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Effect of Emulsifier Content on the Properties of Vegetable Oil Based Cutting Fluid

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Abstract The effect of emulsifier content on the properties of oil-in-water emulsion cutting fluid using palm kernel oil as base oil was investigated. It was observed that kinematic viscosity, thermal conductivity, flash and fire points, pH value all increased with increase in emulsifier content. The growth of microbial contamination decreases with increased in pH value.

Keywords: *additives, cutting fluids, pH value, emulsifier*

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1. Introduction

The effectiveness of any type of cutting fluids, which depends on its properties, has always been an area of focus by researchers. It is a known fact that cutting fluids have been used in machining of metal workpieces so as to obtain optimal results such as improved tool life, reduced workpiece thermal deformation, improved surface finish and to flush away chips from the cutting zone. However, these functions of cutting fluids are influenced by the type of cutting fluids that are in use today. For instance, Wang and Kou [1] investigated the effectiveness of cutting fluid as a coolant in grinding and the results revealed that water has higher cooling effectiveness than oil. In addition, the cooling effect of the grinding fluid becomes more significant at lower workpiece speed, higher grinding depth and greater wheel speed. Bianchi *et al* [2] studied the effect of different cutting fluids, viz. 5% emulsion and pure oil on grinding wheel. They examined the surfaces of the products using Scanning Electron Microscope and results showed a better performance of the pure oil compared to the emulsion, the obvious reason is simple, oil has a better lubrication property compared to the emulsion.

Alves and Oliveira [3] proposed a novel formulation of cutting fluid based on sulphonate vegetable oil which showed a better performance over mineral neat oils. Surface finish in grinding using CBN wheels was observed and reported to be better over the neat oils and the proposed oils were shown to be easily biodegradable. Tsao [4] studied the effect of sulfurous boric acid ester in milling, in which tool wear was observed to decrease with the addition of the ester. 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. Soluble oil is a mineral oil that contains emulsifiers. Emulsifiers are soap like materials that allow the oil to mix with water. Soluble oil cutting fluids have good lubricating properties and also good thermal conductivity, but not as good when compared to water. They owe their cooling properties to the presence of water that has mixed with the oil. It has been observed that combining water and vegetable oil to make cutting fluids advances the properties of the fluid and is also advantageous for metal cutting processes. Rao *et al* [5] have studied the influence of emulsifier content on cutting fluids, in order to improve the properties of soluble-oil cutting fluids. In this study, the effect of emulsifier content on the properties of oil-in-water emulsion cutting fluid formulated using vegetable oil (palm kernel oil) would be investigated.

2. Materials and Methods

2.1. Materials

1. Oil

The oil of palm kernel used in this study was obtained from Gwari market in Minna- Nigeria. Palm kernel oil (PKO) is obtained from processing the kernel from the fruit of the oil palm tree (*Elaeis guineensis*). The major fatty acids in palm kernel oil are lauric acid (C12, 48%), myristic acid (C14, 16%) and oleic acid (C18, 15%) [6]. The Oil palm bears large (up to 20-75 kg), crowded bunches of thousands of fruits (see plate 1). The *Elaeis guineensis* starts to produce fruits as from four to five years after planting. The fruit is 5 cm in diameter, elongated, nutlike, glossy bright red to black when ripe and it takes about 6 months for fruits to ripe.

Plate 1. Ripe oil palm bunch

The palm fruit is drupe, oval in shape, and contains a nut. The nut is surrounded by fibrous fruit pulp or oil-bearing tissue (mesocarp) and the skin (see plate 2). The nut consists of a hard shell and a kernel. Palm oil is an edible vegetable oil derived from the mesocarp (reddish pulp) of the fruit of the oil palm. It is naturally reddish in color because of high beta-carotene content. Palm kernel oil is derived from the kernel of the same fruit. The differences are in color (raw palm kernel oil lacks carotenoids and is not red), and in saturated fat content. Palm mesocarp oil is about 41% saturated, while palm kernel oil is around 81% saturated.

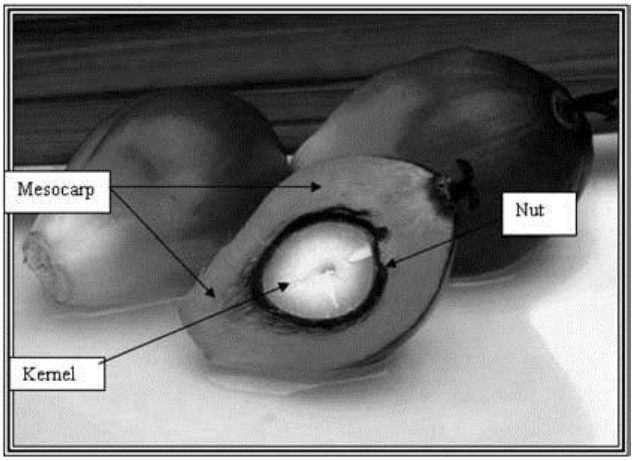

Plate 2. Cross-section of an oil palm fruit

Palm kernel oil is semi-solid at room temperature, and is more saturated than palm oil. It is commonly used in commercial cooking because of its relatively low cost, and because it remains stable at high cooking temperatures and can be stored longer than other vegetable oils [7].

2. Water

Distilled water used for the experiment was obtained 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 [8] 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) as shown in Figure 1.

Figure 1. Stirring the mixture with Magnetic stirrer

The formulation of the cutting fluid adopted the procedure used by Lawal *et al.*[9]) 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^{o}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 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^{o}C respectively. The electrical conductivity was measured and the 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 taking 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 concentrate. Water separability test was investigated by placing 40ml of each samples of the formulated cutting fluid in 100ml measuring cylinder at room temperature as shown in Figure 2. The separation in the mixtures was made by observation after 24 hours.

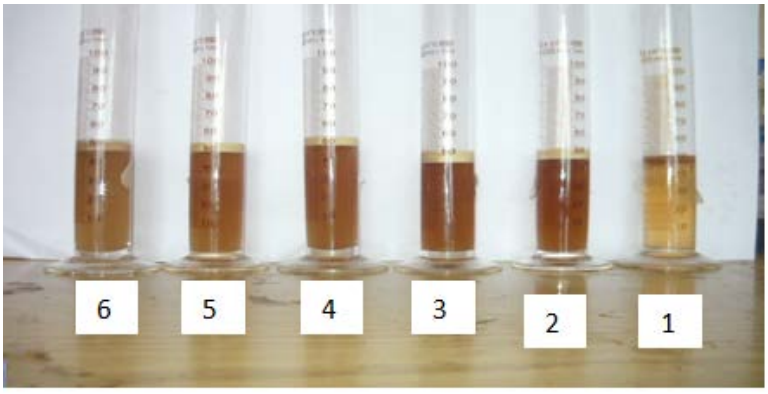

Figure 2. Water Separability experimental setup

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^{o}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^{o}c for 15 minutes, the tubes were auto-calved to sterilize them. The media was brought out to cool to 40^{o}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 incubated at 37^{o}C for 24 hours to check for bacterial contamination, while the fungi plate (SDA) were incubated at 25-38^{o}C for 5days.

3. Results and Discussion

3.1. Cutting fluid formulated from PKO

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

3.1.1. Kinematic viscosity

Results in Table 2 show an increase in the kinematic viscosity of the formulated cutting fluid as the emulsifier content increases. Similarly, the kinematic viscosity equally increased as the temperature increases. This shows an increased in the lubricating property of the fluid with increase in emulsifier content and temperature as shown in Figure 3.

Table 2. Kinematic Viscosity (cSt)

Temperature (°C)	Percentage Composition of Emulsifier					
	Sample 1 0%	Sample 2 2%	Sample 3 4%	Sample 4 6%	Sample 5 8%	Sample 6 10%
30	0.8720	0.8837	0.9130	0.9099	1.0241	1.5446
35	0.8749	0.8851	0.9135	0.9184	1.0256	1.5454
40	0.8795	0.8873	0.9164	0.9193	1.0293	1.5490
45	0.8837	0.8909	0.9186	0.9237	1.0314	1.5519
50	0.8880	0.8931	0.9186	0.9259	1.0322	1.5526

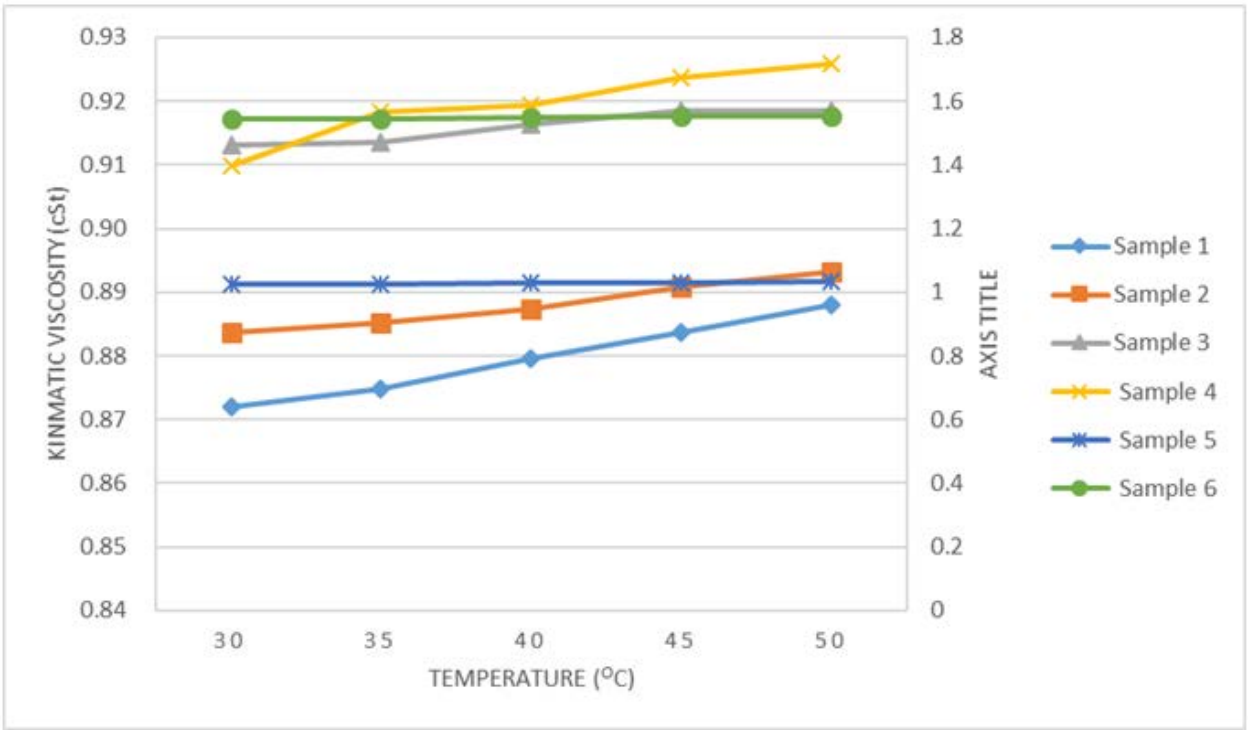

Figure 3. Kinematic Viscosity of the cutting fluids at varying temperatures and emulsifier content

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 contents 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. As it can be seen in Table 3 and Figure 4, the thermal conductivity is high with increase 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	920	931	937	940	943	968
35	928	930	939	944	947	966
40	930	934	940	943	949	971
45	932	933	942	948	953	1011
50	936	935	947	952	955	1030

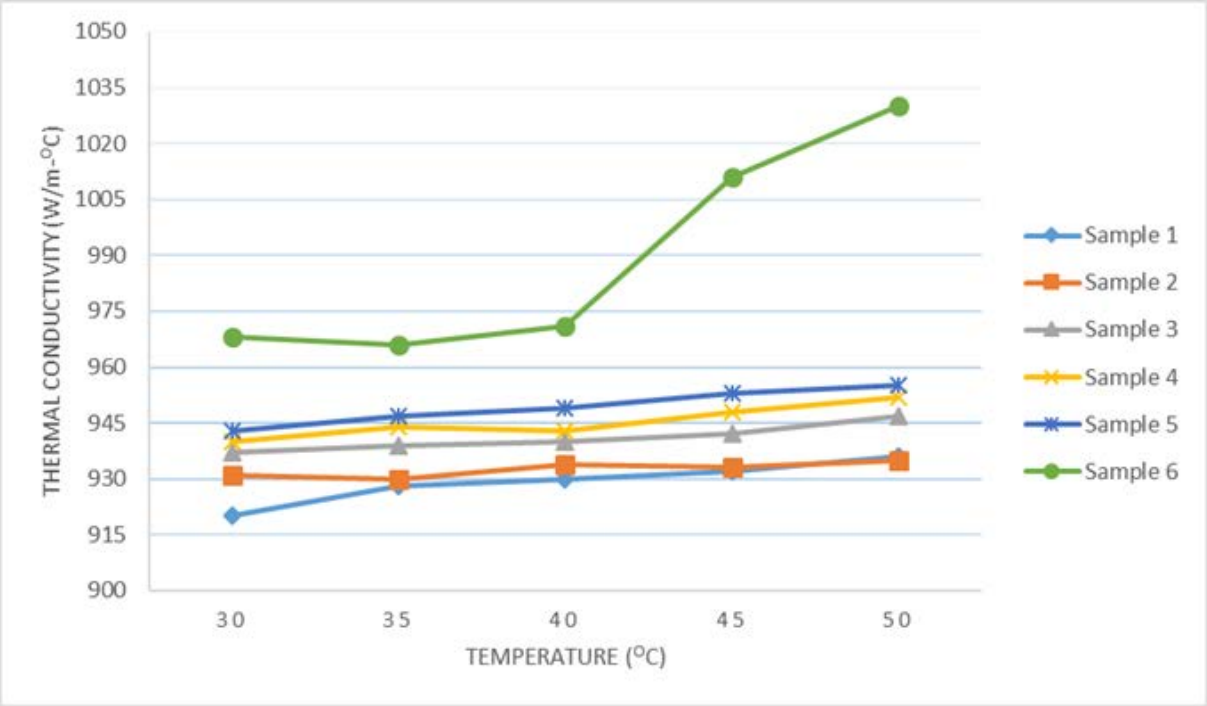

Figure 4. Thermal Conductivity of the cutting fluids at varying temperatures and emulsifier content

3.1.3. Flash and Fire Points

Table 4 shows the results of flash and fire points. It was observed as depicted in Figure 5 that an increase in the emulsifier content increases the flash and fire points of the fluid. This shows that at elevated temperature working conditions, increased emulsifier content will be necessary to avoid early burning of the fluid.

3.1.4. Water Separability

The results are presented in Table 5 as obtained from Fig 2. 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 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)	161.52	162.01	162.33	163.05	163.29	170.17
Fire Point (°C)	165.52	167.21	168.01	168.98	169.47	175.10

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	25 ml of water settled at bottom	20 ml of water settled at bottom	16 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

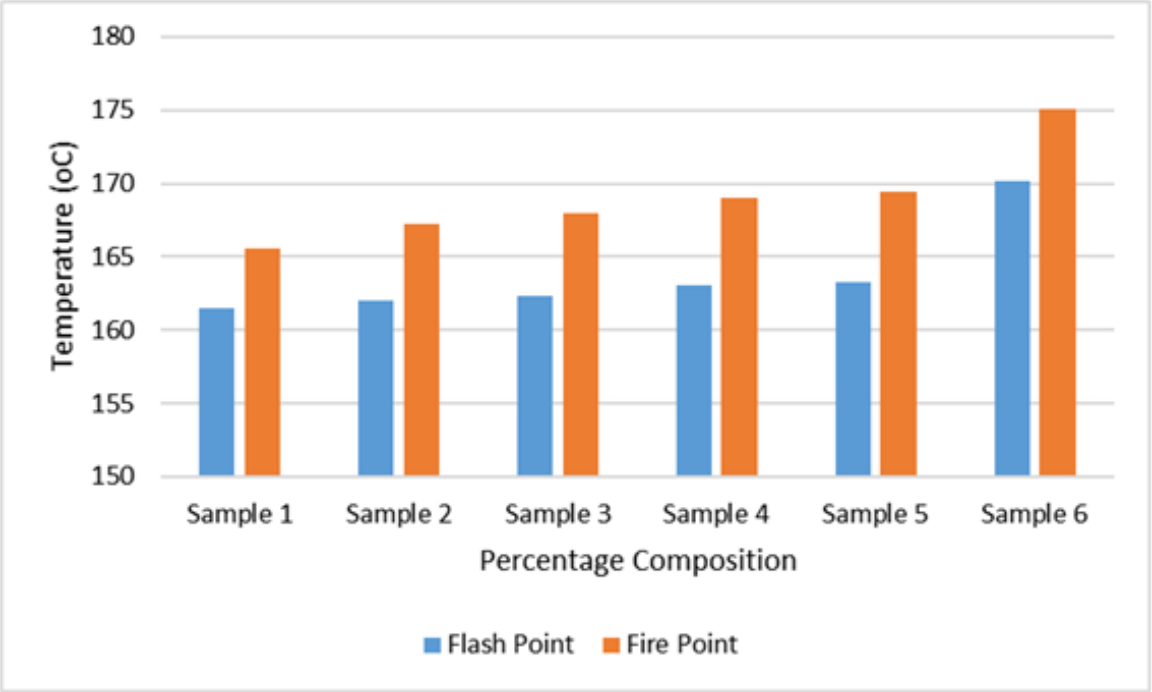

Figure 5. Flash and Fire Points of the cutting fluids with varying emulsifier content

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 iron 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 challenge of waste disposal. Table 6, shows an increase in the pH value as the emulsifier content increased as shown in Figure 6. 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

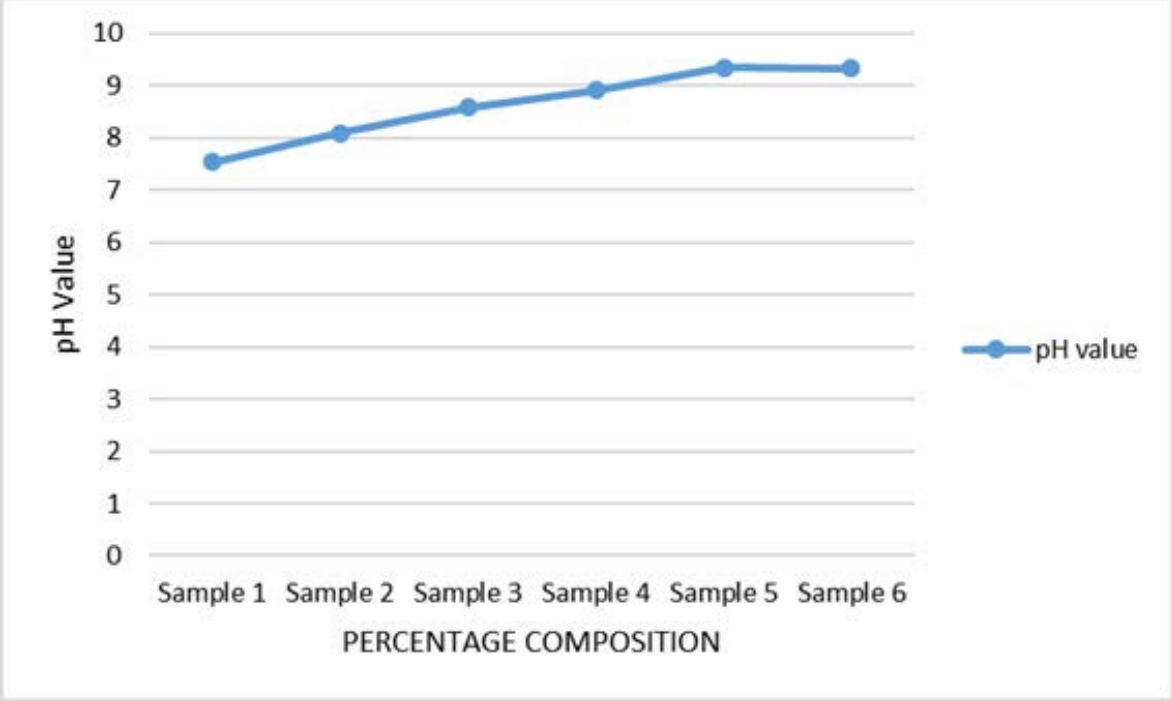

Figure 6. The pH Value of the cutting fluids with varying emulsifier content

Table 6. The pH Value

Percentage composition	Sample 1 0%	Sample 2 2%	Sample 3 4%	Sample 4 6%	Sample 5 8%	Sample 6 10%
pH value	7.54	8.09	8.59	8.92	9.34	9.33

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 contamination 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 contamination.

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

Sample	Sample 1 0%	Sample 2 2%	Sample 3 4%	Sample 4 6%	Sample 5 8%	Sample 6 10%
Bacterial plate count)	131	82	72	51	42	36

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	20	17	10	7	5	2

4. Conclusions

The formulation of cutting fluid using PKO was achieved and it was observed that properties such as kinematic viscosity, thermal conductivity, flash and fire points, pH values of the formulated cutting fluid all increased with increase in emulsifier content. Increased in emulsifier content decreases the microbial contamination of the cutting fluid as less microbiological growth was observed for sample with 10% emulsifier content. As the percentage of emulsifier content increased in the samples of formulated cutting fluid, it was observed that the formulated cutting fluids level of foaming increased. Hence, the needs for anti-foaming agent as an additive in the formulation of this emulsion cutting fluid from palm kernel oil.

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