Research Article

Determination of Thermo Physical Properties of Water-Extract from Fermented Ground Maize (WEFGM) as Possible Alternative to Water Use as Cutting Fluid

Taofeek Ayotunde Yusuf[1*], Bukola Olalekan Bolaji[2],
Salami Olasunkanmi Ismaila[3] and Johnson Kayode Adewumi[4]

[1]*Mechanical Engineering Department, University of Agriculture, P.M.B 2373, Makurdi Nigeria*
[2]*Mechanical Engineering Department, Federal University, Oye Ekiti, P.M.B 373, Ekiti, Nigeria*
[3]*Mechanical Engineering Department, Federal University of Agriculture, P.M.B. 2440, Abeokuta, Nigeria*
[4]*Agricultural Engineering Department, Federal University of Agriculture, P.M.B 2240, Abeokuta, Nigeria*
[*]*Correspondence author. Email address: yusuf.taofeek@uam.edu.ng*

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Abstract

Water has so far been regarded as the best cutting fluid but its corrosion-influence on the work piece has necessitated searching for an alternative. Meanwhile, water-extract from fermented ground maize (WEFGM) processed from two (western yellow and kewesoke white) maize varieties have been considered having been previously found to contain corrosion inhibitors. Its density, viscosity and specific heat capacity (SHC) were determined and compared with that of water. The results showed that white and yellow WEFGM give densities with percentage decrease of 0.1 and 1.0% relative to water respectively. Using Stokes's law, the ratios of the viscosities for white WEFGM, yellow WEFGM and water were 1.22: 1.17: 1.00 and 1.20: 1.26: 1.00 respectively for the smallest (diameter of 0.45 cm) and biggest (diameter of 1.4 cm) spheres. T-test shows that there is no significant difference in the densities and viscosities values of all the samples ($P<0.05$). The result of SHC gives the ratio of 1.16:1.03:1.00 respectively for white, yellow and water samples with white and yellow having higher SHC than water with a difference of 15.7 and 3.6% respectively. Higher thermal capacity, presence of corrosion inhibitors with density and viscosity not quite dissimilar, viewed holistically, makes WEFGM having a better prospect than water as cutting fluid.

***Key Words*:** Cutting fluid; Machine coolants; Maize; Machining; Thermo physical properties

Introduction

Fluids used in machining operations are called cutting fluids or machine coolants. They are best selected with a good knowledge of their thermo-physical properties (TPP). According to Cecil et al. (1996), these TPP's are dynamic viscosity, μ, specific heat capacity, C, mass density, ρ and thermal conductivity, K. They have an invaluable utility in machining operations. Material removal in these operations is accompanied by heat generation due to friction at the tool-work piece interface. Cutting fluid is applied simultaneously in the process to remove heat built-up to prolong tool's life, achieve effectiveness and safe materials. Meanwhile, water has for long time been regarded as the best coolant (McCoy, 1994; Machado and Wallbank, 1997). This is consequent upon its availability, non toxicity, high density, high specific heat capacity and moderate viscosity but its greatest drawback is the corrosion of machine parts and poor lubrication (Astakhov, 2011).

In order to circumvent these challenges associated with water as cutting fluid and improve the performance of machining operations, alternative coolants such as water

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emulsifiable, straight cutting oils, semi-synthetic and synthetic cutting fluids were developed by adding oils, chemical fluids or both in required proportion to water (Schey, 1970). Nevertheless, this novel innovation has not completely solved the problems with cutting fluid as most of these new developed products have been qualified as sources of environmental hazard (Howes et al., 1991; Byrne and Scholta, 1993) such that various legislations are formulated regarding their use and disposal. The same authors also remarked that cutting fluid also incurs a significant share of total manufacturing cost and have a negative impact on the environment.

In a related finding, Brinksmeier et al. (1999) also reported that management of the existing cutting fluid has heavily increased the overall production cost and cannot therefore be justified on economic grounds. Similarly, Astakhov (2001) has stated that cutting fluids, especially those containing oil, have become a huge liability such that Environmental Protection Agency (EPA) regulates their disposal. Apart from the environmental threat due to their poor waste disposal, these modified water-based cutting fluids have been identified as also being responsible for a severe health hazard within the factory (Howes et al., 1991). It has been reported by Shaji and Radhakrishnan, 2003 that dermatological diseases are common in workers using these cutting fluids together with increased susceptibility to respiratory problems. Another research report also has it that poor maintenance of these products may also lead to microbial attack (Hill, 1983; Bartz, 2001).

It is against the following existing research facts that it is discovered that water is not 100 percent satisfactory and that other cutting fluids produced from its modification have also constituted great threats to the environment, factory and market economy. They are generally classified as hazardous wastes (Astakhov, 2001). This must have prompted Inasaki et al., (1993), to conclude that current research in this area must be focused on how to minimize or totally eliminate the cutting fluids and substitute their functions by some other means.

Consequently, there is need for further research on sustainable cutting fluid to savage productive machining operations. Water-extract from fermented ground maize (WEFGM) has been selected for investigation because it is in the water-family. It also shares most of the excellent preferred features with water such as availability, biodegradable and non-toxicity. Most especially, WEFGM has been discovered to contain corrosion inhibitors (Yusuf et al., 2013). More spectacularly, these authors have observed that little or no attention has been given to WEFGM by researchers as regards its relevance in technological and engineering applications. This is because WEFGM is generally considered a waste product of Ogi (wet corn paste) production. Ogi is a staple food supplement in most African countries (Adegunwa et al., 2011; Osungbaro, 2009; Akingbala et al., 1981). Apart from its occasional use for medicinal purposes, WEFGM is largely decanted and disposed off.

The study seeks to investigate the thermo physical properties of WEFGM relevant to the requirement for cutting fluid using water as reference. This is in view of the fact that the use of water influences corrosion of work piece while most alternative options are fraught with environmental and cost challenges. This study is therefore one of the emerging attempts towards finding a safer alternative to existing cutting fluids which are currently being seriously criticized and condemned. Its focus is towards ensuring effective, safe and productive machining operations.

Materials and methods

Raw materials and preparation

Maize grains (*Zea mays*) were used for the study. The kewesoke white and western yellow varieties of the grains were bought from local market in Abeokuta, Ogun State, Nigeria. The distilled water was bought at Kritz Nigeria Limited, High level Makurdi, Benue State Nigeria.

White and yellow samples of WEFGM were produced separately using the fermented procedure method as described by Yusuf et al. (2013). The ground maize pastes were left for 48 h in the laboratory for fermentation to take place. This was then followed by sieving with a sieve clothes spun and squeezed for thorough drain of the residue. The filtrate (wet maize paste) was left for 24 h after which the top water was decanted as WEFGM. Experimental determinations of density, viscosity and specific heat capacity of the samples were carried out in the laboratory at an ambient temperature of 25^{o}C.

Equipment for different tests

Beam balance and 250 ml beaker (for density); masking tape, four steel balls of various sizes, a 130 cm long cylindrical glass tube, stopwatch, vernier caliper, micrometer screw gauge, a wooden meter rule (for viscosity); then variable power supply, calorimeter and thermometer (for specific heat capacity).

Determination of the density, ρ

The density was determined using the fundamental method of mass and volume measurement.

Determination of viscosity

The viscosity of the sample was determined using

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falling sphere method (Stokes's law) described by Kothandaraman and Rudramoorthy (2007). Four steel spheres of varying diameters, one at a time, were allowed to freely fall through a long straight transparent glass tube filled to 130 cm topmark. The reading of the terminal velocity (through measurement of time and distance) was taken between 15 cm and 105 cm marks.

Calculations on viscosities

(a) Stokes viscosities

The falling sphere viscometer depends on Stokes's law. The Stokes's law equation for viscosity of a liquid using a falling sphere is given by

$$\mu_S = \frac{2r^2(\rho_S-\rho_l)g}{9V_t} \quad (1)$$

where: μ_s = Stokes dynamic viscosity of the liquid in Pa.s (kg/ms or Ns/m^2)
r = Radius of the falling sphere (m)
ρ_s = Density of the steel sphere, 7800 kg/m^3 (constant for all the spheres)
ρ_l = Density of the liquid (kg/m^3)
g = Acceleration due to gravity (9.81 m/s^2)
V_t = Terminal velocity (m/s)

Since the spheres fall through a constant distance L (m) in time t (s), then equation (1) can be expressed as:

$$\mu_S = K(\rho_S-\rho_l).t = K.\Delta\rho.t \text{ in (kg/m.s)} \quad (2)$$

where the constant, $K = \frac{(2r^2\, g)}{9L}$ (m^2/s^2) is called the sphere ball constant.

L = falling distance (0.9 m)
t = Average drop time (s)

Thus, the Stokes's kinematic viscosity can be expressed as:

$$V_s = \frac{\mu_s}{\Delta\rho} = K.t \text{ in } (m^2/s) \quad (3)$$

(b) Correction factor

According to Viswanath et al. (2007), the main error in this type of viscometer is due to the so-called wall effect which is the influence of the wall of the tube of finite diameter on the motion of the sphere. It was particularly said that when selecting spheres with different diameters, the wall effect exerted by the wall of the tube on falling spheres must be considered (Kobbekaduwa and Wijayaratna, 2012). The same authors also observed that spheres of smaller diameters produce smaller wall effect. Hence for a sphere falling in a cylinder of finite length, the values calculated from the relationship in Equation (2) and (3) should be corrected by modifying the Stokes's ball constant as:

$$K_c = K \times C_f \quad (4)$$

where K_c = Corrected ball constant.

C_f = Correction factor =

$$\left[1-2.104\frac{d}{D} + 2.09\left(\frac{d}{D}\right)^3 - 0.95\left(\frac{d}{D}\right)^5\right] \quad (5)$$

where d and D are the diameter of the sphere and inner diameter of the cylinder (tube) respectively.

Thus, the viscosities can also be appropriately corrected with equation (5), reducing the wall effect to about 20% (Kobbekaduwa and Wijayaratna, 2012; Shearer and Hudson, 2002). Therefore:

$$V_c = V_s \times C_f = K_c \,.\, t \quad (6)$$

$$\mu_c = \mu_s \times C_f = K_c.\Delta\rho t \quad (7)$$

where ν_c and μ_c are the corrected (true) kinematic and dynamic viscosities respectively.

Determination of specific heat capacity

Specific heat capacity (SHC) of the samples was determined using joule's calorimeter method described by Kumar (2002).The variable power supply (VPS) was switched on indicating the value of the current and voltage immediately. The heating coil became heated up and the changes in temperature of the sample were recorded at interval of 1 minute. Eyes were carefully fixed on the thermometer and stop watch as the stirring continued repeatedly. The readings were continually taken until there was about 10^{o}C increase. Meanwhile, the current and voltage remained constant throughout the experiment. The VPS was immediately switched off at that instant but the stirring continued. The fall in temperature was being observed as the sample began to cool while the stirring still continued. The reading resumed after few minutes when a significant temperature decrease was observed. This fall in temperature was noted for the same time duration as used for the heating.

Calculation on specific heat capacity

The specific heat capacity (SHC) of an experimental sample, C can be expressed as:

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$$C = \frac{Q}{m\Delta T}\ (J/kg.^oC) \quad (8)$$

where Q = Electrical energy =electrical power (P) × time change(Δt) (J)

m = mass of the sample = (mass of calorimer+sample) -mass of calorimeter (kg)

ΔT = Change in temperature (°C)

Equation (8) can now be re-written as:

$$C = \frac{P\Delta t}{m\Delta T} = \frac{P}{m.{}^{\Delta T}/_{\Delta t}} = \frac{P}{m[\frac{\Delta T}{\Delta t} Heating + \frac{\Delta T}{\Delta t} cooling]} \quad (9)$$

The lower expression in the bracket is the summation of the slopes of the heating and cooling curves obtained by plotting graphs of temperature (ΔT) against time (Δt) for the two readings.

P is the actual electric power supplied which is incalculable due to voltage loss via the unknown resistance of the connecting wire. However, it is constant throughout the experiment and much lesser than the constant electrical power output = IV= 2.5 × 4 =10W.

Results and discussion

Masses and density of the samples

The experimental values of masses and calculated densities for the samples are presented in the Table 1, 2 and 3, respectively. The tables show the densities of white WEFGM, yellow WEFGM and water samples as 1.079, 1.071 and 1.080g, respectively. These values give a percentage decrease of 0.1 and 1.0% in densities of white and yellow samples relative to water. Hence, in terms of densities, WEFGM is relatively similar to water while the white sample is much closer.

Specific heat capacity of the samples

The outcome of electrical heat transfer experiment on the samples presents a variation between time and temperatures as presented in Figure 1. Figure 1(a) shows that the yellow sample has earlier response to heating than two other samples. This accounts for its initial rise in temperature during the first 9 min before it coincided with water and later fell below it at 19 min. Water and white WEFGM samples began with a similar behaviour for the first 2 min, parted and reconciled at 34°C in 4 min. after which their temperatures steadily rise to 42 and 41°C respectively at 19 min. Meanwhile, the three samples appear to coincide at 33°C at 2 min before showing a significant rise up to 19 min. The gradient of temperature rise during this period for white, yellow and water samples is estimated at 0.47, 0.52 and 0.53°C/min making water the quickest in response to heat in the overall.

Figure 1(b) shows the cooling effect on the three samples. Water and yellow WEFGM samples coincided after the first 2 min of cooling. They maintained this similar cooling nature for another 4 min and parted after 6 min. The three samples coincided at 41°C after cooling for 4 min. Thereafter, they exhibited different cooling nature till they gradually cooled down to 39.3, 39.2 and 39.0 °C at 19 min yielding cooling temperature gradients of 0.11,

Table 1 Masses and density of the white WEFGM

Samples	Volume (ml)	M_f (g)	M_s (M_f - M_e), g	ρ_s (g/cm^3)
W1	50	173.7±0.35	64.5	1.290
W2	100	217.3±0.35	108.3	1.083
W3	150	262.8±0.14	153.6	1.024
W4	200	309.3±0.07	200.1	1.001
W5	250	358.1±0.14	248.9	0.996
Total				5.394
Average				1.079

- M_e = mass of empty beaker = 109.2 g
- M_f = mass of beaker containing sample
- M_s = mass of the sample

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Table 2 Masses and density of the yellow WEFGM

Samples	Volume (ml)	M_f (g)	M_s $(M_f - M_e)$g	ρ_s (g/cm^3)
Y1	50	172.9±0.21	63.7	1.274
Y2	100	216.4±0.21	107.2	1.072
Y3	150	262.6±0.14	153.4	1.023
Y4	200	309.2±0.00	200.0	1.000
Y5	250	356.3±0.07	247.1	0.988
Total				5.357
Average				1.071

- M_e = mass of empty beaker = 109.2 g
- M_f = mass of beaker with sample
- M_s = mass of the sample

Table 3 Masses and density of distilled water

Samples	Volume (ml)	M_f (g)	M_s $(M_f - M_e)$,g	ρ_s (g/cm^3)
WT1	50	174.0±0.49	64.8	1.296
WT2	100	218.0±0.00	108.8	1.088
WT3	150	262.2±0.21	153.0	1.020
WT4	200	309.7±0.28	200.5	1.003
WT5	250	357.6±0.14	248.4	0.994
Total				5.401
Average				1.080

- M_e = mass of empty beaker = 109.2 g
- M_f = mass of beaker with sample
- M_s = mass of the sample

Table 4 Specific heat capacity of the samples

Samples	Mass of calorimeter + sample (g)	Mass of sample (g)	Heating slope, $\frac{\Delta T}{\Delta t}$ (^{o}C/min)	Heating slope, $\frac{\Delta T}{\Delta t}$ (^{o}C/s)	Cooling slope, $\frac{\Delta T}{\Delta t}$ (^{o}C/min)	Cooling slope, $\frac{\Delta T}{\Delta t}$ (^{o}C/s)	Specific heat capacity, C (J/(kg.^{o}C)
White WEFGM	147.4	112.0	0.47	0.0078	0.11	0.0018	930P
Yellow WEFGM	147.8	112.4	0.52	0.0087	0.12	0.0020	831P
Water	148.4	113.0	0.53	0.0088	0.13	0.0022	804P

- Mass of empty calorimeter = 35.4 g
- P = Constant actual electrical power delivered (undetermined)

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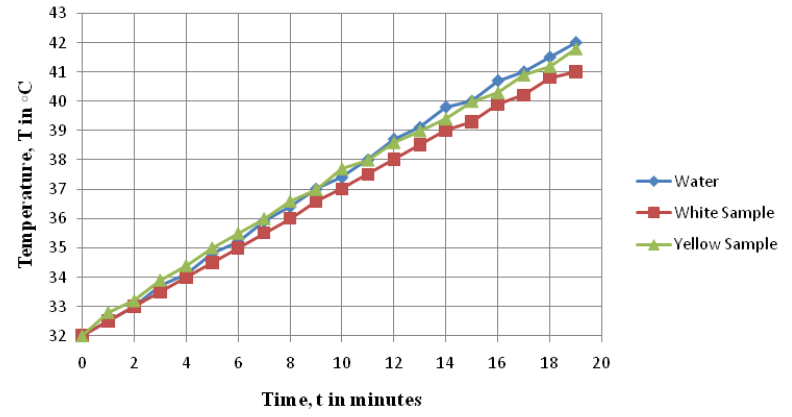
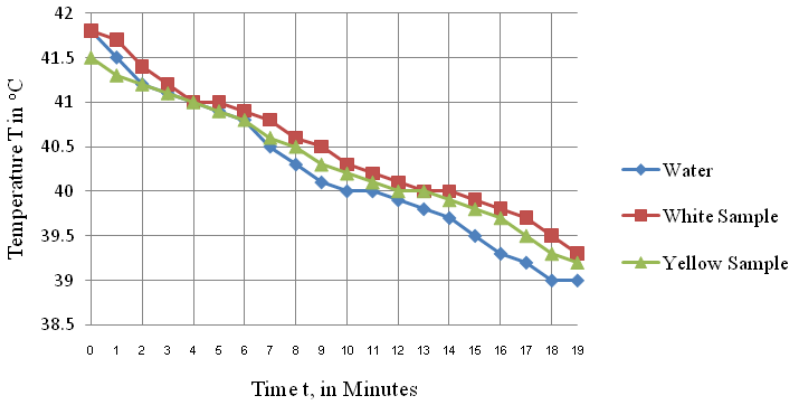


(a) Heating Curve



(b) Cooling Curve

Figure 1 Temperature and time relation during heat transfer

0.12 and 0.13°C/min for white, yellow and water samples, respectively. This makes water the quickest to loose heat or the poorest of the three samples in heat retention.

Table 4 presents the outcome of the calculation on specific heat capacity (SHC) using the information in Figure 1. It shows that the SHC of white WEFGM, yellow WEFGM and water is 930P, 831P and 804P J/kg.°C respectively giving the ratio of 1.16:1.03:1.00 respectively. The recorded values are not absolute due the unknown value of power supplied (P). However, the fact that P is constant has given a desired situation for comparison. Both the white and yellow WEFGM samples have higher SHC than water with a difference of 15.7 and 3.6% respectively. With a difference of 11.9% higher than the yellow sample, it is apparent from this result that white WEFGM sample is the best of the three samples in terms of SHC. This analytical result agrees with experimental facts obtained in Figure 1.

Analytically, water has the least SHC (Table 4) and it has been earlier confirmed to have both the fastest heating rate (Figure 1(a)) and the fastest cooling rate (Figure 1(b)). This is due to the fact that temperature gradient and SHC maintains inverse relationship (Equation 9).This is also accounts for why the white sample which is both the least to heat up and the least to cool off has the best SHC.

Viscosity of the samples

The sphere parameters as well as the analytical results on Stokes's kinematic viscosities of the samples with respect to each sphere using the Stokes's equations (Equation 3) and its corrected (true) values using the correction factor (Equation 6) are presented in the Table 5. The Table shows the diameters of each sphere with a standard deviation of 0.45 and that the ball constant, *K* deceases with decreasing sphere diameters. The effect of the cor-

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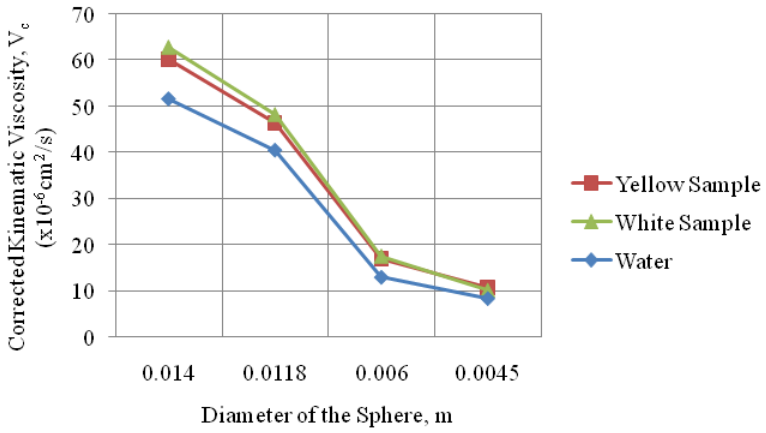

Figure 2 Graph of Diameter of the sphere (steel ball) against corrected kinematic viscosty

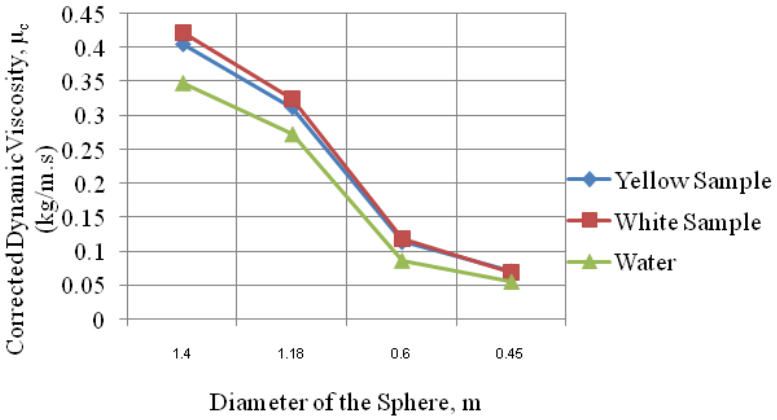

Figure 3 Graph of diameter of the sphere (steel ball) against corrected dynamic viscosity

rection factor has yielded a percentage reduction of 27.7, 23.5, 11.8 and 9.2 in *K* to K_c respectively for decreasing order of sphere sizes. This also accounts for the reduction of Stokes's kinematic viscosities to the corrected values recorded in each of the sample media in respect of each sphere.

The table further shows that the average time taken for the sphere to traverse each sample medium increases with the decreasing sizes (diameters) of the spheres having a standard deviation of 0.10, 0.13 and 0.07 respectively in white WEFGM, yellow WEFGM and water samples. Expectedly, the smaller of the spheres of the same material is expected to be lighterand travel faster in the same medium or media of relatively closer densities as it has been found of WEFGM and water.

Table 6 shows the analytical results of Stokes's and true (corrected) dynamic viscosities of the samples using equation 2 and 7 respectively. The true dynamic viscosities are 27.7, 23.5, 11.8 and 9.2 percent reduced from Stokes's values. The table further shows that with the exception of the smallest sphere (0.45cm) in yellow WEFGM sample, dynamic viscosity decreases down the orderof white, yellow and water samples and with the decreasing sizes of the spheres. For the smallest (0.45cm) and biggest (1.4cm) spheres, the ratios of the viscosities for white WEFGM, yellow WEFGM and water are 1.22: 1.17: 1.00 and 1.20: 1.26: 1.00 respectively.

The results in Table 5 and 6 indicate that WEFGM is more viscous than water and that white WEFGM is the best of the three samples in terms of viscosity. This finding becomes clearer in Figure 2 and 3 showing the relationship between the diameters of falling spheres and corrected values of kinematic and dynamic viscosities respectively. With increasing sphere's diameter, the vis-

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Table 5 Sphere parameters and kinematic viscosities

Sphere parameters						White WEFGM			Yellow WEFGM			Distilled Water		
Diameter d (m)	d^2 (m^2) $\times 10^{-4}$	d/D	K (m^2/s^2) $X10^{-4}$	C_f	K_c (m^2/s^2) $X10^{-4}$	Average Drop Time, t (s)	Kinematic Viscosity		Average Drop Time, t (s)	Kinematic Viscosity		Average Drop Time, t (s)	Kinematic Viscosity	
							V_s (m^2/s) $X10^{-6}$	V_c (m^2/s) $X10^{-6}$		V_s (m^2/s) $X10^{-6}$	V_c (m^2/s) $X10^{-6}$		V_s (m^2/s) $X10^{-6}$	V_c (m^2/s) $X10^{-6}$
0.0140	1.96	0.134	1.19	0.723	0.860	0.73	86.9	62.8	0.70	83.3	60.2	0.60	71.4	51.6
0.0118	1.39	0.113	0.84	0.765	0.643	0.75	63	48.2	0.72	60.5	46.3	0.63	52.9	40.5
0.0060	0.36	0.057	0.22	0.880	0.194	0.90	19.8	17.5	0.87	19.1	16.9	0.67	14.7	13.0
0.0045	0.20	0.043	0.12	0.910	0.109	0.93	11.2	10.1	0.97	11.6	10.6	0.77	9.2	8.4

- Inner diameter of cylinder, D = 10.47cm
- Falling distance, L= 0.9m
- K = Ball constant
- C_f =Correction factor
- The subscripts s and c denote Stokes's and corrected respectively

Table 6 Dynamic viscosities

Samples	Densities, ρl (kg/m^3)	Δρ (ρs- ρl) kg/m^3	Stoke dynamic viscosity, μ_s (kg/m.s)				Corrected dynamic viscosity, μ_c (kg/m.s)			
			d_1 1.4 cm	d_2 1.18 cm	d_3 0.6 cm	d_4 0.45 cm	d_1 1.4 cm	d_2 1.18 cm	d_3 0.6 cm	d_4 0.45 cm
White sample	1079	6721	0.584	0.424	0.133	0.075	0.422	0.324	0.118	0.068
Yellow sample	1071	6729	0.561	0.407	0.129	0.078	0.405	0.312	0.114	0.071
Water	1080	6720	0.480	0.355	0.099	0.062	0.347	0.272	0.087	0.056

- ρ_s =density of steel, 7800kg/m^3 (Shah and Abakr, 2007)
- $d_{1...4}$ = diameters of steel spheres

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cosity value of water lags behind the two samples of WEFGM. However, T-test shows that the difference between the viscosity values recorded for all the samples is not significant ($P<0.05$). This implies that the viscosity of WEFGM is nearly the same as that of water.

Astakhov (2001) has reported water as best coolant due to its low viscosity while its density has also been reported as moderate. More so, high SHC and availability are the major reasons why water is mainly being used as a coolant for over a century (McCoy, 1994; Machado and Wallbank, 1997). This study has reported a close or better viscosity and density for WEFGM relative to water. From this study, WEFGM has also clearly revealed a better SHC than water. Meanwhile, white WEFGM may be considered more suitable as cutting fluid. This is on account of yielding the best TPP, and extractible from kewesoke white maize which has a greater availability in the locality than the western yellow varieties. It has also been confirmed to contain corrosion inhibitors (Yusuf et al., 2013) which may possibly alleviate the corrosion challenges associated with the use of water as cutting fluid in view of which Efeovbokhan and Ohiozua, 2013 have discouraged its use.

Conclusion

Water has so far been regarded as the best cutting fluid due to its availability and acceptable TPP but it however influences the corrosion of the work piece. The outcome of this study has shown that there is no significant difference in the density and viscosity of water and WEFGM but the latter giving an indication of superiority. More significantly, WEFGM reveals a better SHC than water. This, if combined with the fact emerging from a previous finding that it also has a tendency to inhibit corrosion, then, WEFGM has a prospect of offering a better utility as cutting fluid than water. Nevertheless, it is recommended that the practical application of water and WEFGM in a cutting operation should be carried out to enable real performance comparison test.

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