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ASSESSING COCONUT OIL PROPERTIES AS A POTENTIAL REPLACEMENT OF THE TRANSFORMER OIL

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ABSTRACT

The mature meat or kernel of mature coconuts collected from the coconut palm (Cocos nucifera) are used to make coconut oil, an edible oil. According to reports, coconut oil possesses potential electrical properties that are similar to those of transformer oil. In this work, the Soxhlet extraction method was used to obtain coconut oil from the coconut pod. The extracted oil was refined by bleaching with activated charcoal, de-moisturized by heating it at 105 °C to eliminate moisture, and afterwards esterified, with the understanding that the oil includes free fatty acid (FFA) of 14 mg/g to 1.4 mg NaOH/g after esterification. The flash point, pour point, viscosity, and density of the refined oil, as measured and compared to standards, indicate that it can be used as an alternative biofuel to transformer oil, which is an environmentally damaging and costly resource. Major drawback of this study is the inability to examine/test the performance of coconut oil as practical substitute to transformer oil, having demonstrated real potential as evidenced in its properties.

ABSTRAK

Daging matang atau inti kelapa matang yang dikumpulkan dari pohon kelapa (Cocos nucifera) digunakan untuk membuat minyak kelapa, minyak yang dapat dimakan. Menurut laporan, minyak kelapa memiliki potensi sifat listrik yang mirip dengan minyak trafo. Dalam penelitian ini, metode ekstraksi Soxhlet digunakan untuk mendapatkan minyak kelapa dari buah kelapa. Minyak yang diekstraksi dimurnikan dengan pemutihan dengan arang aktif, dide-moisturisasi dengan memanaskannya pada suhu 105 °C untuk menghilangkan kelembapan, dan kemudian diesterifikasi, dengan pemahaman bahwa minyak mengandung asam lemak bebas (FFA) 14 mg/g hingga 1,4 mg. NaOH/g setelah esterifikasi. Titik nyala, titik tuang, viskositas, dan kepadatan minyak sulingan, sebagaimana diukur dan dibandingkan dengan standar, menunjukkan bahwa minyak tersebut dapat digunakan sebagai biofuel alternatif untuk minyak trafo, yang merupakan sumber daya yang merusak lingkungan dan mahal.

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INTRODUCTION

Coconut oil is a type of edible oil derived from the kernel or meat of mature coconuts collected from the coconut palm (*Cocos nucifera*) (Oseni *et al.*, 2017). As reported in the literature, oil yield of coconut is 18-20% (Samikannu *et al.*, 2022). For millennia, it has been the principal source of fat in the diets of millions of people throughout the tropical world. It has a wide range of applications in food, medicine, and industry. Coconut oil is quite stable, making it ideal for cooking. Because of its stability, it has a low oxidation rate and is hence resistant to rancidity for up to two years due to its high saturated fat content. Coconut oil is also commonly used in cosmetics and soaps. The clear liquid coconut water contained within the shell is a delicious drink that can also be processed to produce alcohol (Azis *et al.*, 2014; Ezechukwu *et al.*, 2016; Raeisian *et al.*, 2019). In contrast, transformer oil, also known as insulating oil, is an oil that is stable at high temperatures and has excellent electrical insulating qualities. It is found in oil-filled transformers, high-voltage capacitors, fluorescent bulb ballasts, and high-voltage switches and circuit breakers. It insulates, suppresses corona and arcing, and serves as a coolant. Because it also serves as electrical insulation between internal live parts, transformer oil must remain stable at high temperatures for an extended period of time. To increase cooling of big power transformers, the oil-filled tank may feature external radiators through which the oil circulates by natural convection (Bandara *et al.*, 2017; Muhamad & Razali, 2016; Raeisian *et al.*, 2019). During operation, transformer oils are subjected to electrical and mechanical forces. Furthermore, contamination is induced by chemical interaction with windings and other solid insulation, which is catalysed by high working temperature. Transformer oil's initial chemical qualities progressively deteriorate, leaving it ineffective for its intended purpose after many years. Oil in large transformers and electrical apparatus is checked on a regular basis for electrical and chemical qualities to ensure that it is fit for further use (Sauki *et al.*, 2019). Sometimes, oil condition can be improved by filtration and treatment. A high voltage, highly loaded transformers demands better quality oil than a low voltage, lightly loaded transformer (Abeysundara *et al.*, 2001).

Dissolved gas analysis (DGA), Furan analysis, polychlorinated biphenyl (PCB) analysis, and general electrical and physical tests (such as color and appearance, breakdown voltage, calorific value, water content, acidity or neutralization value, dielectric dissipation factor, thermal stability, oxidative stability, resistivity, sediments and sludge, flash point, fire point, pour point, density and viscosity) are some of the tests commonly performed on this type of oil (Azis *et al.*, 2014; Bandara *et al.*, 2017; Dasari & Goud, 2014; Martins, 2010; Muhamad & Razali, 2016). Details on how to conduct these tests can be found in standards published by International Electrotechnical Commission (IEC), American Society for Testing and Materials (ASTM E1627-94), IS, and BS 148 (1984) (Ezechukwu *et al.*, 2016; Samikannu *et al.*, 2022). Any of the approaches described above can be used to conduct testing. Among these, the furan and DGA tests are particularly not for finding any anomalies in the transformer's internal winding or paper insulation that would otherwise be detectable without a total overrun of the transformer (Azil *et al.*, 2019). Many vegetable oils have already been identified as important insulators in transformers (Danikas & Sarathi, 2020; Patel *et al.*, 2021). However, the oil's potential has not been completely examined. Among these oils, coconut oil has been claimed to have potential electrical characteristics (similar to transformer oil). In view of that, this research aims to extract and refine coconut oil as an alternative to transformer oil. Specific objectives are to extract oil from coconut, refine the extracted oil, determine the properties of the refined coconut oil and compare the extracted oil properties with standards. The findings from this study will improve the understanding of the electrical insulation properties of coconut oil as an alternative to transformer oil. Even in similar studies on coconut oil potential replacement of the transformer oil by Abeysundara *et al.* (2001), which is presumably the first related paper pertaining coconut oil potential, several other properties, including pretreatment effects have not been examined.

METHODS

Materials

Raw material (coconut pod – Figure 1a) used for this research work was obtained from Monday Marrket in Maiduguri Borno state of Nigeria. The extraction and analysis of oil were carried out in University of Maiduguri, Department of Chemical Engineering Laboratory..

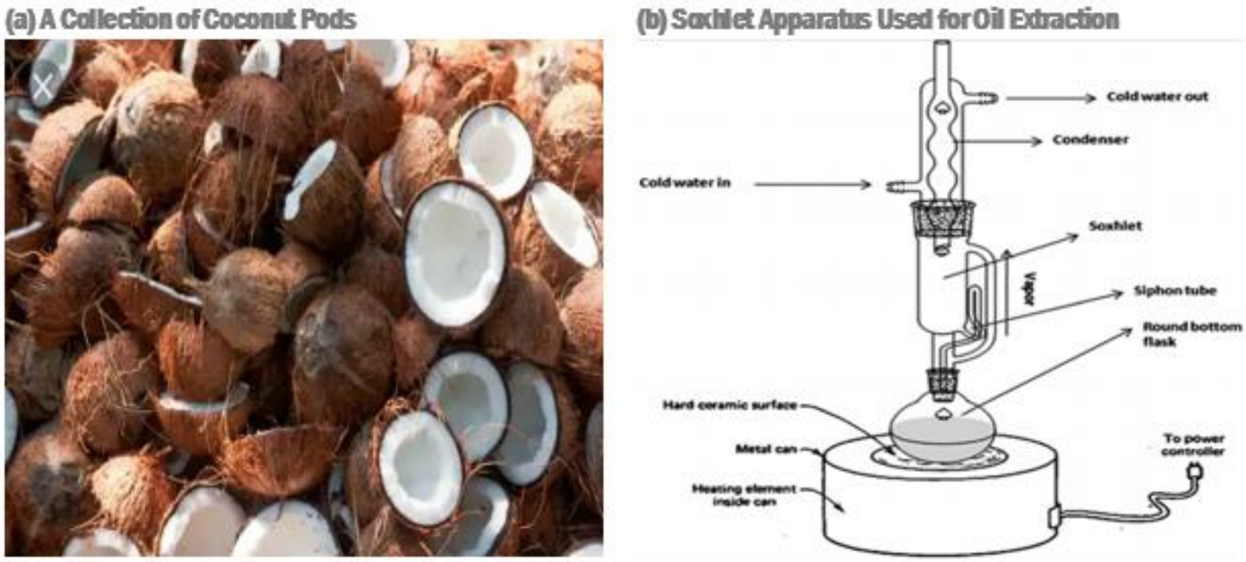

Figure 1. Feedstock and Extraction Method (Dasari & Goud, 2014)

Reagents used are activated charcoal, sodium hydroxide (NaOH), phenolphthalein and hexane (C_6H_{14}), while the equipment used are insulating dielectric strength tester, flash point tester, refrigerator, hot plate, viscometer, conical flask, scrubber, funnel, stirrer, flow cup, extraction flask (250mL), weighing balance, beaker, measuring cylinder, grater, motor and piston, filter paper, thermometer, Soxhlet extractor apparatus, thimble, and condenser.

Extraction Procedure

The coconut pod was grated, scribed, and pounded before placing in an electric oven to allow to dry at a temperature of 100°C for 30 minutes. The sample was removed and allowed to cool in a desiccator. A 250 mL extraction flask was washed and dried in an oven at 105-110°C before allowing it to cool inside a desiccator. The empty flask was then weighed and recorded. Exactly 30g of the sample was weighed, wrapped in a filter paper and placed in the thimble of the Soxhlet extractor (Figure 1b). Exactly 100 mL of C_6H_{14} was poured in the dried extraction flask, followed by assembling the apparatus. The extraction equipment was set up as follows: a round bottom flask was placed in a heating mantle with a Soxhlet extractor fixed on top of round bottom flask and a condenser was also placed on top of the Soxhlet extractor. The extractor has sight glass (double glass tube – the inner tube purge into the round bottom flask when the equipment is completely set, while the other indicate the level of the solvent in the extractor).

Hexane (a solvent) was introduced into the round bottom flask which was placed inside the heating mantle. The minimum amount of solvent required was determined by filling the Soxhlet extractor, to the point where it purges (Aytac, 2022). The pounded sample was placed in the thimble, put inside the extractor and fixed on top of the round bottom flask. The condenser was placed on top of the extractor. The mantle was connected to power source (220 V) and was turn on to make the solvent get heated and vaporized. Its vapour passes through one tube of the extractor into the chamber where the pounded sample was placed. Some of the rising vapours were condensed back into the extractor by the condenser to ensure maximization of solvent. The hot solvent is contacted with the pounded sample inside the thimble which extract the oil from the pounded sample. This continues until the mixture of oil and solvent reached the purge point of the extractor. At this point, the mixture was purged into the round bottom flask. The process was then repeated continuously. When the colour of the solvent in the sight glass was almost the same as its original colour, it was assumed the majority of the oil have been extracted and the process is then stopped (by turning off the heating mantle). After the extraction process, the round bottom flask is observed to house the mixture of grated coconut and solvent. The oil was separated from the solvent by simple distillation while the solvent was recovered by the used of condenser.

Oil Pretreatment

It is intended in this work, to use a pretreated sample of the oil. We rely on the results obtained by Dasari & Goud (2014), where the properties of the castor oil they used did not change significantly before and after pretreatment. Figure 2 depicts a step-wise procedure followed in treating the oil.

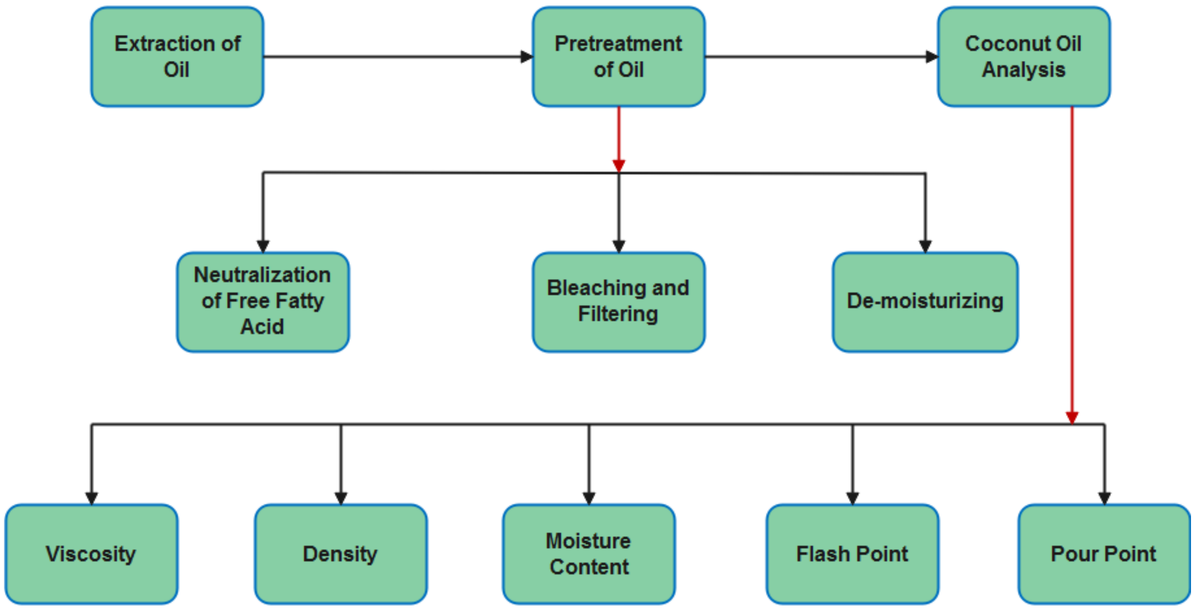

Figure 2: Pretreatment Steps Executed and the Overall Research Step

50 mL of coconut oil was taken into a conical flask and heated using an electric heater maintained at a temperature of about 50°C. After, 10g of activated carbon was added to the preheated coconut oil and was stirred manually for about 30 minutes before the sample was allowed to cool and filtered. Another 50 mL of coconut oil was taken in to a beaker. Then was placed inside an electric oven, to boil above the boiling point of water (precisely 110°C). Esterification was performed by reacting 1% of sulphuric acid (H_2SO_4) with methanol. The molar ratio of methanol to coconut oil was 1:3 in 0.5wt% of oil. The mixture was stirred for 60 minutes at 50°C after which the mixture was poured into a separating funnel for separation to take place. The reaction mixture was allowed to stand overnight while phase separation occurred by gravity settling. Coconut oil (1 mL) was weighted into a conical flask containing 3 mL of neutral ethanol and was warmed for 2 minutes. One drop of phenolphthalein indicator was added, followed by titrating with 0.5 NaOH to determine the pink colour.

Coconut Oil Analysis

Dielectric strength, pour point, flash point, moisture content, density and viscosity of the coconut oil were determined according to methods described in the literature (Dasari & Goud, 2014; Ikyumbur *et al.*, 2022; Samikannu *et al.*, 2022; Sauki *et al.*, 2019).

Determination of Dielectric Strength

Coconut oil sample was poured into the testing vessel. The vessel containing the sample was placed inside an 8o kV insulating dielectric strength tester. The tester was switched ON and allowed to read the values until was stopped. The tester reading was recorded.

Pour Point Determination

The coconut oil was poured inside the bottle and the bottle containing the sample was placed in a refrigerator. Temperature of the sample was observed after every 1-hour interval until when it is about 9°C above the expected pour point. The coconut oil sample bottle was taken out from the refrigerator and then held horizontally for 5 seconds. The temperature reading was not flowing and 3°C was added to the corresponding temperature.

Determination of Flash Point

Coconut oil (50 mL) was poured inside a testing vessel, before placing it inside a flash point tester. The tester was switched ON and allowed to operate. It then automatically, picks the flash point of the sample. The flash point reading was recorded immediately.

Moisture Content Experiment

An empty beaker was washed thoroughly and dried inside an oven, after which it was removed and allowed to cool in a desiccator. The empty beaker was weighed and 50 mL of coconut oil sample was transferred to the beaker and weighed altogether. The beaker containing the sample was placed in the electrical oven operating at 110°C before allowing it to cool for almost an hour. The sample was removed and allowed to cool in the desiccator for 10 minutes. It was reweighed and the percentage moisture content was calculated using the equation presented in Ezechukwu *et al.* (2016).

Density and Viscosity Measurement

A cleaned, empty beaker was weighed, where 50 mL of coconut oil sample was poured into the empty beaker and re-weighed (Figure 3). The difference in mass and volume was calculated. Ratio of oil weight to its volume was calculated as the density of the oil. Using a viscometer, the coconut oil sample was allowed to flow through its capillary tube between two etched marks and the time of its flow was measured using a stopwatch. The given value was calculated and recorded.

Figure 3. Laboratory Density Measurement Setup

RESULT AND DISCUSSION

Properties Determine

Overall results obtained from this research are summarized in Table 1.

Table 1. Electrical and Physical Properties of Coconut Oil

Properties	Coconut Oil	IEC Transformer Oil (Ansyori *et al.*, 2019)
FFA after bleaching (mg NaOH/g)	1.4	0.01
Dielectric Strength (kV)	60	50
Pour Point (°C)	12	−40
Flash Point (°C)	168	154
Moisture Content (mg/L)	0.03	1.5
Density (g/cm^3)	0.77	0.89
Viscosity (cSt)	28.3	13

FFA = Free Fatty Acid

In Table 1, several important properties specified in transformer oil by IEC (60296) standards were compared with the relative value of the refined coconut oil used.

Important Derivations

As evidence in Table 1, the standard transformer oil has density of 0.89 g/cm^3 while refined coconut oil has density of 0.77 g/cm^3. Therefore, the lower the density the better the flow of oil and it facilitates convection. It was observed that the standard transformer oil has the lowest viscosity of 13 cSt while refined coconut oil has viscosity of 28 cSt – which is higher than the recommended level by the IEC 60296 standard and approximately equal to typical value of 29 cSt (at 40°C) reported by Abeysundara *et al.* (2001) and Muhamad & Razali (2016). It can also be observed from Table 1, that the IEC di-electrical strength is towards the standard, which justify its resistance or ability to withstand high electrical strength without breakdown. Also observed is a transformer oil IEC standard flash point equivalent to 154°C and 168°C for pure coconut oil, which compares favorably with 270°C and

340°C obtained by Ezechukwu *et al.* (2016) for transformer and coconut oils, respectively. For the coconut oil to have higher flash point than the standard, shows that the coconut oil is more effective. Higher flash point ensures safety of transformer operating at high temperature and allow its use in adverse conditions, as stated by Azis *et al.* (2014) and Muhamad & Razali (2016).

Also in Table 1, pour point of refined coconut oil as obtained is 12°C, while that of standard transformer oil by IEC (60296) was below 0°C. By implication, the coconut oil cannot flow below 12°C. It can be use in the zones where the ambient temperature is above 12°C. Comparing the pour point of coconut oil (12°C) with the IEC standard of transformer oil (which is −40°C), shows that the transformer in operation generates heat, which result in temperature rise in the oil. But in cold weather conditions (Patel *et al.*, 2021), when the power supply (current flow) is disconnected for a long time, when re-energizing of the transformer, coconut oil can solidify as a result of its higher pour point. This may cause failure in the transformer. A pour point of 23°C and 20°C were previously reported by Matharage *et al.* (2013) and Abeysundara *et al.* (2001) for coconut oil. FFA of refined coconut oil was 1.4 mg NaOH/g after esterification, while the recommended level by IEC (60296) is 0.01 mg NaOH/g (Bandara *et al.*, 2017). The result shows that the FFA of refined coconut oil was slightly higher. Again, coconut oil is safer in areas with high temperature since its flash point and di-electric strength are higher than that of standard transformer oil. The flash point of refined coconut oil and di-electric strength are 168°C and 60 kV (Matharage *et al.*, 2013) respectively, which is a good property of transformer oil. However, viscosity and the FFA are higher than the recommended value in IEC standards.

CONCLUSION

In this experiment, coconut oil was extracted from coconut pod using Soxhlet extraction method. Two hundred gram of sample was used, which yields 57% oil at 150°C with n-hexane as a solvent. The extracted oil was refined by bleaching using activated carbon, de-moisturized by heating it at 105 °C to remove moisture, and later esterified, with the understanding that the oil contains FFA of 14 mg/g to 1.4 mg NaOH/g after esterification. Break down voltage, moisture content, flash point, pour point, viscosity and density of the refined oil as analysed and compared with standards, shows that, it can be used as alternative biofuel to transformer oil. If difficulty associated with vegetable oil storage and handling is addressed, refined coconut oil can be used as substitute to transformer oil which are environmentally unfriendly and scarce resource. Other essential oils such may be examined as potential replacement of transformer oil in the next study. In addition, different existing methods of extracting essential oil as well as a variety of solvents (e.g., petroleum ether, isopropanol, ethyl acetate, methanol, cyclohexane and n-pentane) can be tried.

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