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# Evaluation of Kenaf Fiber and Rice Husk Combination as a Natural Oil Spill Sorbent in the Form of Fuel Briquette

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ABSTRACT

*One kind of pollution that presents serious catastrophic risks to marine ecosystems is oil spills from petroleum industry. Although there are many methods that have been applied to clean the oil spill, nerveless the most popular method is using adsorbent. The objective of this study is to investigate the capability of kenaf fiber and rice husk mixture in the form of fuel briquettes as an adsorbent. Various proportions of these substances were utilised to create fuel briquettes, ranging from a ratio of 20:80 to 80:20, in order to determine the most effective ratio for an oil adsorbent. Besides oil sorption capacity, the briquette sample has also been tested for its reusability and durability. Results indicated that sample with a ratio of 20% kenaf fiber and 80% rice husk display the highest oil sorption capacity with a value of 0.7817g of oil. Meanwhile, sample with a ratio of 80% kenaf fiber and 20% rice husk exhibits exceptional durability, it had the highest compressive strength, reaching up to 68 N/mm$^2$. All samples that are produced in this study can retain over 70% of the sorption capacity after 15 consecutive sorption-squeezing cycles. In term of cost, application of kenaf and rice husk was found to be 45% more economical for each ton acquired as compared to pine sawdust as reported from other research. Therefore, the best sample from this study is sample A with a combination of 20% kenaf fiber and 80% rice husk.*

*Keywords: Oil spill; oil sorbent; kenaf fibre; rice husk; natural sorbent*

## INTRODUCTION

Malaysia have around 4800-kilometer coastline which is very susceptible to marine oil pollution (Wing, 2005). Particularly at the Strait of Malacca there are estimate around 60,000 ship transits annually. Based on reports, the Galapagos ship carrier collided with a 15,000 TEU (twenty-foot equivalent) mega container ship in the Melaka Straits, causing significant damage and an oil spill due to the spillage of hydraulic oil (Mohindru, 2021). Numerous studies have concentrated on regions at high risk to explore diverse techniques for controlling oil spills (Ghaderi 2024; Wing 2005; Zacharias et al. 2024). When there is a spill of hazardous materials in the environment, it is imperative to promptly halt the spill, manage its propagation, and guarantee its secure extraction and disposal. Generally, there are three methods of controlling the oil spill which are non-mechanical, mechanical and physicochemical method (Riyal et al. 2024). Each of these methods have its own advantages and disadvantages in addressing oil spill accidents.

Non-mechanical methods in which dispersant, biological treatment, electrocoagulation or burning are used to break up the oil layer. As example dispersants when used on oil spill, it will decrease the tension oil and water, facilitating the mixing of small oil droplets into the water column with reduced energy consumption (Zhong & You 2011). On the other hand, in situ burning application provides an easier way besides it is quick and affordable. Biosurfactant, which are surfactants produced by bacteria, can also be utilized for the degradation of oil spills (Riyal et al. 2024).

Mechanical methods for controlling oil spills involve using various equipment and tools to physically gather and remove the spilled oil. To start, booms are used to contain the spread of large spills by creating floating barriers on the sea surface. Skimmers are then deployed to collect the oil slick. Skimmers are mechanical devices specifically engineered to extract oil off the surface of water. The efficiency of a skimmer is measured by its capacity to recover oil. Skimmer works best when the oil slick is relatively thick, so it is strategically placed in front of the boom or where the oil concentration is highest to maximize oil recovery (Asadpour et al. 2013). For smaller spills, sorbents are commonly used, and researchers have conducted comprehensive investigations into various natural and synthetic materials with potential sorbent capabilities (Zamparas et al. 2020).

Physicochemical method is another approach to recover oil spills by sorption mechanism. Typically, there is a wide range of sorbents that can be used to effectively and inexpensively remove oil from water, particularly in the event of an oil spill. Furthermore, sorbent possesses the potential to selectively retrieve oil for alternative purpose, while also lacking any secondary pollution (Folly et al. 2023). Generally, the term "sorption" encompasses two simultaneous processes which are adsorption and absorption.

Considering the specific characteristics of the spilled petroleum product, as different types of oil can behave differently in the environment. Some oils can be effectively cleaned using porous surfaces or flushed away, while others may undergo weathering, volatile component evaporation, or sink to the seabed (Bianchi et al. 2020). The lingering oil slicks can contaminate a wide range of coastal environments, including beaches, ports, wharves, marinas, caves, historical sites, tourist attractions, and nature reserves. The detrimental impact of oil spills on these sensitive ecosystems demands careful attention and effective mitigation efforts to minimize long-term damage (Bejarano & Michel 2016).

Sorbents can be categorized into three main groups: inorganic mineral sorbents like graphite, zeolite, active carbon, silica, and wool; natural organic sorbents such as corn cob, kapok fiber, and kenaf; and synthetic organic sorbents like polytetrafluoroethylene, tyre granulates (Lah et al. 2021) polypropylene (PP), polyurethane, polyvinylidene fluoride, and polyvinyl chloride (Jmaa & Kallel, 2024). Inorganic sorbents possess a large specific surface area, but they face challenges in efficiently absorbing oil in marine environments due to the limited buoyancy. Additionally, its oil-sorption capacity is relatively low, and it can be costly. On the other hand, natural organic sorbents exhibit a higher capacity for absorbing oil compared to inorganic sorbents and are frequently employed for separating oil and water. However, inorganic sorbent exhibits poor selectivity between oil and water and tends to sink during or after sorption. In contrast, synthetic organic sorbents are highly effective in cleaning oil-contaminated water due to its high oil sorption capacity, excellent buoyancy, and strong hydrophobicity and oleophilicity. In the comparison between natural and synthetic sorbents, it was found that the sorption capacities are similar, but some natural sorbents demonstrated even higher sorption capacity than its synthetic counterparts (Mojžiš et al. 2019).

When selecting an appropriate sorbent for spill cleanup, it is important to consider properties beyond sorption capacity, such as chemical resistance, non-flammability, cohesion, and the ability to withstand mechanical loading after absorbing hazardous substances (Pham & Dickerson, 2014). Natural organic sorbents have gained popularity as it offers several advantages over synthetic sorbents, including biodegradability, environmental friendliness, and the absence of secondary pollution (Chen et al. 2015).

The rice milling business in Malaysia produce a significant amount of rice husk that if not used accordingly it will become waste. According to estimates, the amount of waste rice husk that is produced annually in Malaysia is approximately 770,000 tonnes (Abd et al. 2023). In a study that investigated the use of rice husks as oil sorbent where the rice husk being subjected to alkali treatment, possessed the maximum oil sorption capacity (Bazargan et al. 2014). The research methodology involved sieving and weighing the alkali-treated husk, which was then subjected to sorption trials using marine diesel. The results indicated that rice husks treated with a strong alkali solution exhibited the highest measured absorption capacity. Other research shows that the optimized cellulosic sorbents show high oil uptake due to low bulk density and the fluffy of rice husk structure (Bazargan et al. 2014; Kumagai et al. 2007).

Meanwhile for kenaf, the Ministry for Plantation Industries and Commodities have allocated about USD 32.41 million for research & development for year 2006 until 2015 (Hanim, 2009). As example, one study was undertaken to investigate the properties of kenaf fibre, including its biodegradability, mechanical strength, and absorption capacity. The methodology involved creating particle sizes from the kenaf fiber and testing its performance. Three different sizes were made from kenaf fiber, which were 0.04 $cm^2$, 0.80 $cm^2$, and 1.70 $cm^2$. The findings concluded that kenaf fiber with the largest particle size, 1.70 $cm^2$, demonstrated the best oil sorption capacity of 8.2 g (Ridwan Shamsudin et al. 2015). It formed a strong network matrix and exhibited the maximum absorption capability.

Basically, the smallest kenaf fiber size (0.04 $cm^2$) exhibited the weakest microstructure network formation. The length of the fibers is one of the factors that can affect network formation. This is due to mechanical entanglement (Korhonen et al. 2014). By using scanning electron microscopic (SEM) allows us to observe the network formation and determine which kenaf fiber size has the most favorable properties (Ridwan Shamsudin et al. 2015). SEM can be utilized to determine the surface area and porosity of rice husk (Palapa et al. 2021). The results revealed that rice husks with smaller pore sizes and surface area exhibited better absorption properties.

There is no study being done on the efficiency of kenaf fiber and rice husk combined as a fuel briquette for absorbing natural oil spills. Kenaf fiber is known for its high porosity and hydrophobic nature, allowing it to effectively soak up oil while repelling water. On the other hand, rice husk possesses excellent absorbent properties due to its porous structure and high surface area, making it a suitable material to complement kenaf fiber in oil sorption applications. Therefore, this research specifically focuses on the examination of the amalgamation of kenaf fiber (KF) and rice husk (RH) in various weight ratios ranging from 20g to 80g for each material alongside a gelatinized starch as binder to create fuel briquettes in tablet form. The sorption capacity, reusability and immersion ability of each sample are investigated.

## METHODOLOGY

### MATERIALS

The main materials utilized in this study were kenaf fiber and rice husk, both of which were obtained from local sources. To serve as a binding agent, starch and distilled water were used. Meanwhile, for the oil medium, Petronas diesel oil was selected to be investigated.

### PREPARATION OF KENAF FIBER AND RICE HUSK

To prepare rice husk and kenaf fiber, a series of precise steps were followed to ensure its appropriateness and eliminate any possible impurities. Initially, these materials were sourced from reputable suppliers, usually obtained from local rice mills or agricultural farms. Once acquired, the materials underwent a meticulous cleaning process using distill water to eliminate unwanted substances like dust, dirt, and impurities that could potentially disrupt the analysis. After the cleaning process, the materials were carefully dried to remove any remaining moisture by heating the materials in an oven at 120°C for 10 hours (Salim et al. 2020). Subsequently, both materials were introduced into a milling machine equipped with a 100-mesh sieve.

### FUEL BRIQUETTE PRODUCTION

In producing the briquette, a different ratio of kenaf fiber and rice husk was used, as shown in Table 1. Mixture of starch and distilled water were also added as the binding material for the briquette.

TABLE 1. Percentage of materials for each sample

| Sample | Kenaf Fiber (%) | Rice Husk (%) | Gelatinized Starch (%) |
|---|---|---|---|
| A | 80 | 20 | 5 |
| B | 60 | 40 | 5 |
| C | 40 | 60 | 5 |
| D | 20 | 80 | 5 |

Each mixing material was then placed in a steel mold before being compressed using a hot press machine for 10-15 minutes at 210°C. The dimensions of the briquette being produced were 10 mm in diameter and 5 mm in thickness.

FIGURE 1. Hot press mold

Lastly, the briquettes were dried in an oven for an hour (Ndindeng et al. 2015). This step was crucial to ensure the briquettes are free from moisture content. Figure 2 shows the produced fuel briquette via methods above.

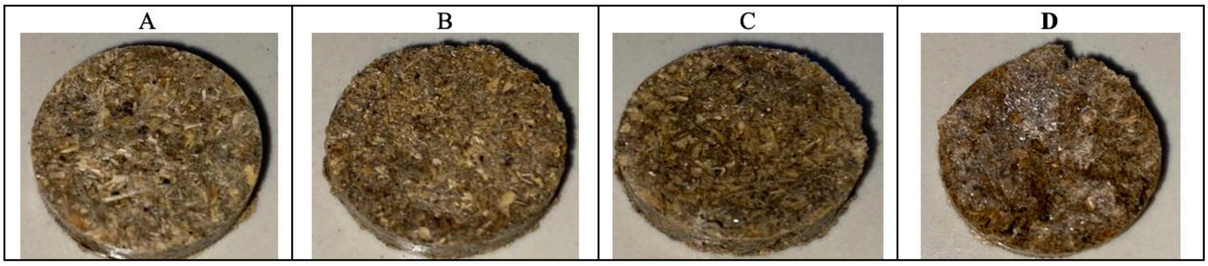


FIGURE 2. Produced fuel briquette

## OIL SORPTION TEST

Prior to immersing the briquette into the beaker, the initial weight of briquette is recorded. The briquettes were immersed in the diesel oil for 60 minutes before it being pulled out and drained for 20 seconds to remove any loosely bound diesel oil from the surface of the briquette. Then the final weight of the oil sorbent being measured. The oil sorption capacity was calculated using equation (1):

$$m_{\max} = m - m_0 \tag{1}$$

where $m_{max}$ is the maximum oil sorption capacity (g), $m_0$ is the initial mass of the sorbent before sorption (g), and m is the mass of the sorbent after sorption (g). The sorption test was conducted three times for each sample to get the average value of sorption capacity of the briquette.

## REUSABILITY TEST

The saturated briquettes obtained from the oil sorption test were subjected to a squeezing process before being reused back for this test. During this process, a weight of 1.5 kg was applied to the sample briquette. To assess the reusability of the sorbent, the sorption-squeezing procedure was repeated 15 times under the same conditions (Wu et al. 2014). The percentage of reusability efficiency was calculated using equation (2):

$$R = \frac{m_{final}}{m_{ini}} \times 100\% \tag{2}$$

where R is the recovery efficiency by sorption/desorption (%), $m_{final}$ is the final oil sorption capacity (g) and $m_{ini}$ is the initial oil sorption capacity (g).

## BUOYANCY AND WATER CONTACT ANGLE ANALYSIS

To confirm the hydrophobic and oleophilic characteristics of the sorbents, the sorbents were immersed in a solution containing both oil and water. More precisely, 100 ml of water mixed with 20 ml of diesel oil was used, and the sorbents were submerged for a period of 1 hour. Afterward, the sorbents were carefully positioned on the surface of the oil. To assess its buoyancy performance the fabricated sorbents must be able to float on the water surface for a long time, this experiment was carried out for all samples.

The AST/VCA-3000S contact angle goniometer model was employed to measure the contact angle between the briquette and both diesel oil and distilled water. The water contact angle served as a supplementary factor in evaluating the buoyancy performance of the briquette (Byun et al. 2022).

## COMPRESSIVE STRENGTH TEST

Compressive strength refers to the maximum load that a briquette can withstand before it cracks or breaks. This parameter is determined through a diametrical compression test, which was conducted using a servo hydraulic system. However, due to equipment limitations, the test involved stacking two briquettes for each sample. The stacked briquettes were positioned between two flat parallel platens, which had a larger surface area compared to the projected area of the briquette. Gradually increasing loads were applied to the briquette until it reached the thickness of 6 mm. The load at which the briquette fractured was recorded on a stress-strain curve and the maximum curve indicates the compressive strength of the briquette. This load estimates the weight a briquette can withstand during storage. To ensure the reliability of the results, the compressive strength test was repeated three times to get the average value.

## IMMERSION TEST

The immersion test was carried out to assess the performance of the briquette when submerged in water. In this test, the briquette was completely immersed in a beaker filled with distilled water. The water resistance of the briquette was determined by measuring the time taken for the briquette to fully disintegrate in water. After the specified immersion period, the briquette was delicately removed from the liquid and examined for any observable changes or reactions.

The objective of the immerse test for briquette is to assess the water absorption capacity and stability of the briquette material when exposed to water or any other liquid. By immersing the briquette in water for a specific period, researchers can determine how well the briquette retains its integrity and how much water it absorbs. This test is important for evaluating the briquette's suitability for applications where it may encounter water, such as during oil spill cleanup, water filtration, or other environmental remediation processes. The test helps to understand the material's water resistance, porosity, and overall performance in wet conditions.

## COMPARATIVE COST BENEFIT ANALYSIS

A comparative cost-benefit analysis was conducted to evaluate the economic implications of using briquettes made from kenaf fiber and rice husk compared to briquettes made from alternative materials specifically for pine sawdust (Stolarski et al. 2013). The analysis aimed to assess the advantages and disadvantages of utilizing kenaf fiber and rice husk as the primary materials in briquette production. The cost of producing the kenaf fiber and rice husk briquette was meticulously calculated, taking into consideration various expenses associated with material procurement, processing, and production.

These costs encompassed factors such as the acquisition cost of kenaf fiber and rice husk, transportation expenses, cleaning and drying costs, and any additional processing requirements (Jasiczek & Kwaśniewski, 2020). For the cost of electrical energy based on Tenaga Nasional's data in 2018, it cost around RM0.445 for every 1 kwh. The calculated cost for this study briquette was then compared to the costs associated with producing briquettes using different materials. By conducting this cost comparison, the economic viability, and benefits of using kenaf fiber and rice husk as materials in briquette production can be assessed.

# RESULTS AND DISCUSSION

## OIL SORPTION CAPACITY

Figure 3 illustrates the measured sorption capacity of diesel oil for all samples after immersed in diesel oil under static conditions. Sample A demonstrated a sorption capacity of 0.1373g, sample B had a capacity of 0.3552g, sample C exhibited a capacity of 0.5441g, and sample D with a ratio of showed the highest capacity of 0.7817g.

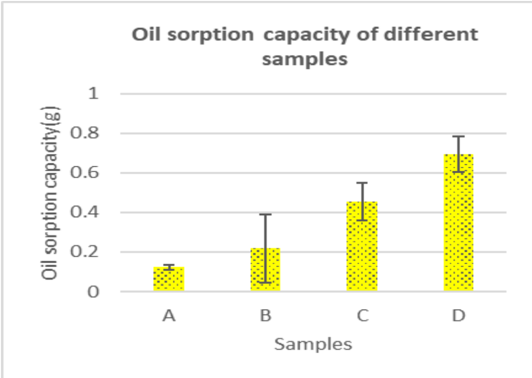


FIGURE 3. Oil sorption capacity of difference sample

The results show that sample D displayed the highest oil sorption capacity, indicating that rice husk has better oil-absorbing properties compared to kenaf fiber. Besides that, the adsorption is influenced by the bulk density of the rice husk. Increase the bulk density leads to greater penetration of the oil into the sample (Bazargan et al. 2014). Additionally, this suggests that the structure of fuel briquette D is more porous and less dense, allowing it to absorb more oil into the briquette. These findings imply that a higher ratio of rice husk (RH) and a lower ratio of kenaf fiber (KF) in the weight composition led to a greater absorption capacity for diesel oil.

## REUSABILITY OF THE BRIQUETTE

Figure 4 illustrates the fluctuating sorption capabilities of the produced sorbents for diesel oil at the oil-water interface over multiple sorption-squeezing cycles. In general, oil sorption capacities of the briquettes reduce gradually after 15 cycles, with about 70% oil sorption capacity remaining. For sample A, B, C, and D the reusability percentage was determined to be 74.14%, 70.33%, 71% and 74.12% respectively. By assuming that the briquettes are reused for 15 consecutive cycles, the accumulated sorption capacity of 1g of sorbents can be calculated as 1350g of oil. This calculation indicates that less than 0.75 tons of sorbents are required to clean 1000 tons of spilled oil. In contrast, approximately 100 tons of commercial PP sorbents would be needed to collect the same amount of spilled oil, as commercial PP sorbents typically exhibit a relatively lower sorption capacity of about 10g and are not reusable (Byun et al. 2022). Therefore, the application of the prepared sorbents in the oil spill cleanup process holds significant economic value.

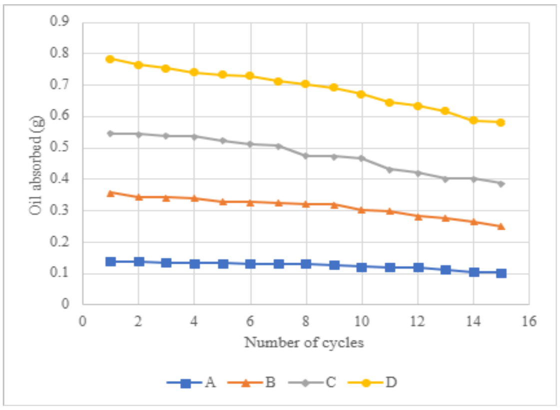


FIGURE 4. Oil absorbed (g) Vs. number of cycles

A notable aspect to consider regarding sorbents is the ability to retain the sorbed oil. A high retaining ability ensures that the sorbed oil remains intact when handling the sorbents. In the case of the prepared sorbents, when sorbent becomes saturated with diesel oil and are subjected to gravity, its overall mass remains nearly constant over an extended period. Only when a weight of 1.5 kg is applied to the top of an oil-saturated briquette does the sorbed oil begin to be squeezed out from the sorbents. This indicates that the sorbed oil is unlikely to leak out during transportation and other handling processes, thus providing assurance of effective oil retention.

## FUEL BRIQUETTE COMPRESSIVE STRENGTH TEST

Figure 5 shows the compressive strength test result of the briquettes. According to the figure, sample A demonstrated the highest compressive strength of 68 $N/mm^2$ meanwhile sample D exhibited the lowest compressive strength with a value of only 3.8 $N/mm^2$. The compressive strength decreases with increase in the quantity of rice husk in the briquette sample. These are due to the high cellulose content in kenaf fiber as compared to rice husk that helps to bind the briquette together and reduce the brittleness of the briquette. Therefore, kenaf fiber strengthens the briquette by forming a less porous and more compact structure.

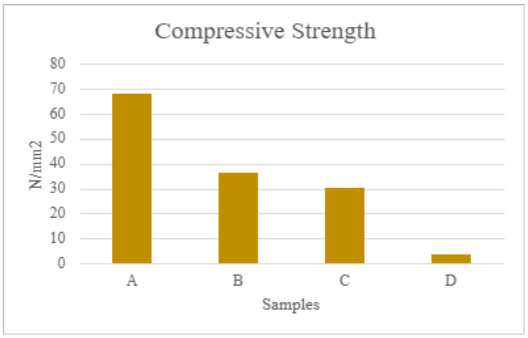


FIGURE 5. Compressive strength test

The findings indicate that increasing the amount of kenaf fiber in the briquette mixture resulted in a denser particle arrangement. Aside from the raw materials, the gelatinized starch used to bind the briquette together also contributed to the compressive strength. The high compressive strength of the briquettes makes them safer to store or transport and less prone to breaking or wearing off easily (Nwabue et al. 2017).

## FUEL BRIQUETTE IMMERSION TEST

Based on the immersion test result presented in Figure 6, it can be observed that sample A exhibited the longest immersion time in water, lasting approximately 102.14 minutes. Longer immersion times indicate higher water resistance, suggesting that the briquette is less prone to disintegration or degradation when exposed to water. Conversely, sample D had the shortest immersion time, taking only 34.22 minutes before the briquette sink completely. The immersion times for samples B and C were 81.88 minutes and 60.18 minutes, respectively.

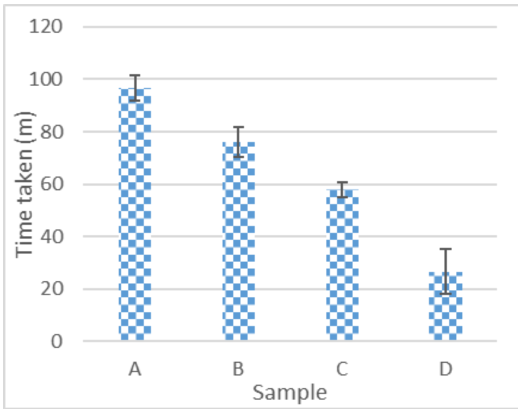


FIGURE 6. Immersion test results

The findings indicate that increasing the ratio of kenaf fiber (KF) in the briquette mixture leads to a more compact and densely packed structure, which enhances the briquette's water resistance. As a result, distilled water finds it more challenging to penetrate the compact kenaf fiber structure, leading to a lower rate of water absorption by the briquette. This demonstrates that briquettes with a higher proportion of kenaf fiber can better retain their integrity when in contact with water, showcasing its improved water resistance properties.

## BUOYANCY AND WATER CONTACT ANGLE ANALYSIS

Buoyancy plays a crucial role in cleaning up oil spills, and experiments were conducted using samples A, B, C, and D in diesel oil and distilled water. Because of its lower density, the oil immediately floated on the water's surface. The sorbents remained afloat for a long time due to its high hydrophobicity and affinity for oil. In Figure 7, the hydrophobic and oleophilic properties of the briquette sorbents are shown based on its contact angles with distilled water and diesel oil. A water contact angle (WCA) of 106° indicates that the sorbent has a hydrophobic structure, as it exceeds 90° (Mokhtar, 2011). On the other hand, the contact angle with diesel oil was 23°, indicating that it is hydrophilic to diesel oil, making it effectively interact with and adsorb oil. Because of these properties, the sorbents are expected to be highly effective in separating oil from water in the event of marine oil spills. The briquette can selectively adsorb oil and remain on the water's surface for an extended period. This also means that the sorbents can be easily retrieved from the ocean after use and either regenerated or safely disposed of.

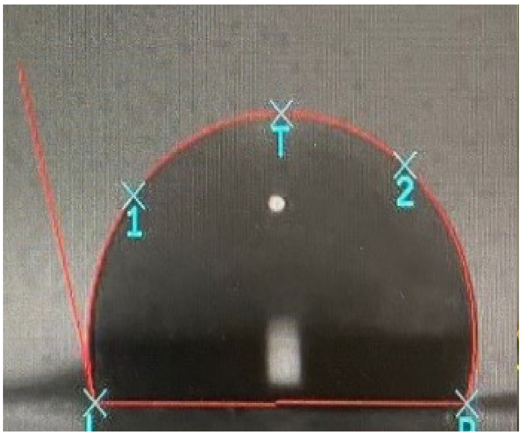


FIGURE 7. Water contact angle for a) Distilled water and; b) Diesel oil

## COMPARATIVE COST-BENEFIT ANALYSIS

For the comparison purpose, KF/RH are compared with pine sawdust. The analyses conducted showed that the lowest cost was that of KF/RH briquette production: RM64.16 $kg^{-1}$ as shown in Table 2. This resulted mainly from the lowest cost of the material purchase compared to pine sawdust with the total cost of RM113.39 kg-1. The reasons for the cost difference were the prices of the raw materials, which depended on the availability of the materials and their demand from various industries.

Commodity prices could fluctuate over time and could be influenced by various factors. Factors such as supply and demand, processing and transportation costs, subsidies, and specific market conditions all played a role in determining the prices of raw materials. Additionally, market dynamics and regional variations could also impact the relative pricing of these materials. Therefore, monitoring market trends and staying informed about the specific context was crucial for making informed decisions regarding the cost of these resources. Pine sawdust was the highest quality briquette and gaining most profit among any other briquettes in the study conducted by Stolarski et al. (2013).

The latest price of kenaf fiber and rice husk combined were approximately RM323.30 per ton while pine sawdust alone cost about RM865.16 per ton (Farhul, 2024). This shows that purchasing kenaf fiber and rice husk proved to be 45% more economical compared to pine sawdust for each ton acquired. The comparison clearly illustrates that the kenaf fiber/rice husk briquette has a significantly lower overall cost compared to the pine sawdust briquette. This cost advantage makes the kenaf fiber/rice husk briquette a more economical choice in terms of production and manufacturing expenses.

TABLE 2. Comparison of The Briquette Production Cost

| Descriptions | Kenaf fiber/Rice husk (RM $kg^{-1}$) | Pine sawdust (RM $kg^{-1}$) |
|---|---|---|
| Repair and maintenance | 0 | 8.81 |
| Purchase of raw material | 5.47 | 25.59 |
| Transport of raw material | 3.0 | 19.1 |
| Drying of raw material | 1.86 | 0 |
| Milling raw material | 1.34 | 0 |
| Electrical power consumed for briquetting | 36.49 | 36.86 |
| Packaging and storage | 16.0 | 23.03 |
| Total | 64.16 | 113.39 |

## CONCLUSION

In summary, the briquette made from kenaf fiber and rice husk exhibits promising characteristics as an alternative fuel source. It displays notable traits such as high compressive strength, effective water resistance, and efficient oil sorption capacity. The findings indicate that sample A is the optimal weight ratio for fabricating durable fuel briquettes, while sample D demonstrates the highest oil absorption capacity but lower durability. Increasing the proportion of kenaf fiber in the mixture enhances the briquette's durability, while a higher ratio of rice husk improves its oil sorption capacity. The sorption and squeezing tests provide evidence of the briquette's effective oil sorption capacity and its ability to retain the sorbed oil. The results demonstrate that the briquette can be reused up to 15 times without experiencing a significant reduction in its sorption capacity. Furthermore, the kenaf fiber/rice husk briquette exhibits excellent durability, maintaining its structure and dimensions even under the stresses of handling and storage. This durability makes it well-suited for transportation and storage purposes. Additionally, the total cost of fabricating the kenaf fiber/rice husk briquette is considerably lower, making it a more economically viable option compared to other alternatives.

Therefore, the best briquette mixture was sample A, containing 80% kenaf fiber and 20% rice husk. It shows promise as a sustainable alternative fuel source and can help address environmental concerns in different applications.

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## DECLARATION OF COMPETING INTEREST

None.

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