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Characterization Of Palm Kernel Oil Under The Influence Of Applied DC Electric Field At Varying Shear Rate Temperature

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***Abstract*—The effort covers the characterization of the fluid (palm kernel oil) under the influence of applied DC electric field at varying shear rate temperature and constant particulate size. An increase in electric field through the fluid increases the electro-viscous strength of the fluid. The relative change in shear rate has small effect on the electro-viscous effectiveness of the fluid if the concentration level is 15% weight or less. The basic idea of making electro-viscous fluid with low concentration level was found successful. An increase in the concentration level of the fluid increases the electroviscious strength of the fluid. Temperature has little or no effect on the electroviscious strength of the fluid when the electric field is applied relatively high.**

Keywords—shear rate, palm kernel oil, electric field, temperature sensitivity, and electroviscious.

1. INTRODUCTION

Electroviscious Fluids EVF is a smart suspension which consists of fine polarisable particles dispersed in a non conductive, low viscosity fluid. Electroviscious Fluid exhibits a rapid, yet reversible induced shear resistance when exposed to applied electric field. The alignment of particles into Fibrilar/columnar/chain-like structures upon the application of an electric field, direct current (dc) or alternating current (ac), transforms the Electroviscious Fluid into a visco-elast solid. The increase in viscosity (or shear stress) is often orders of magnitude higher than the viscosity of the electroviscous fluid without an applied field. This field of approximately 1Kv/mm is often sufficient to induce the desired electroviscious effect within a millisecond. Suspensions that manifest this type of an electrically field-enhanced flow resistance are commonly called electroviscious fluids.

Two broad classes of electroviscious fluid are particle dispersion type electroviscious fluid composed of a dispersed (particulate) phase in a continuous (fluid) phase, and homogenous type electroviscious fluids. Homoegenous (all-liquid) electroviscious fluid do not contain particle and have Newtonian-like flow characteristics, in contrast to the Binghan flow of particles dispersion electrovisciousf fluids.

The homogenous electroviscious fluid is beyond the scope of this study. The particle dispersion electroviscious fluids are the subject of this study and are often generically referred to as suspensions. By the very nature of their composition, they are considered heterogeneous materials.

For the most part, when the alignment of particles within an electroviscious fluid is described by the formation of chains, this refers to a single strand of particles aligned with a cross section that contain are particle. The use of the term "column" typically implies multiple strands of particles composing a wider cylinder of particles. When the structure of particle alignment is undefined, or referred to in a general sense, these terms are often used interchangeably as well as other terms such as fibrous columns and fibrils.

1.2 RHEOLOGICAL MODELS FOR FLUIDS

As a basis for discussion of the experimental results, it is useful first to layout an elemental model for EV fluids.

There are mainly three rheological models that have been popularly considered for representing the mechanical properties of an EVF fluid, as introduced below.

i. The non-linear viscoplastic as expressed by the relationship

$$\tau^{\frac{1}{n}} = \tau y^{\frac{1}{n}}_{+} \left(\frac{n d_u}{d_y}\right)^{\frac{1}{r}} \quad \ldots \ldots \ldots \ldots (1)$$

Where τ is the stress, τy the Bingham stress, N is the plastic viscosity, du/dy is the shear rate and n is constant.

ii. Another non-linear approach, called the power law model which is expressed by,

$$\tau = cn\left(\frac{d_u}{d_y}\right)^{n} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)$$

Where, cn and n are functions of the elective field strength.

iii. The third model is a more popular linear viscoplastic model defined by the relationship:

$$\tau = \tau y + \left(\frac{\mathbf{n d_u}}{\mathbf{d_y}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Which is also called the Bingham Plastic Fluid.

In this study, only the linear, Binham plastic fluid model was used in discussing experimental observations. A more complete constitutive equation for the Bingham plastic fluid is

$$\tau = \begin{cases} -\tau y + \frac{nd_u}{d_y} & \text{if } \frac{d_u}{d_y} < 0 \\ \tau y + \frac{nd_u}{d_y} & \text{if } \frac{d_u}{d_y} > 0 \end{cases} \quad \ldots .(4)$$

$$\frac{d_u}{d_y} = \begin{cases} \frac{\tau + \tau y}{h} & \text{if } \tau < -\tau y \\ \frac{\tau - \tau y}{h} & \text{if } \tau > \tau y \end{cases} \quad \ldots \ldots \ldots (5)$$

This is shown graphically in figure below

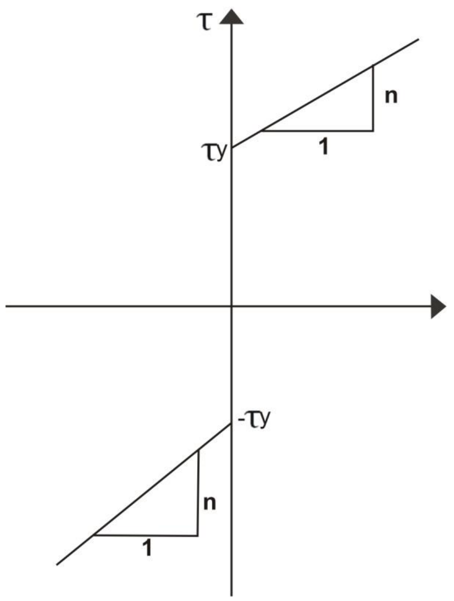

Figure 1: A Bingham Plastic Fluid

The Bingham plastic fluid model impose the basic assumption that both the plastic viscosity, “n”, and the Bingham stress “ty”, are independent of the shear rate d_u/d_y, an assumption which may not hold across all regimes of EV fluid behaviour for a given Electroviscous Fluid (EVF), the Bingham stress ty is a function of the electric field strength, temperature, solid content, excitation frequently and even the shear rate.

Electroviscious Fluid is suspension of extremely fine conducting particles (up to 50 micrometers diameter) in an electrically insulating fluid changes occur in the rheology of electroviscous fluid upon the application of electric field. Higher field result in solidification of fluids. Winslow (!947) observed that upon the application of strong electric field to non aqueous silica suspension, activated with small amount of water caused rapid solidification of the original fluid material. Though ER was first observed by Winslow in 1947, it is only in the past two decades that the controllable, reversible, rapid change in the mechanical behavior of EV fluids has made their materials an attractive choice in a wide range of active devices such as clutches, brakes, values etc. an efficient application of these fluids still encounter a number of technological problems mainly associated with lack of systematic studies in a wide range of working conditions and a conclusive model that include all their rhelogical properties. Jack Kotovsky et al (1998), demonstrated a constrained-layer damping system (CLD) using silicon fluid with viscosity as high as 10million centistokes and shear layer as tin as 0.76mm. With these parameters, damping constant as high as 2.0 = 10^6N-m (0/s) was measured. With this they were able to design a wearable tremor-suppression orthotics. Charles Pfeiffer et al (1999) studied the use of electrorheolgical fluid to allow “feeling” the environment in remote or virtual robotic manipulators. A new device was introduced for operators to sense the interaction of forces exerted upon a robotic manipulators that is being controlled. An analytical model was developed and experiments conducted on the so called electrically controlled stiffness (ECS) element which is the key to the new hepatic interface. It was found that by using elector-active or smart materials can enable to develop many interesting devices and methdogies to support the need for haptic interface in such as automation, robotic, medical, games and others. Mustafa et al (2003) investigated the use of a suspension prepared from poly (Litert butyl methacrylate) ionomer. The electric field viscosity was found to have increased by up to 20% suspension concentration and then decrease. Excess shear stress was found to increase sharply with increasing electric field strength and suspension concentration. The electroviscous activity of the suspension was found to increase with increasing electric field strength and ionomer concentration and with decreasing shear rate. It was discovered that the ionomer was insensitive to high temperature and moisture within the limits studied. Philips (1969) is among the first to develop a set of non-dimensional variables for EV fluids to determine the pressure gradient in the flow through a duct. This approach is also utilized by Coulter and Duclos (1989), and Gavin et al. (1996a and 1996b) where a quasi-static axismmertic model is derived based on the Navier-Stokes equations to predict the damper force-velocity behaviour. The model provides a simple and sufficiently accurate estimate of pressure gradients and force levels for design purposes. The model is made for computational purposes and generally fails to explain the details of observed EV behaviour. Torsten et al. (1999) give and overview on the basic properties of rheological fluids and discuss a brief summary of various phenomenological models of parametric and non-parameteric models. Parametric models are represented by a mathematical function whose coefficients are determined rheologically, and adjusted until the quantitative results of the models closely match with the experimental data. On the other hand, non-parametric models are entirely based on the experimental validation of EV fluid devices. These are models that have combined viscous, Coloumb, stiffness and inertia effects. These models have enabled the inclusion of dynamic effects, such as fluid compressibility and inertia, and they are quite useful. However, there are practical difficulities in obtaining the parameters due to the complexity of the models. Kamath and Wereley (1997) present a nonlinear viscoelastic-plastic model using viscous dash-pots in series to account for fluctuating flow. The model uses the experimental data presented by Gamota and Filisko (1991) as the basis for the quantitative study of EV behaviour, and uses an optimization technique to estimate the parameters of the model to reproduce the shape of the shear stress versus shear strain hysteresis loop. The model is able to accurately capture the experimental dynamic shear stress versus shear strain hysteresis loop at a single frequency. However, the model does not account for the pre-yield viscoelastic behaviour which is important in dynamic studies. Landler and Werely (2003) present an improved experimental validation of their existing quasi-steady EV damper using an idealized Bingham plastic model by introducing an intentional leakage effect. The leakage effect allows EV fluid to flow from one side of the piston head to the opposite side without passing through the EV value. The additional leakage effect round-off the corners of the original Coulomb damping shape, improving the slope of the force versus displacement. The leakage results in the removal of the intial yield force. The effect of leakage does accurately predict the force versus velocity behaviour, but it is able to closely predict the overall energy dissipation. This paper suggests an alternative design to obtain a fit to the prediction model which is far from quasi-steady flow.

Wang and Gordaninjad (1999) claim that the Bingham plastic model may not be an accurate predictor if EV and MR (Magneto-Rheological) fluids experience shear thinning or shear thicknening, since the post yield plastic viscosity is assumed to be constant. The authors propose and adopt the steady flow Herschel-Bulkley model as a design tool for EV and MR fluid dynamics through pipe and parallel plates. Wang and Gordaninejad (1999) demonstrate that the Herschel-Bulkley formulation can collapse to the Bingham plastic model for some particular fluid parameters by comparing the proposed model with Gavin's (1996) approximated solution of Philips (1969) Bingham visco-plasticity model. Results are presented only for MR fluid. Wang and Gordaninejad (2001) extend their earlier studies to include the dynamic effect by using the Herschel-Bulkley constitutive equation, to predict behaviour of EV/MR fluid dampers. Excellent agreement is achieved between the experiment and the models, although results are presented only for MR fluid. MR and EV fluids are very similar macroscopically, but they are quite different when examined in a microscopic sense, such as shear thinning exhibited by MR fluids. Another group of researchers focus entirely on the performance based approach by attempting to reproduce the force-velocity hysteresis. Ehrgott and Masri (1992) use a Chebyshev polynomial fit to approximate the force generated by an EV damper device. Yao et al (1997) use a recursive least-square algorithm to estimate the viscous and Coulomb friction force of both multi-plate and single-plate electrode EV damper. Marksmeier et al, (1998) develop a theoretical analysis based on Hershcel-Bulkey model to predict the behaviour of an EV grease damper. Whilst the model can agree well with the experimental data, it generally fail to explain the observed behaviour. Although the results are impressive, their practical applications are questionable. One of the works relevant to the chapter is by Peel and Bullough (1994). These authors develop a non-dimensional base on Bingham plastic constitutive equation to predict the behavior of and EV damper. Excellent agreement is achieved between the experiment and the predictions, although results are presented with statistically measured shear strength and steady Bingham plastic flow assumption. It is apparent from the above literature survey that EV damping devices can b made in a variety of configurations and techniques. This has resulted in a diverse range of prototypes and models. These papers provide an excellent overview of the current knowledge and an extensive reference section. So far, there has been little work done on the performance-based approach. Due to its starting assumption of uniform steady flow, a Bingham plastic flow based approach cannot predict the performance of an EV damper in a fluctuating flow. The main contribution of this chapter is to develop a correction model for the uniform-flow Bingham approach to model behaviour in a fluctuating flow. Such a correction is essential for meaningful predictions. Many researches of EV fluid have been applied in mechanical components such as valve, clutch brake etc. Calson et al. 1991 and automobile shock absorber, Bhadra et al. (1989), because Bingham fluid effect upon the application of voltage replaces many mechanical link systems and it responses very quickly. What is more, the fluid can be actively controlled. Morishita and Mitsui (1989) worked on the performance of a prototype squeeze-film damper.

2. RESEARCH METHODOLOGY

2.1 EXPERIMENTAL

2.2 PROCEDURES

2.3 EQUIPMENTS:

Hake VT Viscometer,
DC 5 Heater,
12 Volts DC source (Accumulator),
Dial gauge,
Variable Resistor,

2.4 MATERIAL PREPARATION

2.4.1 THE PALM KERNEL OIL:

This was sourced locally from Ekpoma main market.

2.4.2 GROUND PARTICLES:

It is necessary to obtain electrically conducting particles with approximately the same size. Particles of desired sizes are normally obtained by different methods. In this experiment the desired particle size was achieved by the aid of a pepper-grinding machine. The particles were ground repeatedly. A sieve was used to filter the particles and thus particles of size 3 ± 1.5 ℓlm were achieved.

2.5 FLUID PREPARATION:

Three samples of the Palm Kernel Oil was measured each with a volume 200cm^3
To the first sample (Fluid #1)
5% of the particles was added.
To the second sample (Fluid #2)
10% of the particles was added.
To the third sample (Fluid #3)
15% of the particles were added.
To the fourth Fluid 10% of particles was added.

2.6 TEST METHOD:

2.6.1. Experiment 1

The Influence of Shear Rate at Electric Field of 0.5kv/mm and Temperature of 40^{0}c.

Fluid #4 was selected. This temperature was held constant at 40^{0}c and the electric field was kept constant at 0.5kv/mm. the shear rate was varied from 40-440 (^{1}/min) (see table 1).

2.6.2. Experiment 2

The Influence of Electric Field at Temperature of 40^{0}c and Shear Rate of 240 (^{1}/min)

Fluid #4 was selected. The temperature and the shear rate were kept constant at 40^{0}c and 240 (^{1}/min) respectively. The electric field was varied from 0-3.5Kv/mm. the result for Dynamic viscosity was tabulated (see table 2).

2.6.3. Experiment 3

The Influence of Shear Rate at Electric Field of 0.5kv/mm and Temperature of 40^{0}c.

Fluid #1 was selected. This temperature was held constant at 40^{0}c and the electric field was kept constant at 0.5kv/mm. the shear rate was varied from 40-440 (^{1}/min).

The same procedure was repeated for fluid #2 and fluid #3 and the result tabulated. (See table 3)

2.6.4. Experiment 4

The influence of shear rate at electric field of 3.5Kv/mm and Temperature of 40^{0}c

Fluid #1, fluid #2 and fluid #3 were selected in turn. The temperature was kept constant at 40^{0}c. this time, the electric field was increased to 3.5kv/mm. the shear rate was varied from 40-440 (^{1}/min). The result for Dynamic viscosity was tabulated. (See table 4).

2.6.5. Experiment 5

The Influence of Electric Field at Temperature of 25^{0}c and Shear Rate of 240 (^{1}/min).

Fluid #1 was selected. The electric field and Shear Rate was kept constant at 0.5kv/mm and 240(^{1}/min) respectively. The temperature was varied from 25^{0}c – 60^{0}c. The same procedure was repeated using fluid #2 and fluid #3. The results were tabulated in table 5.

2.6.6. Experiment 6

The Influence of Temperature at an electric field of 3.5kv/mm and Shear Rate of 240(^{1}/min) turn.

The Shear Rate was kept constant at 240 (^{1}/min). The electric field was increased to 3.5kv/mm and then held constant. The temperature was varied from 25^{0}c – 60^{0}c. the Dynamic viscosity for the three fluids were measured and tabulated (see table 8).

3. RESULT AND DISCUSSION

All the results obtained from the test are presented below.

3.1. Table 1: Influence of shear rate at electric field density of 0.5kv/mm and temperature of 40^{0}c.

Shear rate (^{1}/min)	#4 DV (mPas)
40.00	28.10
140.00	16.50
240.00	14.00
340.00	13.40
440.00	11.90

The result showed that fluid #4 has a lower dynamic viscosity than the other fluids. As the shear rate was varied from 40-440 1/min, the dynamic viscosity decreased.

3.2. Table 2: The Influence of Electric Field at Temperature of 40^{0}c and Shear Rate of 240 (^{1}/min)

Electric Field (kv/mm)	#4 DV (mPas)
0.00	16.80
1.00	16.80
2.00	16.80
3.00	16.80
3.50	16.80

Results revealed that there was no remarkable effect on the dynamic viscosity at temperature of 40^{0}c and shear rate of 240 1/min when the electric field was varied from 0 - 3.5 (kv/mm). This is because the high temperature seems to counter the effect of the electric field.

3.3. Table 3: The Influence of Shear Rate at Electric Field of 0.5kv/mm and Temperature of 40^{0}c.

Shear rate (^{1}/min)	#1 DV (mPas)	#2 DV (mPas)	#3 DV (mPas)
40.00	38.30	70.95	79.20
140.00	26.40	69.30	40.20
240.00	23.10	69.30	39.60
340.00	23.10	72.60	39.60
440.00	21.45	70.95	36.30

Results showed that as the shear rate was varied from 40-440 (^{1}/min), the greatest effect was shown by #3 initially which experienced a sharp fall in dynamic viscosity between shear range 40-140 (min^{-1}) and then fell steadily as the shear rate was further increased. Fluids #1 and #2 also show similar response. They both fell in dynamic viscosity as the shear rate was increased.

3.4. Table 4: (Influence of Shear rate at electric field density of 3.5kv/mm and Temp. of 40^{0}c)

Shear rate (^{1}/min)	#1 DV (mPas)	#2 DV (mPas)	#3 DV (mPas)
40.00	64.00	64.00	80.00
140.00	34.00	36.00	48.00
240.00	26.00	32.00	44.00
340.00	22.00	28.00	42.00
440.00	22.00	28.00	42.00

As the shear rate was increased, fluids #1, #2 and #3 all showed a sharp fall in dynamic viscosity. Fluid #3 had the highest dynamic viscosity followed by fluid #2 with fluid #1 having the least value.

3.5. Table 5: Influence of external electric field at Temp. of 25^{0}c and Shear rate of 240 ^{1}/min)

Electric field (kv/mm)	#1 DV (mPas)	#2 DV (mPas)	#3 DV (mPas)
0.00	23.30	40.00	73.33
1.00	26.70	43.00	73.33
2.00	23.30	43.00	76.67
3.00	26.70	46.00	76.67
3.50	28.00	49.00	79.60

In this experiment, test results revealed that as the electric field was varied from 0 - 3.5 (kv/mm), the dynamic viscosity for fluids #1, #2 and #3 showed a gradual increase. Fluid #3 had the highest value, while fluid #1 increased between 0 – 1 (kv/mm), decreased between 1-2 (kv/mm) before finally it increased steadily between 2-3.5 (kv/mm).

3.6. Table 6: Influence of external electric field at Temp. of 40^{0}c and shear rate of 240 ^{1}/min)

Shear rate (^{1}/min)	#1 DV (mPas)	#2 DV (mPas)	#3 DV (mPas)
0.00	20.06	26.68	40.02
1.00	20.01	26.68	40.02
2.00	20.01	26.68	40.02
3.00	20.01	26.68	40.02
3.5	20.01	26.68	40.02

The result showed that there was no remarkable effect on the dynamic viscosity at this temperature when the Electric field was varied from 0-3.5 (kv/mm). fluid #1, #2 and #3 showed no remarkable variation in the dynamic viscosity. This is because the high temperature seems to counter the effect of the electric field. However, it was shown that as the particulate concentration of the fluid is increased the dynamic viscosity also increase temperature.

3.7. Table 7: (Influence of external electric field at Temp. of 0.5kv/mm and Shear Rate of 240^1/min)

Shear rate (^{1}/min)	#1 DV (mPas)	#2 DV (mPas)	#3 DV (mPas)
25.00	24.00	39.00	72.00
35.00	24.00	32.00	57.00
45.00	24.00	24.00	42.00
55.00	23.00	17.00	27.00
60.00	23.00	14.00	19.00

From the result, it is revealed that as the temperature was varied from 25^{0}c – 60^{0}c, the dynamic viscosity dropped sharply for fluids #3 and #2 at this electric field. Fluid #1 did not show any significant effect. This was because of its low concentration level. Fluid #3 showed the highest response because of its high concentration level.

3.8. Table 8: Influence of Temperature at electric field of 3.5kv/mm and shear rate of 240 ^{1}/min)

Temp 0^0c	#1 DV (mPas)	#2 DV (mPas)	#3 DV (mPas)
25.00	26.67	46.67	73.30
35.00	23.00	44.50	50.60
45.00	22.00	43.30	46.60
55.00	18.00	43.30	43.00
60.00	17.00	41.50	43.00

The result showed that there was a steady drop in the dynamic viscosity for fluids #1, #2 and #3. Fluid #3 showed the highest response as the temperature was increased.

The response showed by fluid #1 was due to the high electric field even though it has a low concentration. The fall or drop in dynamic viscosity for fluid #2 and #3 was steady even as the temperature was increased because of the high electric field which tends to counter the effect of the temperature.

4. CONCLUSION

An experimental study was conducted and from the results obtained, PK oil is capable of working as a base third for electroviscous suspension. The capability of the fluid to increase its viscosity according to the applied electric field and the dynamic strength of the fluid at different shear rate, temperature and electric field strength is known as efficiency. It can be concluded that electroviscous fluid is based on pure palm kernel oil as the result of fluid #1 showed that if the concentration level of PK oil is 5% wt and under, this fluid cannot work as electroviscous fluid. There is a sharp decrease in the dynamic viscosity when the temperature is raised and the applied fluid kept constant. This is in line with the earlier results (Lingard et al Filsko et al). However if the field is increased, it will counter the effect of the temperature to an extent. The result also showed that electrovicous third strength increases when the concentration of particles in the carrier fluid increases. This is considered normal according to the law of fluid flow mechanics. The influence of shear rate at temperature of 40^0c when the field is increase showed the same trend. As the shear rate is increased there is a decrease in the dynamic viscosity of the carrier fluids. The electric field influence on the DV is only appreciably noticed when the temperature is low. When the field is increased the dynamic viscosity will also increase, but at high temperature there may be no remarkable increment in the DV because the temperature will counter the effect of the electric field. In general, if the increase in viscosity is over 20% from 0.0kv/mm to 3.5kv/mm, the fluid can be considered a possible working fluid. If the percentage increase is over 20%, the fluid can still hold while the machine is not running. Based on the results, the following can be concluded in the case of Electroviscous fluid based on Palm Kernel oil with sharp sand particles at a temperature of between 20^0c-60^0c shear rates between 40-440 (min^{-1}) and electric field strength 0.5-3.5kv/mm.

- If the fluid concentration is 5% or less, the fluid does not express electroviscous phenomenon.
- At equally high electric field, temperature has little or no effect on the electroviscous properties of the fluid.
- An increase in the electric field strength through the carrier fluid increases the electroviscous strength of the fluid if the concentration is more than 5% of weight.
- Grinding decreases the electrovisous strength of the carrier fluid.

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