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Optimization of Biofuel Formulation by Mixture Design

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Abstract

With the full growth of energy needs in the world, several studies are now focused on finding renewable sources. The aim of this work is to optimise biofuel formulation from a mixture design by studying physical properties, such as specific gravity and kinematic viscosity of various formulated mixtures. Optimization from the mixture plan revealed that in the chosen experimental domain, the optimal conditions are: 40% for used frying oil (UFO), 50% for bioethanol and 10% for diesel. These experimental conditions lead to a biofuel with a density of 0.84 and a kinematic viscosity of 2.97 cSt. These parameters are compliant with the diesel quality certificate in tropical areas. These density and viscosity values were determined according to respective desirability values of 0.68 and 0.75.

Keywords

Biofuel, Optimization, Mixture Design

1. Introduction

Energy demand in the world is currently experiencing exponential growth mainly due to the development of the industry and transport sectors [1]. Also, fossil fuels cover 80% of global energy consumption [2].

Furthermore, the production and use of these fossil fuels promote the emission and accumulation of greenhouse gases, the main cause of environmental pollution and climate change [3].

All these reasons have led researchers to focus their work on new energy resources. Biofuels have emerged as an interesting solution, especially in recent years [1] [4] [5]. There are numerous biofuels that can be sorted as biofuels in pure form, and mixtures with fossil fuels. They can be in various states: liquid, gaseous, and solid [6]. Liquid biofuels are divided into the bioethanol sector and the biodiesel sector.

Indeed, biodiesels are obtained by four (4) routes which are: pyrolysis, microemulsion, transesterification and dilution [7] [8]. Biodiesels resulting from dilution are binary mixtures. To this end, several studies have been carried out. These studies have shown that vegetable oil mixed at a maximum of 30% with conventional diesel, can be used directly in diesel engines in the short term without any modification [8].

In order to reduce the diesel proportion in the mixture as much as possible, a ternary mixture can be considered. However, traditional methods of adding components require several tests. Thus, this work aims to optimize the formulation of biofuel based on a mixture design. Thus, we are going to define the mixture plan; to make the formulations according to this plan and to characterize the mixtures.

2. Material and Methods

2.1. Material

2.1.1. Basis Products

In this work, UFO, bioethanol and diesel were used. UFO was collected in the Restaurant of Nangui ABROGOUA University. 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

The experimental domain chosen for this study is presented in **Table 1**.

This area led to the matrix of experiments established by the MINITAB.19 software. Using a 50 mL graduated pipette, the mixtures were obtained according to the volume proportions. Each bottle has a code marked on it which corresponds to precise proportions. These codes and their correspondences are given in **Table 2** (Example HAG (5-5-40) means that for a volume of 50 mL, there are 5 mL of oil, 5 mL of alcohol and 40 mL of diesel or *i.e.* 10% v/v oil, 10% v/v alcohol and 40% v/v diesel).

Table 1. Experimental domain.

Variables	Low level	High level
UFO	0.1	0.4
Bioethanol	0.1	0.5
Diesel	0.1	0.8

Table 2. Experience matrix.

Mixture UFO/bioethanol/diesel			
Codes	**UFO**	**Bioethanol**	**Diesel**
HAG (16-10-24)	32.5%	20%	47.5%
HAG (20-5-25)	40%	10%	50%
HAG (9-20-21)	17.5%	40%	42.5%
HAG (9-10-31)	17.5%	20%	62.5%
HAG (5-25-20)	10%	50%	40%
HAG (20-25-5)	40%	50%	10%
HAG (5-5-40)	10%	10%	80%
HAG (13-15-22)	25%	30%	45%
HAG (16-20-14)	32.5%	40%	27.5%

2.2.2. Characterization of Mixtures

1) Specific gravity

The mass of the 50 mL volumetric flask was determined empty (m_1) and after filling it with the liquid (m_2), before any measurement. The mass m of the liquid is obtained by the following relation

$$m = m_2 - m_1$$

The principle of liquid expansion was used to determine their density. The volumetric flask is immersed in a thermostatically controlled 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 was 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 the samples was 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 [9]. 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. Ternary Diagram Showing the Different Mixtures in the Experimental Domain

Figure 1 presents the ternary diagram in space illustrating the influence of each parameter.

3.2. Experimental Matrix and Responses

Table 3 presents the volume proportions of the elements used in the formulation of the mixtures, the specific gravity and the kinematic viscosity of the different mixtures.

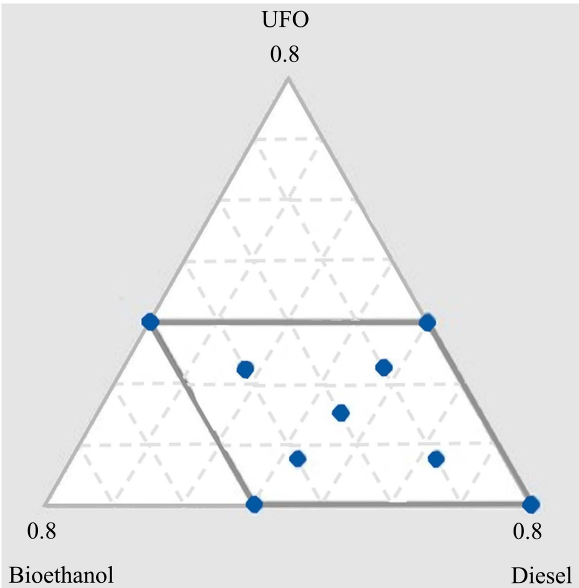

Figure 1. Ternary diagram.

Table 3. Experimental matrix and responses.

Codes	UFO	Bioethanol	Diesel	Specific gravity at 15˚C	Kinematic viscosity at 40˚C (cSt)
HAG (16-10-24)	32.5%	20%	47.5%	0.8532	6.22
HAG (20-5-25)	40%	10%	50%	0.8575	9.03
HAG (9-20-21)	17.5%	40%	42.5%	0.8467	2.38
HAG (9-10-31)	17.5%	20%	62.5%	0.8423	5.88
HAG (5-25-20)	10%	50%	40%	0.8319	1.89
HAG (20-25-5)	40%	50%	10%	0.8325	2.76
HAG (5-5-40)	10%	10%	80%	0.8550	4.50
HAG (13-15-22)	25%	30%	45%	0.8425	4.20
HAG (16-20-14)	32.5%	40%	27.5%	0.840	4.78

This table gives the values of specific gravity and kinematic viscosity obtained for each mixture. It should be noted that there is a very strong variability in specific gravity (from 0.8319 to 0.8575) and kinematic viscosity (from 1.89 to 9.03 cSt) in the chosen experimental domain. This experimental domain is therefore suitable for this study.

3.3. Optimization

3.3.1. Optimization Using Specific Gravity as Response

Analysis of variance and coefficients

Table 4 presents the analysis of variance considering density as response.

The p-values in Table 4 are below the 0.05 threshold; these values are therefore significant. The sum of squares due to the residual error is low compared to the sum of squares due to regression, this result is in agreement with that of Walter [10]. In addition, the coefficient of determination R^2 = 80.50% indicates that the model is relatively well adjusted. The mathematical model governing density is as follows:

$$Y_{\text{specifc gravity}} = 1.215X_1 + 0.8027X_2 + 0.8863X_3 - 0.675X_1X_2 - 0.726X_1X_3 + X_1X_2X_3 \quad (1)$$

There is therefore a good correlation between the predicted values and the experimental ones [11].

3.3.2. Optimization Using Viscosity as Response

Table 5 presents the analysis of variance considering kinematic viscosity as the response.

The p-values presented in Table 5 are below the threshold, so this value is significant. The sum of squares due to the residual error is low compared to the sum of squares due to regression. This result is in agreement with that of Walter [10]. In fact, a model is well adjusted if the sum of squares due to the residuals is less than a third (*i.e.* 33.33%) of the sum of squares due to regression [10].

Table 4. Analysis of variance relative to density.

Source	DL	Sum of squares seq.	Sum of squares ajust.	CM ajust	F value	p value
Linear regression	2	0.000557	0.000557	0.000278	12.39	0.007
Residual error	6	0.000135	0.000135	0.000022		
Total	8	0.000691				

Table 5. Analysis of variance using kinematic viscosity as the response.

Source	DL	Sum of squares seq.	Sum of aquares ajust.	CM ajust	F value	p value
Linear regression	3	199.66	199.66	66.554	15.09	0.006
Residual error	5	22.05	22.05	4.410		
Total	8	221.71				

However, the value of the coefficient of determination R^2 = 93.75% indicates that the model is relatively well adjusted. The mathematical model governing viscosity is as follows:

$$Y_{\text{kinematic viscosity}}\left(X_1, X_2, X_3\right) = 9.8X_1 - 1.20X_2 + 2.95X_3 - 5X_1X_2 - 22\,X_1X_3 + 24X_1X_2X_3 \quad (2)$$

Thus, the value of R^2 of this plan indicates that it is therefore suitable for optimization because there is therefore a good correlation between the experimental values and the predicted ones [11].

3.3.3. Optimal Zone

1) Optimal specific gravity zone

Figure 2 shows the optimal specific zone.

For mixture data, the contour plot shows the relationships between constituent proportions and specific gravity. Throughout the experimental domain, the specific gravity values respect the Ivorian diesel standard [5]. In the zone where the specific gravity values are between 0.830 and 0.850 the proportion of UFO is 40%.

This ternary mixture has a specific gravity close to that of diesel since the values are between 0.82 and 0.88. These results agree with those of Barabàs and Todorut [12] and Chotwichien *et al.* [13].

2) Optimal kinematic viscosity zone

Figure 3 shows the optimal kinematic viscosity zone.

The kinematic viscosity of the mixture increases with UFO content and decreases with bioethanol content incorporated. In this ternary mixture, some samples whose values of kinematic viscosity are between 1.6 and 5.9 cSt (at the temperature of 40˚) comply with the Ivorian diesel standard [5]. In this comparison, it emerges that some mixtures have a viscosity which respects this standard such as: HAG (9-20-21), HAG (9-10-31), HAG (5-25-20), HAG (20 -25-5), HAG (5-5-40), HAG (13-15-22) and HAG (16-20-14).

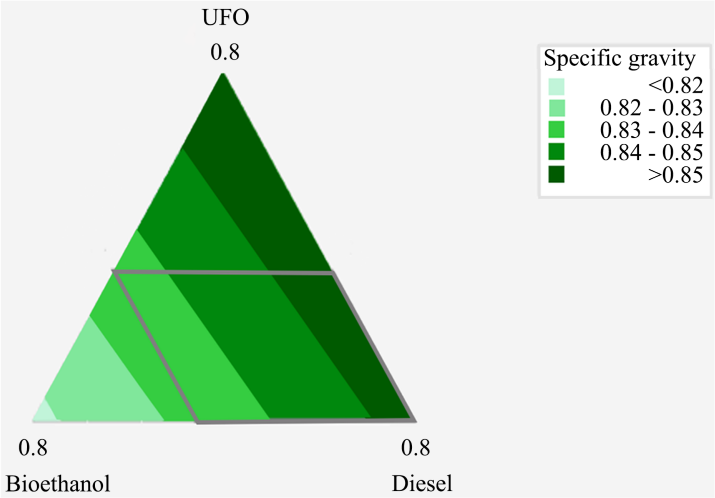

Figure 2. Specific gravity mixture contour plot.

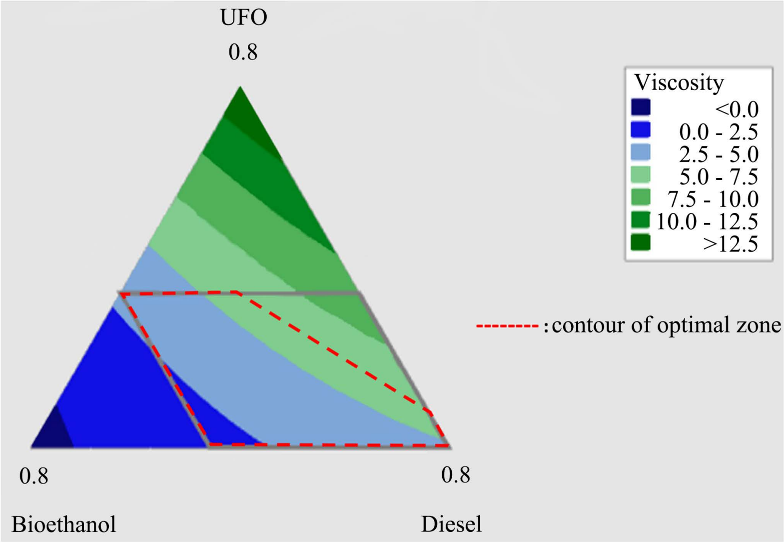

Figure 3. Kinematic viscosity mixture contour plot.

3.3.4. Multi Response Optimization (Specific Gravity, Kinematic Viscosity)

The optimization will fall back on the study of the kinematic viscosity because in terms of specific gravity all the mixtures have a value included in the chosen experimental domain. Thus the optimal conditions depend on kinematic viscosity. According to the results previously obtained, the predicted viscosity response is in the form of Equation (2). To determine the extremum (the minimum in the case of this study) of this function in the experimental domain, the resolution of the system of the following relation is necessary:

$$\begin{cases} \text{Min } Y(X_1, X_2, X_3) \\ 0.1 \le X_1 \le 0.4 \\ 0.1 \le X_2 \le 0.5 \\ 0.1 \le X_3 \le 0.8 \end{cases}$$

This resolution leads to the results Min $Y(X_1, X_2, X_3) = 2.97$ cSt with optimal conditions $X_1 = 0.4$; $X_2 = 0.5$ and $X_3 = 0.1$ which correspond respectively to the proportions of UFO, bioethanol and diesel. Under these conditions, the specific gravity value is 0.84 and that of the kinematic gravity is 2.97 cSt. The responses (specific gravity and kinematic viscosity) obtained under optimal conditions show that these values comply with the Ivorian specification for diesel [5]. These values are of the same order as that of Uzun *et al.* [14]. In the multi-response optimization using the desirability approach, the values of specific gravity and kinematic viscosity were determined with desirabilities estimated at 0.68 and 0.75 respectively.

4. Conclusion

The aim of this study was to optimize the formulation of fuel from a mixture plan by studying the physical properties such as the specific gravity and kinematic viscosity of different mixtures. Thus, this optimization based on a mixture plan revealed that the experimental domain leads to the following experimental conditions: 40% for UFO, 50% for bioethanol and 10% for diesel. These experimental conditions lead to a specific gravity of 0.84 as for the kinematic viscosity. It is 2.97 cSt. The specific gravity and kinematic viscosity values were determined according to desirability values of 0.68 and 0.75. In perspective, it is planned to determine other physicochemical and thermal parameters of the mixture obtained under optimal conditions.

Conflicts of Interest

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

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