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Formulation of Castrol Oil-based Bio-cutting Fluid for Green Machining Operation

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Abstract – Castrol oil derived from Castrol plant (*Ricinus communis L*) was grossly underutilizes in many sustainable manufacturing activities including green machining operation. This work aimed at formulating Castrol-oil based cutting fluid using Castrol oil, emulsifier and other additives and investigate the effect of mixing additive on the physio-chemical properties of this vegetable oil. This bio-lubricant was formulated using on cutting fluid production procedure of America Society of Testing and materials. The flash point was highest for formulated (205.93^{0}C) and lowest for control sample (184^{0}C), which contain Castrol oil without additives. The pour pH, Pour point (^{0}C), Viscosity(cst) (at 40^{0}C Viscosity(cst) and Viscosity(cst) (at 100^{0}C) followed ,which is higher than that of crude Castrol oil. The physiochemical values of formulated samples are observed to perform the same function petroleum-based cutting fluid done in most machining operation. The Castrol oil takes the highest proportion of each of the samples formulated: sample I(90%/100%),sample II(80%/100%),sample III(75%/100%),sample IV(65%/100%), sample V(60%/100%), sample VI(55%/100%), and sample VII(50%/100%).It is observed that addition additives with Castrol oil indicate a better technique for formulating Castrol –based cutting fluid. The samples contain both Castrol oil and additives produce material with non-acidic properties. This indicates a better green machining properties and environmental friendliness of the formulated product.

Keywords: *Ricinus communis L, Castrol-oil, emulsifier, vegetable oil, additives, control sample*

1. Introduction

The primary functions of cutting fluid in machining operations are: to remove heat generated during machining operation, lubrication on the chip–tool interface and aid chip removal (Ejeh,2015;Lopez de Lacalle et al., 2006), and to cool the work piece by carried away heat. Recently, green manufacturing process has emerged with the aim is renewal of production process and the establishment of the environmentally –friendly operations with the manufacturing field (Goodwin, 2020), including machining operation. In other to achieve this process, the selection of right materials including cutting fluid, is as important as choosing the suitable machine tools, speed and feed.

Cutting fluid generally contain pure oil, a mixture of oil and water or a mixture of two or more oils (Mohammed and Abduljeleel, 2018; Akpobi and Enabulele, 2002), which may be in certain proportion. Generally, oils are classified into two main groups: the mineral oils and fixed oils. Comparing the two, fixed oil have greater " oiliness' than, but they are not stable and tend to show gummy character and decompose when exposed to heat. A good cutting fluid should have high flash point to avoid problems associated with heat damage, fluid ignition or production of smoke (Scholar work, 2020) .The major materials in this group include: vegetable oil and animal oil, while common mineral oil example is oil obtained petroleum product.

The use of mineral oil in cutting fluid formulation has been questioned in recent time, due to environmental challenges. The need to produce environmentally biodegradable cutting fluid is high due to the fact that conventional cutting fluids have adverse effects on operators and environment (Ejeh, 2015; Lopez de Lacalle et al., 2006). According to Ezekiel and Aminu, 2018; Alessandro (2011) the use of water-based bio-compatible fluids can help to improve the performance of the product with reduced environmental impact. Water-based bio-compatible fluid already achieved including: Castrol oil based cutting fluid (Holmberg, 2011).

The Castrol oil plant (*Ricinus communis L.),* also called Castrol bean (Britannica, 2020), an oval shape seed of the Castrol plant. This natural has been considered for eco-friendly manufacturing in recent time. It is probably native to tropical Africa; It is extensively found in naturalized throughout warm area of the world (Ezekiel and Aminu, 2018). It is also ubiquitous in Northern Nigeria, especially in savannah belt, which include: Kogi, Nassarawa, Niger State and so on. In Nigeria, Castrol plant commonly known as is known as Ogili or Ugba in south-eastern zone and Ilarun in South-western Nigeria.

Castrol oil can find its application range is very wide with uses ranging from paints, synthetic resins and varnishes, to the areas of national security involving engineering plastic, jet engine lubricants and polymers for electronics and telecommunications (Agbota, 2020). More so, the use of Castrol oil in machining work my allow a bio-cutting fluid, which make it possible to develop a new generation of cutting fluid, where high performance in machining combined with good environment compatibility could be achieved (Canter, 2009).Castor oil is industrially useful due to: its unsaturated bond, low melting points at temperature 5^{o}C, high molecular weight of about 298stable viscosity and low solidification point ranging from -12 ^{o}C to 25 ^{o}C (Nweke, 2019). Other factors favour Castrol oil application includes: its abundant availability, low cost and unique structural featuring and the presence of hydroxyl group on the fatty acid (Scenic, 2020).

Although, the advantages caused by the Castrol oil have been questioned lately, due to its composition. It contain toxic enzyme called ricin, which make it non-edible whenever it is not processed. They are also more suspensible to degradation by oxidation or hydrolytic reaction. However, the heating process that Castrol oil undergoes deactivates allowing the oil to be used safely, according to Kubala(2018) .More so, its unsaturated bond ,low melting point at temperature 5^{o}C,high molecule weight of about 298,stable viscosity and low solidification point of range -12 to -25^{o}C(Nweke,2019),has limited such bean oil application, thus preferred for industrial uses (McGraw, 2000).

Castor oil classified as non-edible oil category by Ujjwal, Atif and Aftab(2015) can perform well as cutting fluid with the addition of certain additives and modifier, which can influence physiochemical properties. Some positive results have been reported the use of vegetable cutting fluid with other material. Avila and Abrao (2001) developed two bio-cutting fluid and mixed them with other materials (two emulsions and one synthetic) and compared them to dry cutting when turning hardened steel (49 HRC) using mixed alumina tools.

The results indicated that the emulsions fluids (no mineral oil) and dry cutting produce better result than synthetic fluids and emulsions with mineral oil. Ujjwal, Atif and Aftab (2015) developed vegetable –based cutting fluid using Coconut and Castor oil with their inherent properties.This work focused on the formulation of bio-cutting fluid using Castrol oil obtained from tropical area, emulsifier and other additives and examine the physiochemical properties of the bio cutting fluid to assess their functionality as cutting fluid (or metalworking fluid).Castrol oil-based cutting fluid can provide better surface finish at higher speed during mild steel turning operation.

2. Materials and Methods

2.1 Sample Collection

Castor seed used in this work were obtained from a local market in Okehi, Kogi state Local Nigeria.

2.2 Preparation of Castrol Oil

The Castrol beans collected were air-dried and crushed into fine power with the aid of a seed shelling machine .The Castrol beans powder was boiled in water for 4-5 hours, then the Castrol oil required is obtained as the condiment has settled.

2.2.1 Composition Castrol oil based-Cutting Fluids

The formulation of the bio-cutting fluids was conducted using cutting fluid formulation method proposed by Mohammad et.al(2018).This method involves combining the three major constituents: base oil, emulsifier and other additives).. Base oil: the base oil used in this work is Castrol oil. Emulsifier: In this case, washing soap was used as emulsifier. The main function of the emulsifier is to allow the mixture of oil particle and water disperses the oil in water, according to Peil et al (2011). Additives: The choice of additive for cutting fluid depends on the function we want the cutting fluid to perform. In this case, the disinfectant employed is Sulphur, while the extreme pressure additive selected is phenol.

2.3 Formulation Ratio

The formulation was done according to cutting fluid production procedure of America Society of Testing and materials. The proportion of the composition is in ratio 80:10:5:5.This represent to 80% of base material (Castrol oil), 10% of emulsifier, 5% of disinfectant and 5% of extreme pressure additive materials.

2.3.1 Mixing of the Castrol oil-based cutting Fluid with Water

The Castrol –based cutting fluid (CBCF) formulated and the reference sample used, were mixed with water in the ratio 1:10(i.e.1 part of cutting fluid to 10 part of water).In each CBCF sample, a 250ml seven necked round bottom flask connected to an overhead motor stirrer to authenticate that homogeneous blends could be gained, a thermometer and an open separating funnel. Processed castor oil in various proportions was blended with additives and emulsifiers along with water. Through the use of standard testing methods as determined by the American society for testing materials (2008). The formulated oils in their various proportions were charged into the round bottom flask. The mixture was allowed to stir for 30minutes at 40^0C.The blending ratios of formulated cutting fluids are presented in Table I below.

Table 1. The summary of bio-cutting fluids sample formulation

S/No.	Materials	Functions	Trial Sample Content (%)						
			I (Reference or Controlled) Sample	II	III	IV	V	VI	VII
1	Castrol oil	Base oil	90	80	75	65	60	55	50
2	Liquid washing soap	Emulsifier	-	10	14	22	25	28	30
3	Sulphur	Disinfectant	5	5	5	5	5	5	5
4	Phenol	Extreme pressure additives	5	5	6	8	10	12	15

2.4. Experimental Procedures

In this experiment, the same material and oil were used. In the experiment on the effect of the emulsifier and other additives concentration on the physio-chemical properties of formulated samples, seven different samples were prepared. Sample I is the control sample (contain only Castrol oil), while sample II-VII contain mixture of Castrol oil with additives in different proportion as explained above.

2.4.1 Flash Point

All prepared samples were weight and poured into 2ml beakers and place inside small scale closed cup for about 2 minutes .The flash point value was determined by flash point determination technique recommended by ASTM D 3828-97 IP 303/83(88) ISO 3679(ASTM, 2020). The values obtained are shown in Table I.

2.4.2 pH Value.

All prepared samples were measured and weight for the pH value determination. Six samples of 2g each were poured into clean dry 25ml beakers and stir slowly. Another 2g sample, control sample was mixed with hot distilled water in a 13ml beaker. It was then cooled in a cold-water bath to 25°C. The pH value of all samples were determined using pH instrument.The pH electrode was standardized with buffer solution. The electrode was immersed inside each .The pH electrode was standardized with buffer solution and the electrode immersed into the sample and the pH value was read and recorded. The pH value was shown in Table II.

2.4.3 Viscosities

A NDJ-9S Digital Display Viscometer was used to measure the viscosity properties of the samples. A prepared sample was heated in a water bath to a temperature of 40°C in a 250ml beaker. The sample was transferred to the viscometer and placed on a fixture located at its base. The spindle of the viscometer was lowered into the fluid using an adjustable nub at the stand. The spindle was lowered until it is about 3/4 below the fluid's surface. The viscometer power source was switch on and the viscometer spindle was stirred continuously during the experiment. The viscosity value of the sample was observed and recorded. This process was repeated for other samples prepared. Table II indicates the values of viscosity obtained.

2.5 Pour Points

The ASTM D97 (ASTM, 2020) method was used in the Pour Point test of the sample of oil. Processed oil sample of 20 ml quantity was introduced into a boiling flask and first heated to 45°C in a water bath, and maintained for few minutes. The oil sample was ice-cooled. The flask was tilted to check the movement of the oil at intervals of time. Further chilling was continued until the oil stop to flow. Table II shows the temperature value of each samples formulated.

3 Result

Table II. Summary of Formulated Bio-Cutting fluid composition

Properties	Sample I	Sample II	Sample III	Sample VI	Sample V	Sample VI	Sample VII
Physical state	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
Colour	Chest	-	-	-	-	-	-
Flash point (^{0}C)	184	206.11	205.74	205.70	205.77	205.93	205.90
PH Value	5.70	9.02	9.00	8.94	8.94	9.03	9.06
Pour point (^{0}C)	-10	-13.53	-13.53	-13.45	-13.45	-12.94	-13.03
Viscosity(cst) 40^{0}C	82.60	110.25	109.63	109.27	96.28	96.12	96.06
Viscosity(cst) 100^{0}C	9.80	13.45	12.4	12.05	8.76	7.53	7.57

4. Discussion

4.1 Flash points of the formulated Castrol oil based cutting fluid

The Flash points for Castrol oil -based cutting fluid (CBCF) was lowest for the unblended CBCF and highest for the formulated sample as shown in Figure 1. This clearly indicates that higher flash points were realized with the addition of additives (emulsifier and other additive) to the base oil. The average flash point for the unblended sample(i.e. sample A) ,was obtained as 184^{0}C ,which is lower compare to average temperatures of206.11, 205.74,205.74,205.77, 205.93 and 205.9^{0}C for the formulated CBCF samples. The standard flash point is above 200^{0}C according to national standard (Sharma, 2005).

4.2. pH Value for the unblended sample

In the pH Figure 2, it was the unblended CBCF that has the lowest value (i.e.5.7), while those for formulated sample fall between 8.894 and 9.06.This clearly indicates that pH values of all formulated samples are basic and that of unblended sample is acidic. In the pH results, sample VI gives a pH value of 9.08, which appears best among the processed samples.

4.3 Pour Point of the formulated Castrol oil based cutting fluid

From the pour point results(Figure 3), it is observed that the flash point of the unblended castor oil is higher, which implies that it freezes faster than the blended samples of the castor oil and this makes it unsuitable for use. samples I-VI of cutting fluid have similar pour point average value, so can favourably compete with each other and with sample I having the best pour point value of -13.53°C.

4.4 Viscosities

In the results (Figure 4 and 5), it is observed that the control sample containing unblended castor oil has lower viscosity compare to sample II-VII contained Castrol oil mixed with additives. For the viscosity test carried out at 40°C sample II has higher viscosity value compared to the remaining samples. Also, the viscosity done at 100 °C, sample II has the highest value of all.

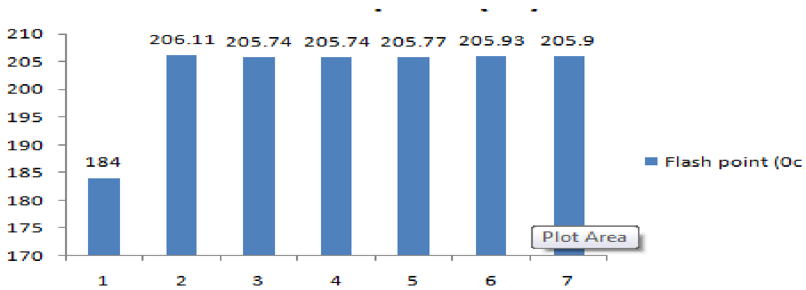

Fig. 1. Comparative analysis graph of flash (^{0}C)and samples

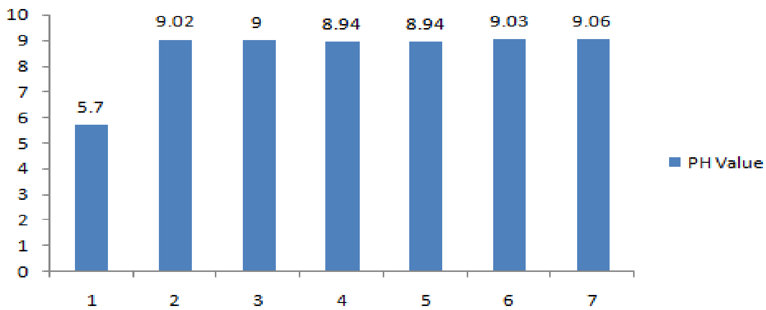

Fig. 2. Comparative analysis graph of Ph values and samples

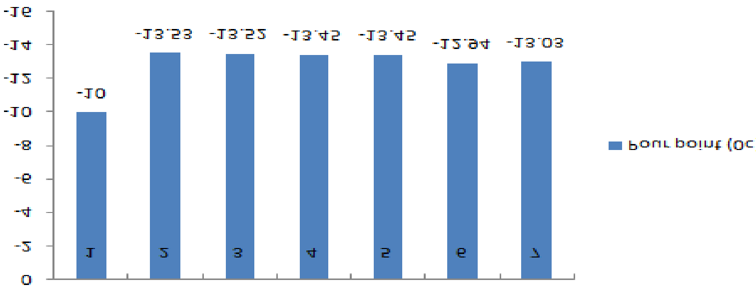

Fig. 3. Comparative analysis graph of pour point values(^{0}C)and samples

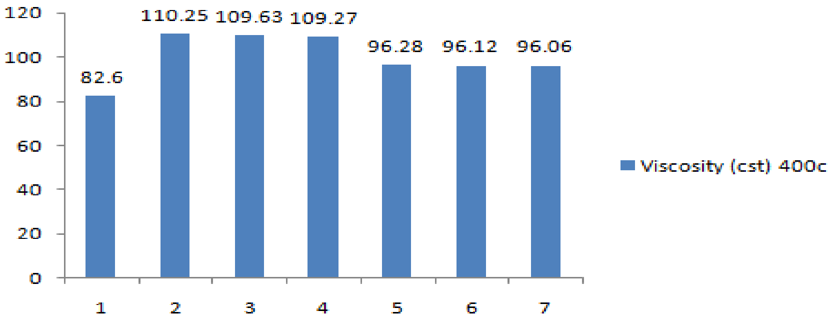

Fig. 4. Comparative analysis graph of viscosity values(cst)and samples at 40 ^{0}C

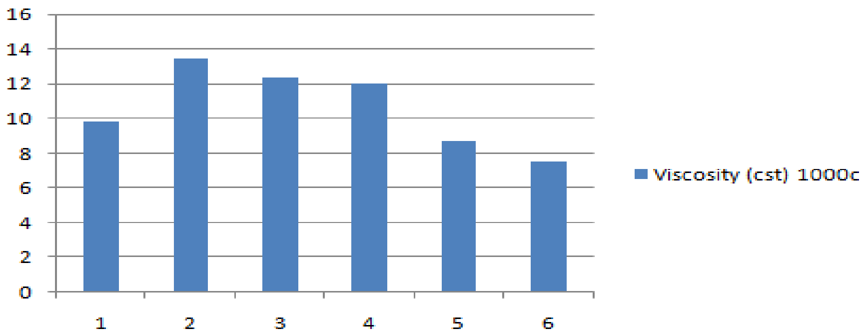

Fig. 5. Comparative analysis graph of viscosity values(cst)and samples at 100 ^{0}C

5. Conclusion

A major conclusion that can be derived from the study was that the Castrol oil derived from Castrol plant (*Ricinus communis L*), emulsifier and other additives possessed good potential to replace petroleum –based substance used as cutting fluid in machining operation and they can be easily modified and explored in the formulation of novel bio-lubricant required for green machining operation.

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