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Manufacturing of Pongamia Oil based Bio-lubricant for Machining Application

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Abstract – Global Bio-Lubricants Market size was valued at USD 2.33 Billion in 2016 and is projected to reach USD 3.36 Billion by 2022, at a CAGR of 6.4% during the forecast period. Bio-lubricants are environmentally friendly. But no industry focuses on the use of these bio lubricants as it is unable to use at high temperature application because, it losses viscosity during operation. Many researchers have used edible oils as bio lubricants which creates a huge gap between supply and demand or even bio fuels but there was lack of research work on the use of non-edible oils which are abundantly available in India to manufacture bio- lubricants and use them in the machining operation. The main objective of this project is to synthesise pongamia oil-based bio lubricant for machining operation.

The raw pongamia oil was procured from biodiesel lab at RVCE, the flash and fire point were tested using Cleveland (open cup) flash and fire point apparatus. It was found to be 254 ^{0}C and 267 ^{0}C. Viscosity was 45x10^{-6} m^2/s was measured using Say bolt viscometer, it was chemically modified through the process of epoxidation to suit it to the lubricant properties and the flash and fire point was 170 ^{0}C and 172 ^{0}C. Viscosity was 50x10^{-6} m^2/s. It was compared with mineral oil whose flash and fire point were 160 ^{0}C and 165 ^{0}C, Viscosity was 38x10^{-6} m^2/s. The epoxidation process was monitored by FTIR. The modified oil was used on the mild steel specimen for turning operation using L27 orthogonal array with 3 levels and 4 factors of depth of cut, feed rate and spindle speed, cutting force and surface roughness were measured and it was compared with the responses when mineral oil and machining without oil was done.

Through bromination liberation method it was found that the percentage epoxidation was found out to be 71.5 %. The viscosity of the epoxidized pongamia oil increased when compared to mineral oil. The formation of epoxy groups in the epoxidized pongamia oil is indicated by a double bond at 800 cm^{-1} and 1200 cm^{-1}. The optimum parameters for cutting force was found to be, when pongamia oil was used at 1.5 mm depth of cut, 0.15 mm feed rate and 360 rpm being the spindle speed and for surface roughness were, when pongamia was used at 0.5 mm depth of cut, 0.14 mm feed rate and 900 rpm being the spindle speed. Hence, the use of pongamia oil-based cutting fluids must be adopted by the industries for machining as it suits the lubricant properties and also because of its availability, renewability, affordability and biodegradability.

Key Words: Pongamia oil, Epoxidation, Machining, Design of experiments.

1. INTRODUCTION

Vegetable oils are triglycerides in which C18 carboxylic acids are dominant. Some of the fatty acids derived from these glycerides are unsaturated; those typically contain stearic oleic, linoleic, and linolenic acids in varying amounts. Trees of these are unsaturated acids, namely, oleic, linoleic, and linolenic. The use of edible vegetable oil to produce lubricants and cutting fluids is not feasible in view of the big gap in demand and supply of such oil. Hence, nonedible vegetable oils are finding importance due to their abundance and also, this would save large quantities of edible oils which are in great demand. The forecast for eco-friendly lubricants for next 10–15 years is a worldwide volume share of approximately 15% and in some regions up to 30%.

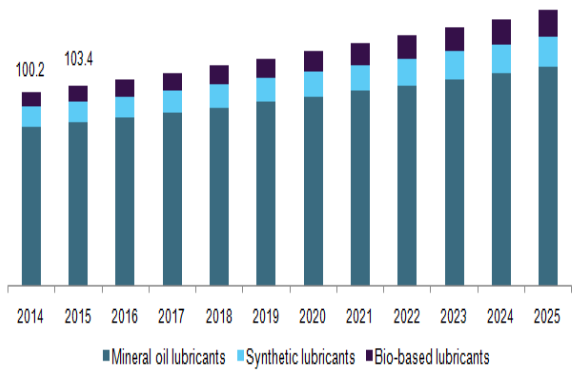


Fig 1: Global growth of bio-lubricants

Major share of cutting fluids being used across the globe are petroleum-based oils. Enormous use of petroleum-based oils has had a lot of negative environmental and health-related consequences like skin diseases. Petroleum-based lubricants from 2016 have increased tremendously on high global consumption, showing at least 1% annual increments with 13,726 million tons of oil equivalent. Vegetable oil-based cutting fluids are highly biodegradable, eco- friendly, renewable, less toxic, high flash point, low volatility, high viscosity index, wide production possibilities, and economical in the waste management. Vegetable oils primarily consist of triglycerides; the triglycerol structure of vegetable oil makes it a strong competitor as a base stock for lubricants and functional fluids. Thus, the use of these oils should be promoted.

2. PRINCIPLES OF EPOXIDATION

Epoxidation is the chemical reaction which converts the carbon–carbon double bond into oxiranes (epoxides), using a variety of reagents including air oxidation, hypochlorous acid, hydrogen peroxide, and organic peracid. An epoxide is a cyclic ether with a three-atom ring. This ring approximates an equilateral triangle, which makes it strained, and hence highly reactive, more so than other ethers. They are produced on a large scale for many applications. In general, low molecular weight epoxides are colorless and nonpolar, and often volatile.

Non edible oils depend mainly on the properties of the various fatty acids and fats although some triglycerides are used as lubricants for industrial applications. The properties of these oils mainly depend on unsaturated fatty acids and any changes in the properties have to be carried out it can happen only at these double bonds.

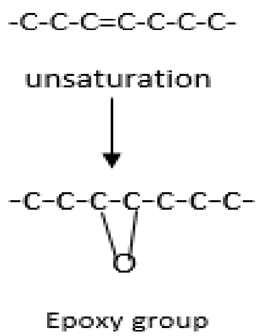


Fig 2: Representation of epoxidation

3. PROPERTIES AND FUNCTIONS OF LUBRICANT FOR MACHINING

- A high boiling point and low freezing point (in order to stay liquid within a wide range of temperature)
- should have low viscosity to permit free flow of the liquid
- Thermal stability
- Hydraulic stability
- A high resistance to oxidation
- It should have high specific heat, high heat conductivity and high heat transfer coefficient.
- It should be non-corrosive to work and machine.
- It should be non-toxic to operating person.
- It should be odorless.
- It should stable in use and storage.
- It should be safe.
- It should permit clear view of the work operation.

4. CHEMICAL COMPOSITION OF PONGAMIA OIL

Fatty Acid	Percentage
Palmitic	3.7%- 7.9%
Stearic	2.4%-8.9%
Oleic	44.5%-71.3%
Linoleic	10.8%-18.3%
Linolenic	2.60%
Archidic	2.2%-4.7%
Eicosenoic	9.5%-12.4%
Behenic	4.2%-5.3%
Lignoceric	1.1%-3.5%

Table 1: composition of acids of pongamia oil

Molecular weight of Pongamia Oil- 418
Molecular formula – $C_{26}H_{26}O_5$

5. DESIGN OF EXPERIMENTS

A systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output. Robust design is an engineering methodology for obtaining product and process conditions, which are minimally sensitive to the various causes of variation to produce high-quality products with low development and manufacturing costs. Taguchi's parameter design is an important tool for robust design. It offers a simple and systematic approach to optimize design for performance, quality and cost. Two major tools used in robust design are:

- signal to noise ratio, which measures quality with emphasis on variation, and
- orthogonal arrays, which accommodate many design factors simultaneously.

6. OBJECTIVES

The Main objective of this project, is chemically modifying the raw pongamia oil to suit it to the lubricant properties through epoxidation process and evaluate the influence and applicability of vegetable oil-based metal working fluids in turning machining operation with respect to mineral oil based cutting fluid and compare the performance parameters in terms of surface finish and cutting force on the specimen.

- Manufactured a pongamia oil-based bio lubricant for machining application.
- Studied the influence of pongamia oil-based metal working fluids in machining.
- Analyzed the performance parameters in terms of surface finish and cutting force on the work piece with mineral oil-based cutting fluids.

6.1 METHODOLOGY

- Literature survey was done on Vegetable oil-based cutting fluids.
- The advantages and disadvantages of Vegetable oil-based cutting fluids over Mineral oil-based cutting fluids was studied and noted.
- Pongamia Pinnata oil was selected for this project as vegetable oil-based cutting fluid
- It was chemically modified through the process of epoxidation.
- The modified oil was tested to suit it to lubricant properties such as flash point, fire point, viscosity was tested.
- Mild steel was selected as specimen for the Turning process.
- Specimens were loaded on to the lathe machine and turning process was done on the specimen using Mineral oil-based cutting fluid and Vegetable oil i.e. pongamia Oil.
- Surface roughness Ra and cutting force were measured using Mitutoyo Surf test SJ-210 surface roughness tester and cutting tool dynamometer.

7. EPOXIDATION OF PONGAMIA OIL

Pongamia oil was procured and epoxidation was done as follows.

Chemicals used	Function
Acetic acid	Give peroxy acetic acid
conc. Sulphuric acid	
Hydrogen peroxide	
Sodium sulphate	drying agent
Potassium Dichromate (0.1N)	for estimation through titrations
Sodium Thiosulphate (0.1N)	
10% Potassium iodide	
conc. Hydrochloric acid	
Starch	indicator
ethyl alcohol	solvent
Bromate bromide mixture	brominating agent

Table 2: Chemicals required

Initially one liter of oil was taken and mixed with sodium sulphate sufficiently, which will remove all the moisture from the oil. If the sodium sulphate particles settle in the bottom that means no moisture was present in the oil where as if it dissolves then it indicates that moisture was present in the oil. Then oil must be passed through silica gel for complete removing of water. Here particles were settled down which indicated that there was no water present in the oil. Later the oil was filtered using filter paper. Initially 10 ml of oil was taken in the round bottom flask and placed on the magnetic stirrer for continuous stirring. The oil was kept in the cold bath initially. To this cold oil 6 ml of acetic acid for over a period of two minutes was added. And then concentrated sulphuric acid of 2 ml was added over a period of five minutes under continuous stirring when oil kept in cold bath. The above mixture is stirred for twenty minutes. Later hydrogen peroxide which is very volatile and has a low boiling point of 4 ml was added drop by drop over a period of ten minutes under continuous stirring while the oil was kept in cold bath. The above mixture was stirred for ten minutes. The ice bath is removed and the temperature was raised to 60 ^{0}C for six hours under continuous stirring.

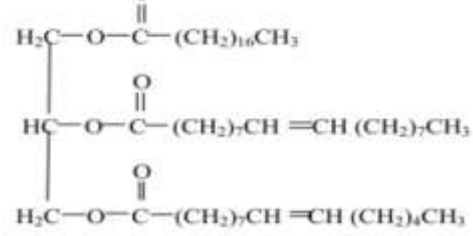


Fig 3: Structure of a triglyceride

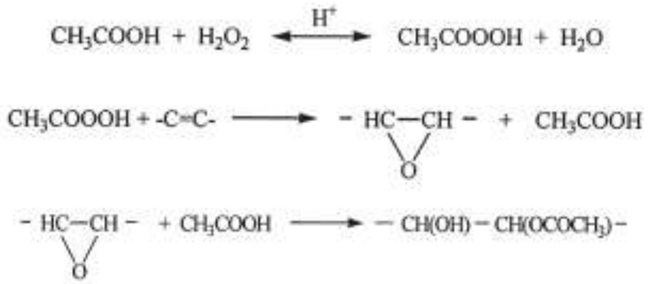


Fig 4: Epoxidation reactions with the of epoxy group

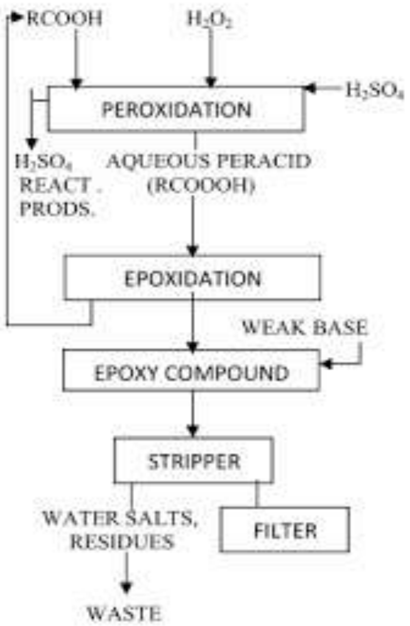
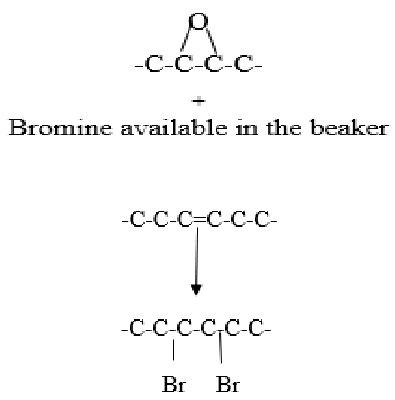


Fig 5: Flowchart of epoxidation process

7.1. Estimation of percentage epoxidation

Once the epoxidation process is done, the percentage epoxidation was calculated by bromine liberation method, which means the amount of bromine reacted or un-reacted in the process derives the percentage epoxidation of the Pongamia oil.



$$Br_2 + 2I^- \longrightarrow 2Br^- + I_2$$

$$Br = I_2$$

8. PROPERTIES OF LUBRICANTS

properties	Pongamia oil (PO)
Viscosity	45 x 10^{-6} m^2/s
Viscosity Index	172
Flash point ^0C	254
Fire point ^0C	267

properties	mineral oil (MO)
Viscosity	38 x 10^{-6} m^2/s
Viscosity Index	135
Flash point ^0C	160
Fire point ^0C	165

properties	Epoxy Pongamia oil (EPO)
Viscosity	50 x 10^{-6} m^2/s
Viscosity Index	195
Flash point ^0C	170
Fire point ^0C	172

9. INFLUENCE OF EPOXIDIZED PONGAMIA OIL ON MACHINING PARAMETERS.

Mild steel rod of length 40 cm and diameter 25 mm.

Elements	% composition
Si	0.131
Mn	0.3042
Ni	0.0071
C	0.057
Sn	0.005
Co	0.0013
Al	0.0257
Cu	0.0029
P	0.0144
Mo	0.0007
Fe	Bal

Machine	engine lathe
Operation	turning
work piece material	mild steel rod
Dimension	length - 30 cm, Dia- 25 mm
Process Parameters	
Spindle speed (rpm)	360, 520 and 900
Feed (mm/rev)	0.14, 0.15 and 0.16
depth of cut (mm)	0.5, 1.0 and 1.5
Cutting tool	
Tool holder	High speed steel (HSS)
Material	Carbide cutting tool
Cutting Fluids	without oil (WO)
	Epoxy Pongamia oil (EPO)
	Mineral oil (MO)

Table 3: Machining conditions

The next nine experiments were using chemically modified Pongamia oil with the same depth of cuts, feed rates, spindle speeds with different combinations and the corresponding cutting force and surface roughness was measured. The next nine experiments using the commercialized cutting fluids those are normally used in the manufacturing industries. But here the cutting fluid that is used in the lab was used for the comparison of machining parameters. Here again nine experiments were done with different speeds, depth of cuts, feed rates and corresponding cutting force and surface roughness was measured. The turning parameters evaluated were cutting speed, feed rate and depth of cut. An orthogonal array, signal-to-noise (S/N) ratio were employed to analyze the effect of these parameters. The analysis gives optimal combination for cutting force and surface roughness. The study showed that the Taguchi method was suitable to solve the stated problem with minimum number of trials as compared with a full factorial design. The entire set of machining operations were compared using design of experiments using Taguchi's design which is L27 array as this is a three level and four factors factorial design, and accordingly the total number of experiments to be conducted were 81 set of experiments as it is 3^4 design which accounts to be a total eighty-one experiments. Here in this project these eighty-one experiments were reduced to twenty seven experiments with different 0.5, 1, 1.5 mm as depth of cuts, 0.14, 0.15, 0.16 mm as the feed rates and 360, 520, 900 rpm as the spindle speeds these were the inputs and corresponding cutting force and surface roughness were measured as the output and this was evaluated using MINITAB software for finding the optimum parameters for turning and the results are tabulate.

Factors	levels		
Cutting fluids	MO (mineral oil)	EPO (epoxidized Pongamia oil)	WO (without oil)
Depth of cut (mm)	0.5	1	1.5
Feed rate (mm)	0.14	0.15	0.16
spindle speed (rpm)	360	520	900

Table 4: Factors and levels used in experiment

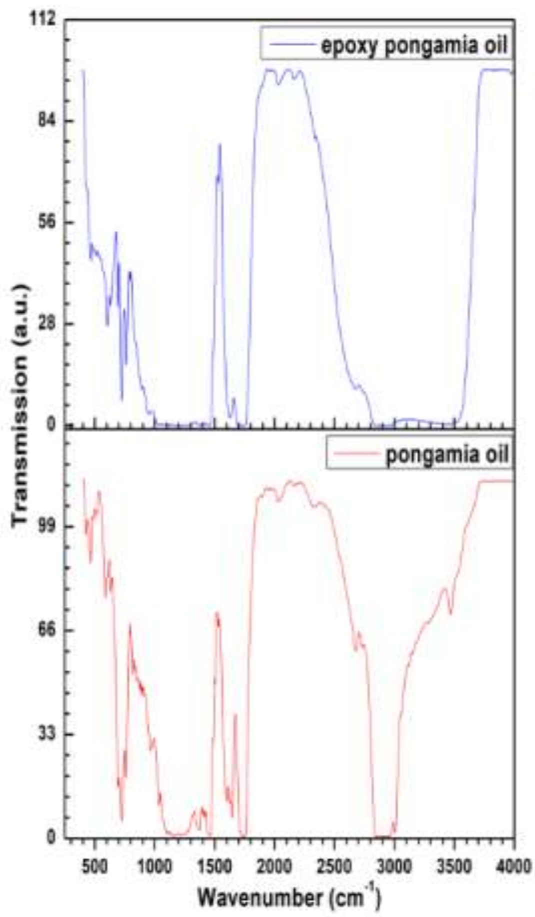


Fig 6: FTIR of Pongamia oil and epoxy Pongamia oil.

The first nine experiments were of normal mineral oil with three depth of cuts, spindle speed and feed rates, the same was repeated for next nine experiments with epoxidized Pongamia oil and the last nine experiments were without lubricant and the corresponding surface roughness and cutting force were measured.

Using the Minitab software, the table values were plotted to get to know the optimum turning parameters. Using Taguchi's design of experiments, L27 orthogonal array the optimum parameters were found. Here there were 4 factors and 3 levels and thus a total of 81 experiments involve in this experiment and was reduced to 27 experiments and the optimum parameters were found using Minitab software.

The graphs plotted were the main effects plot for SN ratios and main effects plot for means for both cutting force and surface roughness. The obtained graphs show one optimum combination of machining parameters which might exist or not in the list of 27 conducted experiments. Its three level and four factors experiment

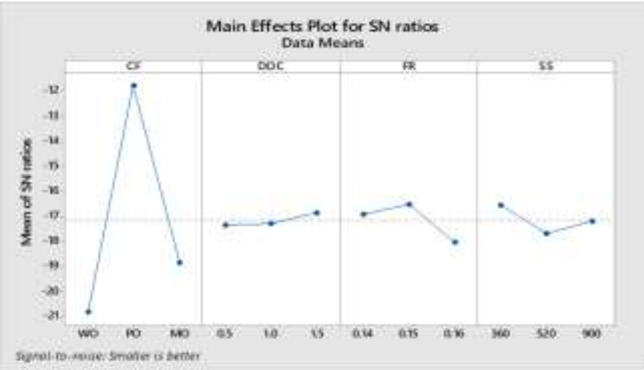


Fig 7: Main effects plot for SN ratios for cutting force

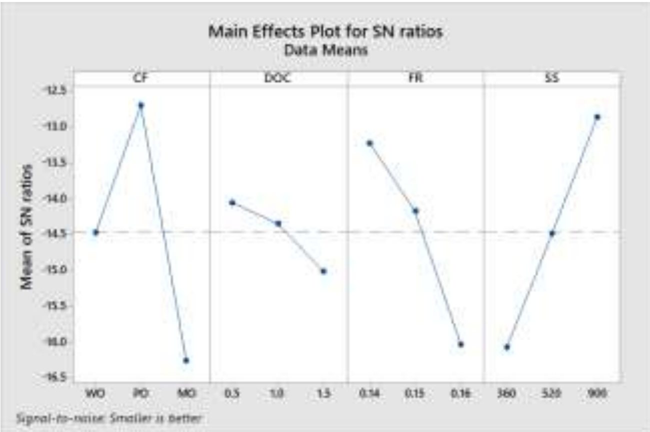


Fig 8: Main effects plot for SN ratios for surface roughness

The optimum parameters for main effects plot for SN ratios for cutting force was found to be, when Pongamia oil was used at 1.5 mm depth of cut, 0.15 mm feed rate and 360 rpm being the spindle speed. The optimum parameters for main effects plot for SN ratios for surface roughness were, when Pongamia was used at 0.5 mm depth of cut, 0.14 mm feed rate and 900 rpm being the spindle speed.

Hence, vegetable oil-based cutting fluids performed well compared to mineral oil with respect to cutting force and surface roughness. The lower cutting forces of vegetable oils can be attributed to better lubricity, higher viscosity index, and better thermal conductivity compared to mineral oils. This was because the modified version has more resistance to molecular breakdown, or a molecular rearrangement at a higher temperature, due to which the presence or absence of oxygen molecules was improved. Previous studies also confirmed that, chemically modified vegetable oil exhibited better lubrication ability and stronger adsorption film onto metallic surface. The better performance with respect to surface roughness was due to the fact that the longer carbon chains of vegetable oil corresponded to a stronger adsorption film which enhanced the surface quality.

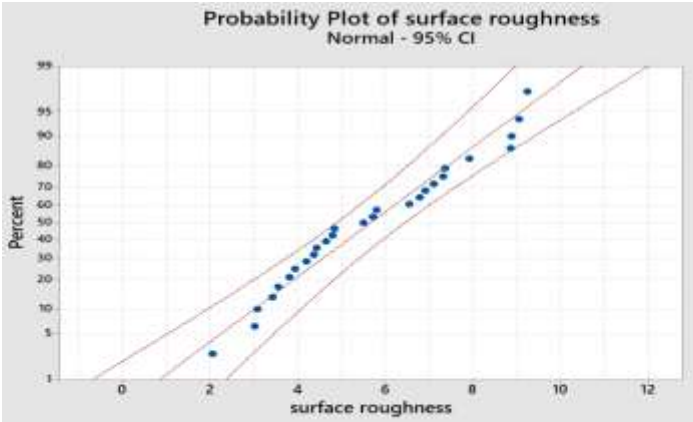


Fig 9: Probability plots for Surface roughness

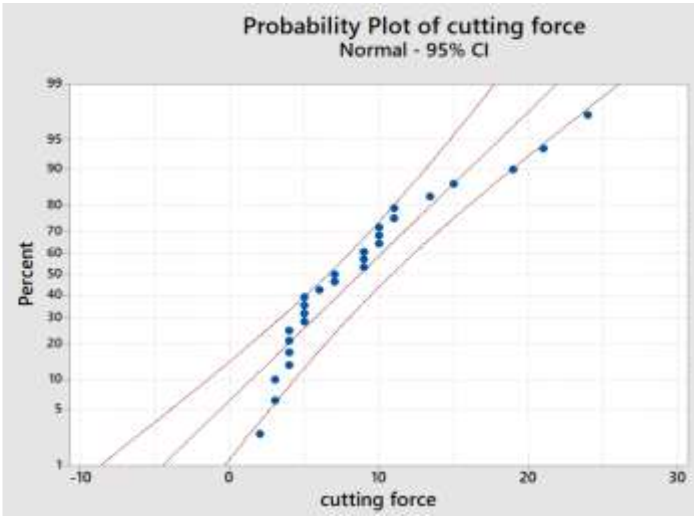


Fig 10: Probability plots for cutting force

10. CONCLUSIONS

In this research work, Pongamia oil was epoxidized successfully using mainly acetic acid, concentrated sulphuric acid and hydrogen peroxide along with the addition of various chemicals at different compositions and temperatures which acts as a bio lubricant for machining application. Their physiochemical properties such as flash point, fire point and viscosity were measured and compared with the commercialized mineral oil and raw Pongamia oil and these values should be considerable to suit it to lubricant properties. Thus, this oil was used in the turning operation of mild steel specimen and the optimal parameters were considered.

- The main reason for considering Pongamia oil is because of its availability, renewability, affordability and biodegradability.
- The percentage of epoxidation was found to be 71.5
- The flash point and the fire point of the epoxidized Pongamia oil were suiting to the properties of the commercialized lubricant with slight increase in the value i.e. flash point 160 ^{0}C to 170 ^{0}C and fire point 165 ^{0}C to 172 ^{0}C which proved to be good as these lubricants must have high boiling point, but the flash and fire point of raw Pongamia oil was more than 200 ^{0}C, whereas the viscosity of the oil increased from 38 x 10^{-6} m^2/s to 50 x 10^{-6} m^2/s which is a disadvantage. Further this must be reduced to suit to lubricant properties.
- The formation of epoxy groups in the epoxidized Pongamia oil is indicated by a double bond at 800 cm^{-1} and 1200 cm^{-1} in the FTIR images.
- The optimum parameters for cutting force was found to be, when Pongamia oil was used at 1.5 mm depth of cut, 0.15 mm feed rate and 360 rpm being the spindle speed and for surface roughness were, when Pongamia was used at 0.5 mm depth of cut, 0.14 mm feed rate and 900 rpm being the spindle speed.
- Thus, in the present work the epoxidation was successful, whereas very few physiochemical properties were tested. The other properties which could be tested were the saponification value, iodine value, density, cloud point, pour point etc. and is recommended for future work.

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