Revista Cubana de Ingeniería Vol. XI (2) 12-19 (2020) ISSN: 2223-1781

Artículo Original

Diesel engine fuelled with blends of *Jatropha curcas* oil and diesel fuel

Ramón Piloto-Rodríguez[1],*, Indira Tobío-Pérez[1], Jesús Suárez-Hernández[2]
[1]Centro de Estudio de Tecnologías Energéticas Renovables (CETER). Universidad Tecnológica de La Habana "José Antonio Echeverría" (CUJAE). Calle 114 No. 11901 e/Ciclovía y Rotonda, Marianao, La Habana, Cuba.
[2]Estación Experimental de Pastos y Forrajes Indio Hatuey. Central España Republicana, Universidad de Matanzas, Cuba.
*Corresponding author: rpiloto@ceter.cujae.edu.cu

Recibido: 1 abril 2020 **Aceptado:** 20 abril 2020 **Publicado:** 7 mayo 2020

Abstract

The development of alternative fuels for diesel engines is important for reduction of environmental impact but for contribution to sustainability. In this order, the use of Jatropha curcas biodiesel or instead of it the neat vegetable oil for fueling engines is an alternative under study. The scope of this research is to test the performance and ignition behavior of JCO as fuel in a diesel engine taking into account that the use of oil as fuel in the engine is feasible. The use of JCO in the engine as fuel decreases the power outlet and engine efficiency. When the percentage of JCO in the blend increased, the exhaust temperature rises, but also exhaust emissions of CO and HC. The results of ignition delay determination showed not significant differences for any blend compared to diesel fuel. The paper is only focused on engine test benches and further researches related to road tests, endurance tests and corrosion effect should be addressed.

Keywords: *Jatropha curcas*, straight vegetable oils, diesel engine, engine test

1. Introduction

Diesel engines have been used worldwide due their high durability and economy. Until today they dominate several transportation sectors such as: agricultural, military, construction, mining, maritime propulsion and stationary electricity production. This kind of engine has attractive features as low consumption under certain conditions, robustness and reliability. Also they are capable to use blends of diesel fuel-biodiesel or diesel-vegetable oil, even pure biodiesel.

The alternative fuels are an answer to the pollution impact of internal combustion engines and the increase of conventional fuel prices. It is known that the use of alternative fuels might reduce the greenhouse effect due to the low HC, CO and CO_2.

Some characteristics of straight vegetable oils (SVO) are similar to diesel fuel, but it is important, for a good "replacement" of diesel fuel, to keep the following characteristic closed to diesel: an adequate viscosity in order to get the proper atomization in the injection spray, especially at low load and low speed conditions. It is also very important to test any direct use of vegetable oils as fuels in engines mainly based on combustion behavior and impact in engine [1].

The ignition quality is related to the ignition [2-4]. Therefore the cetane number influences on this characteristic. In general, higher cetane number means lower ignition delay. *Jatropha curcas* oil (JCO) can be obtained from a simple procedure that includes cold press and a refining stage, and it is possible to fuel an engine with it. It is necessary to take into account some properties of the biofuel that will influence combustion process. However, even doing some changes in the engine or in operational conditions, the low-scale use of pure oil as fuel has potential, due to avoiding this way the transesterification process for obtaining biodiesel.

It’s known that certain properties of fatty acid residues in the molecule of triacylglycerol have significant effects on the fluidity of the oil. Most of the bonds in the hydrocarbon chains of fatty acids are single bonds. This system inhibits flow of the fluid, resulting in the relatively high viscosity of the oils. This is a main handicap of direct use of SVO in diesel engines.

Concerning *Jatropha curcas*, several papers have been published in the field of bioenergy [5-11] addressing the conversion of the oil to biodiesel and its use in diesel engines. Nevertheless, studies exploring its direct use as a biofuel neat or blended are less common [10, 12-15].

The purpose of this work is to test the performance and ignition behavior of JCO as fuel in a Lister Petter diesel engine taking into account that the use of oil as fuel in the engine is feasible. The main idea is to avoid the transesterification process and to bring a solution to those users which are not able to produce biodiesel but could harvest Jatropha curcas trees and after the oil extraction can use as oil. For this reason, through the experiments, the use of Jatropha curcas oil in diesel engine is evaluated.

Materials and Methods

The measurement of viscosity was based in the use of a VISCOTESTER VT-03F viscometer and the density of the JCO using a picnometer standard of 25 ml. Previous to its use in the diesel engine, the JCO was characterized according to viscosity, density and acid value. The viscosity of JCO was 30.5 mPa·s, with a density of 98.3 g/cm^3 and an acid value of 14.68, that is high. The acidity is quite high for its use it as fuel in a diesel engine. The acid value gives an idea of the quantity of free fatty acids found in the oil and this value is directly related with the cetane number. Thus, an increase of the ignition delays when the engine is fueled with this oil or with its blends is expected but also corrosion in engine parts.

A single diesel engine was used and the experiments were developed at a variable speed but using a constant injection pump set. Engines tests were designed for only short test times in order to obtain the engines performance, because long time periods using oil may develop or increase the corrosion phenomenon in several parts of the engine. After the tests the whole system must be exhaustive cleaned.

Due to the strong influence of the fuel viscosity and density on engines performance, combustion process and spray characteristics, the assessment of them and their relationship with temperature and the oil percentage were developed.

The engine used for the tests was a single cylinder Lister Petter. The technical specifications of this engine are shown in Table 1. During the measurements, the exhaust gases, oil, water inlet and outlet temperature were measured. The engine is equipped with load cell, hydraulic brake (type: Froude), four K-type thermocouples and a tachometer (Radio energy). A piezoelectric relative pressure sensor (Kistler; model: 6067C, water-cooled) mounted directly on the cylinder head is used to measure the cylinder pressure. A piezoresistive absolute pressure sensor (4075A10) mounted in the admission duct is used to register the intake air pressure. In addition, a data acquisition system, a signal conditioning platform Kistler with a charge amplifier (model 5064), a piezoresistive amplifier (model 4665), a module NI 9401 (digital) and a module NI 9215-BNC (analog) were used.

Table 1. Technical specifications of the engine PH1W

Type	diesel
Cylinders	1
Bore	87.3 mm
Stroke	110 mm
Cubic capacity	659 cm^3
Compression ratio	16.5:1
Cooling system	Water cooling
Top speed	2000 rpm

The engine is also equipped with a Kistler system 2614A to measure the crank angle position, with a resolution of 0.2 crank angle degrees (CAD). The CAD signals are recorded by a NI data acquisition board. This system provided a correlation between pressure measurement signals and crank angle degrees. It is composed by a mechanical encoder, an electric encoder and a pulse multiplier.

The exhaust emissions are studied using a portable gas analyzer Testo 350. The emissions analyzed are CO and unburned hydrocarbons (HC). The fuel mass consumption is analyzed gravimetrically using a Mettler Toledo IND425 weighing scale and a digital stopwatch. Atmospheric conditions through a TFA station (model: 35.1078.10.IT) are monitored.

Results and Discussion

Due to the strong influence of the fuel viscosity and density on engines performance, combustion process and spray characteristics were developed. The results of the assessment of viscosity and density of fuels and their blends, such as their relationship with temperature and oil percentage are shown in Tables 2 and 3.

Table 2. Viscosity and density of the blends of JCO and standard diesel fuel

JCO (%)	viscosity (mPa.s)	density (g/cm^3)
0	3.4	0.893
5	3.5	0.896
10	5.0	0.900
20	7.2	0.913
30	8.0	0.926
40	11.0	0.930
50	12.5	0.939
55	14.5	0.943
65	15.0	0.948
100	30.5	0.983

The results in Table 2 are at 40°C. Usually diesel fuel has a viscosity between 2 and 4.5 mPa·s and in this case JCO at the same temperature shown a value of 30.5 mPa·s. For this reason in order to use the JCO as fuel, it is necessary to decrease the fuel viscosity. To avoid the use of the pre-heating system [16, 17], two JCO-diesel blends to perform the test were selected and blended. The blends were made with a 10% and 20% of JCO in order to decrease the fuel viscosity. According to Table 3, even using a pre-heating system, values of viscosity near diesel fuel are not possible, and there is a warning limit for heating of the oil without starting the thermal degradation. Normally over 60°C this process starts for any oil or biofuel [18] but is dependent on the oil characteristics and composition. *Jatropha curcas* oil is still able to be heated until 100°C without much thermal degradation [19].

Table 3. Temperature influence in JCO viscosity

Temp. (°C)	Viscosity (mPa·s)
30	60.1
35	45.2
40	30.5
45	28.5
50	25.6
55	23.1
60	20.5
65	17.7
70	16.3
75	15.1
80	14.5
85	13.2
90	12.3
95	12.3
100	11.5

The exhaust temperature values are presented in Table 4. The table shows that when the JCO in the blend is increased, the exhaust temperature is increased. This could be due to increasing the amount of oil in the fuel, the mixture with air in the cylinder becomes worse and the combustion process is less efficient. Thus there is a higher amount of fuel burning in the last phase of the combustion process which takes place during the expansion stroke. This phenomenon is reflected in emissions.

Table 4. Exhaust temperature running with blends of JCO

Temp. of exhaust (°C)			
n	**10%**	**20%**	**diesel**
1200	528	547	517
1300	533	526	533
1400	553	546	548
1500	569	566	567
1600	590	588	586
1700	605	606	601
1800	620	524	617

Concerning the exhaust emissions, the amount of CO is increased while is increased the oil content in the blend. However, at high engine speed, the amount of CO is decreased probably influenced by the turbulence inside the cylinder at high speed and the improved reaction due to oxygen content in the molecule of the triglyceride. The HC has the same behavior; increasing the speed, decreases the amount of HC.

The JCO has less calorific value. Therefore, any fuel blend with JCO will provide less energy during the combustion process, influencing the expected values of power and engine torque. The specific parameters resulted of the engine test bench are presented in Table 6. Diesel fuel has the highest power and blend at 20% shown the lowest. The reduction of power is higher while is increasing the speed of the engine due to its necessary to use more energy to overcome the friction of each part in movement and the hydraulic resistance in the engine.

Table 5. CO and HC exhaust emissions

	10%		20%		Diesel fuel	
rpm	**CO(ppm)**	**HC(ppm)**	**CO(ppm)**	**HC(ppm)**	**CO(ppm)**	**HC(ppm)**
1200	377	565	540	848	186	682
1300	691	627	800	1354	659	1129
1400	757	707	1130	1758	581	1005
1500	1013	1387	2309	3265	503	1128
1600	558	597	508	343	410	973
1700	428	615	270	114	719	978
1800	197	587	16	100	435	1470

Table 6. Behavior of the torque and power with engine speed

Effective Torque (Nm)			
rpm	**10%**	**20%**	**Diesel**
1200	45.4	45.1	46.3
1300	46.2	46.0	47.1
1400	47.1	46.8	47.6
1500	46.3	46.1	47.3
1600	45.4	45.0	46.8
1700	44.2	43.7	46.1
1800	43.1	42.6	45.2
Effective Power (kW)			
1200	5.70	5.67	5.82
1300	6.29	6.26	6.41
1400	6.91	6.86	6.98
1500	7.27	7.24	7.43
1600	7.61	7.54	7.84
1700	7.87	7.78	8.21
1800	8.11	8.03	8.52

The data corresponding to the specific fuel consumption (SFC) are shown in Fig.1. While the percentage of JCO is increased, more fuel is need for the engine requirements. The specific fuel consumption gives an idea of the efficiency in the engine. The engine efficiency is shown in Table 7 at every experimental condition.

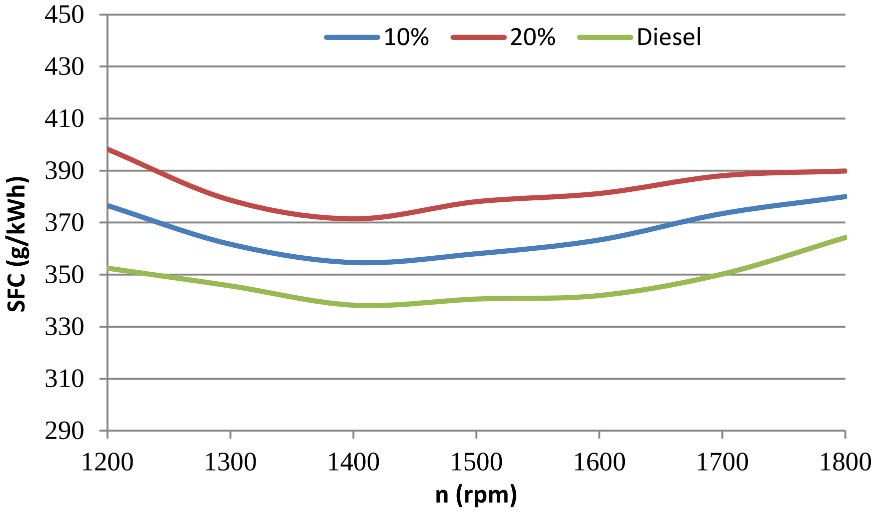

Fig.1 Effective specific fuel consumption for blends and diesel fuel

Table 7. Thermal efficiency for all fuels tested

	η_t (%)		
rpm	**10%**	**20%**	**Diesel**
1200	22.23	21.02	23.75
1300	23.15	22.11	24.22
1400	23.61	22.54	24.75
1500	23.38	22.15	24.58
1600	23.04	21.96	24.48
1700	22.42	21.57	23.90
1800	22.03	21.48	22.98

The cetane number of JCO is lower than diesel fuel. In the tests made, the ignition delay was calculated. The ignition delay when 10% of JCO was used is in between 1 and 2 crank angle degrees (CAD) while 20% of JCO was used, it was slightly increased. Concerning CAD measurements, the resolution of the data acquisition system is one degree indicating that most of the differences observed are under the experimental uncertainty of the measurements, and also that these variations are not really significant in this combustion parameter. The ignition delay determinations are shown in Table 8.

Table 8. Relative ignition delay of the blends

Ignition delay (CAD)	**1400 rpm**	**1600 rpm**	**1800 rpm**
Diesel fuel	-	-	-
10% JCO	2	1	1
20% JCO	2	2	1

The determination of ignition delays were based on the behavior of the in-cylinder pressure but on the first derivate of it [20, 21], as is in Fig.2 shown.

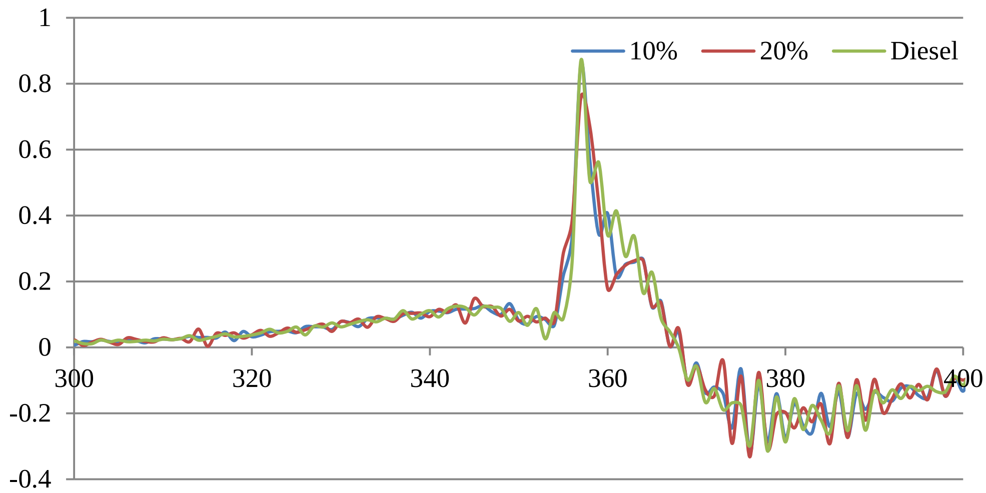

Fig.2 dP/dθ curves vs. CAD at a fixed engine work condition

Conclusions

The use of JCO in a diesel engine as blends is feasible, at the step of engine test benches. The use of JCO in the engine as fuel may decrease the power outlet and decrease the engine efficiency. When the percentage of JCO in the blend increased, the exhaust temperature rises, but also exhaust emissions of CO and HC. The results of ignition delay determination showed not significant differences for any blend compared to diesel fuel. Nevertheless, the paper was only focused on engine test benches and further researches related to road tests, endurance tests and corrosion effect should be addressed.

References

1. Sidibe, S.S., et al., *Use of crude filtered vegetable oil as a fuel in diesel engines state of the art: Literature review.* Renewable and Sustainable Energy Reviews, 2010. **14**: p.2748-2759.
2. Sánchez, Y., et al., *Prediction of cetane number and ignition delay of biodiesel using Artificial Neural Networks.* Energy Procedia, 2014. **57**: p.877-885.
3. Shahabuddin, M., et al., *Ignition delay, combustion and emission characteristics of diesel engine fueled with biodiesel* Renew Sustain Energy Rev, 2013. **21**: p.623-632.
4. Alkhulaifi, K., et al., *Ignition Delay Correlation for a Direct Injection Diesel Engine Fuelled with Automotive Diesel and Water Diesel Emulsion.* World Academy of Science, Engineering and Technology, 2011. **58**: p.905-917.
5. Hsu, T.C., et al., *Upgrading of Jatropha-seed residue after mechanical extraction of oil via torrefaction.* Energy, 2018. **142**: p.773-781.
6. Thapa, S., et al., *An overview on fuel properties and prospects of Jatropha biodiesel as fuel for engines.* Environmental Technology & Innovation, 2018. **9**: p.210-219.
7. Martiñón, A., et al., *Chemical and Physical Characterizaton of Jatropha curcas L. Seed from the Northern Sierra of Puebla, México.* Journal of Plant Sciences, 2018. **6**(1): p.25-30.
8. Dharma, S., et al., *Experimental study and prediction of the performance and exhaust emissions of mixed Jatropha curcas-Ceiba pentandra biodiesel blends in a diesel engine using artificial neural networks.* Journal of Cleaner Production, 2017. **164**: p.618-633.
9. Xu, H., et al., *Performance optimization of diesel engine fueled with diesel-jatropha curcas biodiesel blend using response surface methedology.* Journal of Mechanical Science and Technology, 2017. **31**(8): p.4051-4059.
10. Deshmukh, S.B., et al., *Properties of Jatropha curcas oil and diesel blend as a fuel for C.I. engines.* International Journal of Engineering and Management Research, 2017. **7**(1): p.163-168.

11. Kaewpengkrow, P., et al., *Selective catalytic fast pyrolysis of Jatropha curcas residue with metal oxide impregnated activated carbon for upgrading bio-oil.* International Journal of Hydrogen Energy, 2017. **42**: p.18397-18409.
12. Delalibera, H.C., et al., *Performance of diesel engine fuelled with four vegetable oils, preheated and at engine working temperature.* Engenharia Agricola, 2017. **37**(2): p.302-314.
13. Nayak, C., et al., *Effect of preheated Jatropha oil and Jatropha oil methyl ester with producer gas on diesel engine performance.* International Journal of Automotive and Mechanical Engineering, 2014. **9**: p.1709-1722.
14. Piloto-Rodriguez, R., et al., *Engine performance of a single cylinder direct injection diesel engine fuelled with blends of Jatropha Curcas oil and standard diesel fuel.* Renewable Energy and Power Quality Journal, 2013. **10**(11): p.5-10.
15. Elango, T., et al., *Combustion and emission characteristics of a diesel engine fuelled with Jatropha and diesel oil blends.* Thermal Science, 2011. **15**(4): p.1205-1214.
16. Pugazhvadivua, M., et al., *Investigations on the performance and exhaust emissions of a diesel engine using preheated waste frying oil as fuel.* Renewable Energy, 2005. **30**: p.2189–2202.
17. Senthil-Kumar, M., et al., *Experimental investigations on the use of preheated animal fat as fuel in a compression ignition engine.* Renewable Energy, 2005. **30**: p.1443-1456.
18. Piloto-Rodriguez, R., et al., *Characterization of Jatropha curcas oils and their derived fatty acid ethyl esters obtained from two different plantations in Cuba.* Biomass & Bioenergy, 2011. **35**: p.4092-4098.
19. Piloto-Rodriguez, R., et al., *Thermal behavior of Jatropha curcas oils and their derived fatty acid ethyl esters as potential feedstocks for energy production in Cuba.* Journal of Thermal Analysis & Calorimetry, 2012. **109**(2): p.1005-1012.
20. Assanis, D.N., et al., *A predictive ignition delay correlation under steady-state and transient operation of a direct injection diesel engine.* Transactions of the ASME, 2003. **145**: p.450-457.
21. Piloto-Rodriguez, R., et al., *Ignition delay in a palm oil and rapeseed oil biodiesel fuelled engine and predictive correlations for the ignition delay period.* Fuel, 2011. **90**: p.766-772.

Acknowledgements

The authors express their thanks to the research Project *Bioenergía, Tecnologías limpias para el desarrollo rural* GEF-PNUD for the supply of *Jatropha curcas* oil, likewise the VLIR project *Knowledge Cell on Biofuels obtained from non-edible materials and waste for their use in internal combustion engines*, through which most of the experimental test rig was acquired.

Conflict of Interests

The authors attest that there is no conflict of interest between them or with other colleagues or any external entity to this research.

Credit author's statement

Ramón Piloto-Rodríguez. ORCID: 0000-0002-2583-4189.
Design and development of experiments. Writing of the manuscript.

Indira Tobío-Pérez. ORCID: 0000-0003-0001-0172.
Experiments related to physical properties of biofuel and blends.

Jesús Suárez-Hernández. ORCID: 0000-0002-6232-1251.

Project management and supply of *Jatropha curcas* samples.