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EFFECTS OF THE USE OF D-LIMONENE AS AN ADDITIVE TO DIESEL-BIODIESEL BLENDS ON EXHAUST GASES COMPOSITION OF COMPRESSION IGNITION ENGINES

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Abstract. *The transesterification of vegetable oils results in methyl esters of fatty acid, known as biodiesel. This one presents similar features of diesel oil, such as cetane number, specific weight, heat of combustion and air-fuel ratio. However, arising problems from its higher viscosity leads to a poor spraying by the fuel injectors and so to a low-grade combustion, causing formation of undesirable deposits inside the engine, changes in the properties of the lubricating oil and in the composition of the exhaust gas. Owing to this issue, it is necessary to study an additive able to make biodiesel characteristics more appropriate to be used in compression ignition engines, as well as a monitoring of changes in exhaust gas composition. The chosen additive was d-limonene, a monocyclic terpene obtained as a byproduct of citriculture. This paper presents the preliminary results obtained from the tests in a stationary diesel engine fuelled with mixtures of diesel-biodiesel and d-limonene, in different concentrations, comparing to regular diesel fuel.*

Keywords: *Biodiesel, Additive, D-Limonene, Exhaust Gases*

1. INTRODUCTION

The concept of using vegetable oils, animal fats and even waste cooking oil as renewable diesel fuel is increasingly applicable to our world energy reality and is justified not only by the depletion of the world's oil reserves but also as a renewable and less aggressive alternative to the planet's environment and climate.

The direct use of vegetable oils in compression ignition engines despite being possible is not the best alternative due to the difference of properties such as kinematic viscosity, density and heat of combustion (Agarwal and Das, 2001; Clark et al, 1984; Costa Neto et al, 2000; Hunk and Barsic, 1981; Knothe et al, 2006).

However, when subjected to the transesterification process these properties become much closer to those of mineral diesel oil, but still exhibit high kinematic viscosity that results in a poor spray by the nozzles and consequently a lower grade combustion, leading to the formation of deposits inside the engine, lubricating oil contamination and changes in the exhaust gases composition (Gaurav et al, 2014; Gumus, 2010; Lapuerta *et al*, 2008; Xue *et al* 2008).

In view of these characteristics, it is necessary to use additives in biodiesel in order to make the biodiesel characteristics even closer to mineral diesel, minimizing or eliminating the problems arising from its use.

The chosen additive was d-limonene, a natural, volatile and flammable organic compound (Breitmaier, 2006) obtained from orange peel in the orange juice production industries, which makes it a renewable resource as well (Corazza et al, 2011).

2. EXPERIMENTAL PROCEDURE

The tests were carried out at São Paulo State University (UNESP), School of Engineering, Bauru, in the Engine and Biofuels Laboratory.

Using S-10 diesel oil purchased from the BR supply network, which according to Brazilian legislation has 7% biodiesel in its composition, two blends with different compositions were prepared to be used in the tests. D+L1 containing 1% of d-limonene and D+L3 3% of d-limonene, both in volume percentage. Diesel without additive (d-limonene) was also tested, named D S-10.

A stationary diesel generator set of the Branco brand, model BD-4000-CFE was used for the tests. The engine is air-cooled, a single cylinder direct fuel injection and 7.0 cv (5.12 kW) power rated, volumetric displacement of 0.296 L lubrication by oil pump.

At the output of the generator was connected an electrical system designed to simulate the real operating condition of the assembly, consisting of a bench containing 10 halogen lamps of 500W each, capable of dissipating a total power of 5kW. The assays were performed varying the load dissipated by the lamp assembly in the conditions of 500W, 1000W, 1500W, 2000W, 2500W and 3000W, keeping the engine rotation constant at 3600 rpm.

The exhaust gas measurements was performed by a gas analyzer of the brand TECNOMOTOR, model TM 131 equipped with NO_x detection cell, and the data was collected by the software SOFTGAS provided by the equipment manufacturer who also provided an Opacimeter model TM 133 to measure the smoke opacity (particulate matter) and the software IGOR for its operation. This measurement is performed by the method of light absorption of a partial flow of the exhaust gases, captured by a probe in the exhaust pipe that takes the gases to the measurement chamber.

The exhaust gases temperature was measured through a type K thermocouple installed in the exhaust pipe close to the cylinder head where the exhaust valve is located, and its value was read in an automotive multimeter made by Instrutherm.

Finally, to measure the specific consumption, a Mariotte bottle (as a fuel tank) was placed in a bench scale with capacity of 10kg and resolution of 1g, of the brand DIGI-TRON. This way it was possible to calculate the fuel flow, and then, the specific consumption.

3. RESULTS AND DISCUSSION

The results are presented as graphs, all based on the load imposed on the generator in Watts.

Figure 1 shows the data obtained for unburned hydrocarbons (HC) for different loading conditions. It can be observed that HC emissions were significantly lower up to 2000 W of load, and after this value, the emissions of the two blends and the diesel without additives became closer, but the mixture containing 1% still presents lower emissions of HC up to the load of 3000 W.

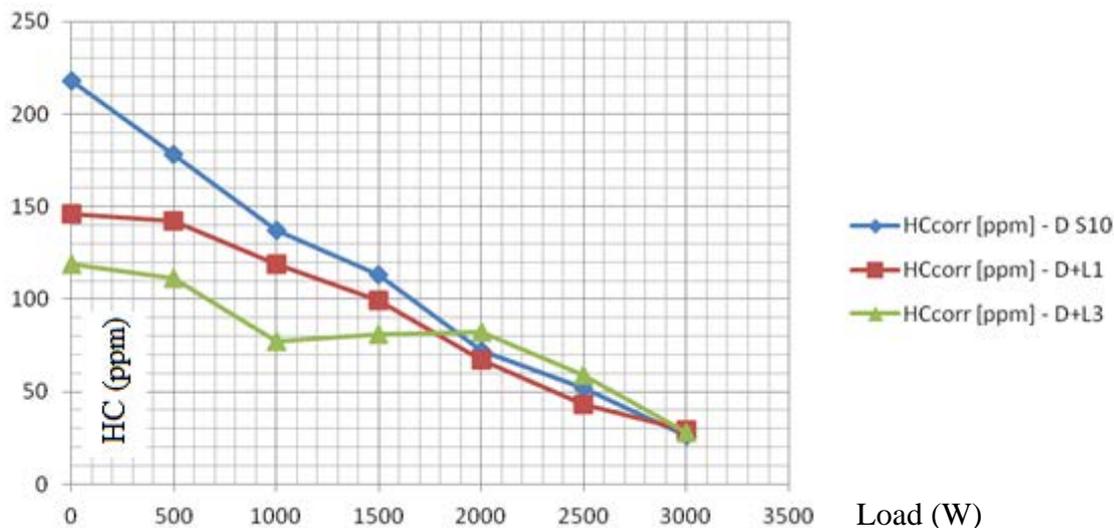


Figure 1: Unburned Hydrocarbons emissions

The decrease of HC is usually followed by an increase in carbon dioxide (CO₂).

Figure 2 presents close values for the three compositions. For smaller loads than 1000 W, the mixture D+L3 showed an increase in CO₂ emissions while for loads above 2000 W there was a decrease. Already the D+L1 presented an increase above 2000 W.

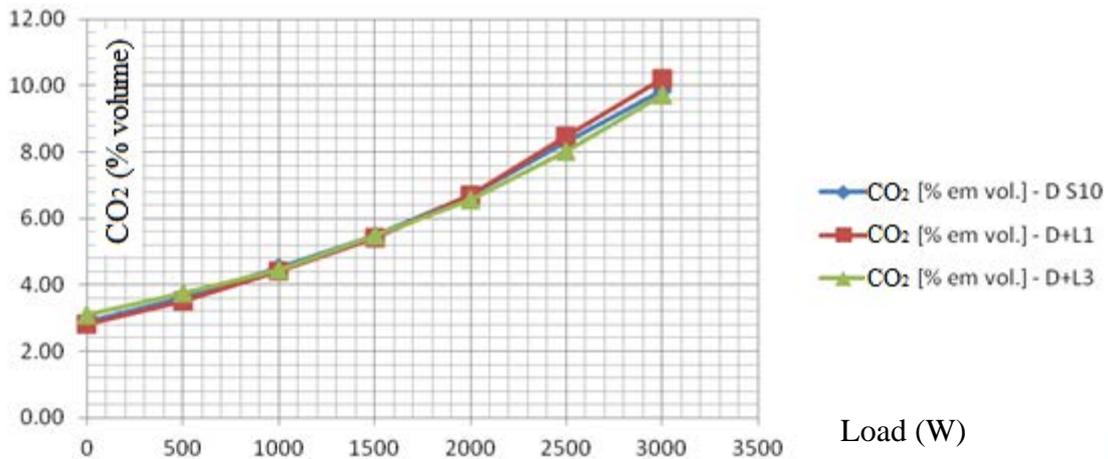


Figure 2: Carbon dioxide emissions

With the decrease of HC and increase of CO₂ when running the blend D+L1, it is expected that the emission of CO would be lower, which can be proved in Fig. 3.

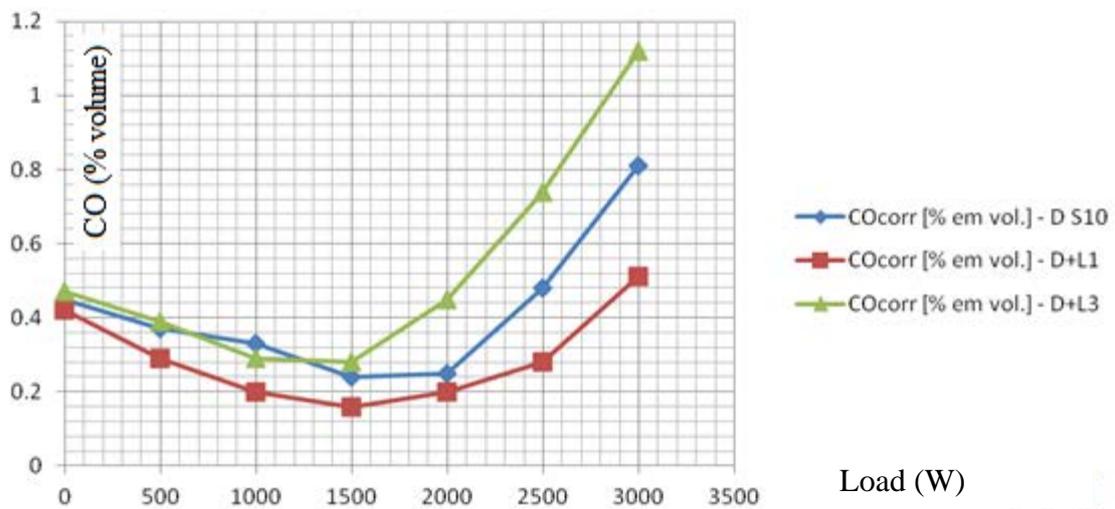


Figure 3: Carbon monoxide emissions

The behavior of the mixture blend D+L3 was not expected, this change may be related to the change in the air-fuel ratio at high loads, the fuel spray shape, the combustion chamber geometry, and an oxidation tendency of limonene, which is flammable, higher than the fuel. The emission values of oxygen (O₂) shown on Fig. 4, were very close.

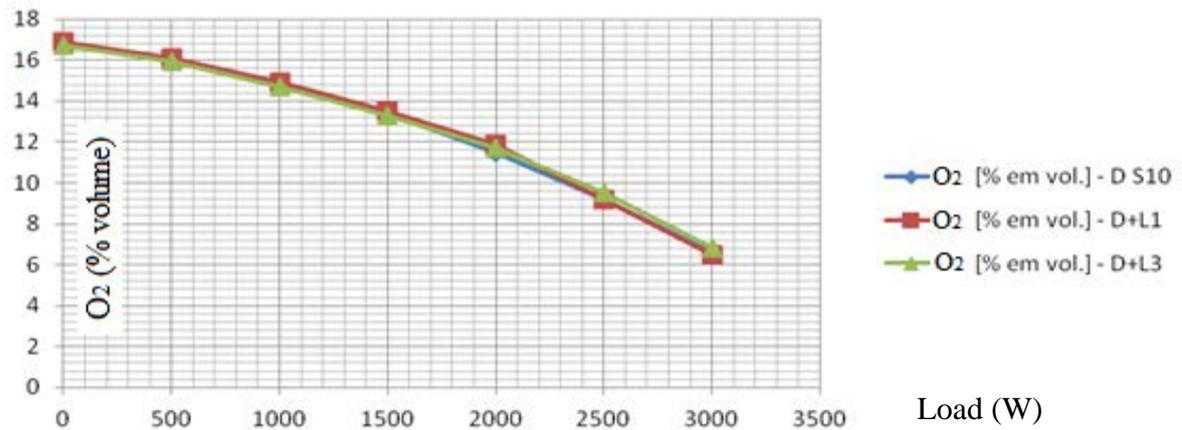


Figure 4: Oxygen emissions

We can observe in Fig. 5 that the emissions of nitrogen oxides follow the same pattern with a point of divergence in 2000 W.

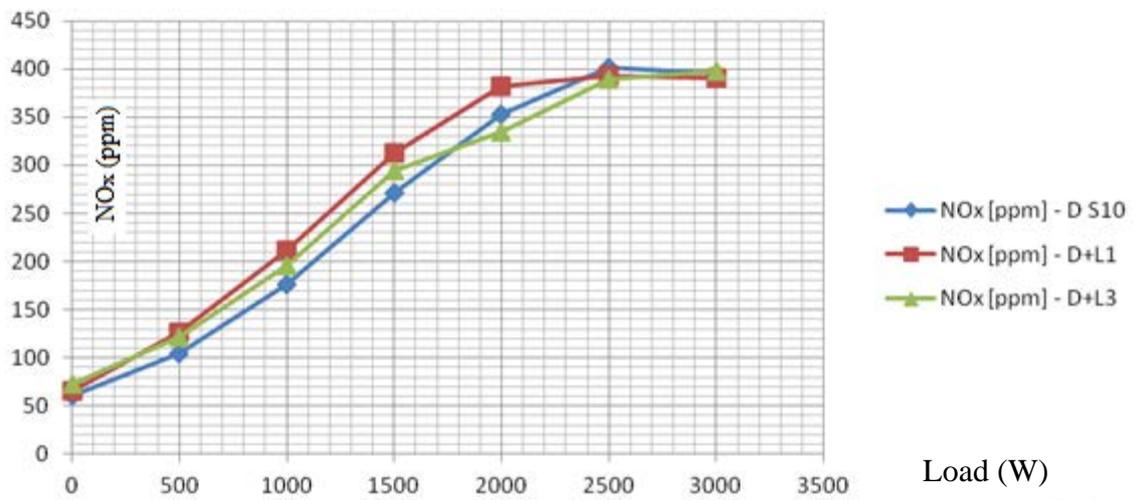


Figure 5: Nitrogen oxide emissions.

With respect to the opacity, we can see a great improvement with D+L1, and a marked variation in heavy loads with D+L3. This fact may be related to some error in the data acquisition and should be investigated

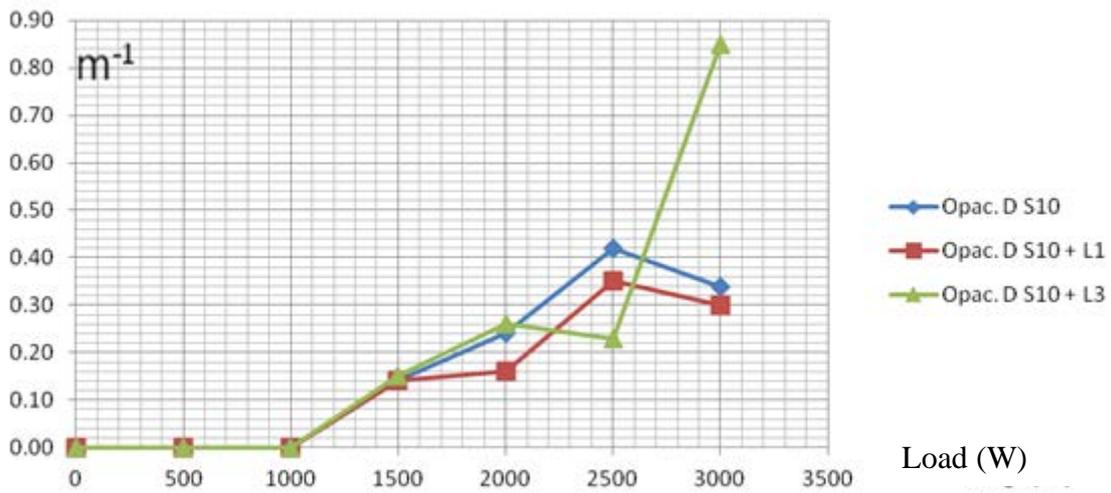


Figure 6: Opacity

A practically identical behavior could be observed both in the temperature of the exhaust gases, Fig. 7, and in the specific consumption, Fig. 8, of the three blends.

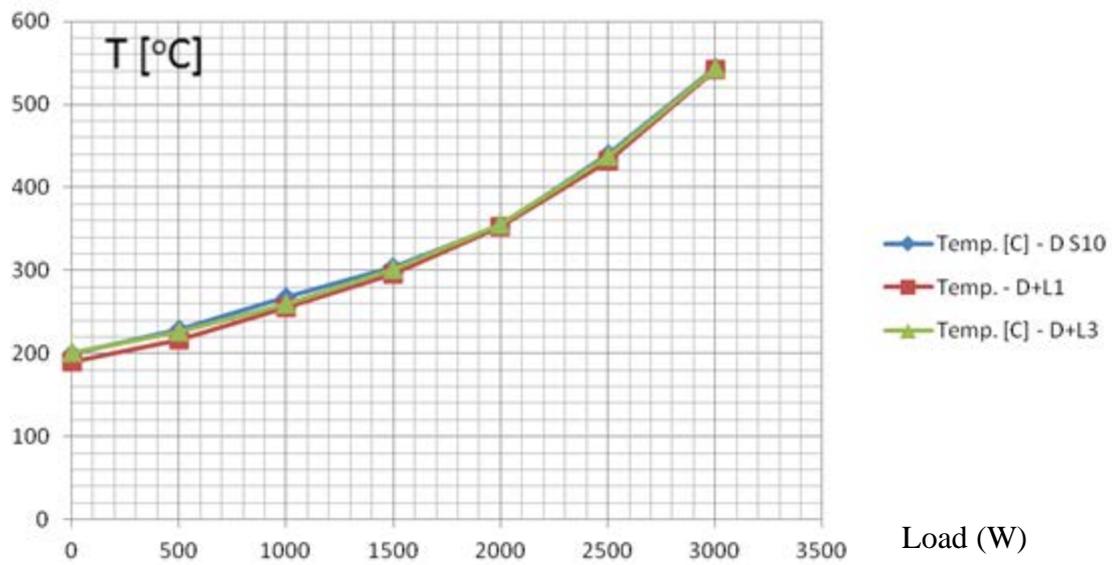


Figure 7: Exhaust gases temperature

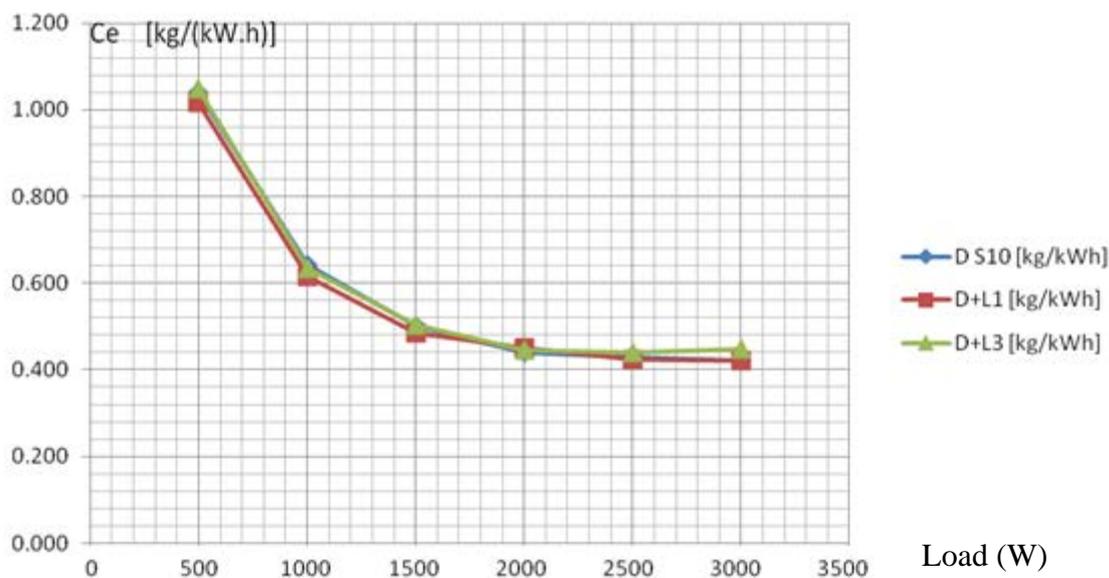


Figure 8: Specific consumption.

4. CONCLUSIONS

In the cases studied there were no problems related to the operation of the equipment.

Although obtaining some desired results such as decrease of HC, CO and opacity, it is still necessary to test new compositions and seek better results, NO₂ emissions is one of them.

New trials will be carried out seeking more conclusive results of the use of d-limonene and the better understanding of the obtained results and the unexpected ones such as the emission of CO using the blend D+L3.

5. ACKNOWLEDGEMENTS

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