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Experimental Investigation of the Effect of Emulsifier Concentration on the Properties of Olechemical Oil Based Cutting Fluid

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Abstract Experimental investigation of the effect of emulsifier concentration on the properties of olechemical-oil -based cutting fluid was studied. It was observed that as the emulsifier concentration increases from 2% to 8%, the kinematic viscosity increased. However, for emulsifier concentration of 10%, the kinematic viscosity started decreasing for all the temperature range used, although an increase was observed with increase in temperature. On the other hand, other properties such as thermal conductivity, pH value, flash and fire points increased as the concentration of the emulsifier was raised. However, microbial growth decreased as the pH value increased.

Keywords: *emulsifier, formulation, olechemical oil, cutting fluid, vegetable oil*

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1. Introduction

Oleochemistry has grown to a major research and technology area in several institutions and industries as from 1950s.. A large variety of products based on fats and oils have been developed since then for different uses, such as specialties for polymer applications, biodiesel, surfactants, emollients for home and personal-care industries, pesticides and biodegradable mineral oil replacements for lubricants [1]. Olechemical oils are chemical compound derived industrially from animal or vegetable oils or fats, such as animal fats (tallow, lard, poultry, etc), vegetable oils (palm kernel oil, coconut oil, palm oil, soya oil, sunflower oil, rape oil, groundnut oil, etc).

As new workpiece materials and cutting tools are being developed, the need for cutting fluid to meet the requirements for machining these new materials became necessary. The effectiveness of cutting fluids has always been of great interest to researchers. In general, a successful cutting fluid must not only improve the machining process performance, but also fulfill a number of requirements which are non-toxic, non-harmful to health for operators, not a fire hazard, not smoke or fog in use and cost less. Waste disposal of mineral based cutting fluid which is non-degradable after use is a big challenge. Hence, the use of olechemical oil as based oil in cutting fluid formulation for machining processes will address these shortcomings in mineral oil based cutting fluids.

Several studies were conducted to estimate the cooling and lubricating effects of the fluids and their impact on the workpiece. For instance, in a turning operation, the maximum amount of heat generated in the cutting zone can be carried away by chip and the minimum amount of heat can equally be carried away by workpiece, tool and cutting fluid, if used [2]. In the absence of cutting fluid, the heat carried away from the cutting zone is decreased, resulting in an increase in tool and workpiece temperature [3]. The elevated cutting zone temperature significantly shortens the tool life, contributes to thermal distortion and poor dimensional accuracy and promotes the formation of built-up edge (BUE) on the tool tip [4,5]. Motta and Machado [6] concluded that the cost of cutting fluids in machining is justified by the returns obtained in the form of savings through enhanced tool life and economic consumption of energy. Minke [7] pointed out that cutting fluids play a decisive role in maintaining the quality of the workpiece. The fluids lubricate the tool in addition to acting as a coolant. Baradie [8] reported the increase of grinding wheel life and improvement in surface texture with effective application of cutting fluids. Improvement in dimensional accuracy and energy conservation were equally reported. Haan et al [9] conducted experiments on aluminum alloys and gray cast iron to determine the function of cutting fluid in drilling. Speed, feed, hole depth, tool and workpiece material cutting fluid condition, workpiece temperatures and drill geometry were examined. The results indicated that the cutting fluid does have an effect on the surface finish, and that the cutting fluid interacts with other variables to have an effect on hole quality. In addition to the effect on the surface finish, the cutting fluids are also known to influence the hardness of the machined surface. The proper application of cutting fluid provides higher cutting speeds and higher feed rates possible. Lawal et al, [10] show that many researchers have successfully used vegetable oil (olechemical oil) as cutting fluid during machining processes. Lawal et al [11] used palm kernel oil and cottonseed oil as oil-in-water emulsion cutting fluids to evaluate its effect in turning AISI 4340 steel with coated carbide tools. In this study, the effect of emulsifier concentration on the properties of formulated cutting fluid using olechemical oil is presented.

2. Materials and Methods

2.1. Materials

1. Oil

The olechemical oil (groundnut oil) used in this study was sourced from a local market in Minna- Niger State, Nigeria. Groundnut oil (a*rachis hypogaea*) belongs to a leguminous family and the seed contain high percentage of oil with the following fatty acid composition: oleic (26.2%), linoleic (5.5%), stearic (4.8%), myristic (1.5%) and lauric (1.25%) [12].

2. Water

Distilled water used for the experiment was sourced from Microbiology Department, Federal University of Technology, Minna. Nigeria

3. Emulsifier

The main function of emulsifiers is to disperse the oil in water in order to make a stable oil-in-water emulsion. The emulsifier used in this studied contains a mixture of 0.5M sodium lauryl sulphate + sodium tripolyphospate + sulphonic acid + calcium carbonate in 5litres of water. The emulsifier was prepared in Chemical Engineering laboratory of Federal University of Technology, Minna- Nigeria.

3. Anti-corrosion agent

The anti-corrosion material was banana plant juice [13] sourced locally from Ajaokuta. Kogi State- Nigeria.

4. Biocide

The biocide contains a mixture of equal concentration of 0.5M hypocholride + phenolic solution + tris(hydroxymethyl) nitro methane. The emulsifier was prepared in Chemical Engineering laboratory of Federal University of Technology, Minna- Nigeria.

5. Anti-oxidant agent

The anti-oxidant contains mixture of equal concentration of 0.5M Zinc Chloride + peroxide + calcium carbonate solution. The emulsifier was prepared in Chemical Engineering laboratory of Federal University of Technology, Minna- Nigeria.

2.2. Methods

2.2.1. Formulation of cutting fluid

The formulation of the cutting fluids involved the mixing of an appropriate measure of oil and water first in a beaker of 1litre capacity. Then the required quantities of additives (emulsifier, anti-oxidant, anti-corrosive agent and biocide) as shown in Table 1 were added to the oil-in-water. The whole mixture (500 ml) was stirred together at 100 rpm for 15minutes at room temperature using magnetic stirrer (model MS7-H550, with hotplate PC-620D, 230V). The formulation of the cutting fluid adopted the procedure used by Lawal *et al*. [14]) except extreme pressure agent, which is not part of the additives in this study. The various percentage ratio of the mixture for difference samples are shown in Table 1. For each of the sample prepared the following properties were evaluated. (i) kinematic viscosity, (ii) thermal conductivity, (iii) pH values, (iv) flash and fire points, (v) water separability and (vi) microbial contamination.

Table 1. Percentage composition of formulated cutting fluid

Materials	Sample 1 (%)	Sample 2 (%)	Sample 3 (%)	Sample 4 (%)	Sample 5 (%)	Sample 6 (%)
Water	92	90	88	86	84	82
Oil	6	6	6	6	6	6
Emulsifier	0	2	4	6	8	10
Antioxidant agent	0.5	0.5	0.5	0.5	0.5	0.5
Anticorrosive agent	1	1	1	1	1	1
Biocide	0.5	0.5	0.5	0.5	0.5	0.5

2.3. Evaluation of the Formulated Cutting Fluid Properties

2.3.1. Kinematic viscosity

Each of the samples was first heated to varying temperatures of 30, 35, 40, 45 and 50°C respectively. The Canon-Ubbelohde capillary viscometer which conforms to ASTM D446 method and related standards for glass capillary viscometers was used to carry out this test. The heated sample was made to flow through a narrow tube of the viscometer with the help of hydrostatic pressure through the capillary tube and the time of the run was noted at each temperature. The kinematic viscosity was determined using the relationship in equation 1.

$$v = k \times t \quad (1)$$

where k = 0.1017cSt/s (capillary constant), v = kinematic viscosity in centistokes (cSt) and t = time of flow in second (s)

2.3.2. Thermal conductivity

The thermal conductivity was done using the Harris Conductivity Meter (model N9243-51). The electrode was placed in each sample of the cutting fluid after it had been heated to temperatures of 30, 35, 40, 45 and 50°C respectively. The electrical conductivity was measured and equation 2 was used to obtain the value of thermal conductivity.

$$K = \frac{L}{\rho \times T}. \quad (2)$$

where K = thermal conductivity (W/m.°C), L = 2.45 x 10^{-8} WΩ/K^2 fluoresce number, σ = electrical conductivity in ohms (Ω) and T = temperature (°C).

2.3.3. Flash and Fire Points

The Automated Pensky-Martens flash point tester (Flash Pointer 34000-0 Multiflash with 34100-2 PenskyMartens Test Module) was used to accurately determine the flash and fire points according to ASTM D93 A method. A sample was placed in the sample chapter and the lid was closed. The equipment was then turned on and there was a noticeable rise in the temperature. A small test flame was passed across the fluid at regular intervals. As the temperature gradually increased, the sample began to vaporize. At this vaporization point, a spark was noticed and this was taken as the flash point of the cutting fluid and the temperature at this point was recorded. The heat was continuously applied steadily to the fluid with the test flame still moving across the fluid. The vaporization continued and at a temperature higher than the flash point temperature, the fluid ignites and began to flame. The thermometer reading was also recorded and this temperature was then noted as the fire point temperature.

2.3.4. Water Separability

The function of emulsifier is to make water and oil miscible. Hence, an experiment was conducted to estimate the water separability of the fluid. Water separability test was investigated by placing 40ml of each samples of the formulated cutting fluid in 100ml measuring cylinder at room temperature. The separation in the mixtures was made by observation after 24 hours.

2.3.5. pH Value

Digital pH meter (Hanna instrument pH 212 K06189) with the following specifications (i) range (0.0 – 14 pH), resolution (0.1 pH), accuracy (±0.2 pH) and environment (0-52°C) was used in this study to determine the pH value of the cutting fluid formulated. The pH probe was first calibrated using a buffer solution of 4 for acid calibration and 7 for neutral calibration and then inserted into the samples one after the other to determine their respective pH values.

2.3.6. Microbial Contamination

The determination of microbial and fungi content of the formulated cutting fluid were conducted by the preparation of diluents, which involved 9ml of distilled water dispensed into test tube, 3 in numbers per sample, i.e. 36 samples. The tubes were corked with cotton wool wrapped in aluminum foil paper and auto-calved at 121°C for 15 minutes, the tubes were auto-calved to sterilize them. The media was brought out to cool to 40°C. Then 1ml of oil was taken and mixed with 1 ml of Di methyl sulfoxide to enable the oil mix with water. (Di methyl sulfoxide has little or no effect; it doesn't reduce or add to the property of the mixture). The sample was added to the first test-tubes and mixed. The tube was labeled 10^{-1}, 1ml from the tube labeled 10^{-1} was taken into another tube labeled 10^{-2}, 1ml again was taken from 10^{-2} and put into another tube labeled 10^{-3}, and 1ml from the third tube was taken and introduced into the petri-dish. The same procedure was done for the remaining samples. The molten nutrient agar was added to the petri dish and rocked on the table. The molten sabouroud dextrose agar was added to the next petri dish and rocked. Then 28g of nutrient agar and 65g of sabouroud dextrose agar were dissolved in1000ml of distilled water respectively. 0.5g of chlorophenicol powder was added to sabouroud dextrose agar. The chlorophenicol powder was used to inhibit the growth of bacteria only allowing the growth of fungi. The media were allowed to gel and incubate at 37°C for 24 hours to check for bacterial contamination, while the fungi plates (SDA) were incubated at 25-38°C for 5days.

3. Results and Discussion

3.1. Cutting Fluid Formulated from Groundnut Oil

Emulsion of oil-in-water cutting fluid was formulated from the mixture of groundnut oil and water with other additives.

3.1.1. Kinematic Viscosity

Table 2 show an increase in the kinematic viscosity of the formulated cutting fluid as the emulsifier concentration increased from 2% to 8%. In the same vein, the kinematic viscosity equally increased as the temperature increases from 30°C to 50°C. This shows an increased in the lubricating property of the fluid with increase in emulsifier content and temperature within this range. However, it was observed that at 10% emulsifier concentration, the kinematic viscosity started decreasing for all the temperature range, although the kinematic viscosity increased as temperature increases.

Table 2. Kinematic Viscosity (cSt)

Temperature (°C)	Percentage Composition					
	Sample 1 0%	Sample 2 2%	Sample 3 4%	Sample 4 6%	Sample 5 8%	Sample 6 10%
30	0.8988	0.9630	0.9739	1.0074	1.0009	0.8830
35	0.8902	0.9645	0.9769	1.0111	1.0083	0.8831
40	0.8902	0.9674	0.9790	1.0111	1.0103	0.8844
45	0.8917	0.9710	0.9819	1.0132	1.0154	0.8851
50	0.8924	0.9746	0.9849	1.0154	1.0169	0.8888

3.1.2. Thermal Conductivity

The thermal conductivity of the cutting fluid was determined at different temperatures and the results show a rise in the thermal conductivity with increase in temperature as the emulsifier concentration increases. These rises in thermal conductivity can be attributed to the water content in the cutting fluids as this attribute is only peculiar to water only, as thermal conductivities of other fluids decrease with increase in temperature. The thermal conductivity values as shown in Table 3 is high with increased in emulsifier, this depicts that fluids with higher emulsifier contents can be used for machining processes at elevated temperatures

Table 3. Thermal Conductivity (W/m-°C)

Temperature (°C)	Percentage Composition					
	Sample 1 0%	Sample 2 2%	Sample 3 4%	Sample 4 6%	Sample 5 8%	Sample 6 10%
30	925	928	929	932	934	962
35	929	935	935	938	939	969
40	931	936	949	938	938	972
45	935	943	947	948	950	982
50	942	947	951	951	953	1001

3.1.3. Flash and Fire Points

Table 4 shows the results of flash and fire points and these values are represented in Figure 1. It was observed that an increase in the emulsifier concentration increases the flash and fire points of the fluid. This shows that at elevated working temperature conditions, increased emulsifier concentration will be necessary to avoid early burning of the fluid.

Table 4. Flash and Fire points

Percentage composition	Sample 1 0%	Sample 2 2%	Sample 3 4%	Sample 4 6%	Sample 5 8%	Sample 6 10%
Flash Point (°C)	159.17	162.41	163.82	164.13	164.22	166.51
Fire Point (°C)	162.13	163.08	166.92	169.07	170.17	170.75

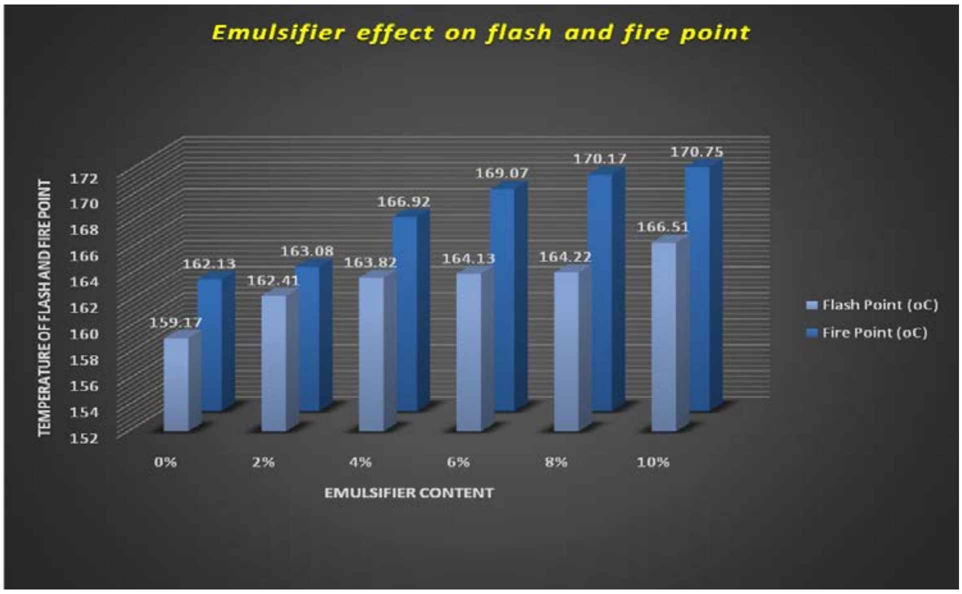

Figure 1. Effect of emulsifier on the flash and fire point values

3.1.4. Water Separability

The results are presented in Table 5. It can be observed that sample 1 without emulsifier content shows that water separability was higher than any of the samples in the experimental set up. The water separability decreases as the amount of emulsifier content increased as shown in Table 5.

Table 5. Water Separability

Time	Sample 1 0%	Sample 2 2%	Sample 3 4%	Sample 4 6%	Sample 5 8%	Sample 6 10%
24 hours	20 ml of water settled at bottom	17 ml of water settled at bottom	14 ml of water settled at bottom	12 ml of water settled at bottom	8 ml of water settled at bottom	5 ml of water settled at bottom

3.1.5. pH Value

The pH value of cutting fluid defines the condition of the fluid. A decrease in the pH value of cutting fluid of less than 7.0, shows that such cutting fluid cannot be used to machine material that is ferrous base. Again, when pH value of cutting fluid are too low or high, it has the tendency to be very hazardous to human operator and the challenge of waste disposal. Table 6, shows an increase in the pH value as the emulsifier concontration increased. An increase in pH value is characterized by increase in alkalinity of the cutting fluid. Hence, the results show that increase in emulsifier content increases the alkalinity of the cutting fluid.

Table 6. pH Value

Composition	Sample 1 0%	Sample 2 2%	Sample 3 4%	Sample 4 6%	Sample 5 8%	Sample 6 10%
pH value	8.75	9.16	9.95	10.11	10.36	10.39

3.1.6. Microbial Contamination

Table 7 and Table 8 shows the bacteria and fungi plate counts of samples 1 to 6 respectively. These results were obtained from the plate counts of the colonies formed during the isolation period of the cutting fluid. The values are in agreement with the pH values in Table 5 in the sense that, microbial growth takes place in acidic medium rather than in alkaline medium. Hence, as the pH value of the cutting fluid increased, it becomes resistance to microbial growth

Table 7. Microbial Contamination (cfu/ml) of bacteria plate count

Sample	Sample 1 0%	Sample 2 2%	Sample 3 4%	Sample 4 6%	Sample 5 8%	Sample 6 10%
Bacterial plate count ($x10^3$)	136	109	106	96	94	88

Table 8. Microbial Contamination (cfu/ml) of fungi plate count

Sample	Sample 1 0%	Sample 2 2%	Sample 3 4%	Sample 4 6%	Sample 5 8%	Sample 6 10%
Fungi plate count($x10^3$)	47	40	30	21	12	7

4. Conclusions

The effect of emulsifier concentration on the properties of formulated cutting fluid using groundnut oil was carried out. It was observed that properties such as thermal conductivity, flash and fire points, pH values of the formulated cutting fluid all increased with increase in emulsifier concentration. Kinematic viscosity increased as the emulsifier concentration increases from 2% to 8%. However, for emulsifier concentration of 10%, the kinematic viscosity started decreasing for all the temperature range used, although an increase was observed with increase in temperature. Increased in emulsifier concentration decreases the microbial growth of the cutting fluid as less microbiological growth was observed for sample with 10% emulsifier concentration.

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