# Study on tribological properties of biodegradable cutting fluid with the addition of additives

**Abi Adil. M.C[1], Dr.P.Thangavel[2]**

[1]*Abi Adil. M.C, Shree Venekateshwara Hi-Tech Engineering College, Erode, India*
[2]*Dr.P.Thangavel,Professor, Mechanical Engineering Department, Shree Venekateshwara Hi-Tech Engineering College, Erode, India*

---------------------------------------------------------------------***---------------------------------------------------------------------

**Abstract** - Cutting fluids are used during machining processes to remove heat generated and to reduce the coefficient of friction. At present, synthetic as well as mineral cutting fluids are used which has high tribological properties. But their cost as well as the rate of pollution is high. Most of the metal working fluid used nowadays are toxic and creates health issues to the machine operators and also the disposal of these fluids are challenging. This project deals with the study of bio degradable cutting fluids and the tribological properties are to be analysed . From the results obtained by adding nano particles in bio-degradable cutting fluids a comparison has to be carrried out with the normal cutting fluid.The vision of this project is to develop a bio-degradable cutting fluid with addition of additives to a vegetable oil as the base oil. Nowadays, to minimize these environmental hazards, several alternative measures such as development of environment friendly cutting fluids and green energy systems are focused.Mustard oil selected as the base oil and ZDDP as the additive for the cutting fluid

***Key Words***: cutting fluid , tribology , mustard oil , biodegradable , four ball test .

## 1.INTRODUCTION

The demand for energy is increasing day by day due to ever going development, modernization and industrialization. Fossil fuels are one of the most commonly used sources of energy.In general, fossil fuels are used in the form of fuel and lubricant to fulfil worlds soaring energy demand.The Petroleum based cutting fluids are subdivided into two categories; straight oils and neat oils. Both consists performance enhancer additives to improve its various properties.Additives such as fatty material, free sulphur, chlorinated paraffin, sulphurized oils and phosphorus compounds are present in petroleum-based cutting fluid.At higher temperature these additives react with work material and form metal chloride, phosphates as well as sulphides, which are hazardous and harmful to the environment.In long run, inappropriate disposal of used petroleum based cutting fluids can cause serious damage to environment. The vision of this project is to develop a bio-degradable cutting fluid with addition of additives to a vegetable oil as the base oil.

## 2. Cutting fluids

Cutting fluids (CFs) in a broader sense metalworking fluids (MWFs) are supplied gravitationally or under appropriate pressure to the chip formation zone to improve the cutting performance by cooling and/or lubrication effects. In general, these effects depend on the amount of heat generated (that is, the lubricating action is more important at low cutting speeds, whereas the cooling is mostly the predominant effect at higher cutting speeds, due to more intensive heat generation). Cooling is achieved by dissipating and conducting a fraction of the generated heat.

## 3. Methodology

Selection of base vegetable oil
↓
Selection of additive and formation of cutting fluid
↓
Study on tribological properties of cutting fluid
↓
Analysis and comparison of the cutting fluid

### 3.1 Selection of base vegetable oil

Vegetable oils are generally of two types- edible and non-edible. Canola, soybean,coconut, sesame, olive, etc. are edible oils commonly used for human consumption and also for biodiesel and biolubricant. Non- edible oils such as waste cooking oil and Jatropha curcas seed oil are suitable candidates for biolubricant and biodiesel production.Vegetable oils are cheap, readily available from biological sources, and are inexpensive than synthetic oils but expensive than mineral oils . Non-edible or lower quality vegetable oils that are unfit for human consumption can be easily used for biofuel and biolubricant production.Vegetable oil tends to solidify at a higher temperature than mineral-based oil limiting its use in low temperature conditions. Low-temperature flow properties of vegetable oil are characterized by the structure of glycerol as well as fatty acid composition. The presence of intermolecular forces between the hydrocarbons disrupts the intermolecular forces of attraction resulting in lower pour and cloud points. The ester groups in triglycerides are arranged such that steric hindrance between the fatty acid groups is minimal.

Mustard oil belongs to the family of Brassicaceae. It is commonly found in India,Nepal, Bangladesh, and Pakistan and is often used for cooking in these regions. Oil can be sourced from seeds of black mustard, brown Indian mustard, and white mustard. Oil has a distinctively pungent smell due to the presence of allyl isothiocyanate. Mustard oils contain about 60 % monounsaturated fatty acids, 21% polyunsaturated fatty acids and about 12% saturated fatty acids.

### 3.2 Selection of additives

To improve certain performance parameters of a lubricant, additives are employed. Additive packages constitute almost 10% of the final lubricant. The nature of additives selected varies with application. Zinc dialkydithio phosphate (ZDDP) is one such additive, half a century old, commonly used in commercially available lubricants. ZDDPs are used for their anti-wear,antioxidant, and mild extreme pressure properties. The term anti-wear usually refers to wear inhibition at moderate load and temperatures whereas the term extreme pressure is reserved for high loads and temperatures. ZDDPs are complexes manufactured by reaction of alcohols, phosphorus pentasulphide, and zinc salts. ZDDPs are generally not available in pure form and contains many impurities that affect lubrication efficiency.

## 4. Testing Methodology

### 4.1 Tribological investigation using four ball tribometer

The experiment consists of wear and extreme pressure test performed on a four- ball tester.Four ball tester is used to determine wear preventing, friction, and extreme pressure characteristics of oil and greases. In this apparatus , a rotating steel ball is pressed against three steel balls that are firmly held and submerged in test lubricant. Test conditions are set as per ASTM standard schedule. Four ball testing apparatus was first developed by Boerlage in 1933 for testing highly doped lubricants. Since very high contact pressures can be achieved, the effectiveness of lubricant at boundary lubrication conditions can be tested easily. A load of 40kg calculates to a contact pressure of 400,000 hertz stress. Fig 1 shows a four ball testing apparatus.


**Fig -1**: Four ball tribometer

The testing apparatus is equipped with a computer-controlled pneumatic loading arrangement, therefore the required load can be precisely controlled. The apparatus is also connected to a data acquisition system and frictional forces are plotted precisely with time. Wear scar induced on the surface during tests can be evaluated using wear scar analyzer.The schematic diagram of the working of four ball tribometer is shown in fig 2.

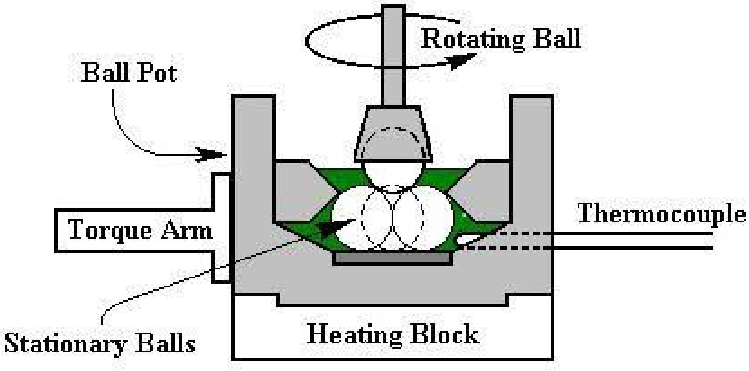


**Fig -2**: Schematic diagram Four ball tribometer

### 4.2 Viscometer

Viscometer is used to measure the dynamic viscometer according to ASTM at temperatures ranging from 40°C to 100°C with an increment of 10°C. Viscometer is a rotating cylinder type viscometer and measures the dynamic viscosity of the liquid. A constant water bath is used to heat the oil in the test chamber. The strain rate is fixed for all the samples. Samples prepared earlier for tribological tests were used for the analysis. Viscosity indices were calculated using equations.

### 4.3 Open cup flash point apparatus

Open cup flash point apparatus was used to determine the flashpoint of oil samples. ASTM test schedule is to be used as standard. Approximately 70ml of the oil was poured into the test cup. Initially, oil in the cup is heated rapidly at the rate of 14-18 °C/min. When the oil temperature reaches a temperature of 56 °C below the expected temperature, the heating rate is decreased to 5-6 °C/min. Test flame is introduced when the oil temperature is 28 °C below the anticipated flashpoint. A test flame is passed above the specimen to check for flashes. The initial ignition point is noted as the flashpoint and if the burning of vapors persists for 5secs then it is considered as fire point.

### 4.4 Experiment to find pour point.

A simple manual method is used to find the pour point of the oil samples. The experiment is conducted as per ASTM. In this method, a 50ml of preheated (40°C) oils is taken in a cylindrical glass vessel and stoppered with a cork that has a provision to insert a thermometer. The vessel is placed in a cooling chamber. The oil is cooled to 9°C above its anticipated pour point temperature after which oil is inspected for every 3°C increment. The temperature at which oil ceases to flow for 5 seconds is taken as the pour point.

### 4.5 Copper strip corrosion test

Copper strip corrosion tests as per ASTM is to be performed to determine the corrosion characteristics of the oil samples. In this method, a copper strip is immersed in a test tube containing oil. The test tube is enclosed in a steel container and immersed in a water bath. The bath is maintained at 100 °C and the samples are immersed for a duration of 3hrs before being taken out. At elevated temperatures, the corrosion process is accelerated and causes the coloration of copper strips. The colour of the stain formed on the strips is identified with the standard shown in Fig 3.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 05 | May - 2021 ISSN: 2582-3930

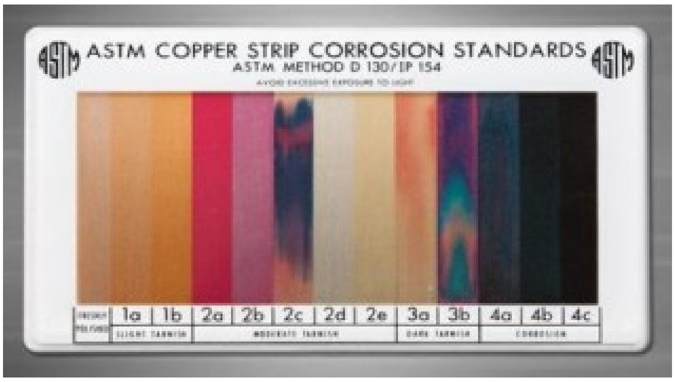


**Fig -3**: ASTM copper strip corrosion standard chart

## 5. Results and discussion

### 5.1 Wear and friction

Both wear and friction characteristics can be obtained from this test. Wear scar induced on the steel balls are quantified using wear scar diameters (WSD). Larger WSD means poor wear preventing ability of the lubricant and vice versa. Frictional characteristics can be found by measuring frictional torques using a transducer and using it to find the coefficient of friction (μ).From Fig.4 it can be observed that WSD for mustard oil is 795 mm and WSD for SAE20W40 is 507 mm. SAE20W40 oil shows better wear preventing property because of the presence of phosphate additives such as ZDDP. Also, at higher speeds due to increased shearing, the adsorbed fatty acid layer on the metallic surface gets desorbed due to higher surface temperature and poor shear strength of the adsorbed layer. This is the probable reason for mustard oil showing severe wear than SAE20W40. Better wear resistance is observed with the addition of ZDDP in the mustard base oil.WSD gradually increases at higher concentrations of ZDDP, with the highest being at 5%wt.

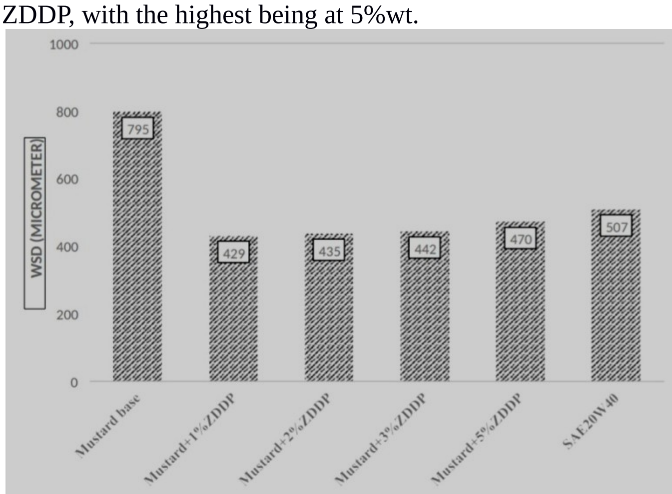


**Fig -4** Wear scar diameters for different oil samples

At 1%wt. ZDDP concentration, WSD is reduced by about 46% as compared to the mustard base oil. WSD for mustard with 1%wt ZDDP is also lower than SAE20W40.

Fig.5 shows the instantaneous CoF values recorded during the entire duration of the test. None of the oils showed any significant changes in CoF over the entire test duration. This signifies that a stable tribofilm is formed throughout the experiment through a continuous supply of fresh lubricant into the contact surface and the lubricant is chemically and mechanically stable at contact temperatures. CoF values averaged over time are shown in Fig. 6.

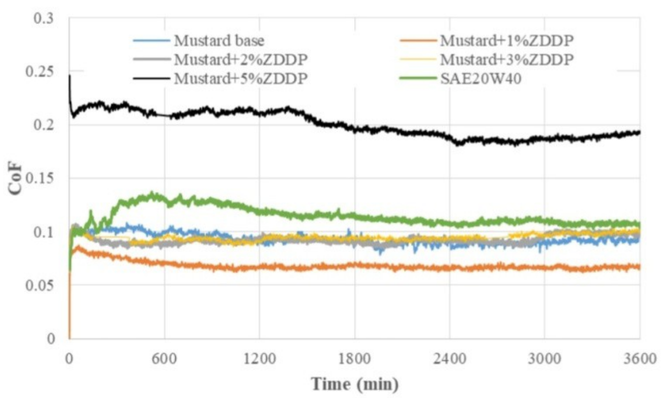


**Fig -5** Coefficient of friction versus time curve

Vegetable oils, due to the presence of fatty acid exhibit better friction reducing properties as compared to mineral oil. From Fig.6 it can be observed that the CoF of mustard base oil is less than that of SAE20W40 oil. This is attributed due to the polar nature of the fatty acid molecule. The carboxyl group is strongly attracted by the metallic surface whereas the alkyl group repels to any other substance. This provides effective adsorption and formation of a densely packed mono- or multimolecular layer that inhibits metal to metal contact. The repulsive tendency of the alky group ensures that shear strength at the interface is relatively lower than dry contact.It can be observed that a decrease in shear strength signifies a decrease in CoF. Mustard oil additivated with 1%wt ZDDP obtained the lowest CoF when compared to other blends. Also, there is a substantial increase in CoF value at 5%wt ZDDP concentration.

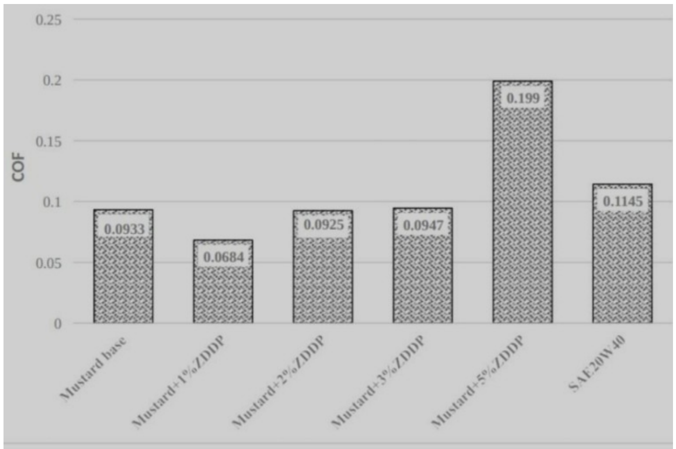


**Fig -6** Coefficient of friction of different oil samples.

Published results for interfacial film thickness for acid phosphate and oleic acid were 5.74 and 0.002μm respectively. Therefore, higher CoF values at 5%wt of ZDDP concentration can be attributed to this thicker interfacial film.

### 5.2 Viscosity Temperature Relationship

The viscosity of any fluid irrespective of its state is a temperature dependent property. For liquids, viscosity decreases with the increase in temperature and for gases, it's quite the opposite, viscosity increases with increases in temperature. The viscosity of oils can drop considerably, in some cases oil viscosity can drop by 80% with an increase in 25°C. Therefore, it is necessary to know the viscosity of the lubricant at the operating temperature, since viscosity determines the lubricant film thickness. The parameter that

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 05 Issue: 05 | May - 2021 ISSN: 2582-3930

can quantify the temperature-viscosity relationship is the viscosity index (VI).The viscosity index is a quantified parameter that signifies the change in viscosity with temperature. The higher the viscosity index lesser is the change in viscosity with temperature and vice versa. The viscosity index can be calculated using below. VI = (L – U )/(L – H ) × 100

Where U is the kinematic viscosity (cSt) of the oil at 40°C, L and H are obtained from table 7.1 corresponding to kinematic viscosity (cSt) of oil at 100°C.Brookfield LV DV2T viscometer is used to measure the dynamic viscometer according to ASTM D445 at temperatures ranging from 40°C to 100°C with an increment of 10°C. Brookfield LV DV2T is a rotating cylinder type viscometer and measures the dynamic viscosity of the liquid. A constant water bath is used to heat the oil in the test chamber. The strain rate was fixed at 100 $s^{-1}$ for all the samples. Samples prepared earlier for tribological tests were used for the analysis. Viscosity indices were calculated using above equation.

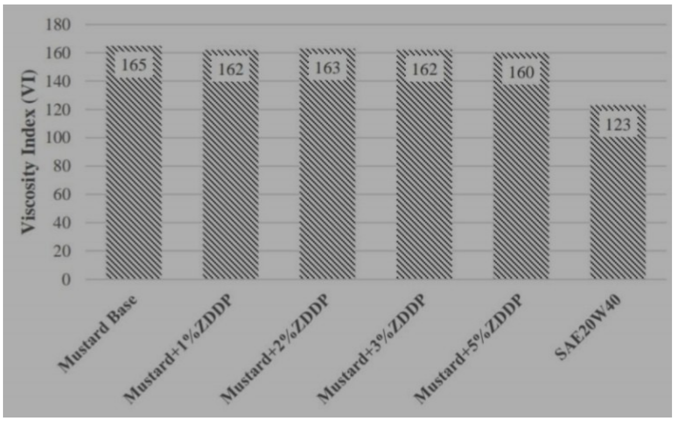


**Fig -7** Viscosity index of different oil samples

## 5.3 POUR POINT

Pour point is the temperature at which an oil ceases to flow when it is cooled. When the temperature is lowered, high molecular weight paraffin waxes precipitate from the oil. These waxes become interlocking crystals and prevent the remaining oil to flow. This oil property is important for any mechanical system that is exposed to low temperature conditions, as in applications such as motor engines, construction equipment, military, and space vehicles. Pour point sets the minimum temperature at which the oil can be used. A simple manual method is used to find the pour point of the oil samples. The experiment is conducted as per ASTM D97. In this method, a 50ml of preheated (40°C) oils is taken in a cylindrical glass vessel and stoppered with a cork that has a provision to insert a thermometer. The vessel is placed in a cooling chamber. The oil is cooled to 9°C above its anticipated pour point temperature after which oil is inspected for every 3°C increment. The temperature at which oil ceases to flow for 5 seconds is taken as the pour point. From Fig. 8, as expected pour point of mustard oil was -14°C due to the higher proportion of unsaturated fatty acids (90%) in the oil. Pour point depends mainly on the structure of the oil and in the case of vegetable oils, it is almost impossible to improve the pour point with additives. Thus, the addition of ZDDP in the mustard oil did not show any effect on the pour point. The 'cis' double bonds found in unsaturated fatty acids inhibit crystal packing, leading to better pour points compared to saturated fatty acids. Yunus et al., 2005, reported that vegetable oils with less than 20% saturated fatty acids in their composition exhibited better pour points. SAE20W40, probably due to the use of pour point depressants such as Polymethylmethacrylate (PMMA) showed the lowest pour points among the tested samples**.**


**Fig -8** Pour point of different oil samples

## 5.4 FLASH POINT AND FIRE POINT

Flashpoint is the temperature at which volatile fumes from the oil are just enough to ignite whereas fire point is the temperature at which enough fumes are produced for sustained burning for 5secs after ignition. It is used to characterize fire hazards of the oil and also poisonous fumes can pollute the environment. Open cup flash point apparatus was used to determine the flashpoint of oil samples. ASTM D92 test schedule was used as standard. Approximately 70ml of the oil was poured into the test cup. Initially, oil in the cup is heated rapidly at the rate of 14-18°C/min. When the oil temperature reaches a temperature of 56 °C below the expected temperature, the heating rate is decreased to 5-6 °C/min. Test flame is introduced when the oil temperature is 28 °C below the anticipated flashpoint. A test flame is passed above the specimen to check for flashes. The initial ignition point is noted as the flashpoint and if the burning of vapors persists for 5secs then it is considered as fire point.

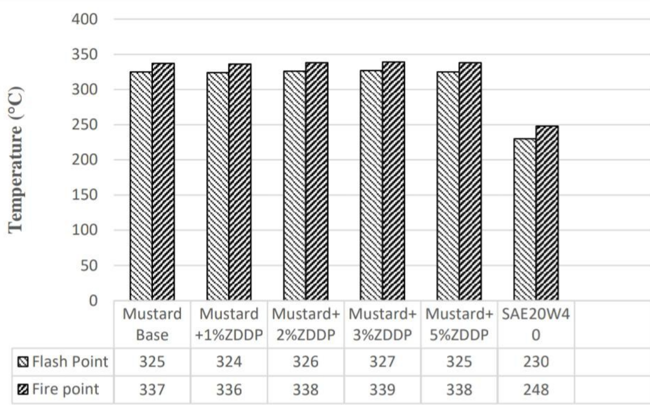


**Fig - 9** Flash and fire points of different oil samples

From Fig.9 , it can be observed that the mustard oil has a higher flash and fire point than SAE20W40. This is attributed to the chemical composition of mustard oil. Wormser, 2007, classified C12-C26, C6-C10, and C2- C24 as long, medium, and short- chain fatty acids. Mustard oil contains about 90% of long-chain fatty acids in its composition and this leads to increased molecular weight and boiling point. Mustard oil has a higher flash and fire point compared to mineral oil since the flashpoint of the oil depends upon the molecular weight of the oil. Also, there is no considerable change in flash and fire points with the addition of ZDDP in any of the samples.

### 5.5 CORROSIVE PROPERTY

Copper strip corrosion tests as per ASTM D130 were performed to determine the corrosion characteristics of the oil samples. In this method, a copper strip is immersed in a test tube containing oil. The test tube is enclosed in a steel container and immersed in a water bath. The bath is maintained at 100 °C and the samples are immersed for a duration of 3hrs before being taken out. At elevated temperatures, the corrosion process is accelerated and causes the coloration of copper strips. The colour of the stain formed on the strips is identified with the standard shown in Fig. 3. All the tests were repeated three times for each additive concentration.

**Table - 1** Colour code of different oil samples

| Specimen | Colour Code |
|---|---|
| Mustard base | 1a |
| Mustard+1%ZDDP | 1a |
| Mustard+2%ZDDP | 1a |
| Mustard+3%ZDDP | 1a |
| Mustard+5%ZDDP | 2c |
| SAE20W40 | 1a |

The Colour code of different oil samples is listed in table 1 using Fig. 3, it can be observed that none of the samples showed corrosive behavior and the corrosiveness of the oil is well within limits. A moderate tarnish was observed for mustard oil additivated with 5%wt. ZDDP, this due to the high acidity (TAN>50) and increased concentration of ZDDP in the oil.

## 6. CONCLUSIONS

Vegetable oils are increasingly being used in industrial and transportation applications due to growing concerns about the environment and depleting hydrocarbon sources. Vegetable oils have certain superior quality characteristics such as renewability, biodegradability, and low toxicity compared to mineral oils. Vegetable oils also have satisfactory performance characteristics such as high viscosity index, high flash point, high lubricity, and low evaporative loss, thus making them attractive potential replacements for mineral-based lubricants. On the other hand, vegetable oils are also known for their poor oxidative, thermal, and hydrolytic stabilities. Further, majority of the vegetable oils also have poor low-temperature characteristics and hence, their applications are confined to hotter working conditions. Mustard oil is one of the few vegetable oils that have satisfactory cold flow or low-temperature properties. This is due to the presence of a very large proportion of unsaturated fatty acids in its fatty acid profile. Works of literature related to the tribological, rheological, and physical properties of mustard oil are scarce and therefore the present work concentrates on the effect of lubrication and cooling properties of mustard oil and mustard oil additivated with standard industrial AW/EP additive-ZDDP. The following conclusions were made regarding the analysis of the effect of additive on lubrication properties of mustard oil. Wear and friction studies as per ASTM 4172 were conducted on mustard oil with and without ZDDP and SAE20W40. Additive concentrations were selected empirically and were fixed at 1%wt., 2%wt, 3%wt, and 5%wt. of base oil. The highest WSD of 795μm was observed for mustard base oil and the lowest WSD of 429μm was observed for mustard oil + 1%wt. ZDDP. SAE20W40 observed a WSD of 507μm which is significantly higher than mustard oil with 1%wt. ZDDP. Also, at higher additive concentrations, wear increased significantly with the highest WSD of 470μm observed for mustard oil + 5%wt.ZDDP. Hence, mustard oil with an additive concentration of 1%wt. exhibited superior wear-resistant property than the SAE20W40. Further, the highest CoF of 0.199 was recorded for mustard oil+5%wt.ZDDP and the lowest value of 0.0684 were observed for mustard oil+1%wt.ZDDP. SAE20W40 showed a moderately higher CoF of 0.1145. From WSD and CoF values of mustard+1%wt.ZDDP indicates that mustard+1%wt.ZDDP exhibited better lubricity out of all oils considered for the study. Appropriate tests were conducted as per ASTM standards to evaluate certain physical properties of the oils namely rheological, flash and fire point, pour points, and oil corrosiveness. Rheological studies carried out in the work indicated a higher VI of 165 for mustard oil compared to 123 of SAE20W40. This is in perfect agreement with the fact that vegetable oils on account of its stronger intermolecular interaction, provide stable viscosity at higher temperatures. Further, the addition of ZDDP did not show any effect on the viscosity of the mustard oil. The range of viscosity available for SAE20W40 is considerably higher than the mustard oil. Pour point of mustard oil was recorded to be -14°C in comparison to -21 of SAE20W40. Thus, mustard oil belongs to the rare club of vegetable oils that exhibit excellent cold flow properties without any prior chemical modification. Flash and fire points were higher for mustard oil compared to SAE20W40. Thus, mustard oil is must safer at higher temperatures than SAE20W40. Corrosive property tests were conducted using a copper strip test and none of the strips indicated any corrosive stains. However, a moderate tarnish (2c) was observed for mustard+5%wt.ZDDP while the remaining oils showed slight tarnish (1a).

## REFERENCES

1. Amrit Pal, Sukhpal Singh Chatha, Hazoor Singh Sidhu.[1] Experimental investigation on the performance of MQL drilling of AISI 321 stainless steel using nano-graphene enhanced vegetable-oil-based cutting fluid (2020).
2. Ayamannil Sajeeb, Perikinalil Krishnan Rajendrakumar.[2] Comparative evaluation of lubricant properties of biodegradable blend of coconut and mustard oil (2019).
3. Kishor K Gajrani and Mamilla R Sankar [3] had undergone studies on Sustainable Cutting Fluids: Thermal, Rheological,

Biodegradation, AntiCorrosion,Storage Stability Studies and its Machining Performance (2018).
4. K Joseph Babu , K Prabhakaran Nair and ML Joy. [4] Development of cutting fluid from transesterified coconut oil and evaluation of its tribological properties (2018). 5. Muzammil S. Khan, Mahendra Singh Sisodia, Shubham Gupta, M. Feroskhan, S. Kannan, Karunamurthy Krishnasamy
[5] Measurement of tribological properties of Cu and Ag blended coconut oil nanofluids for metal cutting (2017). 6. Rakesh Somashekaraiah, Suvin P S , Divya Prakash Gnanadhas , Satish Vasu Kailas , Dipshikha Chakravortty [
6].Eco-Friendly, Non-Toxic Cutting Fluid for Sustainable Manufacturing and Machining Processes (2016). 7. S. Rani, M.L. Joy, K. Prabhakaran Nair.
[7] Evaluation of physiochemical and tribological properties of rice bran oil – biodegradable and potential base stoke for industrial lubricants (2014).
8. VY.M.Shashidhara ,S.R. Jayaram. [8] Vegetable oils as a potential cutting fluid—An evolution (2010)
9. Weiqiang Zhan, Yuping Song, Tianhui Ren, Weimin Liu. [9] The tribological behaviour of some triazine–dithiocarbamate derivatives as additives in vegetable oil (2003)
10. X.C. Tan , F. Liu, H.J. Cao, H. Zhang [10] A decision-making framework model of cutting fluid selection for green manufacturing and a case study (2002) .
11. Allyson M. Barnes , Keith D. Bartle, Vincent R.A. Thibon.[11] A review of zinc dialkyldithiophosphates (ZDDPS): characterisation and role in the lubricating oil (2001).
12. U. S. Choi, B. G. Ahn, O. K. Kwon and Y. J. Chun. [12] Tribological behavior of some antiwear additives in vegetable oils (1998)
13. ASTM D4172-94, 1999, Standard Test Method for Wear Preventive Characteristics of Lubricating Fluid (Four Ball Method), ASTM International, West Conshohocken, PA, USA

## BIOGRAPHIES

Abi Adil. M.C
S4 ME, Manufacturing Engineering
Shree Venkateshwara Hi-Tech Engineering College, Erode, India.