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Research Article

Liquid Fuels Derived from Microalgae: Physicochemical Analysis

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In the analysis of the fuel like the liquid fuels obtained from the transesterification process of Spirulina microalgae biomass, the physicochemical characteristics correspond to fractions of gasoline, paraffin, and diesel, and to determine the environmental sustainability of its use, combustion tests were carried out on a diesel test engine (1000, 2000, and 3000 rpm) to establish a comparison with commercial neat diesel. The results obtained prove, based on the analysis of emissions and combustion, that this fuel can be a direct replacement for diesel.

1. Introduction

The environmental impact caused by waste cannot be easily recycled, making them unusable waste. Inadequate final disposal has a negative influence on environmental quality and human health. This planetary nature of the problem implies that universally approved international policies for gradual reductions in emissions into the atmosphere, as well as common support in anticipation of the large costs required to protect entire populations from the effects of climate change, are required [1]. The necessity to invest in alternative energy such as biofuels derived from crops such as sunflower, soybean, and rapeseed is thus emphasized, especially given the role they may play in achieving the reduction of greenhouse gas emissions. Agriculture's contribution helps us achieve the Kyoto Protocol's goals while lowering pollution levels. A million tonnes of biodiesel produced from domestic crops reduces hydrocarbon and polycyclic aromatic emissions by 80% and particulate matter and fine dust by 50%, respectively [2]. The IPCC (International Panel on Climate Change) identified CO_2 as one of the gases responsible for the greenhouse effect and human activity as one of the reasons in its first report in 1990. That human activity is behind the acceleration of the heating process and that only by drastically reducing greenhouse gas emissions in the atmosphere will it be possible to avoid exceeding the critical, dangerous thresholds even for the maintenance of life on earth has evolved [3]. The recent oil crisis, as well as public interest in environmental issues, has prompted further research into all renewable energy options. More and more sustainable energy sources, including biomass, are gaining popularity in the community. The latest official document presented by the EPA (Environmental Protection Agency) is intended to provide information to interested parties who want to evaluate the possibility of using biodiesel as a substitute for commercial automotive diesel. EPA is an agency of the United States federal government whose mission is to protect human and environmental health. The density of a substance is determined by its mass divided by its volume. When this index is higher, fuel will be more able to generate energy. The density of biodiesel fuel is greater than that of petroleum diesel, so it generates more power [4]. In the same way that gasoline's octane number specifies gasoline's combustibility and ignition characteristics, diesel fuel's cetane number (CN) shows diesel's [5]. The higher the cetane number, the better the combustion, and there is a correlation between it and ignition delay time [6]. Compounds are structurally defined by their cetane number. It is generally the case that the cetane number increases as the chain length and unsaturation decrease in fatty acid esters.

2. Fuel Characterisation

The characterization of fuel consists of identifying its physical and chemical properties through various laboratory tests. It is important to know these parameters because the design of automotive fuel tanks, pumps, and lines is based on the physical and chemical properties of the fuel to be used, to avoid wear, evaporation losses, and pressure drops.

3. Combustion Test

The main combustion tests that an engine undergoes include exhaust emission and combustion process failures. Flue gas analysis consists of measuring the amount of pollutant gases emitted by the engine into the atmosphere. The following gases are typically analysed: emissions of nitrogen oxides (NOx and NO), carbon monoxide (CO), particulate matter, and opacity. The most important of which is the air emission standard from fixed combustion sources, which establishes the maximum permissible levels of gas emissions from the exhaust of internal combustion motorbikes [7]. Failures in the combustion process are necessary for the reliable and safe operation of machinery; the risk of faults and the time an engine is out of service can be reduced only if potential problems are anticipated and avoided. Therefore, one of the tools available for the analysis of failures in the combustion process is the analysis of the engine's performance.

4. Results and Discussion

4.1. Optimization of the Fuel. To establish the factors influencing the performance of the liquid fuel production process, the data given in Table 1 are checked for normal behaviour, which is a necessary condition for the application of the completely randomised design. For the use of this model, temperature is considered as an input factor and liquid volume is an output factor, and the result is a p value of 0.011, which is a value lower than 0.06 with a confidence level of 96%, which shows that the temperature variable has a significant influence on the experiment. Considering the pressure variable with FE, a p value of 0.69 is obtained, and with the residence time FE, the p value = 0.61; as can be seen, the values are greater than 0.05, which shows that they are not statistically significant and are therefore discarded from the experiment. In addition, polynomial regression is performed with the data given in Table 2 to identify the maximum point of the curve (Figure 1), and the optimum temperature (x-axis) is determined to obtain the highest liquid volume (y-axis). Based on fourth-degree polynomial regression, the following equation is obtained:

$$y = -1E - 2.8 + 0.0003 - 0.1356 + 14.9x - 1207. \quad (1)$$

Considering this equation, the maximum critical temperature point is calculated to be 377°C, which produces the highest volume of liquid fuel.

Table 1: Liquid fuel production process tests.

Temperature (°C)	Pressure (Psi)	Holding time (min)	Liquid volume (cm^3)
350	56	10	4.5
	16	10	4.7
	56	20	4.5
	16	20	4.8
460	56	10	4.2
	16	10	4.1
	56	20	4.4
	16	20	4.2

Table 2: Tests to determine greater fuel efficiency.

Temperature (°C)	Liquid volume (cm^3)
290	5.01
320	5.74
350	6.27
380	6.94
410	6.03

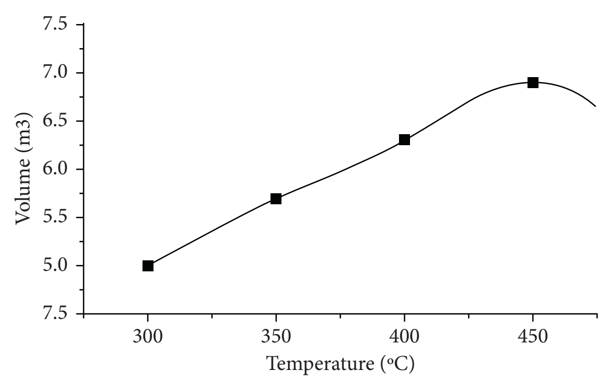

Figure 1: Temperature calibration curve.

4.2. Physicochemical Characterization. The physicochemical analysis of the liquid fuel obtained determined that it has characteristics typical of petroleum-based fuels. Table 3 provides the physicochemical properties of the algae fuel with ASTM standard. The algae fuel has the characteristic color and smell of petroleum products; the density and API gravity correspond to medium crude oil [8].

4.3. Characterisation of Polycyclic Aromatic Hydrocarbons. The gas chromatograph analysis shows that of the six PAHs analysed, the concentration results of which are given in Table 4, fluoranthene and benzo (a) pyrene are those found in the highest proportion in the chemical composition of the algae fuel; the volume percentage of the six PAHs analysed corresponds to 1.49% of the liquid fuel [9].

5. Comparison of the Combustion Process

The emissions of nitrogen oxides (NOx and NO), carbon monoxide (CO), particulate matter, and opacity are analysed, and to establish the failures in the combustion process,

Table 3: Physicochemical characteristics of the fuel obtained.

Parameter	Value
Density (g/cm^3)	0.88
Viscosity (centipoise)	1.11
Flashpoint (°C)	20.5
Freezing point (°C)	−39.3
Cetane number	46.7
Distillation temperature of 90% (°C)	320

Table 4: The concentration of PAHs in the fuel.

PAHs	Concentration	
	ppm	%
Fluoranthene	6090	0.62
Benzo (b) fluoranthene	442	0.05
Benzo (k) fluoranthene	0	0
Benzo (a) pyrene	4893	0.50
Indene pyrene	2100	0.22
Benzo perylene	1377	0.14
Total	14 902	1.5

noise and vibrations are analysed; this comparison is established at 00 rpm and 2000 rpm of the engine.

5.1. NOx, NO, and CO Gas Emissions. The test data at 1000 rpm show that commercial diesel emits 94% more NOx than algae fuel and 110% more NOx. The algae fuel emits 255% more CO than commercial diesel, as shown in Figure 2. With the data obtained from the measurements shown in Figure 2, we proceeded to transform them into units of the reference standard; the value obtained for NOx is 120 mg/m^3, which is less than the value established in the standard (2200 mg/m^3), and as for CO and NO emissions, there is no standard application. In the 2000 rpm test (Figure 2), the process fuel emits 98% more nitrogen oxide (NOx), 98% more nitrogen monoxide (NO), and 276% more carbon monoxide (CO) than commercial diesel [10]. With the data obtained from the measurements shown in Figure 2, we proceeded to transform them into the units of the reference standard; the value obtained for NOx is 120 mg/m^3, which is less than the value established in the standard (2350 mg/m^3), and as for CO and NO emissions, there is no standard application.

5.2. Particulate Matter Emission. For the particulate emission test, a comparison is made with commercial diesel at 1000 rpm and 2000 rpm, taking the measurements with the diesel exhaust gas tester [11]. Figure 3 shows the particulate concentration at 1000 rpm, and it is observed that the particulate emission of the algae fuel is 58.4% higher than that of diesel. Algae fuel compared to diesel at 2000 rpm, as shown in Figure 3, has a higher percentage of 46.3% than commercial diesel. According to the analysis of the fixed combustion sources in the maximum permissible limits of emissions to air for internal combustion engines, the fuel of the process at 1000 rpm is within the limits established for new sources, and at 2000 rpm, it exceeds the established value by 91.3%.

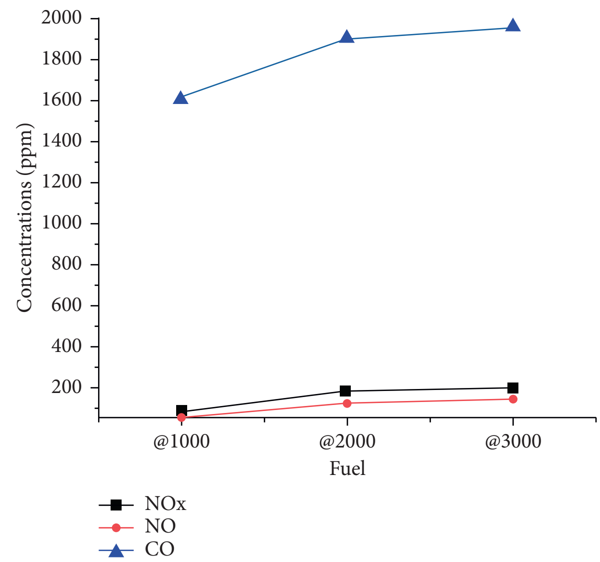

Figure 2: NOx, NO, and CO gas emissions.

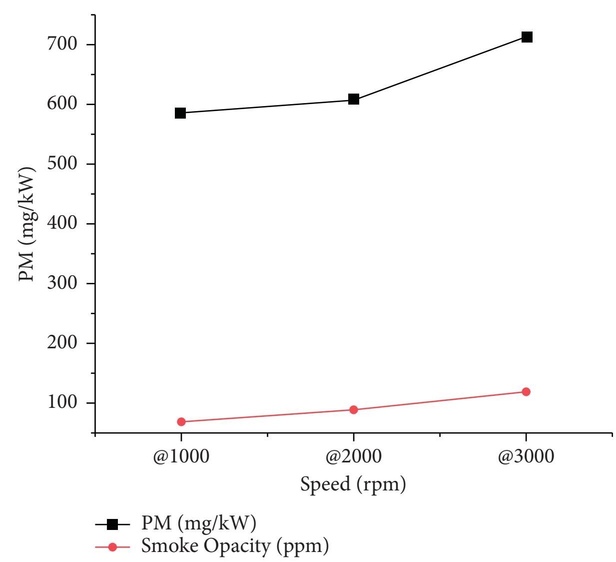

Figure 3: PM and smoke gas emissions.

In the results for smoke opacity, where diesel and algae fuel are compared, both are within the limits established by the ASTM standard. In the 1000 rpm tests, the opacity of the fuel obtained is 538% higher than the opacity of the diesel, as shown in Figure 3. For the 2000 rpm tests, the opacity of the fuel obtained is 2589% higher than the opacity of the diesel, as shown in Figure 3. For the opacity analyses, a diesel exhaust gas tester was used, which determines that the k-factor of the algae fuel is 0.13, equivalent to 1.4% opacity, which represents a higher index compared to the k-factor of diesel which is 0.022, equivalent to 0.3% opacity, for the data obtained at 1000 rpm. Likewise, for 2000 rpm, the k-factor is 3.77, which is equivalent to 37.7% opacity; therefore, it is a higher index compared to the diesel k-factor of 0.15 corresponding to 1.5% opacity [12].

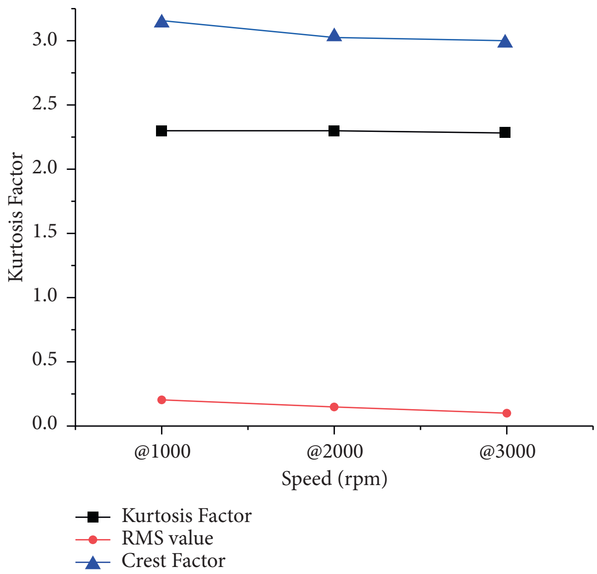

FIGURE 4: Combustion noise.

5.3. Combustion Noise. Figure 4 shows the kurtosis and crest factor values of the algae fuel, which are higher than those of diesel, thus leading to variations in the noise amplitude, while the RMS value showing the noise concentration at 1000 rpm is higher than those of diesel, which leads to variations in the noise amplitude, while the RMS value showing the noise concentration at 1000 rpm is higher than those of diesel [13]. In this case, the kurtosis factor and the crest factor of the algae fuel are lower than the diesel values, which means that there is no considerable variation in the noise amplitude, while the RMS value is higher for the fuel obtained, which means more energy contained in the noise and therefore more noise [14, 15], as shown in Figure 4.

6. Conclusions

After carrying out the gas and particle emissions tests, it was determined that the diesel had better combustion results, showing values well below the emissions of the algae fuel, which also shows an excessive generation of white smoke, a symptom of early combustion in the chamber. When comparing the combustion of algae fuel, it is established that in idling conditions at1000 rpm, the two fuels are within the maximum permissible limits of the Ecuadorian regulations for stationary combustion sources in the emission of NOx and particulates. In the combustion process, acceleration emissions at 3000 engine rpm are determined to be below the maximum permissible limits. The results of the failure of the combustion process are determined using noise and vibration analysis. In the tests at 1000 rpm, 2000 rpm, and 3000 rpm, it is determined that the engine presents more difficulties in the combustion process of the algae fuel in comparison with commercial diesel, finding greater noise and vibrations that generate high wear in the engine parts. Once the results have been analysed, it is shown that the sustainability of the transesterification process does not constitute a methodology for the management through the analysis of the combustion test in the diesel engine because the fuel obtained from the process has higher emissions of pollutants (CO, NO, NOx, particulates, and opacity) and combustion failures affecting the engine.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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