Fuzzy System Algorithm on Processing Methods of Rheological Properties of Oil Lubricants

Ager P., Oseni M. I. and Yanshio .E.T

ABSTRACT - **Fuzzy logic has been shown to be a useful tool for solving complex engineering problems without the need to reproduce the phenomenon under study, when the only information available consists of the parameters of the problem and the results desired. Based on the collection of 144 laboratory test, this paper uses fuzzy logic to determine the Rheology of Jatropha and Calabash Oil lubricants by using Pseudoplastic, Newtonian and Dilatant under Manual, Mechanical, and solvent processing methods. Fuzzy reasoning and aggregation final system output show that the Oil is Newtonia in nature. The result obtained is compared with experimental results and demonstrate the suitability of using fuzzy logic to predict the Rheological properties of Oil lubricants.**

Keywords; Fuzzy logic, Rheology, pseudoplastic, Newtonian, Dilatant.

I. INTRODUCTION

Fuzzy sets are the basic concept supporting fuzzy theory. The main research fields in fuzzy theory are fuzzy sets, fuzzy logic and fuzzy measure. Fuzzy reasoning or approximation reasoning is an application of fuzzy logic to knowledge processing. Fuzzy control is an application of fuzzy reasoning to control. One feature of fuzzy sets is the ability to realize a complex nonlinear input-output relation as a synthesis of multiple simple input-output relations. The simple input-output relation is described in each rule. The boundary of the rule areas is not sharp but "fuzzy". It is like an expanding sponge soaking up water. The FS separates the space into several rule areas whose partial shapes are determined by membership functions and rule output.

The system output from one rule area to the next rule area gradually changes. This is the essential idea of FSs and the origin of the term 'fuzzy'. Zadeh (Zadeh LA.,1965) initiated the fuzzy theory by introducing the fuzzy set which is a generalization of the classical set. In contrast to a classical set which has a crisp boundary, belonging to a fuzzy set is characterized by a membership function which gives the fuzzy set flexibility to reflect the nature of human concepts. The fuzzy theory has been developed by various investigators, after realizing its potentiality in solving real world complex problems. Mamdani and Assilian (Mamdani EH, Assilian S.,1975) proposed a fuzzy systemto establish the basic framework of fuzzy controller and applied it to control a steam engine as the first attempt to fuzzy control of a real system. Extensive research has been conducted by Takagi and Sugeno (Takagi T, Sugeno M.,1985) and Sugeno and Kang (Sugeno M, Kang GT, 1988) to propose a fuzzy system in which a systematic approach was developed to generate fuzzy rules from a given input–output data set. Over the past few years, the fuzzy set theory has been successfully applied to a wide variety of civil engineering and computational mechanics problems (Chen CW,2006). In particular, fuzzy systems have been largely and successfully applied to system modeling (Na MG, Kim JW, Hwang IJ, 2006). In this connection, Tsekouras et al, 2003. proposed a simple and fast algorithm to train fuzzy inference systems using numerical input–output data. In conclusion, the above-mentioned capabilities make fuzzy systems a very powerful tool to estimate the rheological results with computationally less expensive algorithm

II. Fuzzy reasoning and aggregation

As soon as the IF and THEN parts are designed, the next stage is to determine the system output from the designed multiple rules. (1) Determination of rule strength and (2) aggregation each rule output. The class of the fuzzy operators used for this purpose is called t-norm operator. There are many operators in t-norm category. One of the most frequently used t-norm operators is an algebraic product.

Rule strength

$$w_{i=\prod_{j=1}^{k}\mu_j}(x_j) \quad (1)$$

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The final system output, $\boldsymbol{y}^*$ is calculated by weighting the each rule output with the obtained rule strength, $\boldsymbol{w_i}$:

$$\boldsymbol{y}^* = \sum \boldsymbol{w_i} \quad \boldsymbol{y_i} / \sum \boldsymbol{w_i}. \qquad (2)$$

Mandani type of fuzzy controllers defuzzify the aggregated system output and determine the non-fuzzy control value.

The final system output is given as:

$$\boldsymbol{y}^* = \frac{\mathbf{0.46 \times 47.5 + (2.68) \times (0.05) + (0.17) \times (-41)}}{\mathbf{0.46 + 2.68 + 0.17}} = \mathbf{4.5}$$

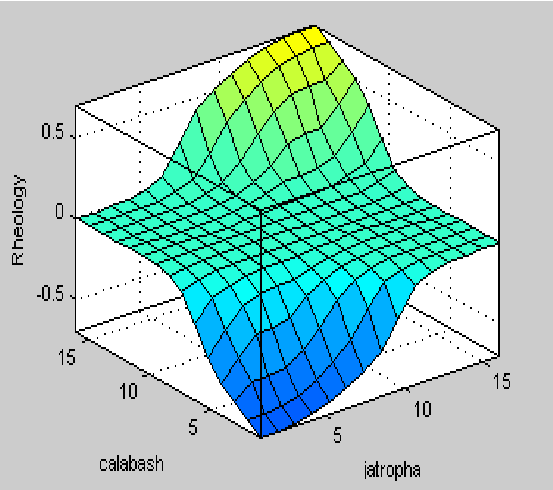

Figure. 1: Graph of the results obtained from a sugeno fuzzy inference system

Current trend in energy consumption is towards renewable energy sources as opposed to conventional energy sources such as hydrocarbons, which are non–renewable (Oseni, 2006). A shift is inevitable from mineral oil base lubricants to natural oil base lubricants in the future because of the abundance and ease of processing of Natural oil base lubricants. The use of oil from seeds of plants as alternative lubricants in tribological surfaces would lead to more interest in their cultivation so that the plants would provide a source of abundant raw material for lubricant production. Natural oils of interest are oils from Jatropha fruits (Jatropha curcas) and calabash seeds (Lageneria vulgaris) and the choice was informed by the availability of Jatropha plants, abundance of calabash seeds in the Northern and middle belt Zones of Nigeria. Jatropha plants have some medicinal values as branches of the plant have been used by the Tiv people in Benue State of Nigeria to cure stomach upset.

Rheology is the science of flow and deformation of matter and describes the interrelation between force, deformation and time. Rheology is applicable to all materials, from gases to solids.

Fluid rheology is used to describe the consistency of different products, normally by the two components viscosity and elasticity. By viscosity is usually meant resistance to flow or thickness and by elasticity usually stickiness or structure.

III. Lubricant Rheology

Rheology is the science that deals with the deformation and flow of lubricating materials. A lubricant during the lubrication process will be subjected to high shear stresses and velocity gradients. Application of loads and pressure during lubrication results in changes in lubricant viscosity due to shear stress and velocity gradients generated by the operating condition (Taylor, 2004).

Mc Cabe et al (1985) and Scales (1999) observed that under the incompressibility assumption, an oil lubricant in subjected to the following effects: presence of velocity gradients and shear stress fields, onset of turbulence, formation and growth of boundary layers and separation of boundary layers from contact with the solid boundary.

Many lubricating oils manifest elastico-viscous (i.e. non-Newtonian) behavior under operating condition based on previous rheological history and present response (Barnes et al, 2001). As lubricating oils are cooled after use wax-like materials are formed out of the solution and the oil eventually gels. Thus, the oil possesses a yield value in this region and the viscosity decreases rapidly with time of shearing and the behavior becomes non-Newtonian even when it was originally Newtonian. Flow of oil lubricant is classified into Newtonian and Non-Newtonian flow, with a high proportion now considered non-Newtonian because of the presence of lubricant additives. Newtonian flow is one in which shear stress is proportional to shear rate at constant temperature and pressure while in Non-Newtonian flows; shear stress is not proportional to shear rate.

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The relationship between viscosity and shear stress/shear rate can be expressed as follows;

$$\eta = \frac{\tau}{r} \quad (3)$$

Where,

η - dynamic viscosity; τ - shear stress; and

r - shear rate

Dynamic viscosity may also be expressed in the form:

$$\eta = \tau \text{ h/v} \quad (4)$$

where:

h - oil film thickness; and V - surface velocity.

Substituting C for h in and putting in the values of V, we have

$$\boldsymbol{\tau = \frac{2\pi r N \eta}{c}} \quad (5)$$

where:

C - diametrical clearance between bearing and journal;

r - shaft radius; and N- speed of shaft.

Torque generated by the shaft is

$$T = \frac{4\pi^2 r^3 LN\eta}{c} \quad (6)$$

Rotational viscometers can measure dynamic viscosity directly (Collet and Hope, 1983).

Newtonian flow is characterized by Newtonian equation (Mohsenin, 1986, Mc Cabe et al, 1985 and Lewis, 1987)

$$\tau = \eta r \quad (7)$$

Where;

τ = shear stress; η = Dynamic viscosity; and

r = shear rate i.e dr/dh.

Non-Newtonian flow is subdivided into quasi–viscous flow, bingham plastics, quasi–plastic flow and time – dependent flow.

Quasi – viscous flow has non-linear relationship between shear stress and shear rate and it is represented by the following Ostward – de Wale equation (Mc Cabe et al, 1985).

$$\boldsymbol{\tau = K r^n} \quad (8)$$

Where;

K - Apparent viscosity; and

n - flow behavior index or power – low

The flow can be pseudo plastic or dilatants .In pseudo-plastic flow, the curve passes through the origin, is concave downwards at low shears and becomes linear at high shears. The power-law is less than one ($n < 1$) in this case. In dilatants flow, the curve is concave upward at low shears and becomes linear at high shears. Here the power – law is more than one ($n > 1$). Pseudo-plastics are said to be shear rate thinning and dilatants shear rate thickening.

Some non-Newtonian flows are time –dependent flows whose shear stress –shear rate curves depend on the duration of active shear. The fluids may either be thixotropic or rheopetric. Thixotropic liquids break down under continued shear and on mixing give lower shear stress for a given shear rate while rheopectic liquids increase in shear stress with time at constant shear rate. The original structures are usually recovered on standing.

The rheological behaviour of oil lubricants is strongly dependent on viscosity. Most extremely viscous materials are non-Newtonian and do not possess (any single) viscosity independent of shear rate. Hutton (1973) observed that viscosity falls with increasing rate of shear in polymer thickened mineral oils. In high stress laminar flows, the polymer molecules can rupture into smaller molecule and hence their efficiency as thickness is reduced.

Hutton (1973) and Tabor (1982) related variation of viscosity with temperature to a variant of Arrhenius equation, which is based on the principle that flow will occur if a molecule has sufficient thermal energy to change its site relative to neighboring molecules. This activation energy is the energy required to activate molecular flow and depends on the intermolecular forces and on the size of the molecule. Thus;

$$\boldsymbol{\eta = k exp^{\{-(Ea/RT)\}}}$$

where:

η - Measured viscosity;

K- apparent viscosity at reference temperature;

T - Absolute temperature; Ea - Activation energy; and

R = Universal gas constant (8.3143 kJ^{-1} mol^{-1}).

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Hutton (1973) concluded that as the temperature is reduced, some oils merely become more viscous until they form a glass at about 10^{13} poise. Oils containing crystallization molecules separate wax that ultimately gel the oil.

Manual method: S_1- pure calabash, S_2- pure Jatropha, S_3- 3:7 (30% calabash and 70% Jatropha), S_4- 1:1 (50% calabash and 50% Jatropha), S_5- 4:6 (40% calabash and 60% Jatropha), S_6-reference oil.

Mechanical method: S_7-pure calabash, S_8- pure Jatropha, S_9-3:7 (30% calabash and 70% Jatropha), S_{10}-1:1 (50% calabash and 50% Jatropha), S_{11}-4:6 (40% calabash and 60% Jatropha).

Solvent method: S_{12} (pure calabash), S_{13} (pure Jatropha), S_{14} -3:7(30% calabash and 70% Jatropha), S_{15} 1:1 (50% calabash and 50% Jatropha) and S_{16} -4:6 (40% calabash and 60% Jatropha).

IV. Rheological Properties

The rheological properties of oil samples at 60RPM and 60^{o}C was carried out with the following results: Manual method; Calabash (1.155), Jatropha (0.8719), S_3 (0.9649), S_4 (1.827), S_5 (1.0971), Reference oil (1.0595), Mechanical method; Calabash (1.1525), Jatropha (1.1370), S_9(1.1892), S_{10}(1.1803), S_{11}(1.0938), S_{14} (1.1833), S_{15} (1.1884), S_{16} (1.1134). It was observed that S_2(0.8719) and S_3 (0.9649) were pseudo plastic while S_9 (1.1892) was a better lubricating oil sample presenting a more dilatant behavior in agreement with Oseni et al (2006).

Figures 2 – 3 show rheograms of viscosity – shear rate for the oil samples at different temperatures. In Figure 2, the rheograms of oil samples S_4, (C_J 3:7), S_2 (Jatropha), S_3 (C_J 1:1), S_6(reference oil) and S_5 (C_J 4:6) showed decrease in viscosity with rise in shear rate due to phase change from semi solid with crystallized wax to liquid phase due to a brokedown of the wax or a temporary realignment of the hydrocarbon Molecules. However at higher temperature, the behaviour of S_4, S_3, S_6 and S_5 was shear rate thickening (Figure 1) in agreement with Oseni (2006), Nnuka et al (2002) and Oyinlola (1984). Increase in viscosity with rising shear rate of the oil resulted in increase in viscous shear stress. Power law index increased with rise in viscous shear stress and shear rate. The natural oils and their blends maintained gradual increase of viscosity with shear rate that can be improved upon by use of' additives.

TABLE 1: RHEOLOGICAL PROPERIES OF OIL SAMPLES AT 60 RPM AND 60 ^{0}C

Sample	η x 10^{-3} Ns/M^2	τx10^{-3} N/M^2	R(S^{-1})	T_R (NM)	Ea Kcal/Mol	K Ns/m^2	N
S1	361	272	0.7541	404	121	0.771	1.1559
S2	299	226	0.7541	335	100	0.2884	0.8719
S3	458	345	0.7541	518	222	0.4962	0.9649
S4	430	324	0.7541	481	143	0.4528	1.1827
S5	228	172	0.7541	255	75	0.2343	1.0971
S6c	138	104	0.7541	154	47	0.1404	1.0595
S7	363	274	0.7541	406	119	0.3790	1.1525
S8	305	230	0.7541	341	107	0.3170	1.1370
S9	430	324	0.7541	481	148	0.4536	1.1892
S10	439	331	0.7541	491	141	0.4619	1.1803
S11	225	170	0.7541	252	74	0.2311	1.0938
S12	372	281	0.7541	416	125	0.3892	1.1607
S13	302	228	0.7541	338	109	0.3142	1.1403
S14	479	754	0.7541	536	143	0.5044	1.1833
S15	452	341	0. 7541	506	148	0.4768	1.1884
S16	231	174	0.7541	259	88	0.2385	1.1134

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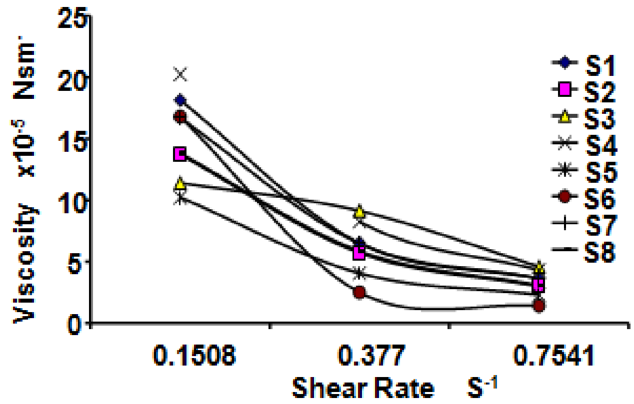

Figure 2: Dependence of Viscosity on Shear Rate at 60 ^{0}C for Samples S1-S8

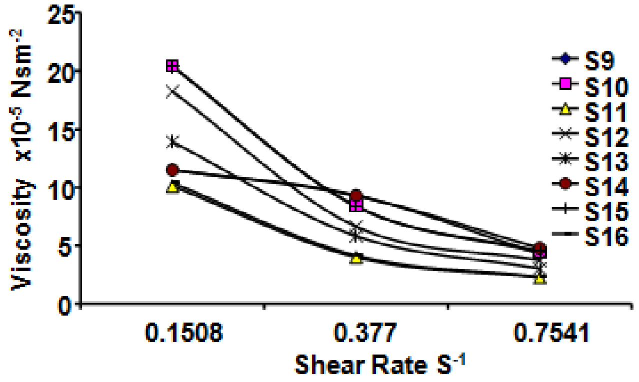

Figure 3: Dependence of Viscosity on Shear Rate at 60 ^{0}C for Samples S9-S16

V. CONCLUSION

The present paper has proposed a Mamdani–Assilian fuzzy system to estimate the Rheological behavior of Jatropha and calabash Oil lubricants. To train and test the fuzzy system, 144 experimental results were provided. The proposed fuzzy system has two input variables (Jatropha and Calabash) and involves one output variable (Rheology). Input variables represent the mechanical, manual and solvent methods to be less than one, equal to one and greater than one. Finally, the final system output was greater than one indicating that the lubricant is Newtonian in nature. In conclusion, the fuzzy system is capable of effectively and accurately simulating the overall Rheological behavior of Jatropha and Calabash Oil lubricants , in terms of different processing methods. At 60RPM and 60 ^{0}C, sample S_2 and S_3 were pseudoplastic and sample S_9 (1.1892) was more dilatants.

REFERENCES

[1]. Barnes, H. A., Hutton, J. F. and Walters, K. (2001). An Introduction to Rheology Oxford, Elsevier Science.

[2]. Chen CW. Stability conditions of fuzzy systems and its application to structural and mechanical systems. Adv Eng Softw 2006;37:624–9.

[3]. Hutton, J. F. (1973) A Limitation on the Use of Cone-and-Plate Rheometers for the Study of Grease Rheology. In: The Rheology of Lubricants, Ed Davenport, T. C., England, Applied Science Publishers Limited. Pp 108-117.

[4]. Mamdani EH, Assilian S. An experiment in linguistic synthesis with a fuzzy logic controller. Int J Man–Machine Studies 1975;7(1):1–13.

[5]. Mc Cabe, W. L., Smith, J. C. and Harriott, P. (1985) Unit Operations in Chemical Engineering, 4th Ed, New York, Mc Graw-Hill Book Company. Pp. 447 - - 559.

[6]. Mohsenin, N.N. (1986) Physical Properties of Plant and Animal Material, New York, Gordon and Breach Science Publishers.

[7]. Na MG, Kim JW, Hwang IJ. Estimation of collapse moment for the wall-thinned pipe bends using fuzzy model identification. Nucl Eng Des 2006;236:1335–43.

[8]. Nnuka, E.E, Nor, J. and Oseni, M.I. (2002) Performance Characteristics of Local Oils as Lubricants in Upset Forging, Development African Consortium, Port Harcourt (in press). .

[9]. Oseni, M. I, Ette, A. O. and Nnuka, E. E. (2006). Comparative Analysis of Rheology of Straight and blended Oil Lubricants, Awka, Nigeria, J, of Engineering and Apllied Sciences, 2(2), 83-94.

[10]. Oyinola A.K. (1984) Determination of Performance characteristics of local oils as lubricants, Nigerian Journal of Engineering, 2 (1). Pp.40-47.

[11]. Poison Plant could help to cure the planet Times Online, 28 July 2007

[12]. Scales, L. E. (1999) Quantifying the Rheological Basis of Traction Fluid Performance, SAEI999-01-3610.

[13]. Sugeno M, Kang GT. Structure identification of fuzzy model. Fuzzy Set System 1988;28(1):15–33.

[14]. Tabor, D. (1982) The role of surface and intermolecular forces in thin film Lubrication. In: Microscopic Aspects of Adhesion and Lubrication, Tribology, series 7, Ed Georges, I.M. New York, Elsevier Scientific Publishing Company.Pp.651-679.

[15]. Takagi T, Sugeno M. Fuzzy identification of systems and its applications tomodeling and control. IEEE Trans Syst Man Cyb 1985;15(1):116–32

[16]. Tsekouras G, Sarimveis H, Bafas G. A simple algorithm for training fuzzy systems using input–output data. Adv Eng Softw 2003;34:247–59.

[17]. Zadeh LA. Fuzzy sets. Inf Control 1965;8:338–5.

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