ANALISYS OF BIODIESEL USE IN STATIONARY ENGINES OF SINGLE AND TWO CYLINDERS

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Abstract. *In this work an analysis of biodiesel fuel use in stationary engines was made through performance tests in dynamometer. In the tests, the characteristics of torque, power, specific consumption, smoke index and emissions were determined with two Diesel engines: one of single cylinder and other of two cylinders. Initially, the engines were tested working with Diesel, and then the tests were done with the engines working with Diesel and biodiesel mixtures specified by B5, B30, B50, B75 and B100. The biodiesel used on the tests was of soy, castorbean and palm. During the tests, problems of combustion due to the high viscosity of the castorbean were detected. The results show that the use of biodiesel is feasible, but with small loss of power (medium value – MV =2.5%) and torque (MV=2.0%), and an increase of the specific consumption (MV=7.6%), to mixtures above B50. However, there was some reduction of the gaseous emissions of the engines working only with Diesel to only with biodiesel (B100). The MV are the followings: smoke index on Bosch Scale reduces from 4.3 to 3.0; CO emission reduces around 45.0%; and CO_2 decreases about 8.7%. Another study was made varying the injection point at the single cylinder engine with soy biodiesel B50. The best results were obtained with a delay of 1° relative to the original operating conditions: the power was practically the same than Diesel original setting; the power was 4.0% higher than original condition with B50; and the specific consumption increase was only around 2.6% over Diesel original setting.*

Keywords: *internal combustion engine, compression-ignition engine, Diesel cycle, biodiesel.*

1. Introduction

The main purpose of this work is to show the use of biodiesel fuel in small stationary internal combustion engines, whose contribution to the Brazilian energetic matrix will be very important. According to Oliveira (2001) and Oliveira and Costa (2002), biodiesel fuel oil constitutes an evolution on the fossil fuel oil (diesel) replacement. Biodiesel is a renewable fuel and environmentally correct substitute of the diesel oil, and constituted by methylic or ethylic ester blends of fatty acids obtained from the transesterification reaction of any triglyceride with alcohol of short chain (methanol or ethanol) (Parente, 2003).

According to IEA (2004), some countries such as Germany, Austria and Sweden, has adopted the use of 100% pure biodiesel (B100) in trucks with only few system modifications. In France, biodiesel is often blended at 5% (B5) in standard diesel fuel and at 30% (B30) in some fleet applications. In Italy, it is commonly blended at 5% in standard diesel fuel. In the US, the most common use is for truck fleets, and the most common blend is B20.

In Brazil, the vegetable oils began to be cogitated as energetic resource in 1975, giving origin to the PROÓLEO Program (Programa de Produção de Óleos Vegetais para fins Energéticos), that foresaw a tendency of diesel prices increase. In this program, the Brazilian Government, through the Ministry of Agriculture, started identifying the proper vegetables, production costs, agronomic problems and to promote researches regarding the energetic uses of the vegetable oils (Oliveira, 2002). On May 1983, the Ministry of Industrie and Commerce of the Brazilian Government creates the OVEG Program (Programa de Óleos Vegetais) to search the amplification of the technical and economical knowledge basis on the vegetable oil uses, due to the advance of the crude oil prices. This program was addressed essentially to the formation of technological basis accomplished of tests with vehicle fleets on normal operation. According to Holanda (2004), although several tests were carried out with biodiesel, resulting in its approval as a fuel, the high production costs compared to diesel oil, avoided its use on commercial scale.

Due to the changes occurred on the international scenary in the last years, such as the elevation of the crude oil barrel prices, wars in the crude oil main producer regions, environmental questions and, also, internal questions such as social inclusion, economic and environment development, led the last governments of Brazil to implement actions to biodiesel production and use. In December 2004, was launched the Production and Use of Biodiesel Program: Regulatory Mark and Physical Goals. This program is constituted by 14 ministries on the wide of the Interministerial Executive Commission (CEI), coordinated by Civil House of the Republic Presidency, with administration of the

Ministry of Mines and Energy. CEI commission was assigned to implement actions aimed at vegetable oil – biodiesel production and use as an alternative energy source.

There are three possible origins for the raw material to produce biodiesel: animal fats, residual oils and fats, and vegetable oils. Oils and animal fats present chemical structures similar to that of the vegetable oils, being the differences attributed to the types and distribution of the fat acids combined with glycerol (Parente, 2003). Some examples of animal fats that can be used to produce biodiesel are the bovine tallow, fish oils, pig fat, etc. The residual oils are used in friers that can be obtained in snack bars and restaurants networks and in food industries. Residual oils can also be obtained in sewer stations, where the oil extraction is possible if the scum is rich in fat material.

At this work the main raw material are the vegetable oils, that are extracted from plants presenting seeds, almonds and pulps. To produce biodiesel, vegetable oils must belong to fixed oils or triglyceride categories. This work focused the use of biodiesel made from soy, castorbean and palm, because an important regulatory mark of the Brazilian Government program is the diversification, utilizing the oleaginous according to the regional availability. In accordance to the organism responsible by strategic subjects of the republic presidency, to supply 5% of biodiesel (B5) derived only from soy, castorbean and palm, it would be needed an area of around 3 million of hectares.

Apparently, the physical and chemical properties of biodiesel are well characterized. According to studies made by IEA (2002), EPA (2002b) and NREL (2000), these properties are very similar to those of diesel oil, nevertheless, biodiesel presents some advantages, such as better lubricity (lower engine wear and tear), practically zero aromatic compounds and sulphur, and a higher cetane number (up to 24.7% higher to biodiesel of animal fat origin). The main disadvantage is relative to greater capacity of degrading certain types of elastomers and natural rubber compounds. Although emissions vary with engine design, vehicle condition and fuel quality, the US EPA (EPA, 2002b) found that potential reductions from biodiesel blends are considerable relative to conventional diesel (for B100, the particulate matter and CO can reduce up to 48%, and HC, up to 68%), however, NO_x rises up to almost 10%.

In Brazil, several studies applying biodiesel in internal combustion engines were made, whose results reveal many discussions and controversies. Studies made by Ministry of Industry and Commerce (1985), demonstrated that vehicles working with B100 (methilic or ethilic route) don't present significative problems during the tests. The engines of high piston displacement working with B30 present the best results, while those of low size present clogging problems of the injectors. In general, the dynamometric tests show an increase between 5 and 12% in the consumption relatively to diesel oil, depending on of biodiesel used. According to Salvador (2004), the tests with a tractor of a brazilian manufacturer and working with biodiesel derived from Joannesia Princeps, weren't noticed great irregularities, however, the formation of a thin layer in the combustion chamber and adjacencies was observed. Also, was pointed out that the effective power not varied when used biodiesel blends up to 67% (B67).

Silva et al (2004) tested a Valmet tractor MWM-4TVA with B100 and B50 blends of biodiesel from residual oil, which presented an average power of 94.0% and 96.5% of that obtained with diesel fuel oil, respectively; while the torque was respectively 93.8% and 97.1%. The consumption with B100 was practically the same of that with diesel oil, but, with B50 the consumption presented a small rise of 7.6%. Santos et al. (2005) carried out tests with soybean biodiesel in an engine of 4 cylinders and 2,500 cm^3. In these tests was observed a power increase for B10 and B20 blends, where to the former, a 7.5% gain compared to diesel operation was observed. However, with B100, the power showed a drop relatively to diesel. The author justifies the power augmentation with basis on the presence of O_2 in the biodiesel composition, what facilitates the combustion. For B100 operation, the power was lower because of its lower heating value relative to the other mixtures with diesel oil. For B10 and B20 blends, the specific consumption were the lowest.

Other brazilian authors (Kaufmann and Ziejewski., 1984; Ramos et al., 2003; Ferrari, 2004;) obtained similar results of those above described in tests of internal combustion engines working with biodiesel produced from different oleaginous. Another important line of work are the experiments conducted on diesel engines using straight vegetable oils. In this sense, Belchior and Pimentel (2005) carried out experimental studies with diesel engines using natural palm oil heated up to 85°C. The authors describe the modifications in a naturally aspirated direct injection four-stroke 70 kW diesel generator required to improve its performance, emissions and durability. On the basis of an experimental study made in an ASTM CFR engine to investigate the variation of operational parameters (power, specific consumption and emissions) varying compression ratio and injection timing, the authors proposed some modifications in the 70 kW engine: addition of a turbocharger, to get an effect similar to a compression ratio increase (higher air inlet temperature and pressure, maximizing combustion pressure and temperature); increasing the injection advance; and installing a fuel pre-heating device for the palm oil.

Also, in the worldwide context, many other works, moreover those commented before (IEA, 2002; EPA, 2002b; and NREL, 2000), were performed to show the advantages and disadvantages of the compression ignition engines fueled with biodiesel. A big list of bibliography of biodiesel studies was recently published by US-EPA (september, 2001) and corroborated more recently by the publication about "Biofuels for transport" (2004). It shows that the state-of the-art on biodiesel technologies is well matured and promptly available to be applied and reduce the great dependency on Diesel oil. Therefore, is important to detach some works that gave support to the achievement of this paper: Machado (2003), Jacobus et al. (1983), Last et al. (1995); Liotta and Montalvo (1993); Monyem and Van Gerpen (2001); Nwafor (2005); Scholl and Sorenson (1993).

2. Materials and Methods

The main purpose of this work was to evaluate the use of biodiesel in stationary single and two cylinder engines to serve as a basis for future improvement of them. The compression ignition engines used are manufactured by Agrale S.A. for several applications: agricultural equipment, civil construction, generator groups, pumps, agricultural vehicles and tractors of small size, etc. On the basis of the NBR 6396 and NBR ISO 1585 Standards, the engines can be tested at three conditions: A (NBR 6396) applied to constant charge and speed; B (NBR 6396) applied to variable charge and constant speed; and F or N (NBR ISO 1585) applied to variable charge and speed. The main characteristics of the engines are presented in table 1.

Table 1 – Main characteristics of the engines

Characteristic	Single cylinder engine	Two cylinders engine
Cylinder bore (mm)	90	90
Piston stroke (mm)	105	100
Compression ratio	20.0:1	18,0:1
Displaced volume (cm^3)	668	1,272
Normal speed (RPM)	1,800 - 2,750	1,800 – 3,000
Nominal maximum power (kW)	A condition = 9.6 at 2,600 RPM B condition = 10.3 at 2,600 RPM F condition = 10.8 at 2,750 RPM	A condition = 17.6 at 3,000 RPM B condition = 19.8 at 3,000 RPM F condition = 22.0 at 3,000 RPM
Nominal maximum torque (daNm)	3.9 at 2,350 RPM on F condition	7,0 at 2,250 RPM on F condition
Specific fuel consumption (g/kWh)	240 at 2,100 RPM	268 at 3,000 RPM
Injection point (BTDP)	17°	20,5°

The Diesel oil used in the tests was a fuel classified as type B in accordance with ANP (Agência Nacional do Petróleo). Since the engines used in the experiments are commercialized in all regions of Brazil, they were tested with biodiesel produced from the three types of oleaginous more cultivated in Brazil: soy, castorbean and palm. Soy is the oleaginous mainly cultivated in the south and center-west region of Brazil and was supplied by Ecomat Indústria e Comércio. Due to the great area planted in the north region, palm is the best option to produce biodiesel and was supplied by Agropalma S.A. In the northeast region the culture of castorbean is predominant and was supplied by the company Brasil EcoDiesel. The fuels used in the study were characterized through some tests based on the ANP Resolution and made in the Chemical Institute of the Federal University of the Rio Grande do Sul State. The kinematic viscosity results are shown in table 2, the cetane index are presented in table 3, and in table 4, the sulphur content of the fuels are reported.

Table 2 – Kinematic viscosity ($mm^2 \cdot s^{-1}$) of the fuels based on the NBR 10441 Standard at 40°C

Mixture	Soy biodiesel	Castorbean biodiesel	Palm biodiesel
B30	5.03	5.42	3.00
B50	3.95	8.21	3.26
B100	4.53	22.27	4.25
Diesel oil	3.45		

Table 3 – Cetane index (minimum) of the fuels based on the ASTM D4737 Standard

Mixture	Soy biodiesel	Castobean biodiesel	Palm biodiesel
B30	48.3	40.2	50.0
B50	49.1	36.0	49.7
Diesel oil	46.6		

Table 4 – Sulphur content (%) of the fuels based on the ASTM D5453 Standard

Mixture	Soy biodiesel	Castobean biodiesel	Palm biodiesel
B30	0.205	0.080	0.089
B50	0.170	0.068	0.064
B100	0.001	0.001	0.000
Diesel oil	0.327		

The high viscosity of the castorbean biodiesel can require a greater pumping pressure to not damage the spray formation inside the combustion chamber. Moreover, the small cetane index can be harmful to the combustion process caused by the delay ignition.

The experiments had been carried out on a Foucault current type dynamometer of the Schenck trademark, W130 – 80 kW model and cooled with water. The figure 1 shows a scheme of the dynamometer with the devices used.

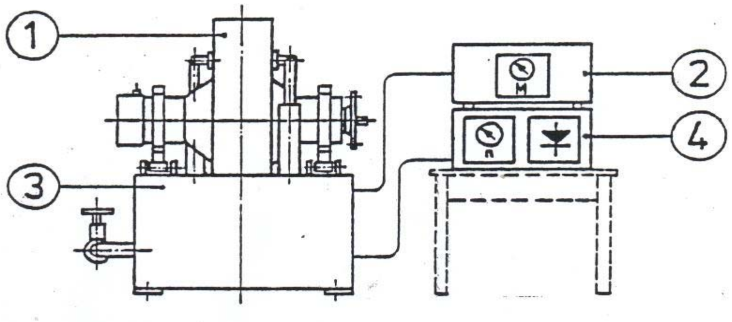

Figure 1 – Dynamometer scheme
1 – shell of the brake; 2 – measurement device; 3 – machine basis; 4 – command device

The parasitic currents produced by the rotation, whose magnetic field avoids the movement, makes that the brake momentum be reflected as a force acting in a defined toggle arm. Power measurement is obtained by this force and by the speed, which is measured with a dentaded disc installed at the end of the dynamometer shaft. The rotation of this disc produces voltage impulses in a speed transducer, and this voltage is used in a tachometer and in the speed regulation.

To the specific consumption measurements a device of AVL trademark was used. The range of measurements of this device is from 0.0 to 50.0 kg/h, which was installed before the injection pump.

The smoke index values were obtained with an UB Bosch device that has an analogical reader and a smoke identification in paper, and has a measurement range from 0.0 to 9.0 UB. The measuring point was after the exhaust collector. The blowby is measured through an AVL device, whose measurement range goes from 5 to 50 liters per minute, with a resolution of 1 liter per minute and an error of ±1%. The gaseous emissions were detected with a device of AVL trademark, Dicom 4000 – Class I model, with capacity to analyze four gases. The samples of gases were collected through a probe mounted in the tubing of the exhaust system at a distance of 1 meter from the exit.

The temperature measurements in several points of the system (fuel inlet, carter oil, gases outlet and environment) were carried out with thermocouples of J type.

3. Experiments and Results

The validation of biodiesel use in the engines was done through tests in the dynamometer system described above, verifying the power, torque, specific consumption, smoke index and gaseous emissions. The main purpose of the study was to compare the performance of biodiesel relative to Diesel oil. The dynamometric tests were based on the NBR ISO 1585 and NBR 6396. Prior to the tests, an engine softening period was established as twenty hours at full load. The engines were first tested with Diesel oil, and, in the sequence, with biodiesel of soy and castorbean, being opened to change some components that suffered damages after the tests especially with this last one. Finally, the engines had been tested with palm biodiesel. In figures from 2 to 6, the results to the engine with single cylinder working with biodiesel of soy are illustrated. In these figures, lines of trend represented by second order polynomials are shown. The objective of these trend lines is only to better represent the data obtained.

According to figure 2, there is a reduction of power in all mixtures. The variation in the maximum power to the mixtures B50, B75 and B100, were 5.8% in average, evaluated at maximum speed (2,750 RPM). The torque results presented in figure 3, as expected, were all smaller than the engine operating only with Diesel oil, but a very good performance is observed at the B50 blend compared to B30. In the specific consumption, figure 4, it is noted an increase in all mixtures relative to the Diesel oil. Evaluating the consumption at 2,750 RPM, the average increase was of 3.8% to the mixtures B30 and B50, and of 8% to the mixtures B75 and B100. In figure 5, at all speeds tested, a reduction is perceived in the smoke index as the soy biodiesel percentage was increased in the mixture. In figure 6, a significant reduction on the CO emissions is observed, although the CO_2 emissions have had a small reduction. After the tests an engine revision was made, mainly of the fuel injector, admission and discharge valves, and of the piston, don't being evidenced any problem in these parts.

During the tests with castorbean B75 and B100, the single cylinder engine presented loss of load, being identified a lack of compression, and so, the performance curves with these mixtures weren't made. Due to this, the engine was revised and presented the following problems: fusing of a small part of the discharge valve by the appearance of hot spots next the fuel injector due to a bad spray formation; formation of a fuel crust partially burnt in the valves seat; and small deposit points in the upper part of the piston. After the tests with palm biodiesel the engine was opened again, presenting itself in perfect conditions.

In the tests with the engine of two cylinders, only the build up of deposits over the discharge valve was noticed.

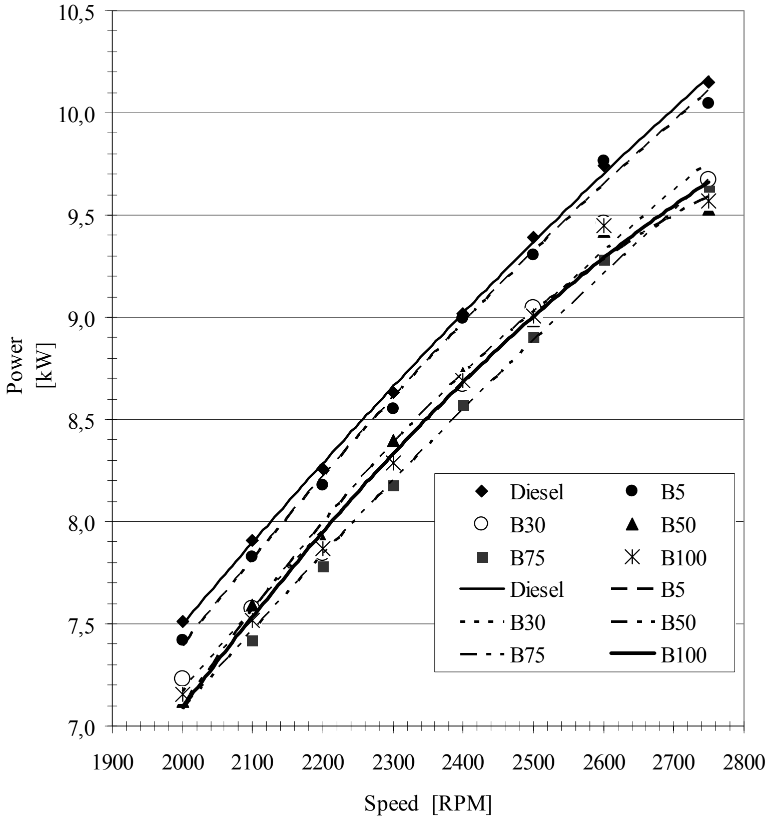

Figure 2 – Power performance of the single cylinder engine – Biodiesel of soy

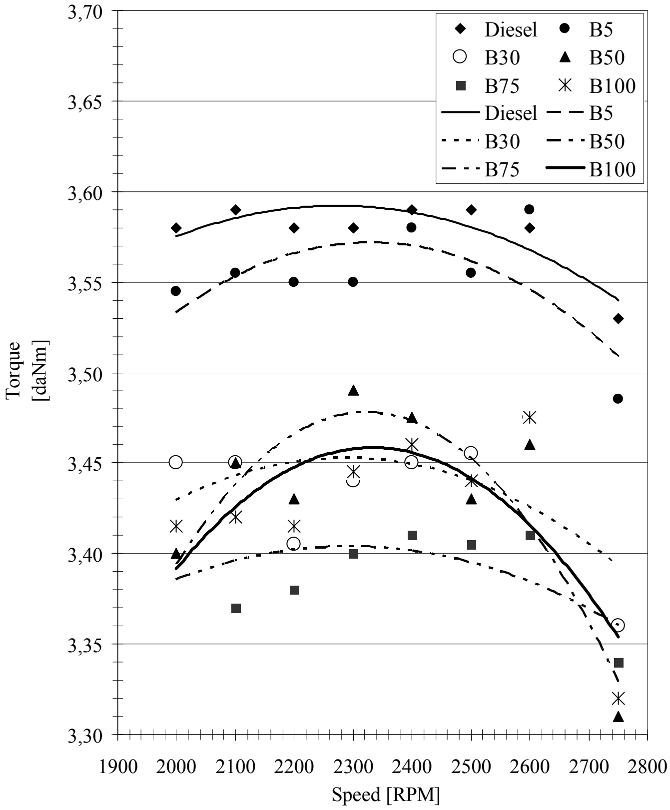

Figure 3 – Torque performance of the single cylinder engine – Biodiesel of soy

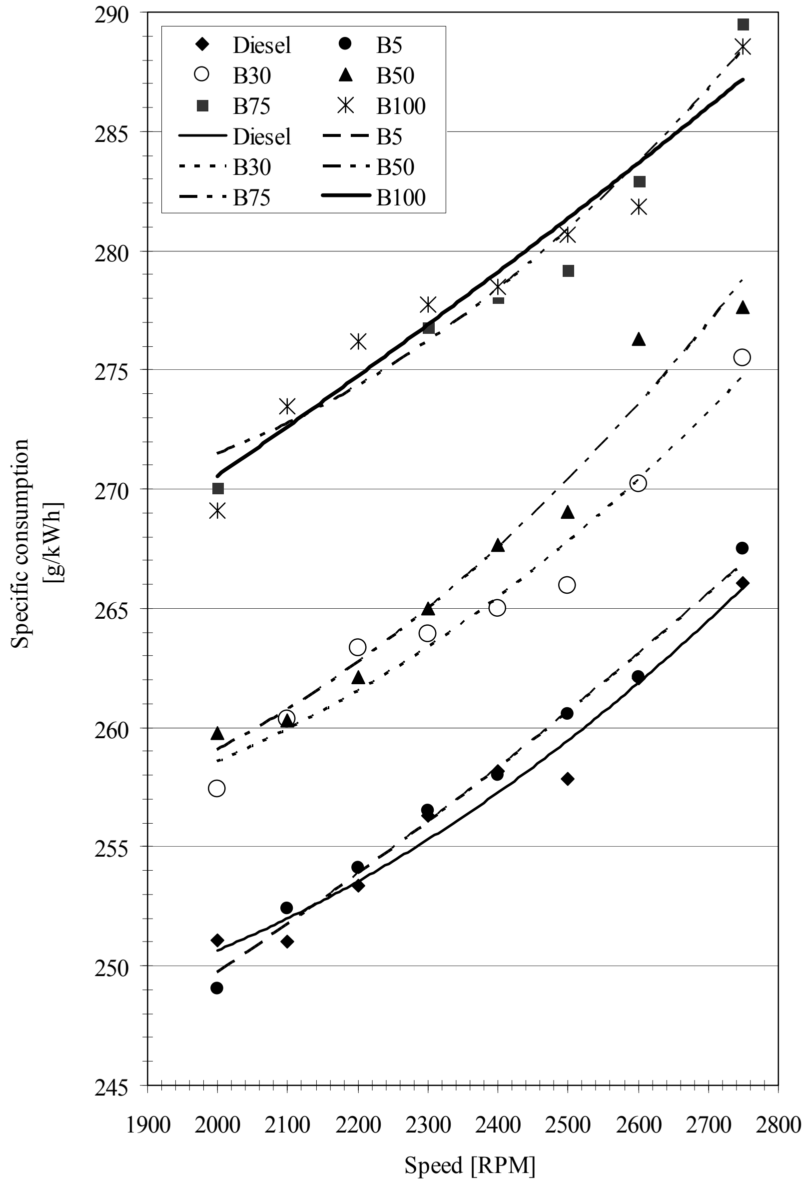

Figure 4 – Specific consumption curves of the single cylinder engine – Biodiesel of soy

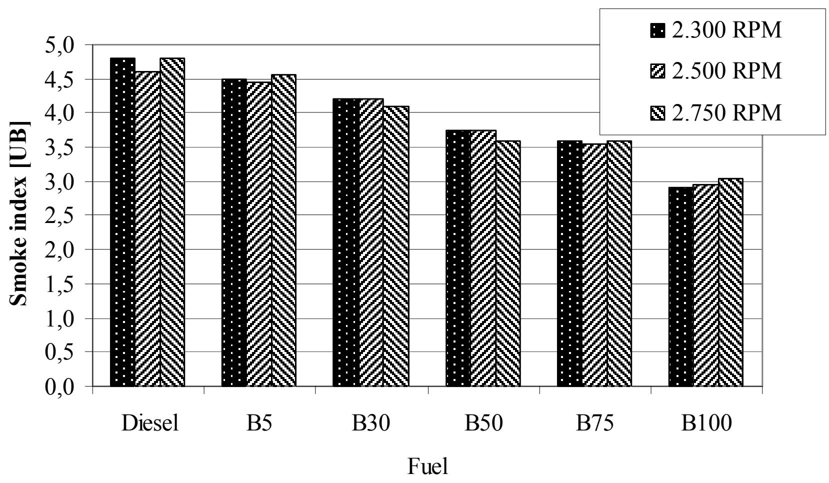

Figure 5 – Smoke index of the single cylinder engine – Biodiesel of soy

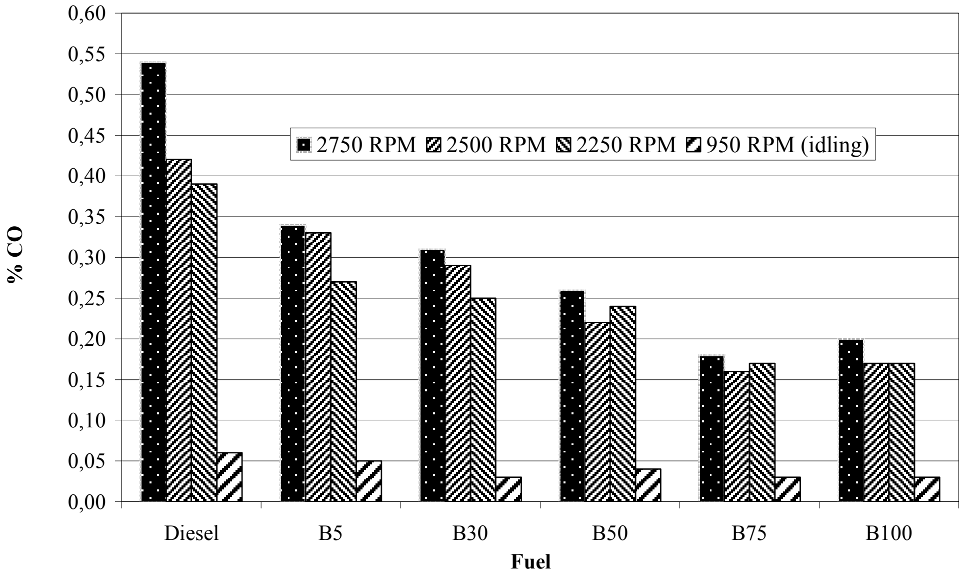

Figure 6 – CO emission of the single cylinder engine – Biodiesel of soy

In table 5, the average results of the performance (power, torque and specific consumption) and emissions are reported. In this table the values are for mixtures equal to and bigger than B50, and the averages are general, not being taken in account the different speeds of work.

Table 5 - Average results of the performance tests

Parameter	Engine of single cylinder			Engine of two cylinder			General average
	Soy	Castorbean	Palm	Soy	Castorbean	Palm	
Power*	- 5.7%	- 5.6% (B50)***	- 1.8%	- 1.0%	- 0,3%	- 3.8%	- 2.5%
Torque**	- 3.3%	- 2.2% (B50)***	- 3.7%	- 1.0 %	- 0.3%	- 1.4%	- 2.0%
Specific Consumption*	+ 8.0%	+ 9.9% (B50)***	+ 6.7%	+ 7.1%	+ 10.5%	+ 5.7%	+ 7.6%
Smoke Index*	4.8→2.9 D→B100	4.8→4.0 D→B50***	4.1→2.6 D→B100	4.2→3.1 D→B100	4.2→3.7 D→B50***	4.1→1.8 D→B100	4.3→3.0 D→B100
CO*(%)	0.54→0.2 D→B100	0.54→0.46 D→B50***	0.54→0,27 D→B100	1.08→0.76 D→B100	1.08→0.99 D→B50***	1.08→0.42 D→B100	- 50.9%
$CO_{Corrected.}$* (%)	0.67→0.28 D→B100	0.67→0.63 D→B50***	0.67→0.37 D→B100	1.38→1.02 D→B100	1.38→1.30 D→B50***	1.38→0.68 D→B100	- 45.0%
CO_2* (%)	11.4→10.4 D→B100	11.4→10.4 D→B50***	11.4→10.7 D→B100	10.6→10.3 D→B100	10.6→10.4 D→B50***	10.6→8.8 D→B100	- 8.7%

* - values relative to the speed of maximum power, i.e., 2,750 RPM to the engine of single cylinder and 3,000 RPM to the engine of two cylinders.
** - values relative to the speed of maximum torque, i.e., 2,250 RPM to the engine of single cylinder and 2,300 RPM to the engine of two cylinders.
*** - not considered in the general average.

In accordance with the results obtained before, there was the interest for improving the performance of the engines working with biodiesel. In this sense, the single cylinder engine operating with soy biodiesel B50 was studied at different injection points. The mixture B50 was chosen because presented the biggest loss of power in the tests reported before. According to the table 1, the injection point (BTDC – Before Top Dead Center) of the single cylinder engine is equal to 17°. The engine tests had been carried out with the standard injection point of 17° and with delays of 1° and 2.5°, and an advance of 3°. From figures 7 to 9, the performance results (power, torque and specific consumption) are shown.

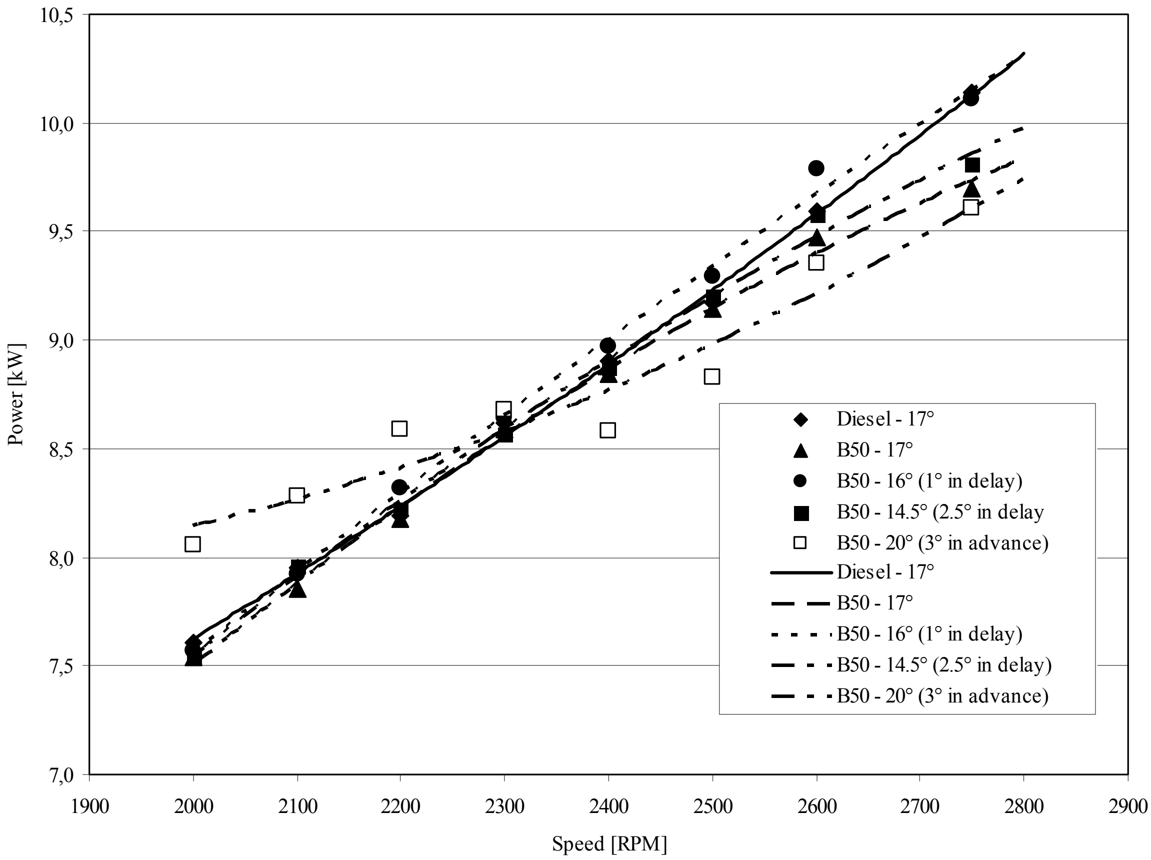

Figure 7 – Influence of the injection point in the power of the single cylinder engine – soy Biodiesel

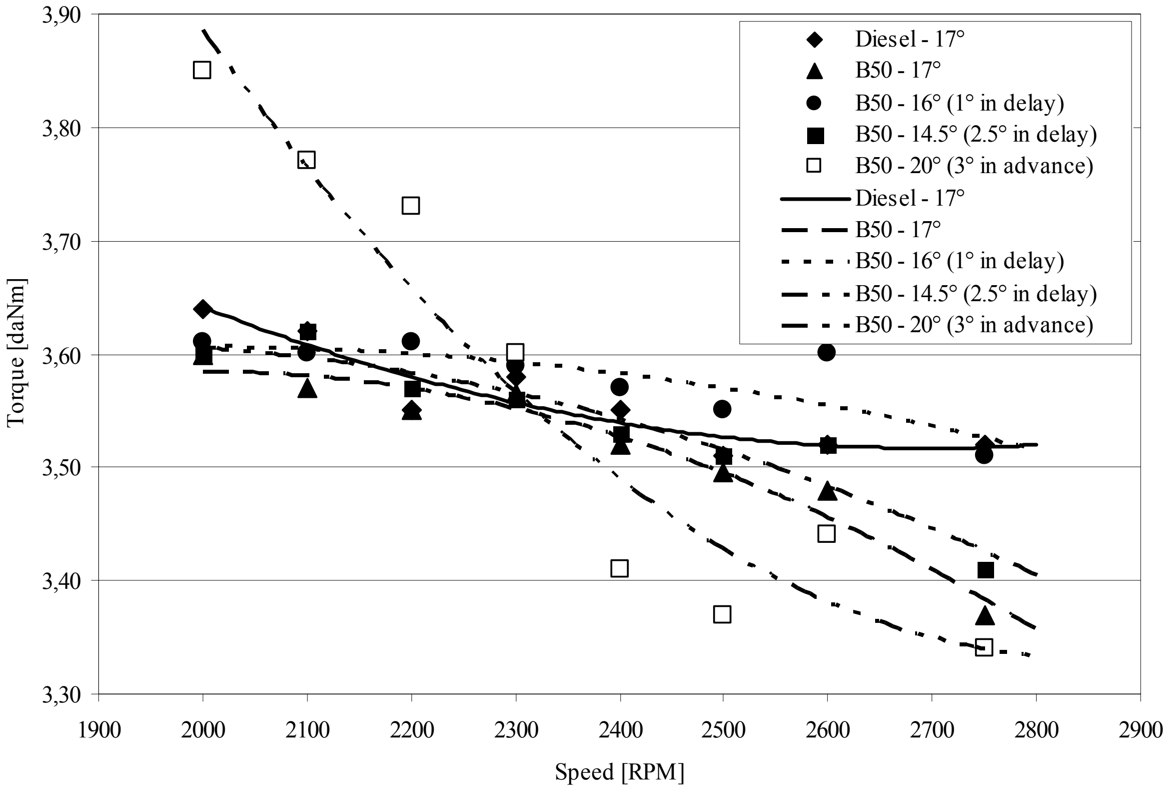

Figure 8 - Influence of the injection point in the torque of the single cylinder engine – soy Biodiesel

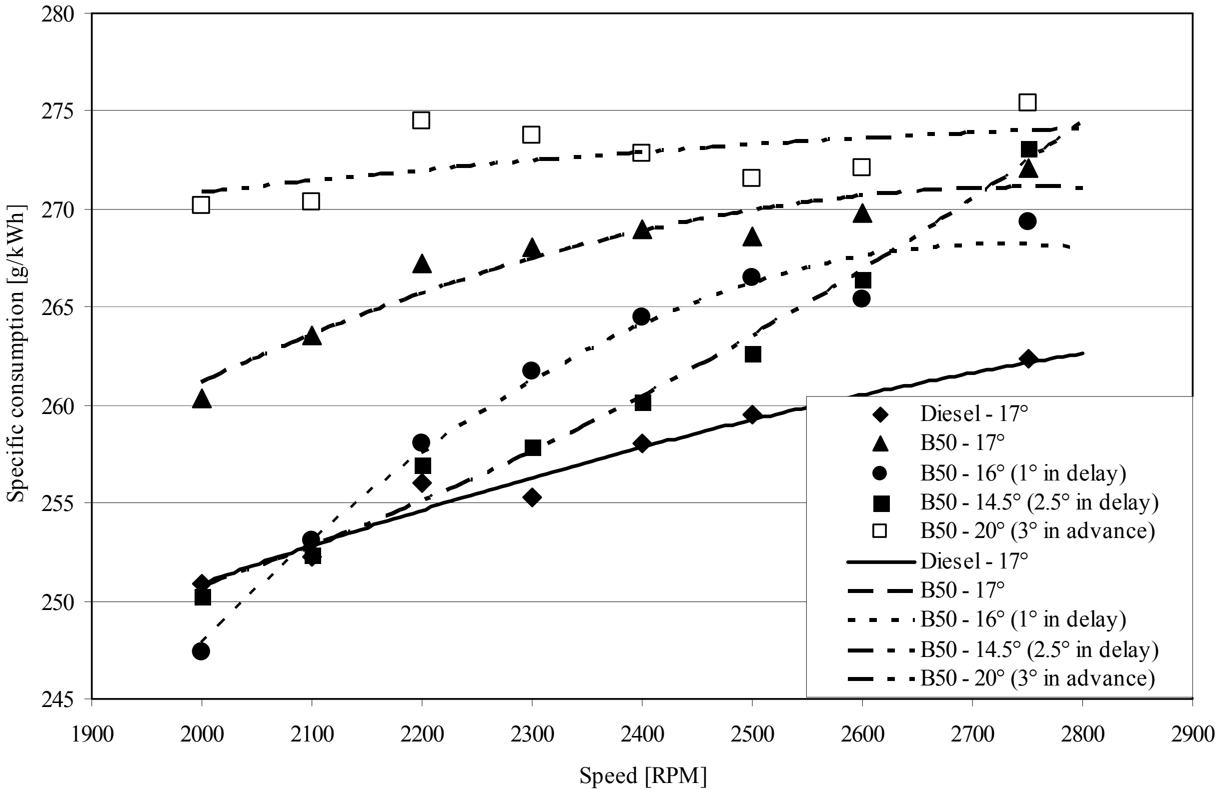

Figure 9 - Influence of the injection point in the specific consumption of the single cylinder engine – soy Biodiesel

In general, the figures show that the best performance was obtained with the engine working at an injection point of 16° delayed. Relatively to the power analyzed at maximum speed (2,750 RPM) with Diesel oil, the loss was only 0.3%. At the injection point of 17°, the loss in the power was 4.3%, and to a delay of 2.5° (i.e., 14.5° delayed), the loss was 3.3%, therefore, with the injection point delay of 1° (from 17° to 16°), a power increase of 4.0% was obtained in the B50 mixture. At the point with 3° advanced (injection point at 20°), the engine operation was instable, and a proper regulation wasn't achieved. Also the torque performance with the injection point of 16° presented the best results. With reference to the specific consumption, the injection point at 16° showed the smallest increase, whose value was around 2.6% higher compared to Diesel.

4. Conclusions

The main purpose of the work developed in this article was to evaluate the performance of biodiesel use in engines of one and two cylinders. The results showed that power decreased 3.8% for the single cylinder engine and 2.4% for the two cylinders engine, considering soy and palm biodiesel oils. The torque also decreased 3.5% and 1.2% respectively, although specific consumption increased 7.4% and 6.4%. These bad results for biodiesel use compared to Diesel might be attributed to the higher viscosity and density and lower heating value of the biodiesel. A solution to minimize the loss of power is changing the injection point, which revealed a similar performance with a slight increase in specific consumption for a small angle delay.

Combustion problems occurred with the castorbean biodiesel for B75 and B100 mixtures, what is an evidence of the bad characteristics of this fuel as showed in Tables 2 and 3 regarding kinematic viscosity and cetane index. The low cetane index of this oil reveals a need of more time for combustion start and the high viscosity harms the spray formation, favoring the build up of carbon deposits and hot spots. A problem regarding palm oil is its high CFPP (Cold Filter Plugging Point) which doesn't allow its use in cold climates due to the possibility of filter clogging and injection pump malfunction.

From the environmental point of view the performance of biodiesel was superior because the CO emissions were considerably lower as with the smoke index. Another good aspect is the very low sulphur content of the biodiesel, what allows to reach the sulphur content specification of metropolitan Diesel only by mixing regular fuel with biodiesel.

Finally, although the performance results are encouraging, more tests need to be done to ensure the consistency of the data collected, and long term tests must be performed to check potential problems like lubricating oil dilution, engine wear and other maintenance issues.

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6. Responsibility notice

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