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Study of the Viscosity and Specific Gravity of the Ternary Used Frying Oil (UFO)-Bioethanol-Diesel System

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Abstract

Fossil fuels cover around 80% of global energy consumption. However, the problems linked to their use justify the choice of using biofuel. In order to reduce as much as possible, diesel rate, an increase in the number of additives may be considered. Thus, in this work, the study of the used frying oil (UFO), bioethanol and diesel ternary system was undertaken. It emerges from this study that the addition of bioethanol reduces the viscosity and the density of the ternary system and permits a 90% substitution rate for diesel between the UFO and bioethanol. Finally, the percentage of oil becomes 40% after adding alcohol compared to the binary diesel crude vegetable oil mixture where this rate is 30%.

Keywords

Biofuel, UFO-Bioethanol-Diesel Ternary, Density, Viscosity

1. Introduction

The world depends largely on fossil fuels, whether in automobile, food, agriculture, or in electricity production [1] [2]. Fossil fuels cover around 80% of global energy consumption [1] [3]. They are present in all developing sectors and are the basis of human evolution.

The increases of oil price, limited reserves, greenhouse gas emissions, and global warming, are so many reasons that lead researchers to find alternative fuels less expensive and more environmentally without any change [1] [2] [4].

Biofuels are in solid, liquid and gaseous form. Among liquid biofuels, two production sectors exist in the literature, namely the bioethanol sector and the biodiesel one.

Indeed, biodiesels are obtained by four (04) routes which are: pyrolysis, microemulsion, transesterification and dilution [5] [6] [7]. The last involves adding an additive to fossil fuels such as diesel.

Generally, biodiesels resulting from dilution are binary mixtures. To this end, several studies have been carried out to show that crude vegetable oil mixed with a maximum rate of 30% diesel can be used directly in Diesel engines without any change [7].

In order to reduce diesel rate as much as possible, an increase of additives number can be considered. Thus, in this work, the study of the ternary UFO-bioethanol-diesel was undertaken.

The general objective sought is the physical characterization of the ternary mixture of UFO-alcohol-diesel. As specific objectives, these will be:

- to determine the viscosity and density of the different base materials (vegetable oil, alcohol and diesel);
- to determine the viscosity and density of each ternary mixture.

2. Material and Methods

2.1. Material

2.1.1. Basic Products

In this work, UFO, bioethanol and diesel were used. UFO was collected from the restaurant of University Nangui ABROGOUA. The diesel is a commercial sample from a Shell station. Bioethanol (96˚) was produced at the laboratory of industrial processes for the synthesis of the environment and new energies (LAPISEN), INP-HB in Yamoussoukro.

2.1.2. Equipment

The equipment used for this work consists of a THERMO SCIENTIFIC HAAKE type C falling ball viscometer; a DENVER INSTRUMENT S-602 digital scale (max 600 g, precision d = ±0.01 g); a BIOBLOCK SCIENTIFIC magnetic stirrer.

2.2. Methods

2.2.1. Obtaining Mixtures

Mixtures were obtained according to volume proportions using a 50 mL graduated pipette. Each bottle is marked with a code which corresponds to precise proportions. These codes and their correspondences are given in **Table 1** and **Table 2**. For example HG19, there are 5 mL of UFO and 45 mL of diesel, for a total volume of 50 mL (10% v/v of UFO and 90% of diesel).

2.2.2. Characterization of Mixtures

1) Specific gravity

The mass of the 50 mL volumetric flask was determined empty (mass m_1) and

Table 1. Proportion of binary mixtures in volume percentage.

UFO/Diesel mixture			UFO/Bioethanol mixture			Bioethanol/Diesel mixture		
Code	UFO	Diesel	Code	UFO	Bioethanol	Code	Bioethanol	Diesel
HG19	10%	90%	**HA19**	10%	90%	**AG19**	10%	90%
HG28	20%	80%	**HA28**	20%	80%	**AG28**	20%	80%
HG37	30%	70%	**HA37**	30%	70%	**AG37**	30%	70%
HG46	40%	60%	**HA46**	40%	60%	**AG46**	40%	60%
HG55	50%	50%	**HA55**	50%	50%	**AG55**	50%	50%
HG64	60%	40%	**HA64**	60%	40%	**AG64**	60%	40%
HG73	70%	30%	**HA73**	70%	30%	**AG73**	70%	30%
HG82	80%	20%	**HA82**	80%	20%	**AG82**	80%	20%
HG91	90%	10%	**HA91**	90%	10%	**AG91**	90%	10%

Table 2. Proportion of the ternary mixture in volume percentage.

UFO/Bioethanol/Diesel mixture				UFO/Bioethanol/Diesel mixture			
Codes	UFO	Bioethanol	Diesel	Codes	UFO	Bioethanol	Diesel
HAG118	10%	10%	80%	**HAG343**	30%	40%	30%
HAG217	20%	10%	70%	**HAG253**	20%	50%	30%
HAG127	10%	20%	70%	**HAG163**	10%	60%	30%
HAG316	30%	10%	60%	**HAG712**	70%	10%	20%
HAG136	10%	30%	60%	**HAG622**	60%	20%	20%
HAG226	20%	20%	60%	**HAG532**	50%	30%	20%
HAG415	40%	10%	50%	**HAG442**	40%	40%	20%
HAG325	30%	20%	50%	**HAG352**	30%	50%	20%
HAG235	20%	30%	50%	**HAG262**	20%	60%	20%
HAG145	10%	40%	50%	**HAG172**	10%	70%	20%
HAG514	50%	10%	40%	**HAG811**	80%	10%	10%
HAG424	40%	20%	40%	**HAG721**	70%	20%	10%
HAG334	30%	30%	40%	**HAG631**	60%	30%	10%
HAG244	20%	40%	40%	**HAG541**	50%	40%	10%
HAG154	10%	50%	40%	**HAG451**	40%	50%	10%
HAG613	60%	10%	30%	**HAG361**	30%	60%	10%
HAG532	50%	20%	30%	**HAG271**	20%	70%	10%
HAG433	40%	30%	30%	**HAG181**	10%	80%	10%

after filling it with the liquid (mass m_2) before any measurement. The mass m of the liquid is given by the following relationship:

$$m = m_2 - m_1$$

The principle of expansion of liquids was used to determine their density. The volumetric flask is immersed in the thermostatically controlled water bath. The variation in volume is read on the graduated neck, depending on the temperature. Knowing the mass of the liquid in the flask, the density is determined by applying the following relationship:

$$\rho(T) = \frac{m_{\text{sample}}}{V_T}$$

with m: the mass of the liquid assumed to be constant [g];

$V(T)$: volume of the liquid linked to the thermodynamic temperature [mL];

$\rho(T)$: the density of the liquid linked to the thermodynamic temperature [g/mL].

Finally, the specific gravity of samples is determined by making the ratio of this density to that of distilled water under the same temperature and pressure conditions.

$$d = \frac{\rho_{\text{sample}}}{\rho_{\text{water}}}$$

2) Viscosity

The falling ball viscometer used is coupled to a thermostatically controlled bath. The measurement principle consists of using as a measurement quantity the travel time of a ball for a given fall distance [8] according to ISO 12058. The ball is dropped into a cylindrical glass tube containing the liquid to be studied. The dynamic viscosity coefficient of this liquid is given by the following formula:

$$\eta = K(\rho - \rho')t$$

with K: a constant given by the manufacturer; ρ: the density of the ball; ρ': the density of the sample; t: the time the ball falls into the liquid.

The kinematic viscosity is given by the following ratio:

$$\nu = \frac{\eta}{\rho'} \quad [\text{Stokes (St)} = 10^{-4}\ \text{m}^2\cdot\text{s}^{-1}].$$

3. Results and Discussion

3.1. Specific Gravity of Mixtures

3.1.1. UFO-Diesel Mixture

Figure 1 shows the specific gravity of UFO-diesel mixtures as a function of the volume fraction of the samples at 25˚C.

At 25˚C, the specific gravity of the mixture increases as a function of the volume fraction of UFO. At 40% oil in diesel, the specific gravity is far from the diesel specification (Min 0.820 Max 0.880). However, several researchers have shown that high specific gravity has detrimental effects on diesel engines [8] [9]. Thus, the high specific gravity of the vegetable oil and diesel mixture will lead to an increase in the length of the fuel jets, driving them to the bottom of the combustion chamber.

3.1.2. UFO/Bioethanol Mixture

Figure 2 shows the specific gravity of the UFO-Bioethanol mixture as a function of the volume fraction of the samples at 25˚C.

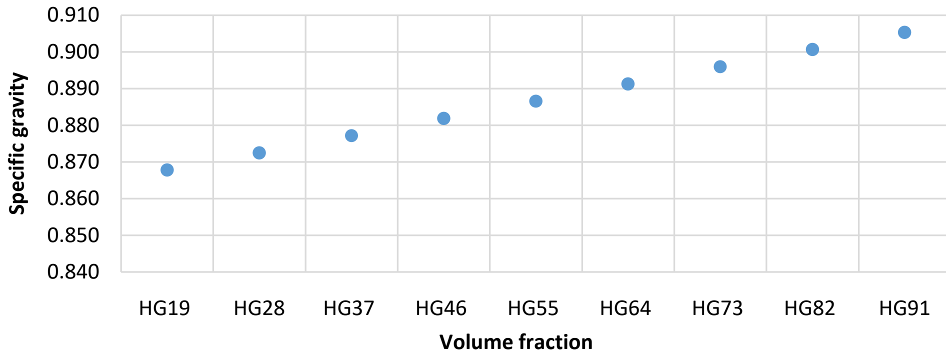

Figure 1. Graph of the density of the UFO-diesel mixture at 25˚C as a function of the volume fraction of UFO in the diesel.

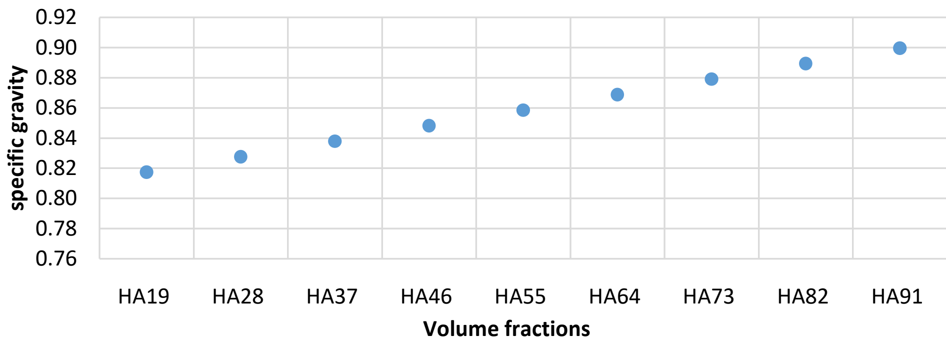

Figure 2. Graph of the density of the UFO-Bioethanol mixture at 25˚C as a function of the volume fraction of the alcohol in the UFO.

At 25˚C, the specific gravity of the mixture increases as a function of the volume fraction of UFO. At 80% UFO in alcohol, the specific gravity of the mixture no longer meets the Ivorian standard and is worth 0.8894.

3.1.3. Bioethanol/Diesel Mixture

Figure 3 shows the density of the Bioethanol/diesel mixture as a function of the volume fraction of the samples at 25˚C.

The specific gravity of the mixture decreases depending on the volume fraction of the alcohol. At 80% alcohol incorporated into the diesel, the density of the mixture drops to 0.8182.

3.1.4. UFO/Bioethanol/Diesel Mixture

Figure 4 shows the density of the UFO/Bioethanol/diesel mixture as a function of the volume fractions of the samples at 25˚C.

The specific gravity of the UFO-Bioethanol-Diesel mixture varies from 0.8229 to 0.8950. Only samples coded HAG514, HAG613, HAG712 and HAG811 have a higher density due to the high oil content in the mixture. They do not respect the standards. The representative graph is made up of lines with approximately equal slopes. The density of the mixtures decreases when the proportion of used cooking oil decreases. This decrease is linear per set. Thus the groups revealed are:

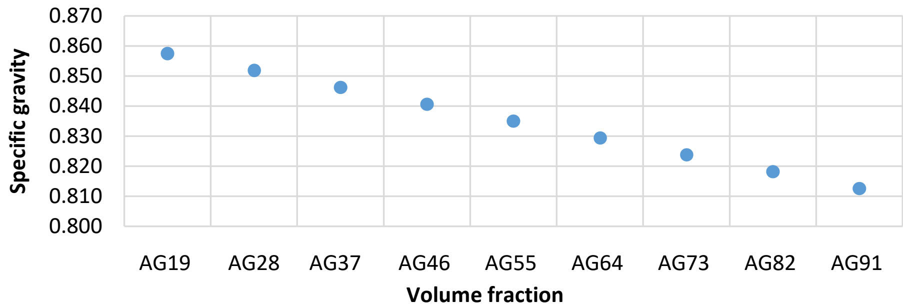

Figure 3. Specific gravity of the bioethanol/diesel mixture at 25˚C as a function of the volume fraction of the alcohol.

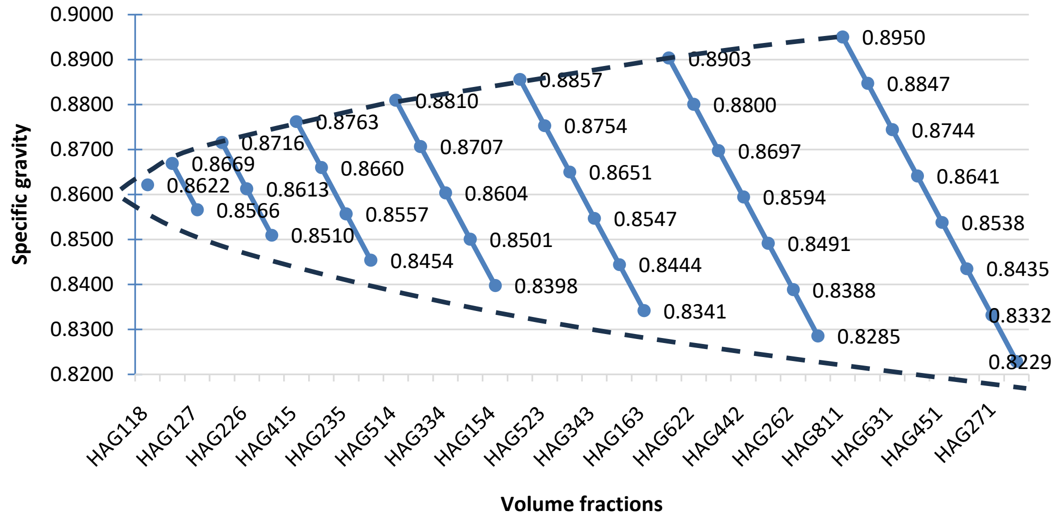

Figure 4. Graph of the specific gravity of UFO/Bioethanol/Diesel mixture at 25˚C as a function of the volume fraction.

Group 0: {HAG118};

Group 1: {HAG217, HAG127};

Group 2: {HAG 316, HAG226, HAG136};

Group 3: {HAG415, HAG325, HAG235, HAG145};

Group 4: {HAG514, HAG424, HAG334, HAG244, HAG154};

Group 5: {HAG613, HAG523, HAG433, HAG343, HAG253, HAG163};

Group 6: {HAG712, HAG622, HAG532, HAG442, HAG352, HAG262, HAG172};

Group 7: {HAG811, HAG721, HAG631, HAG541, HAG451, HAG361, HAG271, HAG181}.

From left to right, each group is characterized by a decrease in the proportion of used cooking oil, an increase in the proportion of bioethanol and a fixed proportion of diesel.

By demarcating all the segments using a dotted line between the groups of segments, a spindle-shaped scope is obtained, which would resemble a homothetic transformation of the center of the focal point. This point corresponds to the lowest proportion of oil and alcohol, therefore much closer to the density of diesel.

Let D = distance between two successive segments starting from the focal point, taken as a reference.

Thus Di = segmenti-segment $i - 1$;

And let Li = the length of segment i.

The different measured values of D and L are recorded in Table 3. The representative curve of D as a function of L drawn in Figure 5 is a straight line showing an increase of D as a function of L.

Figure 5 shows the evolution of the distance between segments and the lengths of the segments.

All the points thus obtained present a linear correlation having the equation:

$D = 0.543L + 0.29$ with a coefficient of determination close to 1.

According to results obtained by Abollé [8], for an ideal mixture, that is to say without volume contraction, the ideal density would be obtained by a simple weighting of the oil, diesel and alcohol.

Thus, $d_{i\text{deal}}(T) = x_1 d(\text{UFO}, T) + x_2 d(\text{Bioethanol}, T) + x_3 d(\text{diesel}, T)$.

Table 4 shows specific gravity values of basic products, some ideal and real samples as function of the temperature

Table 3. Evolution of the distance between segments according to the lengths of the segments.

	D1	D2	D3	D4	D5	D6	D7
Distances between segments (cm)	1.2	1.9	2.6	3.3	4.1	4.9	5.5
	L1	L2	L3	L4	L5	L6	L7
Lengths of segments (cm)	2	3.7	5	6.7	8.3	10	11.7

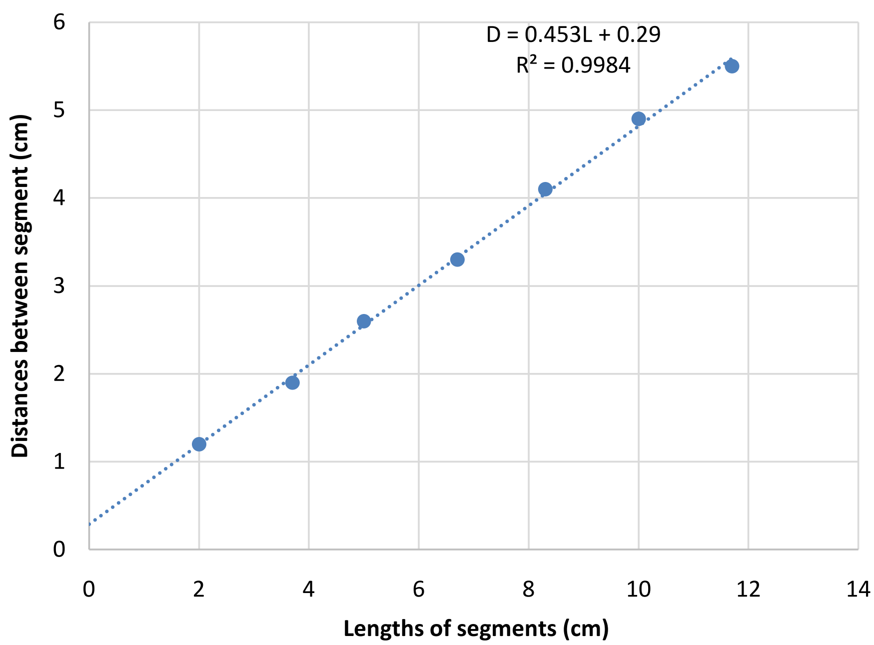

Figure 5. Evolution of the distance between segments as a function of segment lengths.

Table 4. Specific gravity of basic products, some ideal and real samples as function of the temperature.

Temperature	298	303	313	323	333
Diesel	0.8633	0.8464	0.8301	0.8145	0.8145
Bioéthanol	0.8072	0.7914	0.7762	0.7615	0.7615
UFO	0.9102	0.8924	0.8752	0.8587	0.8587
HAG226ideal	0.86146	0.8446	0.82834	0.81274	0.81274
HAG325ideal	0.86615	0.8492	0.83285	0.81716	0.81716
HAG523ideal	0.87553	0.8584	0.84187	0.826	0.826
HAG226 real	0.8613	0.8613	0.8613	0.8444	0.8282
HAG325 real	0.8660	0.8660	0.8660	0.8490	0.8327
HAG523 real	0.8754	0.8754	0.8754	0.8582	0.8417

Table 5 summarizes deviations from the *d*(real)-*d*(ideal) ideality of the specific gravity of the ternaries as a function of the temperature. From the calculations, we traced the evolving curves of the differences as a function of the temperature. The different ternaries giving similar results, we have done the representation for three ternaries as an example.

The deviations from the ideality of the specific gravity highlighted by **Figure 6** show a parabolic evolution as a function of the temperature. This curve denotes the non-ideality of our ternaries.

3.2. Kinematic Viscosity of Mixtures

3.2.1. UFO-Diesel Mixture

Figure 7 shows the viscosity of the oil/diesel mixture as a function of the volume fraction of the samples at 40˚C.

At 40˚C, the viscosity of the mixture increases according to volume fraction of oil. At 20%, for the mixture vegetable oil/diesel, the viscosity does not match with the specification (Min 1.6 – Max 5.9 cSt) and is worth 6.87 cSt. These results are in agreement with those of Abollé (2016) [10] who studied physic-chemical parameters of crude vegetable oils-diesel mixtures in similar conditions. According to this work, at crude vegetable oil levels below 30% the values obtained are perfectly superimposable. This is not the case for higher rates where rather increasing shifts appear from the lightest oils to the heaviest. This dispersion becomes remarkable when the oil content becomes high in the mixture.

3.2.2. UFO-Bioethanol Mixture

Figure 8 shows the viscosity of the oil/alcohol mixture as a function of the volume fraction of the samples at 40˚C.

At fixed temperature, the viscosity varies linearly with respect to the volume fraction of the UFO with a coefficient of determination of 0.998. A proportionality is thus mainly established between the viscosity and the quantity of the oil and the influence of alcohol on this quantity is marginal. When the mixture

Table 5. Deviation from the ideality of the specific gravity of some samples

Samples	298	303	313	323	333
HAG226	−0.00016	0.0167	0.03296	0.03166	0.01546
HAG325	−0.00015	0.0168	0.03315	0.03184	0.01554
HAG523	−0.00013	0.017	0.03353	0.0322	0.0157

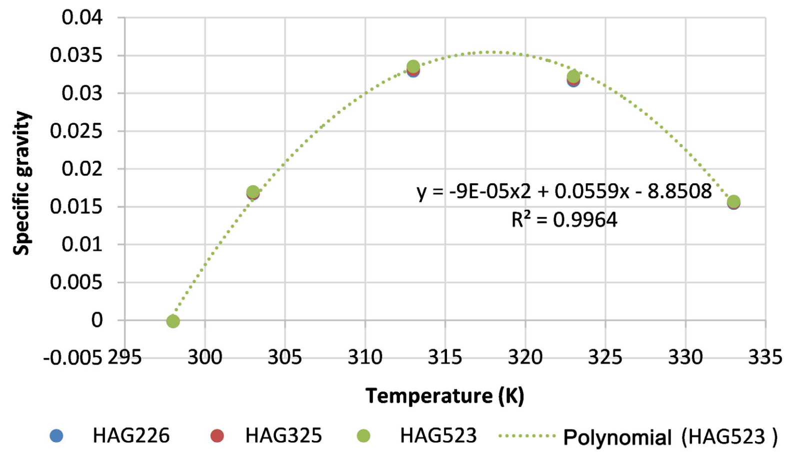

Figure 6. Deviation from the ideality of specific gravity as a function of temperature.

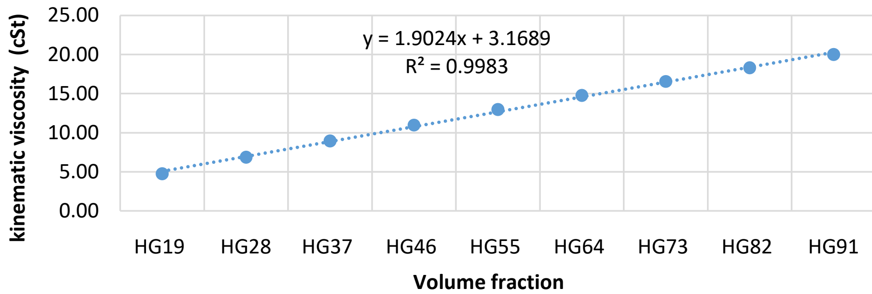

Figure 7. Kinematic viscosity curve of the UFO/diesel mixture at 40˚C as a function of the volume fraction of oil in the diesel.

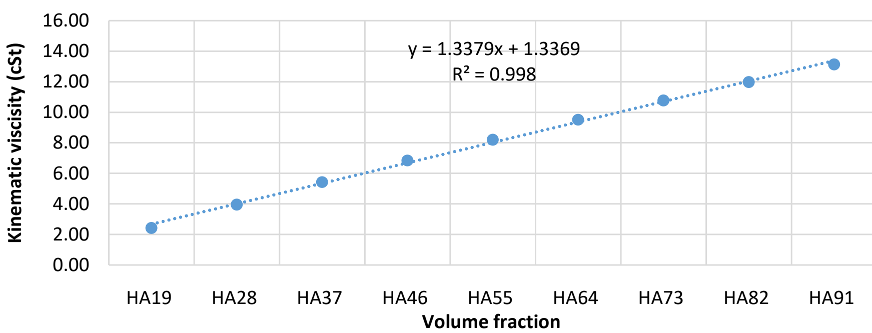

Figure 8. Viscosity curve of the UFO-Bioethanol mixture at 40˚C as a function of the volume fraction of the alcohol in the oil.

reaches 40% oil, the viscosity is 6.84 cSt which remains a relatively high value even in tropical areas.

3.2.3. Bioethanol-Diesel Mixture

Figure 9 shows the viscosity of the alcohol-diesel mixture as a function of the volume fraction of the samples at 40˚C.

Let us now follow the variation in the viscosity of the alcohol/diesel mixture at a temperature of 40˚C. The graph shows a linear trend with the volume fraction of alcohol. It decreases as the quantity of alcohol increases. This trend reveals the diluting nature of alcohol which could be an advantage in a biofuel formulation made from a mixture of base liquids. It turns out to be an additive improving the viscosity of the biofuel like the special additives used during engine tests in Côte d'Ivoire during the 1970s as noted by Abollé in his work [10]. In all mixing proportions done, the biofuel could be used in the engine since its viscosity met the Ivorian standard.

3.2.4. UFO/Bioethanol/Diesel Mixture

Figure 10 shows the viscosity of the oil/alcohol/diesel mixture as a function of the volume fractions of the samples at 40˚C.

The viscosity of mixtures increases as a function of the UFO content and decreases as a function of the alcohol content incorporated. In these ternary mixtures, only samples whose viscosity is between 1.6 cSt and 5.9 cSt comply with the Ivorian standard. The same eight groups are highlighted as previously with the same focal point with a viscosity different from that of diesel which is 3.86 cSt. Here too a homothetic shape appears with a profile not in the shape of a spindle due to the curves. Even if the latter are all decreasing, their appearances differ from each other due to the remarkable predominance of the viscosity of UFO over the mixture.

3.3. Mixture Laws

A mixing law for viscosity is an exact or approximate law, sometimes empirical, aims at predicting the dynamic viscosity of a homogeneous mixture of gases or liquids. For liquids certain mixing laws predict viscosity. The first of these mixing laws, called the Arrhenius one, was published by Svante Arrhenius in 1888 [11] [12] [13]. It postulates that the logarithm of the viscosity of a mixture of

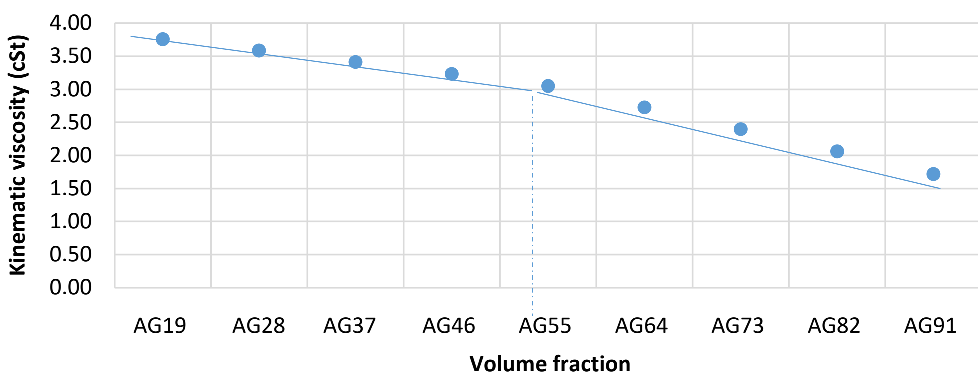

Figure 9. Curve of the viscosity of the alcohol/diesel mixture at 40˚C as a function of the volume fraction of the alcohol in the diesel.

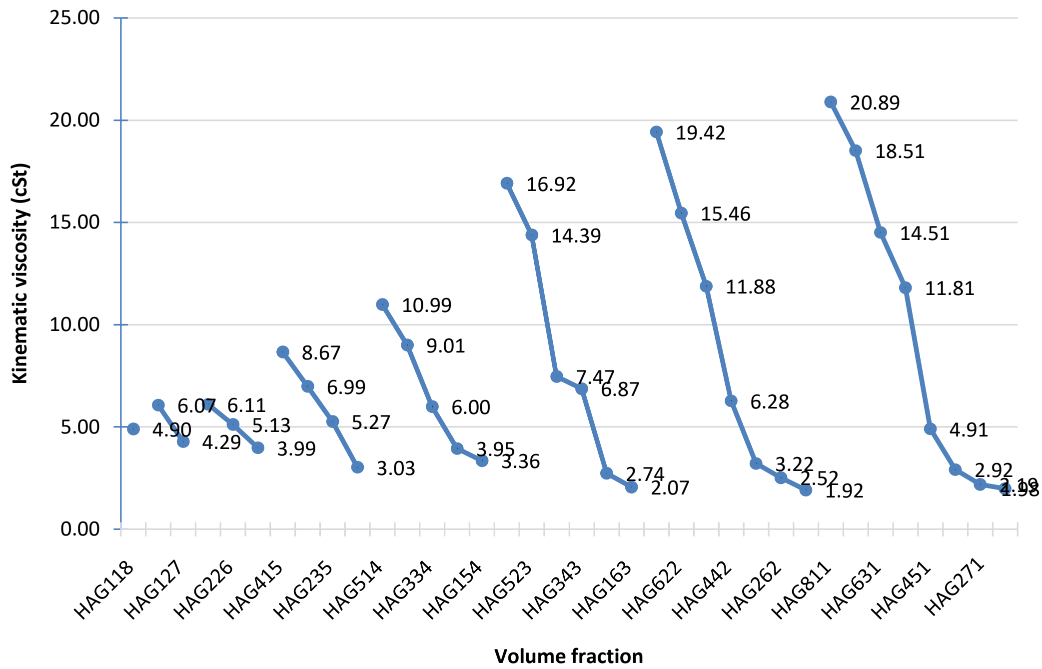

Figure 10. Viscosity curve of the oil/alcohol/diesel mixture at 40˚C as a function of the volume fraction.

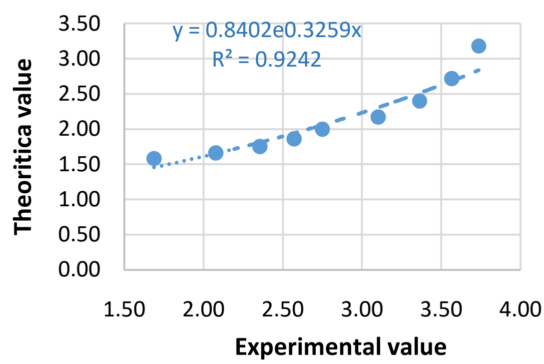

Figure 11. Curve comparing the theoretical and experimental values of the UFO-diesel mixture.

several liquids is a linear combination of the logarithms of the viscosities of the mixed species. Thus, for N species ($N > 2$):

$$\ln(\eta) = \sum_{i=1}^{N} x_i \ln(\eta_i)$$

with η the viscosity of the mixture;

x_i the mole fraction of the product;

η_i the viscosity of the product.

Figures 11-14 present the relationships between the experimental values ($\ln(\eta)$) and the theoretical values ($\sum_{i=1}^{N} x_i \ln(\eta_i)$).

As Koffi *et al.* (2006) explain it [14], by convention, the relationship is perfect if R = 1; very strong if R > 0.8; strong if R is between 0.5 and 0.8; average intensity if R is between 0.2 and 0.5; low if R is between 0 and 0.2; and zero if R = 0. In this comparison study, the values of R are: 0.93; 0.76; 0.94; 0.77. Therefore, there

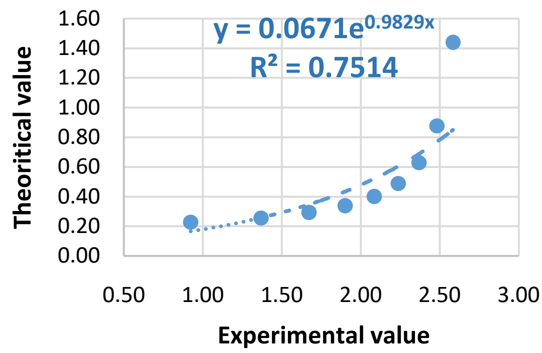

Figure 12. Curve comparing the theoretical and experimental values of the UFO-Bioethanol mixture.

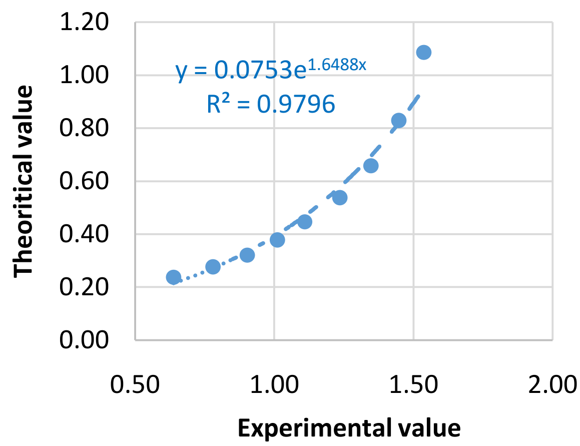

Figure 13. Comparative curve of the theoretical and experimental values of the alcohol/diesel mixture.

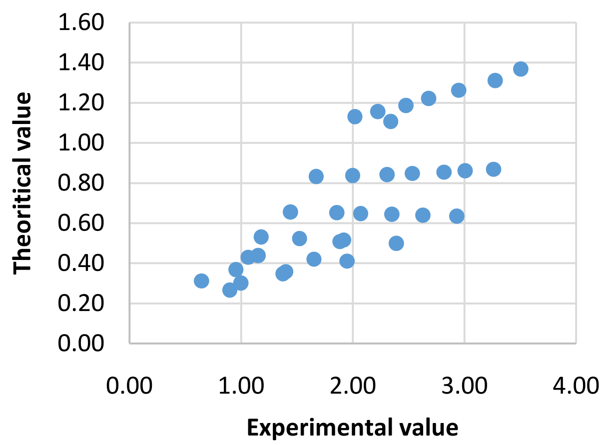

Figure 14. Comparative curves of the theoretical and experimental values of the oil/alcohol/diesel mixture.

is a strong relationship between the theoretical values and the experimental values. By deduction, the logarithm of the viscosity of the mixture of liquids is a linear combination of the logarithms of the viscosities of the mixed species; then the viscosity of these mixtures seems to follow the law of Arrhenius [11].

4. Conclusion and Perspectives

The aim of this work was to formulate fuels using a ternary system (vegetable oil, alcohol, and diesel) by studying their main physical properties which are density and viscosity.

It emerged from this study that the addition of alcohol allows a reduction in the viscosity and density of the ternary system which makes it possible to obtain a substitution rate of 90% for diesel with well-defined volume fractions between the vegetable oil and bioethanol.

Finally, the percentage of UFO increased by 10% after adding the alcohol compared to the binary oil diesel mixture where this rate was 30% maximum.

In perspective, it is planned to determine the other physicochemical and thermal parameters of this ternary system in order to validate the maximum limit of vegetable oil and alcohol incorporated in the diesel.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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