Comparison of the Behavior of biofuel based on Castor and Sunflower Oils

Comparación del comportamiento de biocombustibles basados en aceite de Ricino y Girasol

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Abstract

This article presents the results of the comparison of two experimental studies to obtain biodiesel from castor and sunflower oils. During the development of the projects a standard methodology was adopted that defined the physical and chemical parameters of the biodiesel as a sunflower and Castor oil originated biofuel. To obtain a comparative model and maximize the performance of castor and sunflower oils, the NTC 100/04 standard was chosen, using the mix ratio 5, 10, and 20%, respectively, of biodiesel. Complying with the NTC 100/04 standard, the recommended parameters were followed in the tests performed to compare the results obtained. The methodology chosen allowed assessing the behavior of the combustion gases to achieve the final combustion composition, as well as the development of a comparison between the two biofuels with the fossil fuel (pure diesel) used in diesel engines in Colombia. This study was carried out in Bogotá (2600 m above sea level), and as a result there was a slight decrease in CO₂ and CO output of combustion gases comparing the pure ACPM (oil fuel for engines) and the Biodiesel, for the various mixtures proposed under the ICONTEC norm.

Keywords: Biodiesel, Biofuel, Environmental Sustainability, Transesterification.

Resumen

Este artículo presenta los resultados de la comparación de dos estudios experimentales para obtener biodiesel a partir de aceite de ricino y girasol. Durante el desarrollo de los proyectos se adoptó una metodología estándar que permitió definir los parámetros físicos y químicos del biodiesel como biocombustible proveniente del aceite de girasol e higuera. Para obtener un modelo comparativo y maximizar el rendimiento del aceite de higuera y el de girasol se trabajó bajo la norma NTC 100/04, donde se utilizaron la relación de mezcla 5, 10 y 20%, respectivamente, de biodiesel. Cumpliendo con la normatividad de la NTC 100/04 se siguieron los parámetros recomendados en las pruebas realizadas para comparar los resultados obtenidos. La metodología utilizada permitió medir el comportamiento de los gases de combustión para obtener la composición final de la combustión y el desarrollo de una comparación entre los dos biocombustibles con el combustible fósil (diesel puro) que se utiliza en los motores diesel en Colombia. Este estudio se desarrolló a la altura de Bogotá (2600 msnm) y como resultado se determinó una leve disminución de CO₂ y CO a la salida de los gases de la combustión entre el Aceite Combustible Para Motores (ACPM) puro y la mezcla de Biodiesel para las diferentes mezclas propuestas bajo norma ICONTEC.

Palabras Clave: Biodiesel, Biocombustible, Sostenibilidad ambiental, Transesterificación

1. Introduction

The increase in motor vehicles year after year in Colombia has generated a direct relationship with environmental contamination due to constant gas emissions; additionally, Price variation of oil has permitted considerable increase in the demand of ACPM [1], to the point of displacing gasoline consumption for passenger and cargo transportation in developing countries, which is why it is necessary to have an alternative of a biodiesel using renewable resources.

Currently, some projects have been developed in Colombia to achieve clean production of biodiesel, which is a liquid hydrocarbon derived from plant and animal fats through a transesterification process based on the reaction of an oil or fat and an a half catalyzed alcohol [2].

Biodiesel has certain advantages compared to fossil diesel (oil). Some of these benefits include having non-toxic, biodegradable, as well as aromatic and sulfur-free fuels. Furthermore, its use notoriously lowers noxious gases from internal combustion engine exhausts by behaving as a fuel additive, thus, improving the amount of oxygen in the mix.

Biofuel production focuses on complying with the following variables: environmental sustainability, maintaining and increasing employment in the agricultural sector, energy self-sufficiency, agro-industrial development, improvement of the quality of fuels consumed in the country [3].

To produce biodiesel derived from castor oil, first, the oil is extracted from the seed, later, it is refined and the transesterification process is performed; the result of this process is glycerin, as well as the product of interest: biodiesel that can be used in pure form (100%) in internal combustion engines or blended in any proportion with ordinary diesel of fossil origin.

The castor plant (*Ricinus communis*) is a good source for oil production; the plant is frequently used as base for resins, such as a lubricant for high-performance engines among other applications.

Sunflower oil is conventional oil mostly used for human consumption and it is obtained by pressing the plant's seeds (*Helianthus annuus*); technically it is a blend of unsaturated fats, although the oil generates high-impact pollutants [2].

The research was conducted in two stages: during the first stage, the biodiesel is obtained from the castor and sunflower oils and, in the second stage, the physicochemical properties of the biodiesel were determined in laboratory tests together with combustion tests on a diesel engine to evaluate its performance and compare it with petroleum-based diesel. Finally, a comparison was developed between castor and sunflower biofuels and fossil diesel.

2. Experimental Work

The experimental work was conducted in two phases, which include the characterization of castor oil and sunflower followed by determination of the physical-chemical properties of the biofuels obtained [4].

2.1. Castor Oil

2.1.1. Phase One

The first phase of the production process of biodiesel from castor oil was initiated by mixing methanol with sodium hydroxide as a catalyst, forming sodium methoxide ($\text{Na} + \text{CH}_3\text{O}^-$) in an exothermic reaction, which was subsequently blended with the castor oil based on the mixtures B5, B10, and B20, according to the NTC 100/04 standard.

Then, infrared spectrometry tests were performed and were followed by performing the tests that determined the properties of pure biodiesel, as well as when blended with regular biodiesel at B5, B10, and B20; blends are made in percentage by volume, *i.e.*, to obtain 100 l of B5, 5 l of pure biodiesel (5%) are blended with 95 l of ACPM (95%) [5] [6].

The heat of ACPM combustion, as well that of pure biodiesel and of the blends is also determined to observe its behavior by using a calorimeter pump [7] [8] [9].

2.1.2. Phase Two

In this phase, laboratory tests were performed for the biodiesel mixed with diesel fuel (ACPM), using a diesel engine coupled to an electric generator. This engine is characterized by certain operating parameters based on RPM schemes to facilitate comparison of the fuels. Coupled with a load generator, which allowed establishing the power generated by each fuel, thereby, obtaining a comparison criterion with which working conditions that allowed testing for each of the mixtures were established; hence, determining fuel consumption and measuring combustion gases. The results of the above processes allowed

comparing the characteristics of biodiesel from castor oil and sunflower oil against conventional diesel (fossil).

2.2. Sunflower Oil

2.2.1. Phase One

The process began by mixing methanol with sodium hydroxide as a catalyst, forming sodium methoxide ($\text{Na CH}_3\text{O}-$) in an exothermic reaction and then it was blended with sunflower oil; this process is subdivided into mixture, decantation, and pH stabilization [10] [11].

- **Mixing:** The methoxide was mixed with sunflower oil at 40 °C, shaking it to cause the partition of the fatty acid into Glycerin and ester chains, which then reacted with the methanol giving rise to biodiesel [12].

- **Decanting:** This mixture was recovered and separated in phases by decanting to separate the glycerol ($\text{C}_3\text{H}_8\text{O}_3$). After 24 hours the glycerol was extracted and could be recycled, while biodiesel could be washed, if necessary.

- **Stabilization of pH:** Finally the biodiesel was washed with caustic water ($\text{NaOH} + \text{H}_2\text{O}$) to remove residual glycerol and impurities, neutralizing the pH.

2.2.2. Phase Two

In this phase, laboratory tests were performed showing that the oil had similar properties as those of traditional diesel fuel, minimizing the risk of negative effects on the engine and ensuring that biofuel can be used in any diesel engine [13] [14] [15].

3. Results

3.1. Castor Oil Infrared Analysis

Regarding the verification of the chemical processes of the transesterification, infrared analysis of castor oil and biodiesel was performed. Comparing the two spectra (Figure 1 (a) and (b)), certain characteristics of the esters were observed by means of the transmission bands, which - between the 1220 cm^{-1} and 1125 cm^{-1} wavelength - showed typical ester bands. Analytical results of the infrared of castor oil biodiesel and of the pure castor oil used as a pattern show that the castor oil transesterification process took place correctly, allowing this experimental mechanism to be carried out for the final production of biodiesel. After this

procedure, 6 l of biodiesel were produced, as well as NaOH, methanol, and glycerol (Table 1).

Figure 1. Infrared of: a) castor oil biodiesel b) sunflower oil.

Table 1. Supplies and reagents for biodiesel obtained.

Methanol	NAOH	Biodiesel	Glycerine
1500 ml	18 g	6000 ml	390 ml

3.2. Density of Castor and Sunflower Oils

Figure 2. Diagram of the density variation between ACPM and blends of biofuels.

The density of pure biodiesel and the blends (ACPM with Castor biodiesel) presented an increase in density because biodiesel density is higher and when mixed with the ACPM it gradually increases depending on the mixture (Figure 2). The density in the B5 mixture

increased by 1.44%, in the B10 by 2.04%, in the B20 by 2.88%, and in the B100 by 11.04%, compared to ACPM.

With respect to the sunflower biodiesel, it was proven that it presents suitable chemical and physical stability since it has a density of 884.0 kg/m³, compared with the pattern established in the NTC 100/4 technical standard (between 860 - 900 kg/m³) [16] and the ACPM fossil (850 kg/m³). To measure this property, the room temperature used was 18 °C.

3.3. Castor Oil and Sunflower Oil Viscosity

Viscosity was affected by the density of the castor oil blends and, therefore, caused a similar increase as in the density; the viscosity of the pure biodiesel exceeded ACPM viscosity by almost twofold. The B5 blend increased by 19%, B10 by 22.29%, B20 by 42.6%, and B100 increased 172%, compared to fossil diesel fuel ACPM (Figure 3). Increased viscosity generated better lubrication in the mechanical parts of the engine, thereby, ensuring its integrity. However, the results of this property can potentially cause a problem because the values are so high that it is possible to have complications in the fuel injectors of the diesel engine; for this reason, it is not advisable to consider blends with more than 20% biodiesel (B20).

Figure 3. Diagram of viscosity of castor biofuels

With regards to sunflower oil, the result of kinematic viscosity taken at 40 °C meets the required specification, 1.9-6.0 mm²/s [4] and the sunflower oil biodiesel has 5.03 mm²/s, although this is approximately two times greater than that of diesel fuel 2.36 mm²/s. The results for sunflower biofuel ensure adequate injection of the blend to the engine and maintain a proper operation of the injection system components; using the B100% mixture is not encouraged

because it requires a relatively powerful system to inject fuel into the engine chambers, making it necessary to modify the engine pumping system.

3.4. Calorific value of castor and sunflower oil

The calorific value of the castor biofuel blends was determined by using a calorimetric pump, these values were compared with those of fossil diesel fuel (ACPM), generating a 2.23% decrease in the B5 blend, 6.89% in the B10, 11.37% in the B20, and 18% in the B100 blend (Figure 4). The calorific decrease is because the calorific value of vegetable oils is lower than that of ACPM. Moreover, the value shown in mixture B5 generates the best performance with respect to engine power, as opposed to the 100% blend due to the drop in calorific value.

Figure 4. Diagram of combustion heat of castor oil biofuel

The results of biodiesel calorific value from sunflower were obtained through two tests in the calorimetric pump. By following the procedure developed by the manufacturer, ensuring an almost perfect adiabatic process, all variables were controlled and the necessary corrections were also made to ensure the repeatability of the data; the data obtained were 14621.6571 Btu/lb and 19700 Btu/lb for the castor oil, being very close to the values studied by other authors [17].

3.5. Emissions Analysis of Castor and Sunflower Oil

With respect to the emissions analysis presented in Figure 5 (a and b), these were divided into CO (carbon monoxide), CO₂ (carbon dioxide), SO (sulfur oxide), and HC (hydrocarbons). For the CO, there was a reduction of 25%, while the CO₂ in the B5 blend decreased by 11.47%, by 15.20% in the B10 blend, and 19.19% in the B20; these results indicate that the reduction percentage is related to the amount of biodiesel used in the ACPM blend. For the CO₂ comparison to diesel

and the blends under the NTC 100/04 standard, responses were observed to be similar to the one obtained in the carbon monoxide. This result of CO and CO₂ is favorable because it indicates that the fuel blends are cleaner than pure diesel (100%) from fossil origin [18].

Figure 5. a) Diagram of CO₂ and CO emissions. b) Diagram of C_xH and SO₂ emissions.

For emissions analysis of sunflower oil, measurements were made in a vacuum turbocharged 1600-cc diesel engine, with commercial diesel fuel, B5 ACPM (5% blended sunflower biodiesel) and B10 ACPM (10% biodiesel) in order to find changes in CO, CO₂, SO_x, C_xH_y, and O₂. The procedure consisted of performing emission measurements at different engine speeds, beginning at idle (850 rpm) and

increasing to 1100, 1250, 1400, 1700, and 2000 rpm. Regimes were controlled with an ERASMUSTM ER 20 digital tachometer; five measurements of 15 registries for each RPM regime were recorded. The equipment used to measure combustion gases was a TESTOTM 350-14 [14].

Emissions measurements are presented as a percentage of O₂ and CO₂ (Figure 6) respectively; it can be seen that the percentage of CO₂ reduction is due mainly to low speed revolutions, however, at higher RPM regimes, values tend to converge when relating to the percentage of O₂, indicating that combustion has declined as a result of blending with biodiesel.

The results of measurements of gas emissions are given in parts per million (ppm) for CO; SO_x, C_xH_y are shown in Figure 7 (a and b), respectively, where we can see a substantial reduction of CO at low RPMs in the biodiesel blends compared to fossil diesel fuel. With respect to the presence of SO_x, reduction percentages can be observed similar to the biodiesel blends of 5% and 10% at low RPMs, and convergence of results at higher RPM regimes.

When Involving the Hydrocarbon ppm "C_xH_y" curve (Figure 8), the presence of these hydrocarbons is confirmed at intermediate revolutions in the biodiesel blends; however, at higher RPM regimes, values tend to decrease CO and increase CO₂. Comparing the two biodiesel blends, it can be seen that the 10% blend would have a slightly better performance in the various gas measurement results, becoming apparent that the amount of CO and hydrocarbons diminish, thereby, improving fuel combustion with biodiesel.

Figure 6. Gas combustion curve a) oxygen, b) carbon dioxide

Figure 7. Gas Combustion Curve a) Carbon monoxide, b) Sulfur Oxides.

Figure 8. ppm hydrocarbon emissions curve

Comparing the two blends of castor and sunflower biodiesel, it is shown that the blend at 10% would have a slightly better performance. With respect to the presence of C_xH_y , the 5% and 10% blends have a stable performance initially, but at 1250 rpm the blends show a large increase in fossil diesel ppm and with a 5% blend of biofuels, indicating a reduction in the combustion quality compared to the curve of commercial diesel. At high speeds, greater than 2000 rpm, we can see convergence in the values making it clear that these harmful gases are reduced; this has been evaluated in Bogotá – a condition which is one of the factors affecting complete combustion due to the height above sea level (2600 m).

4. Conclusions

The production of biodiesel from castor and sunflower oils is viable because it has adequate yields; in both cases, the compound with the highest value is the NaOH catalyst concentration, which directly affects fuel efficiency, demonstrating that the lower the catalyst concentration, the more favorable the performance of the mixture becomes.

With respect to the physical-chemical properties, it was found that biofuels and conventional diesel have sufficient similarities so that it can be predicted that negative effects are not potential hazards in any diesel engine. Moreover, the density and viscosity of biofuels have good stability [17].

If the sunflower biofuel blend B100 is used, it would present some problems at low temperature or in cold climates, given that its cloud point is at 3 °C and the water content could decrease combustion efficiency; additionally, both free glycerin, as well as its sodium and potassium content could form deposits that would cause some wear due to friction or cause oxidation, corrosion and/or deterioration of some components containing rubber or plastics that can be degraded.

The 5% and 10% biodiesel blends show a pollutant reduction with respect to commercial diesel in an acceptable amount and according to the requirements of the Colombian Standard Technical Norm ICONTEC NTC 100/04 under Bogotá conditions.

After the two phases of the study, it is concluded that biodiesel made from plant oils (castor and sunflower) is an alternative as a partial substitute for diesel up to a 10% (B10) blend of biodiesel, where the statistical results obtained in the B5 and B10 blends behave similarly in power and consumption compared to the ACPM of fossil origin. In addition to contributing significantly to the reduction of environmental pollution in accordance with current regulations, they can also be promoted in the energy basket as products of the agro-industrial chain. It is important to take into account that biodiesel does not compete with food for human consumption.

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