ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE December 2019. Vol. 15(4):1004-1012
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

COTTON SEED BIO-BASED METAL WORKING FLUID FOR SUSTAINABLE MACHINING OPERATION

S. I. Hassan[1], S. A. Lawal[2], K. O. Adeyemi[3*] and A. A. Adamu[4]

([1]National Agency for Science and Engineering Infrastructure Abuja, Nigeria;
[2]Department of Mechanical Engineering, Federal University of Technology, Minna, Nigeria;
[3]Department of Mechanical Engineering, University of Abuja, Nigeria;
[4]Department of Mechanical Engineering, Bayero University, Kano, Nigeria)
** Corresponding author's email address: kafayat.adeyemi@uniabuja.edu.ng*

ARTICLE INFORMATION

Submitted 11 October, 2018
Revised 15 June, 2019
Accepted 20 June, 2019

Keywords:
cottonseed oil
metal working fluids
machining process and
anticorrosion agents.

ABSTRACT

This work investigated the viability of cottonseed oil as bio-based oil as a contribution to meeting the challenges of developing green industrial materials that are environmentally friendly and sustainable alternatives for use as metal cutting fluid, as many of the conventional metal working fluids were established to be harmful and hazardous both to the environment and health of the operator. The tests revealed that the metal working fluid properties of cottonseed oil were: pH-value, 4.37; viscosity, 33.85 mm²/s at 40 °C, and 7.89 mm²/s at 100 °C; density, 0.911 g/cm³; and a flash point of 263 °C. This result shows that some of these properties compare favourably with those of the conventional mineral oil. It was concluded that at the lower temperature of 40°C the oil is still viscous enough and therefore is suitable for lower temperature operation such as low speed cutting, smaller depth of cut etc., while at a higher temperature of 100°C, the oil becomes less viscous and is thus not viable for higher temperature machining operations such as high-speed cutting operation and larger depths of cut; the density shows that cottonseed oil has high lubricity; the oil is acidic in nature and therefore would require addition of anticorrosive agents to function as a metal working fluid; and that the flash point of the oil is higher than that of the conventional mineral metal working fluid and so can be adjudged to be a very good candidate for the production of bio-based metal working fluid. The analysis indicated that the cottonseed oil, if significantly improved with the use of additives and chemically modified seeds, can be one of the potential candidates to substitute the conventional mineral oil in machining industry.

1.0 Introduction

According to Lawal et al. (2011) cutting fluids have been used extensively in metal cutting operations for the last 200 years. In the beginning, cutting fluids consisted of simple oils applied with brushes to lubricate and cool the machine tool. Occasionally, lard/animal fat or whale oils were added to improve the oil's lubricity. As cutting operations became more severe, cutting fluid formulations became more complex. Today's cutting fluids are special blends of chemical additives, lubricants and water formulated to meet the performance demands of the metal working industry. However, the most essential transformation going on in the energy sector globally and in Nigeria today is the use of renewable energy, largely because they are environmentally friendly with minimal impact, improved energy security, lower maintenance cost and high purity among others. With the growing rate of industrialization, conventional metal working fluids, that is, petroleum and synthetic oil, are extensively used in machining industries. With pressure from environmental protection agencies and global eco-friendly partners, the development in bio-based sustainable cutting fluid began to gain global acceptance due to the aforementioned benefits of renewable energy source. Cutting fluids play a significant role in machining operations and impact shop productivity, (Iowa Waste Reduction Centre, IWRC, 2003). Its importance includes, lubrication, temperature control, and chip removal. However, the metal working fluid possesses a great threat to the health and safety of the operator and the environment. The situation has been further deteriorated by the development of petroleum and synthetic, chemically based cutting fluid in the machining industry. It has been reported by the Occupational Safety and Health Administration (OSHA) that the conventional metal working fluid has given rise to about sixty-three health related problems, chief among which are skin infection, allergy, acute respiratory disorders etc. One of the devastating effects of the metal working fluid on the environment is its discharge which causes oxygen depletion, and nutrients reduction in the soil due to its non-biodegradable nature (Vishnu et al., 2013). There is, as Talib and Rahim (2015) noted, therefore, a need to develop environment friendly metal working fluids as an alternative to the use of the conventional lubricants.

Previously, bio-based oils have been used in wide applications such as automotive lubricant, biofuel, hydraulic oil, grease and metalworking fluids. Bio-based oils from soybean, rapeseed, sunflower, palm oil and coconut have been extensively studied for lubricant applications. Erhan et al. (2006) studied the lubricant properties of soybean while Erhan and Asadauskas (2000) worked on lubricant base stocks from high oleic sunflower oil. Problems associated with the use of bio-based oils are low temperature and lack of oxidative stability; these can however, be improved through chemical modification and mix with additives. Similarly, Shashidhara and Jayaram (2010) showed that soybean, sunflower and rapeseed oil have the potential to be used as metal working fluids. The authors concluded that oil performances can be improved by additive mixtures, chemical modification of crude oil and genetic modification of the oil seed. This is supported by Wu et al. (2000) whose work revealed that the modified rapeseed oil provides better lubrication properties by reducing friction and extreme pressure ability than the crude oil. Khan et al. (2009) reported that bio-based oil has been used as metal working fluids for various material and machining conditions. They concluded that metal working fluids from palm oil, coconut and sunflower have greater lubricating properties and showed similar performance with mineral oil in terms of cutting force, cutting temperature, surface finish and tool wear. The work by Khan et al. (2009) on the effects of minimum quality lubricants using bio-based oil also studied the turning performance of low alloy steel AISI 9310 as compared to completely dry and wet machining in terms of chip-tool interface temperature, chip formation mode, tool wear and surface roughness using uncoated carbide tool. The process parameters were cutting velocity (223, 246, 348 and 483 m/min) feed rate (0.10, 0.13, 0.16 and 0.18 mm/rev) and depth of cut (1.0 mm). The study showed that, with increase in cutting velocity and feed rate, average chip-tool interface temperature increased, even under Minimum Quality Lubrication (MQL) condition, due to increase in energy input and the roles of variation of process parameters. Gradual growths of average principal flank were observed under all the environments. The surface roughness deteriorated drastically under wet machining compared to dry, which might possibly be attributed to electrochemical interaction between tool and workpiece. MQL appeared to be effective in reducing surface roughness. Ojolo et al. (2008) performed an experiment to determine the effect of some straight bio based oils (groundnut oil, coconut oil, palm kernel oil and shear butter oil) on cutting force during cylindrical turning of three materials (mild steel, copper and aluminum) using tungsten carbide tool. The variables of cutting speed, feed rate and depth of cut were employed during the turning process. The spindle speeds of 250, 330, 450 and 550 rpm were investigated at a constant feed of 0.15 mm/rev and 2 mm depth of cut for each of the workpieces. They concluded that the bio oils were suitable for metal working fluids and that the effects of vegetable oils on cutting force depend on material.

Talib and. Rahim (2015) evaluated the performance of chemically modified jatropha oil-based trimethylolpropane ester from crude jatropha oil as bio-based metal working fluids. The modified jatropha oil was developed by transesterification process with different molar ratios of jatropha methyl ester to trimethylolpropane. The modified jatropha oils were then tested on viscosity, density and tribology. The results of their work showed that the lubricant viscosity gave a significant effect on the machining performance, that is, as the lubricant viscosity decreases, the cutting force and maximum cutting temperature increased; that even though crude jatropha oil has better tribology properties, it was not recommended as a lubricant for machining processes due to the lack of oxidation and thermal stability; and that modified jatropha oil recorded comparable performances in terms of lubricant properties and machining performance. They concluded further that modified Jatropha oil improves the coefficient of friction compared to synthetic ester; that the machining performance of Modified jatropha oil was only slightly different from that of the synthetic ester; and that modified jatropha oil would be able to substitute synthetic ester as a sustainable metal working fluid in machining operations.

This study investigated the idea of developing a cutting fluid from cottonseed oil. Although there are a large number of vegetable oil-based cutting fluids available in the market, the question of availability of the product is a vital issue associated with other sources of the fluid. Base material such as cotton which is commercially available in Nigeria can be looked into for the production of sustainable metal working fluid. The specific objective is to measure and analse some of the metal working properties of cotton seed oil, such as the pH-value, Viscosity, Density and Flash point.

2. Methodology

The method followed in carrying out this study involved a comprehensive review of literature related to the development of metal working fluids for both conventional and bio-based, and that enabled the materials for the extraction and performance test to be appropriately selected. The tests for the physicochemical properties were carried out at the Ajaokuta Iron and Steel Rolling Complex. The Flash point, and viscosity tests were carried out according to ASTM D92 and ASTM D445 standards, respectively. This was followed by the performance analysis.

2.1 Materials

2.1.1 Apparatus and Equipment

The materials and equipment used for the determination of various parameters in this research work are listed in the Table 1.

Corresponding author's e-mail address: kafayat.adeyemi@uniabuja.edu.ng

Table 1: List of equipment

S/N	Test	Equipment/Material
1	Determination of pH value	Laboratory pH meter, Distilled water, Buffer solution of pH 4.0 and 9.0, Sample of oil, and Beaker of 50ml.
2	Determination of viscosity	Glass viscosity, Oven or bath, Thermometer, and Stop watch.
3	Determination of flash point	Open crucible, Sand bath, Thermometer and Open cup.
4	Determination of Density	Hydrometer Measuring cylinder of 100ml.

2.1.2 Equipment Components Description

This section explains the various component and accessories of the equipment used in the characterization of the cottonseed oil, obtained directly from National Research Institute for Chemicals Technology (NARICT), Zaria.

Viscosity Apparatus: In line with the procedures set out in SIBATA (2017) the viscosity apparatus consists of u-tube viscometer, which is made up of calibrated glass capillary; it has viscometer ladders which enable the viscometer to be suspended in the viscometer bath, while the viscometer bath is made up of any transparent liquid (water, in this case) and temperature range of 15°C to100°C which is to be maintained via heater and thermostat attached to the set up. It equally consists of thermometer used for measuring the temperatures and stop watch used to calculate the time of fall for the fluid in the viscometer.

Hydrometer cylinder: Hydrometer: The hydrometer cylinder is made from glass which is graduated in unit of density. It is a clear glass having a size of about 100ml. The Hydrometer was also used by Santos et al. (2017) and Ademoh et al. (2016).

pH value Apparatus: The pH value apparatus consists of a laboratory pH meter used for the measurement of the pH value, buffer solution of pH 4.0 and 9.0 and a standard glass beaker of 50ml capacity (Buck et al. 2002, IWRC, 2003, and Brinksmeier, 2015)

Flash point Apparatus: The flash point apparatus consists of Cleveland open cup which is made up of brass material or any other non-rusting material (metal) of equal conductivity, it also consists of a heating plate which has a hole surrounded by an area of plane depreciation and sheet of hard asbestos covering the metal plate except the depreciation. The apparatus also consists of a test flame applicator used in applying flame with an operating device mounted to permit automatic duplication of the sweep of the test flame and it also consist of a thermometer having a temperature range of 6°C and 300°C used in measuring the temperature (Gorbett and Kennedy, (2004).

2.2 Method

The parameters with which the base cotton seed oil is identified were determined for the oil extracted by the National Research Institute for Chemicals Technology (NARICT), Zaria, using the following methods:

2.2.1 pH Value Determination

The Secondary Standard (Buck et al. 2012) of pH determination was used. This procedure for measuring pH is an electronic method using a combination of glass electrode with a reference potential provided by standard calomel electrode.

Before sample measurement the pH meter was standardized with two buffer solutions of different pH value (4.0and 9.0) to serve as check for proper instrument.

The electrode was then rinsed with distilled water after the standardization or calibration. The oil sample was poured 2/3 full into the 50 ml beaker, an electrode was dipped inside the oil in the beaker and a direct reading corresponding to the pH value of the sample under test was taken.

2.2.2 Determination of Viscosity

The essence of the method lies in measuring the time it takes a given volume of the test liquid to flow out of a container by gravity

As described in SIBATA (2017) the viscometer was filled with the cotton oil via tube one until the meniscus of the oil became level at the lines marked M3 and M4 on the viscometer bulb labeled A. Rubber hoses were then attached to tube 2 and 3 and a rubber bulb to tube 3; the viscometer was placed vertically in the liquid oven to the level of thermometric liquid (that is, until the viscometer bulb labelled C was fully submerged). The viscometer was kept at the test temperature (40°C) for 10 to 15 min, and with tube 2 closed, the liquid was sucked to above the mark M1 to about the center of bulb C using the rubber bulb. The cock connected with tube 3 was kept closed. The cock of tube 3 was closed and the clamp on tube 2 was released. The time taken for the liquid to flow from the upper marked line M1 to the lower marked line M2 on bulb labelled B was then measured. When doing this it was ensured that there were no air bubbles in the capillary tube. The outflow time was measured at least 3 times.

The above procedure was repeated using a constant temperature of 100°C for determination of viscosity at 100°C

The kinematic viscosity of the test oil (V) in mm^2/sec is calculated from:

$$V = CT \quad (1)$$

where: V = Viscosity (mm^2/sec)

C = viscometer calibration constant (mm^2/sec^2)

T = average outflow time of test oil in the viscometer (sec)

2.2.3 Determination of Density

The same method as used by Santos et al. (2017) and Ademoh et al. (2016) was used in determining the density of the oil. The oil under test was poured to about 4/5 full of the measuring cylinder. To avoid contamination with dirt or other liquids the hydrometer was cleaned, and then dipped into the oil inside the measuring cylinder so that the hydrometer was lifted to a mark corresponding to the specific gravity of the oil. The density of the oil was than obtained by multiplying its specific gravity by the density of water of 0.997 g/cm3 at the room temperature of 27°C (Annamalai and Puri, 2002).

Corresponding author's e-mail address: kafayat.adeyemi@uniabuja.edu.ng

2.2.4 Determination of Flash Point in Open Crucible

Before the test was conducted, the crucible was washed with a solvent; it was then heated and cooled down to room temperature. Using the method described by Negm et al. (2014) the crucible was positioned in the sand bath so that between its bottom and the cup there was a layer of sand of between 5 and 8mm thickness. It was ensured that the level of sand was about 12 mm away from the edge of the crucible. The thermometer was fixed to stand vertically so that the mercury ball was equidistant between the crucible and the oil level.

A sample of the dehydrated and room temperature cooled oil was poured in the crucible. In the case of oil having flash point of up to 210 °C its level would be 12 mm away from crucible edge and 18 mm in the case of that having a flash pint of over 210 °C. Care was taken to avoid splashing of the oil on the inner crucible above the oil level.

The instrument was placed in a dark draught free place where the flash can be seen very well. The sand bath was then heated at the rate 10°C/min. 40° before the anticipated flash point, and then reduced to 40°C/min .10 °C before the anticipated flash point the flame of the igniter was slowly passed along the crucible edge at distance of 10-14mm from the test oil surface parallel to it. The flame length would be 3-4mm the time of the operation 2-3sec. The procedure was repeated at every 2°C. The temperature at which the first blue appears over part or entire surface of the test oil was taken for its flash point. The average of these temperatures was calculated and taken as the flash point of the oil.

3. Result and Discussion

Table 2 shows some of the physiochemical Parameters of cottonseed oil (CSO) obtained at the Laboratory Unit of Ajaokuta Steel Complex, and that of the Commercial Mineral Metal Working Fluid (CMMWF) obtained from the literature.

Table 2: Physiochemical properties of the CSO and that of CMMWF

Parameter	CSO	CMMWF
Viscosity:		
at 40OC:	33.846 mm^2/sec	
at 100OC:	7.893 mm^2/sec	29 mm^2/sec
Density	0.911 g/cm^3	0.906 g/cm^3
pH	4.37	
Flash Point	263 °C	173 °C

As seen from Table 2, the physiochemical properties of the bio based cutting fluid from cotton seed (CSO) is compared with that of conventional mineral based cutting fluid (CMMWF).

Viscosity: The values of viscosity for CSO as shown in Table 2 are 33.846mm^2/sec at 40 °C and 7.893 mm^2/sec at 100°C. The viscosity tests were carried out at two different temperatures, that is, lower temperature at 40°C and higher at 100 °C, in accordance to ASTM D 445 2006 standard (Negm et al. 2014) to ascertain the viscous nature of the fluid during operation at both low and high temperatures. The result shows that at lower temperature of 40°C the oil is still viscous which implies that the oil is suitable for lower temperature operation such as low speed cutting, smaller depth of cut etc., while at a higher temperature of 100°C, the oil becomes less viscous with kinematic viscosity of 7.893 mm^2/sec. which, because it is much less than that of the CMMWF (as given in Table 2), is an indication that the oil is not viable for higher temperature machining operations such as high speed cutting operation and larger depth of cut., (www.scientific.net).

Density: From Table 2 the value of density of CSO is 0.911g/cm; this is a strong parameter in the characterization of the cutting fluid, as an oil with high density reduces surface roughness of the working tool, (www.scientific.net); the result obviously shows that CSO have high lubricity and is in conformity with the result presented by (Lawal et al. 2011).

pH: it can be seen from Table 2 that the pH value of the CSO is 4.37. The pH is the term used to express the intensity of the acidic or alkaline content of solution. From the pH scale, any value below 7 is acidic and above 7 is alkaline while 7 is neutral. The pH-value of the CSO shows that the oil is acidic in nature and is prone to corrode the work piece and hence there would be need to add anti- corrosive agents like sodium nitrite, lead naphthenate and sodium sulphonate.

Flash point: the value of flash point of CSO oil as contained in Table 2 is 263 0C. The flash point of oil is a point at which the vapours of petroleum product heated under certain condition form with the surrounding air, a mixture capable of flashing when flame is brought close to it. The value is higher than the corresponding value CMMWF as seen from Table 2. This is an indication that the CMMWF does not contain high volatile and flammable material. (IWRC, 2003).

4. Conclusion

The performance evaluation of Cotton Seed Oil (CSO) was carried out and the results obtained were compared with that of the CMMWF and the following conclusions were drawn.

The CSO can be considered in low temperature machining operations such as low speed cutting operations, due to the viscous nature of the oil at such temperature. The lubricant viscosity gave a significant effect on the machining performance. As the lubricant viscosity decreases, the cutting force and maximum cutting temperature increases.

The cottonseed oil extracted by using screw press cannot be wholly used as cutting fluid material because of its acidic contents (pH value of 4.37), but certain anti corrosive additives such as sodium nitrite, lead naphthenate and sodium sulphonate could be added which can prevent rust from forming on metallic parts.

Considering its higher value of flash point (263 °C), the CSO can be adjudged to be a suitable candidate for the production of bio-based metal working fluid.

Based on the result of the test obtained for the density of the CSO (0.911 g/cm^3), it can be concluded that the cottonseed oil is suitable as vegetable cutting fluid.

Conclusively cotton seed oil was found to be a promising alternative for mineral based oils due to its environmentally friendly characteristics. Its excellent biodegradability and nontoxic characteristics along with other technical suitability makes it a promising alternative in metal cutting industries

Based on the result obtained in this research, the following recommendations were made.

Further research may be carried out on some of the physiochemical properties of the oil such as iodine value, thermal stability to ascertain the full performance of the oil as cutting fluid;

It is also recommended that the oil be subjected to further testing in machining shop to ascertain its performance under wider application; and

Additives such as corrosion inhibitors rust inhibitors, anti-wear agent viscosity improver etc., could be added to increase the quality of the oil

Reference

Ademoh, NA., Didam, JH. and Garba, DK. 2016. Investigation of Neem Seed Oil as an Alternative Metal Cutting Fluid. American Journal of Mechanical Engineering, 4(5): 191-199.

Annamalai, K. and Puri, IK. 2002. Advanced Thermodynamics Engineering. CRC Press LLC, New York. 1 – 801.

Brinksmeier, E., Meyera, D., Huesmann-Cordes, AG. and Herrmann, C. 2015. Metalworking fluids—Mechanisms and performance. CIRP Annals - Manufacturing Technology, 64: 605–628.

Buck, RP., Rondinini, S., Covington, AK., Baucke, FGK, Camões, MF., Milton, MJT, Mussini, T., Naumann, R., Pratt, KW., Spitzer, P. and Wilson, GS. 2002. Measurement of Ph. Definition, Standards, and Procedures. International Union of Pure and Applied Chemistry, Pure and Applied Chemistry, 74(11): 2169–2200.

Erhan, SZ., Sharma, BK. and Perez, JM. 2006. Oxidation and low temperature stability of vegetable oil-based lubricants. Industrial Crops and Products, 24(3):292–299.

Erhan, SZ. and Asadauskas, S. 2000. Lubricant basestocks from vegetable oils. Industrial Crops and Products, 11(2–3): 277–282.

Gorbett, GE. and Kennedy, PM. 2004. A Phenomenon in Flash Point Testing for Fire Safety Evaluation. Interflam 2004, Fire Science and Engineering Conference, Edinburgh, Scotland. July 5-7, 2004; 1 - 11.

Iowa Waste Reduction Centre, IWRC 2003. Cutting Fluid Management for small machining operation: A practical pollution prevention guide, 3rd edition, University of Northern Iowa.

Khan, MMA., Mithu, MAH. and Dhar, NR. 2009. Effects of minimum quantity lubrication on turning AISI 9310 alloy steel using vegetable oil-based cutting fluid. Journal of Material Processing Technology, 20(9): 5573–5583.

Lawal, SA., Choudhury, IA. and Nukman, Y. 2011. Application of vegetable oil-based metalworking fluids in machining ferrous metals- a review. International. Journal of Machine Tools and Manufacture, 52(1): 1–12.

Negm, NA., Kandile, NG., Abd El Salam, AM. and Mansour, SA. 2014. Performance

Evaluation of Cutting Fluids Additives Developed from Recycling of Polyethylene Terephthalate. IOSR Journal of Applied Chemistry, 7(5. 1): 69-79.

Ojolo, SJ., Amuda, MOH., Ogunmola, OY. and Ononiwu, CU. 2008. Experimental determination of the effect of some straight biological oils on cutting force during cylindrical turning. Revista Matéria, 13: 650–663.

Santos, E., Camargo, AP., Azevedo de Faria, E., Ferreira de Oliveira Junior, FA., Alves, SM. and

Neto, EL. 2017. The Lubricity Analysis of Cutting Fluid Emulsions. Materials Research, 20(2): 644-650.

Shashidhara, YM. and Jayaram, SR. 2010. Vegetable oils as a potential cutting fluid-an evolution. Tribology International, 43(5–6):1073–1081.

SIBATA 2017. Viscosity Measurement Series – Constant-Temperature Baths for Viscometers:

Glass Viscometers (As per JIS K 2283 3000). SIBATA Scientific Technology, Ltd., Japan.

Talib, N. and Rahim, EA. 2015. Performance Evaluation of Chemically Modified Crude Jatropha

Oil as a Bio-based Metalworking Fluids for Machining Process, 12th Global Conference on Sustainable Manufacturing. 22nd – 24th September, 2014, Universiti Teknologi, Malaysia. Procedia CIRP, 26:346 – 350

Vishnu, P., Anbuudayasankar, SP., Ashokkumar, A. and Sharan, A. 2013. Development of Bio based Semi-Synthetic Metal Working Fluid from Industrial Wastewater. International Conference On design and manufacturing, July 18, 2013 – July 20, 2013, IIITDM Kancheepuram, Chennai, India Procedia Engineering 64: 1436 – 1444.

Wu, X., Zhang, X., Yang, S., Chen, H. and Wang, D., 2000. The study of epoxidized rapeseed oil used as a potential biodegradable lubricant. Journal of the American Oil Chemists' Society, 77(5): 561–563