

**DEVELOPMENT OF VEGETABLE OIL BASED NANO
CUTTING FLUID- EXPERIMENTAL STUDY AND
PERFORMANCE EVALUATION.**

A PROJECT REPORT

submitted by

ANURAG P

TKM20MECI03

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in partial fulfillment of the requirements for the award of the Degree

of

Master of Technology

In

Computer Integrated Manufacturing



Department of Mechanical Engineering

TKM College of Engineering

Kollam

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DECLARATION

I, Anurag. P hereby declare that the project report “Development of vegetable oil based nano cutting fluid- Experimental study and performance evaluation.” submitted for partial fulfillment of the requirements for the award of degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of Dr. Krishnakumar T. S., Associate Professor, Department of Mechanical Engineering, TKM College of Engineering, Kollam. This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

Signature:

Name of the Student: **Anurag P.**

Register No: **TKM20MECI03**

Date:

**DEPARTMENT OF MECHANICAL ENGINEERING
TKM COLLEGE OF ENGINEERING, KOLLAM**



CERTIFICATE

This is to certify that the report entitled '**DEVELOPMENT OF VEGETABLE OIL BASED NANO CUTTING FLUID- EXPERIMENTAL STUDY AND PERFORMANCE EVALUATION**' submitted by '**ANURAG P. (TKM20MECI03)**' to the APJ Abdul Kalam Technological University in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Computer Integrated Manufacturing, Mechanical Engineering is a bonafide record of the project work carried out by him under my guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

Guide: **Dr. Krishnakumar T. S.**

Associate Professor

Department of Mechanical Engineering

TKM College of Engineering, Kollam

Dr. Dileep P. N.

Head of the Department,

Department of Mechanical Engineering

TKM College of Engineering, Kollam

PG Coordinator: **Prof. Kannan S.**

Assistant Professor

Department of Mechanical Engineering

TKM College of Engineering, Kollam

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Place: KOLLAM

ANURAG P.

Date

ABSTRACT

Cutting fluids, used in manufacturing process as coolant and lubricant, are currently based on mineral oils which are depleting and non-eco-friendly. A good replacement is vegetable oil-based cutting fluids which are renewable and non-hazardous to environment being biodegradable. Pongamia oil is one such non-edible vegetable oil extracted from Pongamia seeds. Various vegetable based cutting fluids have been formulated from edible oils but less works is reported on non-edible oils. Measured fatty acid profile of Pongamia oil makes it suitable for selecting Pongamia oil. Moreover, less works has been done on the development of POME (Pongamia Oil Methyl Ester) based oil in water emulsion nano cutting fluids. In the present study, raw Pongamia oil is converted to bio diesel (POME) by transesterification process. The developed POME is converted to POME-water emulsion by adding suitable concentration of polysorbate-80 emulsifier. Nano-cutting fluid was formulated by adding aluminium oxide nanoparticles to a trans-esterified Pongamia Oil water emulsion at different volume fraction. Then thermal conductivity, viscosity and corrosive nature of POME and the formulated nano-cutting fluid was studied. Mild steel workpieces with uniform dimensions were machined on a CNC lathe by applying synthetic, POME-water emulsion, 0.1%, 0.3%, 0.5% samples of cutting fluids. The cutting fluid was delivered to the machining zone by a spraying machine. This machined mild steel samples were subjected to surface roughness test under MITUTOYO SJ-410 surface testing machine. Then the measured surface roughness values were used for evaluating the performance of different cutting fluid samples. The thermal conductivity, viscosity, corrosion resistance and surface finish increased with increase in volume concentration of nanoparticles.

Key words: Cutting fluids, Pongamia oil, oil in water emulsion, POME, Transesterification

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ABBREVIATIONS

Al ₂ O ₃	- Aluminum oxide
BF	- Base fluid
CCF	- Commercial cutting fluid
COF	- Coefficient of friction
FAME	- Fatty acid methyl ester
FFA	- Hydrophilic lipophilic balance
IV	- Iodine value
MQL	- Minimum quantity lubrication
ND	- Nano diamond
NF	- Nano fluid
NP	- Nano particles
PV	- Peroxide value
PO	- Pongamia oil
POME	- Pongamia oil methyl ester
SV	- Saponification value
TAN	- Total acid value
WSD	- Wear scar diameter

CHAPTER 1

INTRODUCTION

1.1 CUTTING FLUIDS

Due to ever-increasing demand, the manufacturing industry is currently moving at a rapid speed. During the process of machining, enormously large amount of heat is generated due to friction, which is harmful to both work piece and tool. As a result, it becomes necessary to reduce the amount of heat generated. Hence cooling substances were introduced, starting with ordinary water in the early days. Cutting fluids are a term used to describe a wide range of options available from the nineteenth century to the present day.

Cutting fluids are very important in modern manufacturing industry. Lubricants and coolants are the other common names for them. They provide a cooling impact to reduce negative thermal effects, as well as a lubricating effect to improve surface finish, rust prevention, and flushing of chip in the metalworking process. Given the current rate of use of cutting fluids, which is around 39.4 million Mt (metric ton), the demand for cutting fluids in 2022 will be 43.9 million Mt.

Base oil, emulsifiers, and additives make up the cutting fluid. Cutting fluid aids in reaching the desired surface quality as well as prolonging tool life, resulting in increased production rate and work quality.

Metal shearing occurs during the machining process, resulting in the formation of chips and the conversion of about 99 percent of the external mechanical energy into heat occurs. The primary zone, secondary zone, and tertiary zone, or tool-chip contact region, all generate heat, as detailed below and illustrated in fig. 1.1.

(i) Primary zone or Shear zone

Plastic deformation occurs in the shear zone. This is where the most heat (80-85%) is produced and taken away by chips (nearly all heat generated by plastic deformation). Only a limited amount of heat is transferred from the cutting tool to the workpiece. Thus, the hottest part of metal machining is the chip

(ii) Secondary zone or Tool- Work interface zone

Friction between the tool's flank face and the work piece causes heat development in the secondary zone, (1-3 percent of the heat generated). Due to increased tool wear, the temperature in this zone rises over time.

(iii) Tertiary zone or Tool-Chip interface

Heat is generated at the chip-tool contact due to friction between moving chips and the tool rake face. Secondary plastic deformation is also happened to the chip. In this area, about 15% of the heat is generated.

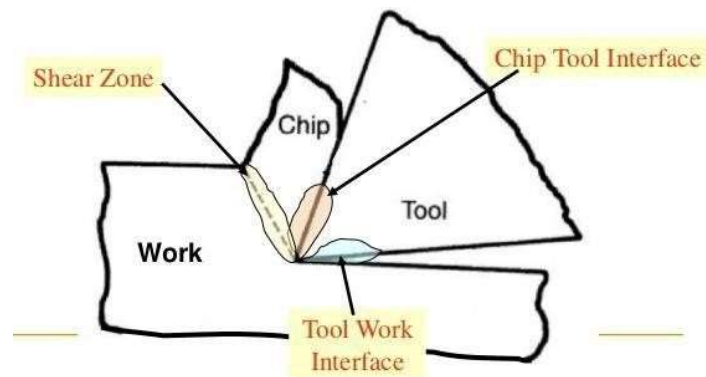


Fig. 1.1 Zone of heat generation [2]

This high temperature spreads over the cutting tool, causing negative effects such as work piece dimensional deformation, tool loss of hot hardness, increased tool wear which leads to premature tool failure, and loss of surface integrity [1]. Cutting fluids keep the temperature of the tool and the work piece in check by providing proper cooling and lubrication.

1.1.1 Properties of Cutting Fluid

Cutting fluids are widely used in machining operations to:

- Cool the cutting zone, thereby reducing work piece temperature, distortion, and improving tool life.
- Lowers friction and wear, thereby improving tool life and surface finish
- Prevent corrosion of the work, the tool, and the machine
- Reduce energy consumption
- Wash away chips
- Provides protection the newly machined surfaces from environmental attacks

The features that good cutting fluids must have in order to perform their intended purpose are as follows:

- An excellent cutting fluid is distinguished by its high thermal conductivity and large specific heat capacity.
- It should be non-corrosive, non-toxic, and non-react with the material of the workpiece and tool.
- It should be readily available and reasonably priced.
- It should have high flash point in order to maintain constant properties.
- It must be physically and chemically stable.
- It should not cause skin irritation or contamination.
- It should not develop a disagreeable odor with extended usage.
- It must not produce a sticky or solid precipitate at normal working temperatures.

1.1.2 Types of Cutting Fluid

Cutting Fluids are mainly classified into 3 types:

(i) Oil based

Mineral, animal, and vegetable oils are the sources of an oil-based cutting fluid. They are often referred to as Straight or Neat oils. Without water, they are mineral or petroleum oils. Mineral oils (petroleum-based) are the predominant variety, due to their desired lubricating properties. These cutting fluids are utilized in processes that call for a strong lubricating characteristic and typically incorporate various additives to improve their uses. These are employed in gear cutting, threading, broaching, and other processes.

(ii) Aqueous based

The aqueous-based products come in concentrated form and must be diluted with water to the required concentration before use. Emulsions and Soluble Oils are the two classifications of Aqueous based cutting fluid. The "emulsifiable" type of this aqueous-based product creates an emulsion when combined with water, while the "soluble" version forms a solution. In high-speed machining processes including milling, turning, and grinding, soluble oils are frequently employed. Mineral oils are absent in Synthetic cutting fluids, which is formed by combining chemicals and additives diluted in water. They can be easily removed from the workpiece surface because of its reduced stickiness. High cooling capacity, lubricity, corrosion resistance, and simple maintenance are the features of these fluids. Semi Synthetic oil is a chemical emulsion made of mineral oil that has been diluted with water and given additives, making it a more effective lubricant by decreasing the size of the oil particles. They offer excellent lubricity, corrosion resistance and bacterial protection [5]. These fluids produce less smoke and oil mist, offer greater control over rancidity and bacterial growth.

(iii) Gas based

The term “gas-based lubricants” often to the chemical substances that are in gaseous form at normal temperature and are regarded as ecologically beneficial cutting fluid. Air, Argon helium, Nitrogen, or Carbon dioxide are examples of gas-based lubricants.

1.1.3 Methods of application of Cutting Fluid

1. Manual application

Applying the cutting fluid manually by the operator himself. This method of application is not acceptable in job shop settings, and is only applicable for those operations where the cutting speeds are relatively low and friction is an issue. Cuttings fluids are employed as lubricants in these cases.

2. Conventional flood cooling

Traditional method of cooling and lubricating the cutting zone is by conventional flood cooling. The flow rate for conventional flood cooling is different in different cases, i.e., for single point cutting tools, the flow rate is 10 l/min and 225 l/min per cutter for multiple tooth cutters, like those used in milling. Fluids are supplied to the cutting zone at a pressure in the range of 700-14000 kPa, to flush away the chips, in operations like drilling, end milling etc.

3. Minimum quantity lubrication (MQL)

Minimum quantity lubrication is one of the most popular strategies used in nowadays for cutting fluid purposes since it can produce good outcomes with least consumption of resource, both power and cutting fluid consumption. The typical flow rate of cutting fluid in MQL technique is in the range of 50-500 ml/hr., which is directly applied to the cutting zone. This method is free of fluid disposal issues when compared to conventional flood type cooling, since it needs only small amount of fluid for machining process.

As this method consumes only little amount of cutting fluid, it is also known by the names like “near dry machining”, “micro lubrication”, “spatter lubrication”.

4. High pressure system

High pressure system increases the effectiveness of the machining process by allowing the cutting fluid to enter the tool chip and tool work contact area more effectively. This reduces friction and eliminates heat from the cutting zone,

5. Mist cooling technique

Water based cutting fluids are mainly used in mist cooling. A high-speed mist of cutting fluids is applied by the pressurized air stream. Effective cooling will result from the evaporation of the liquid droplets suspended in the air. When compared to flood type cooling, this technique provides better visibility of the region being machined and also provides fluids to the regions which are difficult to reach.

1.1.4 Drawbacks of conventional Cutting Fluid

Even though mineral oils are somewhat less expensive, they suffer from the limitations like poor performance results from oxidative instability, viscosity fall at high temperature, low temperature solidification, and propensity to blow up when exposed to oxidizing agents. The environmental aspects of machining have recently been a growing issue because of the hazardous effect of cutting fluids. Cutting fluids have a negative impact of environment and brings permanent changes since they are toxic [6]. Along with that the toxicity of the cutting fluid increases with time upon storage.

Majority of the additives are hazardous to both human s and environment [7]. They pose a serious risk to the employees with whom they come in direct contact and to those who are in close proximity to their application [8]. Cutting fluids which contains chloroparaffin additives

are no longer allowed to be used because, under excess pressure, chloroparaffin transforms to dioxin, which can cause chlorine acne. Also, chlorinated cutting fluids are only allowed to be burned in designated incineration sites because they release harmful dioxins that might cause uncontrolled burning. As a result, it is classified as a hazardous waste for both environment and human life. Cutting fluids with chlorine additives should not be used in machining titanium alloys because they may result in corrosion. Cutting fluids can produce mist, fumes, smoke and odors, especially those containing chemical additives like Sulphur, chlorine, phosphorous, hydrocarbons and biocides, can cause respiratory problems as well as allergic conditions to skin and eyes.

Cutting fluids made from mineral oils are highly dangerous to environment and can also cause cancer. Many environmental organizations classify them into hazardous trash. They also contribute to a number of technological as well as environmental issues and also some major issues such as genetic and dermatological conditions, lung cancer, and respiratory illness [9].

Workers death brought on by the harmful effects of the cutting fluids was also reported. Mineral based cutting fluids that are improperly disposed of, have a negative impact on environment. Mineral oil-based cutting fluid must undergo a particular physical or chemical treatment to eliminate the harmful components before disposal since they are hazardous when disposed of.

There is a rising need for biodegradable products as a result of safety restrictions and rapidly expanding environmental concerns. Because of the higher intrinsic biodegradability and reduced toxicity, bio based cutting fluids have the potential to lower the waste treatment cost while also posing fewer occupational health concerns than cutting fluids made from petroleum oil. Clean and healthier working conditions and less mist in the air are the results. The promotion of sustainable energy policies that enhance economic growth and environmental preservation was the primary goal of the World Energy Outlook 2015.

1.2 VEGETABLE OILS

Triglycerides, which are long fatty acids with many unsaturated double bonds, are the majority of the vegetable oils. An average of 4 to 12 distinct fatty acids can be found in most vegetable oils [1]. Vegetable oils have a greater flash point than mineral oils, which lowers the risk of fire and smoke generation. Vegetable oils have high viscosity, which affects how effectively they can be machined. As the vegetable oils have high viscosity index, the viscosity drop with increase in temperature is much slower when compared to mineral oils. Vegetable oils are more pliable than mineral oils as the temperature drops, causing easy drainage from chips and workpiece.

High viscosity in the vegetable oil ensures more stable lubricity [11]. When compared to mineral oils, the molecules of the vegetable oils are very uniform in size, which results in less fluctuations in their qualities depending on the physical conditions. Because of the heavier molecular weight and higher boiling point, vegetable oils have less evaporation and misting. Cutting fluids made from vegetable oils are highly biodegradable, environmentally benign, less hazardous, renewable, have a high flash point, low volatility, and high viscosity index, as well as numerous production options and cost-effective waste management [12].

Triglyceride composition of vegetable oil offers advantageous lubricating properties. It is because of their polar and long fatty acid chains, which interact with metallic surfaces to generate high strength lubricant and lowers wear and friction. Polarity of the fatty acids creates oriented molecular film, which gave them their oiliness and wear resisting qualities. Thus, it is thought that fatty acids are essential components for lubricity [13]. Glycerol and fatty acids make up the molecules of the vegetable oil. The structure of the vegetable oil is shown in the figure (fig. 1.2) given below.

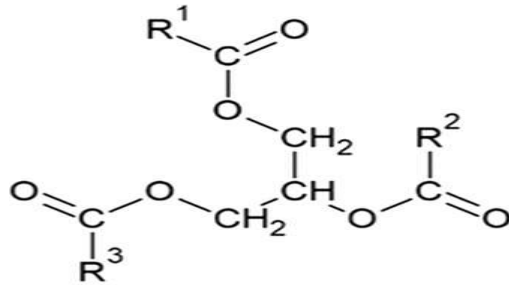


Fig. 1.2 Structure of Vegetable Oil [12]

Research on vegetable oil-based cutting fluids has revealed that these fluids significantly outperform traditional mineral oil-based cutting fluids in terms of reduced surface roughness, lowers cutting forces, reduced tool wear, and increased tool life [1]. In this study, it is suggested that vegetable based Pongamia oil can be utilized as cutting oil for machining processes rather than mineral oils because it is more readily available, less expensive and biodegradable. Higher lubricity and viscosity index, quick biodegradability, and a high flash point are the further advantages of employing non edible oils as an alternative to mineral oil for lubrication.

1.2.1 Pongamia Oil

Pongamia oil is derived from the seeds of *Pongamiapinnata* tree, which is a non-edible oil [13]. It is a thick yellow or reddish-brown oil with a calorific value of 40.756 MJ/kg, which is extracted using several methods such as solvent extraction, expeller pressing etc. The oil is non edible, acerbic in taste and is obnoxious to the scent. Vegetable oils that cannot be used for edible purpose have a triglyceride structure and are linked to various fatty acid chains, creating a complicated fatty acid structure inside a single molecule. Cutting fluids derived non edible

oils are biodegradable, non-toxic, and renewable. They offer good lubricity and cooling, so they can be used as an alternative to the commonly used cutting fluids [1].



Fig. 1.3 Pongamia Oil

Because of the presence of higher esters, Pongamia oil has higher viscosity and improved lubricity. Pongamia oil is suitable for lubrication since it contains a higher percentage of oleic acid fatty acid composition. The high acid value of the above-mentioned oil will significantly improve the corrosive wear and shorten service life in applications [15]. The total acid number (TAN) of vegetable oils can be successfully decreased by transesterification, a chemical modification process, used to produce methyl esters of vegetable oils [16]. The formation of Pongamia oil methyl ester (POME) based oil in water emulsion nano cutting fluid requires more research works.

The property comparison table of both mineral oil and vegetable oil is shown in table 1.1

Table 1.1 Properties of vegetable oils and mineral oils.

PROPERTIES	VEGETABLE OILS	MINERAL OILS
Density	High	Low
Oxidative stability	Fair	Fair
Flash point	High	Low
Pour point	-22 to 12 degree	-15
Biodegradability	80-100%	10-30%
Cold flow behavior	Poor	Fair
Sliding tendency	Poor	Good

1.3 EMULSION

Emulsions are either water suspended in oil (w/o) or oil suspended in water (o/w). Emulsifiers are required stop the suspended droplets from congealing and dissolving the emulsion. They also improve the product stability to achieve a satisfactory shelf life.

Emulsifiers have a hydrophilic (water loving or polar) head group and a hydrophobic (oil loving or non-polar) tail. Hence, emulsifiers are drawn to both polar and non-polar molecules. Emulsifiers surround the oil droplet when they are added to an oil in water emulsion, with their polar head groups towards the water and their non polar tails extending into the oil [18].

The emulsifier's orientation is reversed for the water in oil emulsion: polar head group points into the water droplet while non polar tails stretch outwards into the oil phase. Emulsifiers

stabilize the droplets and stop them from coalescing by reducing the interfacial tension between water and oil phases.

Emulsifiers come in three different types of polar head groups: cationic (positively charged), anionic (negatively charged), and non-ionic (uncharged head groups). The emulsifier is equally drawn to both water phase and oil phase in a perfect emulsion.

HLB or hydrophilic lipophilic balance values are different for different emulsifiers, and can be used to forecast how well they will stabilize particular type of emulsions. The HLB scale has a range of 0 to 20, with 10 being an emulsifier that is attracted equally to both oil and water. Hydrophilic emulsifiers have a HLB value greater than 10 and hence they are better at stabilizing oil in water emulsions. And those emulsifiers with HLB value below 10 are hydrophobic, and hence are better suitable for water in oil emulsions [18].

1.3.1 Properties of emulsifier

- Non- toxic and non-irritant
- Low foaming tendency
- Good solubility in base oils
- Good heat stability
- Good lubricating properties

1.4 NANOFLUIDS

Colloidal suspensions of nanoparticles in a base fluid are known as nanofluids [19]. The well-known property of nanoparticles is their higher thermal conductivity, which is inflated when

compared to base fluid or bulk colloidal suspensions. This characteristic helps to increase the efficiency of nuclear and geothermal power plants by allowing for more energy extraction.

Nanoparticles suspended in various base fluid can affect the fluid motion and also the heat transfer characteristics of base fluid. The relative surface area of nanoparticles is much higher than that of the regular particles, which not only greatly enhances heat transmission capabilities, but also boost up the stability of the suspension.

1.4.1 Classification of Nanofluids

Nanoparticles are mainly classified on the basis of nanoparticle suspended and the base fluid used.

(i) On the basis of nanoparticles

- Metallic nanofluid (Al, Cu)
- Non-metallic nanofluid (CeO₂, CuO)

(ii) On the basis of fluid used

- Ethylene glycol
- Water

Some of the common nanoparticles used for the preparation of nanofluids are:

- Metallic oxides (Al₂O₃, CuO)
- Nitride ceramics (AlN, SiN)
- Carbide ceramics (SiC, TiC)
- Metals (Cu, Ag, Au)
- Semiconductors (TiO₂, SiC)
- Alloyed nanoparticles (Al₇₀, Cu₃₀)

1.4.2 Advantages of nanofluid

- As the particle size is extremely small, the suspended nanoparticle improves the surface area and heat capacity of the fluid.
- The thermal conductivity is improved by the dispersed nanoparticles, leading to an increase in the effectiveness of heat transfer systems.
- Reduced particle clogging, which encourages system downsizing.
- Solar energy absorption can be enhanced by changing the size, shape, composition, and volume percentage of the nanoparticles.
- Lower pumping power when compared to pure liquid to get similar heat transfer intensification.
- High dispersion stability with primarily Brownian particle motion.
- The turbulence and mixing fluctuation of the fluid can be magnified.
- The transverse temperature gradient of the fluid is flattened by the dispersion of nanoparticles.
- The properties of the fluid can be modified by altering the concentration of the nanoparticles, making it suitable for different applications.
- Heat transferred to a tiny region of fluid by heating within the fluid volume, which enables the peak temperature to be positioned far from surfaces that are losing heat to the atmosphere.

CHAPTER 2

LITERATURE REVIEW

Mineral oils have a poor biodegradability and is poisonous by nature, which has a negative impact on the, according to several research studies conducted over the past two decades. Accidental spills and the disposal of mineral oil-based substances after usage, pose a major threat to our aquatic wildlife and are also carcinogenic. The cutting fluids derived from mineral oils are being used extensively in industries in nowadays. The need for biodegradable and renewable cutting fluid is growing as a result of environmental concerns. Vegetable oils are generally a highly desirable alternative to mineral oils, because they are ecofriendly, renewable, non-toxic, and easily biodegradable.

The impact of non-edible vegetable oil-based cutting fluids for the machining process was examined by Rahul Katna et al. in 2019 [1]. A thorough analysis of this study revealed that non edible vegetable oils were economically benign, increases the tool life, and decreases the energy consumption. However, auto oxidation and thermal instability principal drawbacks.

S. Ravi reviewed and assessed the effects of cutting fluids in machining operations. He mentioned the effects of excess heat in the cutting zone and also the need to reduce the same. In this review paper, basic information about the type of the cutting fluids was given. Cryogenic machining one of alternative way for reducing heat was also mentioned in this paper [3].

To comprehend the use of vegetable oils as prospective metal working fluids, Shashidhara and Jayaram provided a review in 2010 [11]. This review was based on the advantages of using vegetable oils as cutting fluid and came to the conclusion that because of their environmental friendliness, they offer a wide range of potential applications.

Vegetable cutting fluid based on neem oil were studied by Rahul Katna et al. (2017), for their impact on tool wear [13]. Polysorbate 80, a biodegradable emulsifier, and a non-edible neem

oil was combined to form a novel cutting fluid. It was observed that the higher viscosity of the neem oil reduces the wear in the tool.

Malaya Naika et al. (2008) investigated the generation of biodiesel from Karanja oil, which contains higher amount of free fatty acid content [15]. They elaborated how biodiesel or fatty acid methyl ester were developed by utilizing transesterification process, with the aim of improving the chemical stability of the Pongamia oil. Because of the presence of larger amount oleic acid content, it was found that Pongamia oil acceptable for lubricating purposes.

By employing an environmentally benign vegetable oil as a lubricant to replace the hazardous and harmful mineral and petroleum-based lubricants from the turning process, Sharma and Singh evaluated the impacts of dry and near dry machining (NDM) of AISI D2 steel (2014) [20]. According to the experimental findings, using near dry machining reduced the cutting temperature by over 50%.

The effects of several vegetable oil-based cutting fluids on specific energy, tool life, and surface roughness for end milling were examined by Ozcelik et al in 2013 [21]. The researcher came to the conclusion that the vegetable oil-based cutting fluid met the goal of greener production while also enhancing machining performance in terms of specific energy, tool life, and surface roughness. Hence, cutting fluids derived from vegetables have a great chance of replacing semi synthetic cutting fluids.

The cutting performance and wettability features of the cutting fluid with 1% inclusions of Al_2O_3 nanoparticles and conventional cutting fluids were compared in an experiment done by Khandekar et al. (2012) [22]. Al_2O_3 nanoparticle inclusion at 1% was shown to be more successful in enhancing the wettability properties of the base fluid and in enhancing surface quality by lowering cutting forces, surface roughness, and tool requirements.

In order to examine the tribological behavior of surfaces coated with Pongamia oil, Yahvir Singh et.al (2018) evaluated the impact of titanium dioxide nanoparticle concentration [23]. By utilizing titanium dioxide nanoparticles, friction reduction properties of Karanja oil are enhanced to certain level.

In 2016, Rabesh Kumar Singh et al. looked into how nanoparticles affected the specific heat and thermal conductivity of the cutting fluids [24]. Titanium dioxide, silicon oxide, and aluminium oxide nanoparticles were suspended in a vegetable oil in water emulsion to create various nano fluids. It was observed that, when the quantity of the nanoparticles in the base fluid increased, so did its thermal conductivity and specific heat. Also, it was observed that nano fluids based on aluminium oxide exhibit superior thermal properties to those based on titanium dioxide and silicon oxide.

The results of vegetable oil-based cutting fluids in turning operations of “EN 24 Steel” were researched by Pankaj Kumar and Ravi in 2020 [25]. Cottonseed and groundnut oils were used to make cutting fluids, in concentration 4:1 and 9:1 respectively. They investigated the effects of cutting temperature, material removal rate, and surface roughness on depth of cut. The highest temperature generated during machining was found to be lower for cutting fluids based on groundnut oil. Material removal rate increased as cutting depth and machining speed increased, and it was most noticeable in cotton seed oil.

A comparison study of vegetable oil derived from ground nuts and conventional cutting fluids on machining copper alloys, was conducted by Mundrathi Saikiran et al. in 2019 [26]. They studied the material removal rate, surface roughness, and cutting forces under different circumstances. It was noticed that the surface roughness of vegetable based cutting fluid shows 16% reduction in surface roughness when compared to conventional cutting fluid. Also,

groundnut based cutting fluid has an optimized cutting force parameter, when comparing the cutting force.

In order to traverse the broad applications of Al_2O_3 nanoparticles and nano diamond (ND), Lee et al. (2012) conducted experimental studies using micro grinding [27]. Al_2O_3 nanoparticles were shown to be more effective than nano diamond particles at reducing surface roughness, particularly when used at higher sizes. This may be a result of the decreased hardness of the nano Al_2O_3 particles when compared to nano diamond.

E. Sneha studied different vegetable oils and its properties to use it as an industrial lubricant. She compares the properties of various vegetable oils like Karanja oil Rice bran oil (RBO) and Jatropha oil that are essential for a lubricant [28].

The impact of nanoparticles on cutting fluid parameters and tribological characteristics were investigated by Nadine Madanchi et al. in 2019 [29]. For two different metal oxides, Al_2O_3 , ZrO_2 , as well as silica, the effect of concentration, particle size and the base fluid were examined. It was found that the inclusion of nanoparticles improves lubricity and increases the viscosity of the various fluids, depending on the concentration.

An overview of the uses and difficulties of nanofluid was completed by Saidur et al. in 2010 [30]. According to the review, it was observed that an increase in volumetric concentration of nanoparticles improves the thermal conductivity of nanofluids compared to base fluids and is one of the important factors that contributes to improved performance in a variety of applications.

Amith Aravind carried out a research study to enhance the characteristic of rubber seed oil using transesterification process [31]. Vegetable oils can be modified to enhance the fatty acid content, tribological properties, oxidation stability and viscosity.

2.1 PROBLEM STATEMENT

Cutting fluids made from mineral oils suffer from a number of drawbacks. It poses major risks to the environment and employees, as well as having the potential to cause cancer. Biodegradable cutting fluids are crucial from a green perspective. Vegetable oil is considered as one of the alternatives for this, which is affordable, widely accessible, biodegradable, renewable, less toxic, and safe for disposal.

Besides that, they pose less health risk to employees. Vegetable oils that have not been treated, however, perform poorly when employed as metalworking fluids due to their high acid value, poor oxidation stability, and poor low temperature qualities. However, chemical modifications such as transesterification offers better lubricating characteristics when compared to unmodified or raw vegetable oils. Instead of using hazardous, non-biodegradable, and depleting petroleum oil-based emulsion cutting fluids, an alternative oil-based emulsion nano cutting fluid is made from Pongamia oil through transesterification and the addition of aluminium oxide nanoparticles.

2.2 SCOPE OF STUDY

The efficiency of the manufacturing process is very crucial and have great importance because of the constantly increasing demand for goods and subsequent rise in production. The primary difficulties encountered are the metallurgical change in the workpiece caused by excessive frictional heat and the material wear in tools. Generally speaking, cutting fluids serves as a lubricant and coolant between the various moving elements of the production machinery, thereby increasing the efficiency. It aids in reducing the wear and tear, clearing chips and debris from the machining area, protecting the material surface from corrosion, preventing the development of built up edge, etc.

Mineral oils are the primary content in majority of the cutting fluids used today in industries. However, the use of synthetic cutting fluids in industrial applications is constrained by their high cost, poor biodegradability, and its hazardous nature. Under these circumstances, cutting fluids derived from non-edible vegetable oils become quite important. Nanoparticles are added to the oil to enhance the properties of the oil and thereby increasing the performance as a cutting fluid

An innovative vegetable oil-based nano cutting fluid is being developed in this research work. The plant oil chosen for this study is Pongamia oil, which comes from *Milletia pinnatta* tree, which is indigenous to tropical regions like South East Asia. The goal of the project is to develop a nano based oil in water emulsion cutting fluid using aluminium oxide nanoparticles as an alternative to petroleum oil-based emulsion cutting fluids, which are hazardous, non-biodegradable and depleting.

2.3 OBJECTIVES

- To synthesis Pongamia oil methyl ester (POME) using transesterification process and its characterization.
- To prepare and characterize water-based emulsion of POME and its nano cutting fluid using Aluminium Oxide nanoparticles.
- To study the effect of nano cutting fluid on machining in an CNC lathe and study the effect of various parameters.
- To compare the performance of POME nano cutting fluid with conventional synthetic cutting fluid.

CHAPTER 3

MATERIALS AND METHODS

The chapter deals with the different types of materials used in this research work and also the methods that are done in the study. They are included under two separate sub titles named materials and methods.

3.1 MATERIALS

3.1.1 Pongamia oil

In the research work, because of the easy accessibility and least expensive of the Pongamia seeds in India, Pongamia oil is being employed as the vegetable cutting oil in the study. The seeds of the tree Pongamiapinnata tree, a member of Leguminosae family, are used for the extraction of Pongamia oil. It is a medium sized, evergreen tree that grows to a height of 12 to 15m [26,27]. The seeds have an oil content of 28-34% with a high percentage of polyunsaturated fatty acids (PUFA).

Pongamia oil is famously known by the name Karanja oil. Honge oil, Pungali oil, and Kanuga oil are some of the other names of Pongamia oil. Pongamia oil is bought from Green Leaf Industries, located in Gujarat.



Fig. 3.1 Pongamia seeds

3.1.2 Emulsifier

Polysorbate 80, also known as Tween 80 or Polyoxyethylene [19] Sorbian monooleate, is the emulsifier employed in this investigation and was purchased from Sisco-Research Laboratories (SRL), Chennai. According to studies, Polysorbate 80 is safe for people and is used as an emulsifying agent in food items. Emulsifiers with HLB value of more than 10 are hydrophilic and perform better at stabilizing in oil in water emulsion. Polysorbate 80 has an HLB value larger than 10, hence it is used in this research work.



Fig. 3.2 Polysorbate 80

3.1.3 Nano Particles

The most crucial component in the preparation of nano cutting fluid is nanoparticles. Aluminum oxide (Al_2O_3) nanoparticles are used in this research work because, they are safe, chemically stable, and more affordable than any other nano particles. It was bought from the company, 'Sigma- Aldrich Chemicals'. The present study uses only analytical grade chemical reagents for all of the assays. The characteristics of aluminium oxide was given in the table 3.1.

Table 3.1 Characteristics of Al₂O₃ Nanoparticles [32].

PROPERTIES	VALUES
Average particle size, nm	13
Density, g/cm ³	3.8
Molecular weight, g/mol	101.96
Purity, %	99.8
Appearance	White powder
Thermal conductivity, W/mK	30
Morphology	Spherical
Specific heat coefficient, J/kgK	880

The powdered form of aluminium oxide is shown in the fig. 3.3.

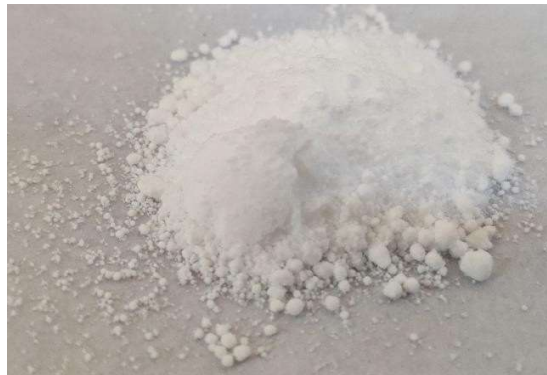


Fig. 3.3 Al₂O₃ Nanoparticles.

3.1.4 Mild Steel Workpiece



Fig. 3.4 Mild Steel workpiece

Mild steel rod with 16mm diameter and 50mm length was chosen as workpiece which is shown in fig. 3.4. Mild steel is a ferrous metal made from iron and carbon. Mild steel possesses properties such as malleability, ductility, weldability and is of low cost which makes it suitable for general engineering applications.

3.1.5 Cutting Fluid Delivery System

The developed nano cutting fluid and POME emulsion was delivered to the machining zone using the delivery system shown below fig. 3.5.

The machine shown here is AGNI A1830 SPRAY MACHINE. It has a flow rate of 250ml/min and the nozzle angle is set as 0° and pressure in the range of 3-4 bar. It consists of a blower and a spraying gun connected by a hose. The cutting fluid is sprayed by external means to the zone between workpiece and tool.



Fig. 3.5 Cutting Fluid Delivery System

3.2 PREPARATION OF PONGAMIA OIL METHYL ESTER

3.2.1 Transesterification

Triglycerides present in vegetable or animal-based oils are composed of three fatty acids bound to a single glycerol molecule. A catalyst is used in the chemical conversion of triglycerides with alcohol into alkyl esters, and is known as transesterification. Three sequential reactions take place in this reaction between triglycerides and an alcohol to form esters and glycerol. Triglycerides are transformed into diglycerides, then into monoglycerides, and eventually into glycerol and fatty acid during the entire transesterification process. In the process of transesterification, vegetable oil can be transformed to FAME or Biodiesel, an useful fuel.

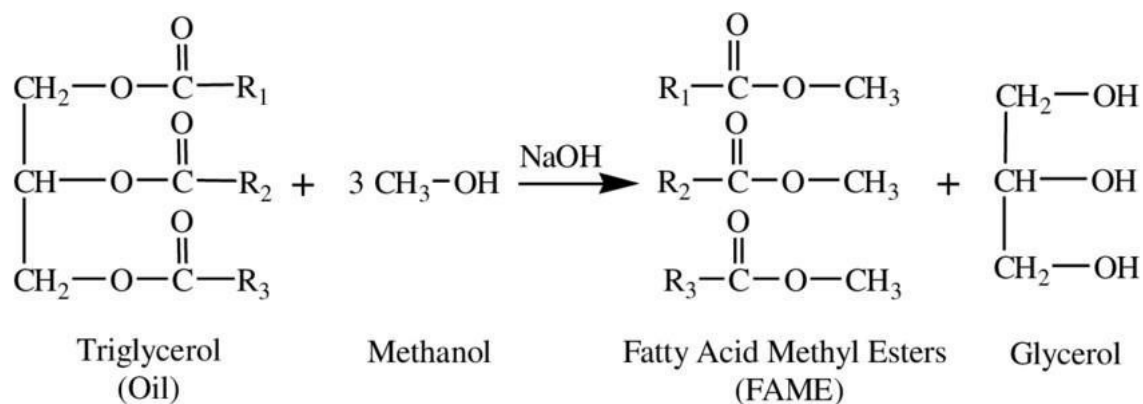
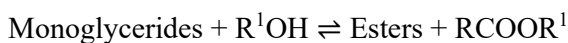
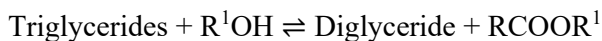


Fig. 3.6 General chemical equation for the entire transesterification reaction, where R₁, R₂, R₃ are hydrocarbons of long chain.

Conversion of triglycerides into esters occurs in multiple stages and are given below.



3.2.2 Acid Esterification

Acid esterification is a chemical process that lowers the high concentration of free fatty acids (FFA) by combining triglycerides with a lower alcohol such as methanol, in the presence of an acid catalyst. The percentage of fatty acids will drop to half the acid value of oil and is reported in many works. Around 200 ml of Pongamia oil were taken in a beaker of size 500ml and was subjected to preheating at a temperature of 60⁰ C and given time to cool. Followed by cooling, around 80 ml of methanol (45 percent of the amount of oil) was added to Pongamia oil and swirled for a short period of time. The aforesaid mixture was then added 4ml (v/v of oil) of concentrated sulphuric acid, an acid catalyst, which was then agitated for an hour at 45 to 55⁰ C, using a magnetic stirrer in fig. 3.7.



Fig. 3.7 Magnetic stirrer

The aforementioned mixture was added to a separating funnel and left there for separation process, at least 8 hours. The oil was then rinsed with water, three to four times, to eliminate the acid content. The second step of alkaline catalyzed transesterification (fig. 3.8) was then performed on the pre-treated oil after the removal of alcohol layer. Also, the water and acid catalyst, which is present in the pretreated oil, must be removed before performing alkaline esterification. The oil layer is separated from the mixture, and is subjected to alkaline catalyzed esterification.



Fig. 3.8 Acid Esterification (Upper- methanol, Middle layer- oil and Lower layer -sediments)

3.2.3 Alkali Esterification

The oil that had already been processed was first weighed. In alkali esterification process, a magnetic stirrer was used to mix methanol (35 % by weight of oil) and KOH (1.5% by weight of oil), which was taken in a conical flask at room temperature for 5 minutes. The oil which was already pretreated, was added to the abovementioned mixture, which was then agitated at 600 rpm for one hour at 60⁰ C. The mixture is then transferred to a separating funnel and kept there still for 8 hours. The glycerol component is removed after 8 hours and the remaining glycerol and other particles are then rinsed away with water, four to five times at an interval of 8 hours. The final product obtained after the serious of steps is Fatty Acid Methyl Ester (FAME), or known as Pongamia Oil Methyl Ester (POME). In order to eliminate the water content present in it, POME is then heated at 100⁰ C. Alkali esterification process was shown in fig. 3.9.



Fig. 3.9 Alkali Esterification (Top layer: POME, Bottom layer: Glycerol)

The different stages of water washing are shown in fig. 3.10.

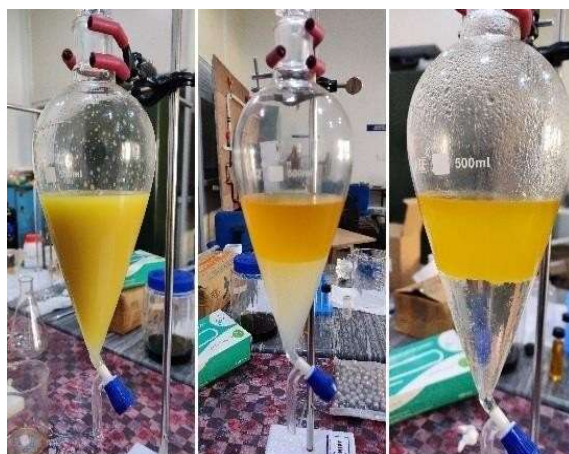


Fig. 3.10 Different stages after water washing to remove glycerol

1.7 liters of POME was developed after transesterification process and is shown in the figure (fig. 3.11) given below.



Fig. 3.11 POME obtained after transesterification

3.3 PREPARATION OF EMULSION

Emulsifiers are particles that lowers the surface tension at the interface between two typically incompatible phases, enabling them to combine and form an emulsion.

Emulsions comes in two different varieties: water in oil emulsion and oil in water emulsion.

The current study makes use of an oil in water emulsion. An emulsion consists of two phases: a continuous phase which is water, and a dispersed phase which is oil which is shown in fig.

3.12. Emulsifiers are selected based on the HLB value.

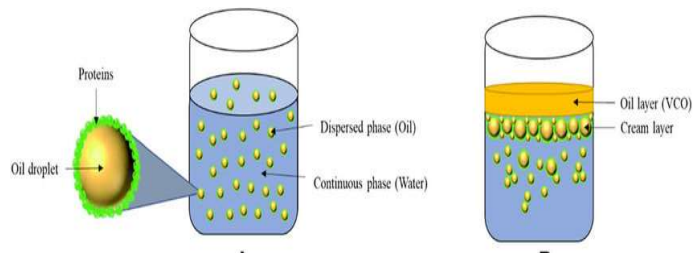


Fig. 3.12 Oil in water emulsion

Tween 80 has the properties of emulsifier as well as surfactant, hence, it is used as both emulsifier and surfactant. It was then added to POME in different concentrations such as 5%, 10%, 20%, 30%, and was swirled continuously for 30 minutes at an average speed of 800 rpm.

To create an oil in water emulsion, water is then added in the ratio of 1:20. The afore mentioned mixtures was left in storage for three days and was observed that 30% concentration produces a homogenous mixture shown in fig. 3.13, which is milky white in colour, devoid of any sediments, hence making it ideal for the emulsion process.



Fig. 3.13 Tween 80 in various concentrations after 3 days

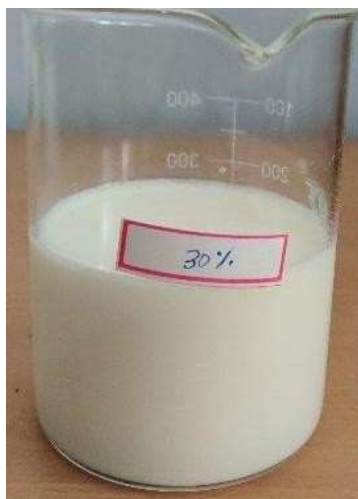


Fig. 3.14 Oil in water emulsion with 30% concentration of Tween 80

3.4 PREPARATION OF NANO- CUTTING FLUID

The next stage of the research work is creating the nano cutting fluid. Nanoparticles suspended in fluids must be properly mixed and stabilized before being used in nanofluids. 60 ml POME were combined with 30% Polysorbate 80 to create the base fluid. Nanoparticles of Al_2O_3 were incorporated into the base fluid at various concentrations such as 0.1%, 0.3%, 0.5% for the preparation of nanofluid (NF). The powdered form of Aluminium Oxide having a size of 13 nm were available.

The mass of the nanoparticles needed to match to the volume fractions are computed using the equation given below (Eq 3.1).

$$\phi = \frac{\left(\frac{m}{\rho}\right)_{np}}{\left(\frac{m}{\rho}\right)_{np} + \left(\frac{m}{\rho}\right)_{nf}} \dots\dots\dots \text{Eqn.3.1}$$

Where ϕ =Volume fractions, m = mass, ρ = density, np =nanoparticle, nf = nanofluid

High precision electronic balance, having a measuring limit of 0.00001g was used for weighing nanoparticles, which is shown in fig. 3.15.



Fig.3.15 Precision Balance

In order to reduce particle agglomeration, the samples were swirled for 1 hour using a magnetic stirrer, followed by agitation process using ultrasonic agitator (fig. 3.17), for 3 hours at a frequency of 40 kHz to uniformly disperse the nanoparticles. It produces a steady nano cutting fluid and there is no particle settlement seen for a long period of time given in fig. 3.16.



Fig. 3.16 Nanoparticles at various concentration



Fig. 3.17 Ultrasonic Agitator

3.5 CHARACTERIZATION

This chapter deals with the characterization or measurement of various properties. All the properties that are significant for lubricating fluids are measured on all the prepared samples. Properties like physicochemical properties, chemical composition, tribological properties, rheological properties etc. are measured for all the developed samples.

3.5.1 Evaluation of Physicochemical Properties

Acid value Iodine value, and peroxide value are used to describe the physicochemical characteristics of vegetable oils. The total acid number (TAN), which is used to assess the ageing of vegetable oils, is the amount of milligram (mg) of base needed to neutralize the acids in one gram of the oil. For effective lubrication, it ought to be low. Triglycerides are broken down into fatty acids by chemical processes such as oxidation, which increases the TAN value. Iodine value (IV) is the gram amount of iodine absorbed by the sample vegetable oil, indicates how much unsaturation is present in the sample. More unsaturated fatty acids are present in the oil when the IV value is higher. Peroxide value is the amount of oxygen content present in the oil as peroxides. Both acid value and peroxide value indicates oxidation resistance and shelf life of product, which is to be at low concentration. Saponification Value (SV) is the mass in mg of KOH required to saponify one gram of the sample. It gives an idea about the tendency of the lubricating oil to saponify at higher temperatures

3.5.2 Fatty Acid Composition

The fatty acid profile of Pongamia oil was evaluated by Gas chromatography- mass spectrography. The fatty acid composition is plant specific and will be different for different species. Tribological properties are determined by the fatty acid composition.

3.5.3 Oxidative Stability

One of the main drawbacks of vegetable oils is their low oxidative stability, which is caused by their high concentration of double-bonded fatty acids. According to the AOCS Cd-12-57 standard, a Hot Oil Oxidation Test (HOOT) was performed on each and every oil sample. The samples were maintained at 100 degrees Celsius in a hot air oven for 120 hours. A kinematic viscometer was used to measure the viscosity variation after 120 h at 40°C. If the viscosity variation is minimal, the oxidative stability of the oil sample will be revealed.

3.5.4 Thermal Conductivity

Transient hot wire apparatus or KD2 Pro thermal property analyzer was used to measure the thermal conductivity of the samples. The instrument has an accuracy of $\pm 0.001\%$ and thermal conductivity in the range of 0.02 to 2 W/mK can be measured. The device works on the principle of transient hot wire and a maximum deviation of $\pm 5\%$. The device meets both ASTM D5334-14 and IEEE 442-1981 standards. The probe of the instrument is an elongated needle with an internal heater and a temperature sensor. The heater receives an electric current, which is then used to measure the temperature of the probe over time. Thermal conductivity of all the samples were measured at 30°C. Each reading was taken five times for each sample and the average of all the five readings is taken, in order to reduce measurement errors. The KD2 Pro apparatus is shown in fig. 3.18.



Fig. 3.18 KD2 Pro thermal analyzer

3.5.5 Tribological Properties

The tribological properties of the sample like wear scar diameter (WSD) and coefficient of friction (COF), are assessed using four ball tester (fig. 3.19), according to ASTM D4172 standard. The four-ball tester comprises of an AC motor driven vertical spindle with a ball collet. A ball locking ring and lock are used, along with a torque wrench, to ensure the three balls in the ball point. Oil sample is placed in the pot. A heater is attached to the ball pot, which is positioned on the top of the anti-friction disc. A loading lever is used to exert the standard load of 392 N onto the balls. The chrome steel balls have 12.7 mm diameter and 64 HRC hardness. The test was run for one hour at a rotating speed of 1200 rpm and a temperature of 75⁰C. an optical microscope (fig. 3.20) was used to assess the wear scar diameter of the fixed balls, and a Leica optical microscope (10 x, 100 μ m), having an accuracy of .01 μ m, was used to collect photographs of the worn surface.



Fig. 3.19 Four ball tester [29]



Fig. 3.20 Optical Microscope

3.5.6 Rheological Properties

Rheological properties were measured using a Brookfield LVDV- II + Pro plate and cone rheometer shown in fig. 3.21, (JULABO F-25, Germany) having a measuring range of 0.1 to 2000 cP. Viscosity of all the samples was measured at different temperatures such as 30,40,50,60,70,80⁰C together with a constant temperature circulator. The device has an accuracy of $\pm 1\%$ and a repeatability of 0.2 %. All the measurements were taken based on ASTM D2196-10 standard. Measure of viscosity is the amount of torque required torque the spindle of rheometer. In order to measure the viscous drag of the test fluid against the spindle, torque is supplied through a calibrated spring to a spindle that is submerged in it. Spindle was calibrated using the Brookfield viscosity standard for this study and maximum uncertainty was 1.9%.



Fig. 3.21 Brookfield Rheometer

3.5.7 Corrosion Test

Corrosion is the metallic reaction with atmosphere or the surrounding environment, which results in changes in surface properties that can be measurable. The corrosion grade of the cutting fluid when it comes into contact with cast iron can be used to determine the amount of corrosion. The test was carried out by adding few grams of cast iron chips to a piece of filter paper in a petri dish after they had been cleaned in acetone and dried. The chips being equally spaced around the filter paper, prevented it from contacting each other. Then test samples were added until all the chips were completely immersed. Then the immersed chips in petri dish were left for 24 hours in a dark room. After 24 hours, the samples were drained, and filter paper was rinsed with acetone after the removal of chips. By observing the number of spots that developed on the filter paper surface, the corrosion grade of the cutting can be identified. Then, we will be able to identify the corrosive properties of the test samples.

The corrosion test which contain filter paper with iron chips immersed in test samples, placed in petri dish was show in the figure given below (fig. 3.22 & fig. 3.23).



Fig. 3.22 Corrosion test

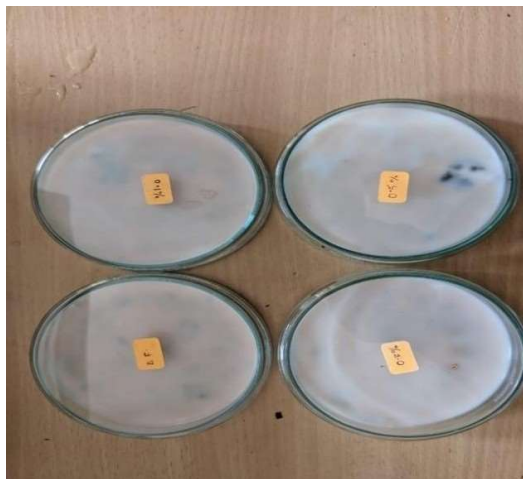


Fig. 3.23 Cast iron chips immersed in different concentration of nano fluids

3.6 MACHINING

The surface quality of items is typically assessed in terms of surface roughness during machining operations. The aircraft and automotive sectors, which continuously work to improve the surface quality of machined parts, use turning processes extensively. A single-point cutting tool removes material off the surface of a spinning cylindrical work piece during the crucial machining process known as turning. A linear feed is used to feed the cutting tool in a direction parallel to the axis of rotation. The turning is done on a lathe, which has the power to feed the cutting tool at a specific rate and depth of cut while turning the workpiece at a specific rotational speed. Machined mild steel rods are shown in the fig. 3.24.

CNC lathe was used to do machining. In CNC lathe the cutting parameters can be controlled automatically and successive machining operation can be done without any deviation. This capability of CNC machine is necessary to compare the properties of machined samples under different volume concentrations of nano cutting fluids. Feed, depth of cut, speed of the machine was kept constant and five different samples of cutting fluid was used for machining. All the developed cutting fluids were brought to the cutting zone by a fluid delivery system. In this work, spraying machines is used for that purpose.

Table 3.2 shows the cutting parameter fixed for the machining process.



Fig. 3.24 Machined Mild Steel workpiece

Table 3.2 Cutting Parameters

Speed	1500 rpm
Feed rate	.05 mm/rev
Depth of cut	1 mm

3.7 SURFACE ROUGHNESS

Surface roughness is an important factor to be considered in machining process. The condition of processed or machined surfaces is referred to as surface quality or surface finish. The texture and look of the surface, which have a big impact on the properties are determined by the irregularities that are present on the surface. Surface quality of the machined parts or the product is most important quality indicators and also customer requirements indicators. The determination of surface finish in industries is a laborious and time-consuming job and thus gaining a lot of attention among researchers.

The two most important surface roughness parameters preferred in industries are arithmetical mean deviation of the roughness profile (Ra) and maximum height of the roughness profile (Rz). The arithmetic mean roughness, noted as roughness (Ra), which indicates the average roughness of the controlled surface. (Rq) is referred to as the root-mean-square roughness. (Rz) helps to measure the vertical distance between the highest peak and the lowest valley.

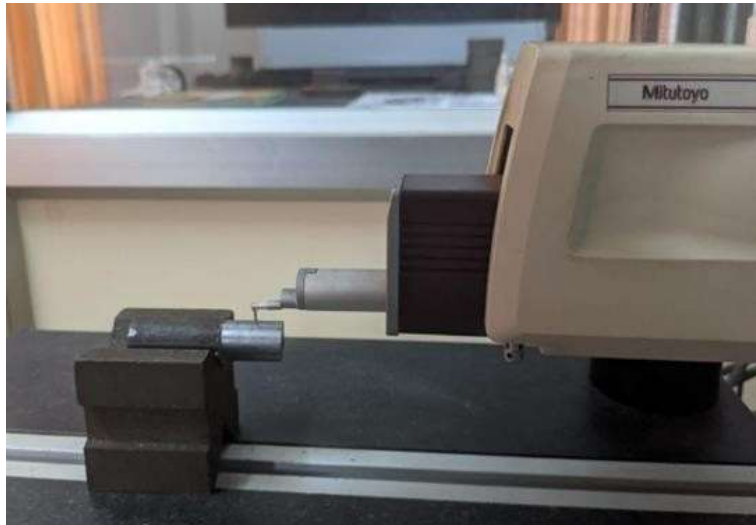


Fig. 3.25 Mitutoyo surface roughness measuring instrument

Surface roughness was measured using MITUTOYO SJ-410 machine. The machine consists of a probe and screen. The probe makes contact with the machined workpiece which is fixed on a chuck. As the probes moves linearly making contact with the surfaces, surface roughness values and graphs was obtained from the screen. The surface roughness values of all the five machined samples of mild steel workpiece under different concentration of nano cutting fluids and synthetic cutting fluid are measured using MITUTOYO SJ-410 machine instrument and are compared. The fig. 3.25 shows the Mitutoyo surface roughness measuring instrument.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 PHYSICOCHEMICAL PROPERTIES

4.1.1 TAN Value

TAN refers to the acid number, which is a measure of free fatty acids present in the oil. The TAN value of Pongamia oil in this study was observed as 8.6 mg KOH/g. After the esterification process TAN value is found to be decreased. The TAN value of the POME obtained after the whole transesterification process was 0.86 mg KOH/g. The tribological properties and oxidation stability with lower TAN value. High acidity promotes hydrolysis of oil when stored for extended period of time, which is undesirable and causes corrosion of machine parts and the creation of sludge. The TAN value of servo cut; the synthetic fluid used for the comparison was found to be 1.62 mg KOH/g.

4.1.2 Peroxide Value

The amount of peroxides formed during the oxidation process is given by peroxide value. Peroxides values are preferred to be lowered. The peroxide value of commercial cutting fluids and Pongamia oil is obtained as 0.31 and 2.2 meq/kg respectively. It was observed that the peroxides value of the Pongamia oil falls down after the transesterification process and was obtained as 1.2 meq/kg.

4.1.3 Iodine Value

Iodine value indicates the percentage of unsaturated fatty acids in the oil. Lower iodine values are preferred for better oxidation stability, which depends on the level of unsaturation. Oils and fats are divided into three categories depending on their IV values: drying (IV between 130 and

200), semi drying (IV between 100 and 130), and non-drying (IV less than 100), Pongamia oil has an iodine value of 87.16 gI₂/100g, whereas commercial cutting fluid has an IV value of 18.12 gI₂/100g. it was seen that the iodine value of the oil reduced after transesterification process and was obtained as 76.2 gI₂/100g. Pongamia oil and POME has a low IV value, which indicates it is oxidatively stable.

4.1.4 Saponification Value

The Saponification value of Pongamia oil was 175.83. When the saponification value is high, oil has greater lubricity and low molecular weight and more suitable for soap making. Saponification values have an inverse relation with the average molecular weight of the fatty acids in the oil.

The chemical properties are shown in the table 4.1.

Table 4.1 Properties of samples

PROPERTIES	PONGAMIA OIL	POME	COMMERCIAL CUTTING FLUID
Acid Value (mg KOH/g)	8.6	0.82	1.62
Peroxide Value(meq/kg)	2.2	1.2	0.31
Iodine Value(gI ₂ /100g)	87.16	76.2	18

4.2 Fatty Acid Profile of Pongamia oil

Oleic acid, which makes 41.74% of the fatty acid composition of Pongamia oil, is the predominant one. Linoleic and linolenic acids came after that. Vegetable oils with high oleic acid content are being evaluated as a replacement for synthetic esters and traditional mineral oil-based lubricating oils. When fatty acid comes into touch with metallic surfaces, a soapy film is created due to chemical reaction. The molecules are dispersed densely, decreasing wear by preventing friction between metal surfaces. The fatty acid that make up triglycerides are long and polar. The polarity generates oriented molecule coatings that strongly interact with metallic surfaces and as a result, offer lubrication and antiwear qualities. Tribological characteristics can be improved by high oleic acid concentration. The presence of high amount of oleic acid in Pongamia oil makes it suitable for the purpose of cutting fluids. The chemical composition of the Pongamia oil was given in the table 4.2.

Table 4.2 Chemical composition of Pongamia oil

FATTY ACID	PERCENTAGE (%)
Oleic Acid	41.74
Linolenic Acid	18.79
Palmitic Acid	8.79
Lignoceric Acid	1.24
Linoleic Acid	15.68
Behenic Acid	3.51
Stearic Acid	6.85
11- Eicosenoic Acid	0.87
Arachidic Acid	1.17

4.3 Oxidation Stability

To evaluate the oxidation stability of all the samples, Hot Oil Oxidation Test was conducted. The variations in the viscosity of all the samples after 120 hours of heating was evaluated and shown below. Viscosity increment after HOOT should be low for better oxidation stability. Oxidation stability of the Pongamia oil was found to be increased after the transesterification process. This is because of the reduction of unsaturation, eliminates the formation of higher molecular weight oxidation products. Oxidation stability of nano cutting fluids are similar to that of the POME. Also, nano cutting fluids have better oxidation stability when compared to commercial cutting fluid.

The viscosity increment is shown in the table 4.3 given below.

Table 4.3 Viscosity increment of test samples

SAMPLE	VISCOSITY INCRERMENT (%)
Pongamia Oil	19.23
POME	15.16
0.1 NF	15.168
0.3 NF	15.18
0.5 NF	15.20
Commercial Cutting Fluid	19.1

4.4 Thermal Conductivity

Cutting fluids made from vegetable oil are dependent on free moving ions and molecules for their thermal conductivity. The inert fatty acid that make up vegetable oils increase the temperature gradient because they are not free to migrate. Thermal conductivity of all the test samples were measured at 30 °C. Thermal conductivity of the Pongamia oil was found to be decreased after the transesterification process. Also, all the nanofluids showed improved thermal conductivity as volume concentration increased.

Thermal conductivity measurements of all the test samples are shown below as bar chart in the figure 4.1.

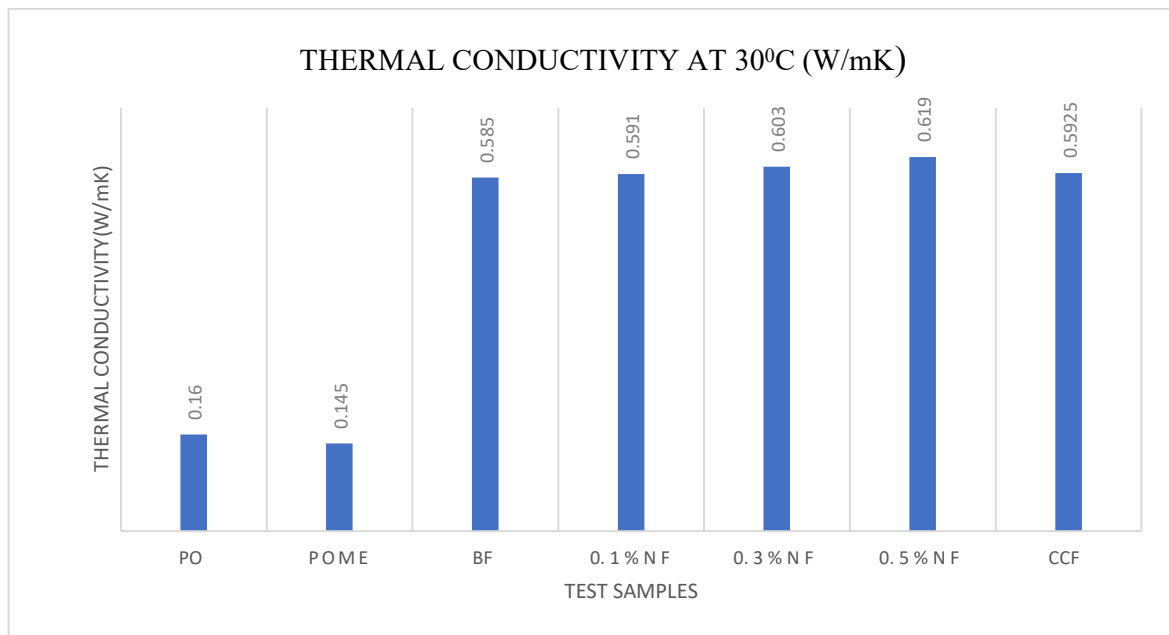


Fig. 4.1 Thermal conductivity of test samples at 30°C

All the nanofluids with concentration 0.1%, 0.3% and 0.5% Al₂O₃ nanoparticles enhance the

thermal conductivity by 1.02%, 3.08% and 5.81% respectively when compared to that of POME emulsion base fluid. From this experimental result, 0.5 % Al_2O_3 nano cutting fluid shows better thermal conductivity. Nano cutting fluids with concentration 0.3% and 0.5% have better thermal conductivity than commercial cutting fluid. The increase in thermal conductivity is due to the increased thermal conductivity of solid particles and also due to the Brownian effect. Brownian effect is due to the bombardment of colloidal particles by the molecules of dispersion medium which are in constant motion.

The percentage increase of thermal conductivity of nanofluids at different concentration with the CCF is shown in the graph given below (fig. 4.2).

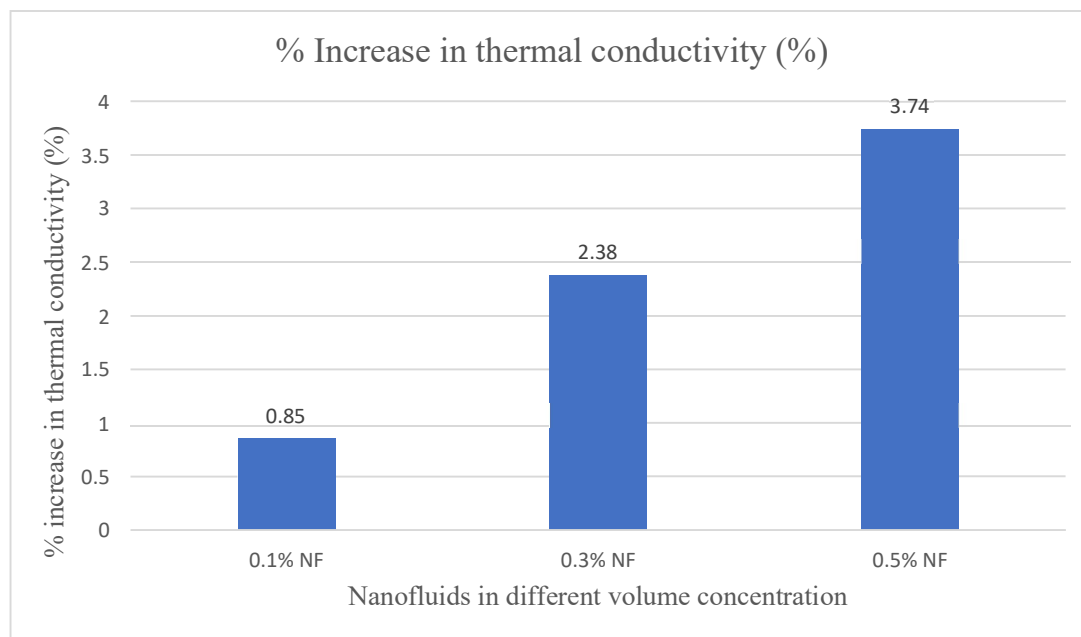


Fig. 4.2. % increase in thermal conductivity of different volume concentration of nanoparticles w.r.t CCF.

Thermal conductivity increases non-linearly with temperature. Addition of suspended nanoparticle in the base fluid increase the thermal conductivity. Also, nanoparticles can alter properties like wettability, convective heat transfer coefficient and lubricating properties.

4.5 Tribological Properties

For better lubricating properties, cutting fluids should have low coefficient of friction (COF) and small wear scar diameter (WSD).

Pure Pongamia oil has better tribological properties than POME and CCF, which is because of the presence of polar headed carboxylic acid (COOH). This acid forms a layer of film at the contact region and reduces the COF and WSD. The elimination of the glycerol component from the oil during the transesterification procedure causes the carboxylic acid (COOH) to dissociate, increasing the COF and WSD in comparison to pure oils. Tribological properties increases as the concentration of the Al_2O_3 nanoparticles increases. This is because, when nanoparticles are added, rolling effect occurs in the region of contact. The COF chart of all samples are shown in fig. 4.3.

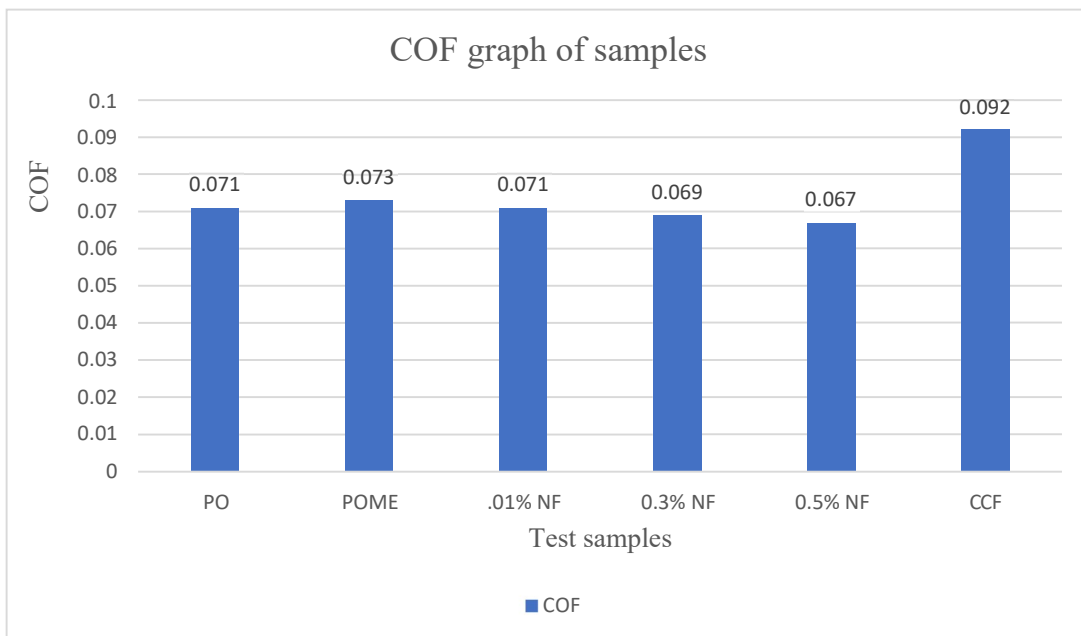


Fig. 4.3 Coefficient of friction of various samples

The result wear scar diameter for all the samples are shown as bar graph in fig. 4.4.

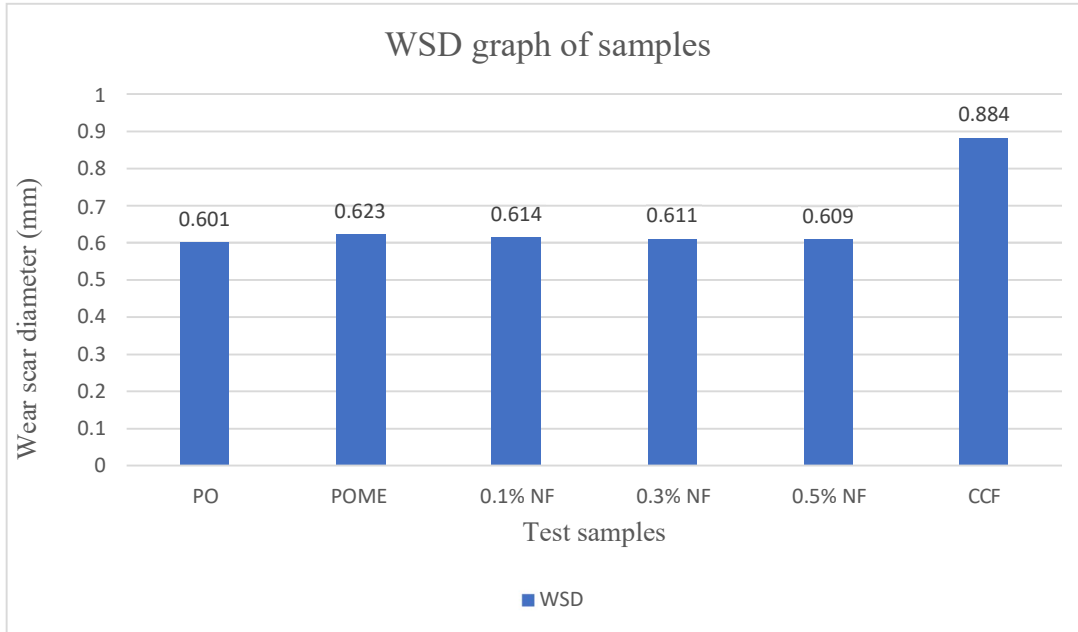


Fig. 4.4 Wear scar diameter of various samples

4.6 Rheological Properties

The viscosity of all the samples under experimentation was evaluated at different temperatures, starting from 30⁰C to 80⁰C and are tabulated below. It was found that, the raw Pongamia oil has high viscosity, which is equal to 52 Cp at 30⁰C. The reason behind this is that, Pongamia oil contains less amount of polyunsaturated acids. POME has low viscosity (7.52cP) compared to Pongamia oil because, after transesterification process, the glycerol part is removed from the oil.

From the experimental results, it is observed that the viscosity decreases with increase in the temperature. Also, as the concentration of the Al₂O₃ nanoparticles increases, the viscosity of the fluid increases. This is because nanoparticles increase the fluid layer resistance. There is an internal frictional force between several layers when fluids flow in relation to one another. Collisions between the base fluid and the suspended nanoparticles enhance viscosity. Increasing the particle concentration will produce larger nano-racemes due to Van der Waals forces, and the particles may agglomerate inside the suspension. The variation of viscosity is represented in graphical form and is given in the fig. 4.5.

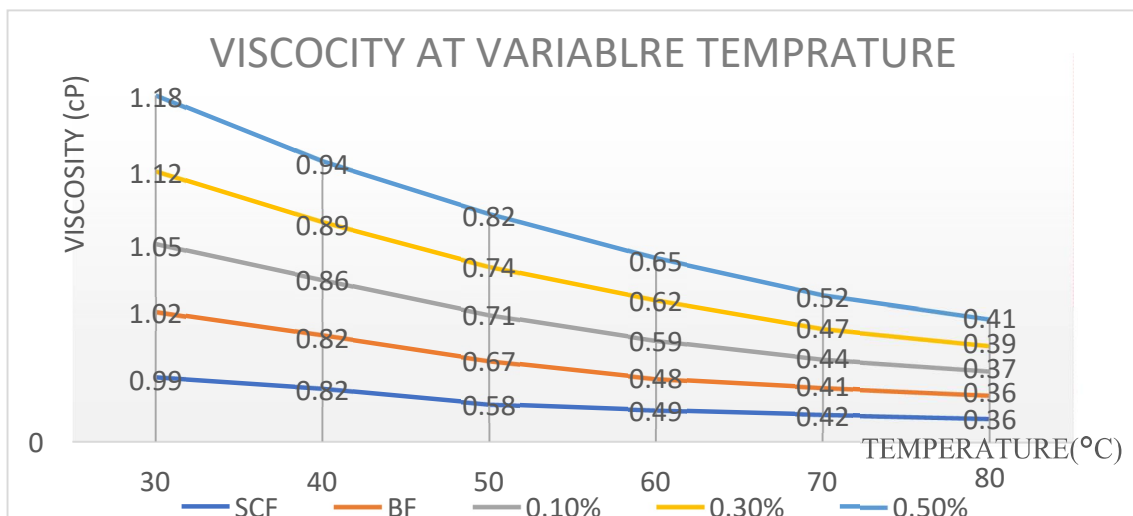


Fig. 4.5 Viscosity of samples at different temperature

At 30°C, the highest increment in viscosity is observed in an increase of concentration of nanofluid from 0.3 to 0.5%. It is also found out that viscosity of nanofluids in three different volumetric concentration decreases with increase in temperature. The percentage increase in viscosity of POME emulsion and 0.5% nanofluid at 30°C, 50°C and 80°C on comparing with Synthetic fluid are 3.03% and 19.19% at 30°C, 15.31 % and 41.37% at 50°C and 13.88% at 80°C respectively compared to Synthetic fluid and is shown in fig. 4.6.

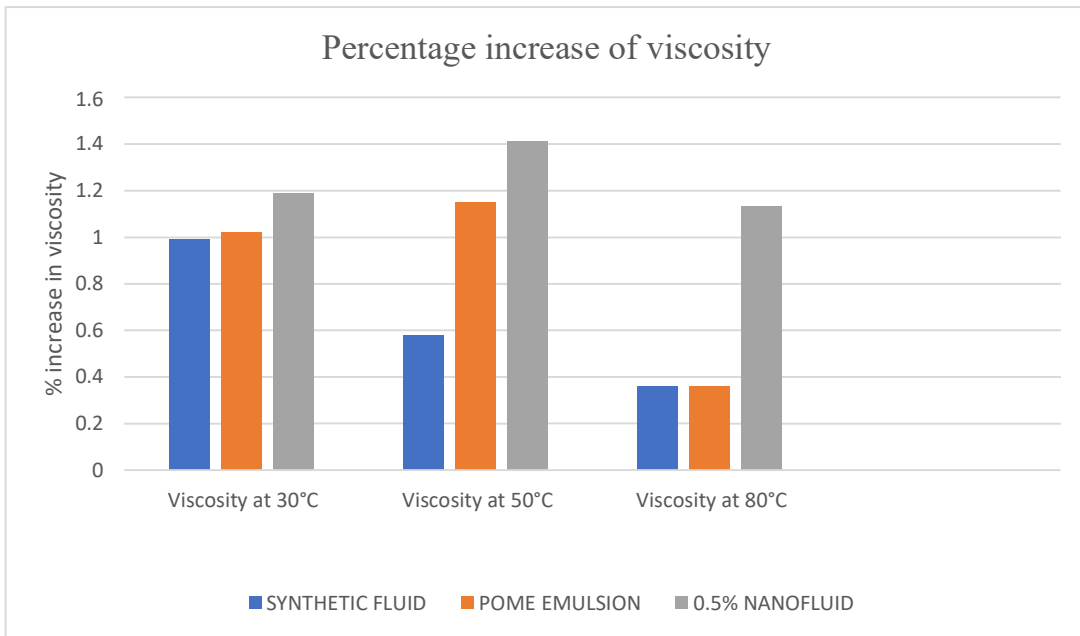


Fig. 4.6 Percentage increase in viscosity of POME water emulsion and 0.5 % nanofluid at various temperature with respect to Synthetic cutting fluid

4.6 Corrosion Results

Corrosion test was done for Pongamia oil and nano cutting fluid. There were no corrosion spots observed in nano cutting fluid compared to Pongamia oil. Based on corrosion grade, Pongamia oil has moderate corrosion and nano cutting fluid has no corrosion. This indicates that formed

nano cutting fluid has good anti corrosive effect probably due to reduction in acid value and nanoparticle addition. The reduction in stain could be due to the formation of protective layer of nanoparticles on the metal surface based on the chemisorption phenomenon and results are shown in fig. 4.7.

Mineral oil is a mixture of hydrocarbons and it is composed with some corrosive compounds such as elemental Sulphur, organic Sulphur compounds, organic acids and salts [34]. Compared to vegetable oils mineral oils has more corrosion properties.

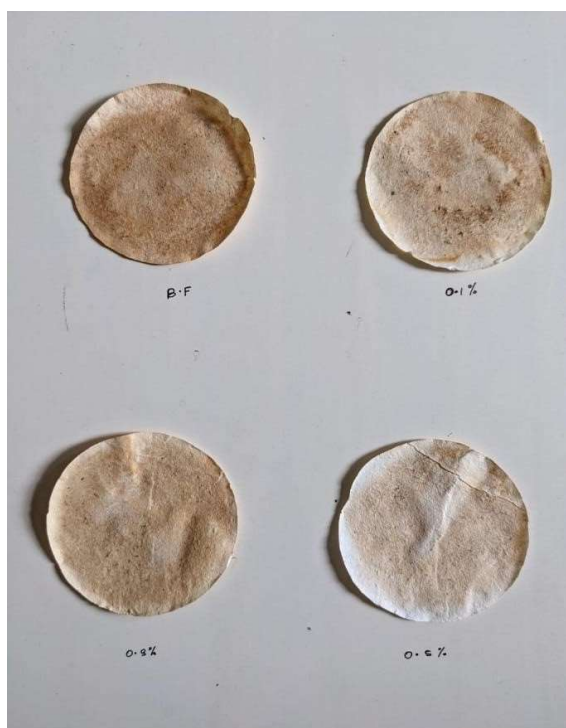


Fig. 4.7 Corrosion test results

No corrosion spots were observed in nano cutting fluid compared to Base fluid (POME-water emulsion). Based on corrosion grade, Base fluid has moderate corrosion and nano cutting fluid has no or little corrosion. This indicates that formulated nano cutting fluid has good anti corrosive effect probably due to reduction in acid value and nanoparticle addition. The corrosive nature decreases with increase in nanoparticle concentration of formulated cutting fluid.

4.7 Surface Roughness

The surface roughness decreases with increase in volume concentration of nano cutting fluid. Synthetic cutting fluid, POME emulsion and nano cutting fluids of different volumetric concentration were used for machining mild steel workpiece. On measuring the surface roughness using MITUTOYO-SJ410 instrument, 0.3% concentration nano cutting fluid outperformed the synthetic fluid where 0.5% concentration of nano cutting fluid shows the best surface finish.

Following are some possible explanations for how nanoparticles reduce friction. Rolling, film protection, patching, and polishing effects. The first two methods are a direct result of nanoparticles improving lubrication. Spherical nanoparticles are anticipated to act as ball bearings and roll between frictional surfaces. The nanoparticles also create a thin layer of protection on the surface, which lessens friction between two surfaces. The other two methods are a result of nanoparticles' additional impact on surface improvement. To make up for the mass loss, the nanoparticles form a tribo-film when they deposit on the surfaces that cause friction (mending effect). Additionally, the abrasiveness of hard nanoparticles reduces the roughness of the rubbing surfaces (polishing effect).

The graph of Ra, Rq, and Rz values plotted against different samples are shown in fig. 4.8

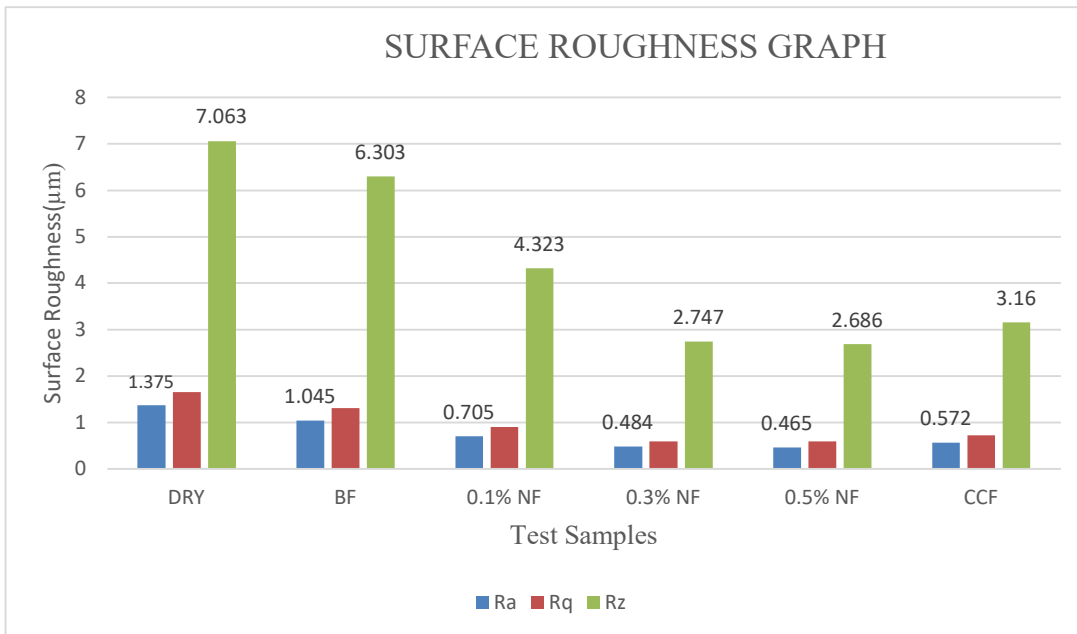


Fig. 4.8 Measure of Surface roughness

Surface roughness graph obtained from Mitutoyo machine of various samples are given in the following figures.

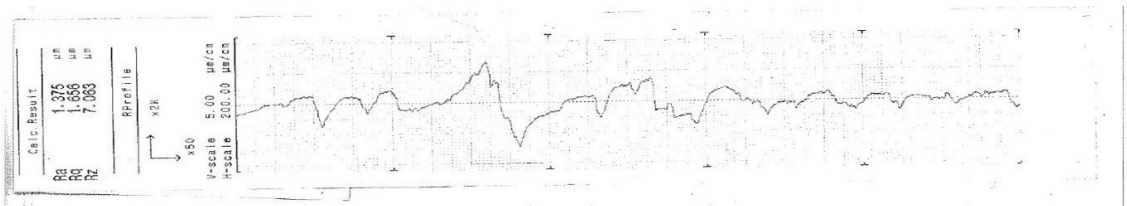


Fig. 4.9 Surface roughness at dry condition

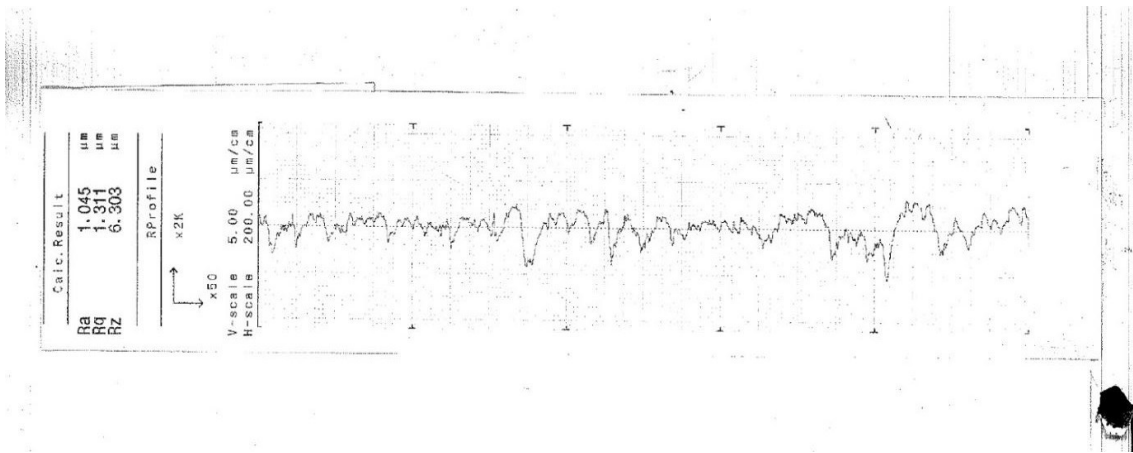


Fig. 4.10 Surface roughness upon POME emulsion

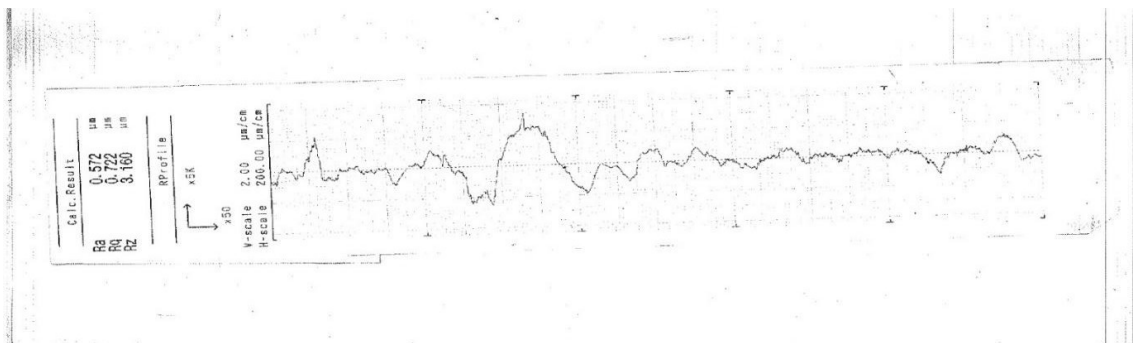


Fig. 4.11 Surface roughness upon CCF

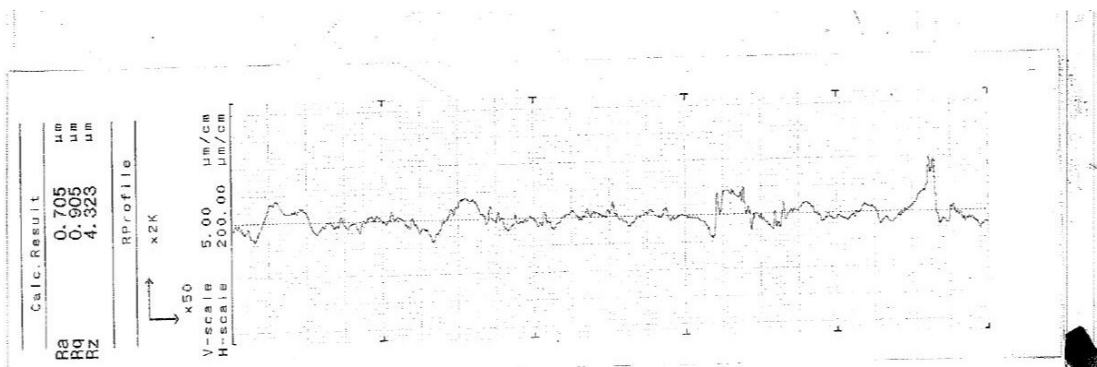


Fig. 4.12 Surface roughness at 0.1% nano cutting fluid

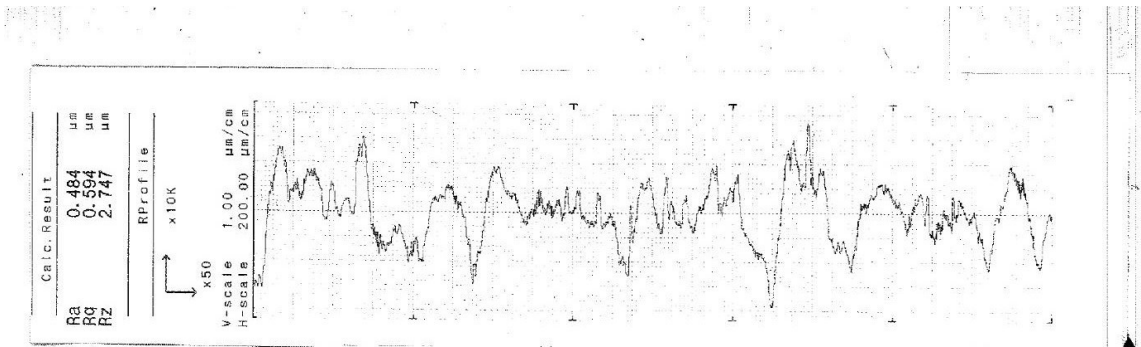


Fig. 4.13 Surface roughness at 0.3% nano cutting fluid

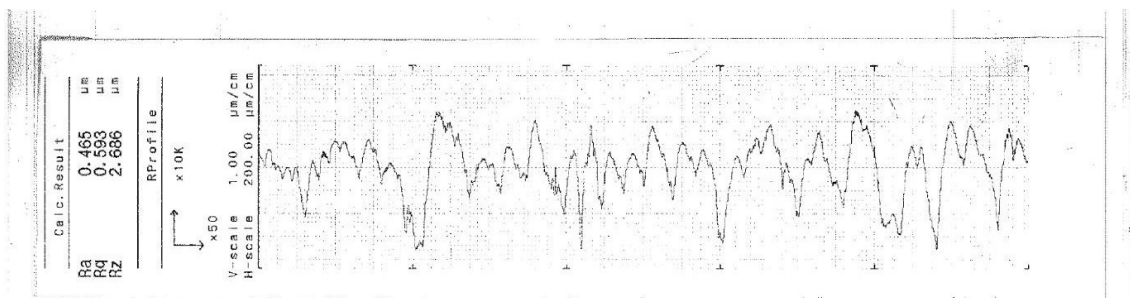


Fig. 4.14 Surface roughness at 0.5% nano cutting fluid

On comparing the average surface roughness (Ra) values of 0.5% nano cutting fluid machined surface and synthetic cutting fluid machined surface, 23% increase in surface roughness is observed in the surface machined by 0.5% nano cutting fluid.

CHAPTER 5

COST ANALYSIS & GANTT CHART

5.1 COST ANALYSIS

Table 5.1 Budget estimation and expenditure

Type of Expenditure	Rating/Specification	Estimated Cost (Rs)	Actual Cost (Rs)
Pongamia oil	5 liters	2000	2200
Apparatus		3500	2500
Chemicals and additives		4000	4500
Spraying machine	300 ml/min	2800	1900
Mild steel	50mm x 16mm	650	450
Testing		5000	4500
Miscellaneous			750
Total		17950	16800

The table 5.1 shows the estimated budget for the experimental study and the overall expenses of the study. The overall expense of the work does not exceed the estimated budget even though some miscellaneous expense occurs and was budget friendly.

5.2 GANTT CHART

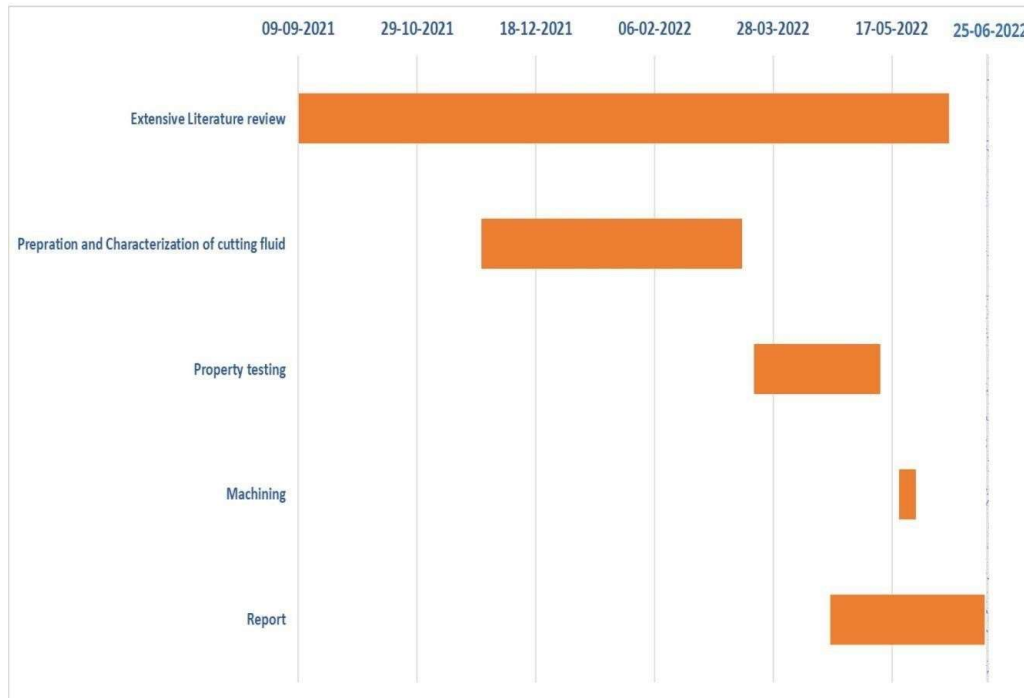


Fig. 5.1 Gantt chart

Fig. 5.1 shows the Gantt chart form, which represents the timeline indicating the time of beginning and ending of each stage in the experimental study. It takes around 9 months to complete the entire work.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

Environmental problems are something we must deal with. Alternatives to cutting fluids derived from mineral oils are suggested because of the rising demand and increasing price of crude oils. The need for environmentally friendly, biodegradable cutting fluid is growing and are more popular now. Oils derived from plant species environmentally beneficial and renewable. A novel cutting fluid was developed from non-edible Pongamia oil with some chemical modifications, and using biodegradable emulsifier and Al₂O₃ nanoparticles.

The following conclusions were drawn from the experimental results;

1. Transesterification process reduces TAN value/ acid value of Pongamia oil that results in stable oxidation.
2. Oxidation stability of the Pongamia oil increases after the transesterification process and nanoparticles does not have much effect in that.
3. Thermal conductivity of ester is lower than that of Pongamia oil and that of POME emulsion increases.
4. Thermal conductivity of nanofluid increased with increase in volume concentration of nano particles.
5. Thermal conductivity of 0.1 %, 0.3%, 0.5% nanofluids were enhanced by 0.85%, 2.38%, 3.74 % respectively when compared to Synthetic fluid.
6. Tribological properties decreases after transesterification process and increases with increase in concentration of nanoparticles.
7. Viscosity of nanofluid increased with increase in volume concentration and decreased with increase in temperature.

8. The percentage increase in viscosity of Pome emulsion and 0.5% nanofluid at 30°C, 50°C and 80°C on comparing with Synthetic fluid are 3.03% and 19.19% at 30°C, 15.31% and 41.37% at 50°C and 0% and 13.88% at 80°C respectively compared to Synthetic fluid
9. Novel cutting fluid has good corrosion inhibiting properties.
10. Surface finish of machined mild steel workpiece increases with increase in volume concentration of nanoparticles.
11. 0.3% concentration nano cutting fluid outperformed the synthetic cutting fluid where 0.5% concentration of nano cutting fluid shows the best surface finish.
12. Average surface roughness (Ra) values of 0.5% nano cutting fluid machined surface and synthetic cutting fluid machined surface, 23% increase in surface roughness is observed while using 0.5% nano-cutting fluid.
13. Transesterification process will reduce the TAN value / acid value of Pongamia oil that results in stable oxidation.

The aforementioned findings lead us to the conclusion that as the quantity of nanoparticles increases, Pongamia oil-based nano cutting fluids exhibit improved thermal conductivity, viscosity, and surface quality. The created nano cutting fluid can be utilized as a more efficient replacement for cutting fluid that is based on minerals. On the Indian subcontinent, Pongamia oil is widely used. Large amounts of it are sold for less money. The Pongamia oil is safe to dispose of, non-hazardous, and environmentally beneficial. It saves on disposal costs because no additional steps are needed for neutralization prior to disposal.

6.2 SCOPE FOR FUTURE WORKS

- Biodegradability and toxicity test of the formulated POME cutting oil can be studied.
- Parameter estimation like tool wear, cutting force, chip morphology etc. of the formulated POME cutting oil CNC milling and turning operations can be observed and compared the results with commercially available mineral oil-based cutting fluid.
- Characterization and evaluation with different nanoparticles.

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