Oil Sorption Behavior of Natural Kapok Fiber as an Alternative to Commercial Synthetic Fiber

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ABSTRACT Oil contamination is attracting the world's attention because it is the major challenge for most river pollution. Considering that as a serious problem, this research attempted to study the oil sorption behavior of natural raw kapok fiber (RKF); which is renewable and inexpensive, as compared to commercial synthetic fiber such as polypropylene fiber. The medium of oil that is used to test the oil sorption fibers' behavior is waste cooking oil (WCO) and used engine oil (UEO). The oil sorption capacity of RKF for WCO and UEO is 50.17 g/g and 49.51 g/g, whereas polypropylene fiber has a lower oil sorption capacity of 34.34 g/g and 30.01g/g, respectively. Interestingly, the efficiency of RKF's oil sorption capacity was further enhanced by NaOH treatment. In this study, the optimum concentration of NaOH treatment on kapok fiber was determined at 0.02M; where the oil sorption capacity of treated kapok fiber (TKF) was further increased to 77.94 g/g for WCO and 62.63 g/g for UEO. In terms of oil recovery from the oil-water mixture, TKF has recovered 98% of WCO at both lowest (0.5%v/v) and highest (2.5%v/v) concentrations of WCO-water mixture used; while RKF has recovered 84% of WCO at 0.5% v/v WCO-water mixture; and 95% of WCO at 2.5% v/v WCO-water mixture. At 0.5% v/v of the UEO-water mixture, TKF and RKF were able to recover 88% and 84% UEO. When the concentration of the UEO-water mixture was increased to 2.5% v/v, both the TKF and RKF achieved high recovery efficiencies of 100% and 99% for UEO, respectively. TKF is proven to have better reusability than the RKF due to its lower percentage reduction of oil sorption capacity after six cycles, TKF has only 22.69% compared to RKF's (30.79%) for WCO, and 25.81% compared to RKF's (40.87%) for UEO.

KEYWORDS: Kapok fiber; treated-kapok fiber; polypropylene; oil sorption and reusability; organic sorbent
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INTRODUCTION

Water pollution is a major problem in the global environment including Malaysia. Oil spill contamination had become the main source of water pollutants (Afroz & Rahman, 2017); and it comes from a variety of sources such as crude oil production, oil refinery, petrochemical industry, and restaurants (Olga *et al.*, 2014). Hence, an interest in utilizing environmentally friendly and economical methods to get rid of these contaminations has increased. Dispersants, skimmers, oil booms, and sorbents are some common methods that had been used to remove oil from water (Wang *et al.*, 2013). Yet, oil sorbent clean-up is still the most efficient method and favorable (Olga *et al.*, 2014).

Oil sorption by sorbents has been identified as one of the most efficient and cost-effective methods due to its high clean-up efficiency (Wang *et al.*, 2013). It is ideal to use sorbents for oil spill clean-up because the high buoyancy property makes it easier to remove the oil (Ge *et al.*, 2016). There are various types of oil sorbent materials available such as inorganic minerals, organic natural, and synthetic fiber. The most important factor for an effective oil sorbent material is its water-repelling (hydrophobic) and oil attracting (oleophilic) behaviors (Semilin *et al.*, 2020); which has a stronger affinity for oils compared to water (Balan *et al.*, 2020). Other characteristics that make an ideal oil sorbent material are high sorption capacity, reusability, and recovery of oil (Rengasamy *et al.*, 2011). Researchers have found that kapok fiber demonstrates hydrophobic and oleophilic properties, high sorption capacity, oil recovery capability, retention capacity, and high reusability (Abdullah *et al.*, 2010), making kapok fiber a good oil sorbent and suitable sorbent for oil spill clean-up.

Three objectives were achieved and emphasized in this present study; first, to evaluate the oil sorption capacity of kapok fiber; second, to investigate the effect of NaOH treatment on the oil sorption capacity of kapok fiber; and third, to determine the reusability of kapok fibers. In the future, kapok fiber can be potentially applied as a filter product to separate oil from water bodies.

METHODOLOGY

Oil Sorption Capacity Test for Pure Oil Medium

The samples of raw kapok and polypropylene fiber (Table 1) are immersed 15 minutes in two pure oils; (1) 100% used engine oil and; (2) 100% waste cooking oil. The sorption capacity test with pure oil was done to determine the maximum amount of oil absorbed by the sorbent.

Table 1. Characteristics of Kapok and Polypropylene Fiber (Rengasamy *et al*., 2011).

Characteristics	Type of Fiber	
	Kapok Fiber	Polypropylene Fiber
Density	0.23 g/cm³	0.91 g/cm³
Diameter	23 µm	19 µm
Length	18mm	12mm
Crystallization Degree	35.90%	50%
Hollow Lumen Structure	YES	NO

The oil sorption capacity test was calculated using the formula in Equation (1). After 15 minutes, the immersed fiber sample was taken out and left to drain for 5 minutes to allow any excess oil to flow out through the filter funnel then it is weighed to obtain the final weight of the sample.

$$Q = \frac{m_2 - m_1}{m_1} \quad (1)$$

where m_1 refers to the initial dry sorbent weight (g), m_2 is the final sorbent weight after 1 minute (g) (Pang, 2010).

Effect of NaOH-Treatment Concentration on Kapok's Fiber Oil Sorption Capacity

According to Wang *et al*. (2012), treatment concentration below 0.1M exhibited maximum fiber's oil sorption capacity; hence, in this study, the NaOH-treatment concentration used was 0.02M to 0.1M. 1g RKF was soaked in the working solution and left for 48 hours. The fiber was placed in 500 ml of distilled water with 1% of acetic acid to obtain pH between 7 to 8 and left to dry overnight in a 70°C oven. The effect of concentration of NaOH-treatment on the oil sorption capacity of treated kapok fiber was determined using the same formula in Equation (1).

Oil Sorption Capacity Test for Oil-Water Mixture

In this experiment, the same formula (Equation 1) was used to calculate the oil sorption capacity. A varying concentration of oil (0.5, 1.0, 1.5, 2.0, and 2.5 %) was added to 500 ml of water to simulate an oil-water mixture medium. The immersed fiber sample was taken out from the oil-water mixture and left to drain for 5 minutes. Then, a mechanical pressing of fiber was done to extract the oil-water mixture from the fiber and placed it in 200ml of n-hexane solvent. After 15-20 minutes, the immersed fiber was taken out and pressed again to extract all remaining liquid. The extracted solvents were poured into a separating funnel to separate water from the hexane-oil layer. The hexane-oil mixture is poured into a 250 ml round bottom flask and placed in a heating mantle and distillation was carried out for 1 hour at 69-70°C. The distilled liquid was placed in an oven for 30 mins at 90°C to further evaporate any remaining n-hexane and it is then placed in the desiccator overnight to allow cool down before weighing.

Reusability Test

Sample of fiber weighing 1g is placed in 400ml of oil in a beaker. After 5 minutes, the sample was allowed to drain for 1 minute and the final weight of the sorbent was recorded. Then vacuum filtration was used with a Büchner funnel to separate the oil from the sorbent. The test is repeated 6 times and the oil absorbency of the sample was evaluated.

RESULTS AND DISCUSSION

Oil Sorption Capacity Test for Pure Oil Medium

Figure 1 compares the sorption capacities of raw kapok fiber (RKF) and polypropylene fiber (PPF) for 100 % waste cooking oil medium and 100% used engine oil. All sorption capacity is expressed on a gravimetric basis which is gram of oil per gram of fiber.

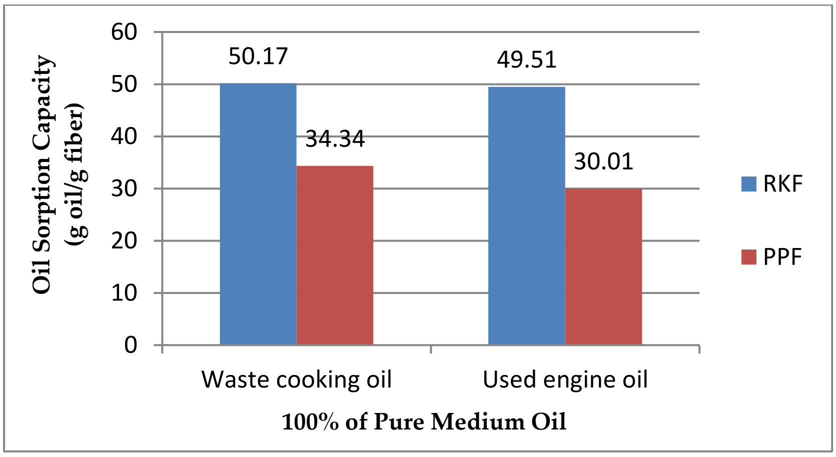

Figure 1. Average oil sorption capacities of RKF and polypropylene fiber for WCO and UEO.

RKF exhibited a higher sorption capacity than the polypropylene fiber for both WCO and UEO. The differences in sorption capacity for both oils might be due to UEO has higher viscosity and density compared to WCO. For this reason, UEO exhibited a lower sorption capacity than that of WCO, ascribed to the low oil flow rate in a viscous oil medium, causing a longer time needed to saturate the fibers (Thilagavathi *et al.*, 2018). A previous study has reported that kapok fibers have strong adhesiveness to vegetable oil compared to used motor oil since WCO is a product of long-chain fatty acids and ester; whereas UEO consists of aliphatic hydrocarbon (Dong *et al.*, 2015). The results suggested that RKF has proven to exhibit higher sorption capacity compared to polypropylene fiber.

Effect of NaOH-Treatment Concentration on Kapok's Fiber Oil Sorption Capacity

Alkali treatment of kapok fiber such as the use of sodium hydroxide (NaOH) as the treating agent is an appealing approach to increase the oil sorption capacity (Wang *et al.*, 2012). Figure 2 shows the average oil sorption capacity of kapok fiber treated with increasing concentration of NaOH treatment from 0.02 M, 0.04 M, 0.06 M, 0.08 M to 0.10 M.

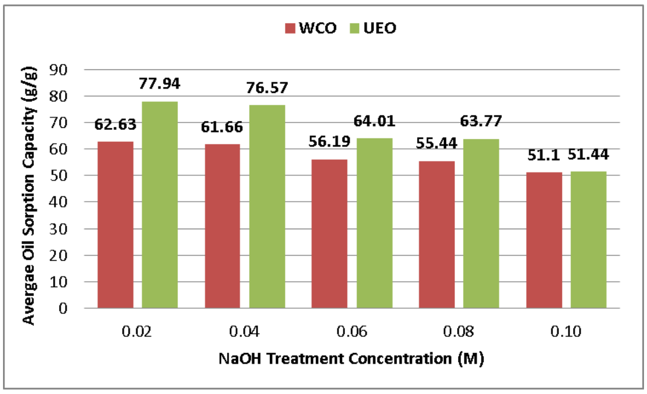

Figure 2. Average oil sorption capacity of treated kapok fiber (TKF) on WCO and UEO with different concentrations of NaOH.

Interestingly, the oil sorption capacity of TKF at 0.02M is the highest, which is about 77.94 g/g for the case of UEO and 62.63 g/g for WCO. It is noticeable that further increasing the NaOH concentrations did not improve the oil adsorption ability of the treated fibers, in which a lower oil sorption capacity of merely 51.44 g/g at 0.10M was recorded. Thus, optimizing the concentration of NaOH is important because an optimum alkalization process may remove the lignin, wax, and natural oil layer from the fiber surface, consequently roughen the fiber surface that helps to enhance the oil adsorption (Zheng *et al.*, 2015). Whereas, an excessive alkaline concentration could have collapsed the rigid and hollow lumen of kapok fiber, thus resulting in a reduction in oil sorption capacity. This effect is in great agreement with other works reported in the literature (Wang *et al.*, 2012). Mukherjee *et al.* (1993) found that cellulose fibers treated with more than 1% NaOH has poorer oil sorption capacity due to the weakening in fiber's sorbent properties.

Oil Sorption Capacity Test for Oil-Water Mixture

The oil sorption capacity of RKF and 0.02M NaOH-TKF was determined in varying concentrations (0.50, 1.00, 1.50, 2.00, and 2.50 %v/v) of WCO and UEO in water. The concentration of oil in water is expressed in volume percent. The initial mass of oil in water is expressed in terms of grams to compare with the final amount of oil that is recovered from the fiber. The findings in this experiment suggested that TKF has a higher oil sorption capacity than RKF at the highest concentration of oil; which indicates TKF has greater oil sorption capacity even at a high concentration of oil in water. Furthermore, TKF has a higher oil recovery percentage than the RKF for all the concentrations of oil-water used. In general, RKF recovers more than 80% of oil; which is lower than TKF that could recover > 90% of oil (Table 2 and 3).

Table 2. Oil sorption capacity of RKF and TKF with WCO-water

Concentration of oil- water mixture(%v/v)	Initial mass of WCO (g)	Oil Sorption Capacity (g oil/ g fibre) / Recovery Percentage (%)			
		RKF (g/g)	RKF (%)	TKF (g/g)	TKF (%)
0.50	2.24	1.89	84	2.19	98
1.00	4.48	4.02	90	3.90	87
1.50	6.71	5.97	89	5.96	89
2.00	8.95	7.46	83	8.35	93
2.50	11.19	10.67	95	10.98	98

Table 3. Oil sorption capacity of RKF and TKF with UEO-water

Concentration of oil- water mixture(%v/v)	Initial mass of UEO (g)	Oil Sorption Capacity (g oil/ g fibre) / Recovery Percentage (%)			
		RKF (g/g)	RKF (%)	TKF (g/g)	TKF (%)
0.50	2.33	1.96	84	2.05	88
1.00	4.65	4.52	97	4.56	98
1.50	6.98	6.22	89	6.96	100
2.00	9.30	8.38	90	9.18	99
2.50	11.63	11.52	99	11.59	100

Based on Tables 2 and 3, a general trend of increased sorption capacity of RKF and TKF was observed as the concentration of oil in water increases. Other factors that affected the percentage recovery of oil from fiber could be due to the material handling during the experiment such as the transfer of hexane-oil-water solvent from beaker to separator funnel to round bottom flask to be distilled.

Reusability Test

Reusability tests with the vacuum filtration method are important to determine how many cycles of absorption and desorption can the fiber endure before losing its efficiency as an oil sorbent. The reusability of RKF and TKF was determined by observing the change in oil sorption capacity after six cycles of sorption and desorption (Table 4).

Table 4. Changes in oil sorption capacity of RKF and TKF for WCO and UEO after 6 cycles.

Cycle	Waste cooking oil sorption capacity (WCO) (g oil/g fiber)		Used engine oil sorption capacity (EUO) (g oil/g fiber)	
	RKF	TKF	RKF	TKF
1	55.99	72.38	51.21	64.36
2	52.84	69.37	40.38	57.28
3	51.73	64.23	38.33	52.64
4	47.32	61.34	38.16	51.59
5	42.36	58.21	35.13	50.64
6	38.75	55.96	30.28	47.73

Figure 3 shows the oil sorption capacity of RKF towards WCO gradually decreased from 55.99 g/g to 38.75 g/g after six cycles; similarly, TKF experiences a reduction in oil sorption capacity towards WCO from 72.38 g/g to 55.96 g/g. Meanwhile, the oil sorption capacity of RKF towards UEO reduced from 51.21 g/g to 30.28 g/g; and TKF's oil sorption capacity also decreased from 64.36 g/g to 47.73 g/g after 6 cycles of reusability tests with UEO.

Based on the trend in Figure 3, it can be observed that TKF has better reusability than RKF. In terms of percentage reduction in oil sorption capacity, TKF decreases 22.69% whereas RKF decreases as much as 30.79% towards WCO after six cycles. Simultaneously, the reduction percentage of TKF's oil sorption capacity is also lower towards UEO compared to RKF after six cycles; which are 25.84% and 40.87% for TKF and RKF, respectively.

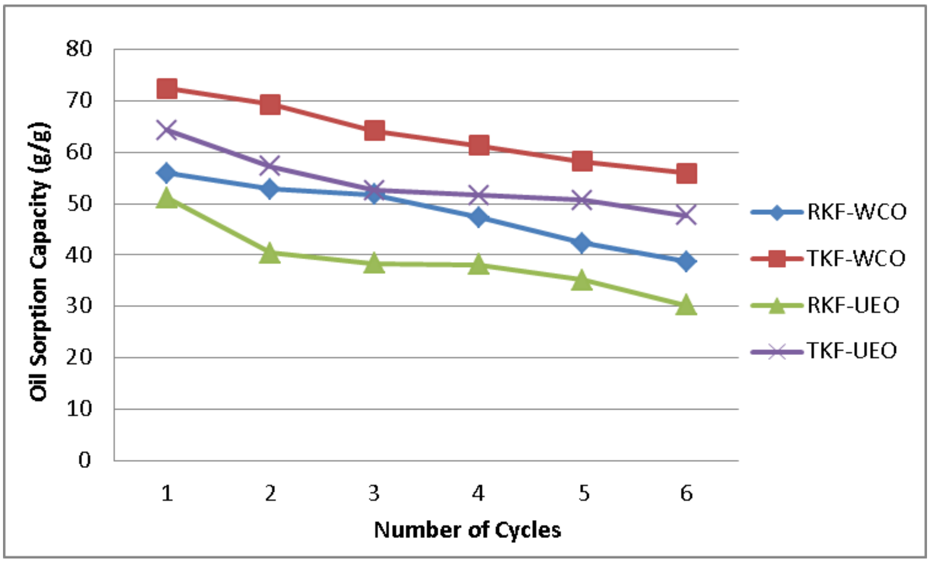

Figure 3. Line Chart represents the relative data obtained in Table 4.

The recoveries of WCO and UEO were done in a mild procedure instead of mechanical pressure. Recovery of oil from the fibers with the aid of a mechanical device could result in severe loss of sorption capacity due to irreversible deformation (Abdullah *et al.*, 2010). UEO exhibited a greater reduction in oil sorption capacity, as compared to WCO. This could be due to the dense and viscous engine oil that could have been trapped in the hollow lumen of fibers; making the recovery process to be tougher. Overall, the reduction in oil sorption capacity of kapok fibers is justified by the remnant oil trapped in hollow lumen after each cycle and the deformation of fiber structure. Excellent reusability of kapok fibers is beneficial to lower the cost of spilled oil treatment (Wang *et al.*, 2013).

CONCLUSION

In conclusion, the oil sorption capacity of all fibers used in this study for both WCO and UEO medium are in the order of PPF<RKF<TKF (i.e. increasing order of oil sorption capacity). The optimum treatment concentration of NaOH on kapok fiber was fixed at 0.02M because the oil sorption capability of kapok fiber decreases in a higher concentration of NaOH. TKF has a higher oil sorption capacity compared to RKF towards the oil-water mixture for both WCO and UEO. Hence, TKF is a better recovery oil agent than RKF. Generally, the oil sorption capacity of fibers is higher for WCO, as compared to UEO. This might be due to higher UEO's viscosity, and thus longer time is needed to attain equilibrium in the fiber. In terms of reusability, TKF is proved to render higher reusability than the RKF due to its lower percentage reduction of oil sorption capacity after six cycles compared to RKF's in both WCO and UEO. Further researches on the application of kapok fiber on river water samples should be done before the real-life application of kapok fiber. Treated kapok fiber on river water samples should be carried out to understand the chemical reactions that can occur between the chemically treated kapok fiber and the compounds in river water.

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