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Study of Packing Density and Temperature on the Oil Sorption Capacity of Packed Local Kapok Fiber as Bio-oil Spill Absorbent

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Oil spills are global concern due to the environmental impact and consequence of release of affluence. Various commercial products have been development and create to control spills, including the use of fibers as sorbents. This study investigates the use bio-based material of kapok fiber as sorbent materials for oil spills absorption. The study characterized the chemical and morphological properties of kapok fiber, experiment conducted involved FTIR and SEM analysis. Sorption tests with oil were conducted in deonized water thickness of oil and water. Oil sorption capacity by kapok fiber was strongly influenced by packing densities and temperatures. As packing densities and temperatures increased, oil sorption capacity of kapok fiber was reduced proportionally. Kapok shows excellent buoyancy and very high hydrophobicity and oil sorption capacity. The research has shown that kapok fiber can be adapted for sorbent materials for oil spills.

Key words: Packing densities, Temperature, Oil sorption capacity.

Oil spills become a big challenge and serious problem. According to recent statistics, 80 % of reported oil spillage incidents are caused by human mistakes. It was suggested that oil spill incident which occur at low energy coastal ecosystem such as marshes, beaches and wetland may require almost 50 years to fully recovering from the impact of an oil spill (Ornitz & Champ, 2002). Petroleum based oil and vegetable oil are two common types of oil components involve in numerous spillage incidents.

There are about 10 million tons of oil and petroleum products used each day worldwide. The threat of oil pollution is increasing steadily with the increasing of the production and consumption of oil and petroleum products. Transfer of petroleum from the oil fields to the consumer requires about 10 to 15 steps of transportation including tankers, pipelines, railcars and tank truck. Oil spillage incidents may occur during transportations or storage time at transfer points, terminals and refineries along the route (Fingas, 2001).

Over the past decades, there are many spill accidents that occurred around the world. During the years 1988-1991 alone, 28 incidents involving up to 3145 barrels of oil spillage had occurred (Bastani *et al.*, 2006). In average, over 1000 gallons of oil were spilled in each incident reported in Canada and United States. It is approximated that almost 12 such oil spill incidents happened everyday in Canada whereas only about

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one spill cases into navigable water. In the United States on the other hand, about 25 spills per day into navigable waters and an estimated 75 spills on land (Fingas, 2001). Table 1 lists several major oil spillage incidents that have been occurred around the world between 1991 until 1999.

Table 1. Major oil spill incidents

No	Year	Month/day	Ship/incident	Country	Location	Tons (x10^3)
1	1991	Apr 11	Haven	Italy	Genoa	140
2	1991	Jan 26	Gulf war	Kuwait	Sea Island	800
3	1992	Dec 3	Aegean Sea	Spain	La Coruna	75
4	1992	Aprl 17	Katina P	South Africa	Indian Ocean	60
5	1993	Feb 4	Oil platform blowout	Iran	Nowruz field	270
6	1993	Jan 5	Braer	United Kingdom	Shetland Island	85
7	1994	Oct 25	Pipeline rupture	Russia	Usinsk	105
8	1994	Mar 2	Oil well blowout	Uzbekistan	Fergana Valley	8
9	1994	Oct 21	Thanassis A	Hong Kong	South China Sea	46
10	1994	Jan 24	Cosmos A.	Hong Kong	South China Sea	23
11	1996	Nov 23	Storage tank	Czech Republic	Litinov	10
12	1996	Feb 15	Sea Impress	United Kingdom	Milford Heaven	72
13	1997	Jan 18	Bona Fulmar	France	Dover Strait	7
14	1999	Dec 12	Erika	France	Biscay Bay	12

Source: Fingas, 2001

Schnoor, (1991) reported that oil spills occurred at Prince William Sound, Alaska on March 24, 1989 had soaked and killed plants and animal over 2,000 miles of shoreline and 500 miles away. The amount of spill reported was approximately 11.2 million gallons of crude oil which was the largest oil spill ever recorded in the United States and one of the largest in the world .

Major challenges of Oil Spill

Oil spillage results adverse effects especially towards aquatic and terrestrial environments. Accidental oil well blow out, loading of oil tank, tank washing activities, runoff of port from pipeline leaks and road tanker accidents are the main sources of oil spillage into the environment (Ogboghodo *et al.*, 2003). The major consequences resulted from oil spillage are the death of seabird (Kingston, 2002) and loss of phytoplankton and microalgae (Fingas, 2001). According to the Essein and Antai. (2005), phytoplankton and microalgae are essential sources for nutrient and oxygen cycling which they are important components of food web for aquatic life. The loss of these sources will interrupt the food chain on which fish and sea creature's rely on. Osuji & Opiah, (2007) reported soil that contaminated with oil will contribute to the agricultural productivity problem according to conducted by Ogboghodo *et al.*, (2003) observed that percent survival rate, plant height and dry matter yield decreased with increase in crude oil contamination. Meanwhile, Luiselli *et al.*, (2005) reported that oil pollution has lead to the decreasing amount of turtles drastically due to their habitat alteration.

Seeking for cost-effective, efficient and environmental friendly approach solution remains as a main challenge in oil spillage treatment. Remediation of oil using oil sorbent offers the simplest and direct in-situ method to overcome oil spillage without the use of chemical compound. However, the use of synthetic sorbent made of polypropylene; polyester and polyamide (nylon) are rather costly and could lead to secondary waste generation due to their non-biodegradable character (Choi & Claud, 1992; Adebajo *et al.*, 2003; Lim & Huang, 2006).

This study proposes the use of local kapok fiber (*Ceiba Pentandra)* as natural absorbent particularly for palm oil removal application. The study hope that kapok fiber could potentially perform as an effective oil removal agent to treat palm oil/water solution.

The study examines the potential of kapok fiber on oil sorption capacity. The study investigates the effect of packing density on the oil sorption capacity of packed local kapok fiber for oil removal application as well as the effect of temperature on the oil sorption capacity of packed local kapok fiber for oil removal application.

Methodology

The methodology for determining the effect of packing densities and temperature on oil sorption capacity of kapok fiber involved:

i) Experimental design
ii) Material selection
iii) Preparation of kapok fiber
iv) Characterization of kapok fiber
v) Performance testing

Experimental design

An experimental design is constructed to outline the overall process of preparing and testing the kapok fiber for oil removal application. Figure 2.1 shows the outline of experimental design that implemented the study.

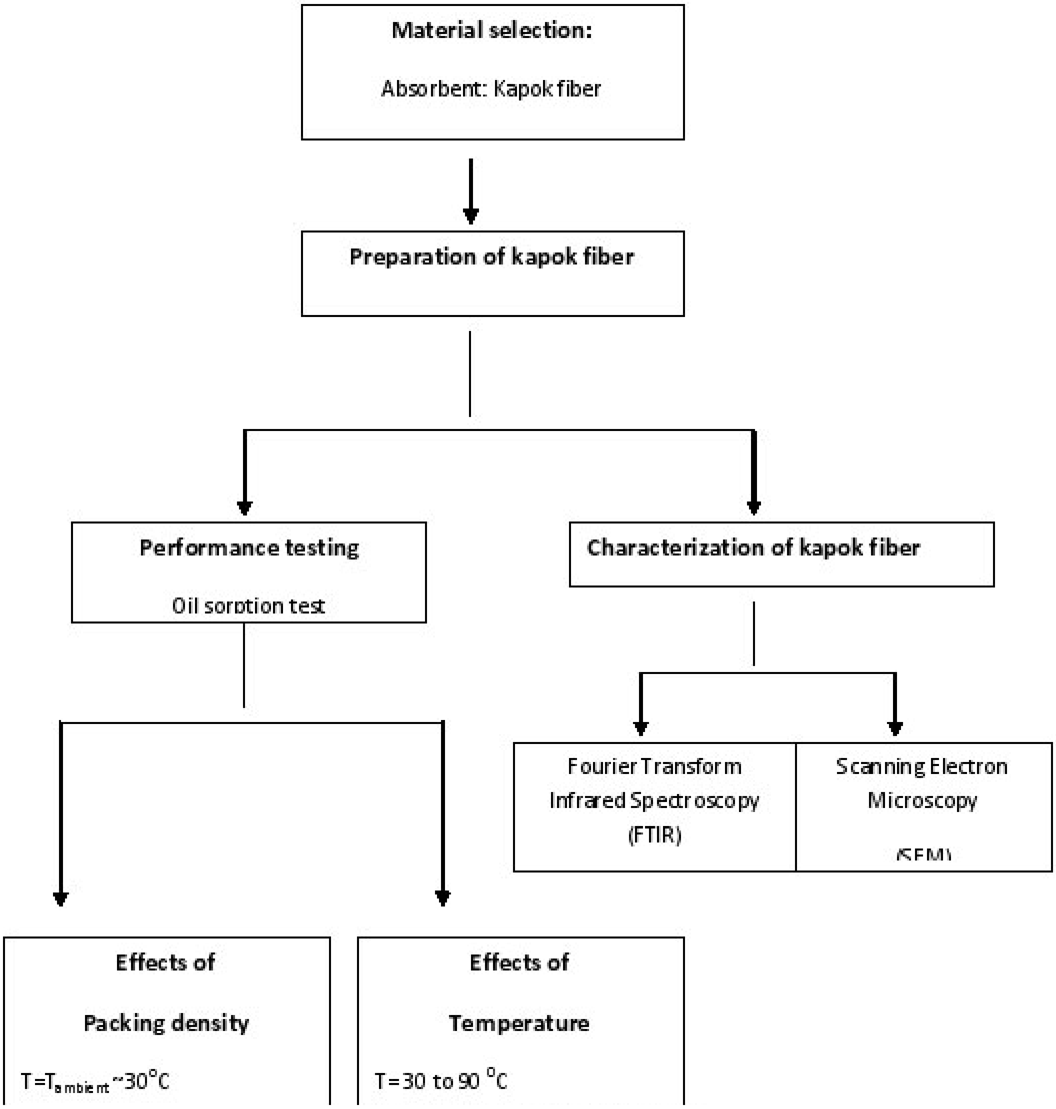

Fig. 1. Experimental design

Material selection

Oil sorbent

In this study, kapok fiber which is a natural agricultural product is chosen as oil sorbent for removing oil. The source of kapok fibers are obtained from Kuala Terengganu area. Kapok fiber is a suitable material to be studied as oil absorbent because it is low in densities which make it float on the water surface, possesses intrinsic hydrophobic-oleophilic and biodegradable characteristics. Kapok fiber has been extensively studied as oil sorbent material in non-aqueous phase liquid such as diesel (Lim & Huang, 2006).

Tested oil

Palm olein is used as the tested oil in this study. Palm olein or Refined Bleaches Deodorized Palm Olein (RBDPO) that is used in oil sorption test throughout the study is manufactured by Delima Oil Product Sdn Bhd. Palm olein is an edible vegetable oil which is commonly used in daily culinary. It is a fractionate component from crude palm oil. Table 3.1 lists some of the general physical properties of palm olein. Palm olein is used because it is less viscous compared to other palm oil fractionate components and could represent low-viscosity vegetable oil. In addition, it is easier to separate from water since palm olein has lower density compared to water. Apart from this, limited studies focusing on removal of vegetable oil using natural absorbent has created the demand for this study.

Kapok Fiber Preparation

Kapok fiber will undergo direct physical pre-treatment process prior use. Firstly, kapok fiber is isolated from its pod cover. Then, kapok seeds is removed manually from its fiber using the basket filter. All visible lumps and impurities found in the kapok fiber is removed. Kapok fiber is washed with distilled water and dried at 40 ^{0}C in a convective oven. Chemical pre-treatment by using solvent in the sample preparation is not be conducted as previous study carried out by Lim and Huang. (2007) demonstrated that kapok fibers in native state shows better oil sorption efficiency compared to the solvent treated kapok fiber. Solvent used in chemical pre-treatment can cause incidental removal of surface wax on the kapok fiber.

Different densities kapok is prepared by loading the intended amount of kapok fiber into a constant volume test cell. The volume of the test cell is 200 cm^3 and made of stainless steel wire mesh (1.13 mm aperture and 0.457 mm wire diameter). The schematic diagram of a constructed test cell is shown in Figure2.2.

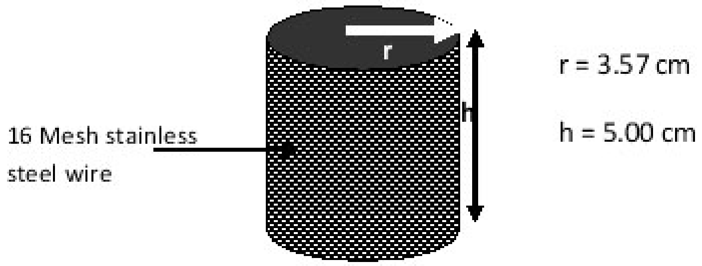

Fig. 2. Test cell

The range of packing density examined in the study is 0.02 g/cm^3 to 0.09 g/cm^3 . The packing density is determined according to Equation 2.1. Example of packing density calculation is shown in Appendix A. Table 2.2 indicates the weight of kapok fiber related to the packing density.

$$\text{Packing density of kapok fiber, PD }(\text{gcm}^{-3}) = \frac{\text{Weight of kapok fiber (g)}}{\text{Volume of test cell (cm}^3)} \quad ....(2.1)$$

Kapok Fiber Characterizations

Two characterization techniques is conducted to determine the physical and chemical properties of kapok fiber. The techniques involved are:

i. Scanning Electron Microscopy (SEM)
ii. Fourier Transform Infrared (FTIR) Spectroscopy

Performance Testing

Performance of kapok fiber is evaluated

in terms of oil sorption capacity and oil/water selectivity. Packed kapok fiber is tested in water absorption test and oil sorption test.

Water absorption test

Water absoption test is conducted to determine the water uptake trend and capacity in kapok fiber over time.

Oil sorption test

Oil sorption test is carried out in order to obtaine the oil sorption capacity in kapok fiber. This test will generally follow the standard method F726-99 (ASTM, 1998) which is extensively referred for evaluating sorbent performance. Sorption a quantity is expressed on a gravimetric basis (e.g., g oil/g kapok).Firstly, desired amount of kapok fiber is is loaded into 200 cm^3 test cell to produce the intended packing density. 100 ml of sample purely palm oil is filled into 200 ml glass beaker. Then, the kapok-filled cylindrical test cell is soaked into the oil bath for 10 minutes to reach equilibrium oil sorption. Oil-saturated test cell then is removed from oil bath and is let to drain for 1 minute. Then, kapok fiber is removed from the test cell and immediately is transferred to pre-weighed dish and is weighed. Testing procedure is performed at room temperature (T~30 °C)

Determination of oil sorption capacity and Oil/ water selectivity

Oil sorption capacity is determined according to Equation 2.2.

$$\text{Sorption capacity, q (g oil/g kapok)} = \frac{S_s}{S_o} \text{ or } [(S_{st}\ S_o) / S_o] \quad ...(2.2)$$

Where S_o is the initial dry weight of kapok (g), S_{st} is the weight of kapok after oil test (g), S_s is ($S_{st} – S_o$) net oil adsorbed (g)

Oil/water selectivity indicates the preference of kapok to absorbed oil over water. Oil/water selectivity is expressed in Equation 2.3.

$$\text{Oil/water Selectivity} = \frac{\text{Weight of absorbed oil (g)}}{\text{Weight of absorbed water (g)}} \quad ...(2.3)$$

Effects of packing density

An effect of packing density on oil sorption capacity is examined by conducting oil sorption test on different kapok packing densities. The range of packing density used is between 0.02 to 0.09 g/cm. Each batch of samples is tested between 3 to 5 sorption experiments and the average value (with standard deviation of less than 0.05) is taken as the result to represent the batch. This method will also be applied in water sorption capacity determination.

Effects of temperature

An effect of tempearture on oil sorption capacity is examined by varying the oil temperature during oil sorption test. Packing density of packed local kapok fiber is sustained at a constant value. Oil sorption test with some modifications is performed. In this experiment, the beaker containing pure palm olein is immersed in hot water bath and a thermometer is used to monitor the oil temperature during oil sorption test. Packed kapok is tested at 30, 40, 50, 60, 70, 80 and 90 °C.

RESULT AND DISCUSSION

Characterization of kapok fiber

Fourier Transform Infrared (FTIR) Spectroscopy analysis of kapok fiber

Figure 4.1 displays the infrared spectrum of raw kapok fiber. Infrared spectrum of raw kapok fiber shows the absorption peak of chemical group characteristic of raw kapok fiber components.

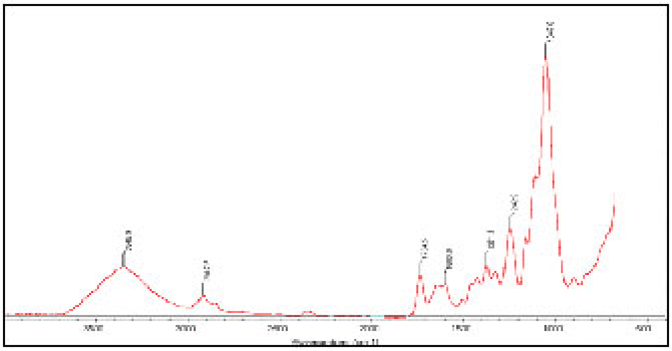

Fig. 3.1: Infrared spectrum for raw kapok fiber

A pronounced peak at 2917.5 cm^{-1} possibly corresponds to the asymmetric and symmetric aliphatic CH_2 and CH_3 stretching as suggested by Tserki *et al.*, (2005). This could be associated to the presence of plant wax which generally comprised n-alkanes, alcohols, fatty acids, aldehydes, ketones and n-alkyl esters. A similar result is also reported in Lim & Huang (2007) and Wisniewska *et al.*, (2003). In consistent with the study by Hori *et al.*, (2000), it was suggested that kapok fiber contain acetyl groups of up to 13%, which was believed to contribute to its waxy and silky appearance. The peak at 3348.9 cm^{-1} corresponds to O-H vibration as reported by Wisniewska *et al.*, (2003).The peak 1047.6 cm^{-1} is within the region of carbohydrate or polysaccharide similar suggested by Lim and Huang, (2007). The band around 1734.5, 1371.7 and 1242.9 cm^{-1} are attributed to the presence of carbonyl group (C=O) in the ester bonds which similarly reported by Sun *et al.*, (2003) and Lim and Huang, (2007). It was believed that C=O stretching vibration is associated with the ketones, esters and aliphatic aldehydes of kapok wax. Meanwhile, the band around 1600.0 cm^{-1} corresponds to C–O stretching in lignin as suggested by Sun *et al.*, (2003). The FTIR spectra analysis show that the kapok fiber exhibit lignocellulosic with hydrophobic waxy coating, similar to that reported previously by(Lim & Huang, 2007; Abdullah *et al.*, 2009).

Morphological observation of kapok fiber by SEM

Kapok microstructures as analyzed by SEM (Fig 3.2 and b) exhibit hollow tubular structures (or lumen). Figure 4.2 illustrated the SEM images of cross section morphology of raw kapok fiber at the magnification 1000x and 2000x.The lumen for kapok in figure 3.2 with an external 20 µm and 40 µm The large pore volume in the kapok assembly is available for oil sorption.

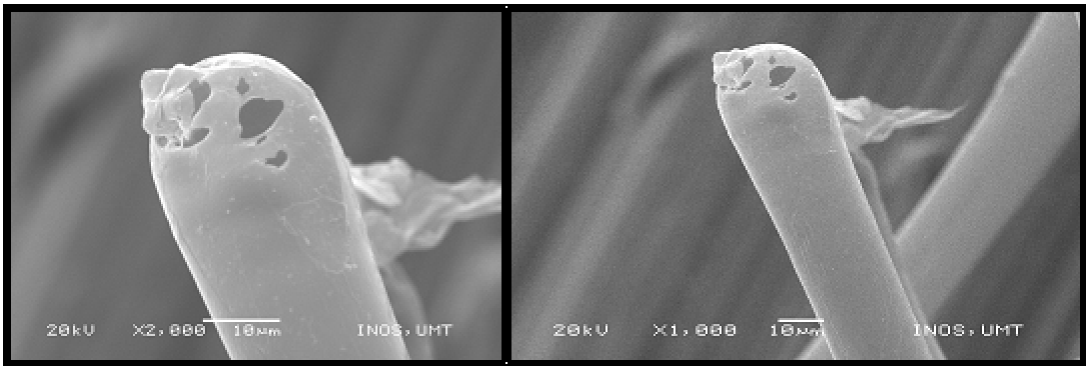

Fig. 3.2 SEM cross-sectional images of kapok fiber at (a) 1000x magnification and (b) 2000x magnification

Clusters of kapok fiber after reacted with l oil exhibited color change and swelling at tubular structure like in Figure 4.3, which show oil absorbed into lumen. Kapok also contains wax cutin on the fiber surface, which makes them water repellent

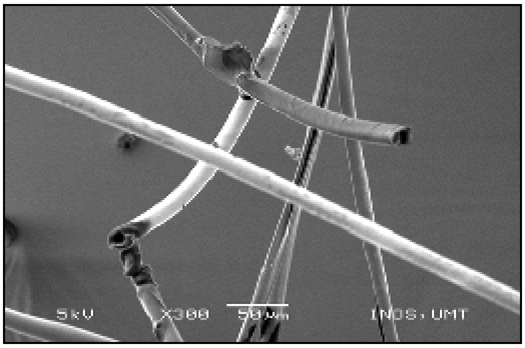

Fig. 3.3: Cluster of kapok fiber image by SEM at magnification 300x

Oil Sorption Performance

Oil sorption performance by kapok fiber was evaluated based on the amounts of oil retained in the kapok after lifting the column cells from the oil bath. For determination of oil sorption capacity, the oil amount retained in the kapok after 1-min dripping time was used as the basis for calculating oil sorption capacity. The 1-min dripping time has been applied by previous researchers (Lim & Huang, 2006, 2007; Choi & Cloud, 1992). Same method was applied for water sorption test. This section comprised 2 main parts which are oil/water sorption performance at different packing densities of kapok fiber and oil/water sorption performance at different temperature of oil and water. In determining the sorption performance of kapok at different packing densities, the test was carried out at room temperature. Table3.2 represents the performance of kapok on the oil and water sorption capacity at 15 minutes immersion time at various packing density of kapok fiber. The values present in this table are based on average value obtained from 3 sample replicates.

Table 3.1. Oil and water sorption capacity at various packing densities of kapok fiber

Packing density (g/cm^3)	Oil sorption capacity (g/g)	Water sorption (g/g) capacity	Oil/water selectivity
0.02	27.77 ± 0.250	1.14 ± 0.025	24.36
0.03	24.66 ± 0.071	0.72 ± 0.030	34.25
0.04	19.49 ± 0.185	0.48 ± 0.020	40.60
0.05	17.34 ± 0.251	0.40 ± 0.030	43.35
0.06	14.17 ± 0.125	0.33 ± 0.020	42.94
0.07	12.11 ± 0.105	0.28 ± 0.020	46.58
0.08	10.57 ± 0.137	0.23 ± 0.025	45.96
0.09	9.13 ± 0.075	0.20 ± 0.025	45.65

Comparison of Oil and Water Sorption Performance at Different Packing Densities

The oil sorption performance of kapok fiber is compared in term of oil sorption capacity, water sorption capacity and oil/water selectivity. Figure 3.4 highlights the comparison of oil and water sorption capacity at various packing densities. The lowest packing density of 0.02 g/cm^3 , showed the greatest of oil and water sorption capacity. The relationship between sorption capacity and packing densities indicates that sorption capacity was reduced proportionally with increasing of packing densities as depicted i in Figure3.4.

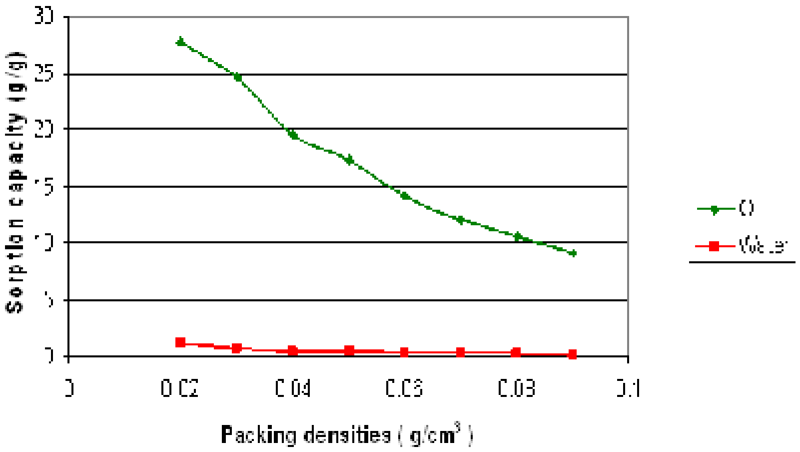

Fig. 3.4. Oil and water sorption capacity at various packing densities of kapok fiber

Comparison of Oil and Water Sorption Performance at Different Temperatures

Figure 3.6 highlights the comparison of oil and water sorption capacity at various temperatures. It was demonstrated that for oil sorption, the sorption capacity was reduced with the increasing of temperatures. Meanwhile, in term of water sorption capacity, the sorption capacity was increased with the increasing of temperatures. However, the trend shows that kapok fiber exhibited a much greater performance on oil sorption capacity compared to the water sorption capacity at each temperature.

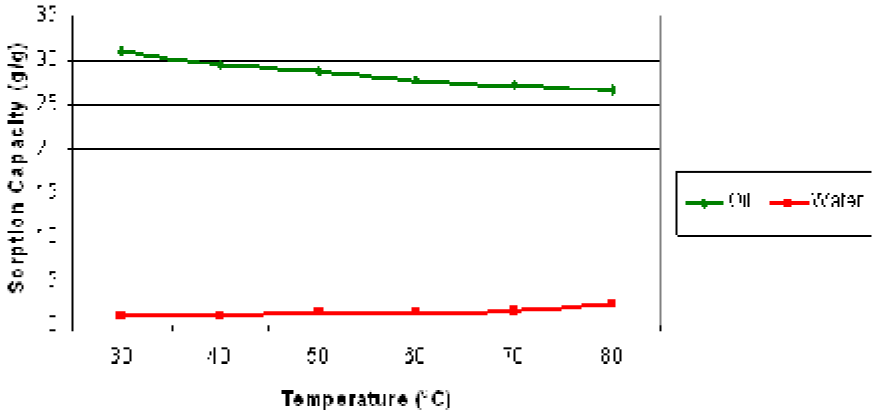

Fig. 3.6. Oil and water sorption capacity at various temperatures

CONCLUSION

The prepared kapok fiber in this study is expected shows high oil sorption performance comparable to those reported in previous studies. Packing densities and oil temperature have significant influences on oil sorption capacity of kapok fiber for palm olein removal application. Optimum packing density of kapok and optimum oil temperature setting is successfully determined for the maximum oil sorption capacity.

Kapok fiber examined in this study has exhibited high hydrophobic-oleophilic characteristics which were associated with its waxy surface and tubular hollow lumens as proven from SEM observation and FTIR analysis.

Recommendation

The findings from this study onthat local kapok fiber have a great potential as oil absorbent for oil/water separation. However, several recommendations can be considered for improvements towards further research. The following are some of the recommendation for improvement of the study:

i. In this study, characterization of kapok fiber was conducted using FTIR and SEM. It is suggested that characterization of kapok fiber using Thermal Gravimetric Analysis (TGA) could be considered in the future work. This analysis could provide the weight loss trend of kapok and determine the decomposition of temperature of raw kapok fiber.

ii. This study focused on a determination of the maximum oil sorption capacity by kapok fiber in the oil bath instead of practical oil/water mixture. Therefore, it is suggested that oil sorption performance test of kapok fiber can be conducted using oil/water mixture in order to evaluate the actual capability and the potential of kapok fiber to absorb oil at different environment condition.

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