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EPOXIDATION OF JATROPHA CURCAS L. OIL TO IMPROVE THE STABILITY AND PERFORMANCE OF ECO-FRIENDLY BIOLUBRICANTS

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ABSTRACT

The decline of petroleum reserves and environmental issues from petroleum-based lubricants have driven interest in biolubricants. Jatropha curcas L. oil is a promising candidate due to its availability and non-edible nature, but it lacks sufficient oxidative stability and thermal performance. This study aims to improve jatropha oil quality through in situ epoxidation. The research included oil extraction, initial chemical analysis (acid value, moisture, saponification value, iodine value), epoxidation with varied reactant ratios and reaction times, and post-modification tests of viscosity and flash point. Results indicated that oil yield from dehulled seeds was higher (60%) than hulled seeds (25%). Epoxidation improved viscosity from 2.39 cSt to 34.2 cSt at 40°C and raised the flash point from 109°C to 270°C. These enhancements demonstrate improved physicochemical properties, making epoxidized jatropha oil a potential eco-friendly lubricant comparable to modern synthetic lubricants.

Keywords: Jatropha Oil, Epoxidation, Biolubricant, Viscosity, Flash Point

INTRODUCTION

Global population growth, infrastructure development, and advances in transportation and industrial technology have significantly increased energy consumption. Petroleum, which for more than a century has served as the primary energy source as well as a raw material for various industrial products, is now under great pressure. The International Energy Agency (IEA) reports that global oil demand continues to rise each year, while available reserves are steadily declining, and the discovery of new wells cannot compensate for this gap [1]. It is estimated that global oil demand continues to increase consistently each year, while available reserves keep declining, and the discovery of new wells is unable to close the gap. This condition not only threatens future energy supply but also worsens environmental problems due to carbon emissions produced by fossil fuel combustion.

In this context, the transition toward clean energy has become a global urgency. One strategic pathway widely explored is the substitution of certain petroleum-derived products with renewable plant-based raw materials. Vegetable oils are considered to have several advantages, such as being biodegradable, having low toxicity, and containing chemical compounds that allow structural modification to meet specific technical requirements. Plant-based oil products are now increasingly being considered, including in the lubricant sector, which has long been dominated by petroleum-based mineral and synthetic feedstocks.

Among the various sources of vegetable oils, Jatropha curcas L. stands out as a prominent candidate. This plant has a high oil yield in its seeds, is capable of growing in diverse land conditions—including dry and less fertile soils—and does not directly compete with food commodities. This agronomic potential offers significant opportunities for tropical countries such as Indonesia, which has a favorable climate and sufficient land availability to support jatropha development. Jatropha curcas can thrive on marginal land without sacrificing productive agricultural areas, making it highly suitable for sustainable energy programs. [2].

The characteristics of jatropha oil are also technically attractive. Its relatively high content of unsaturated fatty acids provides oxidative stability, good natural viscosity, and potential resistance to high-temperature and high-pressure operating conditions. Jatropha-based lubricants show promise as high-performance engine lubricants [3], and they also demonstrate resistance to extreme temperatures and heavy mechanical loads [4], [5]. With certain modification treatments, such as the epoxidation process, these properties can be further enhanced, enabling jatropha oil to compete with modern synthetic lubricants [6].

Domestic research has further reinforced this prospect. Studies indicate that epoxidized jatropha oil exhibits oxidative stability and friction performance comparable to commercial mineral lubricants [7], [8]. In fact, for certain parameters, its performance is able to match synthetic lubricants based on polyol esters. This evidence strengthens the potential of jatropha oil as an eco-friendly lubricant feedstock that can be produced locally and sustainably.

In addition to its technical benefits, the development of a jatropha-based oil industry also has the potential to generate economic value for communities, particularly in rural areas. Jatropha cultivation is relatively easy, and its processing into oil can create new employment opportunities. Thus, the utilization of jatropha oil not only provides a technical solution to reduce dependence on petroleum but also delivers positive impacts on social and economic aspects.

Based on this background, this study is directed at exploring and optimizing the physicochemical characteristics of jatropha oil, particularly through chemical modification processes, so that it can meet modern lubricant performance standards. The findings are expected to serve as a foundation for the development of competitive, environmentally friendly biolubricants that are relevant to industrial needs in the era of sustainable energy transition.

METHOD

This research was carried out in four main stages, consisting of the extraction of jatropha oil, initial chemical analysis, purification through epoxidation, and subsequent chemical and physical testing.

1. Oil Extraction from Jatropha Seeds

Jatropha curcas L. seeds were obtained from Pasuruan, East Java. The extraction process was carried out through several steps. The first stage involved drying the seeds. The seeds, after being separated from the fruit shells, were placed in an oven at approximately 60°C for about two hours to reduce moisture content and prevent oil degradation caused by hydrolysis. Once dried, the seeds were crushed into coarse pieces and pressed using a hydraulic press to produce crude oil. The crude oil was then filtered using a filter press to remove solid particles, fibers, and impurities, resulting in cleaner jatropha crude oil.

2. Initial Chemical Analysis

The extracted oil was then analyzed chemically to determine its initial characteristics. The parameters tested included moisture content using the oven gravimetric method, acid value to determine the amount of free fatty acids, saponification value to measure the amount of alkali required for the saponification process, and iodine value to indicate the degree of unsaturation of fatty acids. These test results served as baseline data prior to the purification process.

3. Epoxidation of Jatropha Oil

The purification process was carried out using the in situ epoxidation method to enhance the oxidative stability of the oil. Jatropha oil was mixed with acetic acid and then heated to 70°C. Hydrogen peroxide was subsequently added slowly along with sulfuric acid catalyst at a concentration of 1% (v/v). The concentration ratios of H_2O_2 to CH_3COOH used were 1:0.075, 1:0.15, 1:0.225, and 1:0.30. The reaction was conducted under constant stirring with varying reaction times of 0, 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0, 2.25, 2.5, 2.75, 3.0, 3.25, 3.5, 3.75, 4.0, 4.25, 4.5, 4.75, and 5.0 hours The variations in reactant ratios (H_2O_2 : CH_3COOH) and reaction times were determined to evaluate the influence of oxidant concentration and reaction duration on the formation of epoxide groups. The selected concentration range (1:0.075–1:0.30) was based on previous studies [4][5], which indicated that an excess of reactants may increase epoxidation conversion but also introduce the risk of side reactions. The 0–5 hour reaction time variation was used to monitor the rate of epoxide formation and to identify the optimum point at which oil stability improves without excessive degradation. Thus, the experimental variations were established based on the principle of optimizing between reaction efficiency and product quality.

After the designated reaction time was reached, the mixture was cooled, washed with warm water until neutral pH, and dried to remove residual water. The epoxidation parameters and variations used are presented in Table 1 below.

Table 1. Parameters and Composition Variations for Jatropha Oil Epoxidation

Number	***Parameters***	***Variations***
1	*Temperature*	70°
2	*Time*	0 ; 0,25 ; 0,5 ; 0,75 ; 1,0 ; 1,25 ; 1,5 ; 1,75 ; 2,0 ; 2,25 ; 2,5 ; 2,75 ; 3,0 ; 3,25 ; 3,5 ; 3,75 ; 4,0 ; 4,25 ; 4,5 ; 4,75 ; *and* 5,0 *hours*
3	*Catalyst concentration*	$H_2SO_4$1% (v/v)
4	*The concentration ratio of (H_2O_2) to (CH_3COOH)*	1:0,075 ; 1:0,15 ; 1:0,225 *and* 1:0,30

4. Chemical and Physical Tests after Epoxidation

The jatropha oil subjected to the epoxidation process was subsequently re-analyzed chemically using the same parameters as in the initial tests, namely moisture content, acid value, saponification value, and iodine value, in order to evaluate changes in chemical properties resulting from purification. Furthermore, physical tests were performed, including viscosity measurement to assess the oil's flow resistance at a specific temperature and flash point determination to identify the minimum temperature at which the oil produces flammable vapors. The outcomes of these analyses were used as the basis for determining the feasibility of epoxidized jatropha oil as a raw material for environmentally friendly lubricants.

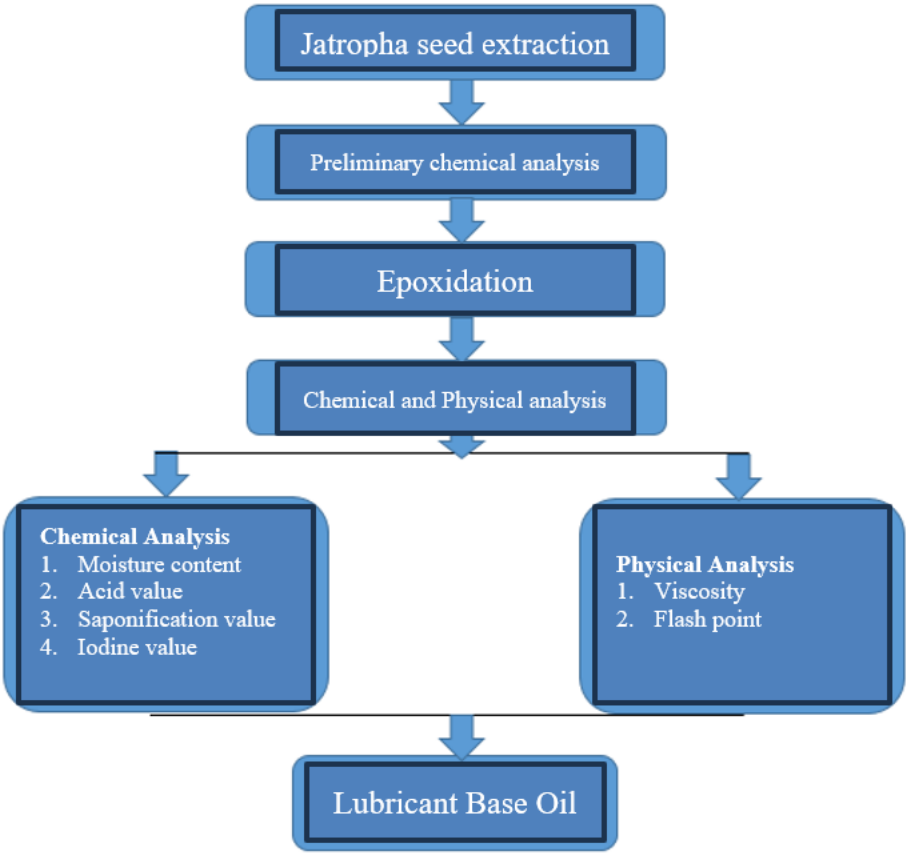

Figure 1. Research Workflow of Jatropha Seeds to Lubricant Feedstock

RESULTS AND DISCUSSION

The discussion in this study is divided into several sub-sections, which are presented as follows.

1. Chemical Analysis Results

The extraction process of jatropha seeds produced crude oil with a certain yield, which was influenced by drying conditions, pressing methods, and the quality of the raw material. The measurements showed that the oil yield before epoxidation was approximately 17% of the dry weight of hulled seeds and 40% of the dry weight of dehulled seeds. After the epoxidation process, a slight reduction in yield was observed, which was likely caused by washing and the removal of residual reactants during the purification stage [9]. The post-epoxidation results are presented in Table 3.

Table 2 illustrates the comparison of oil yield before and after epoxidation. It can be seen that the yield of epoxidized oil (25–60%) was higher compared to crude oil (17–40%). This was attributed to differences in raw material conditions (hulled vs. dehulled seeds) as well as the purification stage, which reduced non-oil fractions. The higher yield in dehulled seeds reflects more efficient extraction, whereas hulled seeds tended to yield less oil due to the presence of lignin and cellulose, which hindered oil release [11][12].

Table 2. Comparison of Jatropha Oil Yield

Process type	Yield %
Crude oil	17-40
Epoxidized oil	25-60

Table 3. Results of Chemical Analysis after Epoxidation

Yield of oil from jatropha seeds with shell	Yield of oil from jatropha seeds without shell	Acid value	Moisture content
25%	60%	5,3	1

The changes in oil yield after epoxidation are consistent with the findings of Singh [5], who reported that the purification of vegetable oils can reduce the final volume due to the loss of volatile and soluble compounds. Kumar and Sharma also demonstrated that the washing stage in epoxidation may reduce oil mass by 2–5%, yet it improves the purity and stability of the final product [3], [10].

The oil yield obtained from dehulled jatropha seeds was generally higher compared to that from hulled seeds. This condition indicates that the seed hull acts as a barrier in the oil release process. Seed hulls are typically rich in non-oil components such as lignin and cellulose, which are rigid and poorly soluble in extraction solvents, thereby slowing solvent penetration into the seed kernel and reducing process efficiency [11], [12]. This constraint is consistent with the principle of oil extraction, which states that the greater the physical resistance to solvent penetration, the lower the amount of oil that can be extracted from the raw material.

In the free fatty acid (FFA) test, oil extracted from hulled jatropha seeds showed a value of 5.30, which is considered relatively high. A high FFA content indicates the degradation of triglycerides into free fatty acids, which negatively affects oil quality. Oils with high acid values are more prone to rancidity due to oxidation, thereby reducing their shelf life. O'Brien emphasized that elevated free fatty acids accelerate oxidative reactions that can deteriorate oil quality, alter its aroma, and affect product stability [8], [13]. This phenomenon may be associated with the presence of the seed hull, which hinders complete oil separation, thereby increasing the fraction of free fatty acids dissolved in the oil.

The moisture content of the extracted oil was recorded at around 1%, indicating that the processing method was sufficiently effective in reducing water content. Low moisture content is important because it can inhibit microbial growth and slow oxidative deterioration. Ewunie explained that excessive water in oil not only decreases stability but can also trigger the formation of compounds that compromise quality [14]. Therefore, a moisture level of 1% in jatropha oil can be considered adequate to prolong product shelf life.

These findings are consistent with the study of Wang, who recommended the use of dehulled jatropha seeds in the extraction process to maximize yield while simultaneously improving oil quality [15]. Additional support comes from Sanjid, who reported that the absence of the seed hull facilitates solvent penetration into the kernel cells, thereby making the oil release process more efficient [16]. This principle was also highlighted by Pingkan, who explained that the hard and insoluble layer of the raw material hinders solvent diffusion, thus its removal becomes an important strategy to improve extraction efficiency [17].

Therefore, the higher yield observed in dehulled seeds is not only due to mechanical factors that ease solvent access but also contributes to reducing free fatty acid content and maintaining low moisture levels. The combination of these factors is key to obtaining jatropha oil with optimal physicochemical quality.

2. Viscosity of Jatropha Oil

Viscosity is an important parameter in assessing the feasibility of jatropha oil as a base material for lubricants. The test results showed that the viscosity of jatropha oil increased after undergoing epoxidation, from 2.39 cSt to 34.2 cSt at 40°C. This increase was caused by the reduction of double bonds and the formation of epoxide groups, which added rigidity to the molecular chains.

As presented in Table 4, the significant rise in viscosity from 2.39 cSt to 34.2 cSt at 40°C confirms the structural changes induced by epoxidation. This higher viscosity is particularly important, as it correlates with the lubricant's ability to maintain a protective film between friction surfaces. Compared to other vegetable-based lubricants (Table 5), this value is considered excellent and places jatropha oil in the High Viscosity Index (HVI) category, making it a promising candidate for high-temperature machine applications.

Table 4. Jatropha curcas oil viscosity

Process type	**Viscosity (cSt, 40ºC)**
Crude oil	2,39
Epoxidized oil	34,2

These results are consistent with the report of Chhetri, who found that the epoxidation of vegetable oils can increase kinematic viscosity by 15–25%, depending on the reaction conditions [18]. The increase in viscosity provides advantages in lubricant applications, as it enhances the protective film between friction surfaces, as also noted by Liu in his study on ester-based biolubricants [11]. The viscosity index of jatropha oil after epoxidation and its comparison with other lubricants are presented in Table 5 and Figure 2 below.

Table 5. Viscosity Data of Oils Based on Raw Materials

Oil types	***Viscosity 40ºC cSt***	***Viscocity index***	***Flash point***
Vegetable oil			
Jatropha curcas oil	34,2	217	270
Coconut oil	27,7	175	-
Jasmine oil	39,9	206	252
Soybean oil	29	247	325
Cooking oil	39,7	188	-
Mineral oil			
HVI-60	-	103	204
HVI-95	-	100	210
HVI-160S	-	100	230
HVI-650	-	96	267
HVI-350	-	-	267
POE (*Polyolester)*	76,7	214	285

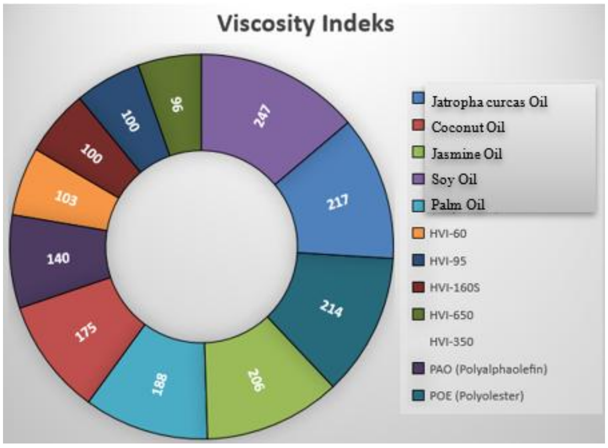

Figure 2. Viscosity Index Diagram

Based on viscosity index classification, there are three main categories: low viscosity index (LVI) with values below 40, medium viscosity index (MVI) ranging from 40–80, and high viscosity index (HVI) for values above 80. The test results showed that jatropha oil falls into the HVI category, with a viscosity index value of 217, as presented in Figure 2 and Table 5. This remarkably high value indicates that jatropha oil possesses exceptional viscosity stability, even surpassing multigrade SAE-type lubricants as shown in Table 6.

In principle, the viscosity of fluids tends to decrease as temperature increases; therefore, lubricants with a high viscosity index are preferred since they can maintain lubrication performance under extreme operating temperatures. In this context, jatropha oil demonstrates superior performance, with a viscosity index approaching that of Polyol Ester (POE) lubricants. Compared to other vegetable oils, the viscosity index of jatropha oil is comparable to that of rapeseed oil, although slightly lower than that of soybean oil.

Table 6. Indeks viskositas minimum pelumas (double viscosity) SAE

SAE viscosity	Minimum viscosity index
5W – 20	127
5W – 30	180
5W – 50	230
10W – 30	145
10W – 40	169
10W – 50	190
20W – 40	113
20W – 50	133

3. Flash Point

The flash point is an indicator of lubricant safety and thermal stability. Based on the tests, the flash point of jatropha oil before epoxidation was recorded at 109°C, whereas after epoxidation it increased to 270°C. This increase indicates that the modified oil is more resistant to the formation of flammable vapors, making it safer for use at high temperatures.

Table 7 shows that the flash point of jatropha oil rose dramatically from 109°C (crude oil) to 270°C after epoxidation. This increase of more than 160°C signifies a very substantial improvement in thermal stability. Lubricants with higher flash points are safer because they are less prone to evaporation and combustion under engine operating conditions. The value of 270°C is even higher than that of several conventional mineral lubricants (approximately 200–230°C), thereby reinforcing the potential of epoxidized jatropha oil as an eco-friendly lubricant candidate with performance approaching that of modern synthetic lubricants.

Table 7. Flash Point Comparison

Process type	Flash point (ºC)
Crude oil	109
Epoxidized oil	270

The increase in flash point is consistent with the findings of Kumar, who reported that epoxidation can enhance the thermal stability of jatropha oil by 10–15°C compared to crude oil [3]. Vegetable oil–based lubricants with higher flash points generally exhibit longer service life and more stable performance in high-temperature engines [4], [9].

Overall, the results of this study demonstrate that the epoxidation process not only purifies jatropha oil but also improves its physicochemical properties. Although the yield slightly decreased due to purification, this was offset by significant increases in viscosity and flash point. These improvements support the potential of epoxidized jatropha oil as a raw material for eco-friendly lubricants with performance approaching, or even equivalent to, petroleum-based lubricants.

One of the key parameters in evaluating lubricant quality and reliability is the flash point, defined as the minimum temperature at which lubricant vapors can ignite when exposed to a flame. The test results showed that jatropha oil (Jatropha curcas oil) had a flash point of about 270°C. This value indicates that the oil possesses very good heat resistance prior to evaporation and combustion, making it suitable for use in machines or equipment operating at high temperatures.

When compared, the flash point of jatropha oil is higher than that of conventional mineral lubricants, which typically range between 204°C, and only slightly lower than that of synthetic lubricants such as Polyol Ester (POE), which has a flash point of around 285°C. This advantage is closely related to its chemical composition. Vegetable oils, including jatropha oil, contain a relatively high proportion of saturated fatty acids, which play an important role in enhancing oxidative stability and increasing flash point [13][19]. These findings are consistent with Zhang's study, which emphasized that jatropha oil–based lubricants exhibit good resistance to oxidation and carbon residue formation, making them a promising alternative as environmentally friendly lubricants [20].

CONCLUSION

This study demonstrates that the epoxidation of jatropha oil (Jatropha curcas L.) can improve its physicochemical quality, making it suitable for development as a raw material for eco-friendly lubricants. The oil yield from dehulled seeds was higher than that from hulled seeds, with low moisture content and an acid value that still requires control. The epoxidation process significantly increased viscosity from 2.39 cSt to 34.2 cSt at 40°C and raised the flash point from 109°C to 270°C. These results confirm that epoxidation enhances the oxidative stability and thermal performance of jatropha oil, highlighting its potential as a competitive biolubricant alternative to petroleum- and synthetic-based lubricants. Future research should focus on tribological testing and long-term stability assessments to ensure the performance of epoxidized jatropha oil in real applications.

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