Engine performance of a single cylinder direct injection diesel engine fuelled with blends of Jatropha Curcas oil and standard diesel fuel

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Abstract. Blends of Jatropha Curcas oil and standard diesel fuel were evaluated (without pre-heating). The engine tests for the blends were performed in a Petter single cylinder direct injection diesel engine under steady state conditions at high loads. Engine speeds between 1300-1700 *rpm* were selected for the engine tests. Torque, power output, specific fuel consumption, in cylinder pressure, ignition delay, rate of heat released and exhaust composition were evaluated. The tested blends between 10-20 % of oil shown lower effective torque and power output joint to a higher specific fuel consumption related to the lower heating value of Jatropha oil compared to diesel fuel. Lower pressure peaks and rates or pressure rises were observed when Jatropha blends are used. A decrease in the rate of heat released and shorter ignition delay were observed for the blends. Decreases in HC and CO emissions were observed for blends compared to diesel fuel. Both alternatives assessed shown that the differences observed compared to diesel fuel, can be partially restored with engines regulation. The use of Jatropha oil in order to be a partial or full alternative to the use of diesel fuel for energy production was achieved.

Key words

Jatropha curcas, blends, ignition delay, diesel engine.

1. Introduction

The limited amounts of fossil fuels joint to the huge increase in the world demand of them are increasing the efforts for finding better energy solutions, mainly based in the renewable energies [1]-[2].

The use of alternative fuels in Internal Combustion Engines (ICE) can influence the reduction of the use of the traditional fossil fuels in the automotive industry, reduction in the exhaust gas emissions and particulate matter [1]-[3].

The use of biodiesel in a diesel engine brings more advantages than the use of crude oil, mainly due to a higher viscosity found in oils compared to biodiesel (up to

10-20 times higher) [4]. Due to the higher oil viscosity, for its appropriate use in an ICE, a pre-heating system is necessary or blends. Also in some cases, modification of the injection systems can be made [5]. There are also reports of non-saturated fatty acid polymerization during the combustion process when oils are directly used [4]-[6].

For the characterization of a diesel engine using any fuel, some parameters are important as: effective power, specific fuel consumption (SFC), effective torque, exhaust emissions as well as the ignition delay. The last one strongly influences some parameters in the combustion process. It can be evaluated through the behavior of the in-cylinder pressure (first derivative) [7]-[9].

Jatropha Curcas (physic nut), native of tropical America, has been later introduced into Africa and Asia and is now cultivated worldwide [10]. Jatropha is a genus of approximately 175-200 plants, shrubs and trees, from the family of Euphorbiaceae. It is resistant to drought and produces seeds containing up to 40 % mass of oil. When the seeds are crushed and processed, the resulting oil can be used in a standard diesel engine [11]-[14] when measures are taken to decrease the viscosity: preheating of the oil, blending with diesel fuel or converting the oil to biodiesel using the esterification reaction.

In a comparison between crop efficiencies for biodiesel production, only algae and palm oil yield better results than Jatropha Curcas. While important amounts of biodiesel are nowadays produced from edible sources, a challenge for biodiesel production is to use feedstocks that would not compete with human food. In that direction, Jatropha Curcas has been identified among the most promising non-edible oil-bearing seeds for biodiesel production. Jatropha produces mainly a non-edible oil due to the phorbol esters that are toxic [15], even at very low concentration.

The purpose of this work is to evaluate the performance of a single cylinder diesel engine fuelled with blends of Jatropha Curcas oil and standard diesel fuel. The comparison of the performance of the Petter engine with two selected blends covers torque, effective power, SFC, ignition delay, rate of heat released (ROHR), HC and CO exhaust emissions.

2. Experimental set-up and procedures

Blends of Jatropha Curcas oil and standard diesel fuel were prepared as binary systems at 10 % (JC10) and 20 % (JC20). The density of the isolated components and the blends selected for engine tests were evaluated using a picnometer standard of 25 *mL*. The dynamic viscosity of the components and the blends were evaluated using a RION viscometer VT 03-F.

The engine used was a Petter single cylinder direct injection diesel engine. The main engine characteristics are given in Table I. The experiments were carried out upper stoichiometric ratio ($\lambda > 1$), steady state conditions at high loads and different engine speeds. Engine speeds (*n*) between 1300-1700 *rpm* were selected for the engine tests.

Table I. - Characteristics of the Petter engine

item	value
bore	87.3 *mm*
stroke	110 *mm*
compression ratio	16.5:1
cubic capacity per cylinder	659 *cm³*
fuel injection timing	24° before Top Dead Center (TDC) (up to 1650 *rpm*)
	28° before TDC (1651-2000 *rpm*)
type of cooling	water-cooled

The schematic diagram of the experimental setup used for the engine tests is shown in Fig.1. Two Kistler pressure sensors were installed for the in-cylinder pressure measurements: a water-cooled absolute pressure sensor type 6067C and a piezoresistive absolute pressure sensor type 4075A. A Kistler signal conditioning platform with a charge amplifier type 5064 and a piezoresistive amplifier type 4665 were also installed. A data acquisition card from Addi-Data was used for the registering of the pressure measurements. A crank angle encoder Kistler type 2613B that is an optical encoder system to provide the correlation between pressure measurement signal and crank angles (°*ca*) position with a resolution of 1°*ca* was used. The equipment used for measuring the exhaust HC and CO emissions was an emissions analyser Testo 350 with a resolution of 10 *ppm*. The measurement of the exhaust gases was developed at the end of the pipe line and outside the installation located six meters from the engine. All the experiments were developed and analysed three times.

3. Results and Discussion

The results of density and viscosity measurements are shown in Table II.

Table II. – Results of viscosity and density measurements

fuel	physical properties	
	density (*g/cm³*)	viscosity (*mPa·s*)
diesel fuel	0.893	3.4
JC10	0.902	5.0
JC20	0.911	7.2
JC	0.983	30.5

As is observed in Table II, the dynamic viscosity of JC10 is 1.6 *mPa·s* higher than the value found for the reference fuel while the difference for JC20 was 3.8 *mPa·s* higher. The density measurements did not evidence significant differences among fuels and according to these results they are adequate for their use in the engine.

Concerning the engine performance, the results of the effective torque (*Te*) comparison between diesel fuel and the blends are shown in Fig.2. A decrease in the effective torque when the percent of Jatropha is increased was observed for every experimental test. Also slight decreases in the effective power output were observed when the Jatropha percent is increased. Both behaviors are associated to the lower heating value of the oil compared to diesel fuel. The general behavior observed in Fig.2 for all the fuels tested is associated to the volumetric efficiency.

The results of the specific fuel consumption are shown in Fig.3. When Jatropha is used, increases in the brake SFC are registered at any experimental condition is observed, mainly due to the lower heating value of the oil and the blends. Same behaviors concerning these engine performance parameters are reported [16].

The evaluation and comparison of the ignition delay results at different engine speeds were based in the first derivative of the in-cylinder pressure. A comparison between the rate or pressure rise diagram for reference diesel fuel and JC10 at 1700 *rpm* is shown in Fig. 4. The dash line represents the reference diesel fuel and the continuous line the JC10. The results shown shorter ignition delay (in crank angles) compared to diesel fuel in agreement with reports [7],[16]. This can be related to the higher cetane number of the oil compared to diesel fuel and therefore that also affects blends tested. It is well known that higher cetane number shortening the ignition delay [8],[17]-[20].

The results above exposed shown that the use of blends of Jatropha Curcas oil between 10-20 % involves some variations in the main engine performance parameters, increasing the fuel consumption, decreasing effective torque, power output and shortening the ignition delay. According to these results, their use for energy production in ICE is possible, but for a better use of the energy, a regulation of the engine is suggested in order to reach closer ignition delay intervals compared to diesel fuel.

1. Diesel engine
2. Pressure sensor
2. Air Filter
4. Hydraulic brake
5. Tachometer
6. Exhaust gas analyzer
7. Control panel

8. Diesel Tank
9. Diesel Tank
10. Control Valve
11. Optical encoder
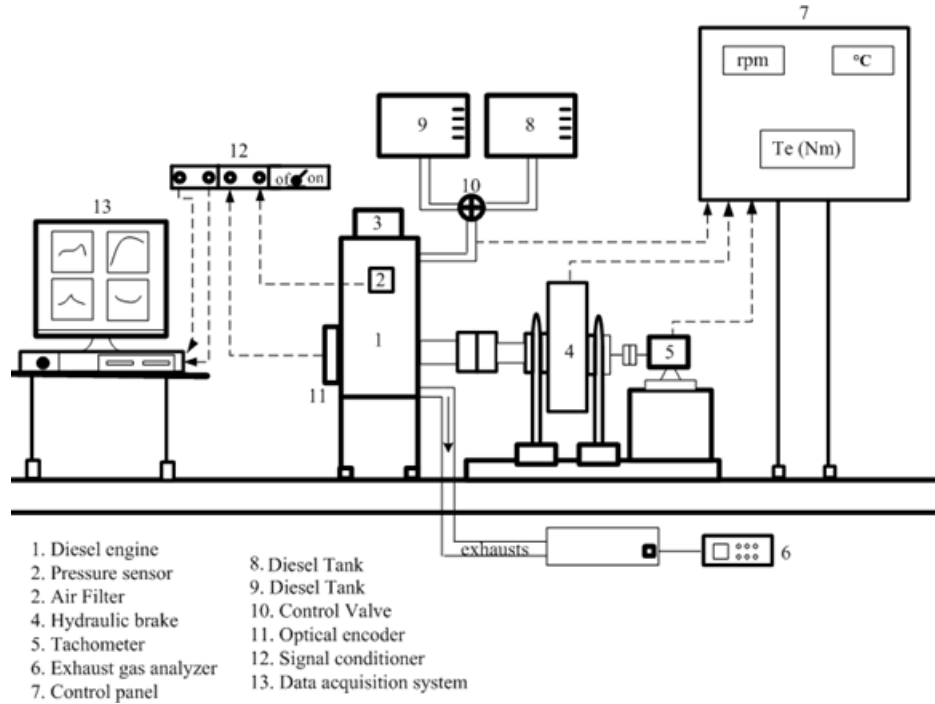12. Signal conditioner
13. Data acquisition system

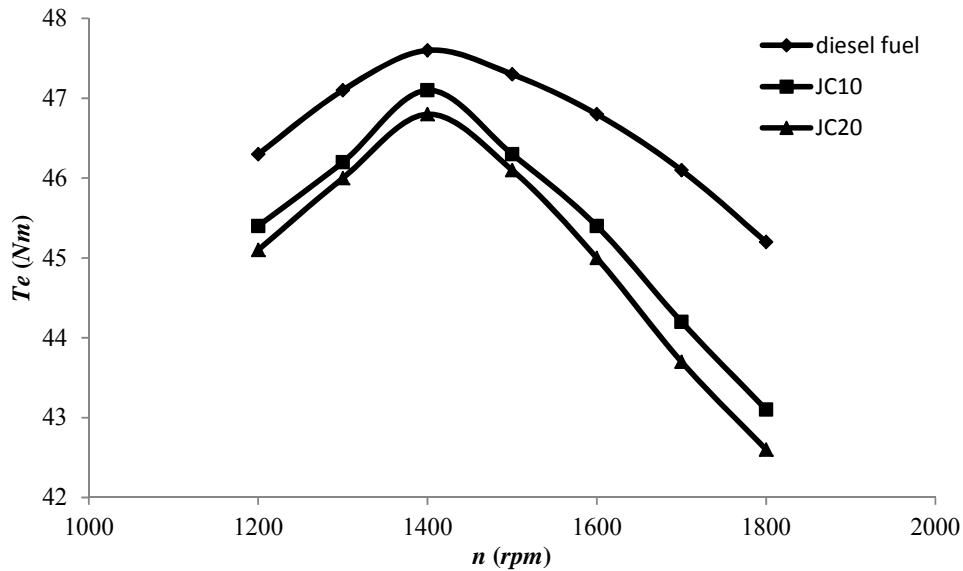Fig. 1. Schematic diagram of the engine bench tests setup

Fig. 2. Effective torque for the engine tests

The evaluation of the ignition delay was also based in the Rate of Heat Released diagrams in order to compare with the obtained under the above described experimental method based on the in-cylinder pressure profile. The results from both methods were in the same order and similar uncertainties in the determinations were found. There are other criteria for the evaluation of the start of combustion and ignition delay [21], but both criteria selected are two of the most sensitive and widely used.

Similar or slightly lower pressure peaks were observed when blended Jatropha Curcas is used. A decrease in the rate of heat released was also observed for the oil and its blends. Concerning the exhausts, decreases in HC and CO emissions were observed for Jatropha oil or its blends compared to diesel fuel. The decreases found down to 5 % compared to diesel fuel. These results can be due to better combustion efficiency due to the higher cetane number of the blends compared to diesel fuel. Therefore, even when the engines performance analysis brought no better results according to the biofuel characteristics, its

use bring two important advantages: reduction of some pollutant species and an alternative fuel to cover in part or totally the use of conventional diesel fuel to produce energy in internal combustion diesel engines.

The use of biofuels can to reduce exhaust emissions, specially lower soot is generated during the combustion process due to the oxygen contained in the fuel. However, the higher viscosity, density, and surface tension levels found may result in poor atomization characteristics, leading to a lower combustion pressure and rate of heat release in an internal combustion engine [22]. In this research, this behavior was not clearly observed and will be checked in further works. It can be associated to the use of diesel fuel and blends of Jatropha curcas at low percents of the oil in the blend.
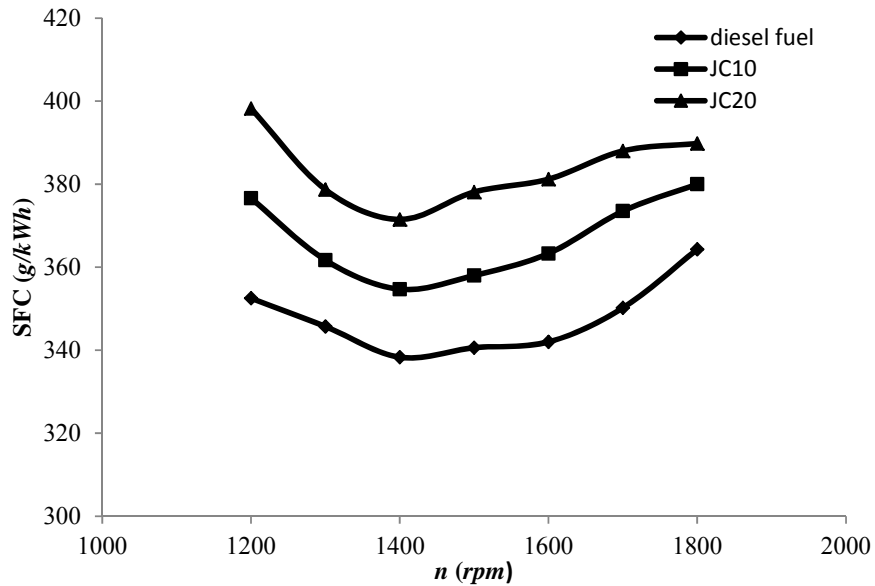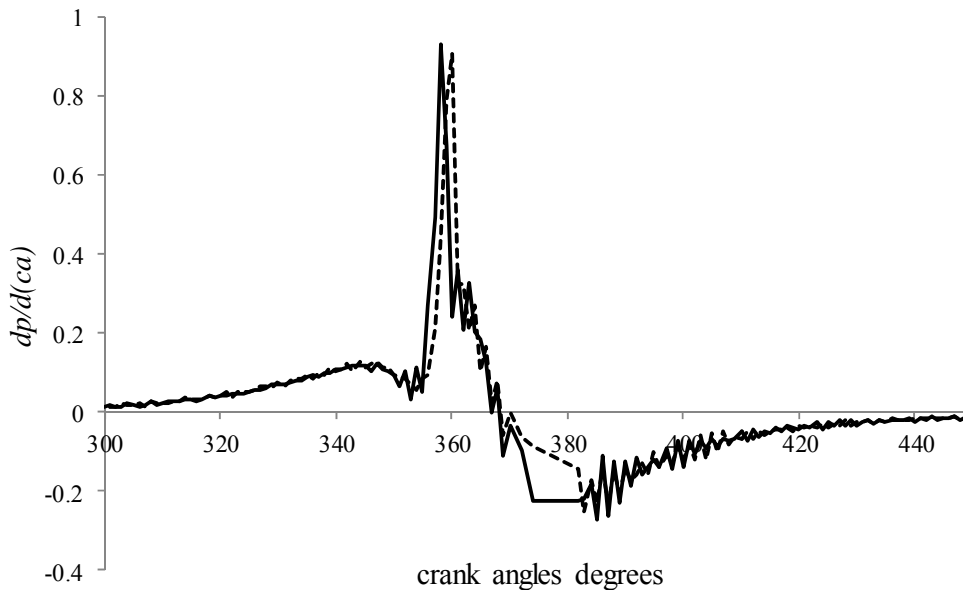
Fig. 3. Specific fuel consumption for the fuels tested

Fig. 4. Plot of *dP/d(ca)* for the ignition delay estimation at 1700 *rpm*

The results obtained in this work are a first step in the introduction of the use of Jatropha Curcas derived biofuels for their use in internal combustion engines in order to solve problems related to the agricultural transport of local farmers in Cuba, a country that depends on the fossil fuels for the automotive engines. In further

works, testing of pure pre-heated Jatropha oil and the derived methyl esters (biodiesel) will be evaluated. Even when in this work was only the blend of Jatropha oil and diesel fuel evaluated, using a pre-heating system is possible to use pure oil for energy production in ICE. The use does not need to be processed and only a filtering process is necessary. Also some by-products of Jatropha can be used for energy production. The shell can be transformed into biogas; the press cake is used as fertilizer and after drying can be used as a solid fuel.

4. Conclusions

The tested blends between 10-20 % of Jatropha Curcas oil shown lower effective torque and power output joint to a higher specific fuel consumption related to the lower heating value of the oil compared to diesel fuel. Lower pressure peaks and rates or pressure rises were observed when Jatropha Curcas is used. A decrease in the rate of heat released and shorter ignition delay were observed for the blends compared to diesel fuel. Also decreases in HC and CO emissions were observed for the blends. Both alternatives assessed shown that the differences observed concerning to the engines performance can be partially restored with engines regulation. The use of Jatropha oil in order to be a partial or full alternative to the use of diesel fuel for energy production in a single cylinder diesel engine was preliminarily achieved.

Acknowledgement

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