Development of Cutting Fluid and Optimization of its Cutting Speed from *Thevetia Peruviana* Seeds Oil

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ABSTRACT

A cutting fluid was developed from Thevetia Pruviana Seeds Fluid (TPSF) also known as yellow oleander and its physiochemical properties and performance evaluation of the fluid were determined. The physiochemical properties showed a lower specific gravity, viscosity index, pH value, flash point and pour point as compared to a conventional castor oil. The flashpoint of TPSF (98 ℃) shows that it is of very low hazard to the operator and the environment, however, the pour point of TPSF (-1 ℃) is high compared with -43 ℃ for the castor oil, which makes TPSF only suitable for tropical countries like Nigeria. Performance evaluation of the developed cutting fluid was compared with a conventional castor oil in machining operation on a lathe machine. It was found that both samples have similar cooling properties. The optimized cutting speed in terms of chip thickness, chip thickness ratio and cooling temperature was found to be 127.3 rpm.

Keywords: *Yellow oleander, cutting speed, seeds oil, viscosity index, optimization*

1.0 INTRODUCTION

Cutting fluids application in metal cutting machining was published first by Taylor in 1894 where he explained that cutting speed could be increased up to 33% by applying large amounts of water in the cutting zone without decreasing tool life [1]. Cutting fluids increase tool life and improve the production efficiency by lubricating and cooling the work surface. Cutting fluids application reduces effects of friction and heat on both workpiece and the tool. The merits of cutting fluids are: lubrication, heat elimination and chip removal [2]. Demerits of cutting fluids however, are negative effects they cause to health of workers and the environment.When disposed inappropriately, cutting fluids may pollute the soil and water resources, resulting in serious environmental impacts and threat to plants and animals. Machine operators in plant may be affected by the negative effects of cutting fluids, such as skin and respiratory problems. Earnestly, to ecologically make machining process safer, minimal quantity lubrication has come be the accepted trend due to its friendly environmental characteristics [3-5].

The use of cutting fluids in most machining operations is unavoidable. For most machining processes, the use of cutting fluids is inevitable. Thus, it is necessary to develop alternative cutting fluid in order to prevent negative environmental hazards. This work deals with the development of a plant waste based cutting fluid that can be used in metal cutting operation to substitute the recurrent use of (chemically based) soluble oil cutting fluid.

Recent developments have shown that bioresources provides practical alternatives to fuels and lubricants and fuels derived from fossil fuels. A locally developed castor oil 30 years ago (in Tanzania), strained through an old sock was used as gearbox engine oil. Many tests carried out showed its suitability as a lubricating oil and then as a jet engine lubricant [6].

Nevertheless, mineral oil or pure vegetable oil does not possess all the properties desirable by modern technology in machining operations, thus, a mixture of the two may beneficial. This development of several cutting fluids using many soluble mineral oils. Lubricants are very essential in machining activity to enhance and achieve cooling, lubrication and or minimize chip adhesion to tool or work piece [7].

Cutting lubricants may consist of pure oil, a mixture of two or more oils or a mixture of oil and water [7]. Oils are generally divided into two groups: the fixed oils and the mineral oils. The fixed oils have greater ‘oiliness’ than the mineral oils, but they are not so stable and tend to become gummy and decompose when heated. In this group are animal and vegetable oils. On the other hand, the mineral oils group is obtained from crude petroleum. During the machining operations, heat is generated and this has adverse effects on the work piece surface finish and dimensional accuracy, tool wear and life, as well as production rate.

Bello and Umar carried out research on the extraction and characterization of *Senna-Tora* seed oil[8]. However, the properties exhibited by the oil shows that it can suitably be used as lubricant as well as coolant in heavy duty machines. Suda *et al*. conducted a study of non-edible vegetable oil as a cutting fluid in the machining of M2 Steel using minimum quantity of lubricant (MQL) [9]. The search for plant waste source of oil-based material to replace mineral based oil as cutting fluid which is environmentally friendly. This study aims to ascertain the economic and technological viability of local oils as a useful substitute for standard cutting fluid in machining of metals. The search for plant waste source of oil-based material to replace mineral based oil as cutting fluid which is environmentally friendly.

2.0 EXPERIMENTAL SET-UP

2.1 Materials and Methods

2.1.1 Materials

The materials used are given in Table 1.

Table 1: Materials and equipment used

Equipment/material/reagents	Parameter measured
Test tube and spring balance	Specific gravity
Soxhlet apparatus;	Extraction of the oil
pH meter (PH Meter 3510JenWay).	Ph
Viscosimeter(*Brookfield* viscometer DV-E)	Viscosity
Multimeter (MY-64)	Temperature
Gromatogram(GCMS-QP2010PLUS SHIMADZU)	Fatty acid contents
UV spectrometer (HACH DREL/2400)	Chlorine
PenseyMartens flash point apparatus	Flash point
Titration apparatus, Standard BaCl2 solution (1ml=0.0004gram of sulphur), 0.02M KOH, 0.02M HCl, phenolphthalein indicator,	Fatty acid weight and sulphur weight

Tetrahydroxyquinone (dipper) indicator, ethyl alcohol	
Test tube, thermometer	Pour point

2.1.2 Method of extracting *Thevetia Peruviana*seeds oil

The seeds of TPSF were first crushed using a grinding stone. A filter paper was folded to form a thimble shape and the sample was placed in a thimble holder and 250ml of petroleum ether was then added using glass funnel and the heater was switched on. When the petroleum ether began to boil, it was checked for leakage by sniffing around the ring clamp. The extraction continued until all the oil was completely extracted.

The separation of the mixture of petroleum ether and oil involved heating so that the petroleum ether was evaporated and collected in a condenser and the oil was left at the bottom of the flask.

2.1.3 Cutting fluid formulation

The formulation (composition) of the proposed fluid in accordance with British Standard as depicted in Table 2. This involved measuring 500ml of fixed oil (using a liter measuring cylinder) and mixing with water in a ratio of oil to water as 1:10 for 2 mins. After adding all the substances, the resultant blend was mixed for 15 mins [10].The cutting fluid developed has the composition listed in Table 2.

Table 2: Formulation table for the TPSF oil

Material	Function	Content volume/volume (%)
Plant oil (thevetia seeds)	Base oil	75
Washing soap	Emulsifier	15
Phenol	Disinfectant	5
Sulphur	Extreme pressure agent	5

3.0 CHARACTERIZATION

3.1 Measurement of TPSF Oil Parameter

3.1.1 Specific gravity

The specific gravity of the oil can be calculated as follows: The mass of an empty test tube was noted. A known volume of the oil was introduced into it and then re-weighed. The difference between the two masses gives the mass of the oil. The density of the oil was calculated as: Density = mass/volume. Hence, its specific gravity is thus calculated as follows:

$$Specific\ gravity = \frac{density\ \ of\ the\ oil}{density\ \ of\ water} \tag{1}$$

3.1.2 Viscosity and pH value

The viscosity of the oil was measured at two different temperatures for the TPSF and castor oil.

3.1.3 Fatty acid weight measurement

Fatty acid weight was measured in accordance with BSI No.684 standard. One gram (1.0g) of oil was weighed in a 250ml conical flask and 25ml of methanol was added followed by two drops of phenolphthalein indicator. Titration was carried out with 0.1mole NaOH solution until a light pink colour persisted for one minute. The end point was recorded [1]. The free fatty acid weight (FAW) was calculated as follows:

$$\text{FAW}= \frac{\text{Titre value } \times \text{molarity of base } \times 28.2}{\text{Weight of sampl e}} \tag{2}$$

3.1.4 Pour point

A cylindrical test tube was filled with TPSF oil to a certain level and clamped with a wooden clamp bearing thermometer. It was then allowed to cool below 0˚C in ice/salt bath. It was then removed and tilted on the clamp. The set up was observed at regular interval. The lowest temperature at which the oil began to flow was then recorded. This gave the pour point of the oil.

3.1.5 Chlorine weight

Chlorine weight was measured with UV spectrometer (HACH DREL/2400). Chlorine in the sample as hypochlorus acid or hypochlorite ion instantly reacts with DPD (N,N-diethyl-phenylene diamine) indicator to form a pink colour having intensity proportional to the chlorine concentration. The test results were measured at 530nm.

3.1.6 Active sulphur and sulphur weight

Oil sample of 0.8g was weighed and sparked with oxygen. The sample obtained was treated with bromine water. The resulting solution was subjected to evaporation to remove excess water present and the then cooled. A 25ml of the solution was pipette to the flask. Some few drops of phenolphthaline was added followed by KOH. A red colour solution was formed and this was discharged by adding HCl. 25ml of alcohol and a dipper of indicator was added. The resulting solution was titrated with $BaCl_2$ solution until the solution changed sharply from yellow to (permanent) red after thorough shaking [11].
Amount of sulphur present was determined as:

$$\textit{Amount of sulphur}= \frac{\text{ml } BaCl_2 \text{ x strength of } BaCl_2 \text{ (g of sulpur per ml) x 100 x 4}}{\text{Weight of oil sample (g)}} \tag{3}$$

3.1.7 Corrosion test

The test comprised of measuring the corrosion grade of TPSF cutting fluid with as its contact with mild steel. Some grams of mild steel chips were washed in acetone, dried in the sun and placed on a piece of filter paper in a *Petri* dish. The mild steel chips were spaced evenly around the filter paper (and prevented from contacting one another) and humidified in 2ml of the test cutting fluid. The chips were then left in the covered *Petri* dish for 2 hours. After which the mild steel chips were discarded and subsequently the filter papers rinsed in acetone. The corrosion grade of the cutting fluid was measured by observing the number of spots that appeared on the filter paper [12].

3.2 Performance Evaluation using Turning Operation

3.2.1 Comparison with conventional oil

The performance of the developed TPSF oil was compared with an established conventional cutting fluid to establish its suitability as cutting fluid. The developed oil was compared with the castor oil.

3.2.2 Turning operation on lathe machine

The performance of the developed oil as cutting fluid was tested in the machining of medium carbon steel on a standard center lathe machine using a high-speed steel (HSS) cutting tool. A turning operation of the medium carbon steel was performed on a centre lathe at five different speeds (90, 120, 140, 180, and 224rpm). A depth of cut of 2 mm was selected and chips produced were collected. The thicknesses of the chip produced were measured using a micrometer screw gauge and the chip thickness ratios were subseqntly calculated. The chip thickness ratio is the ratio of the chip thickness to the depth of cut [13];

$$\textit{Chip thickness ratio} = \frac{\text{Chip thickness}}{\text{Depth of cut}} \tag{4}$$

The performance evaluation of the cutting fluid was also determined by testing the ability of the developed cutting fluid to conduct heat away from the cutting zone and measurement of TPSF oil parameters. During the turning operation the cutting temperature was measured using multimeter (MY-64). The multimeter was switched on. The meter knob was set to temperature calibration and the thermocouple was fixed on the temperature slot. The tip of the thermocouple was fixed to the cutting edge of the cutting tool. This measured the temperature during turning operation.

One factor experimental design of the cutting speed (90 – 225rpm) was evaluated using *Design Expert 7.0* on the chip thickness and the maximum temperature generated (Tables 3 and 4). The design was to determine an optimized cutting speed.

Table 3: Chip thickness and chip thickness ratio with depth of cut, 2mm

S/N	Cutting speed(rpm)	Chip thickness, t_c(mm)	Chip thickness ratio, $r(t_c/d)$
1	90	0.16	0.080
2	120	0.17	0.085
3	140	0.17	0.085
4	180	0.18	0.090
5	224	0.20	0.100

Table 4: Temperature during turning operation using TPSF and castor oil

S/N	Cutting speed (rpm)	TPSF oil max temperature(^{o}C)	Castor oil max temperature(^{o}C)
1	90	52	51
2	120	56	54
3	140	58	62
4	180	60	65
5	224	70	68

4.0 RESULTS AND DISCUSSION

4.1 Physico-chemical

The viscosity of the oil was measured at two different temperatures as shown in Table 5.

Table 5: Viscosity of TPSF oil at set temperature

Temperature (^{o}C)	TPSF oil viscosity(cp)	TPSF viscosity(cSt)
40	24.69	29.50
100	9.08	10.85

The viscosity of TPSF oil measured at 40˚C was 29.50cSt which was lower than that of castor oil by 13.7%. The viscosity of TPSF measured at 100˚C was 10.85cSt which was higher than that of castor oil by 17%. This showed that TPSF oil can retain its viscosity at a higher temperature than the castor oil. In general, the low viscosity of TPSF means that it will have less lubricating capability. There is therefore need for additive to increase its viscosity. The pH of the TPSF oil was found to be 7.71(neutral) compared to that of castor oil of 10.3(basic) showing that TPSF is not corrosive. The low pH value of the TPSF oil makes it suitable for use in machining operations involving mild steel.

Table 6: Fatty acid composition of TPSF oil

Fatty acid	Chain length	Type of bond	Percentage composition (%)
Palmitic	16	1	36.72
Nonadecylic	19	1	5.11
Oleic	18	2	50.49
Stearic	18	1	7.67

For the fatty acid, the presence of 50.49% (Table 6) of unsaturated acid (oleic acid) made it the major component of fatty acid in the oil which enhances the lubricity of the oil. This is because it can react easily to form a film which adheres to the surface of the metal thereby preventing direct metal to metal contact. The presence of free fatty acid (5.64%) in the oil shows its stability. Thus, the oil can be stored for a long period of time without degradation.

The flashpoint of TPSF (98˚C) shows that it is less hazardous to the operator and the environment. However, it is much lower than that of conventional, castor oil, which has flash point of 184˚C. There is therefore need for additives to raise the flashpoint of TPSF oil. TPSF has a pour point of -1˚C compared to castor oil with pour point of -43˚C. This makes TPSF unsuitable to use in (cold) temperate regions but it is suitable for use in tropical countries like Nigeria.

A chlorine content of 0.16 wt % was obtained compared with conventional oil with zero chlorine content. The presence of chlorine acts as an antiseptic agent and it increases the emulsion life of TPSF oil. TPSF has no sulphur content compared to the castor oil with 0.43wt%. This makes it an advantage if it were to be used as combustion oil.For the corrosion test, out of 10 mild steel chips used, three spots were found to exhibit reddish brown pattern. Thus,a maximum of three spots were observed in the corrosion test. This indicates that the corrosion level of TPSF is vestiges, i.e., very low corrosion [3].

4.2 Performance Evaluation

The comparison of the TPSF properties with the conventional castor oil can be seen in Table 4.The chip thickness and chip thickness ratio (Figures 1 and 2) increase with the increase in cutting speed. The low value of chip thickness ratio shows the better performance of the TPSF oil [14]. Figures 3 and 4 showed that the castor oil and TPSF maximum temperature generatedincreases with increasing cutting speed. The close temperature values showed that both fluids have similar ability to control temperature (i.e., conduct heat away from the cutting zone). The optimized (most desirable cutting speed of at peak 0.547) was determined at 127.31 rpm as shown in Figure 5.

Table 4: Comparison of properties of conventional soluble oil and TPSF oil

Properties	Conventional soluble oil[15]	TPSF
Specific gravity @ 60^{o}F	0.919	0.837
Flashpoint (^{o}C)	184	98

Pour point (°C)	-43	-1
Viscosity (cSt) @ 40°C	34.2	29.5
(cSt) @ 100°C	5.0	10.8
Viscosity index	51	15.33
Emulsion stability	Good	Good
Iron chip corrosion test	Pass	Pass
pH	10.3	7.71
Chlorine (wt %)	Nil	0.16
Fatty oil (wt %)	Nil	5.64
Sulphur, Total (wt %)	0.43	Nil
Sulphur, Active (wt%)	Nil	Nil

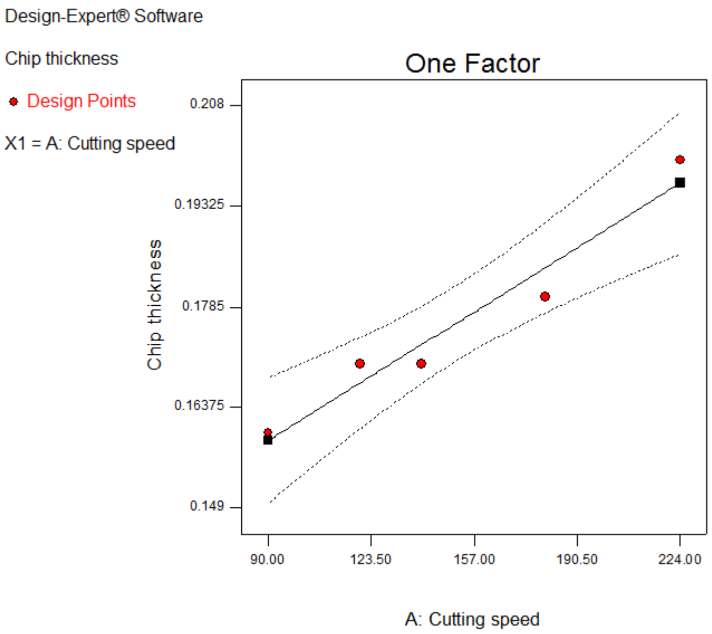

Figure 1: Effect of chip thickness on cutting speed

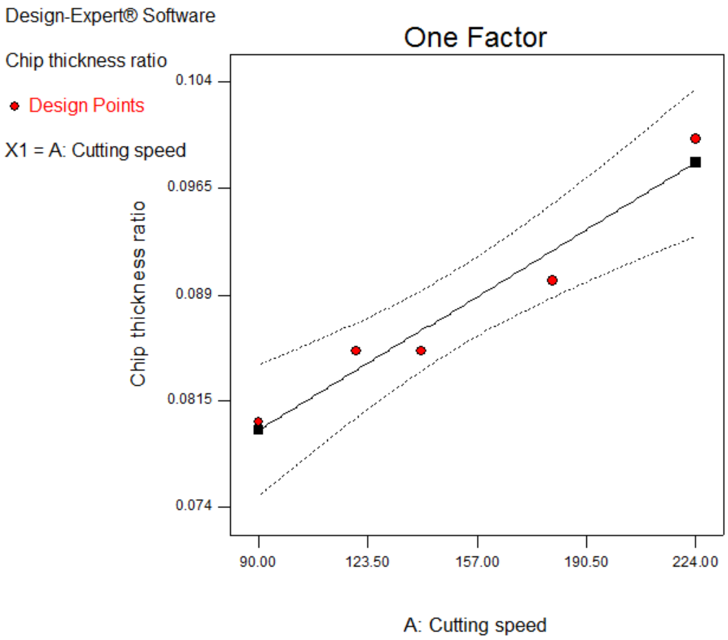

Figure 2: Effect of chip thickness ratio on cutting speed

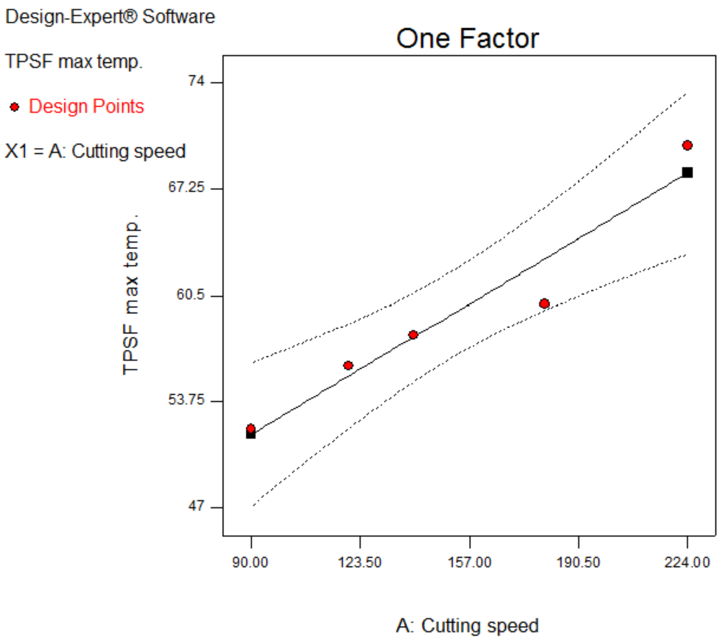

Figure 3: Effect of TPSF maximum temperature on cutting speed

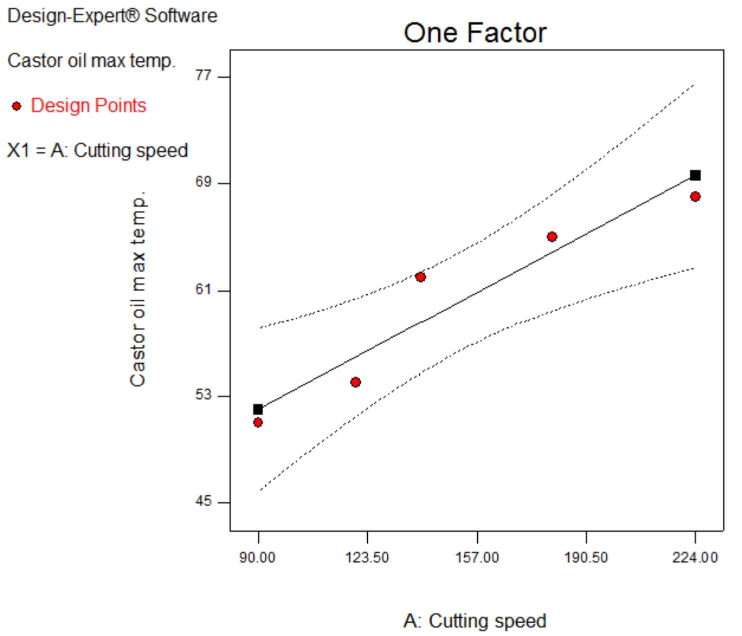

Figure 4: Effect of castor oil maximum temperature on cutting speed

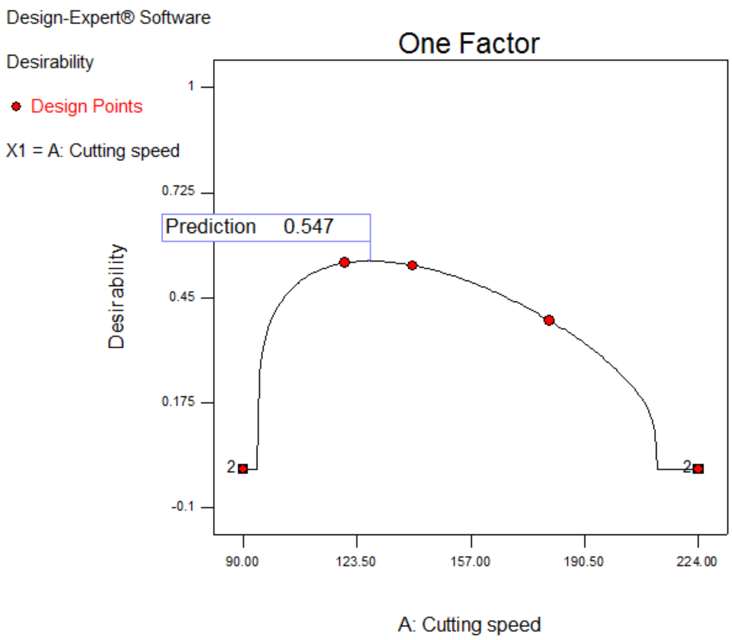

Figure 5: Optimized cutting speed

5.0 CONCLUSION

On the basis of the experiments that were carried out on the developed cutting fluid, the following conclusions could be made:

- TPSF oil has low viscosity. The pH value of the TPSF of 7.71 clearly showed that it had low tendency to corrode metal. The flashpoint of TPSF at 98˚C shows that it is less hazardous to the operator and the environment.

- TPSF has high pour point at -1˚C, making it unsuitable for use in cold temperate region but suitable for use in tropical countries like Nigeria. The presence of chlorine at 0.16 wt% acts as an antiseptic agent which can increases the emulsion life of the base oil.
- TPSF oil can be used as cutting fluid because it has similar ability to conduct (remove) heat away from the cutting zone with castor oil. The low level of chip thickness ratio indicated a better performance of TPSF oil than the conventional cutting fluid.
- An optimized cutting speed of 127.3rpm was determined at lower chip thickness ratio of 0.085 and cooling temperature of 56.28˚C for the TPSF.

It was also deduced that a viscosity index of 15.33 for the TPSF is much lower than that of castor oil (51). It was therefore recommended that a viscosity improver should be used to raise the viscosity of TPSF for use as cutting fluid.

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