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Characterizations, Development and Performance Assessment of Sorrel (*Hibiscus Sabdariffa*) Seed Oil Based Cutting Fluid in Milling of Low Carbon Steel

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Abstract: *The research titled characterizations, development and performance assessment of sorrel (Hibiscus sabdariffa) seed oil based cutting fluid in milling of low carbon steel considered locally grown and readily available sorrel seed (SS) from which sorrel seed oil (SSO) was obtained. The seed oil was extracted by soxhlet method using n-hexane, it was characterized and was used as base oil to develop (formulate) cutting fluid that was used in milling of AISI 1028 steel. To achieve that, the oil was first mixed with water in an appropriate ratio separately. The oil- water mixture was finally blended with the necessary additives to obtain desired cutting fluid-sorrel seed oil cutting fluid (SSOCF)).The feasibility of the oil to serve as cutting fluid was evaluated relative to that of a mineral oil based cutting fluid (control fluid). The workpiece was machined with the prescribed machining parameters based on ASTM standard. During machining, the tool-work interface temperatures were recorded using infra-red gun thermometer. The performances in terms of heat removal from the tool-work interface was best achieved by SSOCF being local vegetable plant oil cutting fluid attaining a temperature of 29.7^{o}C at the highest cutting speed (CS) of 200mpm.Also the same SSOCF proved to be the safest from fire hazard owing to higher flash point standing at 278^{o}C. The local vegetable plant oil have the least tendencies to corrode workpiece surface having the acid value of* 1.470mg/KOH/g *as against that of the control fluid of* 7.876mg/KOH/g. *Similarly, SSOCF has a good viscosity at 40^{o}C and 100^{o}C being* 8.000mm^2/s and 3.760mm^2/s. *Besides, the SSOCF gave the least surface roughness of* 3.6987µm *relative to that resulting from milling with the control fluid standing at* 4.5673µm. *From the foregoing, it can be concluded that the local vegetable plant seed oil (SSO) is feasible for the development of cutting fluid for machining and thus could conveniently substitute the conventional (mineral oil based) cutting fluid for machining operation. It is recommended that more efforts should be put into researches in the use of vegetable plant seed (bio seed) oils for cutting fluids development since they have been proved to have good prospects.*

Keywords*:* characterizations of oils, cutting fluid, low carbon steel, milling operation, performance parameters and vegetable plant seed oil**.**

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INTRODUCTION

Oil seed crops are vital sources of oils of nutritional, pharmaceutical and industrial importance. The characteristics of oils from different sources depend mainly on their compositions and no oil from single source can be suitable for all purposes (Betiku and Adepoju, 2013). Presently, the quest for traditional vegetable oils has increased immensely because of the ever-growing World population and their use for industrial purposes. Several oils such as moringa oil, sunflower oil, rapeseed oil, palm oil, soybean oil, corn oil and pumpkin oil have been used for industrial purposes. New low-cost oilseed crops are needed to produce inexpensive oils suitable for food, pharmaceutical and industrial applications. One of the possible alternative crops is hibiscus sabdariffa, also known as sorrel or Roselle. It is an herb belonging to the malvaceae family, which is grown in Nigeria, India and West Indies, and to some extent in tropical America. The sorrel seed oil is rich in both linoleic and oleic fatty acids (Betiku and Adepoju, 2013).

characterizations and feasibility of sorrel seed (*Hibiscus sabdariffa*) oil as cutting fluid in milling of low carbon steel basically has to do with Oil Extraction from locally grown vegetable plant seed; Sorrel Seed (SS) from which sorrel Oil (SO) was obtained and the formulation of cutting fluid from the oil to be used in milling of AISI 1028 steel. The performances in terms of tool-workpiece interface temperature, safety in use and corrosion tendency of the cutting fluid on the steel sample when machined with the cutting fluids will be evaluated relative to that of a control fluid. Besides, characterizations of the formulated cutting fluids and the optimum machining parameters (Cutting speed-N, Depth of Cut-DC and Feed Rate-FR) for machining processes will determined. The cutting Speed (CS), Depth of Cut (DC) and Feed Rate (FR) are the independent variables for the research while the average temperatures is the dependent (Ayodeji *et al.*,2015).
Locally available Plant seeds of our nation (Nigeria) are not maximally utilized for the benefit of the citizens The seeds or nuts of our economic trees such as Shea Tree, Cashew seed, Mahogany seed, Baobab (Monkey bread seed) etc. with sorrel seeds inclusive are laying mostly unused (Tumba, 2022). However sorrel seed is seldom used for the formulation of animal feeds and production of local soup ingredient (Maggi) on very small scale.

The properties of vegetable oils which enhance their performance in machining operations include the presence of fatty acids, surface active ingredient such as stearic acid and halogen such as chlorine which help to reduce surface energy and improve its wetting power or oiliness (Obi *et-al*, 2013). Bio oils contain high glycerides which gives it the property of high lubricity even when blended with some additives to form cutting fluids (Kuram and Ozcelik 2013). Sorrel seed contains very high percentage of oil content which is being extracted for many purposes and which is the sole concern of this research (Erebor, 2003). According to Kuram (2013), Vegetable oils consist of triacylglycerides otherwise called trigylcerides which are glycerol molecules with three long glycerol molecules with three long chain fatty acids attached at the hydroxyl groups via ester linkages. It is this triglycerides structure of vegetable oils that provides the good lubrication ability.

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The natural relevance possessed by our plants are not being fully explored or maximized due limitation in knowledge and hence for time immemorial these plants had remained ignorantly unbeneficial. However, after some time the oil rich seeds of some of the local trees including sorrel plant seed sampled for the research began to be used. Mineral or fossil oil based cutting fluids are generally expensive and not environmentally friendly. They pose a very serious problem of disposal since they are not bio-degradable.

CUTTING FLUIDS

Cutting fluid is a type of coolant and lubricant designed specifically for metal working processes and could be in the form of oils, oil-water emulsions, gels, etc. However, cutting fluids are more specifically classified into straight oils, soluble oils, semi-synthetic and synthetic fluids. (Saleem, *et al.,* 2013). The primary functions of a cutting fluid are as a coolant and lubricant. Secondarily, it flushes away chips and other metal particles from the tool/work interface and as well enhances protection against corrosion (Yakubu and Bello, 2015). The machining processes cutting fluids used for machining processes application are mostly mineral oils based (Muhammad *et al.,* 2018). This research is intended to formulate bio oil based cutting fluids from locally grown and readily available vegetable plant seed oil to be used in mechanical machining workshops. This endeavor is aimed at substituting the conventional expensive cutting fluid which are not easy to come by in most of the Technological based Educational Institutions in Nigeria. In the nation's technological based institutions, machine tools processes form the core course offered by intending technicians, technologists and engineers especially in the field of mechanical engineering and the use cutting fluids for machining operations cannot be overemphasized (Tumba, 2015).

Metal cutting operations generate heat from work done against friction at the tool-workpiece interface and also work done against the material particles of the work piece; this has adverse effects on the tool and the work piece as the surrounding air is insufficient to dissipate the heat generated as fast as is required (Obi *et al.,* 2013). It therefore becomes imperative that a means of reducing the rate of heat generation as fast as possible, at the lowest cost and with little or no environmental effects should be devised. Over the years, diverse ways and means of cooling and lubricating the cutting tool/work interface have been employed leading to the evolution of what today are known as cutting fluids (Sharma, 2015).

Properties of good cutting fluids, therefore, include the ability to keep tool/work piece interface at a stable temperature, maximize life of cutting tool by lubricating the working edge and reducing thermal deformation (Badau *et al.,* 2016). It has to be chemically inactive in order not to react with the work piece material, ensures the safety of those handling it against toxicity, bacterial and fungal infections, safe to the environment upon disposal, and prevent the rusting of the tool, work and machine parts.

Vegetable or animal oils (fixed oils) which are non-volatile which do not evaporate at room temperature and can easily be sponified (Baba *et al.,* 2018). Water was the first cutting fluid used in cutting steels, animal fats and oils from plant sources were also used before the invention of fossil oils which later took over for many years. Researches or experiments revealed that fossil oils when emulsified in water and mixed with some additives improved upon the cutting properties of the cutting fluids by combining the best qualities in fossil oils and water to produce better metal working fluids. That led to the emergence of the soluble oil. Water-soluble cutting oils, because of their good thermal conductivities have the ability to dissipate heat more readily than neat cutting fluids (Demirbas 2013). Fixed oils based cutting fluids eliminates the heat generated at tool-workpiece interface easily and gives excellent lubrication thereby minimizing friction, wear, improving tool life and surface finish (Lawan *et al.*, 2007).

MATERIALS AND METHODS

Materials

AISI 1028 steel workpiece 900mm x150mm x50mm of a known chemical composition, sorrel seeds, cutting fluid additives and water.

Tool/Equipment

Horizontal Milling Machine, Oswald viscometer, Infra-red gun thermometer, stop watch, weighing balance, measuring cylinder, beakers, pipette, burette, vernier caliper, Soxhlet Extractor, Pensky Martens Close Cup Tester, Tlc40-14 D97 D2500 Bath, Ostwald Viscometer, Pycnometer, SEM and Density Bottle

Methods

Seeds Mobilization and Priming

Sorrel (*Hibiscus sabdariffa*) oilseed samples were collected from Kuburshosho michika local government Area in Adamawa State, Nigeria. The oilseeds had some foreign materials and dirt, which were removed by thorough washing followed by sun-drying for 7 days. Finally, the cleaned oilseeds were made into powder by grinding with a milling machine. All chemicals and reagents used for this work were of analytical grades.

Extraction of Sorrel Seed oil

The oil from the sorrel seeds was extracted in the Department of Chemistry Modibbo Adama University Yola using soxhlet extractor. Sorrel (*Hibiscus sabdariffa*) seeds were collected from Kuburshosho village in Michika Local Government of Adamawa State, Nigeria. The Seeds were soaked in water with detergent and washed thoroughly. The clean seeds were thoroughly dried in laboratory at a room temperature of 30^{o}C. The dried seeds were crushed to smaller sizes and pulverized using a grinding machine for easy extraction of the oils.

The oil was extracted using soxhlet methods in the department of Chemistry, Modibbo Adama University Yola during which 300ml of n-hexane was poured into a round bottom flask; 200g of the sample was placed in the filter paper thimble and was inserted in the centre of the extractor. The soxhlet was heated at 60 -65^{o}C when the solvent was boiling, the vapour rose through the vertical tube into the condenser at the top. The liquid condensate dripped into the filter paper thimble in the center which contains the solid sample to be extracted. The extract seeped through the pores of the thimble and filled the siphon tube, flowing back down into the round bottom flask. This was allowed to continue for 3-4 hours. At the end of the extraction the condenser was removed. The flask containing the resulting mixture was connected to Liebig condenser and heated up to 65-70^oC during which the n-hexane evaporated off and was recovered in a conical flask; the oil extracted weight was taken. This procedure was repeated all through the work to obtain the required quantity. This method of extraction was adopted by Dass (2013).

Physicochemical Properties of the Control Fluid

Table 1 shows physicochemical properties of the control fluid

Table1: Physicochemical Properties of the Control Fluid

S/No.	Parameter	Value
1	Flash Point (^oC)	249.0
2	Pour Point	-10.0
3	Moisture Content (% vol/vol)	88.00
4	Free Fatty Acid (mg/KOH/g)	4.000
5	Acid Value (mg/KOH/g)	7.876
6	Specific Gravity	0.980
7	Saponification Value (mg/KOH/g)	240.8
8	Iodine Value (g/100g)	150.0
9	Peroxide Value (mgeq/kg)	0.007
10	Density (kg/m^3)	1.1287
11	Viscosity at 40^oC and 100^oC(mm^2/s)	1.01, 0.76
12	Viscosity Index	220.0

Characterizations of the Extracted Sorrel Seed Oil (SSO)

The physicochemical properties of oil or liquid determine its suitability for a particular application (Bwade *et al.,* 2018).The physicochemical properties of the extracted sorrel seed oil was done in the Department of Food Science Modibbo Adama University Yola. The result is presented in Table 2 and tell whether the oil will be feasible for cutting fluid development or not.

Table2:.Physicochemical Properties of SSO

S/No.	Parameter	Value
1	Colour	Yellow-Greenish in Colour
2	Flash Point (^oC)	278.0
3	Pour Point	-9.00
4	Moisture Content (% vol/vol)	40.00
5	Free Fatty Acid (mg/KOH/g)	0.400
6	Acid Value (mg/KOH/g)	1.470
7	Specific Gravity	0.886
8	Saponification Value (mg/KOH/g)	197.8
9	Iodine Value (g/100g)	97.77
10	Peroxide Value (mgeq/kg)	5.000
11	Density (kg/m^3)	0.980
12	Viscosity at 40^oC and 100^oC(mm^2/s)	8.000, 3.760

Cutting Fluid Formulation

Cutting Fluid was formulated from the plant seed oil and was used for the machining of the workpiece. The extracted oils was be mixed with water in the ratio 1:10 (i.e., 1 part of cutting fluid to 10 parts of water) according to Lawal *et al.,* (2007). All the formulations and mixing was done at room temperature.

Machining and Temperature Measurement

Work piece will be machined by plain milling operation with different machining parameters at different levels using the cutting fluid and the control fluid. This is meant to test the performance of the formulated cutting fluids. AISI 1028 Steel samples 900mmx150mmx50mm were plain milled on vertical milling machine using inserted carbide milling cutter. Cutting fluids will be handled with different cutting tools. Every experiment would be ran for at least ten (10) minutes. Cutting fluid was automatically supplied to dissipate the heat generated at the tool/work interface. The temperature at the tool/work interface was measured with the aid of an infra-red gun thermometer (Ejeh 2016).

Experimental Design

Factorial design will be used for the research expressed as

$$l^f \times n \qquad (1)$$

Where; $l = levels, f = factors\ and\ n = number\ of\ replications$

The machining parameters will be taken at three (3) levels, two factor and will be replicated twice. This means that, nine (9) experiments will be run for each cutting fluid and eighteen (18) will ran for the entire research. Machining parameters and levels are shown in Table 3.

Table 3: Levels of Machining Parameters

Sample	Cs (m/min)	Dc (mm)	Fr (mm/rev)
I. Control fluid	150	0.20	0.20
	175	0.30	0.25
	200	0.40	0.30
II. SSOCF (Sorrel Seed oil cutting fluid)	150	0.20	0.20
	175	0.30	0.25
	200	0.40	0.30

RESULTS AND DISCUSSION

Corrosion Tendencies of Cutting Fluids

The acidity of the cutting fluid determines its corrosion tendency. The Acidities of the cutting are shown in Table 4

Table 4: Acidity of Cutting Fluids

Cutting Fluids	Acid Value (mg/KOH/g)
I.(Control Fluid)	7.876
II..SSOCF (Shea Butter oil Cutting Fluid)	1.470

The Acid values of cutting fluids are presented in Table 4. Sorrel seed Oil Cutting Fluid (SSOCF), has acidic values of 1.47 mg/KOH/g and has the least tendency to corrode metallic surfaces compared to the control fluid. This is similar to the result obtained by Lawal *et al* (2007). The control fluid has the tendency to corrode metallic surface as its acidic value stands at 7.876 mg/KOH/g

Work – Tool Interface Temperatures

The work piece was milled with the prescribed machine Process parameters at all levels using all the cutting fluids and the average work – tools interface temperatures as recorded by a infra-red gun thermometer is presented in Table 5

Table 5: Average Tool –Work Interface Temperature

Sample	Cs(m/min)	Dc (mm)	Fr (mm/rev)	Temperature (^oC)
I. Control fluid	150	0.20	0.20	40.0
	175	0.30	0.25	41.0
	200	0.40	0.30	43.0
II.SSOCF (Sorrel seed oil cutting fluid)	150	0.20	0.20	29.5
	175	0.30	0.25	30.0
	200	0.40	ffff0.30	30.5

Figure1 shows the graphs of temperatures versus cutting speed for the cutting fluids used

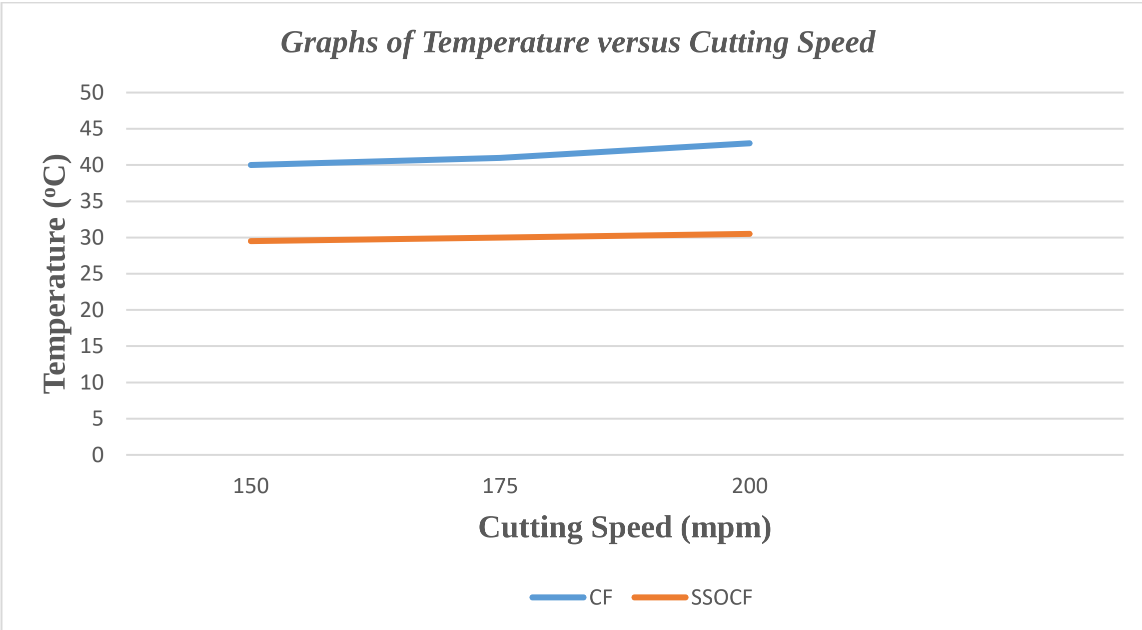

Figure 1: Graphs of Temperature versus Cutting Speed

The work piece being AISI 1028 steel was plain milled on a horizontal milling using inserted carbide milling cutter within the range of machining parameters specified by ASTM. To measure heat generated during the operation the radiant ray of infra-red gun thermometer was focus about 5cm from the tool-work interface and the temperature is automatically recorded as suggested by Ejeh (2016).

The entire experiment was carried out as designed using all the cutting fluids. From Table 4 and from figure 1 it can be seen that for all cutting fluids, the tool –work interface temperatures increase with increase in cutting speed. This is in consonant with a report by Badau *et al.*,(2016). Besides, SSOCF being locally available vegetable plant oil based cutting fluid performs better in terms of heat removal than the control sample which is a mineral oil based cutting fluid contrary to the work by Kuram and Ozcelik 2013. This may be due to the presence of triglycerides which are glycerol molecules in vegetable oils and also having greater wettability as suggested by Kuram and Ozcelik 2013.This may also be due to good thermal properties (specific heat and thermal conductivity) possessed by vegetable oils (Ayodeji *et al.*, 2015) (2007).

Resulting Surface Finish (Roughness)
The surface finish resulting from machining using the control fluid and the formulated cutting fluid is shown in table 5

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Table 5: Surface finish after machining with the cutting fluids

Sample	Cs(m/min)	Dc (mm)	Fr (mm/rev)	Ra (µm)
I. Control fluid	150	0.20	0.20	7.3456
	175	0.30	0.25	5.3210
	200	0.40	0.30	4.5673
II.SSOCF (Sorrel seed oil cutting fluid)	150	0.20	0.20	5.3456
	175	0.30	0.25	4,5763
	200	0.40	0.30	3,6987

Figure.2 shows the graphs of surface roughness versus cutting speed for the cutting fluids

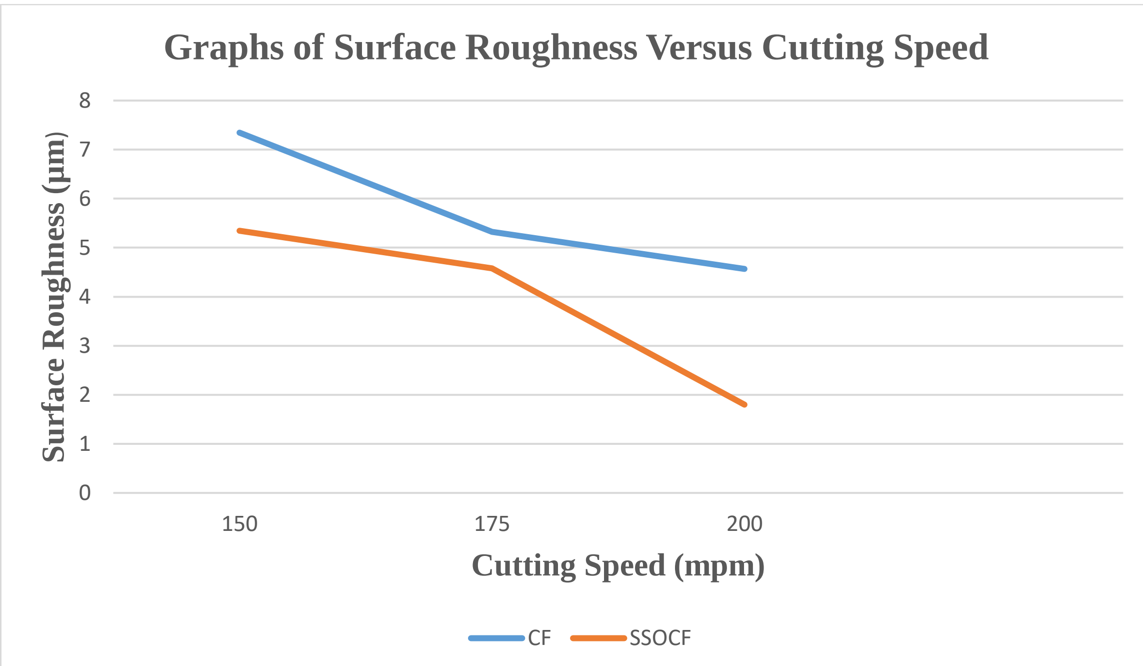

Figure 2: Graphs of Surface Roughness versus Cutting Speed

Viscosities of Cutting Fluids

The viscosities of all the cutting fluids were determined at 40°C and 100°C and are shown in Table

.Table 6: Viscosities of Cutting Fluids

Cutting Fluids	Viscosities at 40°C (mm2/s)	Viscosities at 100°C (mm2/s)
I. Control Fluid	1.01	0.76
II.SSOCF (Sorrel seed oil cutting fluid)	8.000,	3.760

Viscosity as an oil property has a significant impact on machining processing as reported by Badau *et al.*, (2016). Vegetable oils have a high natural viscosity as the machining temperature

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increases as reported by Badau *et al.*, (2016) and Kuram and Ozcelik (2014). The viscosity of vegetable oils drops more slowly than that mineral oils as the temperature falls, vegetable oils remain more fluid than mineral oils facilitating quicker drainage from chips and work pieces. The higher viscosity index of vegetable oils ensures that vegetable oils will provide more stable lubricity across the operating temperature range. Vegetable oil molecules are quite homogeneous in size but mineral oil molecules vary in size. Consequently, the properties of mineral oil such as viscosity, boiling temperature are more susceptible to variation. Vegetable oil has higher boiling point and greater molecular weight and this results in less loss from vaporization and misting. The viscosities of all the cutting fluids are presented in table 6. The results places SSOCF first in terms of viscosity even at higher temperature of 100^{o}C dropping to 3.760mm^2/s. This is followed by CF dropping to a value of 0.76mm^2/s at 100^{o}C from 1.01mm^2/s at 40^{o}C confirming the statement of Kuram and Ozcelik 2014.

Flash Points of the Cutting Fluids

Table 8 shows the Flash points of the cutting fluids.

Table 8: Flash Points of Cutting Fluids

Cutting Fluids	Flash points (^{o}C)
I. Control Fluid	187
II.SSOCF (Sorrel Seed oil Cutting Fluid)	278

The cutting fluids flash points are presented in table 8. This shows that all the cutting fluids are very safe for use without the risk of fire hazard. SSOCF has the highest flash points (278^{o}C) and this proves to be the safest in use. The flash points for all mineral oils is 226^{o}C as reported by Dolan 1992.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Locally available vegetable oils based cutting fluid formulated from Sorrel Seed was used in the milling of AISI 1027 steel and it performance was relatively evaluated alongside that of a control fluid of crude petroleum (mineral oil based) cutting fluid. From the experiments conducted, it can be concluded that vegetable plant oil can be used in the production of cutting fluids which serve as an alternative coolants and lubricants in machine tools processes. SSOCF was found to be better than the control fluids in conducting heat away from tool-work piece interface.

Recommendations

With the knowledge of the fact that no research work can be considered conclusive in itself, the following are recommended:

1. More efforts should be put into research in the use of vegetable plant seed oils as cutting fluids since they have been proved to have good prospects.
2. The cutting fluids formulated in this research work should be experimented in other machining processes, e.g. grinding, shaping, drilling, turning etc.

3. Local contents research initiative drive should be encouraged not only in the area of machining but in all the sectors of manufacturing industries
4. Mass production of the edible plants used in such research should be encouraged in order to avoid food competition

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