Vegetable oil based cutting fluids as an alternative for mineral oils for metal cutting- A review

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***Abstract*—The growing demand for biodegradable materials has opened an avenue for using vegetable oils as an alternative to mineral oils. Vegetable oils are being investigated as a potential source of environmentally favorable cutting fluids, due to combination of high lubricity, better heat conductivity, biodegradability, renewability and excellent lubrication performance. It is a replacement for mineral oil which has poor biodegradability and thus it's potential for long-term pollution of the environment and workers health. It is possible for the development of a new generation cutting fluid where high performance in machining combined with good environment compatibility is achieved with the use of vegetable oils. This review addresses the preparation of vegetable oils as cutting fluids, characterization of vegetable oil cutting fluids and metal cutting performances**

***Key words*— Vegetable oil, Cutting fluid, Performance.**

1. INTRODUCTION

Cutting fluids are used to minimize the negative effects of the heat and friction on both tool and workpiece. The cutting fluids produce three positive effects in the process: heat removal elimination, lubrication on the chip–tool interface and chip removal [1].

Metal working fluids are one of the types of lubricants, which are extensively used in machining operations. There are several types of metalworking fluids (MWFs), which may be used to carry out such tasks [2]. Most of the MWFs are mineral oil based fluids. These fluids increase productivity and the quality of manufacturing operations by cooling and lubricating during metal forming and cutting processes [3]. Due to their advantages, the consumption of MWFs is increasing in machining industry. It is reported that European Union alone consumes approximately 320,000 tonnes per year of MWFs of which, at least two-thirds need to be disposed [4].

Despite their advantages and widespread use, if these cutting fluids are inappropriately discharged they pose significant health and environmental hazards throughout their life cycle. Due to the harmful effects posed by these fluids, it is necessary to develop an alternative solution which reduces these environmental as well as health risks. Vegetable oils are highly attractive substitutes for petroleum-based oils because they are environmentally friendly, renewable, less toxic and readily biodegradable [5, 6].The most important characteristic of vegetable oil is its biodegradability. According to willing [7] biodegradability is the most important aspect of a substance with regard to the environment. The use vegetable oils in cutting fluid applications are limited because of their poor oxidative stability. This problem can be eliminated by structural modification of vegetable oil by chemical reactions. Sulphur and ozone modifications were used in these reactions [7]. In this paper an attempt is made to review the preparation of vegetable oil cutting fluids performed by various authors, its characterization and metal cutting performance. Further, their theoretical and experimental results obtained are reported.

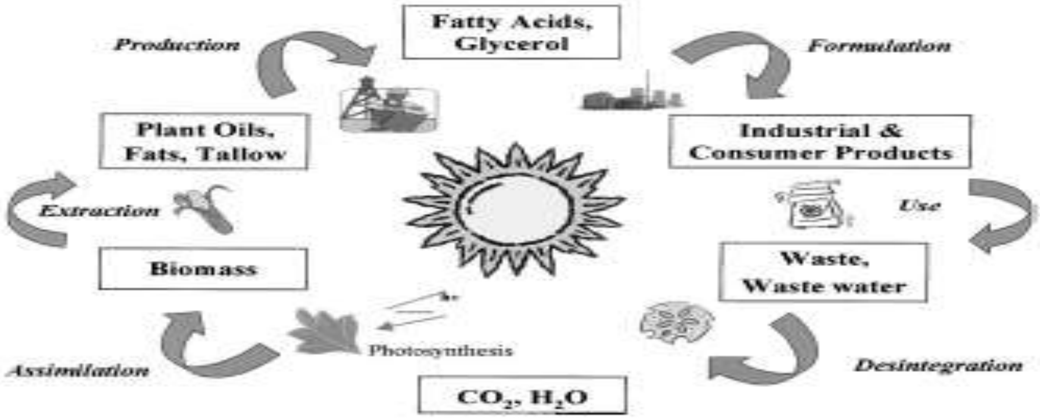


Fig.1. Life cycle of chemical products based on renewable resources [8]

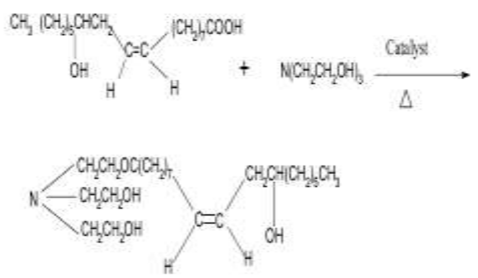
II. PREPARATION OF VEGETABLE OIL- BASED CUTTING FLUIDS

The general composition of water miscible cutting fluids can be characterized as an addition of base oil and emulsifier. Other components may be added to the fluid. such as: solution improvers, neutralization agents, corrosion and rust inhibitors, lubricating additives, biocides and fungicides, agents to improve stability in hard waters and foam inhibitors. For the preparation of the proposed fluid, some steps were followed:

- Selection of components: It is necessary to consider if the chosen components are not problematic, dangerous for the environment or health.
- Mixing: Firstly add oil in water and mix for 2 min. After all substances are added, they are mixed together for 15 min. A test emulsion is prepared in order to verify, the mixture stability. It must repose for 24 hours without oil/water separation. In case the emulsion is not stable, the amount of emulsifier agent needs to be adjusted.
- Verifications**:** Check some chemical and physical properties of the coolant, such as: PH, viscosity, corrosion and biodegradability and adjust the formulation. [9].

The factors influencing in the preparation of cutting fluids are reactants for base oil, molar ratio of reactants, optimal reaction temperature, optimal reaction period, type of catalyst and polymerization inhibitor. Biodegradability of the base oil has a direct effect on that of the obtained cutting fluid. Therefore, the selection of base oil remarkably affects the effects of cutting fluid on the environment. Molar ratio of the reactant has an effect on the reaction. Over high or over low amount of the reactant may result in a direct effect on esterification or wastage. Therefore, a proper molar ratio should be determined. Reaction temperature has a certain effect on the performances of the product. Over heat may lead to the deterioration of the substance. For further increase of reaction speed and production efficiency, selection of suitable catalyst is of high importance.

According to [10] the preparation of the castor oil cutting fluid is as follows-A base oil of excellent water solubility, triethanolamine ricinoleate, is formulated at 90 ^{o}C for 150 min with castor acid and triethanolamine at the molar ratio of 1 to 3, p-toluene sulphonic acid as the catalyst, and ferrous ammonium sulfate as the polymerization inhibitor. An environmentally friendly water-based synthetic metal-cutting fluid is in turn formulated with this self-made base oil and other additives. The reaction is expressed by the following reaction.



The test results indicate that this cutting fluid has good cooling, cleaning, anti-rust, anti-corrosive and lubricating properties, is totally free of mineral oil, animal oil, nitrite that is harmful to the human body, phosphate that causes water pollution and etc., and has stable and reliable quality, long service life, easily available raw materials and low production cost.
The composition of the castor oil cutting fluid formulated by Salete Martins Alves and Joao Fernando Gomes de Oliveria[9] for their experiment of it on the grinding wheel were (% in volume): Sulfonate Castor oil (40%), water (35%), bactericide (Derivate of triasine) (5%), anticorrosive (synthetic ester) (15%), emulsifier agent (polyglycol of synthetic ester) (5%).The amounts of bactericide and anticorrosive are not far from the values used in commercial products. The main difference in this proposed fluid is the higher concentration of vegetable oil. Therefore, the stability of the concentrate emulsion was adjusted, by varying the amounts of emulsifier and water. Another characteristic of this proposed formula is the reduction in the amount of additives, making easier the disposal and degradation of the mixture.
The selected vegetable oil (castor oil) is obtained from a plant called mamona in South America. The scientific name is ricinus communes, or castor-oil plant in English. This oil was selected for this research due to its abundance in South America and its stability. In order to improve the oxidative Stability and others problems with use high temperatures (like temperatures reaching during grinding processes) the castor oil was structurally modified. Castor oil was modified using Sulfurization.

III.PROPERTY CHARACTERISATION OF VEGETABLE OIL BASED METAL CUTTING FLUID

- **pH**

The cutting fluids pH can be determined by digital PH meter. Always before the measurement, the PH meter should be calibrated with standard solutions. The cutting fluid pH should be between 9 and 11.

- **Viscosity**

A ball viscometer can be used to determinate the viscosity of the cutting fluid. This method is very traditional and simple. The equipment consists of a tube with two marks, where the cutting fluid is put, and a ball that, depending on fluid viscosity, have a specific fall time. By Eq. (1) it is possible to calculate the fluid viscosity $\eta = t(\rho 1 - \rho 2)K$ (1) where η is the dynamic viscosity

(MPa s), ρ_1 the ball density (g/cm3), ρ_2 the fluid density (g/cm3),t the fall time of ball between of two marks of tube (s) and K is the ball constant (0.13MPa cm3)/g.

- **Corrosion**

Corrosion is a reaction of a metallic material and the environment. This reaction causes measurable changes in the material surface properties. Amount of corrosion cane be determined by the corrosion grade of cutting fluid by its contact with cast iron. This test was carried out by adding some grams of cast iron chips, previously washed in acetone and dried, and placed on a piece of filter paper in a Petri dish. The chips were evenly spaced around the filter paper, prevented from contacting one another and humidified in 2ml of the test cutting fluid. The chips were left in the covered Petri dish for 2 hours. At the end of 2 hours, the iron chips are discarded and the filter papers are rinsed in acetone. The corrosion grade of the cutting fluid is measured by observation how many spots appeared in the filter paper surface. The objective of this analysis is to determinate the anticorrosive characteristics of soluble cutting fluids. Table 1 shows how the corrosion grade can be determinate [9].

Corrosion Grade	Mean	Filter paper surface
0	Without corrosion	No spots
1	Vestiges of corrosion	Three spots in the maximum
2	Low corrosion	Less 1% paper area with spots
3	Moderate corrosion	Between 1 and 5% paper area with spots
4	High corrosion	More 5% paper area with spots

Table 1: Identification of corrosion grade

3.4 Biodegradability:

The method used to investigate the cutting fluid Biodegradability was Ready Biodegradability: 301B CO_2 Evolution Test adopted on 1992 (OECD), 1997. In this test a system of aeration of continue flux, in order to filter the air various flashes with sodium hydroxyl were used. The test was carried out in dark, under 20–25 ^oC and during 28 days. The cutting fluid biodegradability was evaluate by CO_2 evolution that was absorbed by $Ba(OH)_2$ solution during test period. The CO_2 evolution was determinate by titration with HCl.

IV. METAL CUTTING PERFORMANCE

[11] studied the performance of cutting fluids for turning, drilling, reaming and tapping operation for austenitic stainless steel and other four materials. The emphasis was on austenitic stainless steel to evaluate the fluids. Various parameters such as cutting thrust, tool life and product quality were considered for the evaluation. NT MECH 038, 1997, ASTM D5619-94 standards were adopted for testing the parameters. Two different groups of cutting fluids such as water based and straight oils, including mineral, synthetic and vegetable based formulations, were tested. The results, on austenitic steel, revealed that the cutting force under vegetable oils and esters modes were low compared to reference mineral oils. However, it has been reported that the tool life was escalated under vegetable oils/ester modes of lubrication. Figs. 1–3 indicate the experimentation results.

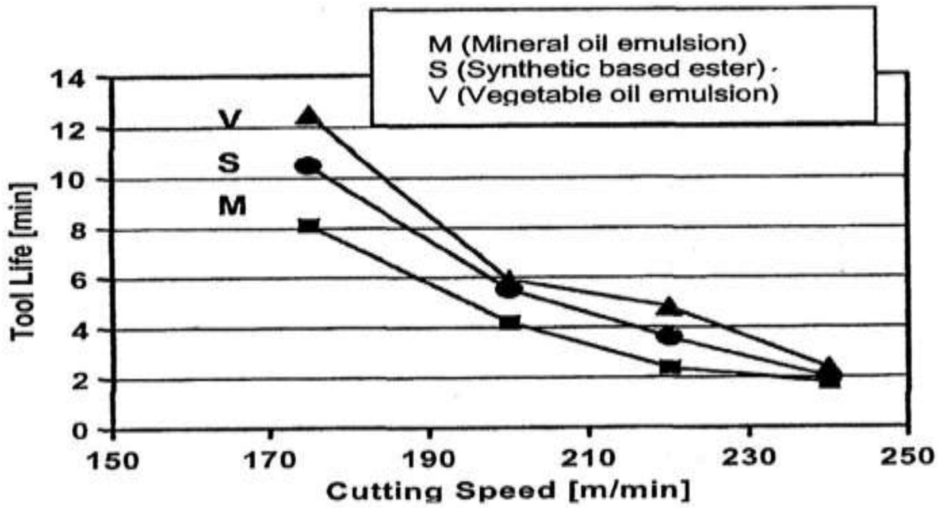


Fig.2.Tool life measurement to catastrophic failure in turning austenitic stainless steel at different cutting speeds using water-based cutting fluids [11].

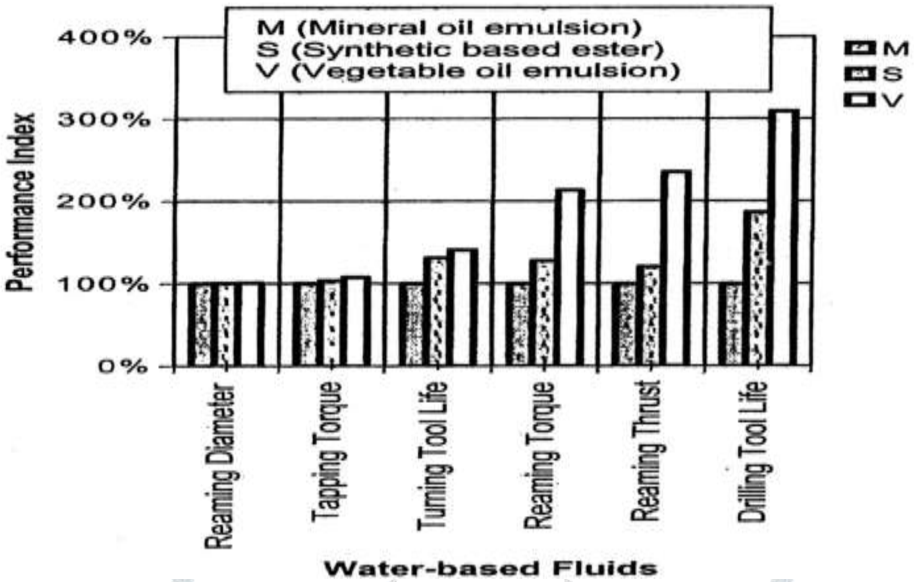


Fig.3. Cutting fluid efficiency evaluated using different operations and performance criteria-Water–based fluids. Work material: austenitic stainless steel [11].

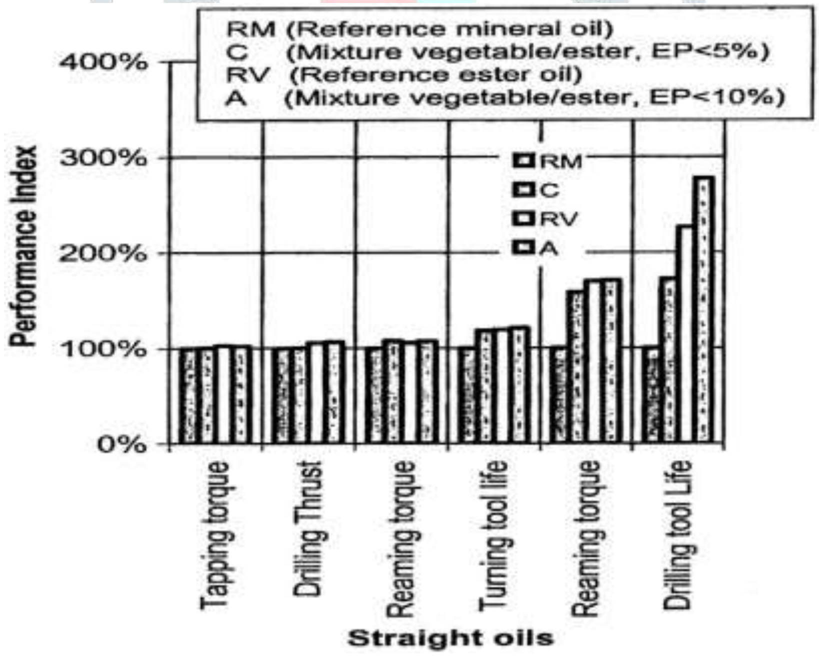


Fig.4. Cutting fluid efficiency evaluated using different operations and performance criteria —straight oils. Work material: austenitic stainless steel [11].

V. CONCLUSION

Vegetable oils were found to be a good alternative for mineral based oils due to their environmental friendly characteristics. These vegetable oils can be used as a lubricant in industrial application reducing the cost. Researchers are being carried out upon the vegetable oils to make it more suitable for other applications also. The review is made in two approaches, one based on the desirable properties of vegetable oil as metal working fluid and other on the performance of these oils for various cutting operations. Finally, the review revealed that the vegetable oils have large scope to utilize them as metal working fluids.

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