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Quantification of opacity in diesel electronic engines using diesel and biodiesel

Cuantificación de la opacidad en motores electrónicos diésel usando diésel y biodiésel

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Abstract

The present study has the purpose of determining the levels of opacity with the use of diesel as biodiesel based on castor oil at 15% (B15). For the determination of the opacity an electronic diesel engine test bench was used, the opacity measurements were made using a duly calibrated opacimeter. The Opacimeter consists of a probe which is installed at the end of the exhaust pipe, which captures the gases and yields values for each test, considering the types of fossil or biofuel fuels and engine speed, subjecting several RPMs that go from 1200 to 3000 for each fuel. At the end of the tests, the opacimeter allowed to obtain values that indicate the difference in opacity and to make a comparative analysis of the use of diesel and biodiesel. At the same time, an average opacity of the tests was obtained for each type of fuel, this value being the same that will be compared with the national standard concerning this study. From the tests carried out, a 96% reduction in the opacity of the engine could be evidenced with the use of B15 biodiesel from Higuerilla oil compared to diesel.

Keywords: biodiesel, B15, fossil diesel, castor oil, opacity, RPM.

Resumen

El presente estudio tiene la finalidad de determinar los niveles de opacidad con el uso de diésel fósil como de biodiésel a base de higuerilla al 15 % (B15). Para la determinación de la opacidad se utilizó un banco de pruebas de motores diésel electrónico, se realizó las mediciones de opacidad usando un opacímetro debidamente calibrado. El opacímetro consta de una sonda la cual se le instala en el extremo del tubo de escape, captando los gases y arrojando valores propios por cada prueba, considerando los tipos de combustibles fósil o biocombustible y el régimen del motor, sometiendo a varias revoluciones por minuto que van de 1200 a 3000 por cada combustible. Al concluir las pruebas el opacímetro permitió obtener una opacidad de 11,1 % con diésel fósil y 0,386 con biodiésel B15 obteniendo una reducción del 96 % de opacidad, a la vez se obtuvo un promedio de opacidad de las pruebas por cada tipo de combustible siendo este valor el que se comparará con las normas nacionales e internacionales concernientes a este estudio. Con estos resultados se contribuye a la mejor conservación del ambiente ya que se emana menor cantidad de hollín, de igual manera se disminuye las enfermedades respiratorias y de corazón de las personas según la organización mundial de la salud.

Palabras clave: biodiésel, B15, diésel fósil, higuerilla, opacidad, RPM.

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1. Introduction

Greenhouse gas emissions (GH) (NO_x, CO_2, CO, HC) are respon-sible for causing global warming, deteriorating the environment and the health of human beings [1]. According to the World Environment Organization, the automotive industry is the cause of 15% of environmental pollution worldwide. Something very important and that should not be overlooked when using fossil fuels is their potential to generate polluting emissions, among which are carbon dioxide (CO_2), the main responsible for the greenhouse effect; Carbon monoxide (CO), which has lethal effects on man; nitrogen oxides (NO_x) and unburned or partially burned hydrocarbons (HC), main photochemical smog formers in the presence of light; sulphurous emissions (SO_x), which cause acid rain, sulphates, and particulate matter, caus-ing respiratory diseases and cancer [2].

In addition, it is known that the automotive fleet with gaso-line and diesel engines is increasing, the latter being responsible for the emission of soot particles into the environment.

Soot, ash and dust are relatively heavy particles that are depos-ited on the ground and the air cleans them quickly. But near their source of origin they are often a health hazard, since they can cause chronic respiratory diseases such as emphysema and cancer [3].

The percentage of opacity is the unit of measurement that determines the degree of opacity of the exhaust emissions of a diesel mobile source. In Ecuador, this unit is determined by the Ecuadorian Standardization Institute through the NTE INEN 2 202:2000 technical standard, which states the maximum opacity limits of emissions for mobile sources with diesel engines as follows: 50% opacity for models from the year 2000 back, and 60% opacity for models from the year 2000 onward [4].

For this reason the scientific community is in a tireless ef-fort to find new sources of clean and renewable energy, which helps to reduce emissions to the atmosphere and therefore reduce the diseases produced in humans.

This is how biodiesel rose as an alternative to fossil diesel, as it is a renewable liquid biofuel that is composed of monoalkyl esters of long-chain fatty acids derived from renewable lipids such as vegetable oils that are mixed, in different percentages, with gasoil [5]. It is also a carbon neutral alternative fuel that must be taken into account as a mechanism to reduce emissions of polluting gases that occur in combustion [6].

Currently, there are several technologies for Biodiesel production. Vegetable oils have properties that allow for the manipulation of their density and viscosity, which is why these oils are suitable for the production of biodiesel [7].

Biodiesel has some very interesting characteristics: No major changes are needed in the engine, it is biodegradable and innocuous for the environment, it generates employment in rural areas, it diversifies energy sources [8].

Through the use of pure or mixed biodiesel, fantastic re-sults have been achieved. The use of this biofuel has signifi-cantly reduced the potential for destruction of the ozone layer by up to 50%. Sulfate and sulfure oxide emissions are eliminated with pure biodiesel. These are the main components of acid rain and are linked to the formation of particles mainly by the content of sulfur and the content of heavy aromatic components [9]. The use of biodiesel in diesel engines causes a signifi-cant reduction in total unburned hydrocarbons, of carbon monoxide and particles in suspension; the emissions of nitrogen oxides are similar or slightly increased [10].

With regard to diesel engines, biodiesel, given the tech-nical, strategic and environmental advantages it offers, is the best alternative to partially or totally replace petroleum diesel fuel [11].

By using biodiesel it is possible to reduce CO and CO_2 emissions resulting from combustion due to the fact that a biodiesel molecule contains between 12 and 18 carbons, and a diesel molecule can contain up to 20 carbons [12].

The properties of biodiesel have a great influence on the emissions of soot to the environment, for this reason the quality of the B15 castor oil biodiesel obtained are: Its high cetane number, 50.5, and its high viscosity, $5.02 mm_2/s$ [11]. On the other hand, castor oil biodiesel has points of cloud and fluidity that give it advantages for use at low temperatures.

The opacity of fumes is an indirect measure of the soot content of the particulate material generated during combus-tion and exhaust. Biodiesel in its chemical structure provides extra oxygen to combustion, so it is expected to facilitate the oxidation of the particles and therefore a decrease in smoke opacity occurs as its concentration increases in the mixtures [13].

1.1. Biodiesel production

Biodiesel originates due to a chemical reaction, such as transesterification, where the glycerol present in the oils is supplied by an alcohol, such as methanol, generally used in the produc-tion of recycled vegetable oils, and in mixtures with ethanol in new oils in the presence of a catalyst.

Potassium hydroxide (KOH) or sodium hydroxide (NaOH) can be used as catalysts. When using KOH, the glycerin result-ing from the process is much less toxic than when using NaOH. Additionally, potassium hydroxide dissolves much better in methanol. For the process to be as efficient as possible, the catalysts must have a purity of at least 96% for NaOH and around 92-85% in KOH; it is quite difficult to find the latter with a higher purity.

Transesterification consists in the reaction between a tri-glyceride (composed of a glycerol molecule esterified by three molecules of fatty acids) contained in castor oil and alcohol (methanol or ethanol), originating glycerin and esters derived from fatty acids. When using methanol, the biodiesel will be composed of methyl esters. The catalyst is dissolved in light alcohol (methanol), then it enters the reactor, along with the crude oil extracted from castor, where they will remain at a minimum temperature of 45.4 °C and maximum of 55 °C, at a rate of 3000 rpm, around 3 hours, giving rise to the transesteri-fication process. Subsequently the glycerin will be separated, which will go through a washing process, which is to add 26% of water in volume of oil.

Finally, the process of water evaporation is carried out, at temperatures of around 100 °C, to then mix it with fossil diesel in B15 proportion and use it in compression engines.

By using biodiesel, it is possible to reduce the emissions of carbon monoxide and carbon dioxide present in combustion, since one molecule of biodiesel contains between 12 and 18 carbons, and one diesel molecule of fossil origin can contain up to 20 carbons [14].

1.2. Properties of B15 castor oil biodiesel

The physicochemical properties of biodiesel B15 were deter-mined in the petroleum laboratories of the Central University of Quito with positive results. Table 1 shows the most relevant:

Table 1. Physicochemical properties of B15

Determination	Result
Density API A 60 F	544,62
Falshpoint* °C	72,1
Sulfur* % P	0,0148
Calculated cetane index	51

One of the main characteristics of diesel fuel is cetane, this indicates the quality of the fuel. As can be seen, it has a value of 51, thus achieving a better expansion and burning of the gases that are generated in the combustion and therefore less environmental pollution. These parameters are found in research projects of the Automotive Engineering Major at Universidad Técnica del Norte.

Due to the great benefits that the use of biodiesel has shown, the purpose of this article is to demonstrate the decrease in opacity with the use of B15 castor oil biodiesel.

2. Materials and methods

The present study is based on an experimental quantitative study of transversal descriptive type.

First of all, of a quan-titative order in obtaining results of percentages of opacity in each test, considering the type of fuel and the engine regime, as well as in the comparative analysis of results versus the tables of limit values of opacity for diesel engines adhering to the INEN 2 207: 2002 standard.

Of experimental type: In obtaining biodiesel from the castor plant and in the opacity measurements made in the vehicle's exhaust system.

Of descriptive type in the analysis of the comparative results, of realization of tests, and in the description of the study itself.

Cross type since it was done in a specific time frame, en-abling us to obtain the information immediately and also corre-late results obtained from the different tests and the values imposed by the current national standard and to determine the benefits of both fuels in the environment.

In order to determine and analyze the opacity of exhaust gases for diesel engines, a Braen Bee opacimeter model OPA 100 [15] was used, owned by the Universidad Técnica del Norte in the city of Ibarra, calibrated to current Ecuadorian regula-tions, as well as an experimental test workbench for diesel en-gines. In this case, tests were carried out on a Mazda diesel engine model BT-50 year 2013, 4 cylinders, power of 157.30 HP at 3500 RPM and torque 363 Nm at 1800 RPM, Direct electronic CRD-i injection system. It is worth noting that the engine was in standard conditions for the respective tests.

In terms of fuel, B15 castor oil biodiesel (15% biodiesel and 85% fossil diesel) and pure fossil diesel was used, and the opacity obtained by each fuel was compared.

Ten tests were carried out for each type of fuel and the previously mentioned RPM prior to a respective cleaning of the fuel injection system in order to obtain optimal and more accurate results.

The opacity measurements were made at the normal op-erating temperature of 80 °C. Once this condition was fulfilled, the opacimeter was heated, this being one of its automatic functions. Then a verification test of the opacimeter was performed to discard possible leaks on what was designated as car zero. Finally, the probe was intro-duced to the opening of the exhaust pipe and tests are carried out with both biofuel and fossil fuel, each of them carried out at various engine speeds: 1200, 1500, 2000, 2500, 3000 RPM.

Next, Table 2 shows the percentages of opacity obtained using fossil diesel, as indicated above, with tests at several RPM, taking into account the most common operating condi-tions of the engine where it can be seen that at higher revolu-tions the opacity is greater due to higher fuel consumption.

Table 2. Diesel fossil opacity tests

RPM	OPA 1	OPA 2	OPA 3	OPA 4	OPA 5	OPA 6	OPA 7	PRO. OPA
1200	9,8	9	10	8,7	9	10	9,9	**9,5**
1500	10,9	9,7	10,8	9,7	9,7	10,1	10,7	**10,2**
2000	11,7	10,8	11,1	10,8	10,5	11,8	11,1	**11,1**
2500	12,9	11,3	11,9	11,5	11,6	12,3	11,9	**11,9**
3000	13,5	12,8	12,6	12,7	12,5	12,7	12,6	**12,8**

Table 3 shows the results of opacity using B15 biodiesel. The same methodology was replicated to perform these tests, lower percentages of opacity were obtained. Likewise, higher revolutions resulted in greater opacity.

Table 3. B15 opacity tests

RPM	OPA 1	OPA 2	OPA 3	OPA 4	OPA 5	OPA 6	OPA 7	PRO. OPA
1200	0,3	0,2	0,2	0,1	0,1	0,2	0,2	**0,19**
1500	0,3	0,3	0,2	0,1	0,15	0,2	0,3	**0,22**
2000	0,4	0,4	0,4	0,1	0,2	0,2	0,4	**0,3**
2500	0,6	0,7	0,8	0,1	0,2	0,3	0,6	**0,47**
3000	0,6	1,1	1	0,55	0,5	0,5	1	**0,75**

According to the INEN 2 207: 2002 standard, Table 4 shows the emission opacity limits for diesel vehicles (free accel-eration tests).

Table 4. Opacity percentage [4]

Year and model	% opacity
2000 and later	50
1999 and earlier	60

The international standards with which we worked for this study are the EURO standards which state: Vehicles with super-charged diesel engines registered for the first time before 01/07/2008: 30% opacity, taking into account that this law indicates the EURO 3 that is in effect in Ecuador.

3. Results and discussion

Figure 1 shows opacity results using diesel fossil fuel, resulting in an average opacity of 11.1%. With these results, the engine would be approved without problems according to national and international standards.

Taking into account that the tests are performed on an electronic engine and that low levels of opacity are obtained due to its operating characteristics, the opacity percentages are analyzed at 1200 RPM, resulting in 9.5% opacity, and 12.8% opacity at 3000 RPM. The average opacity value is 11.1%. Comparing all the data, the opacity law for fossil diesel is acquired in equation (1).

$$Diésel\ fósil_{opa} = 0.0018(RPM) + 7.4619 \quad (1)$$

Where:

Opa: Opacity.
RPM: Engine revolutions.

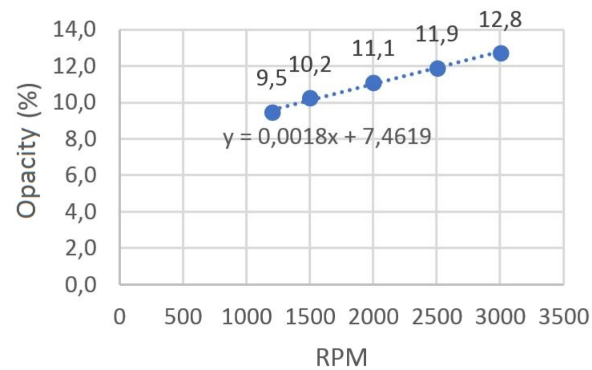

Figure 1. Fossil diesel opacity percentage

Opacity tests using B15 biodiesel were conducted in the same engine and with the same conditions as the previous tests. Before performing the tests, the whole feeding system was purged to ensure the results obtained.

Figure 2 shows the opacity results in 7 tests, at different engine RPM where an opacity of 0.19% was found at 1200 RPM and 0.75% opacity was obtained at 3000 RPM, with an average opacity value of 0.38%, this result being optimal for the engine. Similarly, the law to calculate opacity with the use of B15 biodiesel is shown in equation (2).

$$B15_{opa} = 0.0706e^{0.0008RPM} \quad (2)$$

Donde:

B15: Biodiesel mixture.
Opa: Opacity.
RPM: Engine revolutions per minute.

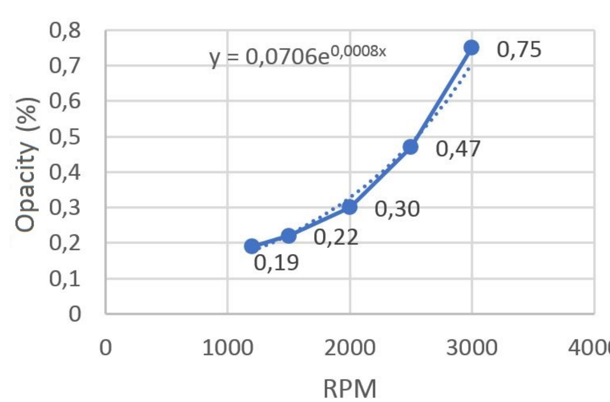

Figure 2. B15 opacity percentage

Figure 2 shows the opacity percentage according to engine RPM. It shows an increase in the opacity percentage, this is because at higher RPM there is greater fuel consumption and therefore a greater amount of unburned fuel originating higher amounts of soot. The Ecuadorian INEN 2 207: 2007 standard states that the opacity limit is 50% for vehicles with diesel engines. Analyz-ing the results, it is concluded that the percentages of opacity decrease in considerable values using biodiesel at 15%.

Comparing the graphs for each type of fuel, B15 and fos-sil diesel, a significant difference of opacity values is evident. An analysis of the diesel trend line shows that, as the engine RPM increases, the percentage of opacity is proportional, with an increase of Opacity at each RPM higher to the use of B15, which increases the percentage of opacity in the same way, the difference being observable in the trend line, where in the same RPM the increase in opacity is lower. An average increase in opacity with fossil diesel of 0.9% per 500 RPM increase is observable, while at the same conditions the opacity with biodiesel B15 increases an average of 0.17%, decreasing 96% of the engine's soot emissions.

Analyzing the national regulations and taking into ac-count the characteristics of the engine, it can be concluded that the engine approves the percentage of opacity with the two fuels without faults; fossil diesel and biodiesel with B15 mix-ture, where the opacity value is 11.1% and 0.38% respectively. The data shows a 96% opacity reduction with the use of B15 biodiesel. Taking into account international EURO standards, which states that vehicles must not exceed an opacity percentage of 30%, the obtained data would be approved by EURO standards, emphasizing that the tests were carried out in an electronic diesel engine test bench Mazda BT-50 in perfect conditions both regarding its mechanical and electronic elements.

Figure 3 shows the comparative data of the opacity per-centage with fossil fuel and B15 biofuel.

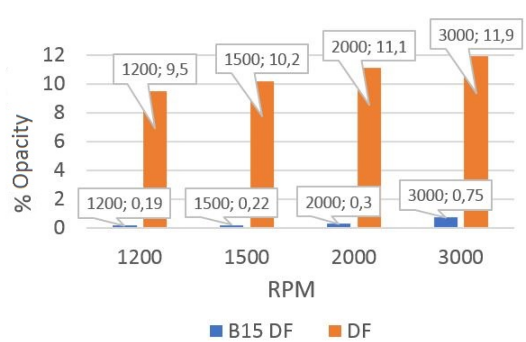

Figure 3. Comparative graphs for fossil diesel and B15 biodiesel

4. Conclusions

With the use of B15 castor oil biodiesel, opacity decreases by 96% with respect to the use of fossil diesel, this is due to the increase in the temperature in the combustion chamber and the better oxidation of the mixture.

With the equations obtained in this study, opacity can be known more quickly with the use of the two fuels, considering the use of motors with the same characteristics as the study.

Using biodiesel can mitigated carcinogenic diseases in the lungs in a large percentage, as stated by the WHO, which points to the smallest particles of soot as a cause of this problem.

The engine model used for the study is in optimal conditions. For this reason its values with fossil diesel and biodiesel are low, in street vehicles these percentages can vary in small amounts.

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