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THE FUTURE OF LUBRICANTS IS IN "CLOSING THE CYCLE" AND ECO-TOXICITY; CUTTING OIL EMULSIONS AS AN EXAMPLE*

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Abstract
For product sustainability "closing the cycle" is the first requirement. If the materials used in making the product is not replenished at the rate at which it is being extracted, the cycle is open and the product would not be sustainable. This includes the materials used in generating the energy used to make the product, the transportation, use and disposal. If the materials used in a product, that includes lubricants, is one that cannot be replenished, it has to be recycled for the product to be sustainable. The other basic condition for sustainability is the eco-friendliness of the product. It is argued that the present lubricants do not fall in this category. Using the example of cutting oil emulsions we have shown that it is possible to meet the conditions of sustainability in terms of both the material extraction-replenishment cycle and eco-toxicity. Cutting oil emulsions made from coconut oil and natural additives are shown to have superior cutting properties and are completely eco-friendly. It is concluded that products made using these conditions are possible and is a necessity for man to lead a sustainable life. Closing the cycle, with respect to the energy used in the cycle will make the product completely eco-friendly.
Keywords: Sustainability; Closing the cycle; Eco-toxicity; Lubricants; Cutting oils.

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1 INTRODUCTION

Lubricants are one of the oldest tribological product used by Man. The use of lubricants increased substantially with the advent of the industrial revolution. The main purpose of lubricants was to reduce friction between rubbing surfaces and to increase life of these components. During a metal cutting operation, where a tool is used to cut away metal, a metal working fluid is used to reduce friction between the tool and the work-piece, removal heat, increase tool life and give a better surface finish and tolerance to the part being cut. Apart from these primary functions a metal working fluid should prevent corrosion, flush away the metal chips, have good anti foaming properties, not form residues, and have low bacterial growth. One of the other primary requirement that has been ignored is that the metal working fluid should be environmentally friendly [1,2].

During the last two decades there has been a considerable increase in the development of metal working fluids that are eco-friendly. Development of eco-friendly products is essential and it should be mentioned that most of today's lubricants are not eco-friendly The requirement to develop completely eco-friendly lubricants becomes a bigger priority as many of them, including metal cutting fluids, are either dumped into the environment or are completely lost to the environment during use. Greases fall in the complete loss category. Even lubricants that can be recycled are partly lost to the environment and around 20% of the lubricants is estimated to be lost to the environment [3]. Metal working fluid emulsions are generally composed of an oil, emulsifier and additives that give the required properties. Most of the present day metal working fluid emulsions are made out of raw materials that are non-biodegradable, toxic, non-renewable and unsustainable [4-7].

Environmental friendliness and sustainability has to go together hand in hand while developing any future product. The question that needs to be asked is, what is the criteria that needs to be used, by which a metal working fluid or any other lubricant becomes environmentally friendly and sustainable? Environmental friendly product should be bio-degradable, non-toxic and renewable [8], while sustainable means that the resources used for making the product should not run out.

To understand the concept of environmentally sustainability, "closing the loop" approach is helpful. In this approach the product developer should trace the path of the materials that go into making the product. If the product is something that goes into the environment during and after use, it should then be completely non-toxic and the raw materials that go into making the product should be regenerated by nature. If the product used materials that are not regenerated then it should be completely recycled. Thus a product that follows the "cradle to grave" process should use materials that are non-toxic and are regenerated. If the materials used in the product are toxic or use materials that are not regenerated, it should follow the "cradle to cradle" cycle. This means that all the materials that go into making the product should be recycled and in a truly sustainable "cradle to cradle" cycle the materials should be 100% recycled. Most of the present day lubricants that are "take-make-waste" products should be non-toxic and use renewable components. The analysis of the concept of sustainability for both the open loop and closed loop should not only include the sustainability of materials used, but has to also include the source of energy used during extraction, production, usage and disposal. The energy consumed during the whole cycle has to be from sustainable sources.

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In the case of metal working fluid emulsions, the only possible way to move out of an unsustainable toxic cycle is to use of raw materials from natural source, where these raw materials has a ”closed loop cycle”. This means that the possible raw materials, with the present rate of consumption, are natural oils (vegetable oils) and other plant based or biological origin based products. Many natural oils can be considered as suitable alternatives to replace mineral oils for base oil stock [9-12]. And many plant based extracts or essential oils can be utilized as additives. Many of these products showed comparable or even better properties than present day cutting fluids and for other lubricants [13-16].
Thus the present study, started with a philosophy, that is different from what is mostly done today; making a non-environmental friendly unsustainable metal working fluid into a more environmentally friendly sustainable product. The philosophy followed was in making a product that is completely environmentally friendly and sustainable in the first place. The challenge of unsustainability and non eco-friendliness was overcome by utilizing coconut oil as the base oil, food based emulsifiers and plant based/extracted additives to make a metal cutting emulsion. In the subsequent sections we present the details about synthesis and characterization of a completely sustainable and eco-friendly metal working emulsion.

2 MATERIAL AND METHODS

Non refined Coconut oil was obtained from a local coconut oil making company. Emulsifier was selected in the laboratory from natural sources by performing aquatic toxicity test and with the ability to make a stable emulsion. More than 7 different emulsifiers from natural sources was screened and finally an emulsifier named Emulsifier BBE-007 was selected for further studies. Emulsifier BBE-007 was obtained commercially and it was of plant origin and in the form of a gum. Additives like addditive-1 and additive-2 were obtained commercially with 99.98% purity and it was originally obtained from plant sources through extraction.

2.1 Aquatic Toxicity

Aquatic toxicity was performed by following OECD 203 method. Seven fish was exposed to the test sample for a period of 96 hours. Mortalities are recorded at 24, 48, 72 and 96 hours and the concentrations which kill 50 per cent of the fish (LC50) are determined.

2.2 Anti-foaming of Emulsion

Test was performed by following ASTM D3601 method a standard test method for foam in aqueous media (Bottle Test). The test sample was put into a test bottle and shaken vigorously. The increase in volume is determined by the increase in total height of the test fluid, including foam. The tests were done at 25± 1°C (77 ± 1.8°F).

2.3 Emulsion Stability

To ensure uniformity of the emulsion, it was mixed thoroughly before removing the quantity required for the test. 75ml of the test emulsion (both the eco-friendly and commercial) was transferred into sample bottles. In the first test, the bottles was capped loosely to prevent pressure build up and were placed in a hot air

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convection oven at 50 ±1ºC for a period of not less than 15 hours and not more than 20 hours. In the second test, the bottles were capped loosely to prevent vacuum build up and were placed in a refrigerator at 0 ±1ºc for a period of not less than 15 hours and not more than 20 hours. At the end of the test period, the sample bottles were removed from the oven or the refrigerator and allowed to stand undisturbed to attain room temperature. The test fluid was examined for signs of turbidity, phase separation or gelling.

2.4 Anticorrosion Test

Anticorrosion test was performed by following ASTM D4627 method, a standard test method that uses cast iron chip corrosion method for water–dilutable metalworking fluids. In the test, cast iron chips are placed in a petri dish containing a filter paper and diluted metalworking fluid. The dish is covered and allowed to stand overnight. The amount of rust stain on the filter paper is an indication of the corrosion characteristics of the fluid.

2.5 Tribological Evaluations

Tribological evaluations were performed in a lathe machine, which is equipped with a three axis dynamometer to measure the cutting forces that include the tangential force, feed force and radial force. The measured forces in dynamometer was channeled to a computer and saved by using LabVIEW® software. Commercial grade aluminum rod of 25mm diameter was used as work piece. Tri edge carbide cutting tool with rake angle of 15° was used to cut and it was attached to tool holder of the dynamometer. An emulsion with 5% of cutting fluid was prepared with distilled water for all experiments. Cutting fluid emulsion was supplied to the point of cut by a pump through a single nozzle with a flow rate of 3.0 LPM. The different cutting parameters used to evaluate the cutting fluid performances are given in the table-1.

Table 1. Parameters used to evaluate the cutting fluid performance in turning

Spindle speed (RPM)	Depth of cut(mm)
421	0.5
421	0.75
421	1.0
646	0.5
646	0.75
646	1.0
1000	0.5
1000	0.75
1000	1.0

3. RESULTS AND DISCUSSION

3.1 Aquatic Toxicity

The results got from the aquatic toxicity is shown in table 2. Coconut oil was completely non-toxic. Natural emulsifier and natural additives also showed relatively non-toxicity. Whereas, commercial cutting fluids were highly toxic and it did not even pass the limit test of 100mg/L as per OECD 203 method. Coconut oil being a vegetable oil, contains triglycerides as its main chemical components. Triglycerides

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are made up of saturated or unsaturated fatty acids. Fatty acids are nontoxic to many aquatic organisms including fishes and, in fact, many of these aquatic organisms utilizes fatty acids as food. This is evident by observing the fishes put in the tests with coconut oil, which grow in size after the test, when compared to that before the test. Natural emulsifiers and natural additives are also composed of fatty acids as their major fraction of its composition, along with many natural terpeniods, alkoloids, flavionoids etc., but are at very minimal concentrations.

Table 2. Aquatic toxicity level of coconut oil, emulsifiers and formulation with green additives. The results of two commercial cutting fluids are also given.

Sample name	Toxicity level (LC50) mg/ml
Coconut oil	>2342.56
Emulsifier BBE-007	>1064.8
Additive-1	>1064.8
Additive-2	>1064.8
Coconut oil+Emulsifier BBE-007	>1064.8
Coconut oil+Emulsifier BBE-007 +Additives 1 and 2	>1064.8
Commercial cutting fluid-1	<100
Commercial cutting fluid-2	<45.45

3.2 Anti-foaming of Emulsion

The maximum foam generated during the foam test of bio based cutting fluid with additives was found to be 3mm and no residual foam was observed after five minutes of the test. The results of the formulated fluid are comparable to the reference mineral oil-based commercial cutting fluid which generated a maximum foam of 2mm with no residual foam at the end of five minutes of the test. From the above results, it can be observed that the tendency of the formulated fluid to foam under low shear conditions is comparable to that of the reference mineral-oil based commercial cutting fluid.

Table-3. Results of Anti-foaming tests of cutting fluid emulsions (Bottle test).

Test samples	Maximum Foam height	Residual foam after 5min
Bio based cutting fluid	3mm	0mm
Commercial cutting fluid-1	2mm	0mm
Commercial cutting fluid-2	2mm	0mm

3.3 Emulsion Stability

Both the bio based and commercial cutting fluid did not show any form of turbidity, gelling and phase separation at the end of the test period. These results clearly shows equal capability of bio based cutting fluids when compared to commercial cutting fluid in terms of emulsion stability.

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Figure 1. High temperature and low temperature stability (1-Biobased cutting fluid; 2-Commercial cutting fluid-1)

3.4 Anticorrosion Test

Corrosion test were conducted at three different concentrations for both the bio based and the commercial cutting fluids. Results showed that the bio based cutting fluids produced higher corrosion percentage than commercial cutting fluids. It is concluded that, fatty acids are responsible for the higher corrosion rate of bio based cutting fluids. Free fatty acids are the byproduct of hydrolytical breakdown of vegetable oils. Triglycerides contains ester bonds which are not resistant to hydrolysis and hence presence of water can degrade triglycerides into its basic fatty acids. This, thus, becomes an area where work need to be done to improve the coconut oil based cutting fluid.

Table 4. Anti-corrosion properties of cutting fluids.

Test Samples	5% Conc.	7% Conc.	10% Conc.
Bio based cutting fluid	12.5%	11.2%	8.0%
Commercial cutting fluid-1	3.2%	1.9%	1.3%

3.5 Tribological Evaluations

Cutting forces generated during turning of a 25mm diameter aluminum alloy rod using a mineral oil based cutting emulsion was compared with that of the bio based cutting fluid. It was observed that the bio based cutting fluid generated lower cutting forces in comparison to reference commercial cutting fluid at spindle speeds of 421RPM and 646 RPM for all the depths of cuts studied. Whereas at rotation speeds of 1000 RPM, the cutting forces generated with the application of the bio based cutting fluid was found to be higher. A similar pattern of variation was also observed in the feed force and radial force generated during the turning operation (Figure-2). In general, during the calculation of power requirements, the force component only in the direction of the cutting speed is considered. The force components in the direction of feed and depth of cut was negligible [17]. Thus, it is concluded from the above experiments that the power required during turning of commercial grade aluminum alloy with the bio based cutting fluid was lower at spindle speeds of 421 RPM and 646 RPM but do not perform as well as the commercial cutting oil at 1000 rpm.

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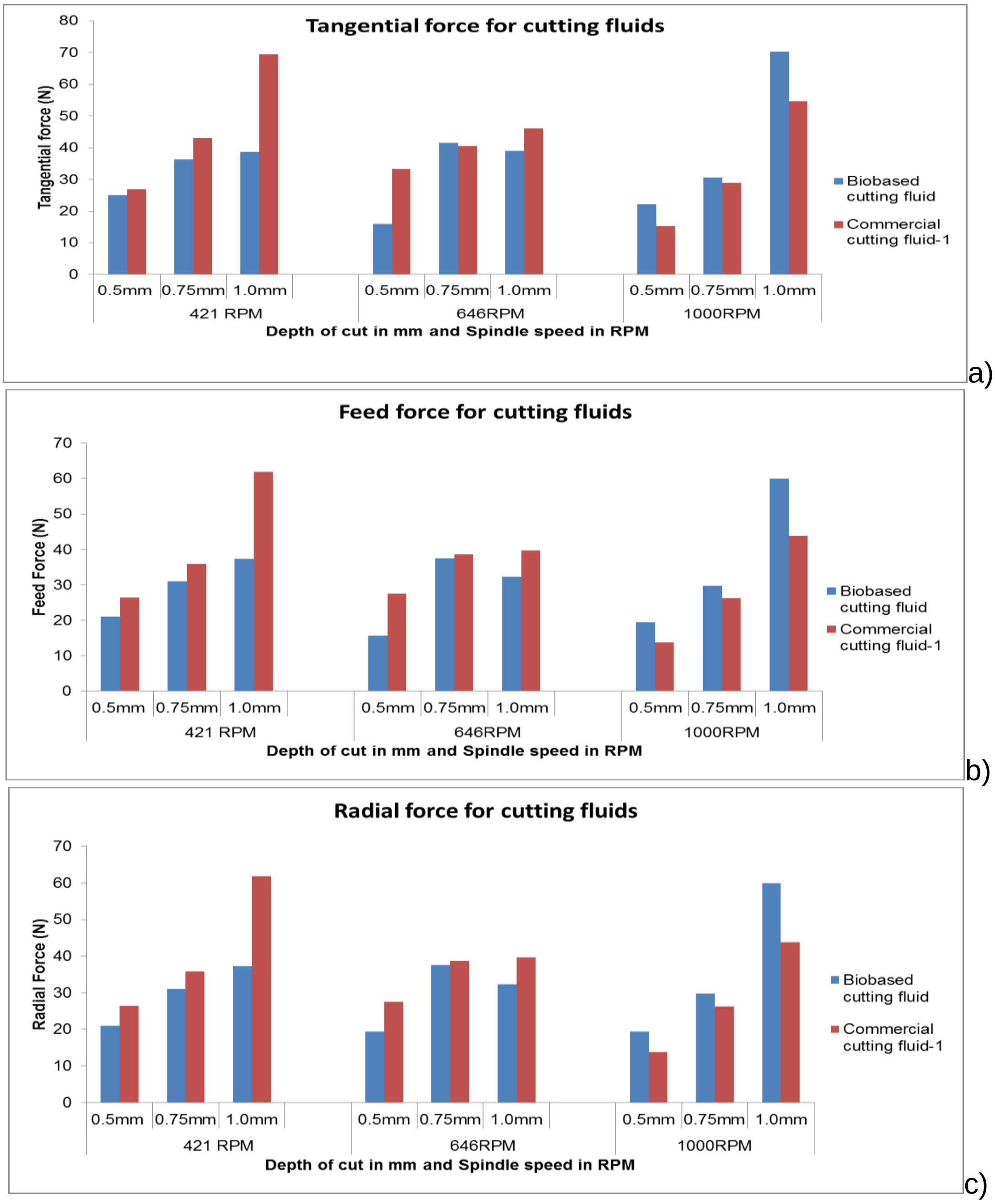

Figure 2. Tribological evaluation for cutting fluids (a)Tangential force; (b) Feed force; (c) Radial force

4 SUMMARY

The present study developed a water based cutting fluid emulsion that is completely environmentally friendly and sustainable. The environmental sustainability was based on the fact that the components that make up the cutting fluid emulsion should use resources that are replenished at the rate at which they are used and should be completely non-toxic. The developed bio based cutting fluid performed both the primary and the secondary functions of a cutting fluid satisfactorily. Anticorrosion properties of bio based cutting fluid was not better than commercial cutting fluid, but it can be improved using further specific green additives from plant sources. Research on this is progressing. The bio based cutting fluid showed equal or better cutting properties in a lathe when compared to a commercial cutting fluid. With some more development the bio based cutting fluid can replace traditional environmentally

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unsustainable mineral oil based cutting fluids. The raw materials used were coconut oil as a base oil, resin based gum obtained from a plant source as bio based emulsifier, essential oils and plant extracts as additives.

5 CONCLUSION

Improvements in additives function by adding different natural or green additives may further improve the cutting fluid properties like anticorrosion, antimicrobial and tribological properties of the developed bio based cutting fluid. Developed bio based cutting fluid could be a benchmark for development of more “closed loop cycle” products for the lubricant industry.

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