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# Characterization of Raw Kapok Fiber as Filtration Medium for Biodiesel Plant Waste Oil

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**Abstract**

The study aims to examine the potential of kapok fiber as a filtration medium for biodiesel plant waste oil. Kapok fiber, derived from the Ceiba Pentandra tree, is a natural fiber with exceptional hydrophobic-oleophilic properties. This properties are attributed to its permeable hollow lumen structure and the presence of a waxy substance on its surface. The objective was to analyze the properties of Kapok fiber before and after its use as a filtration medium using Scanning Electron Microscope (SEM), Fourier Transform Infrared Spectroscopy (FTIR), and Contact Angle measurements. The SEM study of the kapok fiber reveals a waxy surface, hollow lumen, and porous features that are considered to have significant oil storage capacity. The FTIR measurement indicates a prominent peak at 1741 $cm^{-1}$, which corresponds to the stretching vibrations of the C=O bond. This peak is characteristic of ester groups found in biodiesel waste oil. The contact angle measurements of raw kapok fiber, taken was 145.3°, exhibit a significant degree of hydrophobicity. But after filtering, the sample shows a contact angle of 0°, indicating complete wetting. There is a significant difference in filtration efficiency between the two flow directions. The efficiency of horizontal flow filters increases from 36.40% at a width of 20 mm to 49.20% at a width of 40 mm, and further to 61.95% at a width of 60 mm. Vertical flow filters exhibit superior efficiency at various widths: 64.10% at 20 mm, 70.40% at 40 mm, and 78.35% at 60 mm. The vertical flow filters exhibit greater filtration efficiency, indicating that they are more successful in capturing contaminants compared to horizontal flow filters. Lastly, kapok fiber proved to be and effective oil filtration medium for biodiesel plant waste oil.

## 1. Introduction

Oil contamination in wastewater poses a major environmental challenge for a range of industries, such as biodiesel production, food processing, and petrochemical operations. The presence of oil in wastewater can have devastating effects on the environment, causing significant harm to aquatic ecosystems and the overall quality of water [1]. Efficiently managing oil-laden wastewater is crucial to minimize the negative impacts and meet strict environmental regulations.

Synthetic fibers are typically the most efficient in oil recovery. Under certain circumstances, it is possible to reach a weight ratio of 40:1 between oil and fiber, whereas natural fibers typically have a ratio of 10:1. Nevertheless, one significant disadvantage of utilizing synthetic polymers such as polypropylene is their relatively sluggish rate of degradation when compared to natural fibers. Additionally, these polymers are not naturally occurring as sorbent materials [2]. Despite its adsorption capability, natural fibers are appealing due to their abundance in nature and cheap cost or free availability for purchase [3].

One appealing characteristic of natural fibers is their hydrophobic-oleophilic characteristics, which make them effective in removing oil. This property is influenced by various elements, including the quantity of chemical constituents in the surface wax, the physical arrangement of the fiber, and the nature of the fiber's pores. Typically, various natural fibers possess varying oil sorption capacities due to their distinct physicochemical features and chemical contents that enable them to absorb oil [4].

The oil sorption ability of kapok and several other natural fibers is due to the existence of spacious and non-collapsing hollow lumens. These lumens facilitate oil sorption through capillary action and offer sufficient interstitial space for oil trapping. Kapok fibers have been shown to contain a larger percentage of cutin wax, specifically 3%, in comparison to cotton. In addition, it has been observed that it has a high concentration of acetyl groups (13%), which is greater than the amount found in other common plant fibers that usually have about 1-2% of acetyl groups connected to non-cellulosic polysaccharides [5].

Mechanical filtration is a commonly used method of filtration when treating oil contamination in effluent. Mechanical filtration does have a few disadvantages, particularly in terms of the associated costs. The initial investment in filtration equipment and ongoing maintenance cost can be substantial, especially for large-scale industrial applications [6]. Additionally, the disposal of filter media and the necessity for frequent replacement may result in an increase in operational expenses. Despite these challenges, mechanical filters remain an effective method for treating oil-contaminated effluent due to their environmental benefits. This treatment not only ensures water resources but also supports the implementation of environmentally beneficial practices through industries.

Kapok fiber has shown potential as an environmentally friendly and cost-effective adsorbent for the removal of oil from water. On the other hand, further investigation is necessary to obtain the characteristics of kapok fiber and to analyse the filtration efficiency of kapok filters in a variety of flow conditions and configurations. In order to establish an effective filtration medium, it is essential to possess a comprehensive comprehension of the correlation between the properties of kapok fiber and its filtering capabilities.

This study investigated the efficiency of raw kapok fiber filters when tested with two distinct flow orientations, specifically horizontal and vertical, without any modifications to their structure. The properties of kapok fiber have been analyse using characterization techniques including Scanning Electron Microscope (SEM), Fourier Transform Infrared Spectroscopy (FTIR), and contact angle analysis.

## 2. Methodology

### 2.1 Materials

Kapok fiber is a natural fiber derived from the seeds of the Ceiba Pentandra tree. The purification of raw kapok involves the separation or removal of any contaminants and dirt that may be present. To preserve the raw kapok freshness, the sample was handled with care to avoid any form of treatment or harm. The kapok will be used in its raw form without any alterations. Next, kapok was filled in filter with three different widths: 20mm, 40mm, and 60mm.

To begin the experiment, 200ml of oil and 400ml of water were added in a beaker to pour on the filter. The filters are 130mm length and 80mm height with three difference width 20mm, 40mm and 60mm. Firstly, kapok was fully filled in the 20mm width filter before being weighted. After that, the filter was placed in the middle of the containers to start the filtration test. After the filtration test, weighted kapok will be taken again. This step was repeated for 40mm and 60 mm (horizontal flow filter) and 20mm, 40mm and 60mm (vertical flow filter).

The oil filtration efficiency of the kapok fiber was determined by weighting the kapok before and after the filtration and calculated by Eq. (1).

$$Filtrating\ efficiency = \frac{m_1 - m_2}{m_1} x\ 100\% \tag{1}$$

Where:
$m_1$ = volume of oil before the filtration, which is 200 ml
$m_2$ = volume of remaining oil in the containers

## 2.2 Method

The research method can be broken down into several steps. This ensures the analysis is executed smoothly and systematically to satisfy its aim. Fig 1 shows the flowchart procedure for the project.

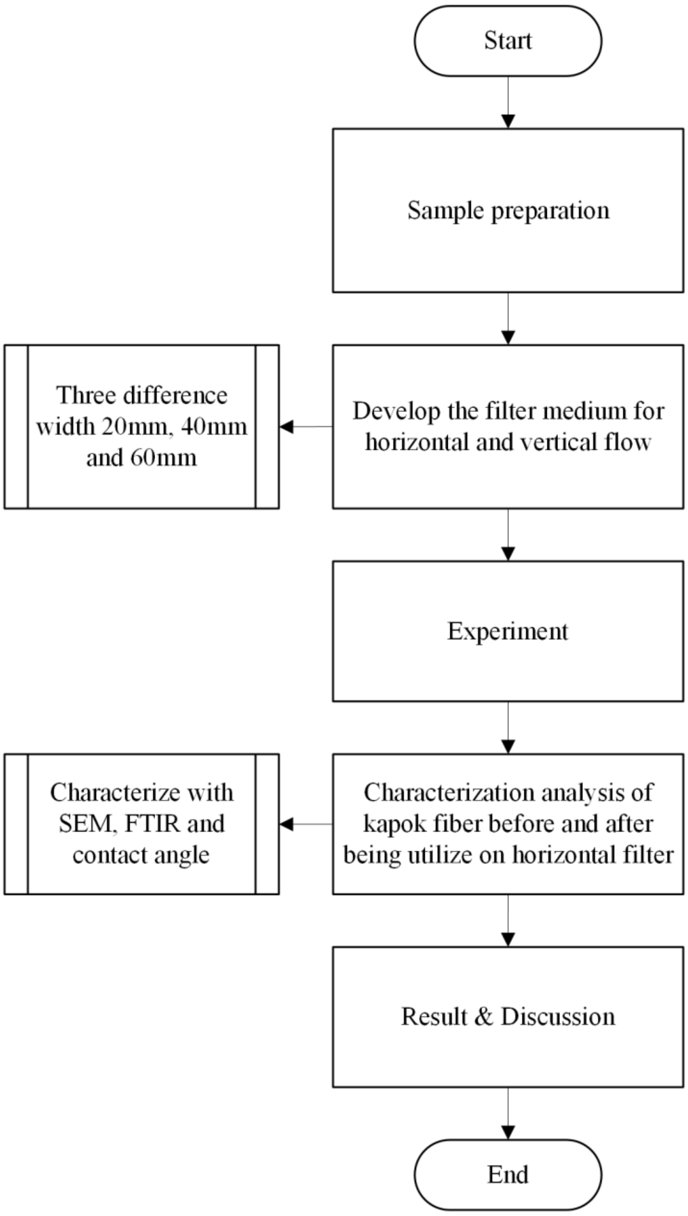


**Fig. 1** Flowchart of methodology

Firstly, for sample preparation of kapok fiber involves the separation or removal of any contaminants and dirt that may be present. To preserve the raw kapok freshness, the sample was handled with care to avoid any form of treatment or harm. The kapok has been in its raw form without any alterations. Kapok is cut into small shapes using cutting implements. Next, kapok was fully filled in filter with three different widths: 20 mm, 40 mm, and 60 mm. Then, the weight was measured. To begin the experiment, the filter was placed in the middle of the containers. A measured quantity of 200 ml of oil was combined with 400 ml of water and then poured into the filter. After that, the weight of the kapok has been taken again and recorded. The volume of remaining oil in the containers was measured and the oil filtration efficiency was calculated by eq (1). Figs 6,7, and 8 present the simply overview of all the recorded result obtained.

After that, the structure of kapok fiber has been analysis using analytical characterization. The methods that have been used to accomplish these are Scanning Electron Microscopy (SEM), Fourier-Transform Infrared Spectroscopy (FTIR) and contact angle.

## 3. Results and Discussion

### 3.1 Surface Morphology of Kapok Fiber

The porous structures that have been identified in kapok fibers are believed to have the potential to provide a substantial capacity for oil storage, as illustrated in Figure 2(a), which displays an image of the sample under magnification of ×75. When magnification of x1000. A uniform texture with a wax coating is visible on the surface of kapok fiber, as shown in Figure 2(b). The hydrophobic nature of the fiber is indicated by the high contact angle provided by this wax layer, which is of paramount importance. Kapok fiber is an exceptional material for oil absorption in aqueous systems due to its hydrophobic properties. Numerous studies have enhanced this quality by eliminating the wax layer, which has led to an increase in surface irregularity and the exposure of the hydrophilic surface. This modification facilitates the adhesion of oil to the outer surface of the lumen and the ease with which it can penetrate the interior surface of the lumen [7].

Figure 2(c) shows the cross-sectional view of kapok fiber at a magnification of x1000. This view shows that the fiber has a measured thickness of approximately 1.0 μm, thin walls that exhibit an oval to round shape, and large lumens that measure approximately 10 μm in diameter. The presence of lumen structure has been identified as a characteristic that facilitates the secure keeping of oil after it has been collected [8]. Furthermore, the results of these aspects are in accordance with those of another relevant research [9]. Due to these characteristics, the fiber is capable of floating in water and selectively absorbing oil, rendering it suitable for use in the filtration process.

(a) (b) (c)

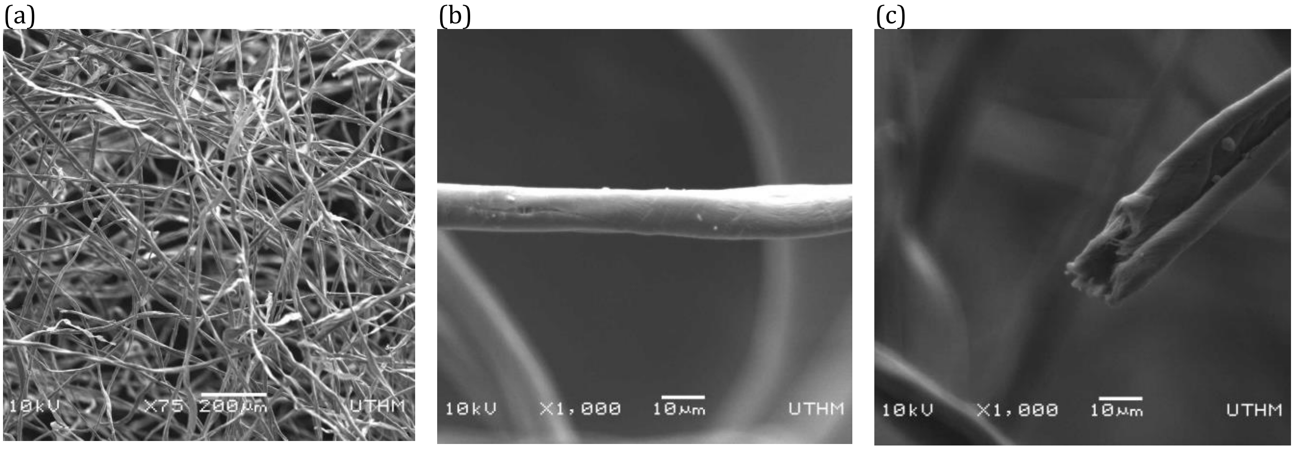


**Fig. 2** (a) kapok porous structure, (b) kapok fiber surface that containing wax and (c) kapok fiber cross-section structure.

### 3.2 Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR spectra analysis of raw kapok fiber before and after it was used as a filter for waste biodiesel oil shows significant chemical modifications, as illustrated in Figure 3. The figure illustrates a few of the most notable peaks for raw kapok fiber: The presence of hydroxyl groups is indicated by O-H stretching vibrations at 3331 $cm^{-1}$, while C-H stretching vibrations that originate from aliphatic hydrocarbons are at 2898 $cm^{-1}$. It is highly likely that the kapok fiber contains plant wax, given the presence of these peaks. Plant wax is frequently composed of long-chain alkanes, aldehydes, fatty acids, esters, ketones, and alcohols [10]. Cellulose and other polysaccharides are characterized by the presence of C-H bending and C-O stretching vibrations, as evidenced by the presence of additional peaks at 1314 $cm^{-1}$, 1159 $cm^{-1}$, 1105 $cm^{-1}$, 1052 $cm^{-1}$, and 1029 $cm^{-1}$.

The FTIR spectrum of kapok fiber with waste biodiesel oil shows several new peaks and shifts. The O-H stretching peak undergoes a slight shift from 3331 $cm^{-1}$ to 3337 $cm^{-1}$, which indicates the hydrogen bonding is altered as a result of the interactions between the kapok fibers and biodiesel components. The fatty acid chains from the biodiesel are reflected in the new peaks at 2922 $cm^{-1}$ and 2854 $cm^{-1}$, which indicate an increased aliphatic hydrocarbon content. Ester groups from the biodiesel residual oil are characterized by a substantial peak at 1741 $cm^{-1}$, which corresponds to C=O stretching vibrations. Kapok wax is thought to contain aliphatic aldehydes, ketones, and easter, which are the sources of these bands [11]. The presence of biodiesel components is further confirmed by the peak at 1434 $cm^{-1}$, which is associated with methyl and methylene groups.

Shifts and new peaks in the C-O-C and C-O stretching regions (1159 $cm^{-1}$, 1105 $cm^{-1}$, 1052 $cm^{-1}$, and 1029 $cm^{-1}$ in raw kapok vs. 1162 $cm^{-1}$, 1109 $cm^{-1}$, 1055 $cm^{-1}$, and 1032 $cm^{-1}$ after been used) indicate interactions between biodiesel components and the kapok fiber, particularly esters and other oxygen-containing groups. The peak signifies the waxy cutin and cellulosic components of the kapok fibers [12]. These changes suggest that the kapok fibers have absorbed and chemically interacted with the waste biodiesel oil, leading to an increase in aliphatic hydrocarbons and ester functionalities in the treated fibers. Table 1 and 2 present a thorough overview of the functional groups found in kapok fiber before and after being utilized as filtration medium.

**Table 1** Major peak observed from the FTIR spectra of raw kapok fiber samples.

| Peak No. | Wavelength $(cm^{-1})$ | Bond type/ Assignment |
|---|---|---|
| 1 | 3331 | OH stretching |
| 2 | 2898 | CH stretching of $CH_2$ and $CH_3$ groups |
| 3 | 1314 | O-H deformation and/or $CH_2$ wagging |
| 4 | 1159 | C-O-C anti-symmetric bridge stretching in cellulose and hemicelluloses |
| 5 | 1105 | C-O-C stretching vibrations in cellulose and hemicellulose |
| 6 | 1052 | C-O stretching vibrations in cellulose and hemicellulose, as well as primary and secondary alcohols |
| 7 | 1029 | C-O stretching in cellulose, hemicellulose and lignin |

**Table 2** Major peak observed from the FTIR spectra of kapok fiber with biodiesel plant waste oil.

| Peak No. | Wavelength $(cm^{-1})$ | Bond type/ Assignment |
|---|---|---|
| 1 | 3337 | OH stretching |
| 2 | 2922 | CH stretching of $CH_2$ and $CH_3$ groups |
| 3 | 2854 | CH stretching of $CH_2$ and $CH_3$ groups |
| 4 | 1741 | Carbonyl C=O stretching ester |
| 5 | 1434 | OH and $CH_2$ bending |
| 6 | 1315 | O-H deformation and/or $CH_2$ wagging |
| 7 | 1162 | C-O-C anti-symmetric bridge stretching in cellulose and hemicelluloses |
| 8 | 1109 | C-O-C stretching vibrations in cellulose and hemicellulose |
| 9 | 1055 | C-O stretching vibrations in cellulose and hemicellulose, as well as primary and secondary alcohols |
| 10 | 1032 | C-O stretching in cellulose, hemicellulose and lignin |

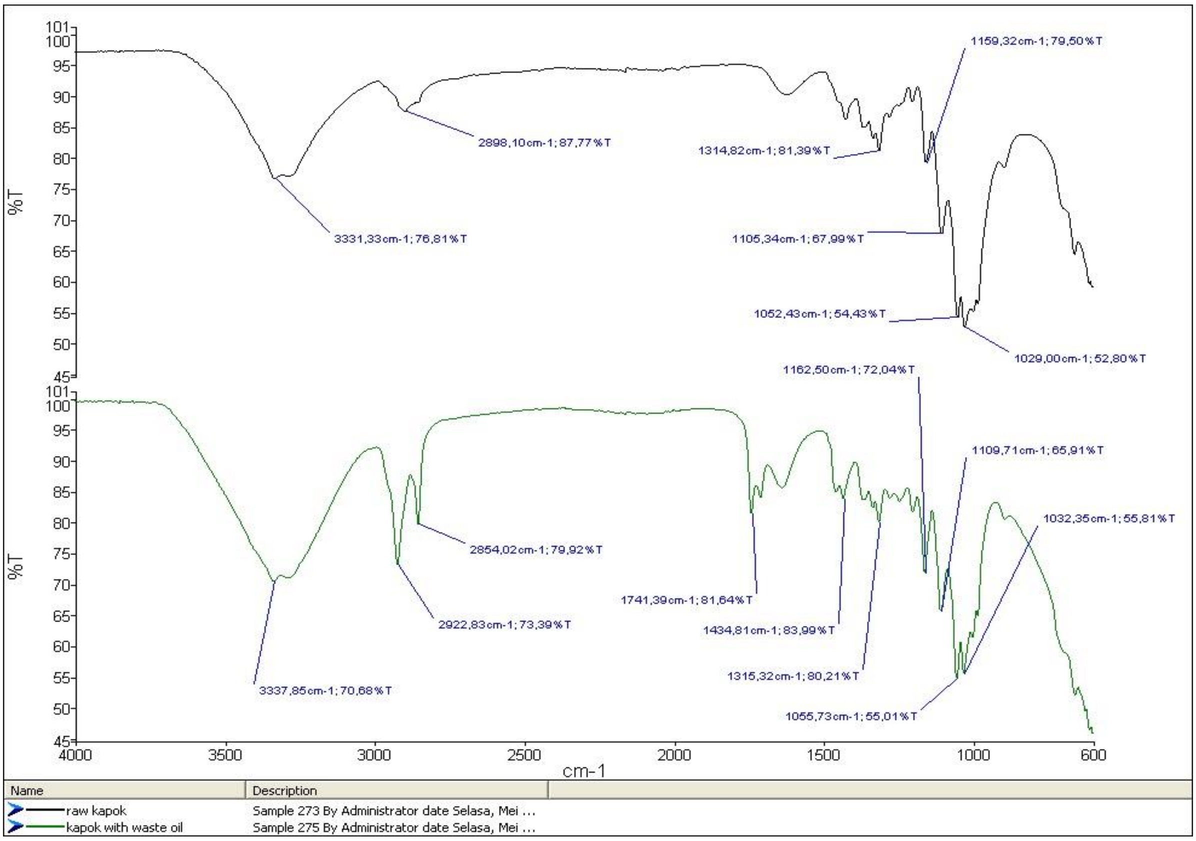


**Fig. 3** FTIR analysis for kapok fiber.

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Figure 4 provides a comprehensive analysis of the functional groups present in waste biodiesel oil, as shown in the provided spectra. The peaks observed at 2922 $cm^{-1}$ and 2853 $cm^{-1}$ are characteristic of C-H stretching vibrations. More specifically, these peaks correspond to the asymmetric and symmetric stretching of $CH_2$ groups, respectively. The occurrence of these peaks is frequent in aliphatic chains, indicating the existence of lengthy hydrocarbon chains that are characteristic of fatty acids and triglycerides. Another notable peak is observed at 1711 $cm^{-1}$, which likewise corresponds to C=O stretching vibrations. However, it is somewhat displaced compared to the ester carbonyl stretch at 1741 $cm^{-1}$. This shift indicates the existence of various carbonyl molecules, such as unbound fatty acids (carboxylic acids) or ketones.

Moreover, the peaks observed at 1464 $cm^{-1}$ and 1436 $cm^{-1}$ correspond to the bending vibrations of $CH_2$ and $CH_3$ groups, respectively. The peak observed at 1464 $cm^{-1}$ is commonly attributed to the scissoring motion of $CH_2$ groups, whereas the peak at 1436 $cm^{-1}$ corresponds to the symmetric bending of $CH_3$ groups. These vibrations offer more proof of extended hydrocarbon chains, which align with the existence of fatty acids and triglycerides in biodiesel and its derivatives. To enhance understanding, Table 3 presents a thorough overview of the functional groups found in waste biodiesel oil.

**Table 3** Major peak observed from the FTIR spectra of waste biodiesel oil.

| Peak No. | Wavelength $(cm^{-1})$ | Functional group |
|---|---|---|
| 1 | 2922 | C-H stretching in aliphatic hydrocarbons |
| 2 | 2853 | C-H stretching in aliphatic hydrocarbons |
| 3 | 1741 | C=O stretching in esters (biodiesel, triglycerides) |
| 4 | 1711 | C=O stretching in carboxylic acids or ketones |
| 5 | 1464 | $CH_2$ and $CH_3$ bending |
| 6 | 1436 | $CH_2$ and $CH_3$ bending |
| 7 | 1170 | C-O stretching in esters or ethers |
| 8 | 722 | $CH_2$ rocking in long aliphatic chains |

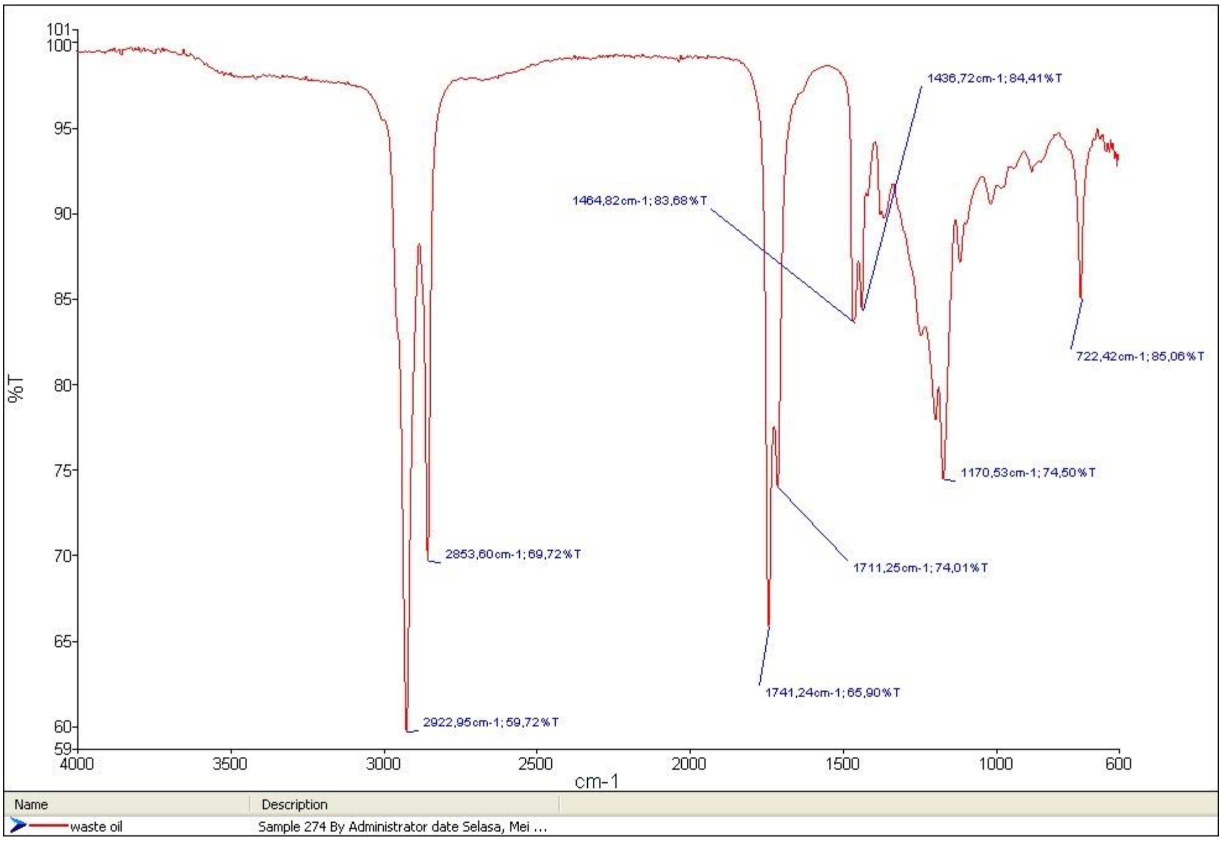


**Fig. 4** FTIR analysis for waste biodiesel oil.

## 3.3 Contact Angle Analysis

The hydrophobic properties of raw kapok fiber are shown by the contact angle of 145.30°, as shown in figure 4.5. Conversely, Figure 4.6 shows that there is no apparent contact angle, 0°. A completely new layer is formed on top of the kapok fiber sample by the water. The contact angle is incapable of determining whether kapok fiber has absorbed oil due to the nature of the measurement and the characteristics of the fiber oil system. This is due to the fundamental character of the testing. It is potential that the wettability of the substance is not precisely represented by the contact angle measurement with water. This is a result of the oil drop on the fiber surface, which may interfere with the water droplet, resulting in a distorted contact angle measurement [13].

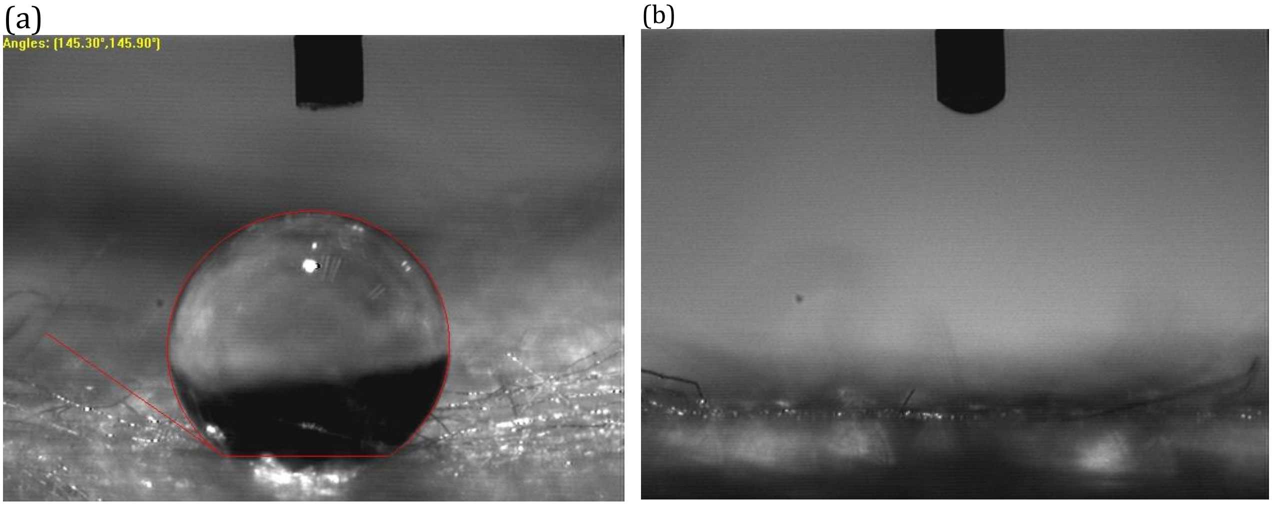


**Fig. 5** Contact angle measurement of raw kapok fiber (a) before, (b) after.

## 3.4 Kapok Filtration

The efficiency of kapok filters is determined using three different filter widths: 20 mm, 40 mm, and 60 mm. The analysis proceeds in two different flow orientations: horizontal and vertical orientations. Figure 6 shows the kapok weight for horizontal flow filters, the kapok weight shows a significant increase after filtration. At 20 mm width, the weight rises from 5.5 g to 78.3 g. For a 40 mm width, the weight goes from 8.8 g to 107.2 g, and at a 60 mm width, it increases from 15.3 g to 139.2 g. In the case of vertical flow filters shown in figure 4.8, the kapok weight also demonstrates substantial gains. At 20 mm width, the weight increases from 6.5 g to 134.7 g. For a 40 mm width, the weight rises from 10.2 g to 151.0 g, and at a 60 mm width, it goes from 14.3 g to 171.0 g. These results indicate that both horizontal and vertical flow filters effectively capture substances, as evidenced by the significant increase in kapok weight post-filtration. However, the vertical flow filters exhibit a more pronounced increase in weight compared to the horizontal flow filters.

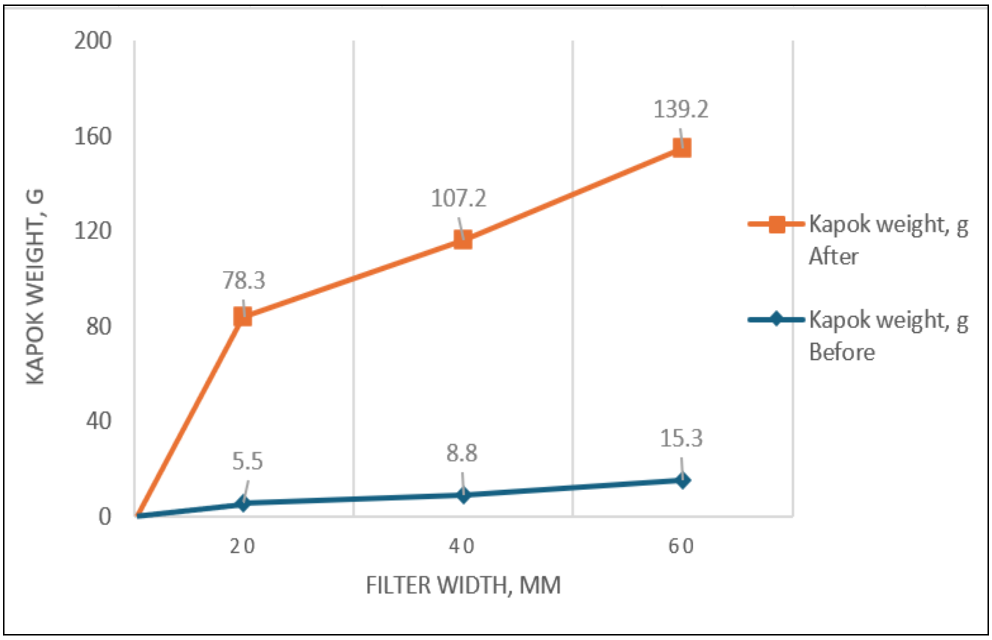


**Fig. 6** Weight of kapok fiber for horizontal flow filters.

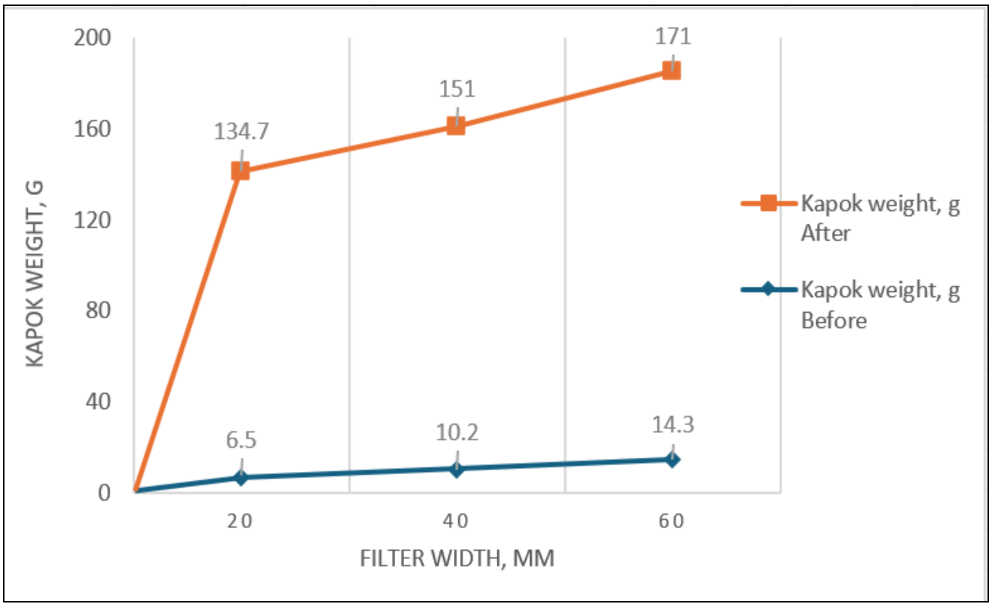


**Fig. 7** Weight of kapok fiber for vertical flow filters.

The filtration efficiency varies notably between the two flow orientations as shown in figure 8. For horizontal flow filters, the efficiency at a 20 mm width is 36.40%, increasing to 49.20% at a 40 mm width and further to 61.95% at a 60 mm width. Vertical flow filters, on the other hand, show higher efficiencies across all widths: 64.10% at 20 mm, 70.40% at 40 mm, and 78.35% at 60 mm. The vertical flow filters superior filtration efficiency suggests they are more effective at capturing substances than horizontal flow filters. This trend is consistent across all filter widths tested in the study.

The higher efficiency observed in vertical flow filters may be due to technical errors in the horizontal flow filter design. These errors could result in an inaccurate flow of substances through the horizontal filters, leading to lower filtration performance. Possible issues include uneven distribution of the substance across the filter surface or leakage around the filter edges [14], which could reduce the capture rate and thus the overall efficiency.

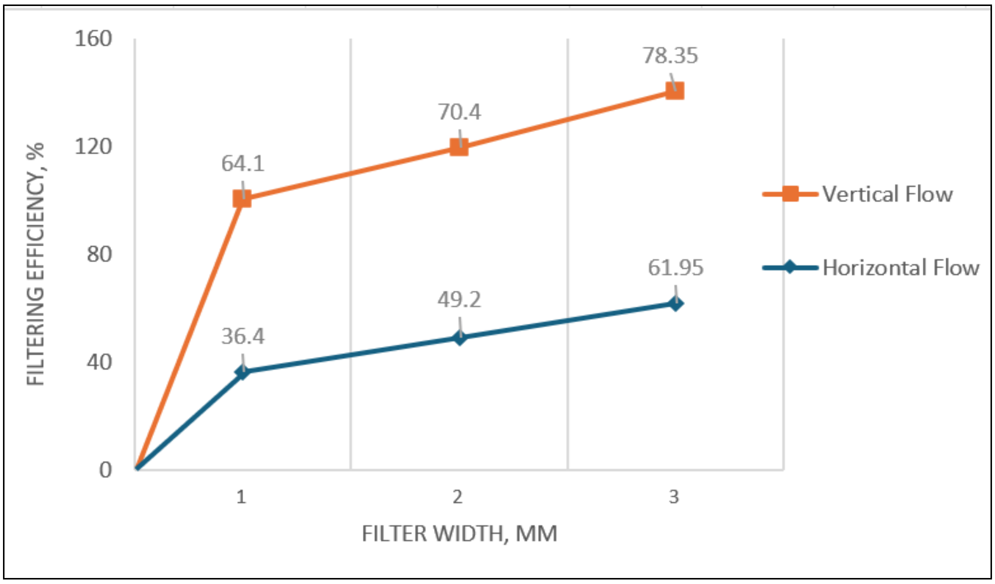


**Fig. 8** Filtering efficiency of kapok fibers.

## 4. Conclusion

In conclusion, this study evaluated kapok fiber as a natural fiber for filtering biodiesel plant waste oil. The characterization using SEM, FTIR, and contact angle measurements showed that kapok fibers have a hollow lumen, waxy surface, and porous structure, contributing to its water repellent and oil attracting properties. Post-filtration FTIR spectra indicated significant chemical changes, including increased aliphatic hydrocarbons and ester functionalities, suggesting strong interactions between the fibers and biodiesel waste oil. The contact angle analysis of kapok fibers exhibits a significant degree of hydrophobicity. The result shows that vertical flow filters consistently outperform horizontal ones, highlighting the importance of precise filtration flow system for optimal performance. Lastly, kapok fiber has proven to be an effective oil filtration medium.

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