

# Performance evaluation of vegetable-based lubricants in metal cutting

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## Technical Note

### Abstract

Over the last decades, mineral oil-based fluids are used in metal cutting operations. The hazardous impacts of mineral based oil on the environment are compelling industries to search for alternative oil. Recently, vegetable based oils have found significant attention from industrialists due to its environment-friendly and biodegradable characteristics. In this paper, five vegetable-based oils are being evaluated as a possible replacement for non-biodegradable mineral oils. Further, an attempt was made to predict the effect of vegetable oils (mustard, palmolien, Sesame, groundnut, rice bran) on wear performance in metal cutting operation employed with four-ball tester equipment. The experimental result shows the wear properties of biodegradable oil samples derived from vegetable oils. As a part of this research work the anti-wear performance of the selected vegetable oils is evaluated according to the standard procedure to understand their wear performance. Among all the vegetable oils studied, mustard oil shows better lubrication behavior.

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## 1 Introduction

At present, the cutting fluids used in machining or metal cutting operation are mostly mineral oil (Petroleum) based. It is, therefore, imperative to look at the alternatives to petroleum-based cutting fluids. Metal cutting fluids play a vital role in machining operations. Different types of metal cutting fluids are available for usage depending on the application. Metal cutting is a process used to remove unwanted material in the form of chips to get desired shape, size and surface finish. The profile of the tool and its dissemination into the surface of the work piece, combined with their relative motions, produce the required geometry of the resulting work surface. Vegetable oil based cutting fluids is one such better alternative to petroleum-based cutting fluid. Vegetable oils are desirable for use in metal cutting fluid applications because they come from renewable feedstock (which reduces dependence on foreign oil), they are less toxic for the use and at the end-of-life, and they have been shown to be more stable and easier to recycle under field conditions. They may also be most suitable for medical applications (e.g. Machining of medical products) since substantially no toxic materials are used, as well as for non-operational processes [1]. Vegetable oils have also been shown to be better lubricants than mineral oils. In addition, CO<sub>2</sub> is sequestered from atmospheric air when the vegetable feedstocks are grown which is a source of global warming, However, before they can be used for commercial applications, a lot of research needs to be done for their commercial viability [2].

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Cutting fluids of various types are usually employed to control the wear occurring during machining. Functions such as improving tool life and machining process efficiency, enhancing surface integrity and part accuracy, reducing cutting forces and vibrations are obtained by using cutting fluids. The opportunities for developing advanced manufacturing capabilities, while at the same time, reducing the impact of manufacturing on energy use, water and resource consumption and, overall, greenhouse gas emission and carbon footprint are numerous [3]. The primary aim of applying cutting fluids during machining is to eliminate, overcome or at least reduce the heat generation effect, friction and corrosion of both the tool and the work piece [4]. Their resulting positive effects include prompt heat removal, lubrication on the chip-tool interface and chip removal by constantly cleaning the machined zone [5].

Heat is generated and built-up in the region between the tool's rake and flank faces and the work piece by the action of rubbing together of the tool and work piece. This may lead to the generation of tensile residual stresses and micro cracks in the material surface [6]. Frictional energy develops between the duo that leads to rapid tool wear and a reduction in tool life. The work reported by Rao et al. [7] indicated that use of soybean-based cutting fluids have advantages in terms of performance improvement comparable or better than the petroleum based fluids. This will improve its main credentials as green cutting fluid since it does not have any harmful additives that complicate the disposal procedures and hence the disposal cost. The trend was extended to formulate environmental friendly metal working fluids. Finally, the review revealed that the vegetable oils have a large scope to utilize them as metal working fluids [8]

Vegetable oils were found to be promising alternative for mineral based oils due to their environmental friendly characteristics. These were utilized to develop biodegradable lubricants for various industrial applications. Performances of three VBCFs developed from crude sunflower oil, refined sunflower oil, refined canola oil and commercial semi-synthetic cutting fluid is compared in terms of tool wear, thrust force and surface roughness during drilling of AISI 304 austenitic stainless steel with HSSE tool [9] The performances of palm oil and groundnut oil were compared with the mineral oil-based cutting fluid during machining operation of mild steel. Groundnut oil possesses better fluidity and faster cooling capacity than other oil samples. Groundnut oil and palm oil are recommended as viable alternative lubricants to the mineral oil during machining of mild steel [10]

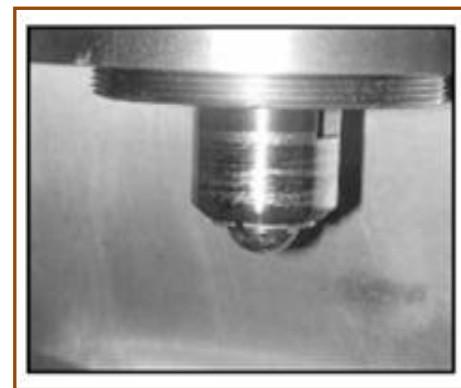
During this investigation, our aim was to understand the application of vegetable oils as potential metal working fluids. Experimental setup is mainly decided to study the wear characteristics of vegetable oils under fixed time and varying load conditions. The vegetable oils include basically palm oil, coconut oil, rice bran oil, Soya oil, sesame oil, castor oil, mustard oil, groundnut oil, and sunflower oil. This work will help in reducing the damage of mineral oils on the environment. On the other hand it will promote the use of eco friendly vegetable oils in various applications.

## 2. Experimental setup

Four ball testers include a test cup with three steel balls positioned inside the test cup as shown in Fig. 1. The steel balls are held very strongly fix together by a conical ring that is secured via threaded fasteners to lock the balls in place. A typical four ball test machine utilizes three steel balls that are 12.7mm in diameter as shown in Fig. 2.



**Fig. 1** Three balls are locked into base fixture



**Fig. 2** Fourth ball is locked into driven shaft

A test fluid is placed inside the cup covering the three balls. With reference to the above figure, the test cup is then positioned in a four-ball tester as shown in Fig. 3. The three balls are placed in the oil cup and the washer, and the upper cover is placed to hold the balls firmly. The oil to be tested is poured in the oil cup till it fully covers the three balls and then the oil cup is placed on the bearing support provided.



**Fig. 3** Test lubricant is poured into the base fixture

The four ball tester illustrated in the Fig. 4 includes a heater block to heat the test cup and fluid. Weights are supported by the lever arm, which pivots about a pivot to push upwardly on the support column. A rotating shaft or spindle has a fourth test ball at the end that contacts the three test balls in the test cup. The shaft is connected to an electric motor via belt for the powered rotation of the shaft. The amount of force pushing the three balls in the test cup against the ball on the rotating spindle can be varied by changing the weights. Typical lever arm have a 10:1 ratio such that a four-kilogram weight causes the bottom three balls in the test cup to push up against the rotating top ball on spindle with a force of 40 kg. The appropriate load is applied on the loading arm and then the collet containing the top ball is lowered so that it presses against the three balls. The temperature is set to a desired value. The heating element is attached to the base of the cup and the temperature is controlled by a thermocouple. The motor is then started and is allowed to run for the desired test time as shown in Fig. 5.



**Fig. 4** Loading arm connected with four ball tester to measure wear

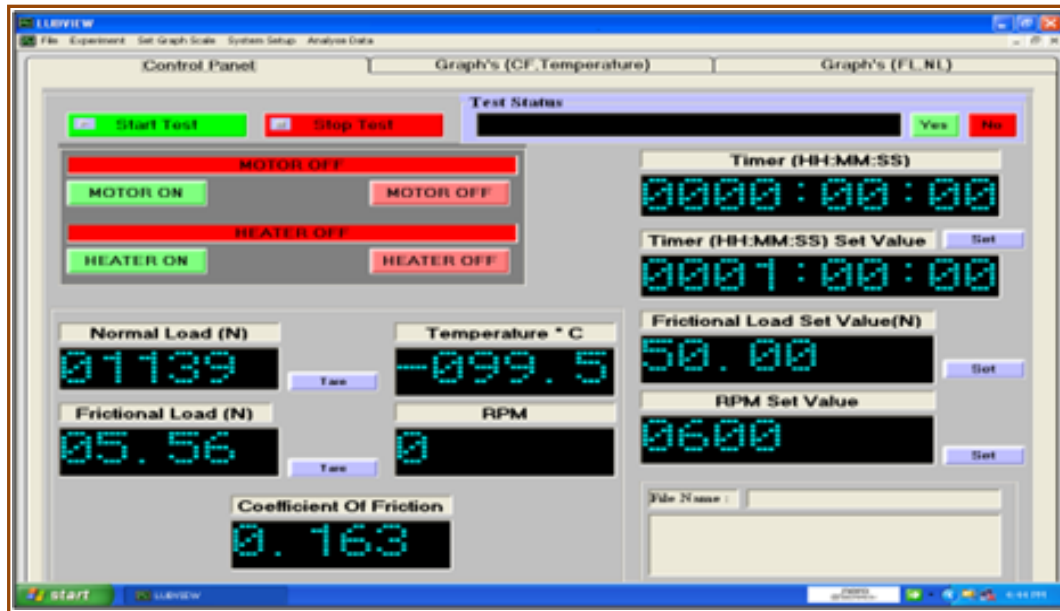


**Fig. 5** Control Panel integrated with LABVIEW software

### 2.1 Test and runs

A common four ball test method utilizes a various loads within the range 100N- 600 N and is running at 1200 RPM at 75° C for one hour which is manually set by an operator as shown in Fig. 6. At the end of the test run the motor is stopped, the heater is turned off, the load is removed, and the test cup is taken off the tester. Upon completion of the test, the test cup is removed from the tester, and the test lubricant is drained. The cup with three bottom test balls still locked in place is placed under a microscope to measure the wear scars. The wear scars result from the top ball rotating against each of the bottom three balls under the test load. The wear scars are measured for each of the bottom three balls. In general, each of the three bottom balls will have a wear scar that is very similar in size and shape of the other two lower test balls. A measurement is made with a microscope of each

wear scar diameter, in both the vertical and horizontal direction. A total of six measurements is taken considered to be the wear scar diameter for a given test fluid under a specific test method.



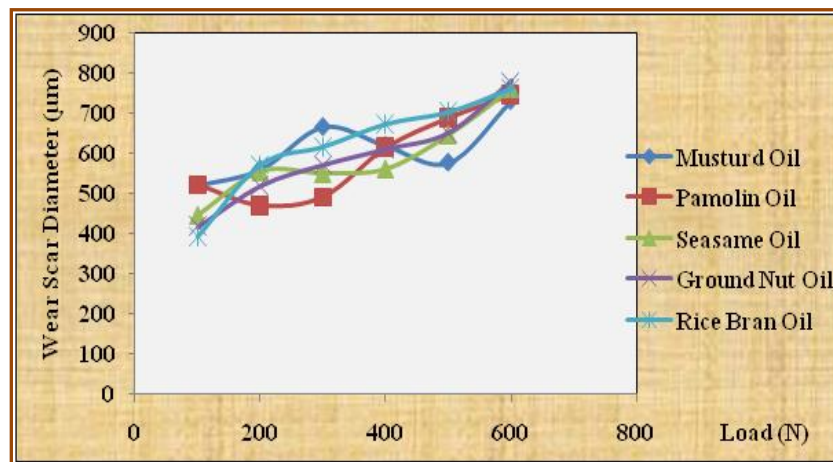
**Fig. 6** Display of experimental parameter setup

### 3. Wear scar diameter

Table 1 explores the wear scar diameter for the tested oils using image acquisition system and magnification with the help of Winducom 2014 software. The image acquisition system used to measure the different wear surfaces of the worn balls.

### 4. Results

As per the details of working procedure given under the section of Methodology, tests were carried out on five vegetable oils, namely Mustard oil, Palmolein oil, Sesame oil, Ground nut oil & Rice bran oil. The various parameters were recorded separately for each oil such as normal load, frictional load, temperature, RPM, co-efficient of friction and time under standard test conditions that is at variable load conditions 100-600N and constant 1200 RPM and 75<sup>o</sup> C is running for one hour duration. After the test is over for one hour duration the bottom three balls which had point contact with top ball will have point wear scar which are measured using a microscope.



**Fig. 7** A Plot based on vegetable oil's load versus wear scar diameter

**Table1. The values obtained from all Vegetable oils of Wear Scar Diameter (WSD) at different loads for 1 hour is tabulated.**

Load (Newton)	Wear Scar Diameter (WSD) (Micron meter)				
	Musturd Oil	Palmolin Oil	Sesame Oil	Ground Nut	Rice bran Oil
100	520	520	446	416	390
200	559	468	555	518	570
300	665	490	550	570	615
400	618	613	561	609	672
500	576	687	646	650	702
600	730	745	761	778	761

## 5. Conclusion

Vegetable oils, are biodegradable, non-toxic and non-hazardous when compared to conventional mineral oils which are used for metal cutting operations. From Fig. 7 It can be easily recognized that with increasing the load the wear scar diameter is increased for the specific oil. An experiment to determine better lubricant among the five samples of vegetable oils was performed. In this study, Wear Scar Diameter (WSD) was measured for individual oil at different loads to evaluate the wear resistance. The results summarized different values of WSD for each oil at extreme load conditions and mustard oil were found to have the least wear properties among all oils. This suggests that mustard oil is a better lubricant among all five oils considered.

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