeared to become constant to four cycles of filtration before an apparent drop because of unrecoverable residual oil (2–5 g/g). The separation process depends on filter packing density and the properties of model oils, while the decrease of flow rate favours the filtration of low viscous oil.

A kind of superhydrophobic kapok fibre for separating oil/water mixtures and oil-in-water emulsion was successfully fabricated by Wang et al. [23]. The facile preparation procedure includes uniform growth of ZnO nanoneedles on the surface of kapok fibre and shows high absorption capacities up to 40.8–70 times its own weight for a variety of oils and organic solvents, rapid oil sorption rate, and selective sorption to oils in water. Furthermore, the superhydrophobic fibre assembly connected to a vacuum system is able to continuously remove and collect a large amount of oils within a short time. More importantly, the obtained fibre is capable of separating oil-in-water emulsion with high separation efficiency (86.4%). The coated fibre can still maintain its hydrophobicity under harsh conditions (acidic, alkaline, salty solutions, oils and hot water). Furthermore, the absorbent is low cost and environmentally-friendly, which makes it a promising candidate to be used in effective oil-spill cleanups and water purification.

4. Discussion

It is generally perceived that surface hydrophobicity is important in determining the oil absorption capacity. However, the absence of hydrophobic waxy layer as in the treatment of kapok fibre with NaClO₃ exposes the finer fibrils that are somewhat hydrophilic, yields a significant improvement in oil absorption [24]. Despite the fact that the smooth waxy surface is favourable for the rate of oil absorption as it brings about small contact angle and surface tension [1], it is not favourable for the adhesion of oil. The oil absorption capacity is mainly affected by the effective space and hollow lumen network inside the kapok fibre assembly.

The oil retention capability of kapok fibre is an important factor that determines the amount of oil that could be lost during the scooping of the absorbent from the liquid media or along the way before the oil is being deliberately extracted from the absorbent. Thus, removing the smooth surface wax and exposing the fibrils increases the surface roughness which directly increases the surface area for intimate contact between oil particles and kapok fibre, and would definitely improve the oil adhesion and retention properties [4].

The coated kapok fibre gives the best improvement due to coarser and more undulant surface. The new surface texture of fibre increases not only the surface area, but also improves the adhesion of oil. It in turns enhances the oil retention, hence offering a high oil absorption capacity. Likewise, the solvent-treated kapok fibre offers the coarse surface which improves the adhesion of fluid to enable the oil particles to penetrate into the inner surface of lumen. However, the degree of surface roughness of solvent-treated samples is not as great as the coated kapok fibre.

Furthermore, it is also interesting to note that the modified kapok fibre samples demonstrate a preference for high viscosity oil. Kapok fibre displays a higher oil absorption capacity for paraffin oil and considering that the capacity is affected by the oil viscosity [26]. The viscosity of gasoline, diesel and soybean oil are 0.7, 4.15, 67.12 mm²/s, respectively [10], while that of paraffin oil is about 80 mm²/s. This could be attributed...
to the fact that a high oil viscosity can improve the adherence of oil onto the rough surface of kapok fibre. As the density of the oil is usually somewhat proportional to the viscosity, kapok fibre favours oils of higher density. Notwithstanding that, acetylation is also useful in improving the hydrophobicity of kapok fibre for a preferential oil absorption over that of water (floating oil). Extraction of oil from absorbent would not be practical if large volume of water is being absorbed as well.

Despite the development of absorbents derived from modified natural kapok fibre, the preparation of oil absorbent with excellent stability and recyclability through cheap and simple method, and most importantly, without the use of hazardous materials is highly desirable. The superhydrophobic/superoleophilic kapok fibre for separating oil/water mixtures and oil-in-water emulsions fabricated by Wang et al. [23] is a promising candidate to be used in effective oil-spill cleanups and water purification but the ZnO used is a hazardous substance. Likewise, a substance such as chloroform [8] is not only hazardous but a probable carcinogen. For oil/water mixtures, excellent results of oil removal are obtained by utilizing the mechanical method [18], filtration system [9] and hybrid assembly [19,20,21] without even having to modify the kapok fibre. Therefore, taking everything into consideration which includes the cost, modification might not be feasible when the performance is not greatly enhanced. Nevertheless, for academic reasons, there is a need for such modifications to evaluate the performance and to ascertain the viability.

5. Conclusion and way forward

Kapok fibre is an excellent oil absorbent due to its waxy layer and hydrophobic character. Recent studies demonstrate the modification strategies with aim to enhance the oil removal capacity. There is a trade-off in certain modification whereby the hydrophobic waxy layer is eliminated, hence compromising the oil absorption. Nevertheless, this can be compensated by the rough surface of fibre to improve the interaction probabilities with oil particles to enhance the oil absorption. The surface modification reveals a better absorption capacity for high viscosity of oil. Hence, to accommodate a wide range of oil viscosity, a hybrid modification of kapok fibre would be a promising direction of way forward. For example, the acetylation of kapok fibre followed by coating with a hydrophobic-oleophilic polymer. It is imperative to sustain the hydrophobic character in order to minimize the uptake of water, especially in the case of oil spill clean-up. Similarly, a systematic study focusing on the removal of dispersed oil (oil in water emulsion) by kapok fibre can be performed in solving the related wastewater issues, and to enrich the body of existing knowledge.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Check Shyong Quek http://orcid.org/0000-0003-0412-5487
Norzita Ngadi http://orcid.org/0000-0002-3480-6016

References

[1] Abdullah MA, Rahmah AU, Man Z. Physicochemical and sorption characteristics of Malaysian Ceiba pentandra (L.) Gaertn. as a natural oil sorbent. J. Hazard. Mater. 2010;177:683–691.
[2] Abdullah MA, Afzaal M, Ismail Z, et al. Comparative study on structural modification of Ceiba pentandra for oil sorption and palm oil mill effluent treatment. Desalin Water Treat. 2014;54(11):3044–3053.
[3] Al-Majed AA, Adebayo AR, Hossain ME. A sustainable approach to controlling oil spills. J. Environ. Manage. 2012;113:213–227.
[4] Annunziato TR, Sydenstricker THD, Amico SC. Experimental investigation of various vegetable fibers as sorbent materials for oil spill. Mar. Pollut. Bull. 2005;50:1340–1346.
[5] Choi HM, Moreau JP. Oil spill sorption behavior of various sorbents studied by sorption capacity measurement and environmental scanning microscope. Microsc Res Tech. 1993;25(6):447–455.
[6] Chung B, Cho J, Lee M, et al. Adsorption of heavy metal ions onto chemically oxidized Ceiba pentandra (L.) Gaertn. (kapok) fibers. J Appl Biol Chem. 2008;51(1):28–35.
[7] Deschamps G, Caruel H, Borredon ME, et al. Oil removal from water by selective sorption on hydrophobic cotton fibers. 1. Study of sorption properties and comparison with other cotton fiber-based sorbents. Environ. Sci. Technol. 2003;37:1013–1015.
[8] Dong T, Wang F, Xu G. Sorption kinetics and mechanism of various oils into kapok assembly. Marine Pollution Bull. 2015;91(1):230–237.
[9] Dong T, Cao S, Xu G. Highly efficient and recyclable depth filtering system using structured kapok filters for oil removal and recovery from wastewater. J Hazard Mater. 2017;321:859–867.
[10] Esteban B, Riba J-R, Baquero G, et al. (2012). Temperature dependence of density and viscosity of vegetable oils. Escola d’Enginyeria d’Igualada (EEI-Escola d’Adoberia), Catalunya, Spain.
[11] Huang XF, Lim TT. Performance and mechanism of hydrophobic–oleophilic kapok filter for oil/water separation. Desalination. 2006;190:295–307.
[12] Hubbe MA, Rojas OJ, Fingas M, et al. Cellulose substrates for removal of pollutants from aqueous systems: a review. 3. Spilled oil and emulsified organic liquids. BioResources. 2013;8(2):3038–3097.
[13] Kartina AKS, Suhaila MHN. (2012). Oil sorption capacity of kapok fiber. IEEE Colloquium on Humanities, Science and Engineering (CHUSER).
[14] Lim TT, Huang XF. Evaluation of hydrophobicity/oleophilicity of kapok and its performance in oily water filtration: comparison of raw and solvent-treated fibers. Ind. Crops Prod. 2007;26:125–134.
[15] Lim TT, Huang XF. Evaluation of kapok Ceiba pentandra (L.) Gaertn. as a natural hollow hydrophobic–oleophilic
fibrous sorbent for oil spill cleanup. Chemosphere. 2007;66:955–963.

[16] Patel S, Nelson DR, Gibbs AG. Chemical and physical analyses of wax ester properties. J Insect Sci. 2001;1:4.

[17] Quek C, Ngadi N, Zaini MAA. Kinetics and thermodynamics of dispersed oil sorption by kapok fiber. Ecol Chem Eng S. 2019;26(4):759–772.

[18] Quek C, Ngadi N, Zaini MAA, et al. Stirring enhances removal of oil by kapok fiber. Appl Mech Mater. 2015; 695:69–72.

[19] Thilagavathi G, Praba Karan C, Das D. Oil sorption and retention capacities of thermally-bonded hybrid non-wovens prepared from cotton, kapok, milkweed and polypropylene fibers. J Environ Manage. 2018;219:340–349.

[20] Thilagavathi G, Praba Karan C, Thenmozhi R. Development and investigations of kapok fiber based needle punched nonwoven as eco-friendly oil sorbent. J Nat Fibres. 2020;17(1):18–27.

[21] Thilagavathi G, Praba Karan C. Investigations on oil sorption capacity of nettle fibrous assembly and 100% nettle and nettle/kapok blended needle-punched nonwovens. J Ind Text. 2018;49(4):415–430.

[22] Wang J, Geng G, Liu X, et al. Magnetically superhydrophobic kapok fiber for selective sorption and continuous separation of oil from water. Chem Eng Res Des. 2016;115:122–130.

[23] Wang J, Wang A, Wang W. Robustly superhydrophobic/superooleophilic kapok fiber with ZnO nanoneedles coating: highly efficient separation of oil layer in water and capture of oil droplets in oil-in-water emulsions. Ind Crops Prod. 2017;108:303–311.

[24] Wang JT, Zheng YA, Wang AQ. Effect of kapok fiber treated with various solvents on oil absorbency. Ind. Crops Prod. 2012;40:178–184.

[25] Wang JT, Zheng YA, Wang AQ. Investigation of acetylated kapok fibers on the sorption of oil in water. J. Environ. Sci. 2013;25(2):246–253.

[26] Wang JT, Zheng YA, Wang AQ. Coated kapok fiber for removal of spilled oil. Mar Pollut Bull. 2013;69(1-2):91–96.

[27] Wu J, Wang N, Wang L, et al. Electrosprun porous structure fibrous film with high oil adsorption capacity. ACS Appl Mater Interfaces. 2012;4:3207–3212.

[28] Xiang H, Wang D, Liu H, et al. Investigation on sound absorption properties of kapok fibers. Chinese J Polym Sci. 2008;31(3):521–529.

[29] Zheng Y, Wang J, Zhu Y, et al. Research and application of kapok fiber as an absorbing material: a mini review. J Environ Sci. 2015;27:21–32.