INVESTIGATION ON THE PROPERTIES OF MAHOGANY (*KHAYA SENEGALENSIS*) OIL FOR USE AS A CUTTING FLUID

Abubakar U. Babuje[1], Nuhu Muhammed[2], Babagana B. Gaje[3], Bature Abdullahi[4]

aubabuje@gmail.com (A.U. Babuje),

Department of Mechanical/Production Engineering, Abubakar Tafawa Balewa University Bauchi[12]

ABSTRACT

"Cutting oils" are used to cool and/or lubricate metal work pieces when they are being machine, grinded, milled, etc. In this study, bio-based cutting fluid was produced using non-edible mahogany (*khayasenegalensis*) seed oil as the base oil and a physio-chemical test was carried out to ascertain its properties for use as cutting fluid, which is then used for the formulation of the cutting fluid oil according to the standard. The cutting fluid formulated was then subjected to functionality test, which are cooling ability, lubrication and corrosion inhibition test. The oil was extracted using the solvent extraction process with n-hexane as the solvent. The physio-chemical properties of the oil were determined and compared to ASTM standards. The properties are: viscosity at 26^0C (127.2 cst), density (958.2 Kg/m^3), flash point (334^0C), pour point (-39^0C), free fatty acid (1.692 wt%), saponification value (142.5 Mg/KOH/g), iodine value (60.91 g/100g), acid value (3.367Mg/KOH/g). The test result shows that the oil has the characteristics of lubricants that could be used in machining processes. In formulating the cutting fluid, 80% of the oil was blended with 10% emulsifier, 5% phenol and 5% of sulphur and oil to water ratio of 1:10 was used. It was found that the cutting fluid produced was comparable to the conventional soluble oil cutting fluid in terms of performance. The three major functionality test of cutting fluid carried out shows that the cooling ability of the cutting fluid is 2.13ºC/S while that of the conventional cutting fluid is 0.73ºC/S, lubrication action of the formulated cutting fluid is 12s/mm while that of the conventional cutting fluid is 20s/mm and for the corrosion inhibition test, a PH value test was carried out on the formulated cutting fluid which was found to be 10.1. It can be seen that the PH value is within the stipulated range for a cutting fluid to function effectively (i.e. within 9 to 11). It is therefore cleared that eco-friendly vegetable-based oil can successfully replace petroleum-based cutting fluid which are imported to the country. Also with slight modification and careful alteration in some components of the oils, better performing cutting fluids could be obtained.

Key Words: Bio-lubricant, Cutting fluid, *khayasenegalensis oil*, , alternative, and renewable

1.0 INTRODUCTION

Metal working oils is the name given to a range of oils and other liquids, it also called "cutting oils" that are used to cool and/or lubricate metal work pieces when they are being machined, ground, milled, etc. Cutting fluids are special blends of chemical additives, lubricants and water formulated to meet the performance demands of the metalworking industry. There are several types of cutting fluids in the market, the most common of which can be broadly categorized as cutting oils or water-miscible fluids. Water-miscible fluids, including soluble oils, synthetics and semi-synthetics, are now used in approximately 80 to 90 percent of all applications [Stephenson and Agapiou, 1996; Astakhov, 2004].

Cutting fluids are used to reduce the negative effects of the heat and friction on both tool and work-piece. The cutting fluids produce three positive effects in the process: heat removal, lubrication of the chip–tool interface and flushing the chips away. However, the advantages caused by the cutting fluids have been questioned lately, due to the several negative effects they have caused in the environment and worker health. When inappropriately discharged, cutting fluids may damage soil and water resources, causing serious environmental impacts. On the shop floor, the machine operators may be affected by the negative effects of cutting fluids, such as skin and respiratory problems.

In order to make machining process more ecologically friendly, it is necessary to developed alternative solution in order to avoid environment and heath damages. The use of vegetable oils will allow this mixture, to make possible the development of a new generation of cutting fluid where high performance in machining combined with good environment compatibility could be achieved.

Interest in vegetable oil-based cutting fluids is growing. Compared to mineral oil, vegetable oil can even enhance the cutting performance, extend tool life and improve the surface finishing according to some recent analysis from industry. Although, they have many environmental benefits, vegetable oils are more susceptible to degradation by oxidation or hydrolytic reactions.

Therefore, the correct selection of the vegetable substance, the pH of the resulting solution and its control are important issues.

Smith *et al.*, (2010) discuss on some of the benefits of bio-based lubricants. After his findings he concludes that petroleum-based oils get lubricity from additives such as chlorine and sulfur. Bio-based products don't need these additives due to the much higher natural lubricity.

Francis, (2012) on his study on the extraction and characterization of soybean oil based bio-lubricant. His findings was: flash/fire point (310 ^{0}C/320 ^{0}C) of the crude soybean oil obtained is in line with those obtained from both light duty oil (SAE 30) and heavy duty oil (SAE 40) with flash/fire points of 243 ^{0}C/290 ^{0}C and 260 ^{0}C/ 300 ^{0}C, respectively.

This work focuses on the development of a vegetable based emulsion or cutting fluid from mahogany (*khayasenegalensis*) seed oil that can be used to replace the commonly used mineral oil based emulsion. The work encompasses the extraction of the mahogany seed oil, its refining and characterization.

2.2 Mahogany Plant (*khayasenegaensis*) Khayasenegalensis is a species of tree in the Meliaceae family that is native to Africa. Common names includeAfrican mahogany, dry zone mahogany, Gambia mahogany, khaya wood, senegal mahogany, cailcedrat, acajour, djalla and bois rouge.

2.2.1 Description of mahogany plant

African mahogany is a medium-sized tree which can grow up to 15 to 30m in height and 1m in diameter. The back is dark grey to grey-brown while the heartwood is brown with a pink-red pligment made up of coarse interlocking grains. The tree is characterized by leaves arranged in a spiral formation clustered at the end of branches. The white flowers are sweet-scented; the fruit changes from grey to black when ripening.

2.2.2 Distribution and habitat of the mahogany plant

The tree is native to Benin, Burkina Faso, Cameroon, Central African Republic, Chard, Ivory Coast, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Mali, Niger, Nigeria, Senegal, Sierra Leone, Sudan, Togo and Uganda. It is found in riparian forest and higher-rainfall savannah woodlands; in moist regions it is found on higher ground. Within its first year, the seedling develops a deep root system that makes it the most drought resistant member of its genius.

3.0 MATERIALS AND METHODS

3.1 Materials

The major raw material used for this work is the mahogany (khayasenegalensis) seed, with some chemical/ reagents. Methanol (N-hexane Phenolphthalein Potassium hydroxide), tetrachloride, Chloroform Distilled water, Ethanol Glacial acetic acid, Potassium iodide, Sodiumthiosulphate Starch, Wiji's solution and Sodium hydroxide.

3.2 Seed Preparation

The mahogany *(khayasenegalensis)* seeds were decorticated or peeled manually to remove the kernel from the husk.



Plate 1: Mahogany Bud with Seed Plate 2: Mahogany Seed Husk Plate 3: Mahogany Seed kernel

3.3 Oil Extraction

Solvent extraction method using n-hexane was adopted.

Plate 4: Extracted Mahogany Seed Oil

3.3.1 Determination of the percentage oil yield from the seed

170g of the ground mahogany seed was used as described in the above procedure. The mass of the extracted mahogany oil was recorded at the end of the extraction process. The percentage of oil extracted was determined using the following equation:

$$\%\ yield = \frac{mass\ of\ oil\ extracted}{total\ mass\ of\ seed\ kernel} \times 100 \qquad \text{- - - 2}$$

3.4 Characterization of the Mahogany Oil

The characterization processes was carried out on the oil by determining the physical and chemical properties of the oil as follows:

3.4.1 Determination of viscosity

The viscosity of the samples was determined using a viscometer. The appropriate spindle was chosen and the speed set at 60rpm, the viscosity was measured in centistokes

3.4.2 Density determination

An empty beaker was weighed and recorded. 50cm^3 of the oil sample was then poured into the beaker and weighed again. From the sample weight obtained, the density was determined by taking the ratio of the weight of the oil to the known volume (50cm^3) according to the following equation:

$$Density = \frac{sample\ weight}{sample\ volume} g/cm^3 \qquad \text{- - - 3}$$

3.4.3 Determination of flash point

An improvised method was used to determine the flash point. A conical flask (150 ml) was filled with 2 ml of oil and heated at as low constant rate on the hot plate. The flash point was obtained when application of a test flame causes the vapour above the oil to ignite.

3.4.4 Determination of pour point

A manual method was used to determine the pour point. The oil was cooled inside a cooling bath to allow the formation of paraffin wax crystals. At about 9°C above the expected pour point, and for every subsequent 3°C, the test tube was removed and tilted to check for surface movement. When the specimen does not flow when tilted, the test tube was held horizontally for 5s. It does not flow and 3°C was added to the corresponding temperature and the result was the pour point temperature.

3.4.5 Free fatty acid (%FFA)

A titration set up was prepared. Here, 2 g of oil was placed in a 250 ml conical flask and warmed, which was followed by addition of two drops of phenolphthalein indicator. The content was then titrated with 0.14 M potassium hydroxide solution while shaking vigorously until a permanent light pink colour was observed. The end point was recorded and used to calculate the free fatty acid.

The percentage free fatty acid calculated using the formula below:

$$\%FFA = \frac{titre \times M}{weight\ of\ sample\ oil\ used}\%wt \qquad - - - 4$$

where M = Molarity of the base (KOH)

3.4.6 Determination of saponification value

2g of the sample was weighed into a conical flask; 25ml of 0.1M ethanolic potassiumhydroxide was then added. The content which was constantly stirred was allowed to boil gently for 1 hour. A reflux condenser was placed on the flask containing the mixture 1ml of phenolphthalein indicator (1%) was added to the warm solution and then titrated with 0.5MHCl to the end point until the pink colour of the indicator just disappeared. The same procedure was used for the blank. The formula for calculation of the saponification value is given by:

$$Saponificatio\ value = \frac{(b-a)\times 28.05}{weight\ of\ sample} \qquad - - - 5$$

Where:

b = blank titration

a = sample titration

3.4.7 Iodine value (IV)

0.5g of the sample was weighed into a conical flask and 15ml of chloroform was added to dissolve the oil. 25ml of wijis solution was subsequently added to the conical flask and covered tightly in the dark for 30minutes. 20ml of potassium iodide solution (10%) and 150ml of water was added to the mixture and the solution turned to red colour. This was titrated using 0.1N solution of sodium thiosulphate until the reddish colour separates out of the solution. 5ml of starch indicator was added and a blue coloration appeared. The titration was continued until the blue coloration disappeared. The same procedure was used for the blank.

The Iodine value (IV) is given by the expression:

$$IV = \frac{12.69\times M \times (V2 - V1)}{weight\ of\ sample} \qquad - - - 6$$

Where:

V2 = volume of sodium thiosulphate used for blank

V1 = volume of sodium thiosulphate used for determination

M = Molarity of sodium thiosulphate solution

12.69 is the atomic weight of iodine.

3.4.8 Acid value determination

25ml of diethyl ether and 25ml of ethanol was mixed in a 250ml beaker. The resulting mixture was added to a conical flask containing 10g of the sample and 1m1 of 55 phenolphthalein (1%) was added to the mixture. The mixture was titrated with aqueous 0.1MNaOH shaking constantly until a pink colour which persists for 15seconds was observed.

The acid value was determined by the formula:

$$AV = \frac{V\ titre(ml) \times 5.61}{weight\ of\ sample} \qquad - - - 7$$

3.5 Method of Formulation of the Cutting Fluid

The oil sample used in this work was prepared into cutting fluid using the suggestions given by earlier researchers in this field (Ibahadode, 2001 and Chapman, 2002). In preparing the sample of cutting fluid, 500 ml of vegetable oil was measured (using a 1-litre measuring beaker) and mixed with water in oil to water ratio of 1: 10 (Chapman, 2002). This mixture was thereafter blended with 10% vol/vol washing soap, 5% vol/vol phenol, 5% vol/vol sulphur, all at room temperature.

Table 3: Cutting Fluid Formula

Material	Function	Content (% vol/vol fixed oil)
Fixed oil	Base oil	80
Washing soap	Emulsifier	10
Phenol	Disinfectant	5
Sulphur	Extreme pressure agent	5

Plate 5: Formulated Cutting Fluid

3.5.1 Determination of emulsion stability of the cutting fluid

The cutting fluid so prepared was poured into a flask with graduated neck, allowed to stand for a specific time and separation was observed.

3.6 Performance Evaluation of the Formulated Cutting Fluid

The major test parameters that will be used in determining the performance of the formulated cutting fluid are the tendency of the cutting fluid to conduct away heat from the cutting zone during machining operation, its lubrication ability and its corrosion free tendencies.

3.6.1 Determination of the cooling ability of the formulated cutting fluid

The cooling ability was determined using the method described by Sales (1999) (Sales, Diniz and Machardo, 2001).

This involves mounting a circular bar of certain diameter to the jaw of a lathe machine and turning the itto a certain length (say 50mm) until its temperature was raised to a certain value. The conventional cutting fluid that was used as standard was continuously applied on to the cutting zone at an interval of 15s until the temperature reaches the room temperature. Similarly, the above process was repeated using the formulated cutting fluid. In each case, the temperature and time were recorded.

The cooling curves of the fluids were then compared by plotting the graph of temperature against time, from which inferences were drawn.

3.6.2 Determination of the lubrication ability of the formulated cutting fluid

Turning operation on the lathe was used in carrying out this test in which the depth of cut for turning HSS to a given length (50mm) was varied, and in each case the corresponding cutting

time were observed and recorded. The process was carried out using both the conventional and the formulated. The graphs of depth of cut against cutting time were plotted in each case from which inference was drawn on the ability of the formulated cutting fluid to lubricate a cutting zone.

3.6.3 **Determination of pH value**

50ml of the sample was poured into a beaker. Then pH electrode was standardized with buffer solution and immersed into the sample and the pH value was read and recorded. The PH value was used as bases in determining whether the cutting fluid is corrosive not.

4.0 RESULTS AND DISCUSSION

4.1 The Percentage Yield of Soxhlet Extraction of Mahogany Oil

The yield of mahogany oil calculated using equation 2 is 31.8% which is within the standard range for vegetable seed i.e. 30 - 55% (Marter, 1981: Weise, 1983)

The 31.8% yield result indicates that mahogany seed contains appreciable quantity of oil enough to be extracted for commercial scale production of bio-lubricant.

4.2 Results of Characterization of Mahogany Seed Oil

The values of the parameters obtained are tabulated in Table 4 below, and it can be seen from the Table that:

The value of the viscosity is not within the range of the specification but this cannot be a drawback because the standard viscosity is measured at 40^0C. This implies that if the viscosity of the mahogany oil is measured at 40^0C, the value will fall within the standard range.

The values of density, flash point, free fatty acid, iodine value and acid value all satisfy or conform to the standard specification.

The saponification value of the oil is 142.5 which is below the standard specification, this can be increased or improved considerably by blending the oil with basic oxide such as sodium hydroxide (NaOH).

Table 4.Result of Characterization of Mahogany Seed Oil.

S/N	Parameter	Unit	Test method	Value obtained	ASTM Standard
1	Viscosity	Cst	ASTM D7544	127.2	125 max

2	Density	Kg/m^3	ASTM D4052	958.2	800-1100
3	Flash point	^0C	ASTM D7546	334	45 min.
4	Pour point	^0C	ASTM D7544	-39	<-9
5	Free fatty acid	Wt%	ASTM D 5555-95	1.692	<7.3
6	Saponification value	Mg/KOH/g	ASTM D5588-95	142.5	181.4±2
7	Iodine value	g/100g	ASTM D5768-02	60.91	80 max.
8	Acid value	Mg/KOH/g	ASTM D1980-87	3.367	<4
9	Colour	-	-	Pale yellow	-
10	Appearance	-	-	Transparent	Transparent

4.3 The Determination of the Cooling Ability of the Formulated Cutting Fluid

The Table below shows the results of variation of temperature with time during the machining (turning) of the work-piece on lathe machine with cutting fluids being applied at an interval of 15s.

Table 5. Variation of Temperature with Time during Turning of HSS using the Formulated C/F

Time (s)	Temperature (ºC)
0	74
15	42
30	33
45	30
60	28

Table 6. Variation of Temperature with Time during Turning of HSS using the Conventional C/F

Time (s)	Temperature (ºC)
0	73
15	59

30	49
45	41
60	37

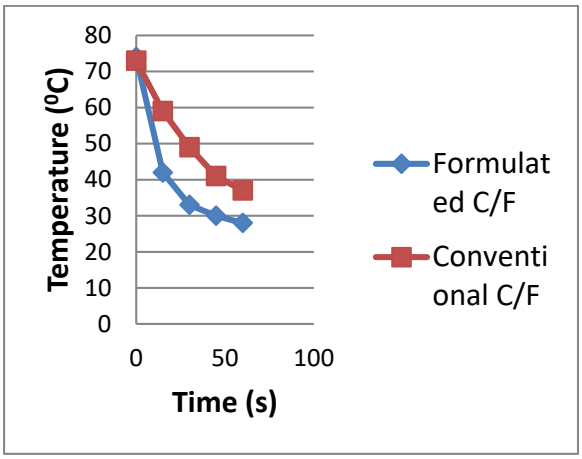

Figure 3. Effect of using C/F on the temperature drop during machining of HSS

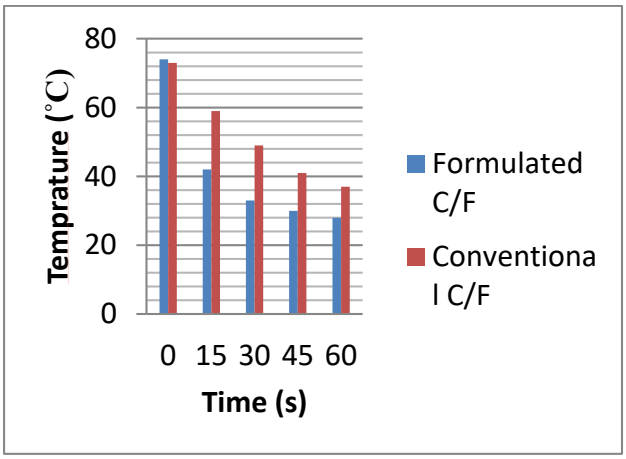

Figure 4. Bar chart showing the effect of using C/F on the temperature drop during

The graph in Figure 3 and the chart in Figure 4 all derived from Table 5 and Table 6, shows that the temperature of the cutting zone decreases as the cutting fluids are continuously applied. This is due to the cooling ability of the cutting fluids under consideration. The average temperature drop obtained from the formulated cutting fluid was found to be 11.75^0C, which is higher than that obtained with the conventional cutting fluid (i.e. 9^0C).

4.4 Determination of the lubrication ability of the formulated cutting fluid

The Table below shows the effect of increasing the depth of cut on the time taken to cut the work piece through a certain length using both the formulated cutting fluid and the conventional one.

Table 7. Effect of Increasing the Depth of Cut on the Cutting Time using the Formulated C/F

Depth of cut (mm)	**Cutting time (s)**
1	18

2	24
3	31

Table 8. Effect of Increasing the Depth of Cut on the Cutting Time using C/F

Depth of cut (mm)	Cutting time (s)
1	26
2	40
3	56

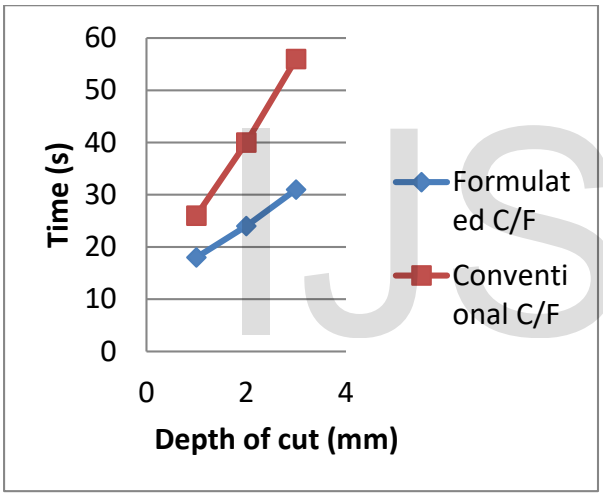

Figure 5. Effect of increasing the depth of cut on the cutting time

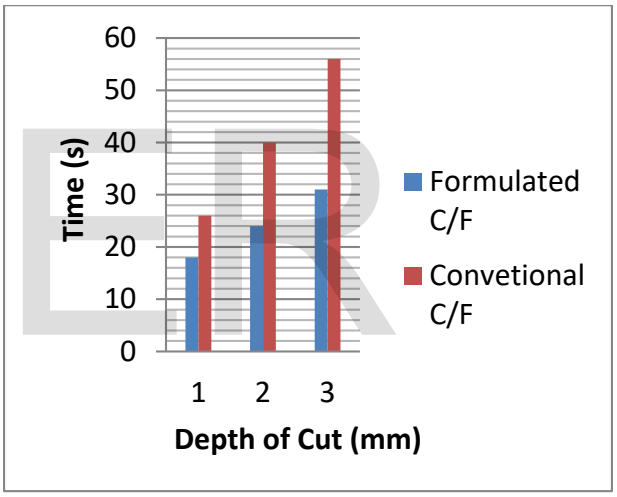

Figure 6.Chart showing the effect of increasing the depth of cut on the cutting

The graph in Figure 5 and the chart in Figure 6 all derived from Table 7 and Table 8 shows that as the depth of cut increases, the time taken to cut through a certain length also increases. This is due to the fact that increase in depth of cut generally reduces the feed rate. The average increase of the cutting time obtained with formulated cutting fluid (6.5s) which is lower than that of the conventional one (15s).

4.5 Determination of PH value of the formulated cutting fluid

The PH value of the formulated cutting fluid was found to be 10.1It can be seen that the PH value is within the stipulated range for a cutting fluid to function effectively (i.e. within 9 to 11).

5.1 Conclusions

It has been established that eco-friendly vegetable-based oil could successfully replace petroleum-based ones for the formulation of cutting fluids used in machining operations. However, with slight modification and careful alteration in some components of the oils, even better performing cutting fluids could be obtained.

The overall conclusion to this research is as follows:

(i) The high rate of temperature drop obtained with the formulated cutting fluid is due to its better cooling ability and this property allows for machining with certain desirable features such as less thermal deformation, better surface finish, greater dimensional control etc.

(ii) It was observed that there was less cutting time when the formulated cutting fluid was used which signifies that it has high ability to reduce friction in the cutting zone which in turn indicates that it has high lubrication ability.

(iii) The high PH value of the formulated cutting fluid indicates that it is more basic than acidic, and therefore it can be said it has low tendency to corrode a metal.

5.2 Recommendation

Further research should be conducted on this cutting fluid to determine its effect on the mechanical properties such as toughness, hardness, strength etc of the work piece being machined.

REFERENCES

Akpobi, J.A. and Enabulele, W.O.(2002) Formulation of a water-soluble oil as a metal cutting fluid, Nig. Inst. of Production Engineers Technical Transactions, Special Edition, 7(3) p. 97-106.

Asadaukas, S., Perez J.M, Duda J.L(1996)s, Oxidative stability and antiwear properties of high oleic vegetable oils, Journal of Lubrication Engineering 1996;52(12):877 -882.

Belafi, B.N., Dormo, K., Bartha, L., Ehrenstein, U., Gubicza, L., (2004), Manufacture of an environmental-safe biolubricant from fusel oil by enzymatic esterification in solvent-free system Biochemical Engineering Journal, 2(1): 229–234.

Biochemistry Department (2011): Laboratory Manual for BCHM 247 Munich.

Chapman W. A. J. (2002) Workshop Technology, Edward Arnold Publishers Limited, U.K. p.167-191.

Fox, N.J., Stachowiak, G.W., Vegetable oil based lubricants-A review of oxidation, Tribology International 40 (2007)1035 – 1046

Francis, U. O. (2012), Extraction and Characterization of Soybean Oil Based Bio-Lubricant. African Journal of science and Technology. 15(4): 260-264.

Herold CH, Limia JM, Steber J, 1995, Comparative evaluation of anaerobic biodegradability of hydrocarbons and fatty derivatives currently used as drilling fluids. Chemosphere, 31:3105-3118.

Holmes PM, 1971. Factors Affecting the Selection of Cutting Fluids.Ind. Lubr.Tribol, 2:47-55.

http//:goggle.com/mahogany tree: retrieved on 3 December 2015.

Ibhadode A. O. (2001) Introduction to Manufacturing Technology, Ambik Publishers, Benin-Nigeria

Journal of Lubrication Technology; Transactions of the ASME, vol. 1: 72-80.

McGannon, H. E. (1970). The Making, Shaping and Treating of Steel.United States Steel, 9th Ed., Herbick and Held, Pittsburgh, Pennsylvania.

Rowe, G. W. (1978). Principles of Metalworking. Edward Arnold Press Ltd, London. PP. 1, 265-266, 277-279.

Sales W. F., Diniz A. E., Machado A. R., Application of cutting fluids in machiningprocesses, J BrazSocMechSci 23(2), 2001, [online], Retrieved 9 September 2015 from: http://www.scielo.br/scielo.php?pid=S0100-73862001000200009&script=sci_arttext

Sales W. F., Guimaraes G., Machado A. R., Not always the cutting tool that has thehighest cooling ability guaranty the lower cutting tool temperatures, Maquinas e Metais,407, 1999, p. 46-61.

Sales W. F., Cooling and Lubricant characteristics of cutting fluids, PhD thesis, Federal University of Uberlandia, Brazil, 1999.

Sharma P.C. (2005) A textbook of production Technology, S.Chand and Co., New Delhi, p. 412-41.

Schey J. A. (1970). Metal Deformation Processes: Friction and Lubrication. Mercel Decker Inc. New York. PP. 109, 121, 166-167.

Smith, D., Frazier, B., (2010), The Benefits of Bio-Based Lubricants, Drilling and Drilling Fluids, G. V. Chilingarian and P. Vorabutr.

Stephenson DA, Agapiou JS, 1996, Metal Cutting Theory and Practice. Marcel Dekker, New York.

Szeri, A.Z. (1980). Tribology: Friction, Lubrication and Wear. Hemisphere Publishing Corporation, U.S.A. PP. 1, 427-457, 467.

Weiss E. A. (2002) Oil seed crop, Longman Publisher. Inc. London, p. 6-15; p. 528-555.

Woods, S., (2005), Going Green. Cutting Tool Engineering 57/2, pp. 48-51.