

Production of a Mathematic Equation Using Statistical Data for the Determination of Kinematic Viscosity in Blends of Diesel Fuel with Biodiesel

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Abstract: In this paper, the authors try to export an equation which describes the variation of kinematic viscosity in blends of diesel fuel with biodiesel. Using specific volume of these blends, the authors determine kinematic viscosity via method ASTM D 445-06 using a capillary glass viscometer in order to study the contribution of quantity of biodiesel and convert the statistical data into mathematic relation as a specific formula, attempting to achieve an empirical evaluation. Trying to accomplish this, the authors studied the way how the values of variables are changed and whether a relation exists using dispersion diagrams. From the graphic depiction, the authors realized that the relation is linear and they proceeded to regression analysis. The analysis extracted the conclusion that the relation was strong and the values of the dependent variable kinematic viscosity was depended on a large percentage of the values of the mixture of fuels.

Key words: Diesel, biodiesel, statistical analysis, kinematic viscosity, equation.

1. Introduction

The market of petroleum products is enlarged as a consequence of the changes in the environment of life that have originated from the improvement of the living conditions, the cities expanding as a result of the massive population movement and the expanded basic needs.

Next to this, the national trade balance and the

economic development are influenced by this compulsory demand since the country imports more crude oil products owing to the expansive requirement.

Additionally, the transportation energy use of diesel causes a serious environmental pollution by its gases, leading EU countries to command against them and avoid the bad side effects of the polluted environment that are green house effect, acid rain and serious health issues.

So, all the referred arguments make the biodiesel an only-way solution that will replace the diesel oil as long as it is able to respond to the current increased needs of the means of transport and has also the diesel oil characteristics so as to meet the requirements of producing the appropriate energy. Its main features are to be mixable, efficient and stable unexceptionally [1].

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Microemulsions, thermal cracking (pyrolysis), transesterification (alcoholysis) are the basic four proper procedures of producing biodiesel and according to the usual course of things the direct utilization and mixing follows [2].

At this point, the authors refer that the transesterification of natural and fats oils is the method that is mainly used. So the application of alkalis, acids or enzymes facilitate the process since they implement the catalysis to the transesterification chemical reaction of triglycerides with alcohols (ethanol, propanol, methanol, amyl alcohol or butanol) [3-4].

As far as the research is concerned, reference to an important property of fuels, viscosity should be made.

Viscosity is the fluid resistance to shear or flow and is a measure of the adhesive/cohesive or frictional fluid property. The resistance is caused by intermolecular friction exerted when layers of fluids attempt to slide by one another. The knowledge of viscosity is needed for proper design of required temperatures for storage, pumping or injection of fluids [5-6].

The viscosity of fuels is an important property which impacts the performance of fuel injection systems. Some injection pumps can experience excessive wear and power loss due to injector or pump leakage if viscosity is too low. If fuel viscosity is too high, it may cause too much pump resistance, filter damage and adversely affect fuel spray patterns. In general, fuels with low viscosity tend to have poorer lubrication properties. Viscosity is primarily related to molecular weight and not so much to hydrocarbon class. For a given carbon number, naphthenes generally have slightly higher viscosities than paraffins or aromatics [5-6].

There are two related measures of fuel viscosity: dynamic (or absolute) and kinematic viscosity. Kinematic viscosity is the ratio of absolute or dynamic viscosity to density, a quantity in which no force is involved and can be obtained by dividing the absolute viscosity of a fluid with its density (Eq. (1)),

$$v = \frac{\mu}{d} \quad (1)$$

where:

v = kinematic viscosity (cSt or mm^2/s);

μ = absolute or dynamic viscosity (cP or $10^{-2} \text{ g/cm}\cdot\text{s}$);

d = density (g/cm^3).

In this paper, the variation of kinematic viscosity in blends of diesel fuel with biodiesel is presented because kinematic viscosity could be determined in the authors' laboratory.

In this framework, D. Greene [7] suggests that the environmental and energy issues increase the demand for different fuel types of altered and mixed oils. Moreover, the ICT branch, E. Stiakakis and P. Fouliras [8] have implemented a study focusing on the effect of companies on the environment that has led to the application of the method called the Data Envelopment Analysis (DEA). Next to this, the methods of econometrics will be applied to the variables targeting to retrace the connection points between the mix and the fuels kinematic viscosity in the tested models.

So, the researchers attempt to succeed in defining the accurate new fuels characteristics based on the extracted equations by this method in order to preview the fuels kinematic viscosity without any other experiments. Naturally, as far as mixes are concerned, the $Y = ax + b$ is the suggestive linear equation that is capable of pointing variables reactions. Finally, the referred estimating process should be applied to fuels identified with similar properties under the advisable temperature of 40°C , (focusing on the comparison between the kinematic viscosity values and the fuel features). The paper is organized as follows: Section 2 discusses the production of biodiesel and physicochemical properties of biodiesel and diesel; section 3 presents results of kinematic viscosity of fuel samples; section 4 introduces statistical empirical findings; section 5 gives conclusions.

2. Production of Biodiesel and Physicochemical Properties of Biodiesel and Diesel

Biodiesel [9] is produced by transesterifying (See Fig. 1) the parent oil or fat with an alcohol, usually methanol,

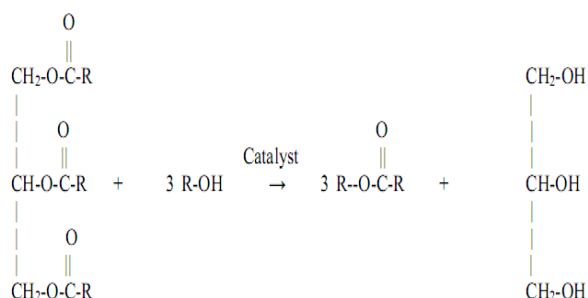


Fig. 1 Transesterification reaction [10].

in presence of a catalyst, usually a strong base such as sodium or potassium hydroxide, or preferably and increasingly more commonly, alkoxides. The resulting product therefore can contain not only the desired alkyl ester product but also unreacted starting material, residual alcohol, and residual catalyst.

Glycerol is formed as by-product and separated from biodiesel in the production process, however, traces thereof can be found in the final biodiesel product.

After the production of biodiesel, the authors have to certify the appropriateness of the end product, measuring its physical properties and compare their values to its specifications (See Table 1). For example, biodiesel can absorb a certain amount of water during storage. Such issues are addressed in biodiesel standards.

Some specifications in biodiesel standards are carryovers from diesel standards. However, not all test

methods carried over from diesel standards into biodiesel standards are well suited for biodiesel analysis. European Biodiesel Standards show that the upper limit of kinematic viscosity for Biodiesel is higher than diesel.

Although there are many standard methods used for analyzing the various properties, emphasis is placed on methods determined in the authors' laboratory.

The diesel oil constitutes blends of many hydrocarbons with different properties. Diesel of internal combustion should have attributes that ensure auto ignition of fuel and furthermore sure and smooth combustion without problems in the conditions of booth combustion. The properties of fuel depend on the type of hydrocarbons that it contains, as well as from their contents.

Greek Specifications (See Table 2) require a kinematic viscosity range of 2.00 minimum to 4.5 maximum mm²/s at 40 °C, for diesel fuels (note that the term mm²/s replaces the former term of centistokes [cSt]).

3. Measurements of Kinematic Viscosity of Fuel Samples

In this study, the authors used pure Diesel and one kind of biodiesel: biodiesel by vegetables (vegetable oil fuel). These samples met the specifications of diesel fuel and biodiesel standards (Tables 1-2).

Table 1 Laboratory values of vegetable biodiesel and biodiesel standards (European Biodiesel Standards EN 14214 for vehicle use) [11].

Physico-chemical property	Vegetable biodiesel lab values	Biodiesel standards	Methods (ASTM)
Density (15 °C), g/mL	0.884	0.860-0.900	D1298-99 [12]
Kinematic viscosity (40 °C), mm ² /s (cSt)	4.54	1.9-6.0	D 445-06 [13]
Humidity, mg/kg	296	< 500	D 1744-92 [14]
Heat of combustion, kJ/kg	40.036	> 35.000	D 4809-09a [15]
Total acid number, mg/g KOH	0.24	< 0.50	D 664-09a [16]

Table 2 Laboratory values of pure diesel and Greek specifications (enarmonized with European Community) of diesel fuel (FEK 332/B/11-2-2004, EN 590: 1999).

Physico-chemical property	Diesel lab values	Diesel standards	Methods (ASTM)
Density (15 °C), g/mL	0.829	0.820-0.845	D1298-99 [12]
Kinematic viscosity (40 °C), mm ² /s (cSt)	2.49	2.00-4.50	D 445-06 [13]
Humidity, mg/kg	50.0	< 200.0	D 1744-92 [14]
Heat of combustion, kJ/kg	46.428	> 42.600	D 4809-09a [15]
Total acid number, mg/g KOH	-	-	D 664-09a [16]

The total volume of each blend was 100 mL (for example 20% blend included: 80 mL diesel and 20 mL animal fats biodiesel or 20 mL vegetable biodiesel) and in every measurement the volume of biodiesel was changing.

The authors measured kinematic viscosity via the method ASTM D 445-06 [13] firstly in pure diesel and then in all blends. Each fuel sample (15 mL volume) is placed in a calibrated capillary glass viscometer tube (Cannon-Fenske Routine Viscometer Capillary No. 75) and held at a closely controlled temperature (Visco-System AVS 470 including Transparent Thermostat CT 52 of SCHOTT INSTRUMENTS). The time required for a specific volume of the sample to flow through the capillary under gravity is measured. This time is proportional to the kinematic viscosity of the sample. Using Eq. (2):

$$v = k \cdot t \quad (2)$$

where:

v = kinematic viscosity (cSt or mm²/s);

k = constant of Cannon-Fenske Routine Viscometer Capillary No. 75 (0.008 mm²/s²);

t = time (s).

The authors determined kinematic viscosity. Results are presented in Table 3.

From Table 3, it is noticed that blending biodiesel, which has a kinematic viscosity rating near the maximum limit, could cause the biodiesel blend to exceed the maximum viscosity limit specified diesel, especially for higher concentration biodiesel blends.

4. Statistical Empirical Findings

In this paper, the authors try to export an equation which describes the variation of kinematic viscosity in blends of diesel fuel with biodiesel [17]. The selection of the suitable model will be realized by using the Regression Analysis targeting to be used for the prices evaluation of the dependent variable in the specific prices of the independent variable.

The preliminary statistical analysis of the series, that are the kinematic viscosity (Y) and mix (X) (fuels),

has led us to the accurate conclusion that the relation which connects the two variables is linear as defined in Fig. 2.

The variables relation could be stated by the simple linear regression model as it is showed as follow:

$$Y_i = b_0 + b_1 X_i + U_i \quad (3)$$

where:

Y_i : i is the observation of the dependent variable Kinematic Viscosity;

X_i : i is the observation of the independent variable mix;

b_0, b_1 are the straight regression coefficients.

U_i represents the equation error.

The relation that connects the variables kinematic viscosity and mix could be simply defined by the dispersion diagram supporting the authors to create the nature of the tested relation and considering proceeding the research.

Table 3 Values of kinematic viscosity of diesel and its blends with biodiesel (vegetable biodiesel).

Blend (diesel + vegetable biodiesel)		Method of determination
Blend (% v/v)	Kinematic viscosity (40 °C), mm ² /s (cSt)	
0.00	2.72	
10.00	2.82	
20.00	2.95	
30.00	3.14	
40.00	3.40	ASTM D 445-06 [13]
50.00	3.74	
60.00	3.94	
70.00	4.14	
80.00	4.38	
90.00	4.61	
100.00	4.98	

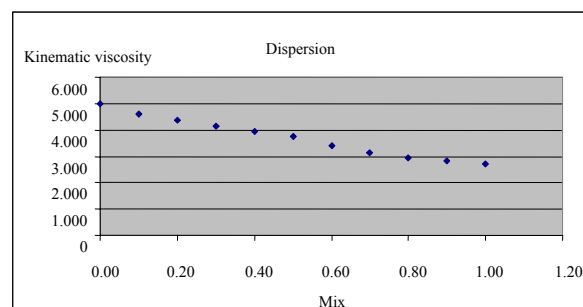


Fig. 2 Dispersion of kinematic viscosity of mix of fuels.

So proceeding to the research, the authors have created a mix which is the mix that refers to the pure diesel with biodiesel. The mix was studied in terms of the kinematic viscosity in order to find the equation that will define the kinematic viscosity of the tested mixes.

As far as the mix is concerned, the authors expected that the upgrade of the animal and vegetable biodiesel would be proportional to the increase of the kinematic viscosity arithmetic outcome due to the linear relation that connects the two variables. So studying on the regression, the authors notice that Eq. (4) has correct signals as they are aware of theory, so that the bigger addition of biodiesel on pure diesel will make the mix quote lower and lower real values to kinematic viscosity. The authors come to the relative conclusion as it is defined by the following:

$$\begin{aligned} \text{Kinematic viscosity} &= 4.860 - 0.022 \text{ mix} \\ \text{or} \\ Y &= 40.914 + 0.0540X \end{aligned} \quad (4)$$

With reference to the mix1, the accounted price of the statistical element F is 99.949 and the p -value is 0.000000, therefore the tested model is statistically significant disallowing the zero case that demands at least one $\beta_k \neq 0$ in significance level α (meaning 0.05 or 0.01). Next to this, the authors terminate that the selected regression model for the mix is able to clear an important part of the kinematic viscosity variability, namely Eq. (5):

$$Y = \sum (Y - \bar{Y})^2 \quad (5)$$

The examination of the single variables by the t test suggests the significance of the mix variable because after re practicing the theory, the t test is equivalent to p price examination, regarding the mix variable the p value is 0.0000 much lower than any significance level if taken (even 10%), then the authors are able to reject the case that tested variable coefficient is zero ($H_0: \beta_j = 0$) and the authors conclude that the relation to the dependent variable is statistically important.

Proceeding with the analysis, the authors assume that it is intentional to make a reference to the regression results in terms of the variability ratio. Next to this, the specification coefficient is an index of the

efficiency of the evaluated model. So aiming to examine the relation between the dependent and the independent variables, the authors study the multiple correlation coefficient R . As the authors have already substantiated the fuel mix alteration is proportional to Eq. (4) output alteration and eventually to the fuel kinematic viscosity. This is statistically supported with regard to the b_1 parameter modification. The regression model explanatory value is upgraded by the price increase of the multiple correlation coefficient which tends to one. As long as the $R^2 = 1$, the straight line goes through all the points (x_i, y_i) of the dispersion diagram. The adaptation or definition index pinpoints the dependent variable rate that is defined by the independent variable variations.

It can be noticed in Table 4 that the adjusted R^2 is high and close to one which indicates the fact that the independent variable defines at about 98% in the tested mix the dependant variable prices, namely the fuel kinematic viscosity.

The nearly perfect relation (it could be said negative) between the tested mix variables, by applying the R^2 adjusted, ensures the dispersion diagrams that were used to support the linear relation that involves the variables. Speaking specifically, based on the R^2 adjusted, the approximately 98% of the dependant variable variability is attributed by the regression. The 1% residual is proceeded by foreign factors and are not included in this question model. The t test is comparable to the p -value examination and taking into account that the rate of the question index should be very low so as to be statistically significant, Table 4 supports the statistically significance of mix is high provided that the p -value is lower than 1% (based on the regression output). The model suitability test was

Table 4 Values of t -statistic and R^2 .

Mix		
b_0	b_1	Adjusted R^2
4.860	-0.022	0.987
99.949	-27.970	
0.00001	0.00001	

Notes: * indicates t -statistic; ** indicates p -value.

realized by the application of diagnostic tests and the existence examination of standardized residuals serial correlation. Next to Table 5, this took place using the statistical elements LB for the standardized residuals and the squared standardized residuals [18].

It is remarkable that, according to Table 5, the standardized and the squared standardized residuals are independent inter each other since a thinkable line is not imprinted without special fluctuations and not a prices mix so that a positive residuals autocorrelation is not submitted. The reasonable conclusion is the autocorrelation and the heteroskedasticity absence.

Attempting to reject the autocorrelation and

heteroskedasticity existence suspicion in this model, we proceed to the above diagnostic test such as the Breusch-Godfrey as it is showed in Table 6.

In Table 6, it is observed that the Probability is $> 5\%$ which implies that a and b grade autocorrelation issue is not faced.

The heteroskedasticity issue concerns most of the researchers in the frames of econometric subject studies such as the specific econometric model. With regard to Table 7, the proposed model does not show heteroskedasticity since according to the White test, the probability is $> 10\%$ (it is the highest significance grade that is able to study on).

Table 5 LB test for residuals and squared residuals from the regression estimation of kinematic viscosity and the blend.

Standardized residuals				Squared standardized residuals			
Lags	Autocorrelation	Partial correlation	$LB(n)$	Lags	Autocorrelation	Partial correlation	$LB(n)$
1	0.234	0.234	0.7843	1	-0.035	-0.035	-0.035
2	-0.218	-0.289	1.5408	2	-0.068	-0.068	-0.068
3	-0.354	-0.255	3.7844	3	0.158	0.158	0.158
4	-0.113	-0.023	4.0458	4	-0.019	-0.019	-0.019
5	0.212	0.138	5.1218	5	-0.220	-0.220	-0.220
6	-0.104	-0.371	5.4301	6	-0.175	-0.175	-0.175
7	-0.258	-0.188	7.8174	7	-0.017	-0.017	-0.017
8	-0.185	-0.091	9.4484	8	-0.132	-0.132	-0.132
9	0.003	-0.180	9.4489	9	-0.231	-0.231	-0.231
	Autocorrelation	Partial correlation			Autocorrelation	Partial correlation	
1	. ** .	. ** .		1	. .	. .	
2	. ** .	. ** .		2	. * .	. * .	
3	. *** .	. ** .		3	. * .	. * .	
4	. * .	. .		4	. .	. .	
5	. ** .	. * .		5	. ** .	. ** .	
6	. * .	. *** .		6	. * .	. ** .	
7	. ** .	. * .		7	. .	. * .	
8	. * .	. * .		8	. * .	. * .	
9	. .	. * .		9	. ** .	. ** .	

Note: $LB(n)$ are the n -lag Ljung-Box statistics for the residual series. $LB(n)$ follows chi-square variable with n degree of freedom; the series of residual contains 9 observation.

Table 6 Breusch-Godfrey serial correlation LM test [19].

Mix			
F-statistic	0.875116	Probability	0.045790
Obs* R-squared	2.200234	Probability	0.033283

Table 7 White heteroskedasticity test.

Mix			
F-statistic	3.875206	Probability	0.066557
Obs* R-squared	5.412844	Probability	0.066775

5. Conclusions

In the framework of this research on the fuels relation (diesel + biodiesel = mix or blend), the authors have come to the conclusion that there is an actual strong linear relation that connects the above mix with the kinematic viscosity. It is remarkable that the mix independent variable has a strong linear relation to the

kinematic viscosity as the index of adjusted R^2 is equal to 0.98%. Normally, before the question index testing, we have already established the statistical model significance basing on the price p-value and the statistical F. Likewise, the authors substantiated that the model variables are statistically significant as the $H_0: \beta_j = 0$ case was rejected. Furthermore, the LB elements suitability test showed that there is no residuals correlation no heteroskedasticity existence suspicion.

However, attempting to confirm this theory the authors applied the diagnostic test-Godfrey and White Heteroskedasticity and indicated that the suggested model does not include autocorrelation and heteroskedasticity.

The autocorrelation heteroskedasticity absence that is combined to the strong linear relation of the variables makes the authors conclude that Eq. (4) is able to preview the kinematic viscosity of the model fuels.

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