Comparative Study on Raw and Modified Kapok Fibers as Sorbent Materials for Oil Sorption

by

Zamilah binti Ismail

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering) 2013

MAY 2013

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Comparative Study of Raw and Modified Kapok Fibers as Sorbent Materials for Oil Sorption

by

Zamilah binti Ismail

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

Approved by,

____

(Associate Professor Dr. Mohd Azmuddin Bin Abdullah)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done unspecified sources or persons.

ZAMILAH BINTI ISMAIL

ABSTRACT

In despite of rapid development of palm oil industry in Malaysia, a large volume of palm oil mill effluent has been produced concurrently which required some treatments before discharge into the surroundings. Oil is one of the important energy resources in modern world and need to be transported across the globe via oceans and inland transports. However, the risk of oil spillage over water body during transportation is very high due some accidents and other factors .Both of these issues are some examples which contributed to oily wastewater contamination problems and attracted a lot of concerns recently. Kapok fibers or scientifically named as *Ceiba pentandra* (L.) Gaertn is a natural sorbent that has the feasibility as filter material to separate the immiscible liquids such as oil in water mixture. Different modifications have been proposed in order to enhance the characteristics of the kapok fibers in oil sorption including surface modification and chemical modification. This research project evaluates and compares the performance of different type kapok fibers in application of removing residual oil from palm oil mill effluent (POME) and diesel oil as represent the oil contaminant for oils spill cleanup. Three types of kapok fibers which are raw kapok fiber, sodium hydroxide treated kapok fiber and surface modified kapok fiber are evaluated for their sorption characteristics and compared. The effect of packing densities on the sorption characteristics of each prepared kapok fiber were studied in batch system. Oil sorption capacity and percentage of dynamic oil retention were evaluated. Apart from that, the effectiveness of the removal of residual oils using the kapok fibers would be evaluated in a continuous packed bed column where the effect of packing densities on the Chemical Oxygen Demand (COD) reduction and pH value changes would be evaluated.

ACKNOWLEDGEMENT

“Praise to Allah, the most Gracious and the most Merciful”

I have taken a lot of efforts during these two semester to complete the Final Year Project. However, it would not been possible without the kind guidance and support of individuals for this project. Thus, I would personally like to express deep gratitude to my supervisor, AP Dr Mohd Azmuddin bin Abdullah for his guidance, comments , supports and patience during this project.

Other than that, I would like to acknowledge Mr. Muhammad Afzaal Bhatti and Mr. Ashfaq Ahmad Bangash who have lend their hands with the works, sharing their idea and continuous guidance for me to complete the project. Thank you very much and I really appreciate every support that has been given to me.

I am as ever, especially indebted to my family for their support and trust throughout my life. Apart from that, great appreciation was given to my friends who always giving their support and motivation throughout the semesters.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Oil in water emulsion has raised great concern and increasing issues regarding this problem should be tackled systematically. Several major issues related to oil in water emulsion are including the increasing palm oil waste from palm oil industries (Rupani et al., 2010) and the high risk of petroleum product contamination with approximately 10 million tons of petroleum and derivative are used daily across the globe(Abdullah et al., 2010).

Palm oil mill effluent (POME) is composed of high volumes of oil-in-water emulsions as basic contaminants. Palm oil processing consumes high amount of water for the extraction of crude palm oil from the fresh fruits where about 50% of the water goes into palm oil mill effluent (POME) with an estimated 5-7.5 tonnes of water resulting in POME from 1 tonne of crude palm oil produced (Ahmad et al.,2003). Oil pollution resulting from palm oil industry is not only occurs in Malaysia, one of the highest producer of palm oil in the world (Singh et al., 2010). However, it is also raised a great concern in Indonesia as reported by Mukri Friatna, head of advocacy for WALHI (Friends of Earth Indonesia), in her quote “oil palm plantations ranked first as producers of pollutants” (Allen, 2011).

Oil spill accident is not a recent issue that posed serious threat to the environment. For example, in March 1989, the Exxon Valdez incident spilled 11.2 million gallons of crude oil into the coastal water of Prince William Sound, Alaska causing severe environmental damage (Teas et al., 2001). The destruction of oil storage tanks in Kuwait, 1991, during the Gulf war resulted in 4-inch thick oil slick that spread across 4,000 square miles in the Persian Gulf (Moss, 2010). The oil spill incidents which contribute to the oil pollution would affects in many aspect including sea life, economy, tourism and leisure activities.

The major difficulty in oily residual removal is the emulsified oil droplets which are sheltered from the spontaneous coalescence into larger flocs (Ahmad et al., 2005). A lot of oil in water separation techniques have being investigated in order to overcome the oil pollution. For example, oil spills skimmer, oil dispersant, oil gelling agent and oil adsorbent have been used for oil spills cleanup up to now (Wang.J., 2012). In palm oil mill effluent (POME) treatment, several methods have been applied for efficient and effective treatment methods including adsorption, flocculation, coagulation and solvent extraction (Ahmad et al., 2005; Hameed et al., 2003). The use of adsorption method seems to be attractive as the residual from the POME can be trapped in the sorbent material for further handling and removal. Various natural sorbents have been investigated and been used in the application of residual removal from POME including chitosan, bentonite and activated carbon (Ahmad et al., 2005).

Ceiba petandra (L.) Gaertn. (Kapok) has shown a great potential as effective natural oil sorbent based on its physicochemical and sorption characteristics due to its high sorption and retention capacity, structural stability and high reusability (Lim et al,. 2007). In addition, to increase the efficiency and effectiveness of the raw kapok fiber, chemical and surface modification should be investigated. The chemical modifications such as acetylating of other sorbent fibers such as rice husk and raw bagasse modified with fatty acid have proved successful and improvement on the sorption capacity of oily wastewater (Wang et al,. 2012)

1.2 Problem Statement

Palm oil industry has been backbone of Malaysia and economic development with more than 90% of its production is exported and contributing about RM 45.2 billion in foreign exchange. However, the disposal of processing waste which is the palm oil mill effluent (POME) triggers a major problem with an estimation of 54 million tonnes of POME has been produced in 2011. Major problem encountered is the POME residual oil content where the emulsified oil droplets experience spontaneous coalescence into larger flocs and pollute the environment. Realizing the potential pollution that can be resulted from this effluent, the Malaysian Department of Environment (DOE) has already set the maximum allowable limit for oil and grease level at 50 mg/l during the discharging or disposal of POME (Hameed et al., 2003).

Oil is one of the most significant sources of energy and also used as raw material for synthetic polymers and chemical worldwide. Primarily, major oil spills accident last few decades which have affected the coastal environments and marine resources has created increased public and government awareness. However, a numbers of minor oil spills accident occurred frequently should not be neglected. For example, release of ship-board oily waste from M/T Elias into the Houston Ship Channel due to malfunctioning oily-water separator in January 2013, release of 10 bbls of saltwater and crude oil mixture into central Vermillion Bay, LA in February 2013 and the latest accident on March 2013 which was caused by the collision of barge with the natural gas pipeline and resulted of 100 ft tall of fire and 2215 barrels of oil spilled in Bayou Perot, Lafitte, LA(IncidentNews). Thus, an urgent need to develop a wide range of materials for cleaning up oil from oil impacted areas is very significant.

1.3 Objective

The objectives of this research are:

1) To explore on modifications and characterization kapok fibers for oil sorption study
2) To optimize sorption study in batch and packed-bed column mode of operation
3) To evaluate and compare the performance of raw and modified kapok fibers in residual oil removal using palm oil and diesel oil

1.4 Scope of Study

The scope of the study involves preparation of three different types of kapok which is raw kapok fiber (RKF), sodium hydroxide treated kapok fiber (SKF) and surface modified kapok fiber (SMKF). Each of kapok fibers will be characterized after the preparation using for the morphology and chemical analysis using Scanning Electron Microscopy and Spectrum One FTIR respectively. The comparative study on the sorption of different kapok fibers will be studied in both batch and continuous mode of study. In continuous packed bed column, pH change and Chemical Oxygen Demand (COD) change before and after residual oil treatment would be evaluated whereas in batch mode of study, the sorption capacity and percent of retention time would be determined.

CHAPTER 2

LITERATURE REVIEW

2.1 Sorbent Materials for residual oil removal

Sorbent is an insoluble material or mixture of materials used to recover liquids through the mechanisms of absorption or adsorption, or both (Praba Karan et al., 2011). Various types of sorbent materials have been tested and investigated as well as has been considered as most effective in oil removal application. Sorbent materials can be divided into three types which are inorganic mineral materials, synthetic organic polymers and organic natural materials. Inorganic mineral materials include graphite, perlite, vermiculite, silica, zeolites, organic clay and fly ash whereby the examples of synthetic organic polymers materials is polypropylene, polyethylene and polyacrylate. Organic natural materials used as sorbent include straw, corn cob, sawdust cotton fiber, wool fiber, coconut husk and kapok fibers (Abdullah et al.,2010). Table 1 below shows benefits and disadvantages of current available types of adsorbent material in different forms.

Synthetic sorbents are generally the most effective in recovering oil. In some cases a ratio by weight of oil to sorbent of 40:1 can be achieved compared to 10:1 for organic products and as little as 2:1 for inorganic materials (Use of sorbent materials in oil spill response). However, the major drawback in using synthetic organic polymer like polypropylene is the slow degradation rate compared to the use of natural material as well as not naturally occurring as sorbent material (Teas et al.,2001). In despite of adsorption capacity, inorganic and organic sorbent materials are attractive as they often either abundant in nature or are the waste by-product of an industrial process and can be purchased readily at low cost or are freely available (Use of sorbent materials in oil spill response. Retrieved Apri1,13 2013)

Organic sorbent materials have one attractive feature in oil removal which is the hydrophobic-oleophilic properties. This feature is determined by several factors such as the chemical constituent amount of surface wax physical configuration of fiber and fibers’ pores nature. Generally, different types of organic sorbent material would have different oil sorption capacity (Table 2) as they have different physicochemical properties and chemical constituents for oil uptake (Ur Rahmah, Anisa.2009).

Table 1 Benefits and disadvantages of sorbent material (Use of sorbent materials in oil spill response. Retrieved Apri1,13 2013)

	Materials	Benefits	Disadvantages
Bulk	Organic– including bark, peat, sawdust, paper-pulp, cork, chicken feathers, straw, wool and human hair. • Inorganic – vermiculite and pumice • Synthetic – primarily polypropylene	- Naturally abundant or widely available as waste by-product of industrial processes - Can be low cost - Can serve to protect wildlife at haul-out sites	-Difficult to control, can be spread by the wind - Difficult to retrieve - Oil and sorbent mixture can be difficult to pump - Disposal of oil sorbent mixture more limited than oil alone
Enclosed	All of the above bulk materials can be enclosed in mesh or nets	- More straightforward to deploy and retrieve than loose sorbent - Enclosed boom has a greater surface area than continuous boom	- Structural strength limited to that of the mesh or net -Organic booms can rapidly become saturated and sink. -Oil retention is limited
Continuous	Synthetic – primarily polypropylene	- Long-term storage -Relatively straightforward to deploy and retrieve - High oil recovery ratio possible if used to full capacity	- Limited efficiency for weathered or more viscous oils - Do not readily decompose limiting disposal options
Fibre	Synthetic – primarily polypropylene	Effective on weathered and more viscous oils	Less effective on fresh light and medium oils

Table 2 Types of organic sorbent material and oil uptake (Ur Rahmah, Anisa.2009).

Organic sorbent materials	**Oil type**	**Oil Uptake(g oil/g fibers)**	**Form**
Cotton	Diesel oil	30.6	Ground fiber
Kenaf bast	Diesel oil	7.2	Ground fiber
Kenaf core	Diesel oil	7.1	Ground fiber
Garlic peels	Crude oil	0.4	Sheets
Onion peels	Crude oil	0.5	Sheets
Natural wool	Motor oil	5.6	Fiber
Wool	Crude oil	31.8	Fiber
Milkweed	Crude oil	39.0	Fiber
Kapok	Crude oil	38.5	Fiber

Based on oil uptake of 30-40 g oil/g sorbent (Table 2), cotton, wool, milkweeds and kapok show high performance as oil sorbent compared to other natural organic sorbents.

2.2 Kapok as natural sorbent

Ceiba pentandra (L.) Gaertn or known as kapok is an agricultural product. Its fiber is lustrous, yellowish-brown in color which derived from the fruits of silk-cotton tree mainly composed of cellulose, lignin polysaccharide and small amount of waxy coating. To date, kapok fiber have received great attention as a natural sorbent material due to its hydrophobic – oleophilic characteristics. The kapok fiber has a hollow structure with large lumen which contributed to its great oil absorbency and retention capacity. Apart from that, the high amount of waxy cutin on the kapok surface has also contributed towards its high water repellency (Abdullah et al., 2010; (Lim & Xiaofeng, 2007).

Table 3 Chemical composition of kapok fibers (Praba Karan et al.,2011)

Chemical composition	**Percentage**
Cellulose	64%
Lignin	13%
Pentosan	23%

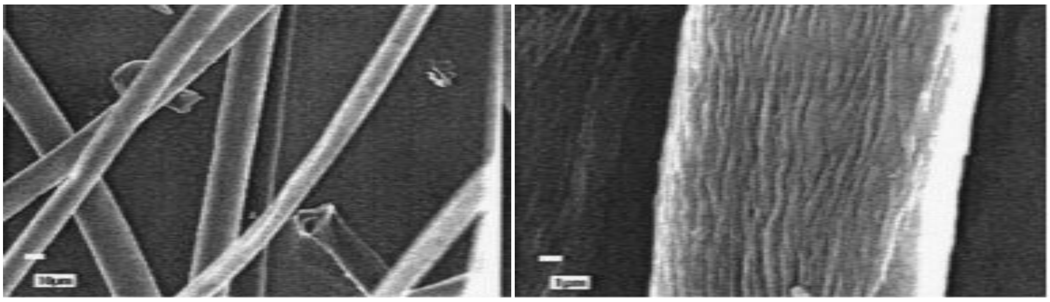
From an investigation of the physicochemical and sorption characteristic of Malaysian kapok, its microstructure exhibit hollow tubular structure with an average external diameter of 2.15 ± 6.5µm. The raw kapok fiber showed smooth surfaces with density of 1.3g/cm^3.Besides, the oil sorption and retention capacity of kapok fibers was affected by its physicochemical characteristics such as surface wax, molecular arrangement, physical configuration and porosity (Abdullah et al., 2010).

The plant wax is the main contributor to the water repellency and solubility. Kapok fiber contain high wax content of about 3% compared to cotton and high acetyl content where it was found the it has contributed to its high hydrophobicity (Abdullah et al., 2010). In some research, esterification as chemical modification has been used in increasing the hydrophobicity of fibers to enhance the oil sorption capacity. For example the modification that has been applied for sawdust, rice husk, bagasse and banana trunk has proved the improvement in their sorption capacity (Wang et al., 2013)

2.3 Modification on kapok fibers

The oil sorption capacity of kapok and a numbers of other organic natural sorbents are attributed to the presence of large and non–collapsing hollow lumens that enable oil sorption through capillary action and provide ample interstitial space for oil entrapment. Kapok fibers has been reported to have a higher amount of wax cutin content which is 3% compared to cotton. Moreover, it has been characterized to have high level of acetyl groups (13%) which is higher than other typical plants fibers which contain about 1-2% of acetyl groups attached to non-cellulosic polysaccharides (Praba Karan et al.,2011).

As the sorption capacity of kapok fibers is dependent on its physicochemical properties, further investigation and modification on the chemical constituents and surface structure seemed to be attractive and has attract numbers of studies. Wang et al.(2012) in Industrial Crops and Products journal studied the effect of kapok fiber treated with various solvents on oil absorbency. This study use solvents including water, hydrochloric acid, sodium hydroxide, sodium chlorite and chloroform. As a result, sodium hydroxide has shown the lowest performance for the oil absorbency. This low performance of the sodium hydroxide treated kapok fiber might be due to the removal of wax content and together with collapsed of the rigid, hollow structure of the kapok fibers reported by Abdullah et al (2010). The spectra image of the raw kapok and sodium hydroxide treated can be compared as in the Figure 1 and the analysis as per Table 4 below.



(a) (b)

Figure 1 SEM of (a) raw kapok fiber and (b) 400% sodium hydroxide treated kapok fiber (Mwaikambo et al., 2002)

Table 4 Characterization of sodium hydroxide treated kapok fibers (Wang et al, 2012)

Analysis	Discussion
FTIR spectra	-Removal of plant wax from fiber surface - Strong alkali resulted in deesterification of kapok fibers
Morphology analysis	-Trivial fibrils, broken hole, shallow pit observed -Alkalization produce serious damage to structure of kapok fibers
XRD spectra	Crystallinity is not affected by NaOH treatment

In other journal, Wang et al. (2012) investigated the surface modification on the kapok fiber known as superhydrophobic which prepared by incorporation of silica nanoparticles onto the kapok fiber via sol-gel method. As a result, the oil/water selectivity has improved and the oil sorption capacity has become higher. This study conclude that the prepared fiber is promising as candidate for the replacement of organic oil sorbent and applied in large scale removal of residual oil.

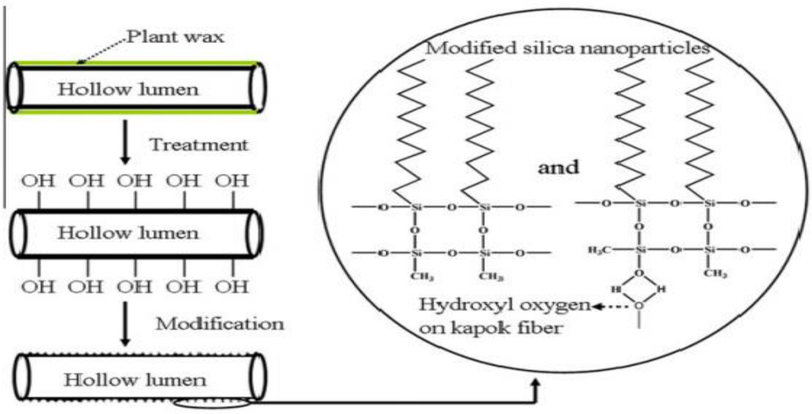


Figure 2 schematic representation of transition from raw kapok fiber to superhydrophobic kapok fiber (Wang et al. 2012)

Recently, another chemical modification studied by Wang et al. (2013) in chemical environmental science journal investigate the acetylated of kapok fibers using two different catalyst on the sorption of oil in water which show higher oil sorption capacity compared to raw fibers.

Table 5 Oil sorption capacity of different types of kapok fibers (Wang et al., 2013)

Sorbent	Type of oil	Oil sorption capacity (g oil/ g sorbent)
Raw kapok fiber (RKF)	Diesel	30.5
Pyridine catalyzed acetylated kapok fiber (PAKF)	Diesel	36.7
N-bromosucinimide catalyzed acetylated kapok fiber (NAKF)	Diesel	34

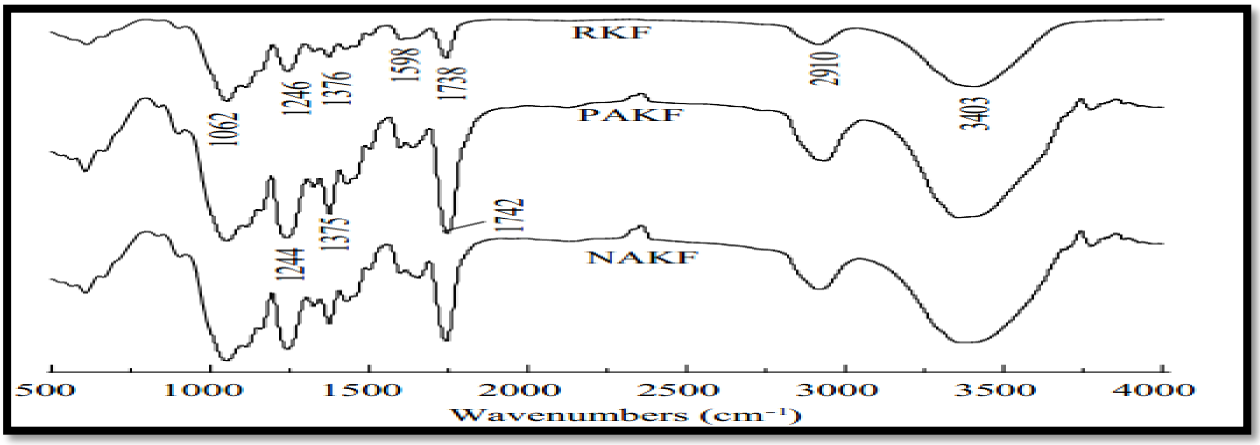
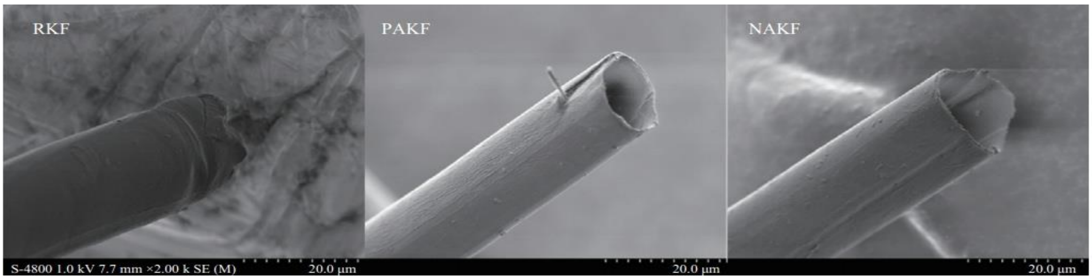


Figure 3 FT-IR spectra of RKF (raw kapok fiber), PAKF (pyridine-catalyzed kapok fiber), and NAKF (NBS-catalyzed kapok fiber) (Wang et al. 2013).



(a) (b) (c)

Figure 4 SEM images of (a) Raw kapok fiber (b) pyridine catalyzed acetylated kapok (c) N-bromosuccinimide catalyzed acetylated kapok fibers (Wang et al., 2013).

Table 6 Result of characterization of acetylated kapok fibers

Analysis	**Discussion**
FTIR spectra (Refer to Figure 3)	Resulted band and interpretation: 1246cm^{-1} & 1376 cm^{-1} – C-O and C-H vibration 1598 cm^{-1}- carbon skeletal stretching of aromatic ring 1738 cm^{-1} – C=O stretching vibration of ketones, carboxylic groups in xylan 2910 cm^{-1} – asymmetric and symmetric stretching vibration in CH_2 and CH3 3403 cm^{-1}- OH stretching vibration
	Apparent increase of absorption bands on PAKF and NAKF at around 1742 cm^{-1}, 1375 cm^{-1}, 1244 cm^{-1}, 2910 cm^{-1} – gives evidence on acetylation of RKF
Morphology analysis (Refer to Figure 4)	-Shows tiny groove on the fiber surface and open lumen orifice - Indicate generation of rough surface beneficial for adhesion of oil

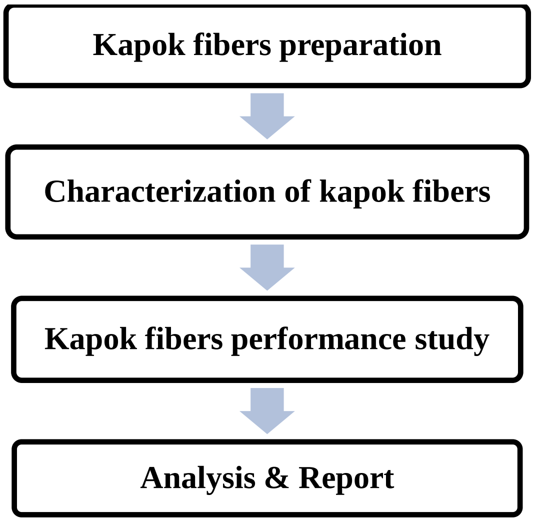
CHAPTER 3

METHODOLOGY

3.1 Research Methodology and Project Activities

The methodology if this research is based on experimental work where three different types of kapok fiber will be prepared including raw kapok fiber, sodium hydroxide treated kapok fiber and surface modified kapok fiber. In this study, raw kapok fiber, sodium hydroxide treated kapok fibers and surface modified kapok fiber will be denoted as RKF, SKF and SMKF. For the performance study, these three types of the kapok fibers will be use and the measurement as well as evaluation on the sorption capacity and efficiency will be conducted. The Fourier Transform Infra Red Spectrometer (FTIR) Field–Emission Scanning Electron Microscope (FESEM) would be used for the characterization to compare and contrast the structural and composition of the raw and modified kapok fibers. Packing density and type of experimental oil are used as the study parameters in batch mode whereas packing density and flow rate would be studied in continuous mode using crude palm oil in water as the residual oil. For continuous operation, several effluent discharge parameters would be determine to evaluate the performance which include Chemical Oxygen Demand (COD) and pH value before and after oil treatment.

3.2 Experimental Procedure/ Approach



3.2.1 Kapok fibers preparation

Three different types of kapok fibers will be prepared for the research project.

- Raw kapok fiber (RKF)
- Sodium hydroxide, NaOH treated kapok fiber (SKF)
- Suurface modified kapok fiber (SMKF)

3.2.1.1 Raw kapok fibers

1) Raw kapok fibers are cut into a small shape using cutting tool.

3.2.1.2 Sodium hydroxide, NaOH treated kapok fibers(SKF) (Wang et al. (2012)

1) Prepare 5 g of raw kapok fibers
2) Prepare 200ml caustic soda of 1% concentration in a beaker
3) Soak the kapok fibers into the beakers containing caustic soda.
4) Place the beaker in a water bath controlled at 20±2°C for 48 hours.
5) Remove the fibers and wash it with distilled water containing 1% of acetic acid to neutralize excess sodium hydroxide and thoroughly rinsed with distilled water
6) Dry the fibers to remove free water.

3.2.1.3 Surface modified kapok fibers(SMKF) (preparation was as reported by Wang et al. (2012) for superhydrophobic kapok fiber preparation and several steps has been eliminated and modified)

1) Place raw kapok into 400ml of sodium chlorite, $NaClO_2$ solution (0.5 wt.%)
2) Adjust to pH 4.5 using certain amount of acetic acid and keep the treatment at 80°C for1 hour.
3) Wash the treated fiber with distilled water until the pH of the filtrate reached neutrality and dries the fibers in oven at 70°C.
4) Add tetraethylorthosilicate (TEOS) (4 wt.%) and sodium dodecyl benzene sulfonate (SDBS)(1.2 mmol/L) to a certain amount of distilled water and stirred for 1 hour at room temperature.
5) Add the $NaClO_2$-treated kapok fibers into the mixture prepared in step 4 and stirred for 20 minutes followed by a gradual addition of $NH_3.H_2O$(1.8wt.%)
6) Maintain the reaction at room temperature for 1 hour.
7) Filtered the obtained sample and cured at 120°C.

3.2.2 Characterization of kapok fibers and experimental oil

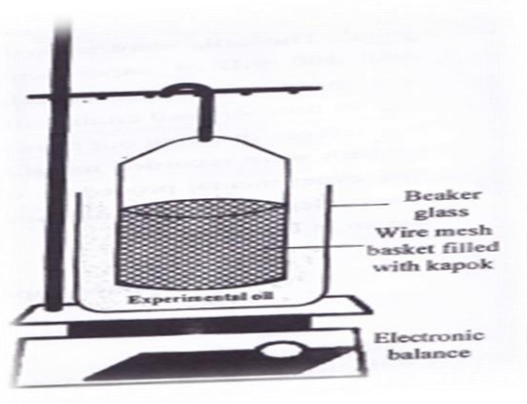
Table 7 Kapok fibers characterization

Parameters for characterization	Equipment
Infrared spectrum	FTIR spectrophotometer, Spectrum One FTIR(Perkin Elmer, USA)
Microstructure/morphology	Scanning Electron Microscopy (SEM, LEO 1430P VPSEM)

3.2.3 Investigation on Oil sorption characteristics of kapok fibers

3.2.3.1 Batch mode (Effect of packing density on fibers sorption capacity and oil retention capacity)

This method followed the method F726-99(ASTM, 1998c), Standard test method for sorbent performance of adsorbents. Several packing density (Table 8) would be investigated. The cell is soaked inside 500mL beaker filled with 400 mL of experimental oil for 30 minutes. The mass of 400 mL of experimental oil would be weight using weighing balance before the cell was soaked into the beaker. The oil-saturated test cell is lifted and the oil left out dripping out from the test cell above oil baths. The transient weight of oil bath is recorded using balance for each minute for 30 minutes.



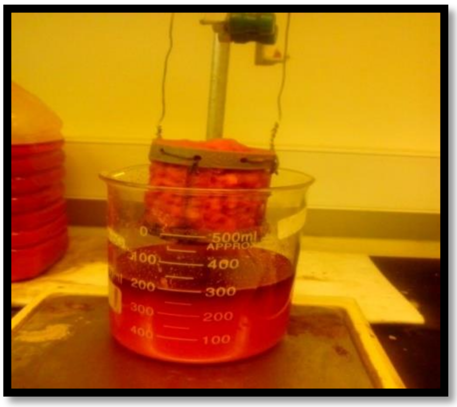


Figure 5 Experimental set up for batch mode of study (Ur Rahmah, Anisa.2009

3.2.3.2 Continuous Packed Bed Column Mode

The column was customized using an acrylic to develop kapok fiber packed-bed column. Wire mesh was used as the perforated disk and placed in the two column ends. The experimental oil in the inlet tank is drawn into the column using a dosing pump. The sample (effluent) is collected when the droplet appeared at the column outlet flow into the outlet tank.

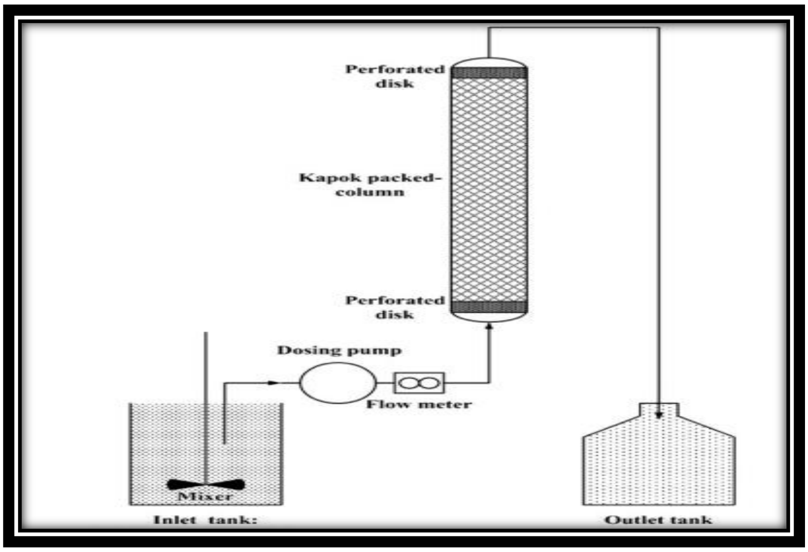


Figure 6 Experimental set up for continuous packed bed column (Rahmah et al., 2011)

Sorption parameters studied

a) Packing density
b) Flow rate
c) Types of experimental oil

A. Packing density

Packing density would be used varied from 0.02 g/cm^3 to 0.10 g/cm^3

Table 8 Packing density variables

No	Packing density(g/cm3)
1	0.02
2	0.04
3	0.06
4	0.08
5	0.09
6	0.10

B. Flow rate for continuous packed bed column

2 flow rates would be investigated in continuous packed bed column which at 0. 5L/h and 1.5 L/h

C. Types of experimental oils

There are two types of experimental oils that will be studied and compare in batch mode which is diesel oil and crude palm oil. In continuous mode, crude palm oil and water mixture of 4000mg/L is used to represent the palm oil mill effluent in this study where it was reported that the oil content in the POME is 4000-6000 mg/L.

3.2.4 Data analysis and report

3.2.4.1 Batch mode of study

In a batch study, the transient weight of the oil bath will be recorded in every one minute for 30 minutes. The average value of the final mass of the oil bath would be calculated and the sorption capacity will be calculated using the following equation.

$$\boldsymbol{oil\ sorption\ capacity = \frac{S_1 - S_F}{S_A}}$$

where :

S_1 = *the weight of the oil before sorption inside the oil bath (g)*

S_F = *the weight of oil inside the beaker at 1 min dripping (g)*

S_A = *dry weight of kapok (g)*

Besides, the percentage of dynamic oil retention could also be calculated using the equation:

$$\boldsymbol{percentage\ of\ dynamic\ oil\ retention\ = \frac{W_t}{W_i} \times 100}$$

where:

W_t = *Weight of oil bath (g) at 1 min dripping*

W_i = *Weight of oil bath (g) at t min dripping, i=1,2,3,4,…*

3.2.4.2 Continuous packed bed column

The kapok fibers performances in continuous packed bed column are evaluated based on Biological Chemical Oxygen Demand (COD) and pH change. These two parameters were chosen as for its simplicity in preparation and measurement as well as faster result analyses. The COD value and pH value of the oil and water mixture would be measured before and after the sorption studies. The COD reduction and pH change would then be calculated and an evaluation the sorption performance of each studied kapok fibers would be made.

3.3 Key Milestones

Several key milestones for this research project must be achieved in order to meet the objective of this project:

Literature and proposal

Gathering as much information as possible from various sources such as journals and websites and prepare the proposal

Experiment Design

Identifying the subjects that need to be investigated and the experimental procedures, as well as the chemicals needed

Experimental work

Conducting all the designed experiment and collect all the data required for the analysis

Data Analysis and Interpretation

The findings obtained are analyzed and interpreted critically. Comparison with other literature readings will also be done.

Documentation and Reporting

The whole research project will be documented and reported in detail. Recommendations or aspects that can be further improved in the future will also be discussed.

3.4 Project Gantt Chart

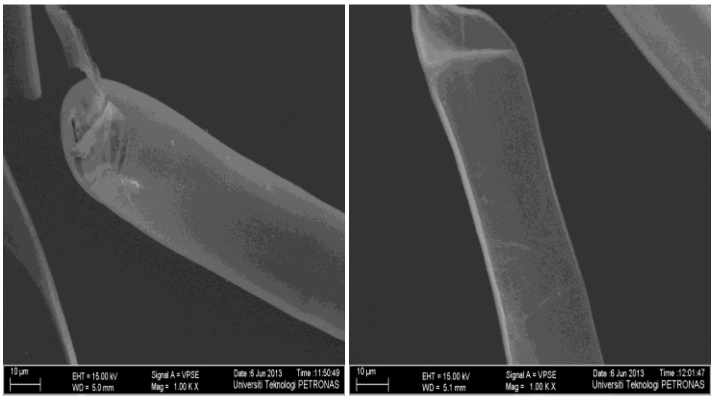
	February				March				April				May				June				July				August			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Literatures, proposal																												
Chemicals, equipment preparation																												
Preparation and study on raw kapok & NaOH treated kapok fiber																												
Preparation and study on surface modified kapok fiber																												
Characterization of kapok fibers																												
Result, Analysis & Report																												

CHAPTER 4

RESULT AND DISCUSSION

4.1 Characterization of kapok fibers and experimental oil

Raw kapok (RKF) and sodium hydroxide treated kapok fiber (SKF) physical properties were characterized based on morphology. The fibers morphologies were analyzed using Field- Emission Scanning Electron Microscope (FESEM). Consequently, the prepared surface modified kapok fiber (SMKF) was unable to undergo characterization due to time and equipment limitations on the project. The SEM microphotographs of raw kapok fiber (RKF) and sodium hydroxide treated kapok fiber (SKF) are shown in Figure 8 below.

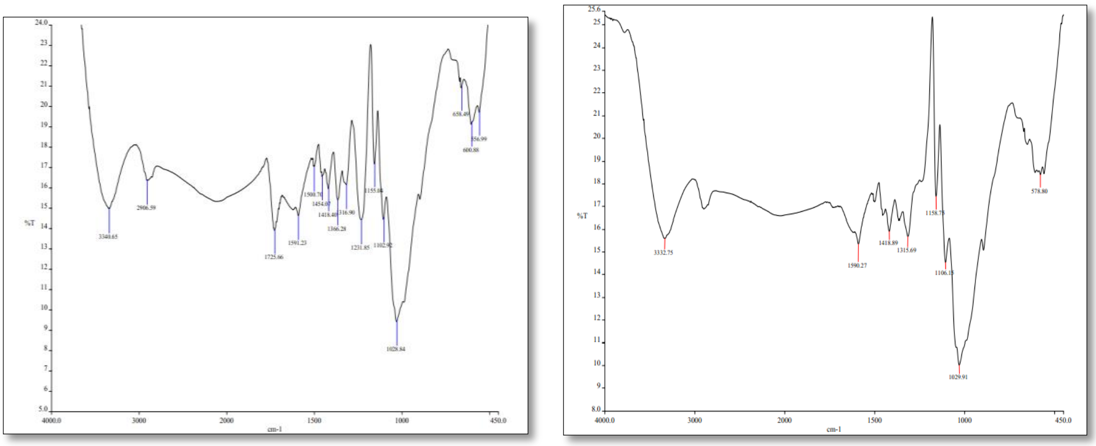


(a) (b)

Figure 7 SEM images of kapok fibers (a) RKF (b) SKF.

From the Figure 7(a), it is obvious that raw kapok fiber (RKF) has a hollow tubular structure or lumen and smooth surface area without any ripple. The smooth surface exhibit by the RKF is concluded due to the plant wax coverage on the surface (Wang et al., 2012) and the structure of the fiber prove the buoyant features exhibit by the kapok fibers and the use of kapok fibers as stuffing materials (Praba Karan et al.,2011). However in according to Figure 7(b), the structure of the sodium hydroxide treated kapok fiber (SKF) has shown a significant different as compared to kapok fiber (RKF). The hollow structure is no longer exhibit by the fibers and it seems that the fiber has been compressed with no tubular configuration as well. This confirmed that the alkaline treatment of the kapok fibers damaged the structure and caused the collapse of the hollow tube. The significant different of these kapok fibers suggest the removal of the plant wax and the hydrophilic surface has been exposed after the treatment (Wang et al., 2012; Abdullah et al., 2010).

To determine the constituent in the kapok fibers prepared, the samples are subjected to analysis using FT-IR spectroscopy. Figure 9 display the FTIR spectra of RKF and SKF.



(a) (b)

Figure 8 FTIR spectra of (a) Raw kapok fiber (RKF) (b) Sodium hydroxide treated kapok fiber (SKF)

As illustrated in Figure 8, the spectra of both raw and sodium hydroxide treated kapok fiber show a similar pattern. In despite of similar pattern in raw kapok fiber and sodium hydroxide treated kapok fiber, several findings have been observed like the disappearance of a few of peaks and the reduction of the intensity at each peak in the sodium hydroxide kapok fiber and Table 9 shows the assignments absorption of infrared band of typical cotton which comparable to this study and has been used as reference to this study (Adebajo., 2004; Mwaikambo et al., 2002; Wang et al., 2012) and Table 10 shows the infrared transmittance of primary peaks (cm^{-1}) of raw kapok and sodium hydroxide treated kapok fiber resulted from this study.

Table 10 Assignments of Infrared absorption bands (Adebajo., 2004; Mwaikambo et al., 2002; Wang et al., 2012)

Frequency (cm^{-1})	Assignment
3337	OH stretching
2891	CH stretching of CH_2 and CH_3 groups
1742	Carbonyl C=O stretching ester
1420	OH and CH_2 bending
1368	C-H bond in –O(C=O)-CH_3 group
1337	CH_3 bending or OH in-plane bonding
1312	O-H deformation and/or CH2 wagging
1234	C-O stretching of acetyl group
1203	OH in-plane bending
1157	C-O-C anti-symmetric bridge stretching in cellulose and hemicelluloses
1017	C-O stretching in cellulose, hemicellulose and lignin
609-668	-OH
467	Symmetric stretching vibration of Si-O-Si

Table 10 Infrared transmittance of peaks (cm^{-1}) of raw kapok and sodium hydroxide treated kapok fiber.

Raw kapok fiber (RKF)	Sodium hydroxide treated kapok fiber (SKF)	Bond type/ Assignment
3340.00	3332.75	OH stretching
2906.59	2906.59	CH stretching of CH_2 and CH_3 groups
1725.66	1590.00	Carbonyl C=O stretching ester
1418.40	1418.89	OH and CH_2 bending
1366.28	1315.69	C-H bond in –O(C=O)-CH_3 group
1231.85	Nil	C-O stretching of acetyl group

1155.04	1158.75	C-O-C anti-symmetric bridge stretching in cellulose and hemicellulose
1029.91	1029.00	C-O stretching in cellulose, hemicellulose and lignin
600.88	578.80	-OH
-	-	Symmetric stretching vibration of Si-O-Si

From the comparison of the raw and sodium hydroxide treated kapok fiber, there is the reduction of the band intensity from raw kapok fiber to sodium hydroxide treated kapok fiber which is from 1725.66 cm^{-1} to 1590.00cm^{-1} for carbonyl C=O stretching ester group which suggesting that there is significant de-esterification of kapok fiber or removal of carboxylic group resulting from the alkali treatment of the fibers (Wang et al., 2012).The peak at 1366.28 cm^{-1} and 1315.69 cm^{-1} for respective raw kapok fiber and sodium hydroxide kapok fiber indicate the presence of lignin and hemicellulose and the intensity is reduced as the kapok fiber undergoes alkali treatment. Besides, the disappearance of the absorbance band at 1231.85 cm^{-1} in the sodium hydroxide treated kapok fiber suggested that the complete removal of hemicelluloses materials as compared to lignin (Mwaikambo et al., 2002). In addition, the peak around 850-900 cm^{-1} and 550-600 cm^{-1} are also observed in both kapok fiber which indicate there is β-glycosidic linkages between monosaccharides and presence of C-OH bonding respectively. From the results of the FT-IR, it is obvious that there were several different between the raw kapok fiber and sodium hydroxide treated kapok fiber due to some reactions involve during the alkalization.

4.2 Properties of experiment oils

The characteristics of experimental oil have importance influence on the oil sorption capacity of kapok assembly (Wang et al., 2012).Table 11 shows the properties of experimental oils based on several parameters as reported by May et al. (2005). Diesel showed both lower density and viscosity values than crude palm oil. As for experiment B (continuous mode of study), crude palm oil used had lower densities than water, causing the oil to float on water surface. The oil density could influence the oil sorption characteristic where the oil with higher density could contribute to higher sorption capacity of the sorbent. In addition, viscosity also plays the main role oil absorption performance where it determines the flow resistance in the sorbent structure. At lower viscosity, the oil would drains out and reaches equilibrium in a shorter time compared to oil with the higher viscosity

Table 11 Physical properties of experimental oil

Experimental oil	Density @ 40°C (ASTM D 4052) (kg/L)	Viscosity @ 40°C (ASTM D 445) (x 10^{-6} m^2/s)
Crude palm oil	0.854-0.857	4.4-5.2
Diesel	0.823	4.0

4.3 Treatment using kapok fibers as sorbent material

4.3.1 Effect of packing density on fibers sorption capacity and oil retention capacity

Sorption capacity is the essential parameter that would be evaluated during the selection of the fibers that would be used as sorbent material. The higher sorption capacity would contribute to the high performance of the residual oil and vice versa. The obvious change of the physical property of kapok fibers after the study is the color of the fiber which changes from white to yellowish-brown for palm oil and light yellowish for diesel batch study. Therefore, the color change could suggest that the experimental oil is trapped inside the structure and shows the ability of the oil to penetrate inside the hollow lumen of kapok fiber structure. Table 12 below shows the sorption capacity of the batch study for raw kapok fiber, sodium hydroxide treated kapok fiber and surface modified kapok fiber at various packing density.

Table 12 Sorption capacities of RKF, SKF and SMKF

Type of oil	Packing density(g/cm3)	Sorption capacity(g oil/g sorbent)		
		Raw kapok fiber (RKF)	Sodium hydroxide treated kapok fiber (SKF)	Surface modified kapok fiber (SMKF)
Crude Palm Oil	0.02	51.24	48.95	56.67
	0.04	29.59	27.70	30.33
	0.06	20.16	18.52	20.47
	0.08	14.50	14.73	14.68
	0.09	11.84	10.98	13.89
	0.10	11.74	10.42	10.97
Diesel Oil	0.02	31.53	20.12	33.7
	0.04	19.48	17.19	20.10
	0.06	14.30	12.59	14.24
	0.08	11.00	10.51	11.20
	0.09	10.66	9.90	10.92
	0.10	9.20	8.87	10.34

The tabulated data in Table 12 is further analyzed as per Figure 9 below and it is observed that the sorption capacities of surface modified kapok fiber, raw kapok fiber and sodium hydroxide treated kapok fiber show a decreasing values as the packing density increase. This inverse proportional trend is observed for both type of experimental oils which suggested that the low packing density portray the best performance in absorption of the residual oils compared the high packing density. It is estimated that the sorption capacities at 0.02g/cm^3 packing density for all types of kapok fibers using both palm oil and diesel oil are reduced at approximately of 50-80 per cent to 0.1g/cm^3 packing density. As comparison, the sorption capacities of the surface modified kapok fiber shows the highest value compared to raw kapok and sodium hydroxide treated kapok fiber for both in palm oil and diesel oil. This indicates that the surface modified kapok fiber has the best performance in oils sorption as compared to both raw kapok fiber and sodium hydroxide treated kapok fiber. Meanwhile, the sorption capacity values of the palm oil show a higher result compared to diesel oil. This could indicate the better performance of kapok fiber in palm oil rather than diesel oil which it could be applied in palm oil industries.

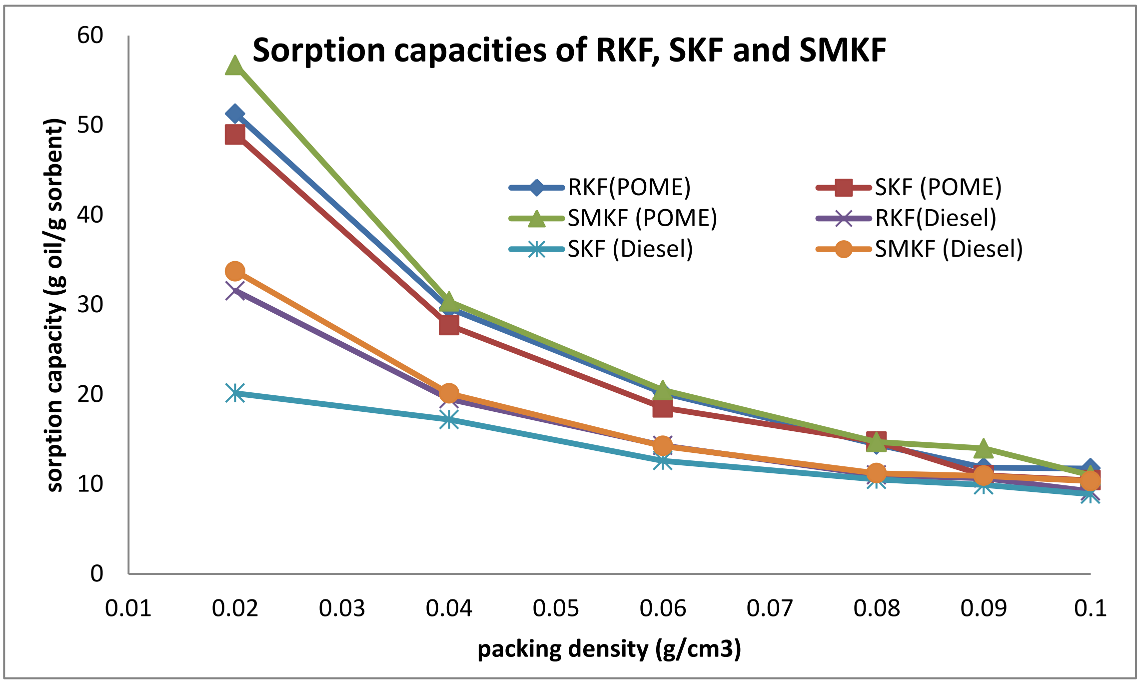


Figure 9 Sorption capacities of RKF,SKF and SHKF

The decreasing order of the sorption capacities of the kapok fibers as the packing densities are increase could be the result of the more compact configuration of the kapok assembly in the cell from the higher packing density. This would make the experimental oil is harder to be absorbed as compared to loosely packed assembly of kapok fiber. The higher sorption capacity of the raw kapok fiber (RKF) compare to the sodium hydroxide treated kapok fiber (SKF) is a result of the removal of the wax from the kapok surface as suggested by Abdullah et al. (2010). This was supported by Lim, T., (2007) where he reported that the interactions and van der Waals forces between the oils and the wax on the kapok fiber initiated the absorption mechanism of oil into the hollow lumen. It was further supported by Wang et al. (2012) which described that the alkalization can change the fine structure of kapok fiber where the hollow lumen to store the oils disappears partially or completely and the damaging effect on tubular structure is prominent. In addition, the surface modified kapok fiber shows a better performance compared to the raw kapok fiber which is concluded due to the incorporation of the silica nano-particles on the surface of the fiber. This SMKF was concluded to have a slight similarity to superhydrophobic kapok fiber prepared by Wang et al. (2012) due similar procedure used for surface modification. In according to Wang et al. (2012), in addition to the rougher surface, the superhydrophobic modified kapok fiber also contributes to the decreasing of the surface energy which affects the oil affinity. The oil affinity is increased due to the surface roughness and low surface energy in which the fabrication can make the oleophilic surface to be more oleophilic as a result of capillary effect.

The capability of the kapok fibers to retain the residual oil within its structure is also one of the important parameters to evaluate kapok fiber performance as sorbent material. In this study, the dynamic oil retention of prepared kapok fibers at various packing densities evaluated for both experimental oils. This was conducted by allowing the oil to drip from the test cell for specified time. The results are shown in Figure 10, 11 and 12 below.

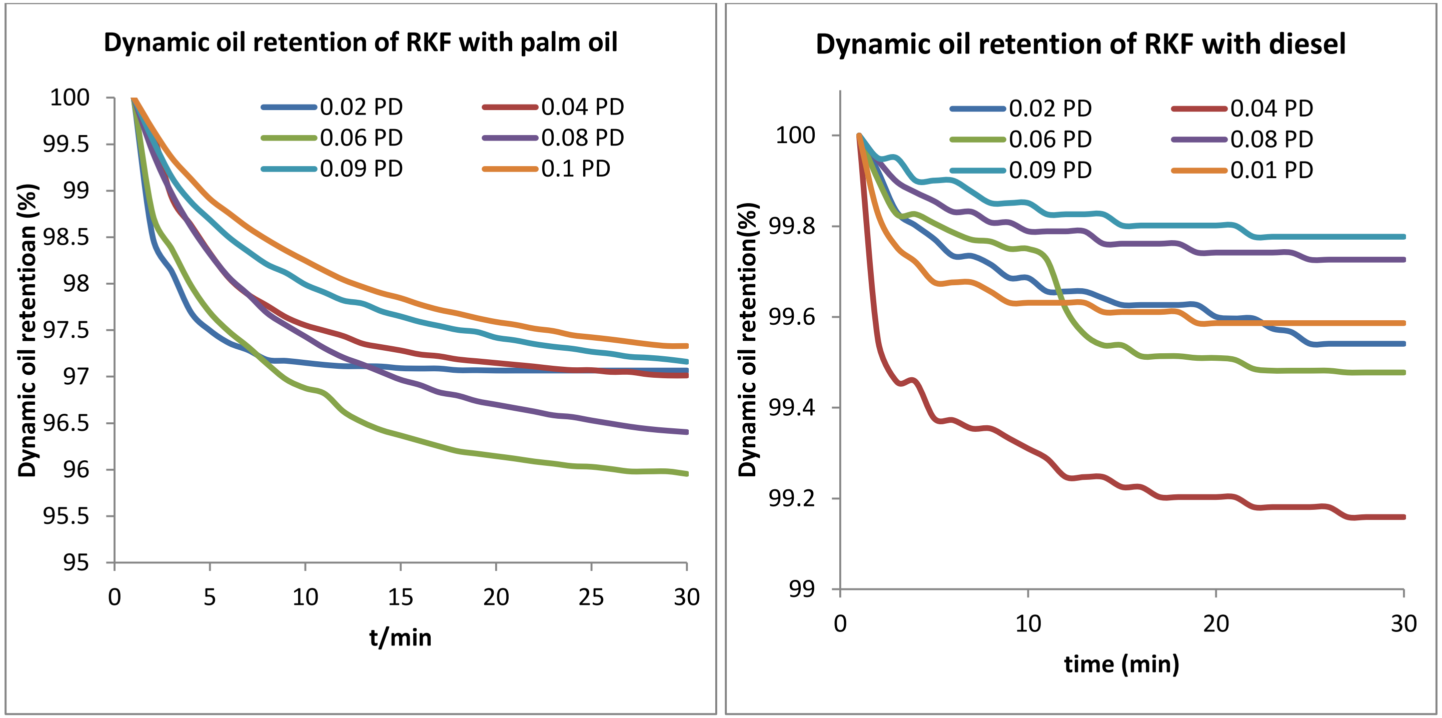


Figure 10 Percentage of dynamic oil retention of raw kapok fiber with palm oil and diesel

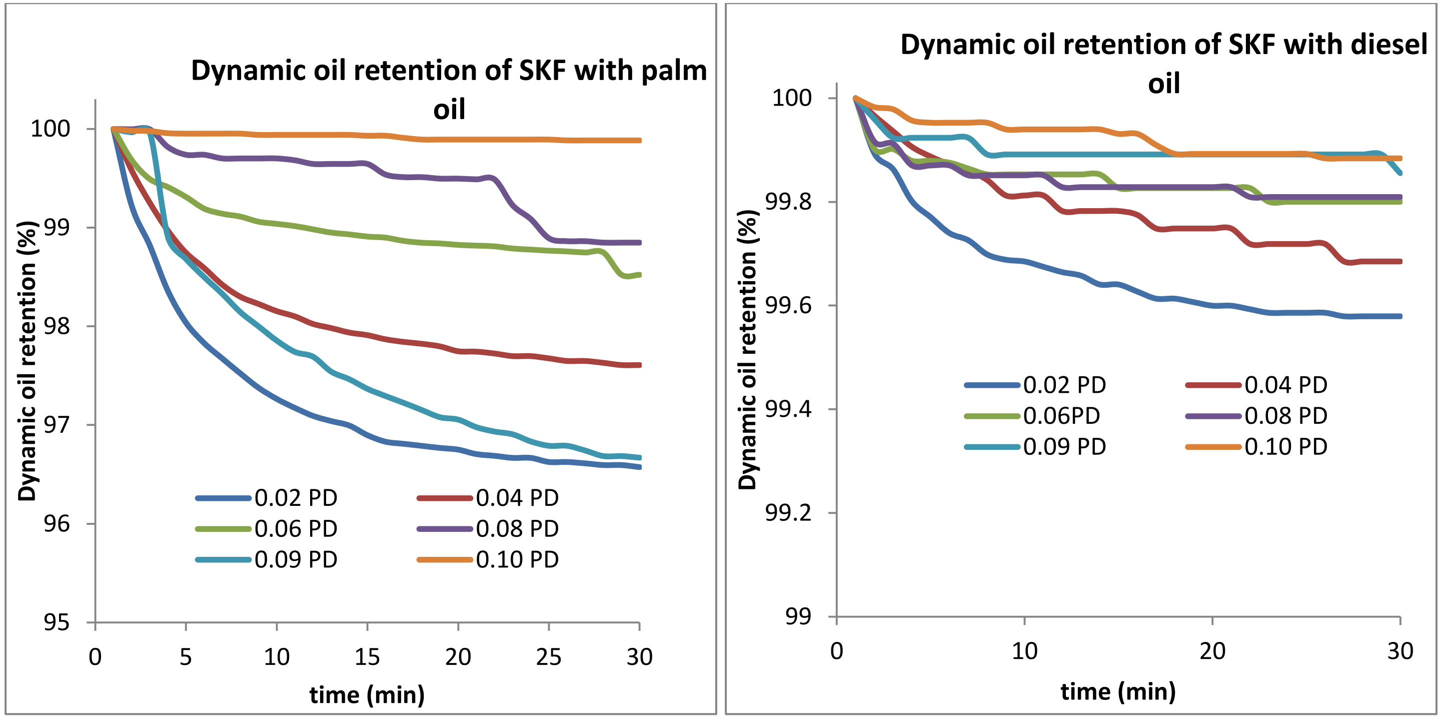


Figure 11 Percentage of dynamic oil retention of sodium hydroxide kapok fiber with palm oil and diesel

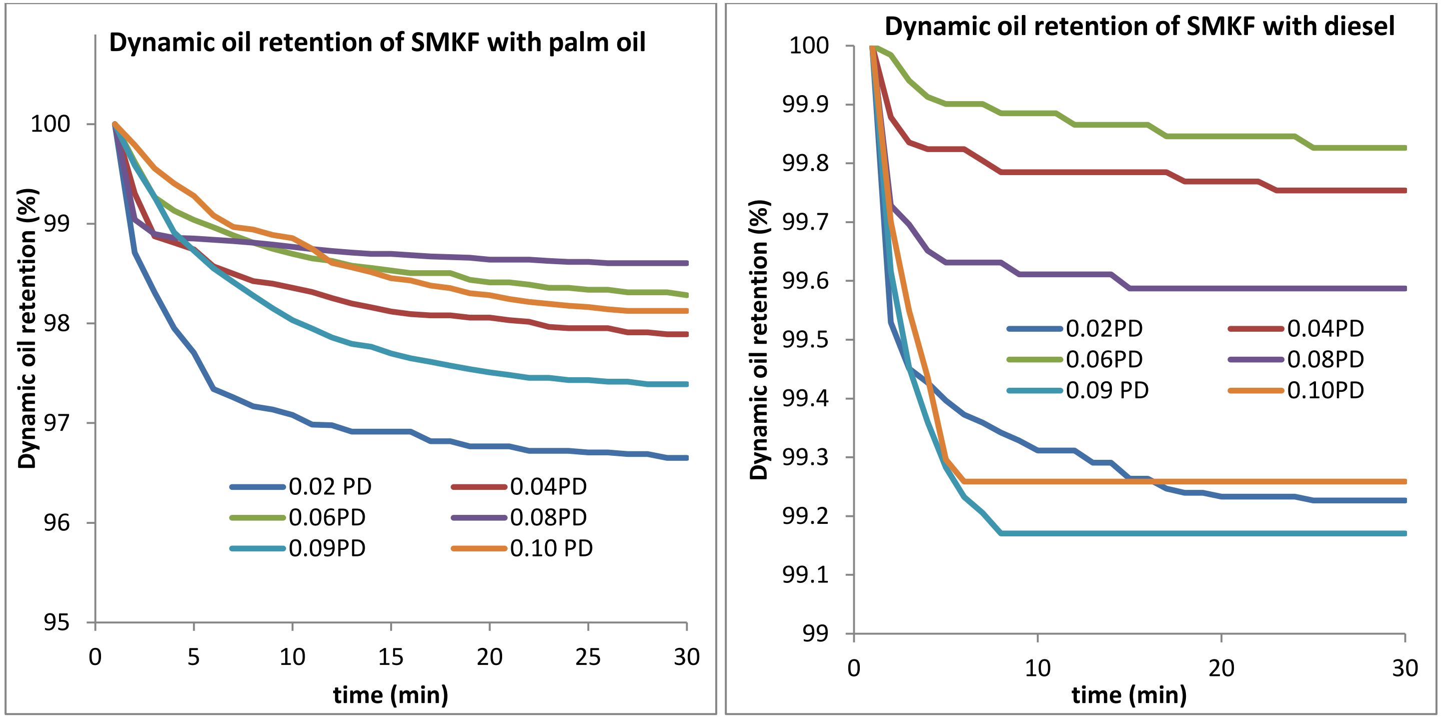


Figure 12 Percentage of dynamic oil retention of surface modified kapok fiber with palm oil and diesel

For crude palm oil as the experimental oil, the amount of oil readily dripping out of any packing density was lesser than diesel. The oil retained was only between 96-99% whereas for the diesel oil the oil was retained more than 99.00% for any packing density. Besides, it is observed that the diesel oil reached equilibrium faster compared to palm oil. This is due to difference in the viscosity value of the experimental oil where the less viscous oil reached the equilibrium faster than more viscous oils (Lim, T., 2007). From the figure, it is obvious that much more oil could be retained at the higher packing density. This was due to the high loosely packed kapok fiber would allow a higher percentages of oil dripping out from the cell. In according to Lim et at., (2007) in his journal, there were two factors that triggered the draining process which were the instantaneous dripping of oil out from external surfaces of kapok assemblies and surface of test cell and oil draining out from the extra lumen liquids, then continue over a longer period. In comparison of the kapok fibers used, the sodium hydroxide treated kapok fiber show the best performance in retaining the oil inside the kapok assembly as compared to raw kapok fiber and surface modified kapok fiber respectively for both type of experimental oil.

4.3.2 Continuous Packed Bed Column Oil Treatment

The performance of different kapok fiber was also evaluated in continuous mode of operation. A continuous flow of residual oil (experimental oil and water) was pumped into the kapok assembly of different packing densities (Figure 13) using a dosing pump with two different flow rate. Upon completing each run of experiments, each of effluent would be evaluated based on several parameters include pH and Chemical Oxygen Demand (COD) and the results as tabulated in the Table 13. Those parameters were selected due to the ease of handling during preparation and measurement as well as faster response time.

For the influent preparation, 4000 mg of experimental oil of palm oil was mixed with 1 liter of distilled water where it was reported that the amount of the oil content in the palm oil mill effluent (POME) is 4000-6000 mg/L (Ahmad, A.L. et al., 2005). As the densities of both palm oil and diesel are lower than water, the oils would float on the water surface during the experimental preparation (Figure 14). Figure 15 shows the influent and effluent that was pumped into the kapok assembly and the results after the treatment respectively for both palm oil and diesel. It is obvious that the resulting effluent give the clearer solution compared to before treatment.

Figure 13 Experiment set up for continuous packed bed column

Figure 14 Palm oil and water solution

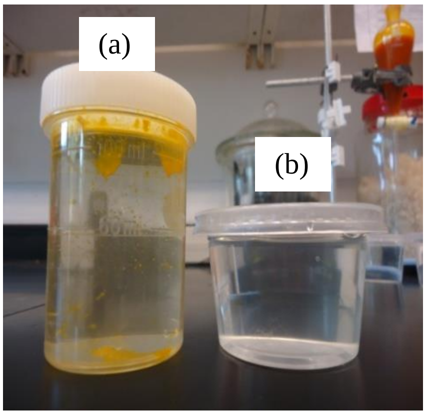


Figure 15 (a) Before and (b) after the oily water treatment

Table 13 Results for evaluation on the influent and effluent

Experimental oil	Kapok fiber	Flow rate (L/h)	Packing density (g/cm3)	COD reduction efficiency (%)	pH value after treatment
pH value: 4.70 COD: 111 mg/L	RKF	0.5	0.04	99	6.30
			0.06	99	6.43
			0.08	99	6.72
		1.5	0.04	99	6.07
			0.06	99	6.82
			0.08	99	6.84
	SKF	0.5	0.04	99	6.23
			0.06	99	6.88
			0.08	99	6.88
		1.5	0.04	99	6.47
			0.06	99	6.47
			0.08	99	6.64
	SMKF	0.5	0.04	99	6.32
			0.06	99	6.47
			0.08	99	6.97
		1.5	0.04	99	6.30
			0.06	99	6.31
			0.08	99	6.79

As a result, the Chemical Oxygen Demand of all of the effluent evaluated shows very small values which even reaching negative value which indicates that the COD reduction efficiency using packed bed column is very high which at more than 99% of each tested effluent. At initial before the treatment, the chemical oxygen demand (COD) value of the oil solution is high which evaluated at 111 mg/L which shows a continuous filtration method of the residual oil solution using packed bed column is very effective in reducing the organic content in the residual oil at various flow rate. The reduction of the organic content in the effluent after each run of treatment is due to the entrapment of the residual oil in the kapok fiber assembly. This proved the high selectivity of the kapok fiber to the oil compared to water. The entrapment of the oil at surface of kapok fiber is obviously observed during the treatment runs as shown in Figure 16.

In addition, from the pH value increment after the residual oil treatment, it was observed that the fiber assembly has higher efficiency as the packing density is increase and low flow rate was used. This shows that treatment was able to reduce the acid value in the oil emulsion and giving the value of pH to almost neutral for all types of kapok fibers and all packing densities.

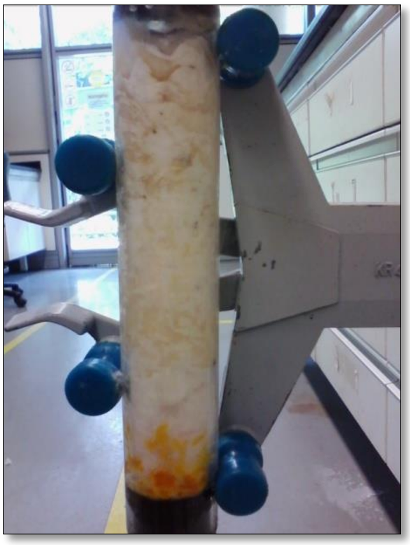


Figure 16 Entrapment of oil in the kapok fiber surface

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

This study evaluates and compares the different prepared kapok fibers on the sorption capacity and efficiency for residual oil removal in palm oil mill effluent treatment and oil spill cleanup. With many studies and researches on the modification of kapok fibers that have been conducted for further improvement, a comparative study is very significant in determining the best fibers for effective and systematic residual oil removal.

From literatures, raw kapok fibers, acetylated kapok fibers and superhydrophobic kapok have been investigated for residual oil removal. Meanwhile, sodium hydroxide treated has been proved of reducing the sorption capacity for oil remediation. Instead of utilizing sodium hydroxide treated kapok fibers for oil remediation, the fiber was investigated for the potential of polymer reinforcement. Apart from that, this study also evaluates and compares the oil sorption capacity of two different residual oils, where this evaluation would help in comparing the compatibility of each kapok fibers to the experimental residual oil.

In conclusion, *Ceiba pentandra* (*L.*) Gaertn (Kapok) is a promising natural sorbent for oily waste water treatment include palm oil mill effluent (POME) and oil spill recovery. The characterization on the kapok fibers proved that there were some different that composed by the raw kapok fibers (RKF) and sodium hydroxide kapok fibers (SKF) which influenced the performance of the fibers the residual oil sorption. The investigation on the properties of the two different experimental oils is also explain the different behavior of and results of the experiments.

The sodium hydroxide treated kapok fiber experienced a huge structural disruption and significant chemical constituent changes which related to plant wax remove after 48 hours of treatment. In addition, the surface modified kapok fiber shows the best performance in oil sorption of both type of experimental oil. This suggests that the surface modified kapok fiber is an effective method in the improvement of the sorption capability of the raw kapok fiber.

Other than that, it was conclude that lower packing density has higher sorption capacity but lower dynamic oil retention. The dynamic oil retention time is lower for palm oil compared to diesel but in overall, more than 95 % of oil still retained inside the kapok assembly. The results would indicate that the Malaysian kapok fiber has excellent properties as oil sorbent material and stable.

Meanwhile, the simple set up of the apparatus to evaluate the performance of the kapok fiber in continuous mode of operation proved the high selectivity of the kapok fiber towards the oil rather than water. Above 99% of COD reductions are observed for all kapok types and at different packing densities and flow rate. This experiment portrayed the significant interaction of the packing density and flow rate in changing the pH where the highest packing density with the lower flow rate resulted to highest pH incremental value.

5.2 Recommendation

This study has proved the high performance of the kapok fibers as sorbent material and compared the three types of prepared kapok fibers. Thus, the modified kapok fiber which is the surface modified kapok fiber which has shown the best performance among the prepared kapok fibers should be further investigated for further commercial and large scale application.

Other than that, another parameter includes packing configuration which the combination of different types of kapok fibers and treatment time should be further study in order to evaluate the performance. The parameters to achieve an optimum performance should also be evaluated like the temperature and the dimension for the kapok packing assembly. Besides, the kapok fiber should also be evaluated for the sorption of other type of effluent or waste such as heavy metal in order to widen the application of this natural sorbent.

REFERENCES

1) Abdullah, M. A. Rahmah, A. U. & Man, Z. 2010, "Physicochemical and sorption characteristics of Malaysian Ceiba pentandra (L.) Gaertn as natural oil sorbent," *Journal of Hazardous Materials* , 683-691.
2) Adebajo, M.O., and Frost, R. L., Infrared and 13C MAS nuclear magnetic resonance spectroscopic study of acetylation cotton. *Spectrochimica Acta Part A, 2004* . 60 (449-53)
3) Ahmad, A. Bhatia, S. Ibrahim, N. & Sumathi, S. 2005, " Adsorption of Residual Oil from Palm Oil Mill Effluent using rubber powder," *Brazilian Journal of Chemical Engineering* , 371-379.
4) Ahmad, A. L. Ismail, S. & Bhatia, S. 2003, "Water recycling from palm oil mill effluent (POME)using membrane technology." *Desalination* , 88.
5) Ahmad, A. L. Sumathi, S. & Hameed, B. 2005, "Adsorption of residue oil from palm oil mill effluent using powder and flake chitosan:Equlibrium and kinetic studies," *Water Research* , 2484.
6) Ahmad, A. L. Sumathi, S. & Hameed, B. 2005, "Residual oil and supended solid removal using natural adsorbents chitosan,betonite and activated carbon: A comparative study," *Chemical Engineering* , 179.
7) Ahmad, A. Sumathi, S. & Hameed, B. 2006, "Coagulation of residue oil and supended soild in palm oil mill effluent by chitosan, alim and PAC," *Chemical Engineering Jurnal* , 99-105.
8) Allen, L. (2011, January 28). *Fruits Pollutes more than Coal?* Retrieved April 17, 2013, from understory.ran.org: http://understory.ran.org/2011/01/28/fruit-pollutes-more-than-coal
9) Hameed, A. A. L., & N. A. (2003). Removal of Residual Oil From Palm Oil Mill Effluent Using Solvent Extraction Method. *Jurnal Teknologi* , 34.
10) Hameed, B. H., Ahmad, A. L., & N. A. (2003). Removal of Residual Oil From Palm Oil Mill Effluent Using Solvent Extraction Method. *Jurnal Teknologi* , 34.
11) *IncidentNews*. (n.d.). Retrieved April 13, 2013, from Office of Response and Restoration,National Ocean Service: http://incidentnews.noaa.gov
12) Karan, C.P., Rengasamy, R.S., Das, D., (2011). Oil spill cleanup by structured fiber assembly. *Indian Journal of Fiber & Textile Research*, 190-200.
13) Lim, T., & Huang, X. (2007). Evaluation of kapok (Ceiba pentandra (L.) Gaertn.)as a natural hollow hydrophobic-oleophilic fibrous sorbent for oil spill cleanup. *Chemosphere* , 955-963.
14) Lim, T., Huang, X. (2007). Evaluation of hydrophobicity/oleophilicity of kapok and its performance in oily water filtration:Comparison of raw and solvent treated fibers. *Industrial Crops and Products 26* , 125-134.
15) May, C.Y., Liang, Y.C., Foon, C.H., Ngan, M.A., Hook, C.C., Basiron, Y. (2005). Key fuel properties of palm oil alkyl esters. *Fuel 84*, 1717-1720.
16) Moss, L. (2010, July 16). *13 largest oil spills in history*. Retrieved April 17, 2013, from Mother nature network: http://www.mnn.com/earth-matters/wilderness-resources/stories/the-13-largest-oil-spills-in-history

17) Mustapa, S. H. (2008). *Treatment of Palm Oil Mill Effluent based on flocculation.* M. Sc. Pahang: Faculty of Chemical and Natural Resource Engineering.
18) Mwaikambo, L. Y., & Ansell, M. P. (2002). Chemical Modification of Hemp, Sisal, Jute, and kapok Fibers by Alkalization. *Applied Polymer Sciene* , 2222-2234.
19) Rahmah, A.U. Abdullah, M.A. 2011, "Evaluation of Malaysian *Ceiba pentandara* (L.) Gaertn. For oily water filtration using factorial design," *Desalination.*266.51-55.
20) Rupani, P. F., Singh, R. P., Ibrahim, M. H., & Esa, N. (2010). Review of Current Pal Oil Mill Effluent (POME) Treatment Methods: Vermicompositing as a Sustainable Practice. *World Applied Science Journal* , 1190-1201.
21) Singh, R., Ibrahim, M. H., Esa, N., & Iliyana, M. (2010). Compositin of waste from palm oil mill:A sustainable waste management practice. *Environmental Sciene Biotechnology* , 331-344.
22) Teas, C., Kalligeros, S., Zanikos, F., Stournas, S., Lois, E., & Anastopoulos, G. (2001). Investigation of effectiveness of absorbent materials in oil spills clean up. *Desalination* , 259-264.
23) Ur Rahmah, Anisa. 2009, *Characterization of Physicochemical Properties and Process Design for Oil Removal using Ceiba pentandra (L.) Gaertn. as a Natural Sorbent.* M. Sc. Universiti Teknologi Petronas.
24) *Use of sorbent materials in oil spill respons*. Retrieved April 13, 2013, from Technical Information Paper: http://www.itopf.com/information-services/publications/documents/TIP8UseofSorbentMaterialsinOilSpillResponse.pdf
25) Wang, J., Zheng, Y., & Wang, A. (2013). Investigation of acetylated kapok fibers on the sorption of oilin water. *Journal of Environmental Science* , 246-253.
26) Wang , J. Zheng, Y. & Wang, A. (2012). Superhydrophobic kapok fiber oil-absorbent: Preparation and high oil absorbency. *Chemical Engineering Journal,* 1-7.
27) Wang.J., Zheng, Y. (2012). Effect of kapok fiber treated with various solvent on oil absorbency. *Industrial Crops and Products* , 178-184.
28) Zainudin, H.,(2012,September 21) Malaysia produced 80m tonnes oil oil palm biomass in 2011.*The Star Online.* Retrieved from http://biz.thestar.com.my

APPENDICES

APPENDIX A

Effect of Packing Density on Fiber Sorption Capacity and Dynamic Oil Retention time

A) Raw Kapok Fiber with Crude Palm Oil

Packing density(g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.02	1.75	1	262	100
		2	266	98.4962406
		3	267	98.12734082
		4	268.19	97.69193482
		5	268.73	97.49562758
		6	269.1	97.36157562
		7	269.31	97.28565594
		8	269.6	97.1810089
		9	269.63	97.17019619
		10	269.69	97.148578
		11	269.75	97.12696942
		12	269.79	97.11256904
		13	269.79	97.11256904
		14	269.8	97.10896961
		15	269.85	97.09097647
		16	269.86	97.08737864
		17	269.86	97.08737864
		18	269.91	97.0693935
		19	269.91	97.0693935
		20	269.92	97.06579727
		21	269.92	97.06579727
		22	269.92	97.06579727
		23	269.92	97.06579727
		24	269.92	97.06579727
		25	269.92	97.06579727
		26	269.92	97.06579727
		27	269.92	97.06579727
		28	269.92	97.06579727
		29	269.92	97.06579727
		30	269.92	97.06579727

Packing density(g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.04	3.5	1	245.52	100.00
		2	246.47	99.61455755
		3	248.19	98.92421129
		4	248.93	98.63013699
		5	249.7	98.32599119
		6	250.38	98.0589504
		7	250.83	97.88302835
		8	251.14	97.76220435
		9	251.46	97.63779528
		10	251.68	97.55244755
		11	251.83	97.49434142
		12	251.98	97.43630447
		13	252.19	97.35516872
		14	252.29	97.31658013
		15	252.38	97.28187654
		16	252.49	97.23949463
		17	252.54	97.22024234
		18	252.63	97.18560741
		19	252.68	97.16637644
		20	252.73	97.14715309
		21	252.78	97.12793734
		22	252.83	97.10872919
		23	252.89	97.08568943
		24	252.93	97.07033567
		25	252.93	97.07033567
		26	252.98	97.05115029
		27	252.98	97.05115029
		28	253.05	97.0243035
		29	253.08	97.01280228
		30	253.08	97.01280228

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.06	5.25	1	242.17	100.00
		2	245.26	98.74011253
		3	246.18	98.37111057
		4	247.16	97.9810649
		5	247.90	97.68858411
		6	248.42	97.48409951
		7	248.84	97.31956277
		8	249.31	97.13609562
		9	249.74	96.9688476
		10	249.98	96.87575006
		11	250.13	96.81765482
		12	250.63	96.62450624
		13	250.93	96.50898657
		14	251.15	96.42444754
		15	251.3	96.36689216
		16	251.45	96.30940545
		17	251.6	96.25198728
		18	251.74	96.19845873
		19	251.81	96.17171677
		20	251.88	96.14498968
		21	251.95	96.11827744
		22	252.03	96.08776733
		23	252.09	96.06489746
		24	252.16	96.0382297
		25	252.18	96.03061305
		26	252.24	96.00777038
		27	252.31	95.98113432
		28	252.31	95.98113432
		29	252.31	95.98113432
		30	252.38	95.95451304

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.08	7.00	1	252.53	100
		2	254.02	99.41343201
		3	255.17	98.96539562
		4	256.08	98.61371446
		5	256.85	98.31808449
		6	257.51	98.06609452
		7	257.99	97.8836389
		8	258.52	97.68296457
		9	258.87	97.55089427
		10	259.19	97.43045642
		11	259.52	97.30656597
		12	259.79	97.20543516
		13	259.99	97.13065887
		14	260.21	97.04853772
		15	260.43	96.96655531
		16	260.58	96.91073759
		17	260.79	96.83270064
		18	260.89	96.79558435
		19	261.05	96.73625742
		20	261.15	96.69921501
		21	261.25	96.66220096
		22	261.35	96.62521523
		23	261.46	96.5845636
		24	261.51	96.5660969
		25	261.61	96.52918466
		26	261.7	96.49598777
		27	261.79	96.46281371
		28	261.86	96.43702742
		29	261.91	96.41861708
		30	261.95	96.40389387

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.09	7.875	1	262.78	100
		2	263.98	99.54542011
		3	265.05	99.14355782
		4	265.76	98.87868754
		5	266.28	98.68559411
		6	266.79	98.49694516
		7	267.2	98.34580838
		8	267.58	98.20614396
		9	267.83	98.1144756
		10	268.17	97.99008092
		11	268.40	97.90611028
		12	268.64	97.81864205
		13	268.73	97.78588174
		14	268.96	97.70226056
		15	269.11	97.64780201
		16	269.27	97.58977977
		17	269.39	97.54630833
		18	269.51	97.50287559
		19	269.57	97.48117372
		20	269.74	97.41973753
		21	269.82	97.39085316
		22	269.93	97.35116512
		23	270.01	97.3223214
		24	270.07	97.30069982
		25	270.16	97.26828546
		26	270.22	97.24668788
		27	270.31	97.2143095
		28	270.34	97.20352149
		29	270.39	97.1855468
		30	270.46	97.1603934

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.1	8.75	1	253.34	100
		2	254.21	99.65776327
		3	254.99	99.3529158
		4	255.57	99.12744062
		5	256.13	98.91070941
		6	256.53	98.75648072
		7	256.93	98.60273226
		8	257.27	98.47242197
		9	257.58	98.35390947
		10	257.86	98.24711084
		11	258.14	98.14054389
		12	258.40	98.04179567
		13	258.60	97.96597061
		14	258.78	97.89782827
		15	258.92	97.84489418
		16	259.10	97.77692011
		17	259.25	97.72034716
		18	259.36	97.67890191
		19	259.49	97.62996647
		20	259.60	97.58859784
		21	259.68	97.55853358
		22	259.79	97.51722545
		23	259.86	97.49095667
		24	259.98	97.44595738
		25	260.04	97.42347331
		26	260.10	97.40099962
		27	260.17	97.3747934
		28	260.24	97.34860129
		29	260.29	97.32990126
		30	260.29	97.32990126

B) Raw Kapok Fiber with Diesel Oil

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.02	1.75	1	266.74	100
		2	266.95	99.92133358
		3	267.19	99.83158052
		4	267.27	99.80169866
		5	267.35	99.77183467
		6	267.45	99.73452982
		7	267.45	99.73452982
		8	267.50	99.71588785
		9	267.58	99.68607519
		10	267.58	99.68607519
		11	267.66	99.65628036
		12	267.66	99.65628036
		13	267.66	99.65628036
		14	267.70	99.64138962
		15	267.74	99.62650332
		16	267.74	99.62650332
		17	267.74	99.62650332
		18	267.74	99.62650332
		19	267.74	99.62650332
		20	267.81	99.60046301
		21	267.82	99.59674408
		22	267.82	99.59674408
		23	267.88	99.57443631
		24	267.90	99.56700261
		25	267.97	99.54099339
		26	267.97	99.54099339
		27	267.97	99.54099339
		28	267.97	99.54099339
		29	267.97	99.54099339
		30	267.97	99.54099339

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.04	3.5	1	267.65	100
		2	268.86	99.54995165
		3	269.11	99.45747092
		4	269.11	99.45747092
		5	269.33	99.3762299
		6	269.34	99.37254028
		7	269.39	99.35409629
		8	269.39	99.35409629
		9	269.45	99.33197254
		10	269.51	99.30985863
		11	269.57	99.28775457
		12	269.68	99.24725601
		13	269.68	99.24725601
		14	269.68	99.24725601
		15	269.74	99.2251798
		16	269.74	99.2251798
		17	269.80	99.20311342
		18	269.80	99.20311342
		19	269.80	99.20311342
		20	269.80	99.20311342
		21	269.80	99.20311342
		22	269.86	99.18105684
		23	269.86	99.18105684
		24	269.86	99.18105684
		25	269.86	99.18105684
		26	269.86	99.18105684
		27	269.92	99.15901008
		28	269.92	99.15901008
		29	269.92	99.15901008
		30	269.92	99.15901008

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.06	5.25	1	247.59	100
		2	247.83	99.90315942
		3	248.02	99.82662688
		4	248.02	99.82662688
		5	248.07	99.80650623
		6	248.12	99.78639368
		7	248.16	99.77030948
		8	248.17	99.76628924
		9	248.21	99.75021151
		10	248.21	99.75021151
		11	248.27	99.72610464
		12	248.54	99.61776776
		13	248.68	99.5616857
		14	248.74	99.53766986
		15	248.74	99.53766986
		16	248.80	99.51366559
		17	248.80	99.51366559
		18	248.80	99.51366559
		19	248.81	99.50966601
		20	248.81	99.50966601
		21	248.82	99.50566675
		22	248.87	99.48567525
		23	248.88	99.48167792
		24	248.88	99.48167792
		25	248.88	99.48167792
		26	248.88	99.48167792
		27	248.89	99.4776809
		28	248.89	99.4776809
		29	248.89	99.4776809
		30	248.89	99.4776809

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.08	7.00	1	255.17	100
		2	255.31	99.9451647
		3	255.43	99.89821086
		4	255.49	99.87475048
		5	255.54	99.85520858
		6	255.60	99.83176839
		7	255.60	99.83176839
		8	255.66	99.8083392
		9	255.66	99.8083392
		10	255.71	99.78882328
		11	255.71	99.78882328
		12	255.71	99.78882328
		13	255.71	99.78882328
		14	255.78	99.7615138
		15	255.78	99.7615138
		16	255.78	99.7615138
		17	255.78	99.7615138
		18	255.78	99.7615138
		19	255.83	99.74201618
		20	255.83	99.74201618
		21	255.83	99.74201618
		22	255.83	99.74201618
		23	255.83	99.74201618
		24	255.83	99.74201618
		25	255.87	99.72642357
		26	255.87	99.72642357
		27	255.87	99.72642357
		28	255.87	99.72642357
		29	255.87	99.72642357
		30	255.87	99.72642357

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.09	7.875	1	241.51	100
		2	241.63	99.95033729
		3	241.63	99.95033729
		4	241.75	99.90072389
		5	241.75	99.90072389
		6	241.75	99.90072389
		7	241.81	99.87593565
		8	241.87	99.85115971
		9	241.87	99.85115971
		10	241.87	99.85115971
		11	241.93	99.82639606
		12	241.93	99.82639606
		13	241.93	99.82639606
		14	241.93	99.82639606
		15	241.99	99.8016447
		16	241.99	99.8016447
		17	241.99	99.8016447
		18	241.99	99.8016447
		19	241.99	99.8016447
		20	241.99	99.8016447
		21	241.99	99.8016447
		22	242.05	99.7769056
		23	242.05	99.7769056
		24	242.05	99.7769056
		25	242.05	99.7769056
		26	242.05	99.7769056
		27	242.05	99.7769056
		28	242.05	99.7769056
		29	242.05	99.7769056
		30	242.05	99.7769056

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.1	8.75	1	243.26	100
		2	243.68	99.82764281
		3	243.86	99.75395719
		4	243.94	99.72124293
		5	244.05	99.67629584
		6	244.05	99.67629584
		7	244.05	99.67629584
		8	244.10	99.65587874
		9	244.16	99.63138925
		10	244.16	99.63138925
		11	244.16	99.63138925
		12	244.16	99.63138925
		13	244.16	99.63138925
		14	244.21	99.61099054
		15	244.21	99.61099054
		16	244.21	99.61099054
		17	244.21	99.61099054
		18	244.21	99.61099054
		19	244.27	99.58652311
		20	244.27	99.58652311
		21	244.27	99.58652311
		22	244.27	99.58652311
		23	244.27	99.58652311
		24	244.27	99.58652311
		25	244.27	99.58652311
		26	244.27	99.58652311
		27	244.27	99.58652311
		28	244.27	99.58652311
		29	244.27	99.58652311
		30	244.27	99.58652311

C) Sodium Hydroxide Treated Kapok Fiber with Crude Palm Oil

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.02	1.75	1	269.18	100
		2	271.28	99.22589207
		3	272.39	98.82154264
		4	273.67	98.35933789
		5	274.57	98.03693047
		6	275.15	97.8302744
		7	275.59	97.67408106
		8	276.02	97.5219187
		9	276.43	97.37727454
		10	276.75	97.26467931
		11	277.01	97.17338724
		12	277.24	97.09277161
		13	277.39	97.04026821
		14	277.52	96.99481118
		15	277.80	96.89704824
		16	277.99	96.83082125
		17	278.05	96.80992627
		18	278.11	96.78904031
		19	278.17	96.76816335
		20	278.22	96.75077277
		21	278.35	96.70558649
		22	278.40	96.68821839
		23	278.46	96.6673849
		24	278.46	96.6673849
		25	278.58	96.62574485
		26	278.58	96.62574485
		27	278.62	96.6118728
		28	278.67	96.59453834
		29	278.67	96.59453834
		30	278.73	96.5737452

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.04	3.5	1	252.56	100
		2	253.62	99.58205189
		3	254.46	99.25332076
		4	255.19	98.96939535
		5	255.77	98.74496618
		6	256.17	98.59077956
		7	256.61	98.42172947
		8	256.93	98.29914763
		9	257.12	98.22650902
		10	257.31	98.15397769
		11	257.45	98.10060206
		12	257.65	98.02445178
		13	257.76	97.98261949
		14	257.88	97.93702497
		15	257.95	97.91044776
		16	258.06	97.8687127
		17	258.13	97.84217255
		18	258.18	97.82322411
		19	258.25	97.79670862
		20	258.38	97.74750368
		21	258.39	97.74372073
		22	258.44	97.7248104
		23	258.51	97.69834823
		24	258.51	97.69834823
		25	258.57	97.67567777
		26	258.64	97.64924219
		27	258.64	97.64924219
		28	258.69	97.63036839
		29	258.75	97.60772947
		30	258.75	97.60772947

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.06	5.25	1	266.66	100
		2	267.50	99.68598131
		3	268.02	99.49257518
		4	268.24	99.41097525
		5	268.51	99.31101263
		6	268.83	99.19279842
		7	268.97	99.14116816
		8	269.05	99.11168928
		9	269.19	99.06014339
		10	269.25	99.03806871
		11	269.31	99.01600386
		12	269.40	98.98292502
		13	269.49	98.94986827
		14	269.54	98.93151295
		15	269.60	98.90949555
		16	269.63	98.89849052
		17	269.72	98.86549014
		18	269.77	98.8471661
		19	269.79	98.83983839
		20	269.83	98.82518623
		21	269.85	98.81786178
		22	269.87	98.81053841
		23	269.93	98.78857482
		24	269.96	98.77759668
		25	269.99	98.76662099
		26	270.01	98.75930521
		27	270.04	98.74833358
		28	270.04	98.74833358
		29	270.66	98.52213109
		30	270.66	98.52213109

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.08	7.00	1	266.94	100
		2	266.95	99.99625398
		3	266.95	99.99625398
		4	267.43	99.81677448
		5	267.64	99.73845464
		6	267.64	99.73845464
		7	267.74	99.70120266
		8	267.74	99.70120266
		9	267.74	99.70120266
		10	267.74	99.70120266
		11	267.79	99.6825871
		12	267.89	99.64537683
		13	267.89	99.64537683
		14	267.89	99.64537683
		15	267.89	99.64537683
		16	268.18	99.53762398
		17	268.25	99.51164958
		18	268.25	99.51164958
		19	268.29	99.49681315
		20	268.29	99.49681315
		21	268.31	99.48939659
		22	268.31	99.48939659
		23	269.02	99.22682328
		24	269.40	99.08685969
		25	269.93	98.89230541
		26	270.01	98.86300507
		27	270.01	98.86300507
		28	270.05	98.84836141
		29	270.05	98.84836141
		30	270.05	98.84836141

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.09	7.875	1	233.66	100
		2	233.74	99.96577394
		3	233.74	99.96577394
		4	236.24	98.90789028
		5	236.78	98.68232114
		6	237.22	98.49928337
		7	237.63	98.32933552
		8	238.08	98.14348118
		9	238.43	97.99941283
		10	238.78	97.85576681
		11	239.06	97.74115285
		12	239.18	97.69211473
		13	239.55	97.54122313
		14	239.74	97.46391925
		15	239.98	97.3664472
		16	240.16	97.29347102
		17	240.33	97.22464944
		18	240.51	97.15188558
		19	240.69	97.07923055
		20	240.75	97.05503634
		21	240.94	96.97850087
		22	241.05	96.93424601
		23	241.12	96.90610484
		24	241.30	96.83381683
		25	241.41	96.78969388
		26	241.41	96.78969388
		27	241.53	96.7416056
		28	241.67	96.68556296
		29	241.67	96.68556296
		30	241.71	96.6695627

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.1	8.75	1	232.26	100
		2	232.3	99.98278089
		3	232.31	99.97847703
		4	232.36	99.95696333
		5	232.37	99.9526617
		6	232.37	99.9526617
		7	232.37	99.9526617
		8	232.37	99.9526617
		9	232.40	99.93975904
		10	232.40	99.93975904
		11	232.40	99.93975904
		12	232.40	99.93975904
		13	232.40	99.93975904
		14	232.40	99.93975904
		15	232.42	99.93115911
		16	232.42	99.93115911
		17	232.47	99.90966576
		18	232.51	99.89247774
		19	232.51	99.89247774
		20	232.51	99.89247774
		21	232.51	99.89247774
		22	232.51	99.89247774
		23	232.51	99.89247774
		24	232.51	99.89247774
		25	232.51	99.89247774
		26	232.53	99.88388595
		27	232.53	99.88388595
		28	232.53	99.88388595
		29	232.53	99.88388595
		30	232.53	99.88388595

D) Sodium Hydroxide Treated Kapok Fiber with Diesel Oil

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.02	1.75	1	291.09	100
		2	291.40	99.89361702
		3	291.49	99.86277402
		4	291.67	99.80114513
		5	291.76	99.7703592
		6	291.85	99.73959226
		7	291.89	99.72592415
		8	291.97	99.69859917
		9	292.00	99.68835616
		10	292.01	99.6849423
		11	292.04	99.6747021
		12	292.07	99.664464
		13	292.09	99.65763977
		14	292.14	99.64058328
		15	292.14	99.64058328
		16	292.18	99.6269423
		17	292.22	99.61330504
		18	292.22	99.61330504
		19	292.24	99.60648782
		20	292.26	99.59967153
		21	292.26	99.59967153
		22	292.28	99.59285617
		23	292.30	99.58604174
		24	292.30	99.58604174
		25	292.30	99.58604174
		26	292.30	99.58604174
		27	292.32	99.57922824
		28	292.32	99.57922824
		29	292.32	99.57922824
		30	292.32	99.57922824

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.04	3.5	1	265.86	100
		2	265.95	99.96615905
		3	266.03	99.93609743
		4	266.11	99.90605389
		5	266.16	99.88728584
		6	266.20	99.87227648
		7	266.23	99.86102242
		8	266.28	99.84227129
		9	266.36	99.81228413
		10	266.36	99.81228413
		11	266.36	99.81228413
		12	266.44	99.78231497
		13	266.44	99.78231497
		14	266.44	99.78231497
		15	266.44	99.78231497
		16	266.46	99.77482549
		17	266.53	99.74862117
		18	266.53	99.74862117
		19	266.53	99.74862117
		20	266.53	99.74862117
		21	266.53	99.74862117
		22	266.61	99.71869022
		23	266.61	99.71869022
		24	266.61	99.71869022
		25	266.61	99.71869022
		26	266.61	99.71869022
		27	266.70	99.68503937
		28	266.70	99.68503937
		29	266.70	99.68503937
		30	266.70	99.68503937

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.06	5.25	1	264.76	100
		2	265.02	99.9018942
		3	265.02	99.9018942
		4	265.08	99.87928173
		5	265.08	99.87928173
		6	265.09	99.87551398
		7	265.12	99.86421243
		8	265.15	99.85291345
		9	265.15	99.85291345
		10	265.15	99.85291345
		11	265.15	99.85291345
		12	265.15	99.85291345
		13	265.15	99.85291345
		14	265.15	99.85291345
		15	265.22	99.82655908
		16	265.22	99.82655908
		17	265.22	99.82655908
		18	265.22	99.82655908
		19	265.22	99.82655908
		20	265.22	99.82655908
		21	265.22	99.82655908
		22	265.22	99.82655908
		23	265.29	99.80021863
		24	265.29	99.80021863
		25	265.29	99.80021863
		26	265.29	99.80021863
		27	265.29	99.80021863
		28	265.29	99.80021863
		29	265.29	99.80021863
		30	265.29	99.80021863

Packing density (g/cm^3)	weight of kapok used	time(min)	S_F	Percentage dynamic oil retention
0.08	7.00	1	261.77	100
		2	261.99	99.91602733
		3	262.00	99.91221374
		4	262.11	99.87028347
		5	262.11	99.87028347
		6	262.11	99.87028347
		7	262.16	99.85123589
		8	262.16	99.85123589
		9	262.16	99.85123589
		10	262.16	99.85123589
		11	262.16	99.85123589
		12	262.22	99.82838838
		13	262.22	99.82838838
		14	262.22	99.82838838
		15	262.22	99.82838838
		16	262.22	99.82838838
		17	262.22	99.82838838
		18	262.22	99.82838838
		19	262.22	99.82838838
		20	262.22	99.82838838
		21	262.22	99.82838838
		22	262.27	99.80935677
		23	262.27	99.80935677
		24	262.27	99.80935677
		25	262.27	99.80935677
		26	262.27	99.80935677
		27	262.27	99.80935677
		28	262.27	99.80935677
		29	262.27	99.80935677
		30	262.27	99.80935677

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.09	7.875	1	248.48	100
		2	248.58	99.9597715
		3	248.67	99.92359352
		4	248.67	99.92359352
		5	248.67	99.92359352
		6	248.67	99.92359352
		7	248.67	99.92359352
		8	248.75	99.89145729
		9	248.75	99.89145729
		10	248.75	99.89145729
		11	248.75	99.89145729
		12	248.75	99.89145729
		13	248.75	99.89145729
		14	248.75	99.89145729
		15	248.75	99.89145729
		16	248.75	99.89145729
		17	248.75	99.89145729
		18	248.75	99.89145729
		19	248.75	99.89145729
		20	248.75	99.89145729
		21	248.75	99.89145729
		22	248.75	99.89145729
		23	248.75	99.89145729
		24	248.75	99.89145729
		25	248.75	99.89145729
		26	248.75	99.89145729
		27	248.75	99.89145729
		28	248.75	99.89145729
		29	248.75	99.89145729
		30	248.84	99.85532873

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.1	8.75	1	251.48	100
		2	251.74	99.89671884
		3	252.07	99.76593803
		4	252.56	99.57237884
		5	252.80	99.4778481
		6	252.88	99.44637773
		7	252.88	99.44637773
		8	252.88	99.44637773
		9	252.88	99.44637773
		10	252.95	99.41885748
		11	252.95	99.41885748
		12	252.95	99.41885748
		13	252.95	99.41885748
		14	252.95	99.41885748
		15	252.95	99.41885748
		16	252.95	99.41885748
		17	252.95	99.41885748
		18	252.95	99.41885748
		19	252.95	99.41885748
		20	252.95	99.41885748
		21	252.95	99.41885748
		22	253.02	99.39135246
		23	253.02	99.39135246
		24	253.02	99.39135246
		25	253.02	99.39135246
		26	253.02	99.39135246
		27	253.02	99.39135246
		28	253.02	99.39135246
		29	253.02	99.39135246
		30	253.02	99.39135246

E) Surface Modified Kapok Fiber with Crude Palm Oil

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.02	1.75	1	261.76	100
		2	265.18	98.71031
		3	266.25	98.31362
		4	267.23	97.95307
		5	267.91	97.70445
		6	268.91	97.34112
		7	269.14	97.25793
		8	269.39	97.16768
		9	269.48	97.13522
		10	269.63	97.08119
		11	269.90	96.98407
		12	269.91	96.98047
		13	270.09	96.91584
		14	270.09	96.91584
		15	270.09	96.91584
		16	270.09	96.91584
		17	270.36	96.81906
		18	270.36	96.81906
		19	270.51	96.76537
		20	270.51	96.76537
		21	270.51	96.76537
		22	270.63	96.72246
		23	270.63	96.72246
		24	270.63	96.72246
		25	270.68	96.7046
		26	270.68	96.7046
		27	270.72	96.69031
		28	270.72	96.69031
		29	270.83	96.65104
		30	270.83	96.65104

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.04	3.75	1	254.88	100
		2	256.66	99.30648
		3	257.78	98.87501
		4	257.95	98.80985
		5	258.12	98.74477
		6	258.57	98.57292
		7	258.76	98.50054
		8	258.96	98.42447
		9	259.03	98.39787
		10	259.14	98.3561
		11	259.25	98.31437
		12	259.41	98.25373
		13	259.55	98.20073
		14	259.65	98.16291
		15	259.76	98.12134
		16	259.83	98.09491
		17	259.87	98.07981
		18	259.87	98.07981
		19	259.93	98.05717
		20	259.93	98.05717
		21	259.99	98.03454
		22	260.04	98.01569
		23	260.17	97.96671
		24	260.21	97.95165
		25	260.21	97.95165
		26	260.21	97.95165
		27	260.32	97.91026
		28	260.32	97.91026
		29	260.37	97.89146
		30	260.37	97.89146

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.06	5.25	1	249.33	100
		2	250.28	99.62043
		3	251.17	99.26743
		4	251.51	99.13324
		5	251.75	99.03873
		6	251.94	98.96404
		7	252.14	98.88554
		8	252.33	98.81108
		9	252.49	98.74847
		10	252.62	98.69765
		11	252.73	98.65469
		12	252.80	98.62737
		13	252.92	98.58058
		14	252.98	98.5572
		15	253.05	98.52993
		16	253.11	98.50658
		17	253.05	98.52993
		18	253.11	98.50658
		19	253.29	98.43657
		20	253.35	98.41326
		21	253.35	98.41326
		22	253.41	98.38996
		23	253.49	98.35891
		24	253.49	98.35891
		25	253.54	98.33951
		26	253.54	98.33951
		27	253.61	98.31237
		28	253.61	98.31237
		29	253.61	98.31237
		30	253.68	98.28524

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.08	7.00	1	262.47	100
		2	265.01	99.04155
		3	265.40	98.89601
		4	265.50	98.85876
		5	265.52	98.85131
		6	265.55	98.84014
		7	265.59	98.82526
		8	265.63	98.81038
		9	265.68	98.79178
		10	265.74	98.76947
		11	265.80	98.74718
		12	265.85	98.72861
		13	265.90	98.71004
		14	265.93	98.69891
		15	265.93	98.69891
		16	265.97	98.68406
		17	266.00	98.67293
		18	266.02	98.66551
		19	266.04	98.6581
		20	266.09	98.63956
		21	266.09	98.63956
		22	266.09	98.63956
		23	266.12	98.62844
		24	266.15	98.61732
		25	266.15	98.61732
		26	266.18	98.60621
		27	266.18	98.60621
		28	266.18	98.60621
		29	266.18	98.60621
		30	266.18	98.60621

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.09	7.875	1	241.21	100
		2	242.21	99.58714
		3	242.98	99.27154
		4	243.86	98.91331
		5	244.31	98.73112
		6	244.75	98.55363
		7	245.09	98.41691
		8	245.43	98.28057
		9	245.75	98.15259
		10	246.05	98.03292
		11	246.26	97.94932
		12	246.49	97.85793
		13	246.65	97.79445
		14	246.72	97.7667
		15	246.89	97.69938
		16	247.01	97.65192
		17	247.10	97.61635
		18	247.20	97.57686
		19	247.29	97.54135
		20	247.37	97.5098
		21	247.44	97.48222
		22	247.51	97.45465
		23	247.51	97.45465
		24	247.57	97.43103
		25	247.57	97.43103
		26	247.61	97.41529
		27	247.61	97.41529
		28	247.67	97.39169
		29	247.67	97.39169
		30	247.67	97.39169

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.1	8.75	1	259.28	100
		2	259.82	99.79216
		3	260.44	99.5546
		4	260.83	99.40574
		5	261.16	99.28013
		6	261.68	99.08285
		7	261.98	98.96939
		8	262.05	98.94295
		9	262.20	98.88635
		10	262.28	98.85618
		11	262.56	98.75076
		12	262.94	98.60805
		13	263.06	98.56307
		14	263.19	98.51438
		15	263.35	98.45453
		16	263.41	98.4321
		17	263.55	98.37981
		18	263.62	98.35369
		19	263.76	98.30149
		20	263.81	98.28286
		21	263.91	98.24561
		22	263.99	98.21584
		23	264.04	98.19724
		24	264.09	98.17865
		25	264.13	98.16378
		26	264.19	98.14149
		27	264.23	98.12663
		28	264.23	98.12663
		29	264.23	98.12663
		30	264.23	98.12663

F) Surface Modified Kapok Fiber with Diesel Oil

Packing density (g/cm^3)	Weight of kapok used (g)	time (min)	S_F	Percentage dynamic oil retention
0.02	1.75	1	289.87	100
		2	291.24	99.5296
		3	291.47	99.45106
		4	291.54	99.42718
		5	291.63	99.3965
		6	291.70	99.37264
		7	291.74	99.35902
		8	291.79	99.34199
		9	291.83	99.32838
		10	291.88	99.31136
		11	291.88	99.31136
		12	291.88	99.31136
		13	291.94	99.29095
		14	291.94	99.29095
		15	292.02	99.26375
		16	292.02	99.26375
		17	292.07	99.24676
		18	292.09	99.23996
		19	292.09	99.23996
		20	292.11	99.23317
		21	292.11	99.23317
		22	292.11	99.23317
		23	292.11	99.23317
		24	292.11	99.23317
		25	292.13	99.22637
		26	292.13	99.22637
		27	292.13	99.22637
		28	292.13	99.22637
		29	292.13	99.22637
		30	292.13	99.22637

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.04	3.75	1	255.18	100
		2	255.49	99.87866
		3	255.6	99.83568
		4	255.63	99.82396
		5	255.63	99.82396
		6	255.63	99.82396
		7	255.68	99.80444
		8	255.73	99.78493
		9	255.73	99.78493
		10	255.73	99.78493
		11	255.73	99.78493
		12	255.73	99.78493
		13	255.73	99.78493
		14	255.73	99.78493
		15	255.73	99.78493
		16	255.73	99.78493
		17	255.73	99.78493
		18	255.77	99.76932
		19	255.77	99.76932
		20	255.77	99.76932
		21	255.77	99.76932
		22	255.77	99.76932
		23	255.81	99.75372
		24	255.81	99.75372
		25	255.81	99.75372
		26	255.81	99.75372
		27	255.81	99.75372
		28	255.81	99.75372
		29	255.81	99.75372
		30	255.81	99.75372

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.06	5.25	1	252.57	100
		2	252.61	99.98417
		3	252.72	99.94065
		4	252.79	99.91297
		5	252.82	99.90112
		6	252.82	99.90112
		7	252.82	99.90112
		8	252.86	99.88531
		9	252.86	99.88531
		10	252.86	99.88531
		11	252.86	99.88531
		12	252.91	99.86556
		13	252.91	99.86556
		14	252.91	99.86556
		15	252.91	99.86556
		16	252.91	99.86556
		17	252.96	99.84583
		18	252.96	99.84583
		19	252.96	99.84583
		20	252.96	99.84583
		21	252.96	99.84583
		22	252.96	99.84583
		23	252.96	99.84583
		24	252.96	99.84583
		25	253.01	99.82609
		26	253.01	99.82609
		27	253.01	99.82609
		28	253.01	99.82609
		29	253.01	99.82609
		30	253.01	99.82609

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.08	7.00	1	246.05	100
		2	246.72	99.72844
		3	246.80	99.69611
		4	246.91	99.65169
		5	246.96	99.63152
		6	246.96	99.63152
		7	246.96	99.63152
		8	246.96	99.63152
		9	247.01	99.61135
		10	247.01	99.61135
		11	247.01	99.61135
		12	247.01	99.61135
		13	247.01	99.61135
		14	247.01	99.61135
		15	247.07	99.58716
		16	247.07	99.58716
		17	247.07	99.58716
		18	247.07	99.58716
		19	247.07	99.58716
		20	247.07	99.58716
		21	247.07	99.58716
		22	247.07	99.58716
		23	247.07	99.58716
		24	247.07	99.58716
		25	247.07	99.58716
		26	247.07	99.58716
		27	247.07	99.58716
		28	247.07	99.58716
		29	247.07	99.58716
		30	247.07	99.58716

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.09	7.875	1	254.68	100
		2	255.66	99.61668
		3	256.08	99.4533
		4	256.32	99.36017
		5	256.52	99.28271
		6	256.65	99.23242
		7	256.72	99.20536
		8	256.81	99.17059
		9	256.81	99.17059
		10	256.81	99.17059
		11	256.81	99.17059
		12	256.81	99.17059
		13	256.81	99.17059
		14	256.81	99.17059
		15	256.81	99.17059
		16	256.81	99.17059
		17	256.81	99.17059
		18	256.81	99.17059
		19	256.81	99.17059
		20	256.81	99.17059
		21	256.81	99.17059
		22	256.81	99.17059
		23	256.81	99.17059
		24	256.81	99.17059
		25	256.81	99.17059
		26	256.81	99.17059
		27	256.81	99.17059
		28	256.81	99.17059
		29	256.81	99.17059
		30	256.81	99.17059

Packing density (g/cm^3)	Weight of kapok used (g)	time(min)	S_F	Percentage dynamic oil retention
0.1	8.75	1	183.50	100
		2	184.05	99.70117
		3	184.33	99.54972
		4	184.54	99.43644
		5	184.80	99.29654
		6	184.87	99.25894
		7	184.87	99.25894
		8	184.87	99.25894
		9	184.87	99.25894
		10	184.87	99.25894
		11	184.87	99.25894
		12	184.87	99.25894
		13	184.87	99.25894
		14	184.87	99.25894
		15	184.87	99.25894
		16	184.87	99.25894
		17	184.87	99.25894
		18	184.87	99.25894
		19	184.87	99.25894
		20	184.87	99.25894
		21	184.87	99.25894
		22	184.87	99.25894
		23	184.87	99.25894
		24	184.87	99.25894
		25	184.87	99.25894
		26	184.87	99.25894
		27	184.87	99.25894
		28	184.87	99.25894
		29	184.87	99.25894
		30	184.87	99.25894