Original Article

Mathematical Model to Predict Biofuel Mixture Consumption in a Generator

Modelo matemático para la predicción del consumo de mezclas de biocombustible en un grupo electrógeno

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ABSTRACT: The need to replace fossil fuels is now a priority in the world. The biodiesel from non-edible crops is a line of work to apply in agricultural communities fundamentally. In this work the use of mixtures of diesel-biodiesel of castor oil in a 7.46 kW generator set with a diesel engine was studied. The behavior of different mixtures of diesel-biodiesel and pure diesel was studied at different loads of the generator set and the fuel consumption was measured as a response variable. A multiple linear regression model in the statistical program SSP was used to process the data. A mathematical model with an adjustment R^2, able to predict the consumption for different mixtures and at different loads was obtained. In field conditions, its energy performance can be determined from the variables studied and thus, determine the consumption required in each case.

Keywords: alternative fuels, consumption indices.

RESUMEN: La necesidad de lograr sustituir los combustibles fósiles constituye actualmente una prioridad en el mundo. El biodiesel a partir de cultivos no comestibles, es una línea de trabajo para aplicar en comunidades agrícolas fundamentalmente. En el trabajo se estudia el uso de mezclas de diesel-biodiesel de aceite de higuerilla en un grupo electrógeno de 7.46 kW con un motor diesel. Se estudió el comportamiento de diferentes mezclas de diesel-biodiesel y diesel puro a diferentes cargas del grupo electrógeno y se midió el consumo de combustible como variable respuesta. Los datos fueron elaborados por un modelo de regresión lineal múltiple en el programa estadístico SSP. Se obtuvo un modelo matemático con un ajuste R^2, capaz de predecir el consumo para diferentes mezclas y a diferentes cargas. En condiciones de campo se puede determinar el desempeño energético del mismo a partir de las variables estudiadas y determinar así el consumo necesario en cada caso.

Palabras clave: combustibles alternativos, índices de consumo.

INTRODUCTION

The use of biofuels is one of the current ways of replacing fossil fuels in the world. Researchers from different latitudes see it as a renewable and ecological resource for fuel, devote their effort in this regard and have discussed about it (Nahar y Dupont, 2012; Xuan *et al.*, 2009). In the world, 30 billion liters per year are produced, which represents 19% of the world production of biofuels (Diop *et al.*, 2013). Other authors have pronounced for the use of biodiesel in the diesel engine (Graboski y McCormick, 1998; Canakci y Van Gerpen, 2001; Rakopoulos *et al.*, 2006a; Lin *et al.*, 2006; Altın *et al.*, 2001; İşcan y Aydın, 2012).

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INTRODUCTION

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The use of biofuels in agricultural communities is a source to reduce costs and damage to the environment. Small-scale generator sets are an option of power service for isolated agricultural communities, to complement their services from biofuels obtained from surrounding crops. In this research, it was proposed to evaluate the use of biodiesel from castor oil in different mixing proportions and loads of the generator set, with the aim of establishing a fuel consumption model in the different work variables. The studies were carried out using a 7.46 kW power unit with a diesel engine of a cylinder as an experimental model. The work was carried out in the laboratories of the Facultad de Ingeniería Agrícola of the Universidad Técnica de Manabí located in Lodana. The analysis of the data was performed using the multiple regression method to obtain the mathematical model and 32 runs were carried out. This method was developed through the statistical computer program SSP. A mathematical model that represents the physical model was obtained. It allowed determining the relationships between the use of biodiesel mixtures, the electric charge and the fuel consumption and thus being able to predict the consumption within the range studied.

METHODS

The research was carried out in the laboratories of the Facultad de Ingeniería Agrícola of the Universidad Técnica de Manabí. In the study, a 7.46 kW power generator that uses a one-cylinder diesel engine was used as experimental model. Figure 1 shows the model and its installation and Table 1 shows the main characteristics of the engine.

FIGURE 1. Experimental model.

TABLE 1. Technical data of the diesel motor

Produced in	Korea
Brand	JING DONG (JD)
Motor nº	DG6500
Power	10 Hp.
Regime of work	3000 rpm 6 KW Y 3600 rpm 6.7 KW
Model	186 FA
Cilinder	418 C.C.
Year Model	2010
Capacity	1.65 L.
Voltage	110 V. 220 V.

Experimental Design

In the experimental design, three variables to be evaluated were considered: fuel, electric charge of the group and hours of work. In the case of fuel, pure diesel was used for the mixtures of B0, B5, B10, B15, B20, B40, B60 and B100; in the electric charge, light bulbs with values between 0 and 500 W were used. To guarantee the reliability of the results, the data were taken considering each hour up to 40 working hours. A total of 32 variants were evaluated from the values of the different factors. The factors were coded for identification in the equation. Table 2 shows the factor and the code.

TABLE 2. Factors code

Factors of study	Code
Biodiesel mixture	X_1
Electric load to the generator	X_2
Working hours	X_3
Fuel consumption	Y

For the measurement of fuel consumption, 500 cm^3 graduated cylinders were used. As shown in Figure 2, 8 specimens connected to the engine were mounted on the model using a flexible hose and a quick-closing valve to control the use of each mixture. In the change from one mixture to another, the power system was cleaned and the engine was operated with 300 cm^3 of the variant to be used and from this the measurement was started.

FIGURE 2. Graduated cylinder used in the research.

For the installation of the power energy to be consumed, 10 W bulbs were used, placed as shown in Figure 3, taking into account that the load is known, it was only controlled by the wattmeter of the generator set, to take into account the losses in the circuit.

FIGURE 3. System of power charge used.

Statistical Methodology

The data analysis was carried out using the multiple regression method to obtain the mathematical model. This method is developed through the SSP computer program. By this method it is possible to have different variables that taken together can serve as a satisfactory basis for the estimation of the desired variable, made by linear functions. For this purpose, the available variables are represented by Y, X1, X2, ... Xk, and the problem of estimating Y is considered by means of a linear function of the remaining variables. If Y is designated as the variable, its estimated is obtained by means of the expression:

$$Y = C_0 + C_1X_1 + C_2X_2 + ...C_kX_k \quad (1)$$

Coefficient of Determination of the Regression

The coefficient of determination of the regression determines the degree of adjustment of the model, accepting as results, values greater than 0.9 (Hoel y Yuste, 1976).

Mathematical evaluation of Fischer Test. This is accomplished by means of Fischer Test from the comparison of the two types of errors "pure error" and "error due to lack of adjustment". If the Fischer coefficient calculated for the model is smaller than the tabulated one, the hypothesis that the determined mathematical model presents a good fit to the physical model is accepted. Fischer criterion is based on the comparison of the variance of the two types of errors cited above.

Independence of the Variables

Independence is determined by the correlation matrix, if it is zero there is mismatch between the variables, which shows that each variable gives the model a different effect and that there is no effect of interaction between them, showing independence. If there is any value, the interaction in the model, must be studied and its incorporation to the model must be decided. The tabulated F is searched in the table with 0,95 percentile, according to the degrees of freedom of the numerator (K-1) and denominator (n-K). If the calculated F is less than the F of the table, the hypothesis that the variances are equal and therefore the mathematical model determined adequately represents the experimental model, is accepted.

RESULTS AND DISCUSSION

The model that represents the fuel consumption based on diesel-biodiesel mixtures and the generator load is represented by the equation:

$$y = 844.238 + 3.44x_1 + 0.162x_2 + 0.078x_3$$

The coefficient of determination of the regression, R^2 of the model, is 0.945. This value demonstrates the high degree of adjustment obtained, accepting that the model adequately describes the phenomenon represented. Therefore, it can be stated that the mathematical model represents the physical model studied with a confidence level of 95%.

The independence of the factors was determined by the correlation matrix. Table 3 shows the correlation coefficients between the factors studied. The correlation between the factors is zero, which shows that each factor gives the model a different effect and that there is no effect of interaction between them, and independence is demonstrated.

TABLE 3. Factors correlation

Factors	X_1	X_2	X_3
X_1	1	0	0
X_2	0	1	0
X_3	0	0	1

Evaluation of Fischer Test

The tabulated F was determined in Fischer F table with 0.95 percentile, according to the degrees of freedom of the numerator and the denominator. The value is 161.146 and the calculated F is 77.84.t The F calculated is lower that the F of the table, so the hypothesis that the variances are equal and, therefore, the mathematical model determined adequately represents the experimental model is accepted.

When analysing the factors in the model, it is obtained that, x_1, which represents the proportion of the diesel-biodiesel mixtures, is presented with a positive sign and with a coefficient of 3.44. It indicates that, with the increase in the percentage of biodiesel in the mix, increases fuel consumption. This is the strongest factor in the model, in contribution to the response with 91.8%. This result coincides with Pérez-Sánchez et al (2015), mainly conditioned by the lowering caloric value of the mixture by adding the biodiesel from castor oil which is 8,553 kcal/kg (measured in the laboratories of the Pontificia Universidad Católica del Ecuador, in Ibarra). Nevertheless, Armando *et al.*, (2015) report, in California, values of 8,964 kcal/kg, smaller than diesel in the two cases, which is 10,552 kcal/kg. Regarding calorific power, Altın *et al.* (2001) and İşcan and Aydın (2012), referred that biodiesel produced from other sources such as cotton, soy, palm, sunflower, show no significant changes in this value. Other physical factors influence consumption, such as viscosity and density. In the case of biodiesel, it is 52.2 cp and 0.950 g/cm^3 (kinematic viscosity 5.5 cSt), respectively. For diesel, kinematic viscosity is 3.2 cSt and density of 0.850 g/cm^3. The viscosity is higher in biodiesel than in diesel, which influences the movement of the fluid through the pump and the injector. Researches have reported that the properties that present the greatest variation between biodiesel and diesel are density, cetane number, calorific value and, in greater proportion, viscosity of the fuel (Lin *et al.*, 2006; Rakopoulos *et al.*, 2006b; Scarpa and Guerci, 1982). The model has a linear nature and referred to that, Abdalla (2018) stated that the results for the properties of density and viscosity in the mixtures strongly indicate a linear increase when increasing the percentage of B100 in the mixture.

The factor x_2, which represents the power load to the generator's electrical system, is presented with a positive value with a coefficient of 0.162, which indicates that an increase in the load on the generator brings about an increase in fuel consumption, what was expected, once the system requires more energy. Although the weight of this factor is lower in its influence on consumption in proportion to x_1, it is considered for consumption in the range studied. The factor has a weight in the response of 7.2% much lower than 91.8% of the factor of diesel-biodiesel mixtures.

The factor x_3 represents the number of hours worked in each run; two levels were taken at 20 hours of work and at 40 hours. In the resulting model, this factor has the least influence on consumption with a coefficient of 0.078 and with a positive sign, which means that the increase in working hours shows an increase in fuel consumption. The increase in fuel consumption by this factor is 1%, which is considered non-representative as a study factor.

In general, with the model obtained, the amount of fuel needed for a given power and a selected biodiesel mixture can be planned, using the generator set of the experimental model within the ranges studied.

CONCLUSIONS

The model was obtained according to the variables studied, which allows to determine the consumption from the power charge and the mixture of diesel-biodiesel used.

$$y = 844.238 + 3.44x_1 + 0.162x_2 + 0.078x_3$$

The factor x_1 that represents the percentage of biodiesel mixtures is the one that has the greatest influence on fuel consumption with a 91.8% weight in the fuel consumption of the engine.

The factor x_2, which represents the electric power load to which the generator is subjected, has a weight in the fuel consumption of 7.2%.

REFERENCIAS BIBLIOGRÁFICAS

ABDALLA, I.E.: ¨Experimental studies for the thermo-physiochemical properties of Biodiesel and its blends and the performance of such fuels in a Compression Ignition Engine¨, *Fuel*, 212: 638-655, 2018, ISSN: 0016-2361.

ALTIN, R.; CETINKAYA, S.; YÜCESU, H.S.: ¨The potential of using vegetable oil fuels as fuel for diesel engines¨, *Energy conversion and management*, 42(5): 529-538, 2001, ISSN: 0196-8904.

ARMANDO, P.-S.; GISELA, M.-A.; RAMÓN, A.-B.; ALBERTO, C.-O.M.; ENRIQUE, C.-R.H.; CONRADO, G.-G.: ¨Simulación en Aspen de la combustión de mezclas diesel-biodiesel¨, *Ingeniería, investigación y tecnología*, 16(1): 83-92, 2015.

CANAKCI, M.; VAN GERPEN, J.: ¨Biodiesel production from oils and fats with high free fatty acids¨, *Transactions of the ASAE*, 44(6): 1429, 2001, 2151-0032, E-ISSN: 2151-0040.

DIOP, D.; BLANCO, M.; FLAMMINI, A.; SCHLAIFER, M.; KROPIWNICKA, M.A.; MARKHOF, M.M.: ¨Assessing the impact of biofuels production on developing countries from the point of view of policy coherence for development¨, *Tanzania Field Mission. Draft Version*, 2013.

GRABOSKI, M.S.; MCCORMICK, R.L.: ¨Combustion of fat and vegetable oil derived fuels in diesel engines¨, *Progress in energy and combustion science*, 24(2): 125-164, 1998, ISSN: 0360-1285.

HOEL, P.G.; YUSTE, H.: *Introducción a la estadística matemática*, USA, 1976, ISBN-84-344-0131-2.

İŞCAN, B.; AYDIN, H.: ¨Improving the usability of vegetable oils as a fuel in a low heat rejection diesel engine¨, *Fuel processing technology*, 98: 59-64, 2012, ISSN: 0378-3820.

LIN, Y.-C.; LEE, W.-J.; HOU, H.-C.: ¨PAH emissions and energy efficiency of palm-biodiesel blends fueled on diesel generator¨, *Atmospheric Environment*, 40(21): 3930-3940, 2006, ISSN: 1352-2310, E-ISSN: 1873-2844.

NAHAR, G.; DUPONT, V.: ¨Hydrogen via steam reforming of liquid biofeedstock¨, *Biofuels*, 3(2): 167-191, 2012.

RAKOPOULOS, C.D.; ANTONOPOULOS, K.A.; RAKOPOULOS, D.C.; HOUNTALAS, D.T.; GIAKOUMIS, E.G.: ¨Comparative performance and emissions study of a direct injection diesel engine using blends of diesel fuel with vegetable oils or bio-diesels of various origins¨, *Energy conversion and* *management*, 47(18-19): 3272-3287, 2006a, ISSN: 0196-8904.

RAKOPOULOS, C.D.; ANTONOPOULOS, K.A.; RAKOPOULOS, D.C.; HOUNTALAS, D.T.; GIAKOUMIS, E.G.: ¨Comparative performance and emissions study of a direct injection diesel engine using blends of diesel fuel with vegetable oils or bio-diesels of various origins¨, *Energy conversion and management* , 47(18-19): 3272-3287, 2006b, ISSN: 0196-8904.

SCARPA, A.; GUERCI, A.: ¨Various uses of the castor oil plant (Ricinus communis L.) a review¨, *Journal of ethnopharmacology*, 5(2): 117-137, 1982, ISSN: 0378-8741.

XUAN, J.; LEUNG, M.K.; LEUNG, D.Y.; NI, M.: ¨A review of biomass-derived fuel processors for fuel cell systems¨, *Renewable and Sustainable Energy Reviews*, 13(6-7): 1301-1313, 2009, ISSN: 1364-0321.

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