Investigation of Oil Spill Absorbents Using Different Materials

by

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CERTIFICATION OF APPROVAL

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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 by unspecified sources or persons.

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ABSTRACT

Catastrophic oil spills such as that in Gulf of Mexico remind us of the necessity of prompt action to develop an environmentally friendly, cost-effective and large scale technology to minimize environmental consequences caused by such disasters. This research will provide an alternative for oil spill absorbent using organic vegetable products. The applications are for offshore purposes. Three materials that are used for the study are: kapok (*Ceiba Pentandra*), coconut husk (*Coir*), and human hair. Dulang crude oil and Shell diesel oil were used throughout the experiment together with sea water from Teluk Batik. The interfacial tension test that was carried out shown that kapok has a lower contact angle compare to Coir and Human hair. This proved that Kapok is a better natural absorbent for oil spill combat. Oil absorbency test was conducted to measure the oleophilic/hydrophobic capability of each material. All of the three materials were found to have low hydrophobic and high oleophilic characteristic. However, human hair required five times the standardize amount to able to absorb all the oil present in the experiment. It was also found that Kapok can absorb up to five times its own weight. Coir sunk to the bottom after a few minutes which complicate the retrieving process. Overall, the results suggested that organic vegetable products can replace the existing synthetic sorbents for a more environmental friendly method to combat oil spill pollution.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

On 20th April 2010, 11 men lost their lives on the Deepwater Horizon rig. This was due to the explosion that happened under the waters of the Gulf of Mexico (G.O.M). The 4.1 million barrels of oil that been spewed in the G.O.M had made this incident the biggest offshore oil spill in the history. Sorbents are used more than 80% of the time [J.Stephen Dorrler, 1972] for oil spill cleanup.

1.2 Problem Statement

In the process to clarify the purpose of the research was being carried out, the problem statement are divided into two sections:

1.2.1 Problem Identification

There are three types of oil absorbents in the market which are organic vegetable products, inorganic mineral products and organic synthetic products [Schatzberg, 1971]. Organic synthetic absorbents are usually used for oil spill cleanup because "Most synthetic sorbents can absorb as much as 70 times their weight in oil and some types can be cleaned and re-used several time [Agata Radvanska, 2010]. However the cost of the synthetic absorbents is very high and it take a longer time to degrade.

1.2.2 Significant of the Project

This research is carried out with the aim to study on natural organic that can be use to replace synthetic absorbents.

1.3 Objectives

The objectives of my research are:

i. To investigate on the possible materials that can be use to replace the synthetic sorbents.
ii. To investigate on rate of oil and water absorption and wettability effects of the materials on crude oil and diesel oil.

1.4 Scope of Study

Three materials had been chosen from organic vegetable products to be the test materials. They are Kapok (Ceiba Pentandra), Coconut Husk (Coir) and Human Hair. The scope of study will be on the rate of oil and water absorption and wettability effects of the materials on crude oil and diesel oil.

1.5 The Relevancy of the Project

New organic absorbents are required for cleaning up oil spill as the cost of the synthetic sorbents is very expensive. A disadvantage of these materials is that they degrade very slowly as compared with mineral or vegetables products [Hyung-Min Choi, Rinn.M.Cloud, 1992]. "It was shown that with the aid of suitable mechanical retrieval equipment, sorbed crude oil can be recovered, so the sorbents can be recycled several times for oil spill cleanup. The results suggested that a total or partial substitution of commercial synthetic oil sorbents by natural sorbent materials could be beneficial in the oil spill cleanup operation by improving the efficiency of oil sorption and by incorporating other advantages such as biodegradability" [Hyung-Min Choi, Rinn.M.Cloud, 1992].

1.6 Feasibility of the Project within the Scope and Time frame

The project is divided into two sections. Section one will basically be on collecting, finding and reading of the journals, technical papers and books of the research topic. In this section one, the author will propose three organic vegetable products for the research. The author will also research on the common type of oil that can be found in the oil spill incident as different oil has different properties.

The second section of the project will be mainly on carrying out experiment to test the rate of oil and water absorption and wettability effects of the materials on crude oil and diesel oil.

CHAPTER 2

LITERATURE REVIEW & THEORY

2.1 Organic Vegetable Products

Organic product application in the oil spill cleanup for every oil spill had proven effective even in which oil concentration is relatively high [Johnson et al., 1973]. Approximately 33% of all organic vegetable products consist of the structural component called cellulose. Cellulose is the main component that allows these plant stems to stand erect. Other plant components include hemicelluloses, lignin, waxes and most importantly for the oil spill cleanup process, a rigid, non-collapsing lumen. The lumen is a cavity that is bounded by a plant cell wall; the lumen provides large gaps where the oil collects and become trapped. These gaps exert capillary action and surface tension on crude oil similar to a sponge. The presence of cellulose, waxes and non-collapsing lumen gives these organic products hydrophobic and oleophilic abilities even in salt water [Rosemary Stephen., 2010]. Thus, the organic products to be used in oil spill cleanup must have high cellulose content, hydrophobic and oleophilic abilities, good absorption capabilities, buoyancy even when saturated with oil, are resistant to wave action and reused to soak up more oil.

2.2 Absorbents Background

The utilization of absorbent materials for the removal of oil normally is done manually. The absorbents may be defined as materials with the capacity to recover oil by means of absorption and/or adsorption. There are three basic types of absorbents.

i. Natural organic mineral/organic vegetable product such as cork, hay, fennel, sugar cane, coconut husks and peat.
ii. Mineral materials such as vermiculite, perlite and volcanic ash.
iii. Synthetic organic absorbents such as polypropylene fibers and polyurethane foam.

Absorbents are insoluble product that retain or recover liquids through the mechanism of absorption or adsorption or both. Absorbents are materials that pick up and retain liquid distributed throughout its molecular structure causing the solid to swell (50% or more). The absorbent must be at least 70% insoluble in excess fluid. Adsorbents are insoluble materials that are coated by a liquid on its surface, including pores and capillaries without the solid swelling more than 50% in excess liquid. To be useful in recovering oil, absorbent need to be both oleophilic (attract oil) and hydrophobic (water repelling) [Natasha Luqman., 2006]. These absorbent are used 80% of the time for oil spill cleanup [J.Stephen Dorrler., 1972]. Absorbents are often used to remove final traces of oil or in areas that cannot be reached by skimmers. Absorbent materials used to recover oil must be disposed of in accordance with local/state approval and federal regulations. Absorbents that contained oil need to be disposed properly or recycled.

2.2.1 Absorbent Characteristics

The characteristics of both absorbents and oil must be considered when choosing the type of absorbent for oil spill cleanup:

i. Rate of absorption – The absorption of oil is faster with lighter oil products. Once absorbed the oil cannot be released. Effective with light hydrocarbon (eg; gasoline, diesel fuel, benzene).
ii. Rate of adsorption – The thicker oil adhere to the surface of the adsorbent more effectively.
iii. Oil retention – The weight of recovered oil can cause a sorbent structure to sag and deform and when it is lifted out of the water, it can release oil that is trapped in its pores. Lighter, less viscous oil is lost through the pores more easily than heavier, more viscous oil during recovery of adsorbent materials causing secondary contamination.
iv. Ease of application – Sorbents may be applied to spills manually or mechanically using blowers or fans. Many natural organic absorbents that

exist are loose materials such as clay and vermiculite are dusty and difficult to apply in windy conditions and potentially hazardous if inhaled.

2.3 Natural Organic Minerals

A brief description of the materials suggested will be explain to give a better understanding on why these materials are chosen.

2.3.1 Kapok (Ceiba Pentandra)

Kapok is a tropical tree of the order Malvales. It is known as the Java Cotton, Java Kapok or Silk cotton tree. Also referred to as Ceiba, it is sacred symbol in Maya mythology. Local in Malaysia called kapok as "kekabu".

The tree grows to 60-70 feet tall and have trunk up to 3 ft in diameter with buttresses. The tree produces several hundred seed pods. The pods contain seeds surrounded by a fluffy, yellowish fiber that is a mix of lignin and cellulose.

Figure 1 : Kapok [http://kekabuworld.blogspot.com/2010/11/about-kapok-or-in-malaysian-language.html]

The fiber is light, very buoyant, resilient, highly flammable and resistant to water. It cannot be spun but is used as a filling for bedding or insulation. When the fiber assembly is placed on a tranquil water surface, it floats on the water surface, causing slightly water surface depression due to the inability of water to penetrate into the kapok assembly. The air channel entrapped in the kapok finer lumen apparently prevented the entrance of water which has high interfacial tension with the kapok.

2.3.2 Coconut Husk (Coir)

This fruit fiber is contained in the husk of coconuts. Fiber length ranging from 10-30 cm. Coir fibers are light in weight, strong and elastic and have a low light resistance and a high durability (because of the fiber composition; 35-45% cellulose, 40-45 % lignin and 2.7-4% pectin and 0.15-0.25 % hemicelluloses).

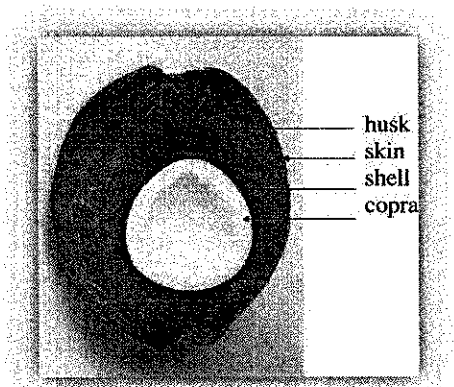


Figure 2 : Coir [http://www.fao.org/DOCREP/005/Y3612E/y3612e03.htm]

Several kinds of coir fibers can be distinguished based on the type of raw material or kind of extraction method. Here, the distinction is made between white, green and brown coir fibers; White fiber is considered to be superior by color and quality and gained by the most traditional extraction method: no machines are used, extraction by retting and hand beating. Green fibers are gained by mechanical fiber extraction and the quality of green fibers is slightly inferior to white fibers. The brown fiber is inferior of quality and also gained by mechanical extraction.

Coir fiber is produced in India, Sri Lanka and Thailand. The coconut palm yields fruit about five years after planting, with full bearing in 10 years time, until a palm age of 70 years. On average one palm produces 30 coconuts every year. Fibers are gained from coconut husks. Approximately 40-50% of a mature husk consists of fibers.

2.4 Oil Spill Pollution

An oil spill is a release of a liquid petroleum hydrocarbon into the environment due to human activity, and is a form of pollution. The term often refers to marine oil spills, where oil is released into the ocean or coastal waters. Oil spills include releases of crude oil from tankers, offshore platforms, drilling rigs and wells, as well as spills of refined petroleum products (such as gasoline, diesel) and their by-products, and heavier fuels used by large ships such as bunker fuel, or the spill of any oily white substance refuse or waste oil. Spills may take months or even years to clean up [G.M Dunnet, D.J Crisp, et al, 1982].

2.5 Environmental Disaster

On April 20, 2010, the Macondo well blew out, costing the lives of 11 men, and beginning a catastrophe that sank the *Deepwater Horizon* drilling rig and spilled over 4 million barrels of crude oil into the Gulf of Mexico. The spill disrupted an entire region's economy, damaged fisheries and critical habitats and brought vividly to light the risks of deepwater drilling for oil and gas – the latest frontier in the national energy supply.

2.5.1 Timeline of Oil Spill

On May 23, 2010, the National Incident Command (NOC) appointed Dr. Marcia McNutt, Director of the U.S Geological Survey and Science Advisor to lead a group of experts to generate a preliminary flow rate as soon as possible and a final flow estimate based on reviewed within two months. The estimate made will determine how bad the pollution and the containment plan for the cleaning of the spill.

May 27, 2010 Estimate (12,000-25,000 bbls/day)

First estimate on May 27, 2010, showed that the range of flow rates is 12,000 to 19,000 barrels per day. Higher flow rates of up to 25,000 bbls/day are expected. A few members had also produced maximum estimates, several of which were in excess of 50,000 bbls/day, but this upper bound was not released.

June 10, 2010 Estimate (20,000-40,000 bbls/day)

On June 10, 2010, a revised flow-rate estimate of 25,000 to 30,000 bbls/day with a lower bound of 20,000 and a higher bound of 40,000 bbls/day. The June 10, 2010 press release announced that two new teams had been added to the group: the Reservoir Modelling Team, which would help determine the rate at which oil flowed from the reservoir into the well, and the Nodal Analysis Team, which would use that information to determine the rate at which the oil travelled through the well and into the Gulf.

June 15, 2010 Estimate (35,000-60,000 bbls/day)

On June 15, 2010, a new official flow estimate of 35,000 to 60,000 bbls/day. According to the accompanying press release, the new estimate was "based on a combination of analyses of high resolution videos taken by remotely operated vehicle (ROVs), acoustic technologies, and measurements of oil collected by the oil production ship together with pressure measurements inside the top hat."

The Current Estimate (52,700-62,200 bbls/day)

The June 15, 2010 estimate was finally updated on August 2, 2010. A press release announced that, at the outset of the spill, the flow rate was 62,000 bbls/day (±10%), but that it had declined to 53,000 bbls/day (±10%) by the time the well had been capped on July 14, 2010. Given the new figures, the Deepwater Horizon Gulf Incident concluded that the total amount of oil discharged during the spill was 4,928,100 barrels (± 10%, which gives a range of 4,435,290 to 5,420,910 total barrels), a number not reduced by the amount of oil captured at the wellhead.

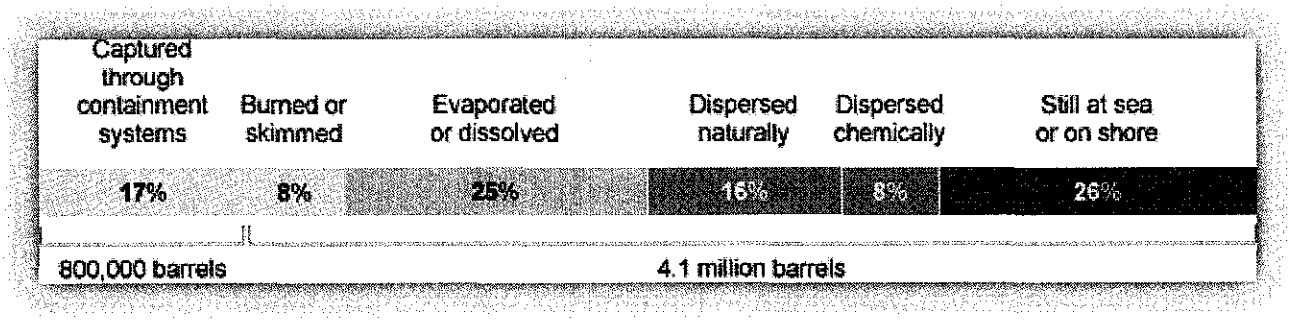


Figure 3 : The Estimated Amount Spilled by Deepwater Horizon [Cutler Cleveland, 2010]

2.6 Ten Largest Oil Spill in US

Oil enters the marine environment from a variety of natural and human sources. The largest sources from human activity originate in the exploration, production and transportation stages of the oil and gas industry. These include offshore oil platforms, tankers, pipelines, barges, railroads, trucks and various oil storage facilities. The ten largest individual releases of oil from accidents in the U.S. are:

Rank	Date	Name	Location	Size (Barrels)
1	April 22, 2010	Deepwater Horizon	Gulf of Mexico, Off Louisiana	4,900,000
2	February 29, 1968	Mandoil II	Pacific Ocean, Off Columbia River, Warrenton OR	300,000
3	March 24, 1989	Exxon Valdez	Prince William Sound, Valdez, AK	261,905
4	November 1, 1979	Burmah Agate	Gulf of Mexico, off Galveston Bay, TX	254,762
5	February 8, 1968	Pegasus (Pegasos)	Northwest Atlantic Ocean, off U.S. east coast	228,500
6	March 26, 1971	Texaco Oklahoma	Northwest Atlantic Ocean, off U.S. east coast	225,000
7	November 5, 1969	Keo	Northwest Atlantic Ocean, SE of Nantucket Island, MA	209,524
8	December 12, 1976	Argo Merchant	Nantucket Shoals, off Nantucket Island, MA	183,333
9	April 4, 1975	Spartan Lady	Northwest Atlantic Ocean, off U.S. east coast	142,857
10.	October 24, 1966	Gulfstag	Gulf of Mexico	133,000

Table 1: Ten Largest Individual Oil Spill [Cutler Cleveland, 2010]

2.7 Paper Review

In order to have deeper understanding and knowledge regarding the oil spill absorbents, some journal papers have been studied and analysed.

Most of the objective of the researcher was to look for materials that possess the quality of having high oil rate absorbency, hydrophobic/oleophilic, reusable and biodegradable. Organic vegetable products or inorganic mineral products are the main categories of material that these researchers used due to the ability to degrade in reasonable time frame.

Method that were used by these researchers are like placing the sorbents in the oil, actively shaking the container to observe the relative retention ability, some uses the FESEM (Field Emission Scanning Electron Microscope) to observe the contact angle of the oil droplet on the sorbent, some observed the optimum absorption time of the oil by the sorbents and some uses chemical agent to increase the ability of the sorbents to absorb more oil.

Throughout the results and findings of these researchers, they had proven that some organic and inorganic products are highly capable of substituting the synthetic type of sorbents. However, inorganic mineral products are least favour as "Most of them have poor buoyancy and oil sorption capacity [Teik-Thye Lim, Xiaofeng Huang, 2007].

The relevancies of these journals are that, these researchers had narrowed down the scope of searching for an alternative sorbents in oil spill cleanup. The methods used in carrying out the test can also be apply in the author's project which will assist the author in choosing materials that can be use to replace synthetic sorbents like polypropylene and polyurethane.

2.8 Theory

Since the project will be testing on the materials absorption rate, these equation presented below can be use.

2.8.1 Absorption Test

i. A quantity of about 0.02 g of dried oil-absorbent sample with known weight (m3) was put into a filter bag and immersed in oils at room temperature. After a predetermined time (12 h is needed for full oil absorbency), the filter bag with the sample was lifted from the oils and drained for 1min. Then the sample was immediately taken out and weighed.

The oil absorbency was calculated by the following formula:

$$Q = \frac{m4 - m3}{m3}$$

where Q represents the oil absorbency; m3 and m4 are the weights of the oil-absorbent before and after oil absorption, respectively [Lei Ding, Yi Li et al., 2010]

ii. The procedure for determining oil sorption capacity generally followed the simplified method F726-99 [ASTM, 1998]. The procedure is divided into two parts:

a. First, determine the weight of oil sorption by 1g o material.
b. Second, determine the best based for material sorption capacity.

For the first part, 1g of material was attached to a wire mesh and immersed in an oil bath. The setup was left for 10 minutes and another 10 minutes for free oil dripping. For the second part and remaining procedures from now till the end follow a similar method which include weighting empty beaker together with wire mesh, weighting beaker stuffed with material and wire mesh and weighting recycled beaker containing absorb material and wire mesh [Natasha Luqman, 2006].

iii. A 500ml sample of artificial seawater was placed in an 800ml glass beaker. The desired amount of oil (10, 20, 30, 40, 50g) was added to the beaker. The beaker containing crude oil and artificial seawater was mounted in a shaking apparatus. Approximately 1g of a sorbent material was added in the system, which was shaken for 10 min at 98 cycles/min. The wetted sorbent material was weighed after being drained for 1min in the sustainer.

Water content of the sorbent was analyzed by the distillation technique described in ASTM D95 [ASTM, 1998].

Oil quantity absorbed is :

$$S_T - S_W - S_A$$

where S_T is the total weight(g) of oil, water and absorbent material as determined gravimetrically, S_W is the water weight(g) as determined by distillation and S_A in the absorbent material weight(g) [Ch. Teas, S. Kalligeros et al., 2001].

2.8.2 Wettability Test

In order to investigate the wetting behavior of the treated powder, two different approaches were employed for contact angle measurements. In the first measurement, a thin layer of powder was fixed on a glass slide after a thin layer of glue was applied on the surface [Tina Arbatan, Xiya Fang et al., 2010].

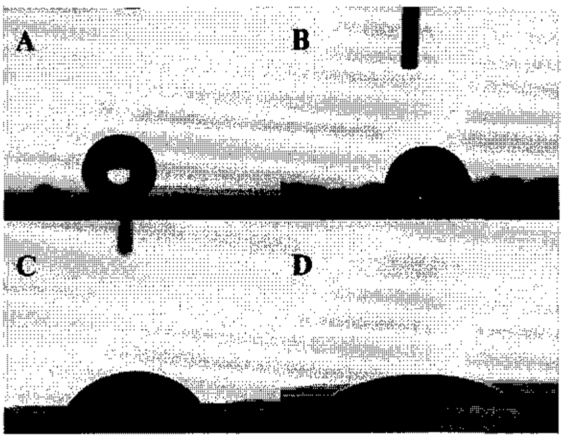


Figure 4 : Sample of water droplet contact angle [Tina Arbatan, Xiya Fang et al, 2010]

CHAPTER 3

METHODOLOGY

3.1 Introduction to Project Activities

In the process of achieving the main objective of this project, research and study has been carried out prior to the submission of preliminary report. The Society of Petroleum Engineers (SPE) Technical Papers, textbook references, One Petro technical paper and journals from Science Direct have been studied to acknowledge the past and current applications of oil spill absorbent, the most suitable natural organic materials, and the methods and finding from the researchers. The details of the papers are listed in Reference.

Some of the planned processes for the absorbents evaluations are as follows:

A. Literature Review
B. Research on suitable materials to be selected from natural organic material.
C. Material Preparation
D. Laboratory Experiments

i. Viscosity and Density Test
ii. Granulator
iii. Surface Morphology and Micro Porous Structure Analysis
iv. Oil sorption Test
v. Wettability Test

3.2 Materials Preparation

The materials proposed were kapok, human hair and coconut husk. Kapok was obtained from Kampung Bali, a nearby village near Universiti Teknologi Petronas (UTP) that harvests the tree. Human hair was obtained from a hair salon at Tronoh. The last material, the coconut husk was also obtained from a shop near Kampung Bali as well.

Kapok that was obtained from the village need to be purified as it was in its nature state.

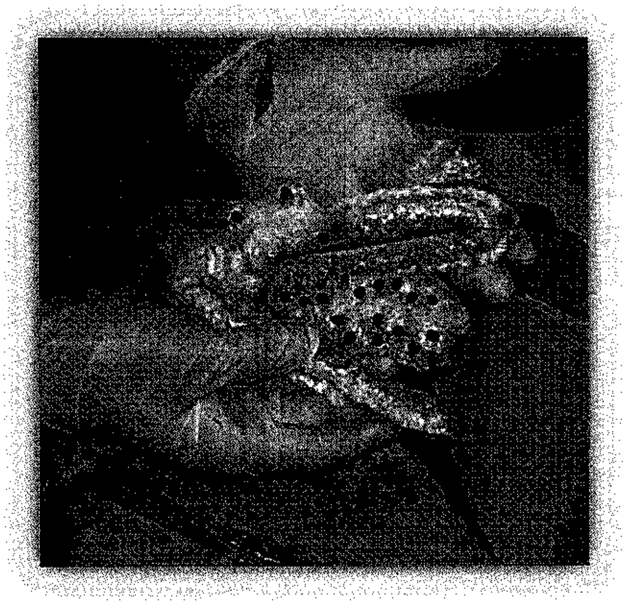


Figure 5 : Raw Kapok

As shown in the picture, the raw kapok had seeds inside it that need to be taken out to obtain the kapok fiber.

Coconut husk need to be granulate to obtain the fiber, same goes to the human hair but it is granulate to produce a standardize size of human hair.

3.3 Laboratory Experiments

3.3.1 Viscosity and Density Test

Viscosity test will be done for the crude oil from Dulang and diesel oil by using Brookfield LVPV -1 Viscometer. There are a few spindles that can be used during the test. However, a suitable spindle and suitable rpm must be selected in order to get the most constant results which are the accurate viscosity. The test will be carry out several times for each type of oil until it shows a constant value. The value of viscosity is appeared in unit centipoise (Cp).

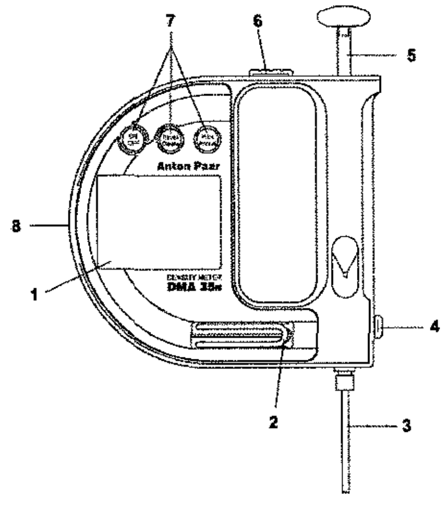


Figure 6 : Density Meter DMA35N

The density test will conducted using the Density Meter DMA35N. Before using the equipment, the density meter need to be clean with toluene and water. The reason is to clean the fluids that were used by the equipment in the previous study. Unable to perform this, we lead to a wrong reading of the density for the fluid that is being examined. The unit will appear in kg/m^3.

3.3.2 Granulator

As stated above, the raw materials will undergo the granulating process to standardize the size of the investigation – since we do not have a fix length of fiber for each material.

Figure 7 : Low Speed Granulator SG 16-21 machine

The process is very crucial for the coconut husk as the fiber cannot be extracted without using this machine.

Before **After**

Figure 8 : Coconut husk after granulation

3.3.3 Surface Morphology and Micro-Porous Structure Analysis

There are two equipments that will be use in this study.

i. *Scanning Electron Microscope (SEM)*

   It is used to analyze the surface morphology and micro-porous structure of the materials. It can magnify a microscope picture with magnification factor of 50 till 1000.

ii. *Field Emission Scanning Electron Microscope (FESEM)*

   FESEM produce clearer, less electrostatic distorted images with spatial resolution down to 1nm. Is it 3 to 6 times better than SEM. The equipment is available at Block N.

3.4 Project Work

The project activities flow is shown in Figure 3.5:

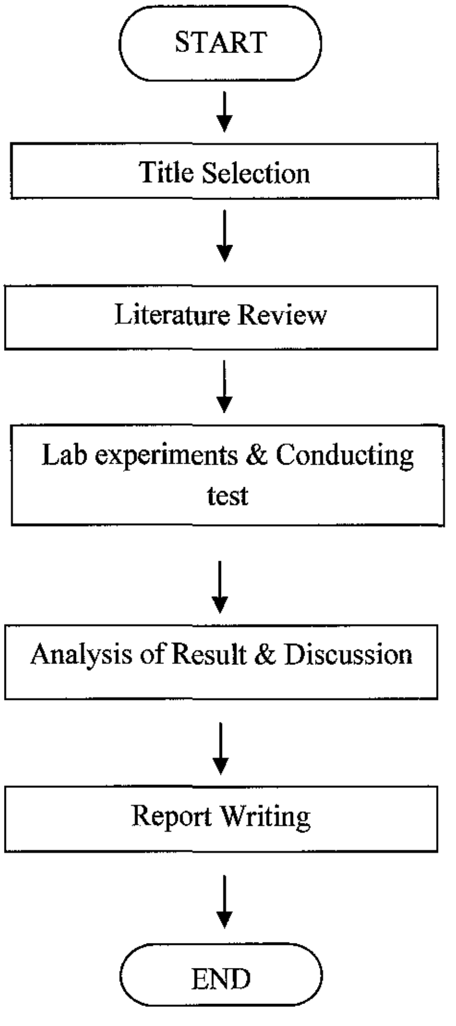


Figure 9 : Project Activities Flow Chart

3.5 Tools Required

i. Interfacial Tension Meter IFT 700
ii. Scanning Electron Microscope (SEM)
iii. Field Emission Scanning Electron Microscope (FESEM)
iv. Brookfield LVPV-1 + Viscometer
v. Density Meter DMA35N

3.6 Experimental Procedure

3.6.1 Water Absorbency

Based on the ASTM F 726-99 [ASTM, 1999] which is designed for measuring the water pick up on an absorbent. The test must be performed at room temperature. According to ASTM F 726-99, kapok, coir and human hair are categorized as Type II absorbent since the materials are unconsolidated, particulate material without sufficient form and strength to be handled with scoop and similar equipment.

The procedure for determination of water absorbency is shown below:

1) Weigh 4g of Kapok and is known as W_1 in unit gram.
2) 400ml of seawater is poured on the 1 liter beaker.
3) The 4g of Kapok is place in the 1 liter of beaker.
4) It is left for 2 minutes to settle.
5) Observe the condition of Kapok on seawater.
6) Record Observation

   Note: If 10% or more of the absorbent material has sunk, the absorbent is considered to have failed the test.
7) Strain the contents of the beaker using a mesh to catch the Kapok.
8) After 30 seconds drain, weight the sample as W_2 unit gram.
9) Calculate the water absorbency using equation (1).

$$\text{Water Absorbency} = \frac{W_2 - W_1}{W_1} \quad \text{------------------} (1)$$

10) Repeat step 1 – 9 for other types of absorbent like coir and human hair.

3.6.2 Oil Absorbency

Based on ASTM F 726-99 [ASTM, 1999], the objective of this test is to determine the optimum absorbent capacity without competing presence of water. This test is performed at room temperature. According to ASTM F 726-99, Type II absorbent (kapok, coir and human hair), the test liquid layer should be of a minimum thickness of 2.5cm if the thickness of the absorbent sample spread over the area of the test cell is under 2.5cm. If the absorbent is thicker than 2.5cm, then a liquid layer at least as thick as the absorbent sample should be use.

The procedure for determination of water absorbency is shown below:

1) Weigh 4g of Kapok and is known as W_1 in unit gram.
2) 400ml of seawater is poured on the 1 liter beaker.
3) 200ml of Dulang crude oil is poured on top of the 400ml of seawater.
4) The 4g of Kapok is place in the 1 liter of beaker.
5) It is left for 2 minutes to settle.
6) Observe the condition of Kapok on seawater.
7) Record Observation

   Note: If 10% or more of the absorbent material has sunk, the absorbent is considered to have failed the test.
8) Strain the contents of the beaker using a mesh to catch the Kapok.
9) After 30 seconds drain, weight the sample as W_2 unit gram.
10) Calculate the oil absorbency using equation (2).

$$\text{Oil Absorbency} = \frac{W_2 - W_1}{W_1} \qquad (2)$$

11) Repeat step 1 – 10 for other types of absorbent like coir and human hair.
12) Repeat step 1 – 11 for diesel oil.

3.7 Project Planning – Gantt chart for Final Year Project

No	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Collection of Sea Water from Lumut																
2	Viscosity and Density Test																
3	Extraction of materials																
4	SEM Test																
5	Compression of materials																
6	Interfacial Tension Test																
7	Oil Absorption Test								Mid-Semester Break								
8	Submission of Progress Report																
9	Pre-EDX																
10	Submission of Draft Report																
11	Submission of Dissertation Report (Soft Copy)																
12	Submission of Technical Paper																
13	Oral Presentation																
14	Submission of Project Dissertation																

Key Milestone

Process

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Data Gathering and Analysis

4.1.1 Density Test

Before starting the absorption and interfacial tension test, the properties of the fluids that are going to be use need to be analyze. The density test was carried out on 3 fluids, namely:

i) Seawater Lumut
ii) Diesel Oil – Shell
iii) Dulang Crude Oil

The test was conducted in block 15 lab using Density Meter DMA35N. The results are shown below.

Table 2: Density Test

Type	Density, g/cm^3	Temperature, $^{\circ}C$
Distilled Water	0.9999	24.5
Sea Water	1.0228	24.2
Crude Oil	0.8267	26.3
Diesel Oil	0.8352	24.3

Based on the table shown, Dulang crude oil and diesel oil shown a lower density reading compared to the seawater. This proved that during an oil spill, the oil will be floating on top of the seawater due to a lower density value. Thus, application of using the organic absorbent materials to pick up or retrieve the oil that had been spewed to the sea is applicable.

Temperature of crude oil is higher as prior to the test, the oil was place outside the lab to avoid wax from forming which might lead to false reading.

A column chart is attached in the appendix B.

4.1.2 Viscosity Test

The viscosity test was conducted at block 20 using the Brookfield LVPV viscometer. The test was done using Spindle 3. Two speeds were used (30 & 60 RPM) to ensure data consistency. Several tests were conducted to choose the suitable spindle which provides the desirable results.

Results are shown in the table below:

Table 3: Viscosity Test

Type	RPM	Viscosity, cp	Torque, %
Sea Water	30	1.4	0.7
	60	2.4	2.4
Diesel oil	30	4.4	2.2
	60	5.6	5.6
Crude Oil	30	42	10.2
	60	63	10.4

The period for each sample test time was 20 minutes. The viscosity test for the Dulang crude oil was conducted outside the lab. This is due to the fact that the testing time of 20 minutes will caused wax to form. The forming of a layer of wax on the surface of the crude oil affects the reading.

Based on the results in the table, Dulang crude oil has the highest viscosity value follow by diesel and seawater. It means crude oil is harder to flow compare to seawater and will be present in a group for cleaning up process.

Figure 10: Wax - Dulang

A column chart is attached in the appendix C.

4.1.3 Scanning Electron Microscope Images (SEM)

The SEM test was conducted to observe the surface morphology and micro-porous structure of the materials. The test was conducted at block 17.

Three materials were tested. Kapok at 100$\mathcal{M}$ looks like a *white straw mushroom*. The tip of a strain of kapok on a 1000$\mathcal{M}$ showed a non-collapsing lumen. The cavity of this lumen provides large gaps where the oil collects and become trapped. [Rosemary Stephen, 2010]

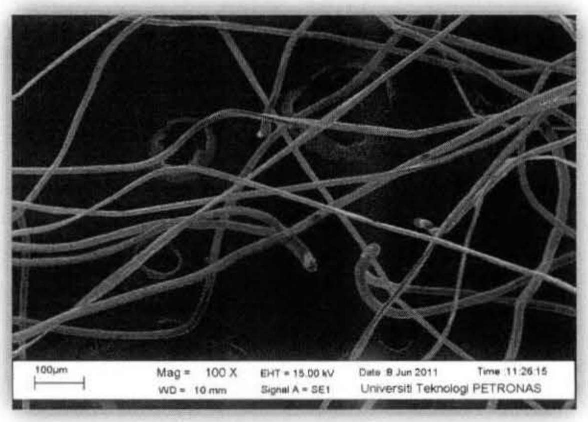


Figure 11: Kapok at 100 $\mathcal{M}$

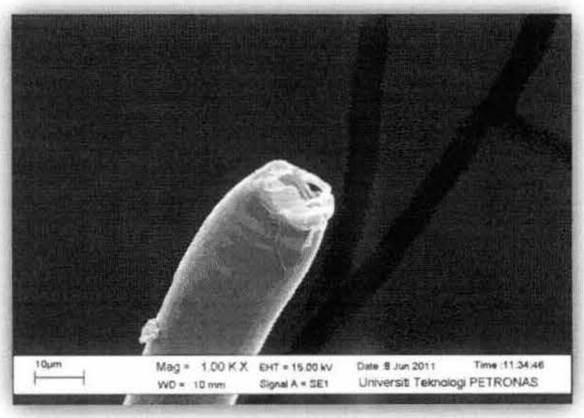


Figure 12: Kapok at 1000 $\mathcal{M}$

Human hair at 1000$\mathcal{M}$ showed that the material looks like fish scale. A multi-layer of hair stacks on each other which provide a non-collapsing lumen which enables it to collects and trapped oil.

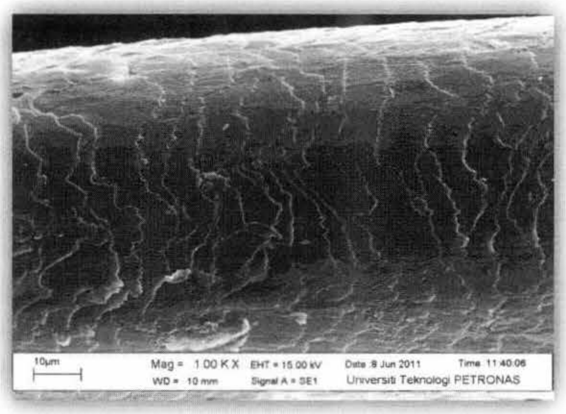


Figure 13: Hair at 1000 $\mathcal{M}$

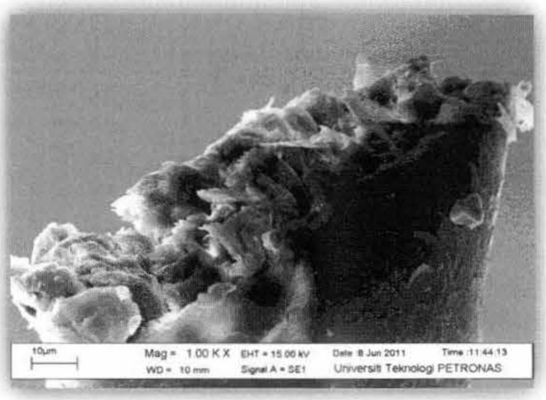


Figure 14: Hair at 1000 $\mathcal{M}$

Coir or more commonly known as coconut husk when seen under the microscope for a magnification of 100$\mathcal{M}$, the surface morphology looks like the outer surface of a guava fruit. It is rough.

On a magnification of 1000$\mathcal{M}$, there are some similarity between the coir and human hair. It seems as if the coir has a layer of surface stack on each other. These layers might posses as a capillary that enables it to collect and trapped oil.

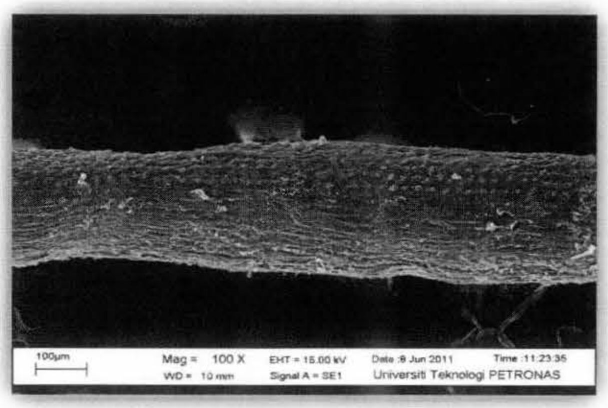


Figure 15: Coir at 100 $\mathcal{M}$

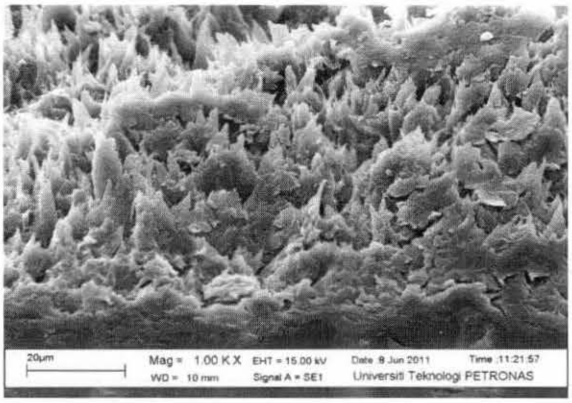


Figure 16: Coir at 1000 $\mathcal{M}$

Based on preliminary scanning of the surface morphology, it is proven that these three materials passed the pre-requirement of basic absorbent characteristics which is able to collects and trapped oil.

4.1.4 Interfacial Tension Test

Interfacial tension (IFT) meter is used to measure the contact angle of the liquid (crude oil and diesel oil) on the surface of the materials – kapok, coir and human hair. Two method were used which is the sessile up and sessile down drop.

Sessile drop mean a drop of oil droplet is drip on the surface of the material. Then using the camera of the IFT machine, the contact angle will be calculated automatically.

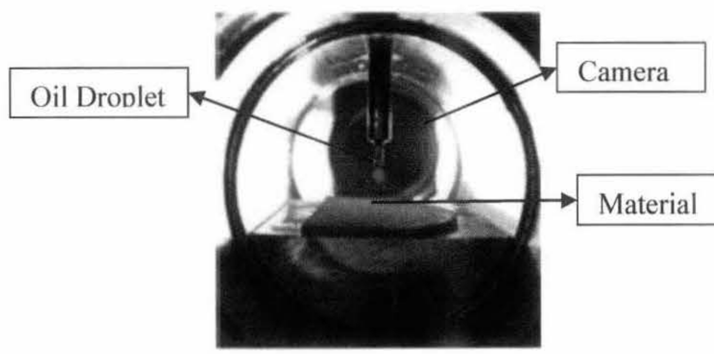


Figure 17 : Sessile Down

In sessile up, the material will be on the ceiling of the chamber. Then the chamber which is sealed will be flooded with seawater to simulate real life condition. Then a drop of oil will be drip up to the ceiling and the contact angle will be calculated.

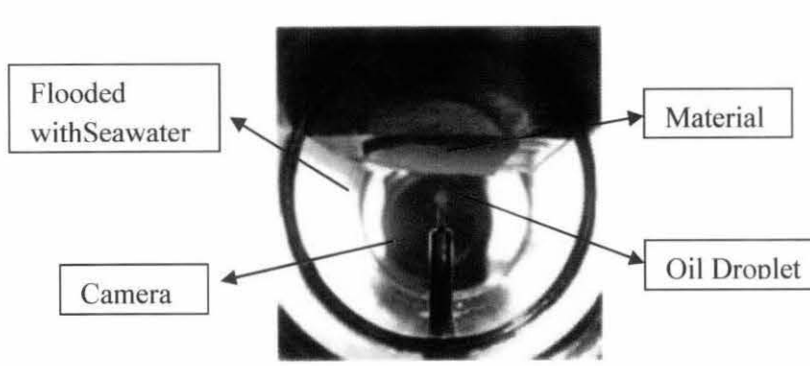


Figure 18 : Sessile Up

Before conducting the interfacial tension test, the materials were compress into pallet size. Four gram was used for each material. The *Auto Pellet Compression machine* was used with compression strength of 15 tan.

Figure 19 : Compressed Coir

The experiment was conducted with three types of liquid namely; Dulang crude oil, Shell diesel oil and seawater.

Sessile Down

The first run was done using the sessile down method. All of the material exhibit high absorbency rate. It mean when a drop of crude oil or diesel oil is drip to the surface of material, it was absorbed in a split second.

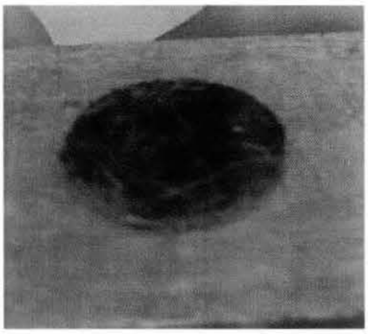


Figure 20 : Oil absorb by Coir

Kapok as proven by many technical papers had shown to have the lowest contact angle when dripped with Dulang crude oil followed by Coir. Dulang crude oil needs to be heated up to prevent wax from building.

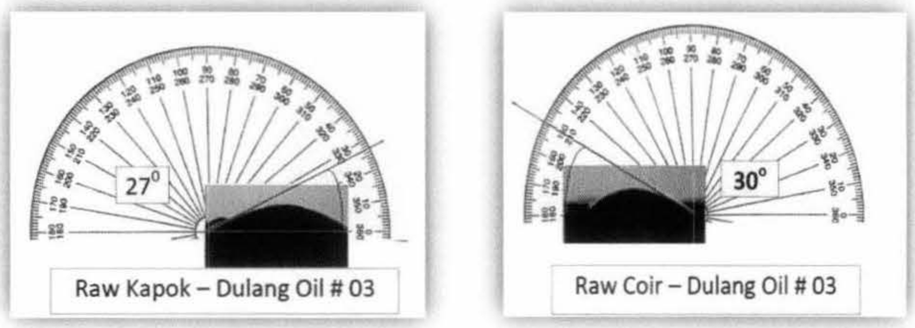


Figure 21 : Contact angle with Dulang Oil

Human hair was unable to be tested in this experiment as it was not able to be compress. This experiment requires the material to have a smooth surface for the camera to capture the contact angle.

It is recommended that a high speed shutter camera or video camera is used to capture each second of the process to obtain the optimum contact angle of the material when a drop of oil is dripped.

Sessile Up

In this method, the chamber needs to be flooded with seawater. Unfortunately, the compress material dissolves from its compacted form when surrounded by the seawater. Thus, further experiment cannot be carry out as there is not flat surface for the oil droplet to be contacted.

4.1.4 Water Absorbency Test

The water absorbency test is conducted to determine the amount of water that can be absorbed by each material. An excellent absorbent material needs to absorb minimum water. If the materials absorb more water than oil, it will not be a good absorbent for oil spill cleanup. The amount of water that is absorbed by each material is calculated based on equation (1).

Table 4 shows the result of water absorbency for kapok, coir and human hair.

Materials	Weight of Material,g Before	Weight of Material,g After	Water Absorbency, g/g
Kapok	4.000	4.103	0.026
Hair	4.000	11.712	1.928
Coir	4.000	50.842	11.711

Table 4 : Seawater Absorbency result

Based on the result shown in Table 4, Kapok has the lowest water absorbency rate follow by human hair and coir. Kapok does not dissolve in the seawater but rather sat on top of the water.

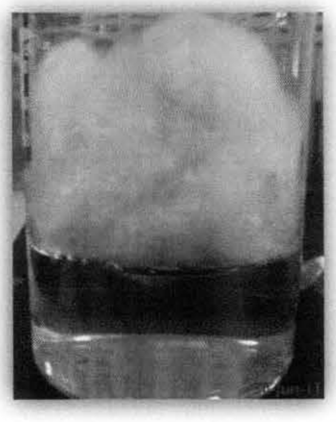


Figure 22 : Kapok water absorbency test

Kapok seems to have a layer of coating that prevents it from being wet by the seawater – rain coat characteristic. When kapok was pushed lower into the seawater, it does not absorb the seawater but displace the seawater at the same time. This may be the reason why Kapok has the lowest water absorbency rate which mean low hydrophobicity. This is one of the characteristic that could lead to a good oil spill absorbent material replacement.

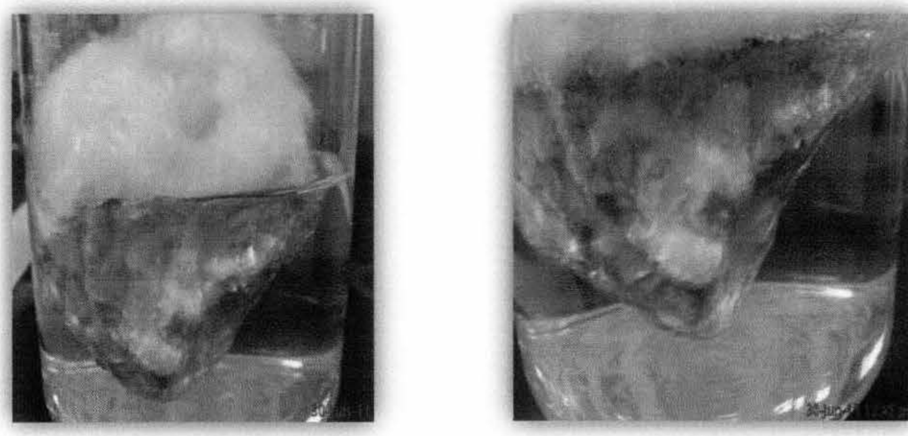


Figure 23 : Kapok water resisiting layer

Human hair have the second lowest water absorbency rate of 1.928g/g. Most of the hair dissolve and occupied the seawater. Even fully submerged in the seawater, the human hair still absorb little amount of water compare to coir. The water absorb can be disposed by a simple squeezing method. Thus it can be reused again as if it were new.

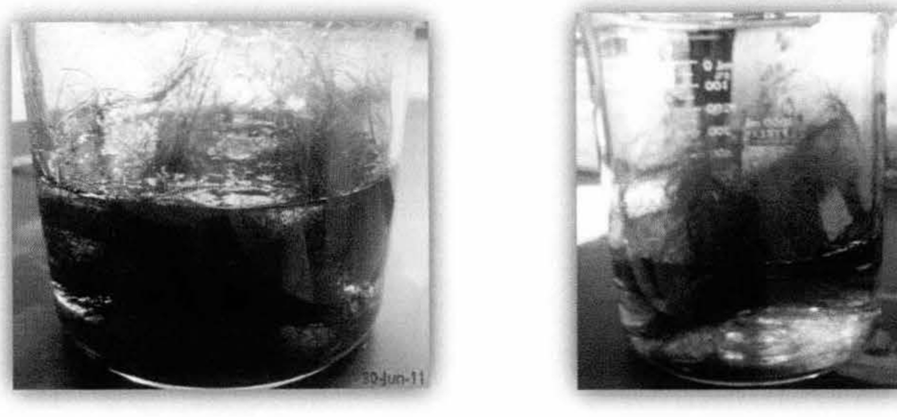
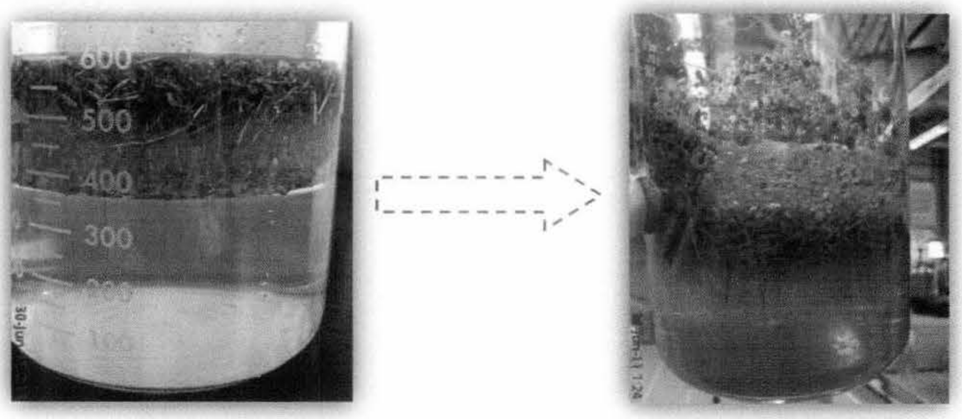


Figure 24 : Human hair water absorbency test

Coir absorbed the most seawater (11.711g/g). This happen because coir which had been granulated dissolve in the seawater which made it hard to retrieve it. The color of the seawater also had changed due to the lignin content of the coir dissolve in the seawater.



Before **After**

Figure 25 : Coir water absorbency test

Figure 26 shows the column chart for the water absorbency test for kapok, coir and human hair.

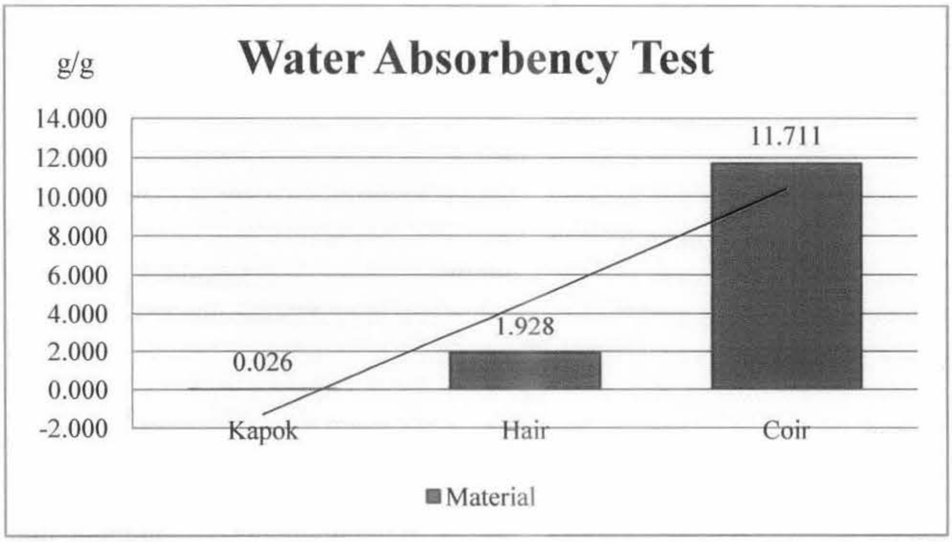


Figure 26 : Water absorbency test column chart

Therefore, for this test kapok and human hair are to be considered to have low hydrophobicity and is a good candidate for oil spill absorbent.

4.1.5 Oil Absorbency Test

The oil absorbency test is conducted base on procedures discuss in **3.6.2.** Two type of oil were use in this experiment – Dulang crude oil and diesel oil from Shell petrol station. The amount of oil being absorbed by each material is calculated using equation (2).

Table 5 shows the result of Dulang oil absorbency for kapok, coir and human hair.

Material	Weight of Material,g Before	Weight of Material,g After	Dulang Oil Absorbency, g/g
Kapok	4.000	181.743	44.436
Hair	4.000	45.838	10.460
Coir	4.000	54.728	12.682

Table 5 : Dulang oil absorbency result

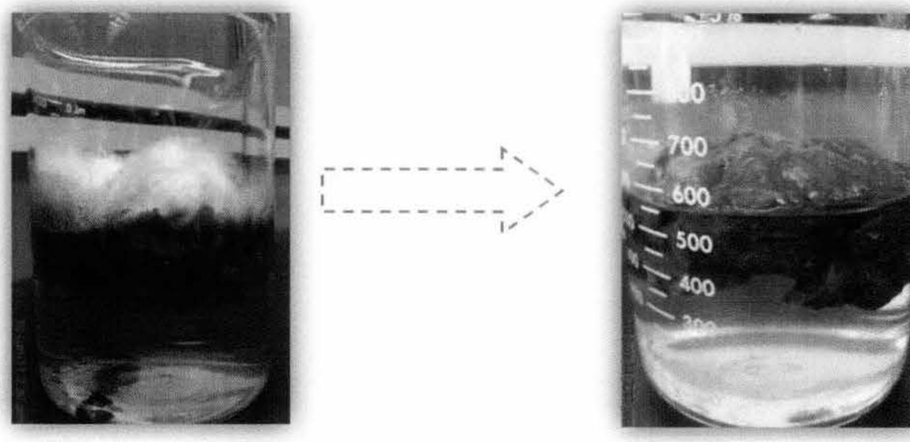
Table 6 shows the result of Diesel oil absorbency for kapok, coir and human hair.

Material	Weight of Material,g Before	Weight of Material,g After	Diesel Oil Absorbency, g/g
Kapok	4.000	189.604	46.401
Hair	4.000	24.316	5.079
Coir	4.000	35.617	7.904

Table 6 : Diesel oil absorbency result

Based on table 5 and table 6, kapok shows the highest crude oil and diesel oil absorption followed by Coir and human hair. An excellent absorbent material should have oil absorbency more than 10g/g and 5g/g to be an oil spill absorbent [Bordesorn, 2004]. Referring to the table 5 and table 6 again, Kapok is an excellent absorbent material in crude oil and diesel oil. The same goes to coir and human hair, they are excellent oil spill absorbent in crude oil but normal oil spill absorbent in diesel oil.

Kapok which had the highest oil absorbency rate leaves no oil behind. All of the oil that was in the beaker was being absorbed in second. The seawater is clean of oil spill pollution. After the absorption, kapok looks like a soaked tissue paper. This ease the process of retrieving as it does not dissolve into the seawater rather float on top of the seawater and present in a group.



Before **After**

Figure 27 : Kapok – Dulang crude oil absorbency test

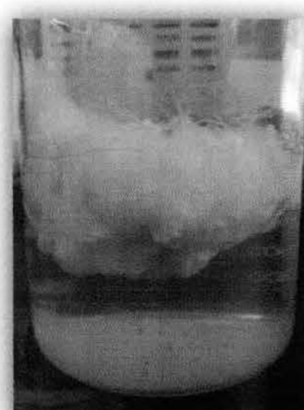


Figure 28 : Kapok – Diesel oil absorbency test

The chances of reusability will be low as kapok will be in wet condition after each absorption process (oil still trapped in kapok lumen) that will decrease the rate of absorption on each test.

Human hair has the second highest crude oil absorbency and third for diesel oil absorbency. Human hair is known to attract oil thus the need of shampoo for daily usage to remove the oiliness. Kapok absorbs oil as it has lumen which is a cavity that is bounded by the cell wall. These lumen provides large gaps where oil collects and becomes trapped. Human hair is different as hair does not get trapped but stick to it like a "magnet". Thus, it is easy for it to be remove - daily hair wash application.

Diesel Oil

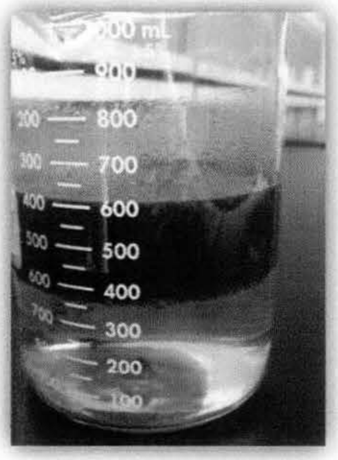
Dulang Crude Oil

Figure 29 : Human hair – oil absorbency test

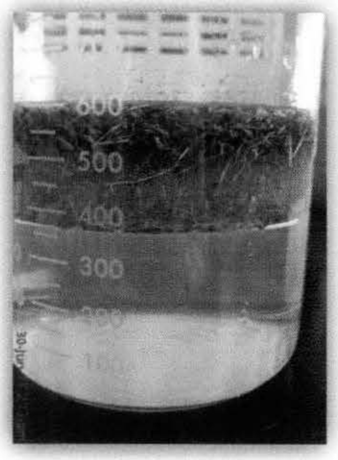
Human hair is a bit different compare to the kapok and coir. Kapok is the best oil absorbency but staying afloat on the seawater surface and absorption all the oil on top of it. Coir does the same but some of the material sunk to the bottom. Human hair stays in between. Based on the result, in order for human hair to be able to absorb all the 200 ml of oil on top of the seawater surface, the amount of hair needed is times more (20g).

A simple squeezing method will retrieve all the oil that is absorbed. Then it can be reused again to combat oil pollution. Recent incident in G.O.M, the hair is stuffed inside pantyhose to suspend it on the surface of water. Thus ease the process of retrieving and reusing.

Coir has the second highest diesel oil absorbency and the lowest for crude oil absorbency. When coir is first dispersed on the surface of the oil, it remains afloat on the oil surface. After a few seconds, it starts to sink into the seawater. This decrease the oil absorbency rate as the oil remains above the seawater. It also makes it harder to retrieve the coir once the experiment time period is up.



Dulang Crude Oil



Diesel Oil

Figure 30 : Coir – oil absorbency test

Table 3.1 and table 3.2 shows the column chart for the diesel and dulang crude oil absorbency test.

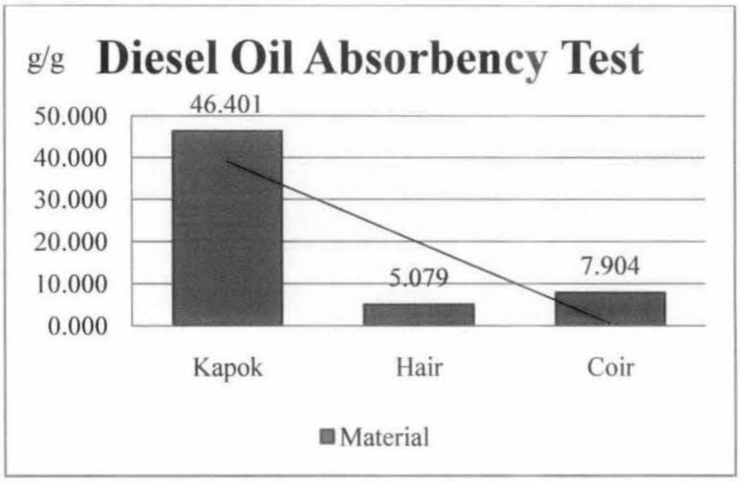


Figure 31 : Diesel oil absorbency test column chart

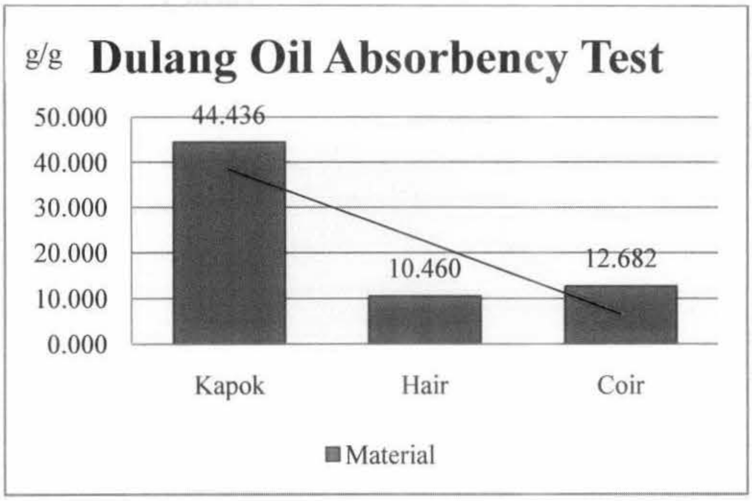


Figure 32 : Dulang crude oil absorbency test column chart

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The aim of the project is to identify which material (kapok, human hair or coconut husk) will be the best substitute for oil spill absorbent rather that then the commercial synthetic absorbent. The preferred absorbent material will be the one that exhibit high oil sorption, low water pickup, and high buoyancy

Kapok is a common natural mineral product that had been used by many researchers. The results had shown that kapok have the highest oil absorbency rate and lowest seawater absorbency rate. This is the characteristics of an excellent absorbent which has low hydrophobic and high oleophilic characters.

Human hair came close to kapok standard but a huge amount is needed for it to be as effective as kapok. A statistic showed that 60 million pounds of human hair are disposed of in landfill each year. This mean human hair is abundant and it is easy to obtain. Human hair is ready for the job while kapok and coir need to be extracted and process before usage which in real sense, cost effective.

Coir absorbed roughly the same amount of seawater and oil. It also dissolved in the seawater which makes it harder for retrieving process. Even though it maybe use as oil spill absorbent but the practicality does not present. There are much more process involved and thus increase the cost of using coir as absorbent.

Therefore, organic vegetable products are able to substitute the synthetic absorbent present in the market. Organic vegetable products are easily available and low cost. Since this material is biodegradability, using these absorbent will not bring more damage to the environment. Kapok is the best material follow by human hair and coir.

5.2 Recommendations

1) During the experiments with Dulang crude oil, it is recommended that it is first place outside the room or heated up to prevent wax from building.

2) During cleaning of apparatus, it is recommended that gloves and mask is worn all time as toluene is hazardous if inhale or contact with eyes and skin.

3) Interfacial tension meter needed to be upgraded to high speed shutter camera or video camera to capture each second of the process for an optimum contact angle calculation.

4) This experiment should be conducted on an offshore lab to simulate the offshore waves which will affect the oil absorbency rate in real situation.

5) Kapok and human hair is recommended to be used as alternative oil spill absorbent due to their highest oil absorbency and lowest water absorbency.

REFERENCES

1. A.B.D Cassie and S.Baxter, 1944, "Wettability of Porous Surfaces".

2. Agata Radvanska, July - September 2010, "The Environmental Impacts of Inland Water Transport and Possibilities of Oil Spills Cleaning", ACTA Technica Corviniensis, Bulletin of Engineering.

3. Alessandro Delle Site, 2001, "Factors Affecting Sorption of Organic Compounds in Natural Sorbent/Water Systems and Sorption Coefficients for Selected Pollutants", Environmental Department Rome Italy.

4. A. Venkatesware Rao, Nagaraja D. Hegde, Hiroshi Hirashima, 2006, "Absorption and desorption of organic liquids in elastic superhydrophobic silica aerogels", Journal of Colloid and Interface Science.

5. Bordosern. M, 2004, "Natural absorbents in oil spill cleanup", Master dissertation, Mahidol University.

6. Ceiba Pentandra (Bombacaceae), April 1, 2011, *http://florawww.eeb.uconn.edu/acc_num/198500310.html*

7. Ch.Teas, S. Kalligeros, F. Zanikos, S. Stournas, E.Lois and G. Anastopoulos, 2001, "Investigation of the effectiveness of absorbent materials in oil spill clean up", Desalination 140 (2001) 259-264.

8. Cutler Cleveland, December 5, 2010, "http://www.eoearth.org/article/Deepwater Horizon oil spill".

9. E.Erasmus, F.A. Barkhuysen, 2009, "Superhydrophobic cotton by fluorosilane modification", Indian Journal of Fibre and Textile Research.

10. Gerald Deschamps, Herve Caruel, Marie Elisabeth Borredon, Chistophe Bonnin and Christian Vignoles, 2003, "Oil Removal from Water by Selective Sorption on Hydrophobic Cotton Fibers. 1. Study of Sorption Properties and Comparison with other Cotton Fiber Based Sorbents', Environ. Sci. Technol, 37, 1013-1015.

11. G.F. Meenaghan, J.E Halligan, A.A. Ball and John. F Leary, May 3-6, 1976, "Cotton-The Natural Sorbent for Combating Oil Pollution", paper OTC 2698 presented at the 8th Annual OTC in Houston, Texas.

12. G.M Dunnet, D.J Crisp, G.Conan and W.R.P Bourne, 1982, "Oil Pollution and Seabird Populations (Discussion)", Philosophical Transactions of the Royal Society of London.

13. Hiroshi Moriwake, Shiori Kitajima, Masahiro Kurashima, Ayaka Hagiwara, Kazuma Haraguchi, Koji Shirai, Rensuke Kanekatsu, Kenji Kiguchi, 2008, "Utilization of silkworm cocoon waste as a sorbent for the removal of oil from water", Journal of Hazardous Materials.

14. Hyung-Min Choi and Rinn. M. Cloud, 1992, "Natural Sorbents in Oil Spill Cleanup", Environ. Sci. Technol. 1992, 26, 772-776.

15. John. A Little and Al. Smith, Oct 4-7, 1970, "Oil Pollution Incidents in the Southeast-Damage, Cleanup and Future Control", paper SPE 3046, presented at the 45th Annual Fall Meeting of the Society of Petroleum Engineer of AIME in Houston, Texas.

16. J.Stephen Dorrler, May 1-3, 1972, "Use of Sorbents for Oil Spill Cleanup", presented at the 4th Annual Offshore Technology Conference in Houston, Texas.

17. Lei Ding, Yi Li, Di Jia, JianPing Deng, Wantai Yang, 2010, "B-Cyclodextrin-based oil-absorbents : Preparation high oil absorbency and reusability", Carbonate Polymers 83.

18. M.A Abdullah, Anisa Ur Rahmah, Z. Man, 2009, "Physicochemical and sorption charaterisctics of Malaysia Ceiba Pentandra (L) Gaertn. as a natural oil sorbent", Department of Chemical Engineering, Universiti Teknologi PETRONAS.

19. Masahiro Toyoda, Junichi Aizawa, Michio Inagaki, 1998, "Sorption and recovery of heavy oil using exfoliated graphite", Department of Material Science, Fukui National College of Technology, Geshi Sabae Japan.

20. Moses O. Adebajo and Ray. L. Frost, 2003, "Acetylation of raw cotton for oil spill cleanup application: An FTIR and C MAS NMR Spectroscopic Investigation", Spectrochimica Acta Part A 60 (2004) 2315-2321.

21. M. Hussien, A.A Amer, I.I. Sawsan, 2007, "Oil Spill sorption using carbonized pith bagasse: trial for practical application", Int. J. Environ. Sci. Tech.

22. Natasha Luqman, 2006, "Assessment of Ceiba Pentandra (L.) Gaertn. (Kapok) as Absorbent Material for Oil Spill Control", Final Project Report, Universiti Teknologi PETRONAS, Malaysia.

23. O.Torsaeter, 1988, "A Comparative Study of Wettability Test Method Based on Experimental Results from North Sea Reservoir Rocks", 63rd Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Houston.

24. Ralph. A. Bianchi, Edward. E. Johanson and James H. Farrell, April 29 – May 2, 1973, "The Application of Skimmers, Piston Films, and Sorbents for Open Water Spills", paper OTC 1746, presented at the 5th Annual OTC in Houston, Texas.

25. R.D. Delaune, C.W Lindau, A. Jugsujinda, 2000, "Effectiveness of 'Nochar' Solidifier Polymer in Removing Oil from Open Water in Coastal Wetlands", Spill Science and Technology Bulletin.

26. Rosemary Stephen, 2010, "Green Oil Spill Clean-Up?", Environmental Health Intelligence.

27. Saied Gitipour, Mark T. Bowers, Warren Huff, Andrew Bodocsi, 1998, "The Efficiency of Modified Bentonite Clays for Removal of Aromatic Organics from Oily Liquid Wastes', Spill Science and Technology Bulletin.

28. S.A. Marinello and K.W. Fucik, May 4-7, 1992, "A Performance Comparison of Selected Commercially Available Sorbents", paper OTC 6868 presented at the 24th Annual OTC in Houston, Texas.

29. S.A. Sayed & A.M.Zayed, 2005, "Investigation of the effectiveness of some adsorbent materials in oil spill clean-ups", Desalination 194 (2006) 90-100.

30. Scatzberg, 1971, "US Coast Guard Report (No. 724110.1/2/1)", US Coast Guard Headquaters, Washington DC.

31. S.Suni, A.L Kosunen, M. Hautala, A. Pasila, M. Romantschuk, 2004, "Use of a byproduct of peat excavation, cotton grass fibre, as a sorbent for oil spilss", Marine Pollution Bulletin 49.

32. Teik-Thye Lim and Xiaofeng Huang, 2006, " 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 (2007) 125-134.

33. Tina Arbatan, Xiya Fang, and Wei Shen, 2010, "Superhydrophobic and oleophilic calcium carbonate powder as a selective oil sorbent with potential use in oil spill clean-ups", Chemical Engineering Journal 166 (2011) 787-791.

34. Wael Abdallah, Jill S.Buckley, Andrew Carnegie, John Edwards. Bernd Herold, Edmund Fordham, Arne Graue, Tarek Habashy, Nikita Seleznev, Claude Signer, Hassan Hussain, Bernard Montaron and Murtaza Ziauddin, 2007, " Fundamentals of Wettability", Schlumberger.