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Production of Bio-lubricant from Neem Oil

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Abstract. Fast increment in fuel cost is a major issue for developing nations, which import the greater part of their interest. Presently the utilization of vegetable oils as lubricants have been expanded in numerous nations. An ideal approach to utilizing non-edible vegetable oil as a fuel is to change it over into bio-lubricant. This produced from many vegetables, edible and non-edible oils such as soya bean oil, castor oil, jatropha oil, palm oil, sunflower oil and karanja oil. Neem oil is a non-edible oil and has great potential for being a source of bio-lubricant. In this research, the production and characterization of bio-lubricant extracted from neem oil. Neem seeds oil was extracted by using hexane in the soxhlet apparatus. The physical and chemical properties of the extracted oil were studied. The oil corresponds to lubricant except for the high free fatty acid content and higher pour point. Esterification was performed to decrease the free fatty acid (FFA) content, followed by trans-esterification and double trans-esterification to produce bio-lubricant. The conditions for both were optimized and found to be 8 mole % ethanol and 1mol % NaOH for trans-esterification and 3.5 mole % ethylene glycol and 0.8 mole % NaOH for double trans-esterification. Main lubricating properties of the sample such as viscosity index, pour point density, flash point and % FFA content were analyzed and found to be 212, -7 °C, 889Kg/m^3, 223°C and 0.79 % whereas the properties of mineral oil-based lubricant were 145, -23 °C, 894Kg/m^3, 209 °C. AC1402 (PMMA) was used as an anti-freezing agent. The lubricant characteristics such as pour point, viscosity index, density and flash point were changed to -20 °C, 231, 882Kg/m^3 and 231 °C, making it suitable over a wide range of temperatures.

Keywords: bio-lubricant, neem oil, pour point, viscosity index, density, flash point

Introduction

Lubrication is the procedure utilized to lessen the wear one of the two surfaces in contact and move comparatively with each other by mediating a substance known as a lubricant between the surfaces to carry the load (pressure produced) amid the contacting surfaces. The primary reason behind lubrication is to diminish heat loss and wear those outcomes because of surfaces in contact with motion. To shield it from erosion and lessen oxidation and act as a protector in transformer applications and perform as a sealant against dust and water (Kareemullah *et al*., 2021; Suresha *et al*., 2020).

Although wear and heat can't be dispensed with and can be diminished to irrelevant or satisfactory levels by utilizing lubricants. As they are related to friction, they can be limited by minimizing the coefficient of friction among the surfaces which are in contact. Any material utilized to diminish friction in this manner is a lubricant. Lubricants are accessible in solid, liquid and vaporous structures among which liquids and solids or semi solids are utilized generally in everyday life. It might have the capacity of transmitting force, transmitting un-familiar substances and heating or cooling the surfaces. The property by which friction reduces is called lubricity. Although its usage is as old as human kind's, scientific attention on lubricants and lubricant innovation is moderately new. Humans have utilized lubricants from the start of progress to help with decreasing the energy expected to slide one item in contradiction of another. Previously oil, grease or mud have been used as a lubricant and liquid lubricant was significant for transporting sledges during the Egyptian and Sumerian human advancements (Chebattina *et al*., 2018; Idris *et al*., 2018).

The utilization of bio-lubricants includes biodegradability as the most significant model for benevolent climate lubricants. Biodegradability implies the inclination of a lubricant to be ingested, debased and used by micro-organisms. The most significant properties of bio-lubricants among the different lubricants are eco-friendliness and non-toxicity. Additionally, they have

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superb tribological properties, for example, high flash points, lower friction coefficient, slower evapouration and greater viscosity index in correlation with mineral oil-based lubricant. Despite that, they have some genuine drawbacks. They are thermally less stable, more sensitive to hydrolysis, oxidative instability and low temperature is insufficient and they are the principal source of restricting the utilization of bio-lubricants (Bhan *et al*., 2020; Olufemi and Essien, 2020).

Nearly mineral oil-based lubricants have great oxidative stability and outstanding thermo-oxidative nature, causing better flash and fire points. The harmful emissions and degradation make the environment contaminated and unsafe for people and the wild also once they are delivered. The discharged gases convert themselves into oxides and free radicals which likewise cause extreme respiratory illnesses and disorders. Lubricants are classified as physical appearance, base oil resource and applications.

Physical appearance includes, solid material's film consisting of organic or inorganic compounds, like graphite, molybdenum and cadmium disulfide. Semi solid-liquid is suspended in a solid matrix of thickener and additives, like grease. Examples of liquid lubricants are oils such as mineral, animal, synthetic and vegetable oil. Base oil resources are natural oils obtained from vegetable oils and animal fats. Refined oils are obtained from mineral reserves for example paraffinic, aromatic oils and naphthenic. Synthetic oils are obtained as the final product of modified reactions according to the requirement for example, synthetic esters, poly alpha-olefins and silicones (Tulashie and Kotoka, 2020; Sharma *et al*., 2017).

The types of lubricants are mineral oil-based, bio-based and synthetic lubricants. Mineral oil-lubricants are lubricants taken from a mixture of liquid hydrocarbons

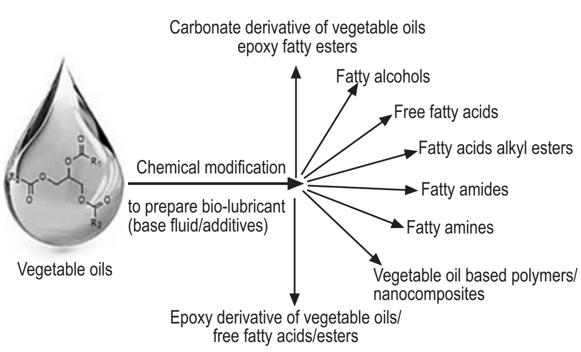

Fig. 1. Chemical modification of bio-lubricant.

acquired from raw petroleum by various strategies of distillation and refining. There are three kinds of mineral oil-based lubricants. The hydro-cracking extraction process forms paraffinic oil-based lubricants. Most of these oils have a non-ring long-chained structure. Crude oil distillates from naphthenic oil-based lubricants, most of these oils have a saturated ring structure. Aromatics oil-based lubricants are formed during the refining process in the production of paraffinic oils. Mostly they have a non-saturated ring structure (Singh *et al*., 2021; Mahara and Singh, 2020).

Figure1 represents the chemical modification of bio-lubricant. Bio-lubricants are esters of heavy alcohol produced from vegetable oil and have lubrication properties (for example, viscosity index, density, pour point, flash point and corrosion resistance). There are two kinds of bio-based lubricants. Vegetable oil-based lubricants are based on soybean, castor, corn, canola, rapeseed oils and cotton seed. Vegetable oils are a climate friendly substitute for mineral oils as they are biodegradable. Animal lubricants are derived from the animal's fat. The two types of animal fats are soft fats (lard) and hard fats (stearin), mainly utilized for producing lubricants.

There are numerous advantages of bio-lubricants that make them superior to mineral oil-based lubricants. It has amazing lubricity of 2-4 times their mineral oil-based related lubricants. The polar nature of the lubricant upgrades it. Bio-lubricants have a greater viscosity index. The viscosity doesn't change with temperature compared to the mineral oil-based lubricants, making it reasonable for wide temperature applications. They have less volatility, greater flash/fire point, low evapouration loss and oil mist that make them deal with better safety. They show good skin compatibility and lower skin issues. They likewise have non-water contaminating properties and biodegradability, decreasing the expense of removal, not making them eco-friendly. They are likewise cost saving money under the less operating cost because of larger intervals between lubrication. The expanded utilization of bio-lubricants will also be relied upon a reduction in mineral oil-based lubricants, increasing the utilization of sustainable resources, better dealing with the carbon cycle and contributing to reducing unfriendly ecological and safety effects (Hassan *et al*., 2019; Woma *et al*., 2019).

Lubricants have a wide scope of properties that affect their physical and chemical properties. Thinking about these properties is significant in figuring out which lubricant is best for which condition, while there are numerous properties, the most significant are viscosity and the resistance to flow which directly relates to the formation of film that protects the surfaces of the metal, which is called viscosity. The lubricants which have higher viscosity are thick and they don't flow while lubricants that have lower viscosity have a consistency that is closer to water and do flow. The pour point is the minimum temperature of a liquid at which it ceases to flow under endorsed conditions. The cloud point is the temperature at which the mixture begins to separate into two phases and becomes cloudy. Flash point is the minimum temperature upon which an external source ignites the vapourized oil. Fire point, the temperature at which a material will continue to burn after providing an ignition source for at least 5 sec is called fire point. Oxidation stability, the resistance towards forming oxide, which increases at increased temperatures and it is called oxidation stability. The neutralization number shows an amount of acid/base content for neutralization is called the neutralization number (Panneer and Panneerselvam, 2020; Sathishkumar and Rajmohan, 2020).

The main purpose of lubrication is to facilitate the free movement of the parts in contact and minimize friction and wear. To keep up the minimum temperature of the surfaces by taking away the heat. The lubricant must form a good seal between piston rings and cylinder walls. The depreciation of the world's unrefined petroleum reserves coupled with the utilization rate, increment in mineral oil costs and in sufficiencies and concerns identified with conservation have restored interest in the utilization of bio-fuels. Accentuation on the improvement of sustainable, biodegradable and nature-friendly industrial fuels for example, lubricants, diesel and different fuels have raised the requisite to look for elective fuels which can be renewed renewed (Alang *et al*., 2018; Menkiti *et al*., 2017).

Figure 2 shows the production cycle of bio-lubricant, which has been obtained from different edible oils due to the disturbance in the food chain. Neem oil is obtained from the seeds and fruits of the neem, an evergreen tree that is easily available in Pakistan. The colour of neem oil is reddish-brown or greenish-brown. Neem seeds are taken and oil is extracted from the seeds by using the soxhlet apparatus.

Some past studies for bio-lubricant are deliberated as; an expansion in the viscosity of the base oil, which was due to the depreciation in wear loss. The increment in the viscosity was related to the number of particles available per unit volume of oil. The formation of palm oil-based bio-lubes, which have been used as an additive in the engine and lubricants for minimum quantity lubrication (MQL) (Yadav *et al*., 2021; Pathmasiri *et al*., 2019) The growing new generation of heavy duty lubricants is a case of the industry's reaction to the interest for lubricated automotive hardware that will diminish natural stacking by diminishing emissions and accomplish biodegradability and non-toxic nature. Bio-lubricants are generally acknowledged as offering various intrinsic benefits over regular mineral oil-based lubricants to figure this era's automotive motor oils (Yadav *et al*., 2021; Karmakar *et al*., 2017).

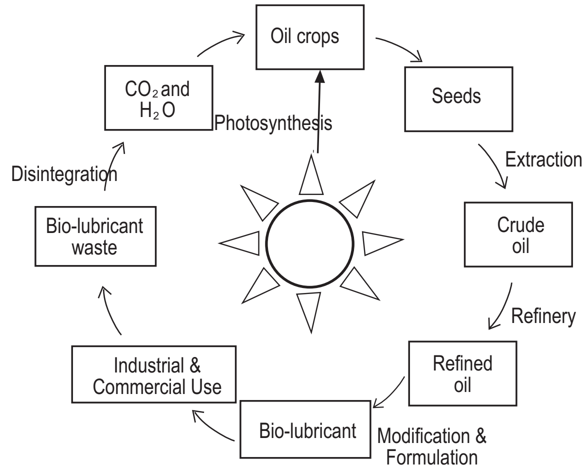

Fig. 2. Production cycle of bio-lubricant.

The bio-lubricant is interpreted as a lubricant produced from natural raw materials both vegetables and animal oils, renewable and harmful to humans and other living beings, as well as nature friendly. Vegetable oil utilized for the formation of bio-lubricant can be taken from plant seeds, for example, vegetable oil that can be consumed or cannot be consumed. A portion of the vegetable oil can be utilized as bio-lubricant, for example, castor oil, neem, karanja, rice bran, linseed, rapeseed, palm oil, sunflower oil, coconut, soya bean, olive and canola. The production of bio-lubricants from jatropha oil is because of their high fatty acid content (61– 64%). The investigation of manufacturing techniques and optimal parameters for producing greater yields of lubricant from Jatropha oil is still not completed (Owuna *et al*., 2020). Previous studies discussed the greater potential for the formation of bio-lubricant from non-edible oil seeds in south Asia. The nation is enriched with more than 100 types of tree-conceived non-edible oil. Seeds present in wild or cultivated yield oil in significant amounts. In south Asia, the amount of vegetable oil-based lubricants and esters utilized is little (Shankar *et al*., 2021; Yadav *et al*., 2021). Among all these research works, the study mentioning the production of bio-lubricant from jatropha-oil is more pertinent to our research.

It is economically beneficial to use domestic non-edible oil, specifically neem oil, as it grows in eroded soil. It is known as a living plant requiring only hot weather and requires less water to survive and is easily available in Pakistan, as well as it is cheaper than mineral oil and other edible and non-edible oils. Neem oil gives a greater yield than other non-edible oils (approximately 60-70%). It is also used for medicinal purpose and produce a large amount of waste, so its waste can be used to extract oil from it which will be three times less expensive than other non-edible oils. A country like Pakistan, which has a huge amount of neem trees, requires little plantation. It is a strong reason to strengthen the development of neem oil-based bio-lubricants. Because of the overwhelming use of non-biodegradable assets and their shortage in the coming future, this research is focused on the synthesis of environmentally friendly biodegradable lubricants from neem seed. Comparison between the properties of the lubricant obtained from neem oil with mineral oil. Effect of pour point depressant on the properties of bio-lube (Yadav *et al*.. 2021; Ashokkumar *et al*., 2020).

Meterial and Methods

The raw materials used in this research are hexane (extraction solvent), neem seeds, sulfuric acid (catalyst for esterification), KOH (catalyst for trans-esterification), NaOH (catalyst for the synthesis of bio-lubricant), ethanol and ethylene glycol. For the production of bio-lubricant, neem seeds were used from which oil is extracted. Since neem oil has higher free fatty acid content so, before the production of bio-lubricant, esterification was done to reduce free fatty acid content. After the reduction of free fatty acid content, trans-esterification was done on the resulting oil. The obtained product is fatty acid ethyl ester which was then subjected to double trans-esterification to produce bio-lubricant.

The temperature for esterification and trans-esterification was below 70°C, as ethanol was used in both processes. The boiling point of ethanol is 78°C. KOH and NaOH catalyze the reaction to give better conversion. Several other processes can do the synthesis of bio-lubricant (Yadav *et al*., 2021; Pathmasiri *et al*., 2019; Karmakar *et al*., 2017). Still, the significance of this method is that the raw materials used are cost-effective and easily available in the market. The production of bio-lubricant is a four step process based on oil extraction, esterification, trans-esterification and synthesis of bio-lubricant. Figure 3, shows the flowchart representing the methodology adopted.

Oil extraction. The soxhlet extractor extracted the neem seeds oil. The solvent used for extraction was n-hexane, which was utilized in the proportion of 6:1. A reflux condenser is fitted and the mixture was kept at a stirrer at 60°C for 8 h. After several cycles, the ideal compound was collected in the flask. After extraction, the solvent was taken out, commonly by a rotary evapourator to yield the extracted compound. The seeds stayed in the thimble and were disposed of the solution was then heated to remove the traces of n-hexane by temperature controlled water bath and finally, the oil was collected.

Esterification of oil. For the production of bio-lubricant that can compete with the ordinary lubricant in the quality aspect in a cost effective way, it was needed to decrease the FFA content of a low to medium quality oil. Good quality oil contains very low amounts of FFA content but is expensive. FFA content has to be decreased as high FFA content may lead to saponification. The easiest possible way to reduce the FFA content is by esterification. Ethanol in a ratio of 8:1 and 4.5% H_2SO_4 catalyst (w/w oil) was heated to 45°C for 90 min. in a round bottom flask. The product was then retained in

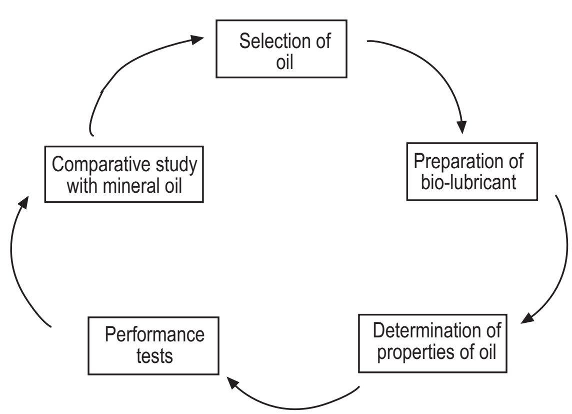

Fig. 3. Flowchart for the methodology adopted.

a separating funnel for 24 h. for separation gravity. A dark brown layer was formed at the bottom containing water and an upper layer formed was separated as reduced FFA neem oil. The chemistry of the esterification of the oil process is shown in equation. (1) (Yadav *et al*., 2021; Owuna *et al*., 2020).

$$R1 - C{\leqslant}^{O}_{O} + C_2H_5 - OH \xleftrightarrow{H_2SO_4} P_1 - C{\leqslant}^{O}_{O-}C_2H_5 + H_2O \quad \ldots\ldots (1)$$

Free fatty acids (FFAs) Ethanol Fatty acid ethyl ester water

R_1 represents the fatty acid group.

Trans-esterification of oil. Trans-esterification is the reaction of an oil or fat with alcohol in which esters and glycerols are formed. An excess amount of ethanol must be added so that the equilibrium must be shifted to the product side because the reaction is reversible. This reaction, as neutralization, further reduces the FFA content by the basic catalyst (KOH). A high amount of ethanol is added and a good amount of catalyst shall be added to ensure that the reaction may continue to proceed (Egbuna *et al*., 2021; Singh *et al*., 2021).

Ethanol in 8:1 was added with 1% (w/w oil) catalyst KOH around the bottom flask and was heated to 60°C for 60 min. The product was then kept for 24 h in a separating funnel for gravity separation. The bottom layer was dark brown and contained mainly glycerol and the upper layer was fatty acid ethyl ester, which also contained a small amount of catalyst. For removing the catalyst, 10% warm water was added and kept for 1 h in a separating funnel. Then the bottom layer formed contained catalyst and water, while the upper layer containing ethyl ester was separated. equation (2) shows the chemistry of the trans-esterification of the oil process (Yadav *et al*., 2021; Owuna *et al*., 2020).

$$C_3H_5(OOR)_3 + 3C_2H_5OH \xleftrightarrow{KOH/NaOH} 3C_3H_5COOR + C_3H_5(OH)_3 \quad \ldots\ldots (2)$$

Triglyceride Ethanol Fatty acid Ethylester Glycerol

Synthesis of bio-lubricant. The synthesis of bio-lubricant was attained by trans-esterification of fatty acid ethyl ester with ethylene glycol, using sodium hydroxide as a catalyst. Fatty acid ethyl ester and ethylene glycol were added in a ratio of 3.5:1, with 0.8% (w/w of total reactants) catalyst (NaOH) in a round bottom flask and was heated at 120°C for 2.5 h. The obtained product was a bio-lubricant given in equation. 3 (Yadav *et al*., 2021; Owuna *et al*., 2020).

$$RCOOC_2H_5 + C_2H_6O_2 \xleftrightarrow{KOH/NaOH} RCOOCH_2CH_2OH + RCOOCH_2CH_2\,OOCR \quad \ldots\ldots (3)$$

Characterization of neem oil. The following properties were estimated for the testing of neem oil bio-lubricant.

Density. It is an important quality parameter, higher density will cause more resistance. For finding the density, firstly weight of an empty R.D. bottle was recorded, then 50 cubic centimeters of the sample (neem oil bio-lube) was added to the R.D. bottle and weighed. From the obtained sample weight, by taking the proportion of the weight of bio-lube to the identified volume (50 cm^3), density is calculated according to the formula given in equation 4.

$$\text{Density} = \frac{\text{Sample weight}}{\text{Sample volume}} \quad \ldots\ldots (4)$$

Viscosity index. Viscosity is measured by using Ostwald's viscometer at 40°C and 100°C. First, clean the viscometer with chromic acid and rinse it with distilled water. Now, wash the viscometer with acetone and dry it. An adequate amount of distilled water is added to the bulb with the help of a pipette so, that the tube and half or the greater part of the bulb are topped off. C inch the viscometer vertically. Using the pipette pump, suck up the water until it transcends the upper imprint and permits it to stream under its weight. The flow of water is noted. After taking at least 3 to 4 readings, remove the water from the viscometer and dry it. Introduce the same volume of bio-lube in a bulb and measure the flow of bio-lube as before. Take at least 3 to 4 readings and find the mean of it. Now, using density, measured by relative density bottle, note the viscosities for calculating the viscosity index.

The viscosity index (VI) is a dimensionless number that is used to portray the viscosity temperature behaviour of lubricants. The viscosity and temperature of a bio-lubricant are inversely related. The higher viscosity index indicates more stability which means that the velocity will remain more stable over temperature fluctuations. Higher viscosity index is favourable for the lubricant. It is determined from the viscosities of bio-lube at 40°C and 100°C. The calculation is done according to ASTM D 2270-74 by using the formula given as equation (5) (Shankar *et al*., 2021; Owuna *et al*., 2020).

$$VI = 100 \frac{L-U}{L-H} \quad (5)$$

where;

VI = viscosity index; U = kinematic viscosity of the oil at 40°C; L = kinematic viscosities at 40°C of oil of 0 VI at 100°C and H = kinematic viscosities at 40°C of oil of 100 VI at 100°C.

Pour point. The pour point is the minimum temperature at which any lubricant terminates to flow when cool under endorsed conditions. It is an important flow property and an indicator of a lubricant's ability to flow at lower temperatures. For this research, a pour point test was conducted according to ASTM D97-05. The lubricant is added to a container and pre-warmed. A cooling stage trails with the goal that lubricant will be at a temperature of 9°C over its normal pour point. The sample is then examined at every 3°C stretch. The investigation appears as eliminating the vessel from the mechanical cooling assembly and inclining it to check whether there is any surface movement from the lubricant. The point at which the lubricant stops flowing is the pour point and 3°C is added to that point. The pour point test gives an approximate value of the pour point as it relies on human expertise.

Percentage free fatty acid (% FFA). It is the percentage by weight of specified fatty acid in the oil. It will be calculated by titration. one gram of bio-lube was weighed and added into a conical flask, isopropyl alcohol 25 ml with 10 drops phenolphthalein as an indicator was also added. Titration was accomplished by 0.1N solution of NaOH until the greenish colour remains for at least 25 sec. The free fatty acid value and % FFA are calculated by using the shown in equation (6) (Yadav *et al*., 2021; Owuna *et al*., 2020).

$$\% \text{ FFA} = \frac{(\text{mL of titrant})(\text{Normality of NaOH})+282}{(\text{Weight of sample})} \times 100 \quad ... (6)$$

The value of % FFA should be less than one because if it is greater than 1, then soap formation will occur, which will have the worst impact on the production of bio-lubricant.

Flash point. It is used in determining bio-lubricant volatility, storage conditions and transportation requirements. If the bio-lube would have a flash point that failed to achieve 38°C, then there would be the requirements of proper precautions and handling with safety is mandatory. Thus, the hazards caused by the flammability of lubricants are characterized by the flash point. It can also be used to detect potential product contamination. Pensky Marten will measure flash points of bio-lubricant closed cup apparatus as per ASTM D 93-18. A lubricant having a lower flash point will be having more contaminants of volatile materials.

Results and Discussion

The compensations of using non-edible oils as bio-lubricants (derived from non-edible oils over mineral oil-based lubricants) are easy accessibility in nature, renewability and biodegradability. This experiment is focused on the use of neem oil with a high amount of free fatty acid. The existing study is focused on the use of non-edible neem oil, rich in free fatty acids. The properties of neem oil obtained from the experimental studies are characterized. These properties of neem oil are competitive with conventional lubricating fluids. It was observed that the density of neem oil is 926 Kg/m^3, which is higher as compared to the densities of light-duty automotive oil SAE 30 and heavy duty automotive oil SAE 40, which are 895 and 889 Kg/m^3. It shows that neem oil can serve as a better option as shown in Fig.4 (Kareemullah *et al*., 2021; Y. Singh *et al*., 2021).

The pour point is the temperature beneath which oil loses its flow characteristics. It is a crucial flow property that indicates the oil's flow ability at low temperatures as shown in Fig. 5. As indicated by a typical general guideline for the choice of oils, the pour point ought to be, in any event 10°C (50°F) lower than the encompassing temperature. Neem oil possesses a poor value of 23°C, which will make it unfeasible for cold regions. Therefore, the pour point of neem oil should be lower by using additives, otherwise, it will limit the usage of neem oil only in temperate regions (Bhan *et al*., 2020; Sathishkumar and Rajmohan, 2020).

Flash point is significant as it determines the volatility of lube. The lower flash point is suspected of having been contaminated with the volatile product. The

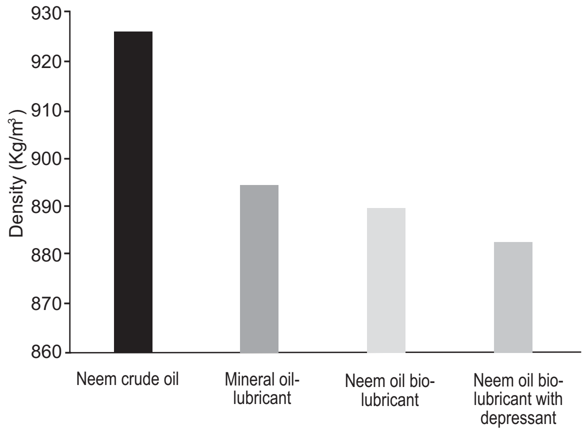

Fig. 4. Density comparison between neem crude oil and different lubricants.

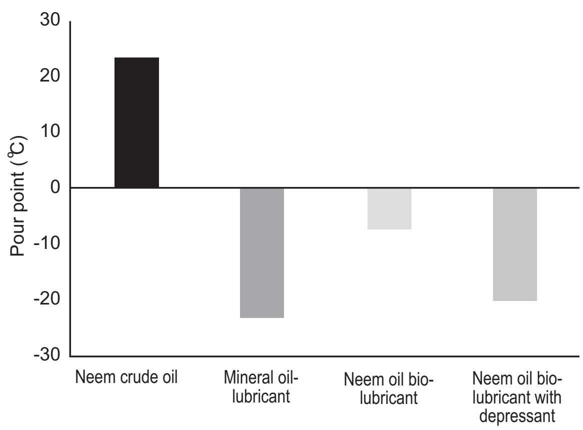

Fig. 5. Pour point comparison between neem crude oil and different lubricants.

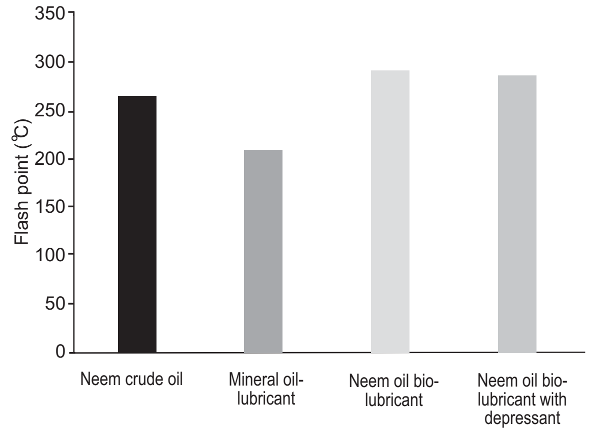

Fig. 6. Flash point comparison between neem crude oil and different lubricants.

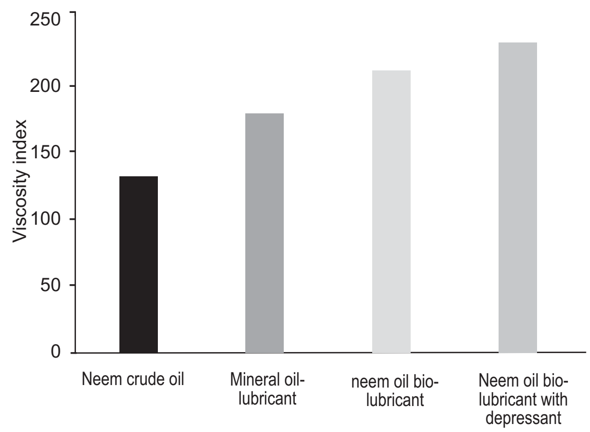

Fig. 7. Viscosity index comparison between neem crude oil and different lubricants.

flashpoint of neem oil is 263°C which fits well as required by standard lubricant specification producers as present in Fig. 6. From the literature survey, the flash points of SAE 30 and 40 were found to be 243°C and 260°C respectively. It clearly shows that the flash point of neem oil falls within the recommended range (Mahara and Singh, 2020; Chebattina *et al*., 2018).

Figure 7, shows the viscosity index value of neem oil is 131 which is a highly recommended lubricant value. Therefore, it is expected that this factor would make neem oil more stable to handle varying operational temperatures, which means the change of viscosity would be small to the influence of temperature (Yadav *et al*., 2021; Mahara and Singh, 2020; Idris *et al*., 2018).

After performing esterification and trans-esterification reactions on neem oil, the properties of bio-lubricant were determined. It is clearly shown that the density of the bio-lubricant was found to be decreased, whereas the viscosity index and flash point were increased. The pour point was also reduced, but this temperature is still not compatible to withstand cold regions. To reduce the pour point further, it is advised to use a pour point depressant.

The properties of neem oil bio-lubricant were compared to the properties of mineral oil-lubricant to ensure that the bio-lubricant can be used as an alternative to the mineral oil-lubricant. The results showed that neem oil bio-lubricant possesses more improved properties like lower density, higher flash point and viscosity index than the mineral oil-lubricant. Still, the pour point was much lower, which makes its usage unfavourable in cold regions. Reduce pour point further and it is advised to use any additive or pour point depressant (Yadav *et al*., 2021; Olufemi and Essien, 2020)

To further reduce the pour point, synthesized bio-lube was blended with a 2% pour point depressant. After the literature survey and some more research on pour point depressants, ACI402 was selected as cost effective and offered a very low pour point (Kareemullah *et al*., 2021; Yadav *et al*., 2021; Olufemi and Essien, 2020). Other properties are also better, as shown in Table 1.

Pour point depressant significantly affects the properties of bio-lubricant as it improves the viscosity index from 212 to 231. The flash point and density were slightly reduced but the pour point was significantly reduced from -7 to -20 °C, comparable with the pour point of mineral lube. These results suggest that the properties of bio-lube are adequate to permit their use in extremely cold areas (Kareemullah *et al*., 2021; Sharma *et al*., 2017).

Table 1. Properties of pour point depressant ACI402

Properties	ACI402
Density (Kg/m^3)	860-900
Pour point (°C)	-33
Flash point (°C)	181
Viscosity index (VI)	212-231

Being eco-friendly makes the usage of neem oil bio-lubricant more significant. Hence, neem oil-based bio-lubricant can serve as an alternative to mineral oil-based bio-lubricant. Because of its lubricant properties, it offers a higher flash point and low pour point, higher viscosity index and low density. The deviation between neem oil-lubricant with and without dispersant for density was 0.79%, pour point -65%, flash point 2.45% and viscosity index -8.22%. It makes it effective in hot and cold regions and its viscosity would remain stable over a wide range of temperatures (Kareemullah *et al*., 2021; Sathishkumar and Rajmohan, 2020; Alang *et al*., 2018; Idris *et al*., 2018; Sharma *et al*., 2017).

Conclusion

This study has successfully prepared bio-lubricant from neem oil using trans-esterification of esters. The properties of the neem oil bio-lubricant were analyzed and compared with mineral oil-based lubricant. The neem oil bio-lubricant produced using alcohol has the potential to replace mineral oil-based lubricants. Neem oil- lubricant was found to have a high flash point than the mineral oil based lubricant, making it suitable to with stand high temperatures. The pour point of neem oil bio-lubricant was found to be higher than mineral oil-based lubricants. After the addition of the pour point depressant, the pour point of neem oil bio-lubricant came close to mineral oil-lubricant. Neem oil bio-lubricant was found to have a much higher viscosity index, Therefore, it can provide better stability over a wide temperature range. The recommendations empower better empathy and improve the outcomes acquired from such experimentations. Freshly extracted neem oil should be used to produce bio-lubricant, as the aged oil has effects on the product's properties, which decreases the quality and efficiency of the bio-lubricant. Additives can be used to increase further the lubricity and viscosity index of the bio-lubricant. FFA content of the oil can be reduced below 1% for better outputs. The lower the FFA content, the higher the quality and the yield of the product, as soap formation reduces.

Conflict of Interest. The authors declare that they have no conflict of interest.

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