Journal of New Technology and Materials (JNTM)
J. New Technol. Mater.
Vol. 08, N°01 (2018)15-21

OEB Univ. Publish. Co.

Evolution of a synthetic fluid from water extract from fermented ground maize (WEFGM) as an alternative to water-based cutting fluids: properties analysis

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Received date: May 18, 2017; revised date: Feb. 06, 2018; accepted date: Feb. 08, 2018

Abstract

Relevant properties of synthetic fluid samples formulated using deionized water, Water Extract from Fermented Ground Maize (WEFGM) and deionized WEFGM as base fluids at 5 and 10%vol additives have been evaluated. The pH value of all the samples lies between 1.01-1.41 with WEFGM being the least acidic. All samples have a boiling point ranging between 140-152°C with the highest value found with Deionized WEFGM and WEFGM at different additive levels. The density of the samples ranges between 928-1008 kg/m^3 with the highest found with WEFGM and deionized WEFGM at different additive levels. The viscosity of the samples ranges from (17.5-18.9) and (10.8-15.4)x10^{-3} m^2/s at 30 and 60 rpm respectively with the lowest found with deionized WEFGM at both additive levels. The fluid samples in order of decreasing specific heat capacity (SHC) are Deionized WEFGM (-2553.52, -2422.19), WEFGM (-2659.32, -2572.99) and Deionized Water (-2751.12, -2589.51) J/kg/K at (5, 10) %vol additive levels respectively. With lower acidity, higher density, lower viscosity and higher SHC, WEFGM has properties superior to water as a base fluid for synthetic fluids.

Keywords: WEFGM; Synthetic fluids; Metalworking;

1. Introduction

Heat transfer fluids such as coolant or cutting fluids are selected based on their relevant thermophysical and physicochemical properties. Because no single fluid possesses all the required properties for effective cooling or heat transfer in any specific application [1], conventional base fluid like water is being enhanced to improve its performance. This idea is the basis for evolution of nanofluids where nanometallic or non-metallic particles are being infused into these traditional base fluids [2, 3]. That development is recently witnessing a new dimension as these nanoparticles are being sourced from agric-based fibres due to lethal nature of synthetic ionic grains previously in use [4]. In related manner, synthetic fluids are formed using certain additives in water; semi-synthetic fluids evolved with additives in much water and little oils while soluble oils are formulated as either oil-in-water emulsions or water-in-oil emulsions [5] incorporating relevant additives in much water-little oils or much oils-little water respectively. These inventions came up to form a composite fluid mixture in order to complement deficiencies in certain properties of the base fluids.These properties are usually identified as pH, microbial content, Total Dissolved Solids (TDS), boiling point, density, viscosity, specific heat capacity, thermal conductivity and so on. The pH in most cases are expected to be weakly alkaline usually between 7-8 [6] or at moderate level of 8.0-9.5 while the pH above 9.5 has been reported as capable of causing skin irritation [7]. Meanwhile, few metalworking fluids (MWF) have been identified with acidic pH [6] because of the tendency of such fluids to have a corrosive effect on the workpiece [7]. The microbial content such as bacteria, fungi and yeast presence within the solution of cutting fluid is expected to be at the most possible minimal level. The presence of microorganisms within the fluid medium has been reported to enhance its corrosive tendency [8]. TDS content of a specific fluid is very important to determine the metallic ions constituent in the bulk volume of the sample. Meanwhile, the usual impression is that fluid samples with lower TDS is better perhaps because high mineral content in tap water has been linked to poor heat transfer in engine coolant [9]. More so, a higher TDS values according to [8] enhances more microbial growth leading to corrosion. Hard water has been described as water with high mineral content and has been noted for causing rust, stains and corrosion of machines or workpiece [10]. However, the fact is that high or low content of TDS of a fluid sample is not sufficient to justify the preference of one fluid over another as mineral content may have either positive or negative influence on some other fluid properties such as the pH, conductivity and corrosiveness of the sample [11]. According to the same author for instance, conductivity increases as mineral accumulates and water with low level of minerals is not suitable as coolant. The boiling point of cutting fluid is much desired to be above that of water. Water boils at 100°C which suggests that its use is not safe during special application where the heat generated is relatively at 100°C or above. The boiling point of water is therefore considered too low which necessitates a search for alternative fluid. Cutting fluids are expected to have a low viscosity such that it does not become sticky and prevent free flow or washing off of the chips at tool-workpiece interface during machining. Since viscosity and temperature obey inverse relation, a cutting fluid with lowest viscosity at highest temperature is most recommended. According to [12], high viscosity improves the lubrication properties of the fluid but decreases the cooling performance and removal efficiency of solid particles. The former is desired for cutting fluids as low viscosity also implies high viscosity index. According to [5], a MWF should have a viscosity that is low enough to allow good chip removal and not reduce cooling functionality, but it should be high enough to provide a friction-reducing hydrodynamic layer. The same authors reported the viscosity of deionized water at 40°C as 0.89cP. In similar analogy, the density of the cutting fluid is best to be high. This is because kinematic viscosity usually being used in qualifying cutting fluids is inversely related to density according to the Newton's Law. The thermal conductivity and specific heat capacity of heat transfer fluids are expected to be higher. In most cases, enhancement of these major properties is the main goals of composite fluids. In most common applications, water has been used as the base fluids despite its apparent deficiencies. A recent work by [13] found corrosion inhibitors in Water extract from fermented Ground Maize (WEFGM). Further analysis confirmed that this emerging organic fluid sample favourably competes with water in terms of its thermophysical properties such as density, viscosity and a higher specific heat capacity [14]. Synthetic fluids have been described as the emerging cutting fluid for the future. It is the choice of fluid samples to which most recent research efforts are devoted. This study has utilized both the WEFGM and water as base fluids in the formulation of synthetic fluids using selected additives, evaluated the properties of the fluid samples produced and compared the outcomes to determine their apparent relative superiority. Water quality has been said to have a greater effect on the efficiency of the coolant [10]. Consequently, deionization was carried out on the base fluids as recommended by these authors to remove minerals and impurities. As no fluid without minerals is suitable for coolant, only metallic ions identified as corrosion factors by [11] are selectively removed.

2. Materials and methods

2.1. Basic Raw Materials

The sources and quantities of basic raw materials used are as shown in table 1

2.2. Preparation of WEFGM

Preparation of WEFGM was done according to the method described by [11] in the Metallurgy Laboratory of Mechanical Engineering Department, UAM with details shown in Table 2. All equipment used such as electronic digital weighing balance, sieve pans (300 and 150 microns), measuring cylinder (500ml) and plastic bowls were provided in the laboratory.

2.3 Preparation of the Synthetic Fluid Samples

Formulation of Synthetic fluids were carried out according to the following steps:

2.3.1 Deionization:

Just like water, metallic ions such as zinc, copper, magnesium, calcium, aluminium, iron and lead regarded as corrosion factors have been previously discovered in WEFGM [11]. Hence, deionization was initially performed on the WEFGM as recommended by [10] and [15] for base fluids. This process was carried out at the Physics Laboratory, UAM where deionized water was also procured.

2.3.2 Selection of Additives

Selection of relevant additives in the formulation of cutting fluids is critical to its performance. [13] have identified a number of bacteria in WEFGM informing the choice of Nipacide BK as Biocides. Nipacide BK is non-flammable, non-explosive, water miscible and effective against bacteria, fungi and yeast. It has been recommended for use as biocides in water-based metalworking fluids [16]. The problem associated with most synthetic fluids is poor lubrication. Therefore, Phosphoric acid (phosphate) ester has been selected as EP lubricant additive. Phosphoric acid ester is fast replacing chlorinated paraffin which was previously the most commonly used EP additives in MWF due to problem of calcinations [5]. According to the same authors, these esters are inversely soluble and can serve as good corrosion inhibitors. They are also used as surfactants [17]

2.3.3 Composition of the Samples

Six samples of the synthetic fluids are formulated using 5 and 10%vol of the additives to make 100ml of each with WEFGM, deionized WEFGM and deionized Water as the three base fluids. This composition model is presented in Table 3.

2.4. Determination of Fluid Properties

2.4.1 Equipment and Apparatus

The determination of the relevant properties (except viscosity) of the samples was carried out at Plateau State Polytechnic (PSP), Barkin Ladi Jos Nigeria using the equipment and apparatus in Table 4.

2.4.2 Analytical Methods

(a) Concentration

The concentration, T(mg/L) of the sample was determined according to Beer-Lambert's formula:

$$T = A/(e \times l) \quad (1)$$

where A = Absorbance of the sample (constant)

e=Wavelength at Absorbance (Absorption coefficient) in L/mg

l= Cuvette Path length, 1cm

(b) Specific Heat Capacity (SHC)

The SHCs (C_3) of the samples were obtained according to the method of mixtures described by [18] using equation (2):

$$C_3 = \frac{m_1C_1(\theta_2-100)-m_2C_2(\theta_2-\theta_1)}{m_3(\theta_2-\theta_1)} \quad (2)$$

Where the constants are:

C_1=390 J/Kg/K, Specific heat capacity of Solid (copper)

C_2=900 J/Kg/K, Specific heat capacity of Calorimeter

m_1=100 g, Mass of the solid (copper)

m_2=156.7 g, Mass of the calorimeter

θ_1=27.5°C, initial (room) temperature of calorimeter and fluid sample

(c) Statistical Analysis

The output of the study was subjected to Pearson correlation coefficient (Bivariate) One-Tailed Test of Significance through IBM SPSS statistics 21 software.

Table 1. Sources and Quantities of Raw materials

S/N	Items	Location	Qty
1	White Maize Grains	Mrs Helen Tyeku Farms, Makurdi.	2400 g
2	Deionized Water	Physics Lab., Univ. of Agric Makurdi (UAM)	5000 ml
3	Distilled Water	Physics Laboratory, UAM	3 litres
4	Phosphoric Acid Ester	Femtech Scientific Nigeria Limited, Nyanya Abuja.	500 ml
5	Nepacide BK	World Corsica Ltd, Benue Crecent Markurdi	1 litre

Table 2. Step-Wise Procedures and Measurements in WEFGM Preparation

S/N	Process	Measurements	Quantity
1	Winnowing of Maize Grains	Weight before winnowing	2400 g
		Weight after winnowing	2380 g
2	Soaking for 72hrs	Volume of distilled water used	3 litres
3	Draining	Weight after draining	3400 g
4	Mechanical Milling/Grinding	Volume of distilled water used	10.5 litres
5	Sieving (in two-step with 300 and 150 microns sieve pans)	Volume of distilled water used	16 litres
6	Decanting/Recovery after 24hours	Volume of WEFGM Recovered	13 litres

Table 3. Composition of the Samples

S/N	Base Fluids	%vol	Additives (%vol)	
			Phosphoric Acid Ester, (min assay: 80 %)	Nipacide BK, (10 % conc.)
Sample 1	WEFGM	90	5	5
Sample 2	WEFGM	95	2.5	2.5
Sample 3	Deionized WEFGM	90	5	5
Sample 4	Deionized WEFGM	95	2.5	2.5
Sample 5	Deionized Water	90	5	5
Sample 6	Deionized Water	95	2.5	2.5

Table 4. List of Equipment and Apparatus

Measurement	Equipment	Location
PH Value	pH Meter LMPH10	PSP
Boiling point	Hot plate REMI 2MLH and mercury bulb thermometer	,,
Viscosity	NDJ-1B Rotational viscometer/ 40°C/Spindle: #4/Diameter of vessel : 40mm	Metallurgy Laboratory, UAM
Mass/Density	Top loaded weighing balance. SAUTER RE2021	PSP
Specific Heat Capacity	Calorimeter/Copper Mass/Mercury Bulb Thermometer	,,
TDS (Evaporation method)	Hot plate REMI 2MLH and weighing balance. SAUTER RE2021	,,
Concentration (Absorbance)	AVI- 722 type Microprocessor Visible Spectrophotometer at a wavelength of 460.	,,

3. Results and Discussion

3.1 Concentration

The outcome of the evaluation experiment carried on the concentration of the samples is presented in Table 5. Table 5 shows that the concentration of all the samples ranges between 0.07-2.95 mg/L. It further indicates that WEFGM-based fluid sample is the most highly concentrated while that based on Deionized Water is the least concentrated at both level of additives. This result may be due to the fact that WEFGM is the only sample not deionized.

3.2 pH, TDS and Boiling Point

The result of test on pH, Total dissolved solids and boiling point of the samples are presented in table 6. Table 6 shows that TDS, pH and Boiling point of the samples ranges between 31.2-65.6 g/L, 1.01-1.41 and 140-152oC respectively. Deionized WEFGM-based and WEFGM based fluids have the lowest TDS of 57.5 and 31.2g/L at 10% and 5%vol additives respectively while Deionized Water-based fluid sample is rated second in terms of TDS at both levels of additives. This may indirectly imply that water has lesser content of TDS than WEFGM. All the samples are strongly acidic with WEFGM being the least acidic. The result of statistical correlation shows that TDS has a significant effect on the pH ($p=0.005$). However, with a lesser acidity observed at 5%vol additive level, the selected additives must have contributed to low pH of the samples. Meanwhile, the result on the pH value agrees with the earlier finding made by [13] and [11] who reported that WEFGM has a pH below 7. However, it appears that the presence of additives have further reduced the pH to a more strongly acidic while deionization has played no significant contribution. It has been said that few cutting fluids are acidic while the majority are weakly alkaline. Hence, pH adjustment may be necessary for all the synthetic samples. On boiling point, all the samples have a boiling point greater than water (100°C). WEFGM and Deionized WEFGM-based samples have the highest point at 5 and 10%vol additives respectively. With consistently lower TDS, higher pH and increasing boiling point, it could be said that 5% level of additives is better than 10% while WEFGM is the best of all the samples. One may not vividly conclude whether this has any relation with its relatively high concentration compared to others.

3.3 Density and Viscosity

The outcome of the determination of density and viscosity is shown on table 7. Table 7 shows that the density of all the fluid samples ranges between 928-1008 kg/m^3. On critical evaluation, Deionized WEFGM-based fluid appears as the best of the samples with maximum specific gravity of 0.962 and 0.978 at 10% and 5% vol additives respectively while 5% level additives also appears better than 10% for better density of the samples. Critical study of the result on viscosity on the table indicates that Deionized WEFGM-based fluid sample has the lowest viscosity while WEFGM-based sample appears to be the most viscous. This may imply that concentration as well as deionization probably has some influence on the viscosity since only WEFGM-based sample is not deionized and also possesses higher concentration. However, statistical test of correlation does not indicate that ($p>0.01$) but that density has a significant effect on kinematic viscosity at 30rpm ($p=0.000$). This result agrees with the conclusion reported by [14] of a close or better viscosity and density for WEFGM relative to water.

3.4 Specific Heat Capacity of the Samples

The result of experiment on Specific Heat Capacity (SHC) is shown in Table 8. Table 8 shows that deionized WEFGM is the best of the samples in terms of its specific heat capacity at both levels of additives. It has SHC values of -2422.19 J/Kg/K and -2553.52 J/Kg/K at 10% and 5%vol levels of additives respectively. This result is scientifically logical as the same fluid sample is the both the least viscous and most dense. Meanwhile, Specific heat capacity is inversely related to kinematic viscosity and directly proportional to density. This result agrees with the fact established by [14] that WEFGM has a superior specific heat capacity than water. Meanwhile, the samples at 10% additives appear better than 5% for better specific heat capacity.

4. Conclusion

The proposal for evolution of fluids based on WEFGM as alternative to water has been consolidated through the formulation and evaluation of synthetic fluids using deionized WEFGM, WEFGM and deionized water as base fluids at 10% and 5%vol additives. All the samples have a boiling point above that of water (100°C) and indicate properties that make them appear suitable as coolant. Meanwhile, both levels of additives seems appropriate for formulation of cutting fluids, 5% level indicated higher pH and boiling point while 10% level indicated higher density and specific heat capacity of the samples. Statistical test of correlation neither indicated any relation between fluid composition and the properties nor between one property and another ($p>0.01$) except between pH and TDS ($p=0.005$) as well as density and kinematic viscosity at 30 rpm ($p=0.000$). More significantly, WEFGM had the best properties in terms of boiling point and pH. Deionized WEFGM had the most excellent properties in terms of density, viscosity and specific heat capacity. Since the sample with deionized water as its base fluid has not significantly indicated superiority in the most relevant properties except that it was the lowest in concentration, this study has further laid credence to the earlier postulation that WEFGM is superior to water and that deionized WEFGM is better than deionized water as base fluids. It is therefore positive about the prospects of evolution of WEFGM or deionized WEFGM-based coolants.

Table 5. Concentration of the samples

	10 % vol Additives		5 % vol Additives	
Base Fluids	Absorbance, A	Concentration, mg/L	Absorbance, A	Concentration, mg/L
WEFGM	1.359	2.95	0.561	1.22
Deionized WEFGM	0.448	0.97	0.491	1.07
Deionized Water	0.060	0.13	0.032	0.07

Absorption coefficient, $e = 460\ L/mg$

Table 6. pH, TDS and Boiling Point of the Samples

	Additives					
	10 % Vol	5 % Vol	10 % vol	5 % vol	10 % vol	5 % vol
Base Fluids	TDS (g/L)	TDS (g/L)	PH @ 28 °C	PH@ 28°C	Boiling Point (°C)	Boiling Point (°C)
Deionized Water	64.5	33.0	1.01	1.24	146	150
WEFGM	65.6	31.2	1.06	1.41	140	152
Deionized WEFGM	57.5	34.7	1.04	1.24	150	148

Table 7. Density and Viscosity

	Density (kg/m^3)		Kinematic Viscosity (m^2/s)x 10^{-3} @30 rpm		Kinematic Viscosity (m^2/s)x 10^{-3} @60 rpm	
Base Fluids	10 % vol Additives	5 % vol Additives	10 % vol Additives	5 % vol Additives	10 % vol Additives	5 % vol Additives
Deionized Water	936	968	18.8	18.1	11.5	11.8
WEFGM	1008	928	17.5	18.9	12.6	15.4
Deionized WEFGM	962	978	18.2	17.9	11.2	10.8

Acknowledgement

Authors deeply appreciate the technical assistance of the technologists in the Science Laboratory and Technology (SLT) department of Plateau State Polytechnic, Barkin Ladi, Jos Nigeria. They are also grateful to Mr. Choji, Gyang Dalyop for initiating the contacts and hosting the researchers.

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