A Novel and Sustainable Approach in Treating Restaurant Wastewater with Kapok Fiber through a Compact Biodegradable Oil Absorption Filter System

by

Dhanaraj Turunawarasu

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

JANUARY 2012

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

A Novel and Sustainable Approach in Treating Restaurant Wastewater with Kapok Fibre through a Compact Biodegradable Oil Absorption Filter System

by

Dhanaraj Turunawarasu

A project dissertation submitted to the
Chemical Engineering Programme
Universiti Teknologi PETRONAS
in a partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CHEMICAL ENGINEERING)

Approved by,

Assoc. Prof. Dr. Zakaria Man
Chemical Engineering Department
Universiti Teknologi PETRONAS

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2012

CERTIFICATE 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.

Dhanaraj.

DHANARAJ TURUNAWARASU

ABSTRACT

Restaurant typically discharges fats, oil and grease (FOG) as well as surfactant (dishwashing detergent) – containing wastewater directly into the waterways that is generated by their daily kitchen activities, for which there is currently no acceptable technology due to its high capital cost, large space requirement to operate, extensive maintenance activities requirement, possesses detrimental hazard to the environment and fail to remove FOG to meet discharge standards. As a result, oil sorption efficiency and hydrophobic-oleophilic characteristics of an agricultural product, Kapok *(Cieba pentandra)* will be thoroughly examined in this paper for its feasibility as an absorbent medium in order to treat restaurant wastewater where the aim is to develop a compact biodegradable absorption filter. The objective of this project is to; (1) Study the effect of various packing densities of Kapok filter and inlet flow rate on the cooking oil absorption efficiency and outlet flow rate, (2) To design a compact biodegradable oil absorption filter based on the chosen packing density to curb the current problem faced in restaurant wastewater and (3) To study the effect of cooking oil and surfactant concentrations on the filtrate turbidity and filtration efficiency. Based on the results obtained, the best possible packing density that should be applied for the Kapok filter design under gravitational pressure gradient would be 0.02 g/cm^3 since it contributes to better outlet flow rate, high filtration efficiency (96%) with the least filtrate turbidity and has larger size of the effective flow channel and area to entrap the emulsified oil. Based on UV Spectrometer test, the result shows that the surfactant could not be separated from the water-surfactant mixture. However, with the presence of surfactant in water-oil mixture the kapok filter system is capable to separate oil efficiently as surfactant enable to break oil molecules to smaller suspended droplets (emulsion) which results in higher filtration efficiency. Kapok has shown a great potential as an natural oil sorbent in treating restaurant wastewater (FOG) due the fact that it is hydrophobic-oleophilic in nature.

ACKNOWLEDGEMENTS

First and foremost, an expression of utmost gratitude towards God for His blessing upon me. A Warmth thankful to my supervisor, Dr. Zakaria Man for his continuous support and advice throughout my research. I would like to take this opportunity to express my heart felt gratitude to Mr.Jailani and Mr. Faisal, technicians of Chemical Engineering Department who painstakingly assisted my laboratory works. Last but not the least, thanks to all my fellow colleagues for their valuable comments and suggestions.

Thank you

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background Study

Restaurant wastewater that is discharged to the environment is one of the contributing factors to water pollution in Malaysia and other developing countries where many restaurants are emerging to cater the need of public due to exploding population. The wastewater that is directly discharged to the drainage system without any sort of pre-treatment is mainly composed of fats, oil and grease (FOG) as well surfactant (dishwashing detergent). These contaminants cause many environmental impacts including fouling and clogging in the drainage and sewer system, generates unpleasant odour and introduce extra burden to the municipal wastewater collection and treatment works which eventually leads to decreased efficiency (Chen et al., 1999).

Figure 1.1: Discharge of Oily Restaurant Wastewater

Figure 1.1 shows an example of restaurant wastewater that is discharged into the drain without any sort of pre-treatment. This picture is captured from one of the restaurant in Tronoh, Perak. It can be observed that there is some grease deposit on the inner wall of the drain due to solidification of oil and grease. Moreover, if it is not treated properly it may enter river and sea causing detrimental environment impact (Hong, 2010). The main problem occurs when oil and grease liquefy at high water temperatures use to wash dishes and solidify in sewer lines which eventually cause clogging and overflow in drainage system due to rigorous rain pour.

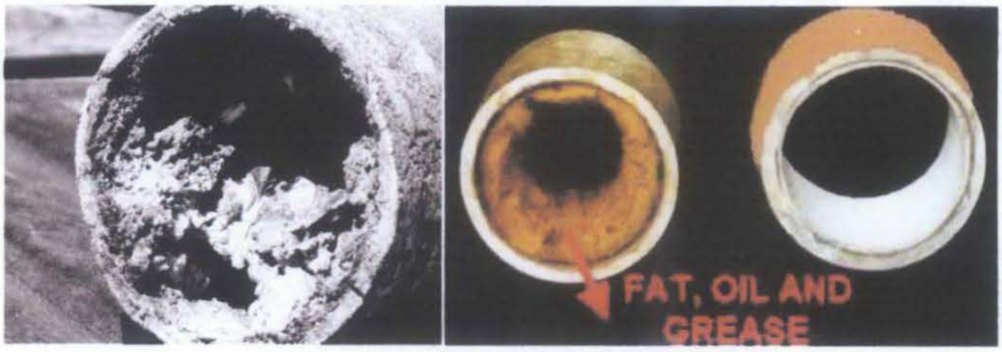


Figure 1.2: FOG deposits in sewer pipes (Stop the clog, n.d.)

Figure 1.2 shows the cross-sectional area of a sewer line that is clogged by FOG due to solidification around the inner wall. It can be seen that the solidified FOG has restricted the cross-sectional area for wastewater flow in the sewer line. Besides that, FOG may also pose high bacteria growth in wastewater due to high level of Biochemical Oxygen Demand (BOD).

Moreover, the dishwashing detergent that is discharge may also be detrimental to the environment because detergent can be relatively toxic to aquatic life (Izabela et al., 2006). Most of the dishwashing detergent composes of high level of phosphate concentration which is a water-softening mineral additive that is able to enhance the performance of detergent as a cleaning agent (Menna, n.d.). However, when they enter waterways, phosphate can stimulate excessive growth of algae which leads to reduction of oxygen in water and as a result depletes other living organisms in the water. This environment impact is well known as Eutrophication.

In order to mitigate this environmental problem, many current technologies have been introduced in the market to separate FOG from wastewater before being discharged to the drainage and sewer line. For instance, grease interceptors that are installed under kitchen sinks in certain restaurants are used to trap grease from kitchen wastewater. However, this technology is costly, requires thorough maintenance, requires large space to be installed and often neglected causing odour nuisance (Wakelin, 1998).

Figure 1.3: Kitchen Grease Trap/Interceptor (Blu Sky Biofuels, 2008)

Fig 1.3 depicts the condition of kitchen grease trap that is not maintained in a proper manner.

Moreover, a biological treatment facility is also known to reduce BOD and decompose grease but somehow it is ruled out due to cost, requirement of large space and skilled technician to maintain (Chen et al., 1999)

There are many studies being conducted to separate oil from water through oil sorption by sorbents but yet to be applied in restaurant wastewater treatment facility. Oil sorbents are inexpensive, abundant, easily utilized, and high oil absorption capacity. Natural sorbents are preferred compared to organic synthetic sorbent due to its biodegradable nature. In this project, a natural sorbent known as Kapok (*Cieba pentandra (L.)* Gaetn) will be studied in order to develop a biodegradable compact absorption system to separate oil and grease from restaurant wastewater before being discharge to drains.

1.2 Problem Statement

At present, there is no efficient and common technology being utilized in treating oil and grease in wastewater effluent from restaurant sinks to the drainage and sewerage system which eventually generates unpleasant odour, drain water contamination and clog due to the solidification of oil and grease deposits on the inner wall of sewer pipes. Besides that, to date, only few wastewater and reuse systems have been installed in restaurants (Chen et al., 2000). However these special systems are costly, requires thorough maintenance and skilled technician to maintain. The current technology requires large space despite the lack of space in most restaurants. Therefore, compactness of the treatment facility is essential (Chen et al., 2000)

The limitations of the current restaurant wastewater treatment facilities have lead to the recent interest in developing alternative treatment which is cost efficient, low maintenance cost and compact. In this particular project, the interest focuses on kapok since it is biodegradable in nature, inexpensive, naturally abundant, high oil sorption capacity, and easy disposal with the least environmental hazard (Abdullah et al., 2009) where the aim is to develop a compact biodegradable absorption filter system.

1.3 Objective

- To study the effect of various packing densities of Kapok filter and inlet flow rate on the oil absorption efficiency and outlet flow rate
- To design a compact biodegradable oil absorption filter based on the chosen packing density to curb the current problem faced in restaurant wastewater
- To study and evaluate the cooking oil and surfactant absorbency and oleophilic-hydrophobic characteristics of Kapok filter through various cooking oil, surfactant and oil + surfactant emulsion concentrations
- To study the effect of cooking oil and surfactant concentrations on the filtrate turbidity and filtration efficiency

1.4 Scope of Study

- Invention of a compact biodegradable oil absorption filter for restaurant sinks.
- Determination of oil & surfactant absorbency/capacity of Kapok Filter through various possible combinations of cooking oil + surfactant emulsion concentrations.
- Evaluation of Kapok filter efficiency based on the turbidity reduction

1.5 Relevancy and Feasibility of the Project

This project is relevant to the author's field of study since environmental sustainability is one of the focus areas in Chemical Engineering. Environment Engineering is one of the sub-disciplinary in Chemical Engineering where Chemical Engineers develop strategies and designs to reduce pollution at the source and treat waste that cannot be eliminated by applying chemistry theories in order to create methods of environmental sustainability, conservation and protecting efforts. In this project, the author has applied mass transfer and separation process theory through absorption in order to remove oil and grease from restaurant wastewater. As a chemical engineer, the author has evaluated the current restaurant wastewater treatment to find the most cost-effective solution where he has proposed kapok as an alternative material for a compact biodegradable oil absorption filter while still maintaining recognized engineering, governmental standards and environmental sustainability (website refer to school in the USA, 2003)

The project is feasible since it is within the scope and time frame. The author has planned to complete the research and literature review by the end of the first semester while purchasing the material after the mid-semester break. He plans to dedicate the first six weeks of final year design project II (FYP II) to design the compact biodegradable oil absorption filter whereas the next six weeks he plans to conduct the experiment to evaluate the efficiency of the filter. Moreover, Kapok is naturally abundant in this region thus there will not be any issue of obtaining them. Besides that, this project does not require sophisticated equipments to operate and Perspex and other tools are readily available at the university Lab (Block-21) and thus there is no wastage of time in ordering and waiting for their arrival.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Current Research on Oily Water Filtration

Oily water is a common pollutant in industries such as petrochemical, food, textile, oil & gas and shipping (Cheremisinoff, 1998; Mueller et al., 1977; Cheryan and Rajagopalan, 1998). There many methods that are being practised in industries to treat oily water such as gravity separation, dissolved air flotation, coalescence, centrifugation, coagulation and flocculation.

In Gravity Separation, the oily water will be fed into a settling tank where by the water will settle down at bottom of the tank through gravity since the specific gravity of water is greater than the oil. The effectiveness of separation depends on the system's temperature, as well as the additive formulation, age of the oil and the base oil type (Machinery Lubrication, n.d.)

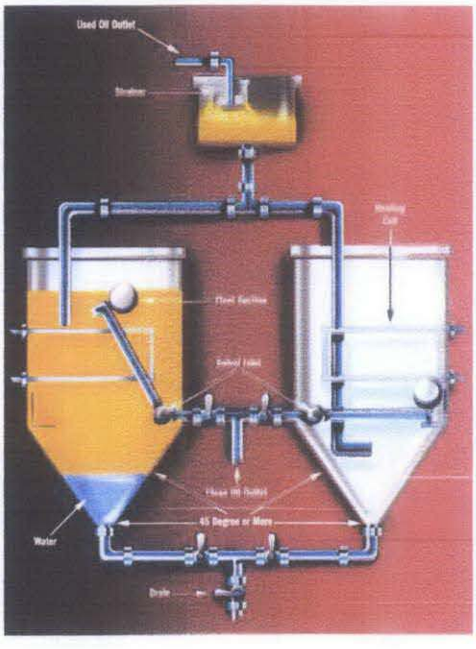


Figure 2.1: Gravitational Settling tank for immiscible fluid separation (Machinery Lubrication, n.d.)

Dissolved air floatation removes suspended matter such as oil by dissolving air in the water or wastewater under pressure and then releasing the air at atmospheric pressure in a flotation tank. The bubbles that are formed through the released air causes the suspended matter to float on the surface of water which can be removed through skimming (Wikipedia, 2011)

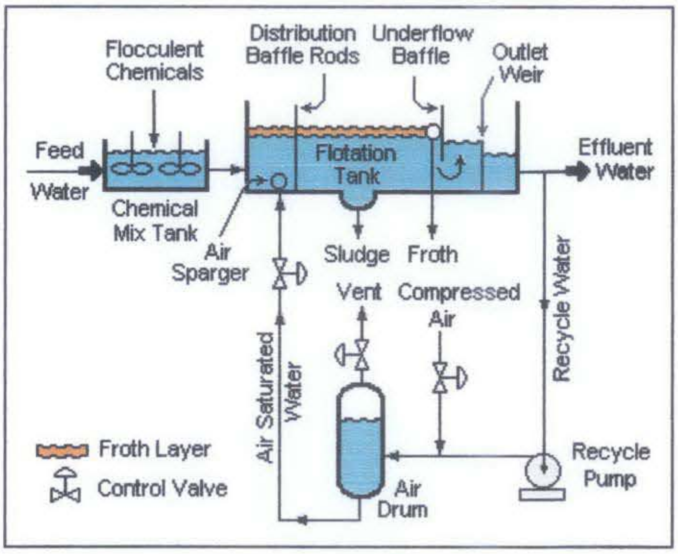


Figure 2.2: Dissolved air floatation tank (Milton, 2008)

Coalescence is the breakdown of surface tension between oil droplets in an oil/water mixture which causes them to join and increase in size (Machinery Spaces, 2010).

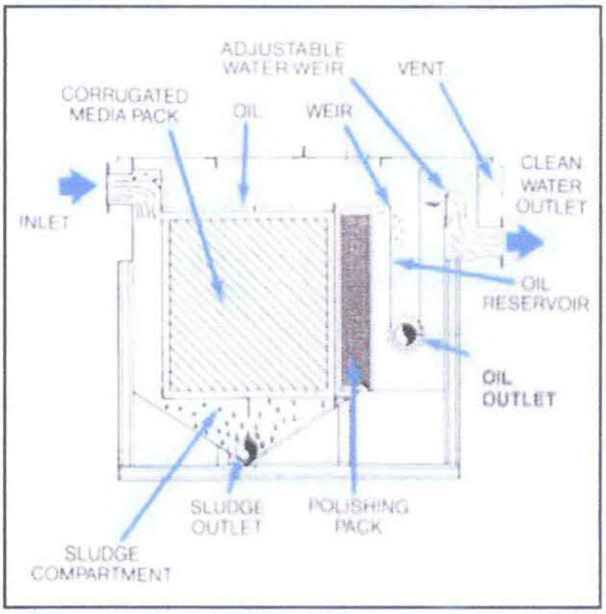


Figure 2.3: Coalescence type Separator (Pollution Control Systems, 2011)

The coalescence type separator consists relatively close tolerance surface areas in order to reduce the distance between the oil droplets collecting surface. The coalescence plates are made of hydrophobic and oleophilic material. The oil droplets will be attached on the coalescence plate surface once the oil droplets come into contact with the plate. The coalescence of oil droplets will contribute to better effectiveness of natural action of oil and water separation (Pollution Control Systems, 2011)

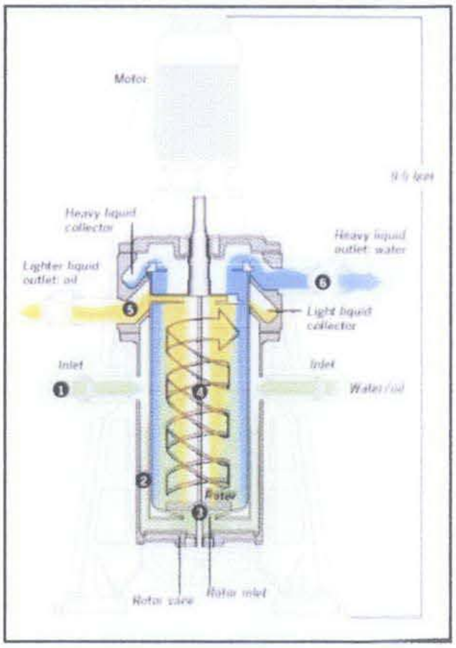


Figure 2.4: Centrifuge Oil Separator (Tom, n.d.)

The principle of the centrifuge is to separate the oil from water by spinning the mixture to create high G-forces in order to separate the oil and water to two different channels respectively.

Coagulation and Flocculation work as one process where coagulation is the destabilization of colloids by neutralizing the forces that keep them apart. Once the charges are destabilized, the small particles will collide to form lager particle microflocs which are still invisible to the naked eye. However, through flocculation, particle size from submicroscopic microfloc may increase to a visible suspended matter to form macroflocs by employing gentle mixing on the solution.

However, these conventional methods fail to remove oil cost-effectively to meet discharge standards (Lim et al., 2007).

One of the most effective approaches to treat oily water is through membrane filtration since the efficiency of filtration is high.

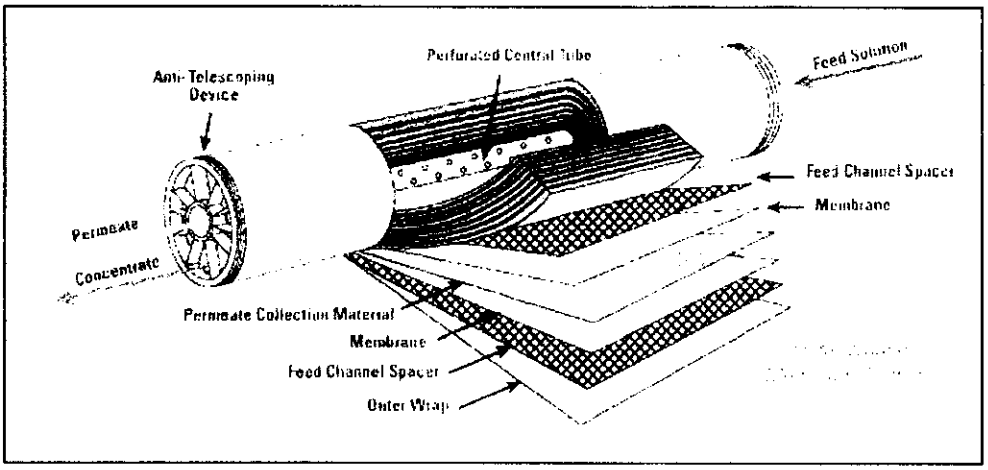


Figure 2.5: Reverse Osmosis Membrane (ESP Water Products, 2009)

Membranes provide a physical barrier to the passage of particulate matter in a water stream. Membranes can be classified by the pore size of the membrane or the molecular weight of the molecules that the membrane can separate. (Peeters et al., n.d.). Nevertheless, membrane filtration technology such as microfiltration and ultrafiltration are costly in terms of capital, operating and maintenance (Lim et al.,2007).

Currently, synthetic fibers such as polypropylene are widely used as oil sorbent especially in oil spill since it is inexpensive and most commercially available. However, they are non-biodegradable in nature thus disposal is a major issue.

The disadvantages of current methods have led to the recent interest in developing biodegradable filtration system from agro-based products since it is environmental friendly in nature (Lim et al.,2007).

2.2 Kapok (*Cieba pentandra* (L.) Gaertn.)

2.2.1 Physical Description

Figure 2.6: Kapok (Astral Currently, n.d.)

Kapok (*Cieba pentandra* (L.) Gaertn.) is an agricultural product of a tropical tree of the order Malvales and the family Malvaceae (previously sseparated in the family Bombacaceae). Kapok contains waxy surface that contributes to its hydrophobic-oleophilic and high oil absorbency characteristics (Lim et al.,2007). It is locally known as kekabu, is cultivated in South East Asia, Malaysia and Africa. The fibers are yellowish brown, fluffy, and lightweight. It is conventionally used as stuffing material for pillows and beds especially in Malaysia (Abdullah et al., 2009).

In comparison with synthetic fibers and other agro-based product, Kapok Fiber is naturally abundant, inexpensive, has a greater potential to be developed into a filter product for oily water treatment because of its lower density (Huang et al., 2006), higher porosity, contains waxy surface which contributes to hydrophobic-oleophilic characteristics and water repellent. Since Kapok its biodegradable in nature, hence it is easily disposed with least environmental hazard.

Based on the image of Kapok fiber from the Scanning Electronic Microscopy (SEM), it can be observed that the fiber consists of a hollow structure which is called the lumen with an average external diameter 16.5±2.4 μm and internal diameter of 14.5±2.4 μm. The specific density of Kapok is 1.31g/cm^3. The fiber is composed of 64% cellulose, 13% lignin and 23% pentosan (Kabayashi et al., 1977).

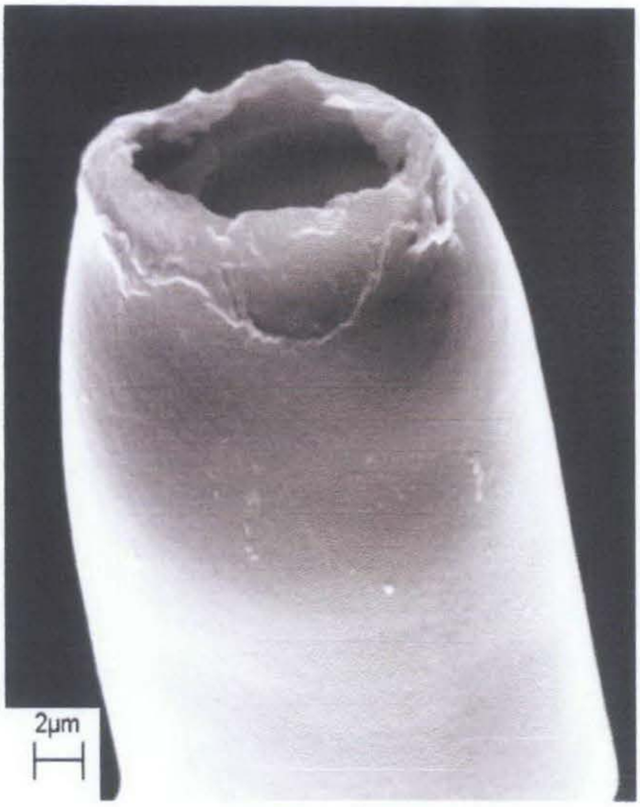


Figure 2.7: SEM images of kapok fiber (M.A Abdullah et al., 2009)

2.2.2 Current Study on Kapok as Oil Sorbent

To date, there is only handful of well published papers on Kapok where Kapok has only been studied on its oil sorption characteristics as natural oil sorbent. Well published literature and journals on its oil absorbency can be found; among these are the early study by Kobayashi et al. (1977) and Choi and his co-workers (Choi and Cloud, 1992; Choi and Moreau, 1993; Choi, 1996) as well as Hori et al. (2000).

Besides that, M.A. Abdullah et al. (2009) from the Department of Chemical Engineering, Universiti Teknologi Petronas (UTP) has recently conducted a simple study on the Oil Absorption Characteristic and capability of Malaysian Kapok. He has concluded that Malaysian Kapok is effective oil sorbent, owing to high sorption and retention capacity, structural stability and high reusability. He mentioned that the Van Der Waals forces and hydrophobic interactions with the availability of void fraction between the fiber and lumen as well as the oleophilicity of kapok fibers, are the contributing factors for high sorption capacity.

On top of that, Kapok has also been studied and evaluated as a potential hydrophobic-oloephilic sorbent for oil spill cleanup (Lim et al.,2007) to replace the current synthetic fibre, polypropylene (PP) as an alternative material. According to this study, Kapok has larger effective pore volume compared to PP due to its hollow structure and Kapok exhibits at least two-times more oil sorption compared to PP, for three oils investigated in the experiment. Kapok even posses the least water pick-up compared to PP due to its hydrophilicity-oleophilicity in nature. Loose packing Kapok may loose its oil sorption capacity to 30% when reused, however it still exhibit higher sorption capacity than PP with consistent oil sorption capacities when reused. More than 83% oil recovery can be achieved from densely packed Kapok through centrifugation. This shows that Kapok exhibit excellent recovery than PP.

Furthermore, Kapok has also been assessed as a deep bed filter medium for oily water filtration (Khan et al., 2004; Huang et. al., 2006). Similar study has also been conducted in UTP by Anisa U.R et al (2010). Based on their research, Kapok with a packing density of 0.07g/cm^3 is the optimum packing for a deep packed bed filter. The Dynamics of oil/water separation theory in a kapok filter was also introduced by Huang et. al (2006) in his study. The oily water separation inside the colum can be divided into four stages: 1) Infiltration, 2) Separation, 3) Displacement, and 4) Equilibrium.

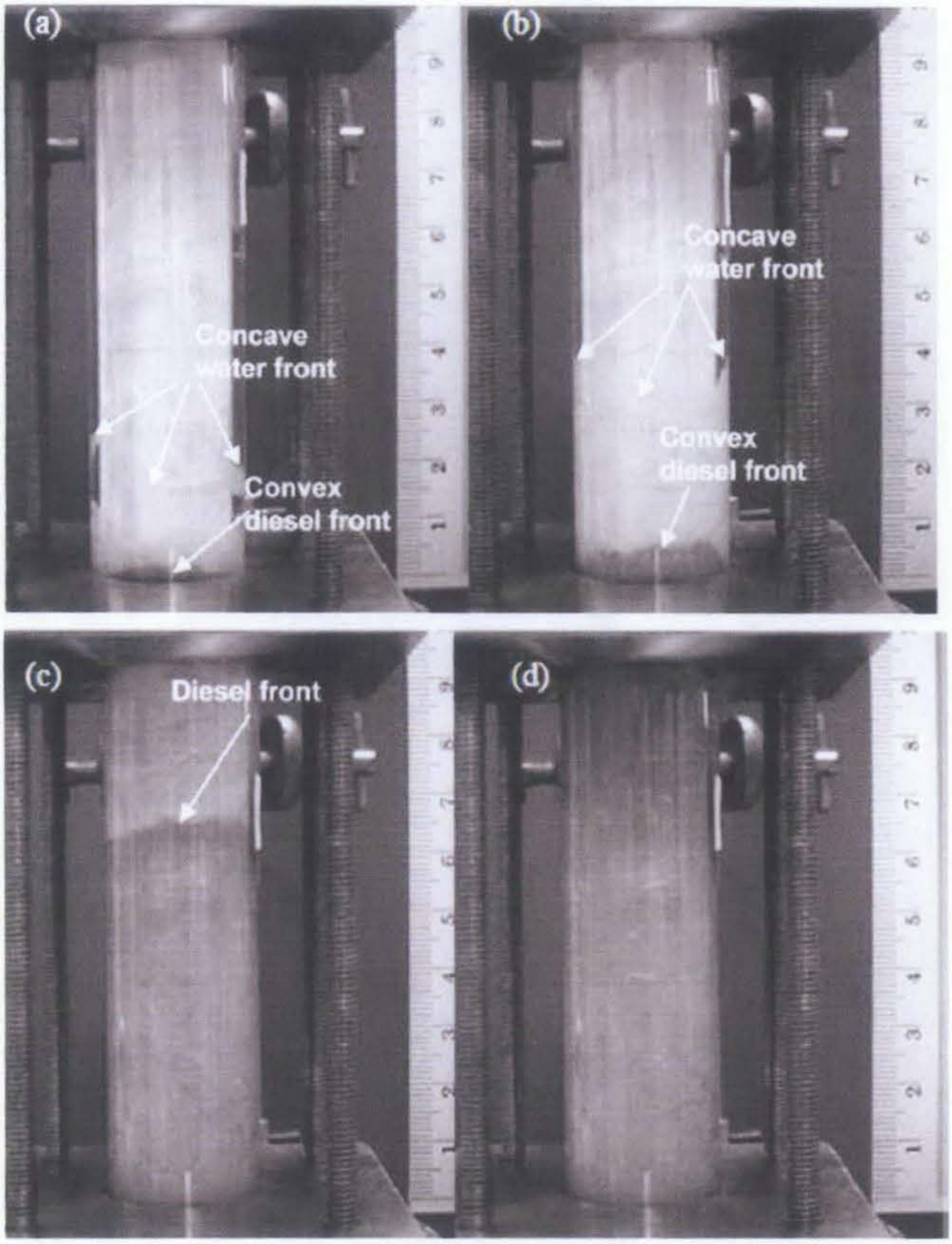


Figure 2.8: Observation of the 5% diesel/water mixture filtration by the kapok filter with a packing density of 0.07g/cm3. (a) 1st s; (b) 5th s; (c) 60th s; (d) 770th s (Huang et al., 2006)

During the infiltration stage, oil water infiltrated into the filter bed and the concave water front can be observed as shown in Fig 2.8(a) while, the convex diesel front can be noticed before the water front. Water will form a continuous flow channel throughout the column once water has flowed through the whole filter bed.

As for the separation phase, the diesel and water flows in the bed as two separate liquid fronts where the water front continues to advance rapidly whilst the diesel front slows down, resulting in phase separation due to physicochemical interactions between fiber and liquids. Displacement stage occurs when water front appears in outlet of the Kapok filter before the first appearance of oil droplet in the outlet. The water that is retained in the column displaces the diesel due to density difference. The oleophilicity characteristic of Kapok fiber makes it more difficult for the diesel to leave the column. Equilibrium stage is achieved after the first appearance of oil droplet in the Kapok filter outlet. The oil sorption occurred until the sorbent reached saturation point where oil-water concentration achieve equilibrium followed by oil breakthrough (Noble et al., 2004).

This project will evaluate the efficiency of Kapok as an oil-sorbent material used in a compact biodegradable oil absorption filter system in order to treat restaurant wastewater which mainly composed of used cooking oil and grease. Up to now, there is no report published on the application of Kapok in treating restaurant wastewater before discharging to the drainage and sewer system. Moreover, according to Lim et. al (2007), he mentioned that further study need to be conducted to assess the effect of oil concentration and to investigate the filter performance in the presence of surfactant that may affect coalescence of oil droplets . Thus, in this particular project the author will study the effect of various cooking oil + surfactant concentration on the Kapok filter performance. On top of that, the current technology in restaurant wastewater treatment does not involve absorption and this report will be the first to study on the absorption characteristics of Kapok on vegetable oil (cooking oil) where previously most research employed mineral oils to investigate oil sorption. Therefore, this project will be the first to be published in this particular field of application. The research of this project will take a step further through real life application of Kapok in treating restaurant wastewater in view of the fact that previous researches on Kapok are just revolved in lab work.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Methodology

The assessment on the efficiency of a compact biodegradable oil absorption filter using Kapok will be constructed based on several studies and experiment conducted on the filter. There are 3 experiments planned to be conducted and the descriptions are listed on the overall flowchart provided below:

Prelim Research

- Conduct literature review on current restaurant wastewater technology and perform literature review on Kapok

Hardware/ Experimental Setup

- Material Identification: Kapok, cooking oil (Canola), surfactant (detergent), Perspex wire mesh and human hair – filter spacer (design filter)
- Design experiment apparatus (design filter)

Experimental Work

- **Experiment 1:** Study on the effect of various packing densities of Kapok filter and inlet flow rate on the oil absorption efficiency and outlet flow rate
- **Experiment 2:** Design and test the compact biodegradable oil absorption filter based on the chosen packing density
- **Experiment 3:** Study the effect of cooking oil and surfactant concentrations on the filtrate turbidity and filtration efficiency.

Analysis of Result and Discussion

- Gather and tabulate data. Discuss the findings from the results obtained and make a conclusion out of the study, determine if the objective has been met.

Report Writing

- Compilation of all research findings, literature reviews, experimental works and outcomes into a final report

3.2 Experiment Setup

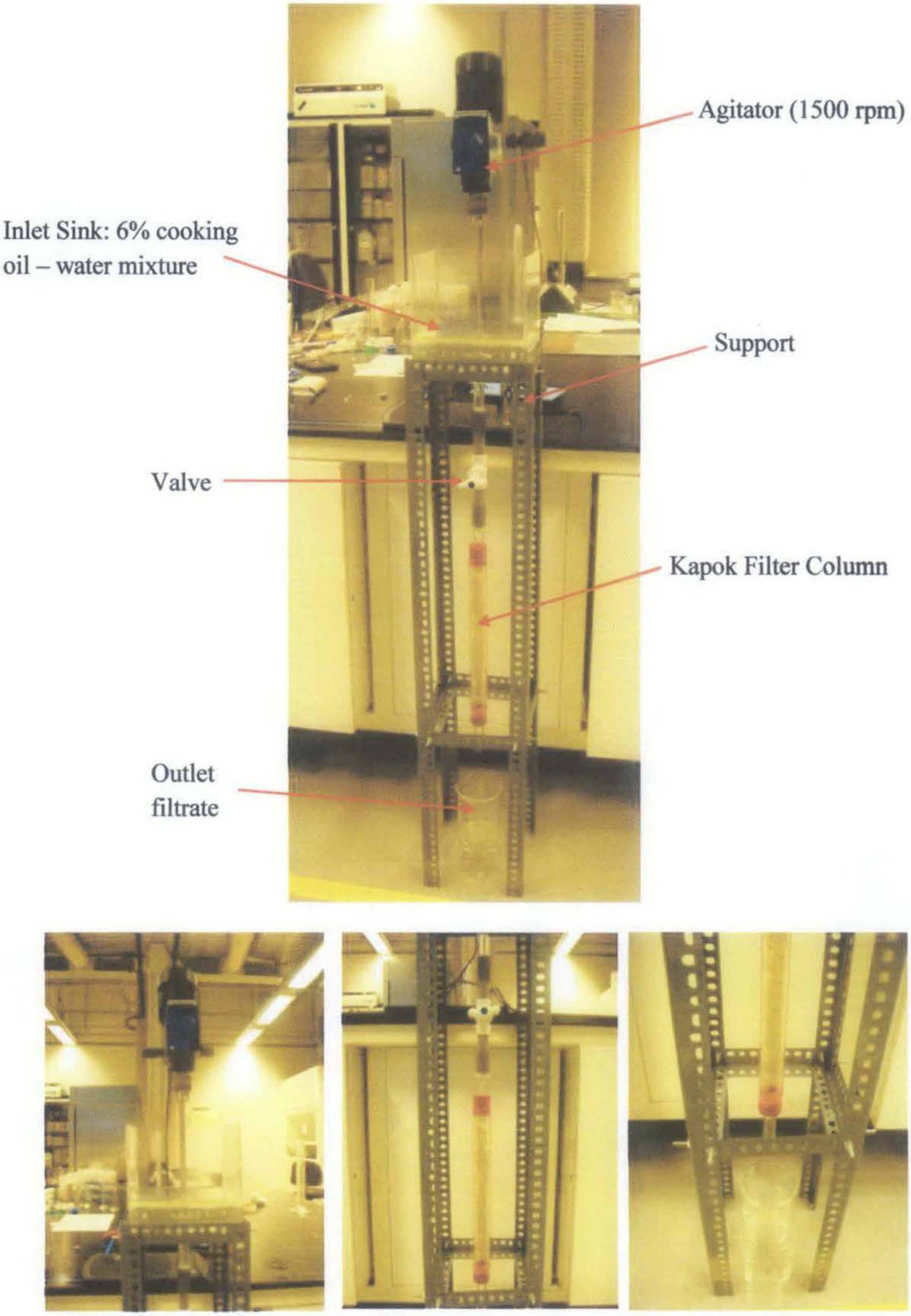
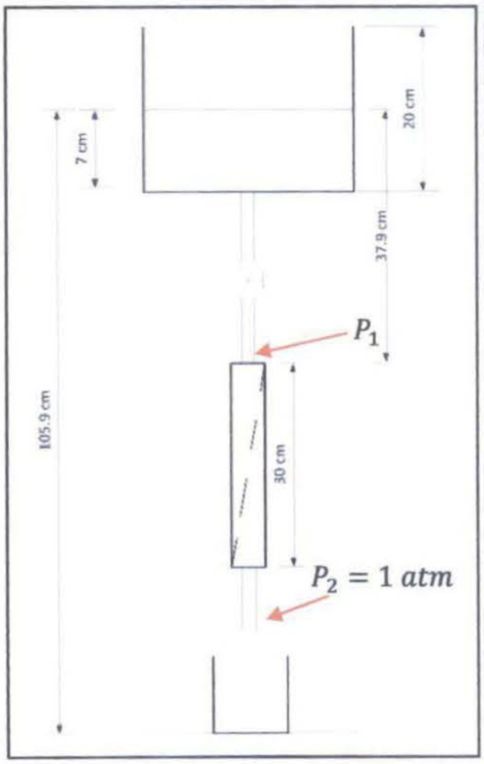


Figure 3.1: Experimental setup for oily water filtration in a Kapok filter

The use of fibrous deep-bed filtration system is beneficial in separating immiscible liquid from wastewater due to its simplicity in operation and cost efficient. This can be achieved with proper filter material used in the system. (Huang et al., 2006). In this study, an oily + surfactant emulsion water mixture sample will be used as a representation of a typical restaurant wastewater sample to give a better insight on the performance of Kapok filter in treating restaurant wastewater.

An acrylic column that is cylindrical in shape with a dimension of 3.1 cm in diameter and 30 cm in length will be used as the casing for the Kapok filter. Wire mesh will be included in the filter in such a way to keep the Kapok in place. In order to obtain a well-mixed cooking oil-surfactant-water mixture, the 2500 ml mixture should be agitated at 1500 rpm before it is fed into the Kapok filter. In previous studies conducted by Lim et. al (2007) and Anisa U.R et al (2010) on oil-water filtration using Kapok, the use of pump is necessary in order create a driving force ($\Delta P = 12.57 kPa$) within the Kapok packed-column to force the flow of oil-water mixture from bottom to top of the filtration column. On the other hand, for this particular experiment, pump is not used since the author is studying the flow of solution from top to bottom of the filtration column that is forced by gravity. This situation of experiment setup depicts the real life application of a filtration system in a kitchen-sink restaurant.



$$\rho_{H_2O} = 1\ g/cm^3$$

$$\rho_{oil} = 0.92\ g/cm^3$$

$$\begin{aligned}\rho_{solution} &= 0.06(0.92) + (0.94)(1)\\ &= 0.9952\ g/cm^3\end{aligned}$$

$$P_1 = 101325\ Pa + h\rho_{solution}g$$

$$= 101325\ Pa + (0.379\ m)\left(995.2\frac{kg}{m^3}\right)(9.81\frac{m}{s^2})$$

$$= 105025.14\ Pa$$

$$\Delta P = P_1 - P_2$$

$$\boldsymbol{\Delta P_{filter} = 3700\ Pa = 3.7\ kPa}$$

3.3 Project Work

Activities	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fabrication of Experiment Setup Parts	🟪	🟪					MID SEM BREAK								
Fix and joint the parts of the Experiment Setup			🟪	🟪											
Prepare Calibration Solution					🟪										
Conduct Experiment on Packing Density					🟪	🟪									
Progress Report Submission								🟧							
Design and test 3 Filters based on chosen packing density								🟪							
Study the effect of solution concentration (oil,surfactant, oil + surfactant)									🟪	🟪					
Study the effectiveness of Kapok filter in treating real restaurant wastewater										🟪					
Pre-EDX											🟧				
Draft Report Submission												🟧			
Dissertation Submission (Soft bound)													🟧		
Technical Paper Submission													🟧		
Oral Presentation														🟧	
Project Dissertation Submission															🟧

Figure 3.2: Gnatt Chart

Legend

🟧 **Important Milestone** 🟪 **Activities**

3.4 Experiment Procedures

3.4.1 Calibration of Solution Concentrations and Turbidity

Calibration curves are necessary to be developed first before initiating the experiments in order to evaluate the efficiency of filtration based on the influent and filtrate oil (effluent) concentration that are obtained during the experiments from the turbidity measurement.

2500 ml mixture of cooking oil + water is prepared based on the concentrations (0%, 2%, 4%, 6%, 8% and 10%) shown in the table below. The prepared solutions are then agitated at 1000 rpm for 5 minutes to ensure well-mixed cooking oil – water mixture. 10ml samples are then taken from every prepared solution to determine its turbidity using DR 2100 P Turbidimeter (HACH, USA). Finally a calibration curve (Turbidiy vs Oil Concentration) is developed in order to calculate the efficiency of filtration based on the filtrate oil concentration from the given turbidity.

Table 3.1: Turbidity measurement with respect to concentration of oil

Concentration of Oil	Turbidity (NTU)
0	1.68
0.02	887
0.04	900
0.06	902
0.08	976
0.1	1000

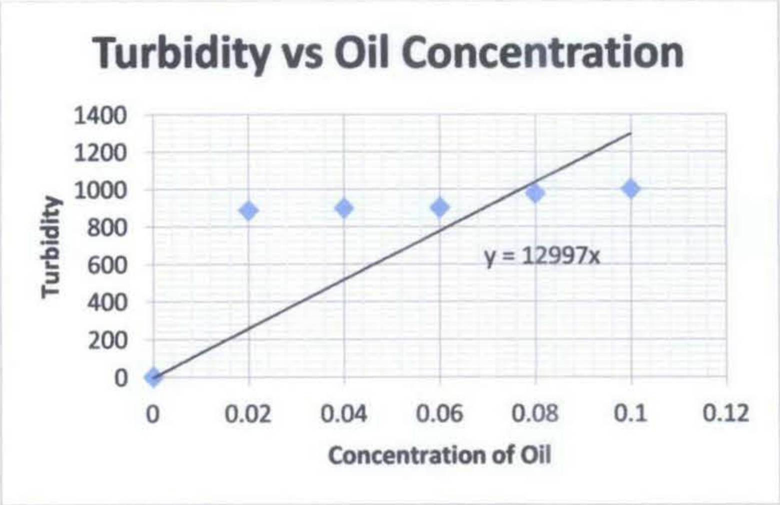


Figure 3.3: Calibration curve of Turbidity vs Oil Concentration

The calibration procedures are repeated for the following mixtures; surfactant + water and oil + surfactant + water emulsion

Table 3.2: Turbidity measurement with respect to concentration of surfactant

Concentration of Surfactant	Turbidity (NTU)
0	1.68
0.02	6.3
0.04	6.5
0.06	8.7
0.08	9.6
0.1	10.8

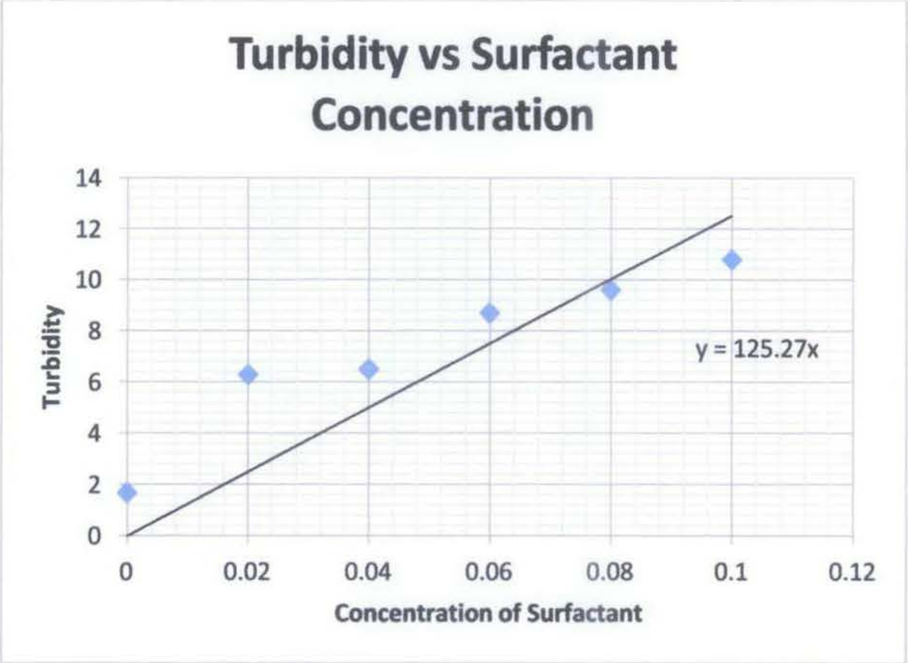


Figure 3.4: Calibration curve of Turbidity vs Surfactant Concentration

Table 3.3: Turbidity measurement with respect to concentration of oil + surfactant

Concentration of Oil + Surfactant	Turbidity (NTU)
0	1.68
0.02	54.9
0.04	263
0.06	412
0.08	653
0.1	872

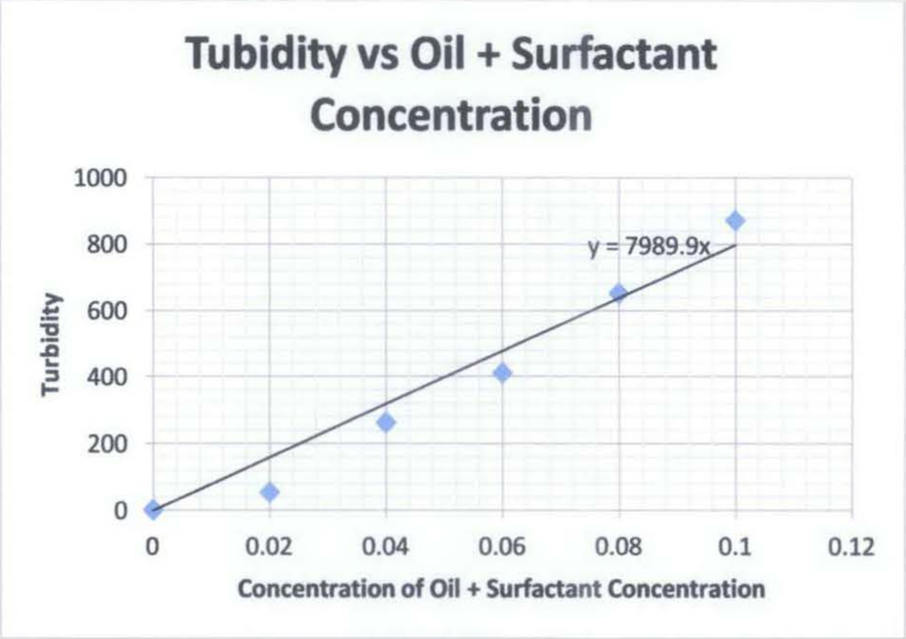


Figure 3.5: Calibration curve of Turbidity vs Oil + Surfactant Concentration

3.4.2 Study on the effect of various packing densities of Kapok filter and inlet flow rate on the oil absorption efficiency and outlet flow rate

Before inventing and designing the filter, the right packing density of Kapok should be determined first. Study shows that the optimum packing density for minimum COD were predicted at 0.07g/cm^3 (Anisa et al., 2010). Moreover, other study has shown that a packing density of 0.07g/cm^3 was the optimum one for diesel and hydraulic oil removal (Lim et al., 2006). However, for this particular experiment, the packing density test should be carried out even though 0.07g/cm^3 has been justified to be the optimum packing density for Kapok filter. The reason here is because the driving force for the filter in this experiment is created by gravitational force as compared to previous studies where the driving force (ΔP) is created by the assistance of a pump since the flow is from bottom to top of the filtration column. Besides that, different type of oil is studied in this project where the oil type may also affect the optimum packing density of Kapok since diesel and cooking oil have different viscosities.

Cooking Oil + water mixture of 6% concentration is first prepared by diluting 150 ml of oil with 2350 ml. The solution is then poured into the inlet sink and the stirrer is switched on where it is regulated to 1500 rpm in order to ensure uniform mixture. The Kapok filter inlet flow rate is measured and recorded manually by determining the time required to fill up 100ml measuring cylinder with the valve opening of 25% and 100%.

Next, the packing density of 0.02 g/cm^3 is prepared by determining the mass of Kapok required to fill the 226 cm^3 filtration column. After determining the mass required, the Kapok with the packing density of 0.02 g/cm^3 is packed uniformly into the filtration column. Finally the tap is opened at 25% and the filtrate is collected at the bottom of the column. After 5 minutes, 10 ml of filtrate sample is taken for turbidity measurement. Next, the tap is opened at 100% and after 5 minutes, 10 ml of filtrate is taken for turbidity measurement using DR 2100 P Turbidimeter (HACH, USA). The turbidity that are obtained is plotted on the turbidity vs oil concentration calibration curve which is prepared earlier in order to obtain the concentration of filtrate. Finally, the efficiency of kapok filter will be evaluated according to the formula below.

$$\boxed{e = \frac{(C_O - C)}{C_O}}$$

Where C is the cooking oil concentration of effluent (filtrate) and C_o is that of influent (Lim et al., 2006). The experiment is repeated for the following packing densities shown in the table below.

Table 3.4: Experimental design for Packing Density Experiment

Run	Concentration of Cooking Oil (%)	Flow rate (% Valve Opening)
1	0.02	25
2	0.02	100
3	0.04	25
4	0.04	100
5	0.06	25
6	0.06	100
7	0.08	25
8	0.08	100
9	0.10	25
10	0.10	100

3.4.3 Design and test compact biodegradable oil absorption filter based on the chosen packing density

The best possible Kapok filter is designed based on the chosen packing density from the previous experiment in order to increase the effectiveness of filtration. The Kapok filter is then tested with 6% oil + water mixture with a constant flow rate (25% valve opening). 10 ml of filtrate sample is taken for turbidity measurement and the turbidity obtained is plotted on the turbidity vs oil concentration calibration curve which is prepared earlier in order to obtain the filtrate concentration. Finally, the efficiency of the Kapok filter is computed and the best design is chosen for the following experiment.

3.4.4 Study on the effect of cooking oil, surfactant and cooking oil + surfactant emulsion concentrations on the filtrate turbidity and Kapok filter efficiency

Based on the chosen Kapok filter design, the study on the effect of various cooking oil concentration is conducted. 2500 ml mixture of cooking oil + water is prepared based on the concentration of 4%, 6% and 8%. The mixture is then poured in the inlet sink and it is agitated at 1500 rpm for 5 minutes. Next, keeping the flow rate constant throughout the experiment, the valve is open at 25%. The filtrate is collected at the bottom of the filtration column and after 5 minutes the 10 ml of filtrate sample is taken for turbidity measurement. The turbidity obtained is plotted on the turbidity vs oil concentration calibration curve which is prepared earlier in order to obtain the filtrate concentration. Finally, the efficiency of the Kapok filter is computed. The experiment procedures are repeated for the following mixtures; surfactant (4%) + water and surfactant (1%, 2% and 3%) + oil + water emulsion (8% oil/92 % water). For the surfactant + water mixture, UV Spectrometer test is conducted to evaluate the efficiency of surfactant filtration from water.

CHAPTER 4

RESULTS AND DISCUSSION

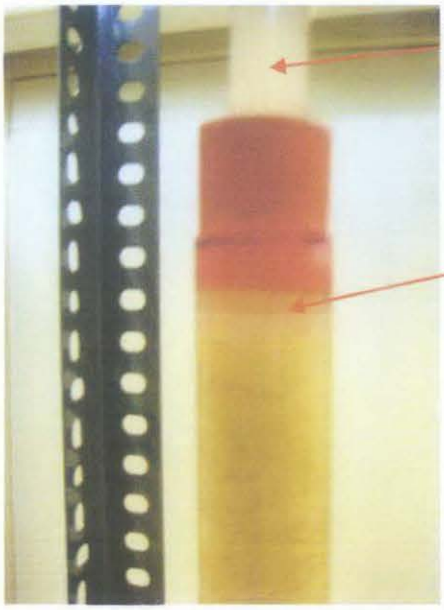
4.1 Effect of various packing densities of Kapok filter and inlet flow rate on the oil absorption efficiency and outlet flow rate

Table 4.1: Effect of packing density and inlet flow rate on outlet flow rate

Packing Density (g/cm3)	Valve Opening (%)	Inlet Flowrate (ml/s)	Outlet Flowrate (ml/s)	Flow rate reduction (%)
0.02	25	27 ± 0.5	18.7 ± 0.02	31 ± 1
	100	50 ± 0.5	35.4 ± 0.02	30 ± 1
0.03	25	27 ± 0.5	1.0 ± 0.02	96 ± 1
	100	50 ± 0.5	1.2 ± 0.02	97 ± 1
0.04	25	27 ± 0.5	N/A	N/A
	100	50 ± 0.5	0.47 ± 0.02	99 ± 1

From the table above, it can be observed that as the packing density increases the percentage of outlet flow rate reduction increases since more packing causes more restriction to flow as Kapok is water repellent. Initially, from the experimental procedures, it was suggested to study on numerous packing densities (0.02 g/cm^3, 0.04 g/cm^3, 0.06 g/cm^3, 0.08 g/cm^3 and 0.10 g/cm^3). However, since the packing density of 0.04 g/cm^3 illustrates that the outlet flow rate has a significant difference (or almost no flow) with the inlet flow rate, therefore 0.04 g/cm^3 has became the benchmark for this experiment and the packing density of 0.06 g/cm^3 to 0.10 g/cm^3 were not considered and could be omitted from the experiment. Nonetheless, a new packing density of 0.03 g/cm^3 is introduced in this experiment to decide on the best packing density with the least flow rate reduction.

It should be noted that the outlet flow rate of the filter should be kept similar to the inlet flow rate as a normal operation of a typical filter to avoid back flow and flooding in the sink. It can be seen that the packing density of 0.03 g/cm^3 and 0.04 g/cm^3 requires larger flow rate in order to sustain its pressure gradient.



Uniform 0.6 % oil + water mixture

Two Immiscible liquids formed

Figure 4.1: Kapok filter 0.04 g/cm^3 at 100% valve opening

From the figure above, the formation of oil + water immiscible liquids can be observed since higher compactness of the Kapok filter restricts the flow of uniform mixture and eventually allows the liquids to settle at the top of the column forming two immiscible liquids. Therefore, as the packing density increases, a higher inlet pressure is required to maintain a certain flow rate of the emulsion mixture to avoid the formation of two separate immiscible liquids as it settles at the top of the column and to maintain the outlet flow rate in order to prohibit the flooding of inlet sink. For higher packing density, a pump is required to increase its pressure gradient in order to provide an even flow pattern during the filtration process.

Figure 4.2: Outlet flow for 0.04 g/cm3 packing density

Table 4.2: Effect of packing density and inlet flow rate on filtration efficiency

Packing Density (g/cm3)	Valve Opening (%)	Outlet Turbidity (NTU)	Outlet Oil Concentration	Filtration Efficiency, e (%)
0.02	25	28.4	0.0021 ± 0.00002	96 ± 1
	100	29.5	0.0022 ± 0.00002	96 ± 1
0.03	25	28.6	0.0022 ± 0.00002	96 ± 1
	100	30	0.0023 ± 0.00002	96 ± 1
0.04	25	N/A	N/A	N/A
	100	98.07	0.0075 ± 0.00002	87 ± 1

The outlet oil concentration is obtained through the turbidity vs oil concentration calibration curve prepared earlier from the measured turbidity. It can be observed that as the packing density decreases, the turbidity of the filtrate reduces resulting in better filtration efficiency. The reason here is because at lower packing density, the interfiber distance inside the Kapok column is larger, which increases the size of the effective flow channels as compared to higher packing density. Therefore, there will be more pores available to entrap the emulsified oil and ultimately reduces the turbidity as compared to higher packing density (Anisa et al., 2010).

However at lower packing density, the Kapok has higher tendency to get compressed and shrink due to the incoming flow rate as shown in figure below resulting in smaller area of effective flow channel to entrap the emulsified oil.

Figure 4.3: 0.02 g/cm3 Kapok Filter before and after treating 6% oil + water mixture

A filtration efficiency of about 96% oil removal has been reported for both packing density of Kapok at 0.02 g/cm^3 and 0.03 g/cm^3 whereas higher packing of 0.04 g/cm^3 contributed to the least filtration efficiency.

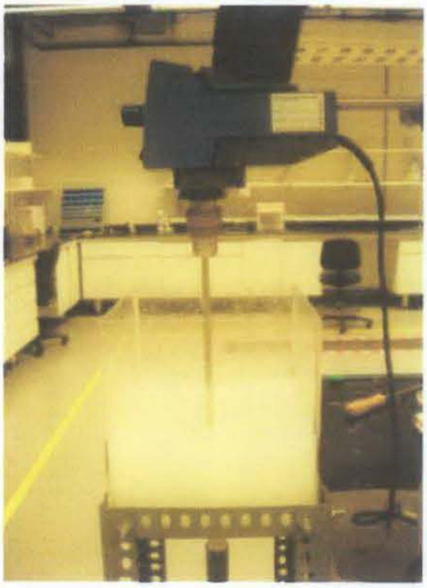


Figure 4.4: 6% oil + water mixture turbidity before treating with 0.02 g/cm^3 Kapok filter

Figure 4.5: Filtrate turbidity after treating 6% oil + water mixture with 0.02 g/cm^3 Kapok filter

Based on the table 4.1, it can be seen that at higher inlet flow rate, the outlet turbidity decreases for all packing densities. Higher flow rates and higher packing density create premature interactions between Kapok and oily water mixtures, which could be observed from only a small area of separation stage at the top of the Kapok column.

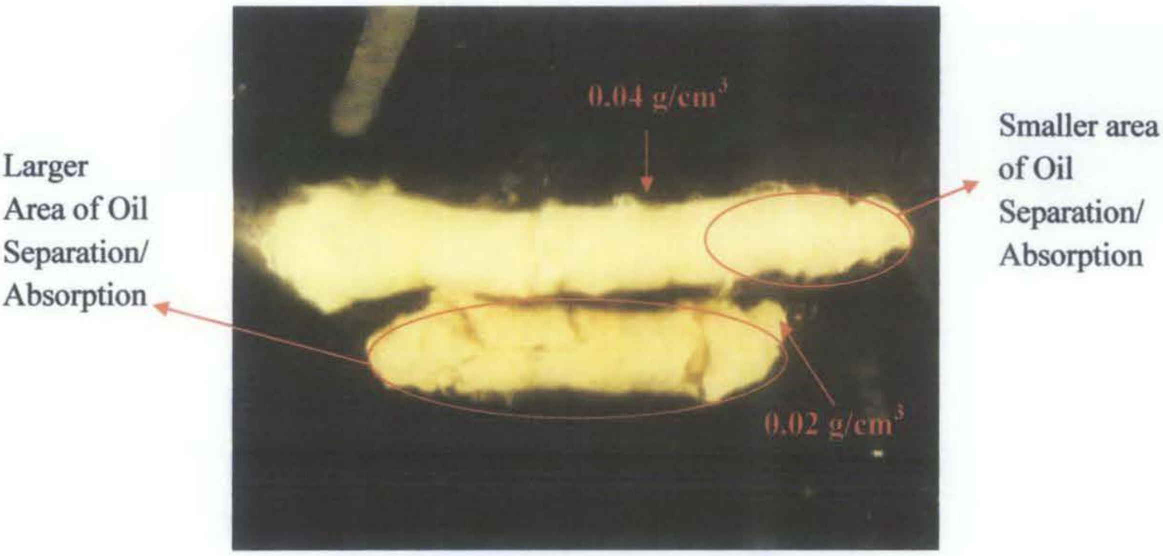


Figure 4.6: Kapok after filtration process

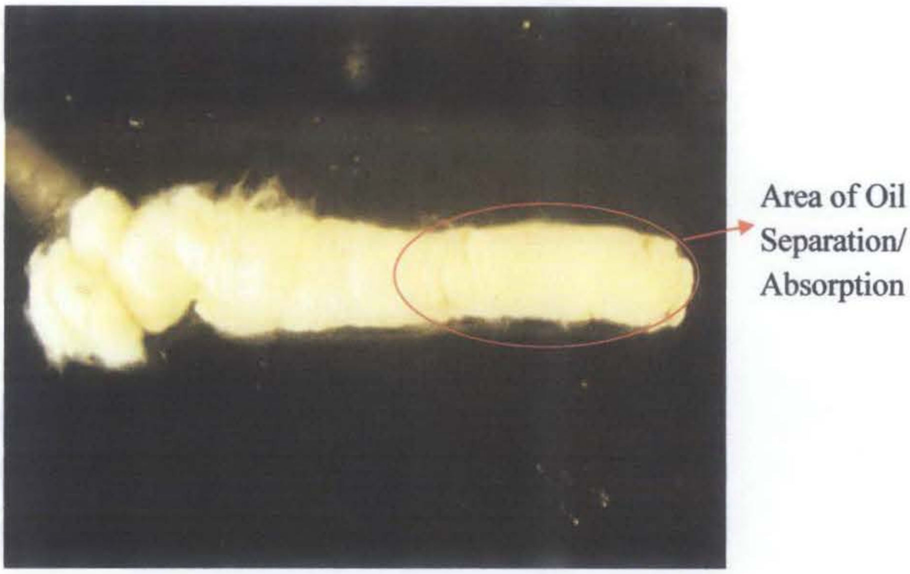


Figure 4.7: 0.03 g/cm^3 Kapok Filter after filtration process

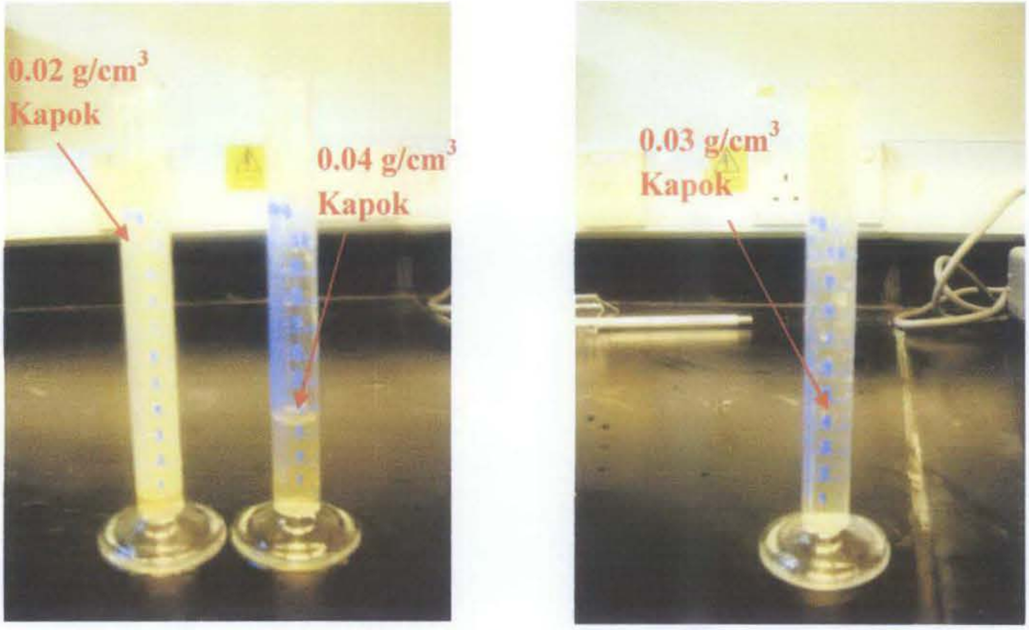


Figure 4.8: Oil Retained in Kapok Filter

Figure 4.8 shows the amount of oil that can be captured after draining out the oil by giving a squeeze. Less amount of oil could be captured for higher packing density (0.04 g/cm^3) due to premature interactions between Kapok and oily water mixture.

Based on previous study by Anisa U.R et al (2010), it was proven that at higher packing density, there was a longer residence time of oily water mixtures leading to longer saturation time resulting in larger volume of oily water mixtures could be filtered. Nonetheless, based on this experiment, the author observed that higher packing density of Kapok has contributed to lower outlet flow rate leading to back flow and flooding in inlet sink under gravitational pressure gradient. Besides that, higher packing density requires higher inlet pressure to maintain a certain flow rate which could not be obtained under gravitational pressure gradient until unless a pump is installed to maintain the outlet flow rate. Therefore, it is not applicable to use Kapok filter with high packing density under gravitational pressure gradient for real life application in kitchen-sink restaurant.

Through this experiment, the author has concluded that the best possible packing density that should be applied for the Kapok filter design would be **0.02 g/cm^3** since it contributes to better outlet flow rate, high filtration efficiency with the least filtrate turbidity and has larger size of the effective flow channel and area to entrap the emulsified oil. The author decided to improve the design of the Kapok Filter by including spacer in between the Kapok Filter in order to avoid the compression due to incoming flow to the filter.

4.2 Design a compact biodegradable oil absorption filter based on the chosen packing density

The Kapok filter should be redesign in such a way that the filter bed retains its shape after the solution passes through it. Previously, the author observed that at lower packing density, the Kapok has higher tendency to get compressed and shrink due to the incoming flow. This situation will result in smaller size of effective flow channel to entrap the emulsified solution. According to the previous experiment, the author has chosen 0.02 g/cm^3 as the optimum packing density for the Kapok filter design. Filter spacers are included in the Kapok filter to increase the packing of the whole column while retaining the packing density of Kapok in the filtration column to prevent the aforementioned situation. The calculation for the Kapok filter design is shown below:

$$D_{column} = 3.1cm \;\&\; H_{column} = 30cm$$

$$V_{column} = (\pi D^2/4)H = 226cm^3$$

$$Mass\ of\ Kapok = Packing\ Density \times V_{column}$$

$$= 0.02\, g/cm^3 \times 226cm^3 = 4.52g\ Kapok$$

The author decided to divide the column into three partitions using 1cm spacers. A total of four spacers will be included in the design. Therefore, the height and mass of Kapok required for each partition are computed.

$$Height\ of\ Kapok\ bed\ for\ each\ partition = \frac{H_{column} - 4(h_{spacer})}{total\ partitions}$$

$$= \frac{30 - 4(1)}{3}$$

$$= \mathbf{8.67cm}$$

$$Mass\ of\ Kapok\ bed\ for\ each\ partitions = \frac{4.52}{3} = \mathbf{1.51g\ Kapok}$$

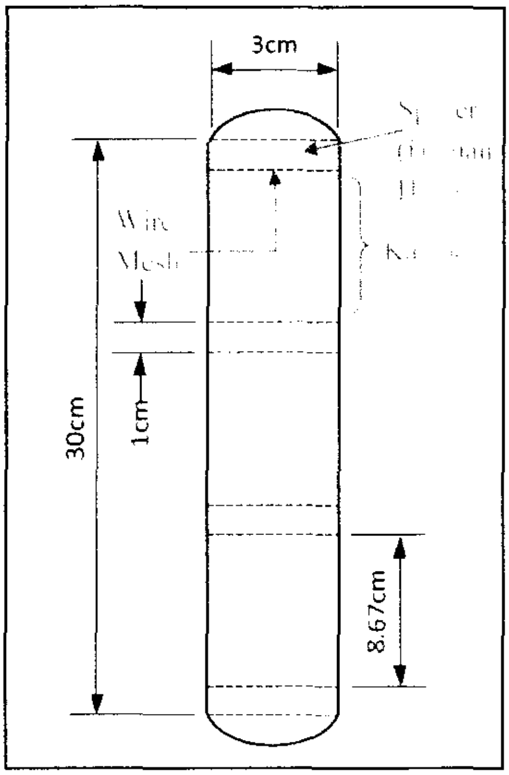


Figure 4.9: Kapok Filter Design

The author decided to use human hair as spacers for the filtration column. Study has shown that human hair has an excellent adsorbent property. The National Aeronautics and Space Administration (NASA) has justified that human hair adsorbs up to 5 times of its weight in oil while not retaining water (Oil Spill Recovery Solution). Recently, NASA has conducted an experiment where 55-gallon drum of oil-water mixture from an actual fuel oil spill was treated with a human hair filter and the filtrate is discharged into a clean 55-gallon drum.

Approximately 300 pounds of oil-water mixture was treated through the filtration system. The filtrate was examined and the result was only 17 parts of oil per million parts of water remained in the filtrate (Ottimat.ca, 2009). This shows that hair efficient oil sorbent.

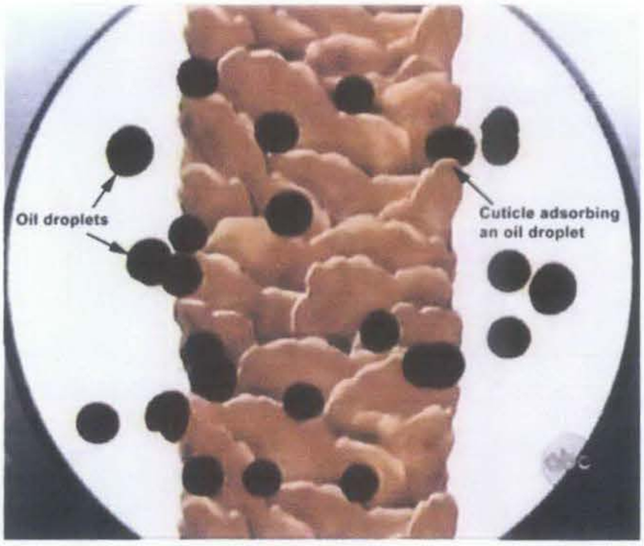
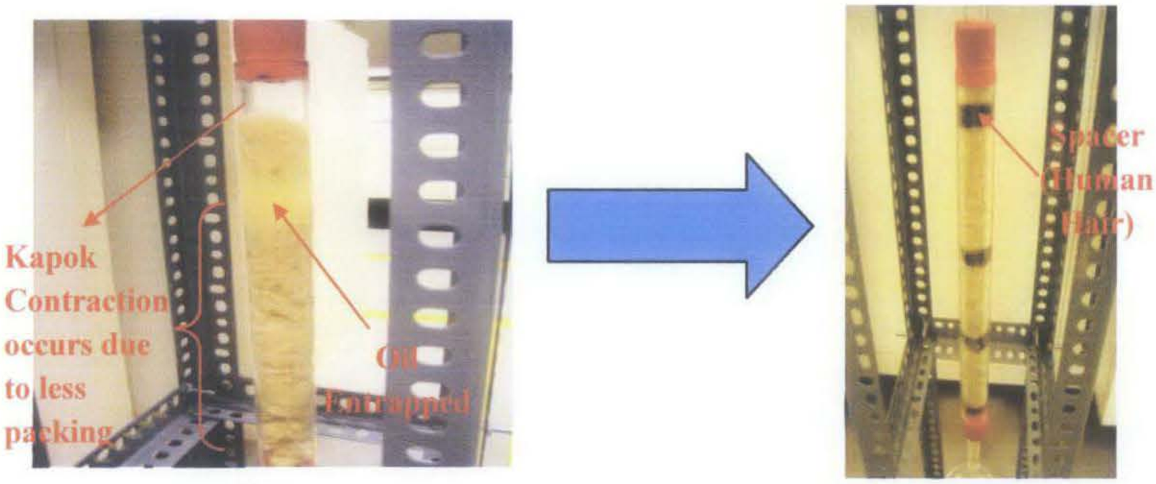


Figure 4.10: Cuticle of Human hair (Ottimat.ca, 2009)

Figure above illustrates the adsorption of oil droplets on human hair. The oil droplet is being attached on the surface of the hair where the cuticle plays an important role in adsorbing oil droplets rather than being absorbed into the hair while not retaining the water since hair is hydrophobic in nature. Recently, a new product called Ottimat has been introduced to the oil and gas market where it uses recycled human hair for oil spill control.

According to statistics, 60 million pounds of human hair are disposed of in landfills each year in the US (Ottimat.ca, 2009). By recycling the human hair as a filtration medium or Ottimat, this will reduce the amount of waste in our landfills. Therefore, no doubt that human hair is abundant, easily available and cost effective.



Before **After**

Figure 4.11: 0.02 g/cm^3 Kapok Filter Design Modification

4.3 Effect of cooking oil and surfactant concentration on filtration efficiency

Table 4.3: Effect of Oil Concentration on Filtration Efficiency

Oil Concentration (%)	**Outlet Turbidity (NTU)**	**Outlet Concentration (v/v)**	**Filtration Efficiency, e (%)**
4	7.4	0.0006 ± 0.00002	98 ± 1
6	18.6	0.0014 ± 0.00002	97 ± 1
8	161.0	0.0012 ± 0.00002	84 ± 1

From the table above, it can be observed that as the oil concentration of the solution increases the filtration efficiency increases since the number of oil molecules increases as Kapok filter requires more capacity to accommodate the increase of oil concentration. Therefore, higher packing density is required since it can contribute to longer residence time of oily water mixtures leading to longer saturation time resulting in larger volume of oily water mixtures could be filtered. The Kapok filter has high filtration efficiency in separating oil from water.

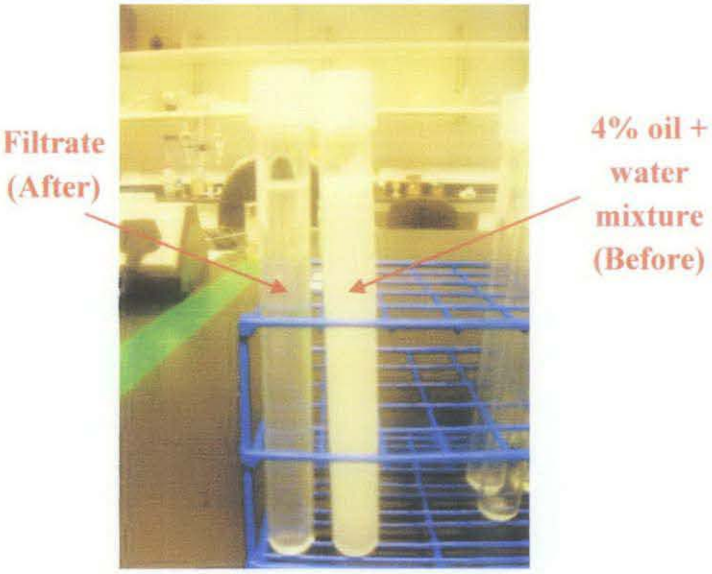


Figure 4.12: Filtration of 4% oil + water mixture

From the figure above, it can be observed that there is a significant reduction on the turbidity of filtrate as compared to the 4% oil + water mixture. This shows that the Kapok filter is capable to treat oily water mixture.

Based on the UV spectrometer curve for surfactant filtration from water, for 4% surfactant + water mixture, it can be observed that there is no significant difference on the wave length and peaks for the filtrate (after filtration) and influent (before filtration)

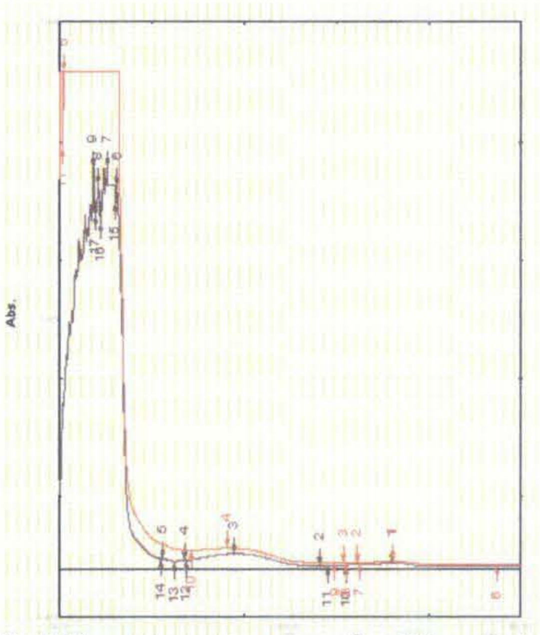


Figure 4.13: UV spectrometer curve for 4% surfactant filtration

🟥 Before Filtration ⬛ After Filtration

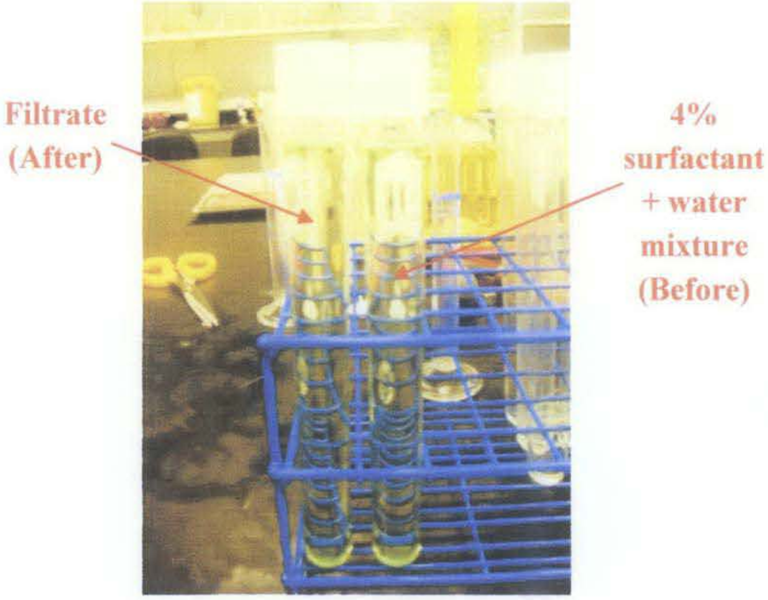


Figure 4.14: Filtration of 4% surfactant + water mixture

The result shows that the surfactant could not be separated from the water-surfactant mixture. However, with the presence of surfactant in water-oil mixture the kapok filter system is capable to separate oil **efficiently** (see table 4.4)

Table 4.4: Effect of Filtration Concentration in oil + water mixture (8% oil /92% water) on Filtration Efficiency

Surfactant Concentration in water + oil mixture (%)	**Outlet Turbidity (NTU)**	**Outlet Concentration (v/v)**	**Filtration Efficiency, e (%)**
1	49.0	0.001 ± 0.0002	88 ± 1
2	65.2	0.0015 ± 0.00002	92 ± 1
3	69.1	0.0016 ± 0.00002	94 ± 1

From the table above, it can be observed that as the concentration of surfactant in oil + water mixture increases the filtration efficiency increasing while keeping the ratio of oil/water constant (8% oil /92% water).

When surfactant and mixes in oil + water solution, the surfactant breaks the oil molecules into many smaller suspended droplets (emulsion). This is due the fact that surfactant molecules have both properties of non-polar and polar at opposite ends of the molecule. The non-polar tail of the surfactant will be attached and dissolve in the non-polar oil molecules. Whereas the polar end of the surfactant will be attracted to the water molecules and eventually makes the surface of the oil molecules negatively charged. This enables the oil to break into smaller suspended droplets (emulsion) as the oil droplets repel each other. Therefore, the oil can be easily separated from the water. As a result, the Kapok filter is capable to separate oil efficiently as the concentration of surfactant increases.

CHAPTER 5

CONCLUSION & RECOMENDATION

5.1 Conclusion

Based on the current experiment completed, the following conclusions can be made:

- The best possible packing density that should be applied for the Kapok filter design under gravitational pressure gradient would be **0.02 g/cm^3** since it contributes to better outlet flow rate, high filtration efficiency **(96%)** with the least filtrate turbidity and has larger size of the effective flow channel and area to entrap the emulsified oil. Objective Achieved.
- The compact biodegradable oil absorption filter is designed based on the chosen packing of 0.02 g/cm^3. Objective Achieved.
- Based on UV Spectrometer test, the result shows that the surfactant could not be separated from the water-surfactant mixture. However, with the presence of surfactant in water-oil mixture the kapok filter system is capable to separate oil efficiently as surfactant enable to break oil molecules to smaller suspended droplets (emulsion) which results in higher filtration efficiency.
- Kapok has shown a great potential as an natural oil sorbent in treating restaurant wastewater (FOG) due the fact that it is hydrophobic-oleophilic in nature.

5.2 Recommendations

- To accurately measure the inlet and outlet flow rate and pressure gradient of the filter, a flow meter and a differential pressure meter should be installed on the experiment apparatus
- Further research and study should be conducted on the reusability and the life span of the Kapok Filter
- The Biodegradable Oil Absorption Filter system should be installed in one of the restaurant kitchen sink and test should be conducted to further justify the feasibility of the project in real life application

REFERENCES

Abdullah, M.A., Anisa, U.R., and Man, Z., 2009, "Physicochemical and sorption characteristics of Malaysia Cieba Pentandra (L.) Gaertn. as a natural oil sorbent," *Journal of Hazardous Materials* **177(2010):** 683-691.

Anisa, U. R., Abdullah, M.A., 2010, "Evaluation of Malaysian Ceiba pentandra (L.) Gaertn. for oily water filtration using factorial design," *Desalination* **266 (2011):** 51–55.

Astral Currently, "Organic Kapok: A Discussion with Astral's Founder Philip Curry," Retrieved 21/8/2011

Blue Sky Biofuels., 2008, "Discounted Grease Trap Cleaning Services," Retrieved 21/8/2011, http://www.blueskybio-fuels.com/grease_trap.html

Chen, G., Chen, X., and Yue, P.L., 2000, "Electrocoagulation and electroflotation of restaurant wastewater," *Journal of Environmental Engineering.*

Chen, X., Chen, G., and Yue, P.L., 1999, "Separation of pollutants from restaurant wastewater by electrocoagulation," *Separation and Purification Technology* **19 (2000):** 65–76.

Cheremisinoff, N.P., 1998, Liquid Filtration, 2nd ed. Butterworth-Heinemann, Boston.

Cheryan, M., Rajagopalan, N., 1998. "Membrane processing of oily streams: wastewater treatment and waste reduction," *J. Membr. Sci.* **151:** 13–28.

Choi, H.M., 1996, "Needlepunched cotton nonwovens and other natural fibers as oil cleanup sorbents," *J. Environ. Sci. Health. Part* A **31 (6):** 1441–1457.

Choi, H.M., Cloud, R.M., 1992, "Natural sorbents in oil spill cleanup," *Environ. Sci. Technol.* **26 (4):** 772–776.

Choi, H.M., Moreau, J.P., 1993, "Oil sorption behavior of various sorbents studied by sorption capacity measurement and environmental scanning electron microscopy," *Microsc. Res. Technol.* **25:** 447–455.

"Dissolved air flotation," *Wikipedia.* Retrieved 21/8/2011, http://en.wikipedia.org/wiki/Dissolved_air_flotation

ESP Water Product, 2009, "How Do Reverse Osmosis Filter Systems Work & What Do They Do?," Retrieved 21/8/2011, http://espwaterproducts.com/about-reverse-osmosis.htm

Hori, K., Flavier, M.E., Kuga, S., Lam, T.B.T., Liyama, K., 2000, "Excellent oil absorbent kapok [*Ceiba pentandra* (L.) Gaertn.] fiber: fiber structure, chemical characteristics, and application," *J. Wood Sci.* **46:** 401–404.

Huang, X., and Lim, T.T., 2006, "Performance and mechanism of a hydrophobic–oleophilic kapok filter for oil/water separation," *Desalination* **190 (2006):** 295–307

Khan, E., Virojnagud,W., Ratpukdi, T., 2004, "Use of biomass sorbents for oil removal from gas station runoff," *Chemosphere* **57:** 681–689.

Kobayashi,Y., Matuo, R., Nishiyama, M., 1977, "Method for adsorption of oils," *Japanese Patent,* **52,138,081**.

Kowalska I., Kabsch-Korbutowicz, M., Majewska-Nowak, K., Pietraszek, M., 2005, "Removal of Detergents from Industrial Wastewater in Ultrafiltration Process," *Environment Protection Engineering,* **31(3):** 207-21

Lim, T.T., Huang, X.F., 2007, "Evaluation of kapok (*Ceiba pentandra* (L.) Gaertn.) as a natural hollow hydrophobic–oleophilic fibrous sorbent for oil spill cleanup," *Chemosphere* **66 (5)**, 955–963.

Machinery Lubrication, "Options for Water Removal," Retrieved 21/8/2011, http://www.machinerylubrication.com/Read/503/water-oil-removal

Machinery Spaces, 2010, "Oily water separator working principles and guidance," Retrieved 21/8/2011, http://www.machineryspaces.com/oily-water-separator.html

Menna, R.K., "Dishwasher Detergent Guide: Dishwasher Detergents – Are They Harmful?," Retrieved 21/8/2011, http://www.dishwasherdetergentphosphate.com/dishwasher-detergents-are-they-harmful/

Milton, B., 2008, "Dissolved air flotation," Retrieved 21/8/2011, http://en.citizendium.org/wiki/File:DAF_Unit.png

Mueller, J., Cen, Y., Davis, R.H., 1997, "Crossflow microfiltration of oily water," *J. Membr. Sci.* **129:** 221–235.

Noble, R.D., Terry, P.A., 2004, "Principles of chemical separations with environmental application, in: A. Varma (Ed.)," *Cambridge Series in Chemical Engineering, Cambridge University Press, Cambridge*: 198–199

Oil Spill Recovery Solution, "OttiMat Efficacy," Retrieved 19/12/2011, http://www.oilspillrecovery.com/page5.html

Ottimate.ca., 2009, "Öttimat," Retrieved 19/12/2011, http://ottimat.ca/

Peeters, J.G., Theodoulou., n.d. "Membrane technology treating oily wastewater for reuse"

Pollution Control System, Inc., 2011, "Oil/Water Separators for the Wastewater Treatment Industry," Retrieved 21/8/2011, http://www.pollutioncontrolsystem.com/Page.aspx/82/Oil-Water-Separators.html

School In The USA., 2003 Retrieved 25/6/2011, http://www.schoolsintheusa.com/careerprofiles_details.cfm?carid=145

"Stop the Clog," *Southern Monterey Bay Dischargers Group,* Retrieved 21/8/2011, http://www.clogbusters.org/

Tom, R., n.d., "Kevin Costner's Oil Separator," *Hubpages,* Retrieved 21/8/2011, http://liambean.hubpages.com/hub/Kevin-Costners-Oil-Separator

Wakelin, N.G., and Forster, C.F., 1998, "The aerobic treatment of grease-containing fast food restaurant wastewaters," *Trans IChemE,* **Vol 76,** Part B