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QUALITATIVE WEAR EVALUATION OF DIESEL INJECTORS NOZZLES' NEEDLES WORKING WITH DIFFERENT TYPES OF BIODIESEL

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Abstract. *Nowadays, the fuel industries are constantly under observation of the environmental, economic and social sectors. There is a constant challenge of performance improvement of the fuel and environmental damage reduction in all aspects, since its production until its usage. In face of this evolution, the fuels and the engines have changed a lot to fit in the excellence standards. This way, it is very important to minutely understand the interaction between the fuel, the engines and its subsystems in operation. The objective of this study is to qualitatively evaluate the wear on the surface of the nozzle's needle working on a stationary diesel engine using two types of biodiesel. The tests were performed with an overall duration of 150 hours for each fuel: a blend of 94% S10 diesel oil and 6% biodiesel acquired in a BR's distributor gas station (B6), and the same fuel blend additivated with tensoactives (B6a) characterized in the Research and Teaching Nucleus of Oil and Gas (NUPEG-UFRN). The nozzles' needles were removed and analyzed with optical microscopy and the fuels' lubricity was tested using a High Frequency Reciprocating Rig (HFRR). The results were treated under the light of recent papers published in Engineering.*

Keywords: *Nozzle's needle, diesel fuel nozzle, biodiesel, diesel engine.*

1. INTRODUCTION

Facing the necessity to pursuit alternative energy sources, the biodiesel is shown as an alternative to substitute or reduce the usage of the petroleum diesel, since the diesel engines can run with blends of diesel and biodiesel with a maximum concentration of 20% (B20) without modifications or even with B100 when some changes in the fuel injection system are made (Filipovic *et al.*, 2014). The biofuel is produced from renewable sources and its combustion presents lower levels of pollutants that are less aggressive to the human health (Fazal *et al.*, 2011). Furthermore, Brazil has a satisfactory climate to the cultivation of oilseeds, the base material to the biodiesel production. However, depending to the seed type, biodiesel concentration or additives present in the composition of the biofuel, it presents a variation of its tribological properties (Farias *et al.*, 2014), what causes different wear rates and mechanisms in the injection system of the engines. Some additives that have free water and free fatty acid in its composition, for example, are more prone to absorb this water which tends to condense on the metal surface and increase the fuel's corrosive potential (Fazal *et al.*, 2010).

Some studies verified losses in the engine performance and an increase of the specific fuel consumption caused by the biofuels (Corrêa *et al.*, 2008). Despite this fact, along the years many technologies have been applied to the diesel injection system, it has changed from pump-nozzle to common rail system, the nozzles have started working with higher pressures and the quality of the materials applied to the system has been improved.

The tribological couple nozzle-needle is susceptible to many types of failures. Gonsalves *et al.*, (2012) simulated the scuffing that occurs in the needle and verified that this wear mechanism occurs more likely due to the presence of contaminants in the fuel, considering that those particles change significantly the contact stress between the needle and its seat, what increases the density of energy of the area. The cavitation as described by Payri *et al.* (2004), occurs due to the cross section variation of the nozzle's needle; according to Pehan (2009), clogging is related to the properties of the biofuel such as viscosity, volatility and unsaturated hydrocarbons chains reactivity that lead to the formation of coking coal around the injector body; oxidation, as reported by Teflan (2012), is intensified due to the environmental temperature, sulfur content, biodiesel percentage and water content; the crack, as stated by Xu *et al.* (2013), occurs due to high cycling fatigue, which starts as micro-fissures around the injector body and tend to spread because it is under variable load and variable pressure of the oil.

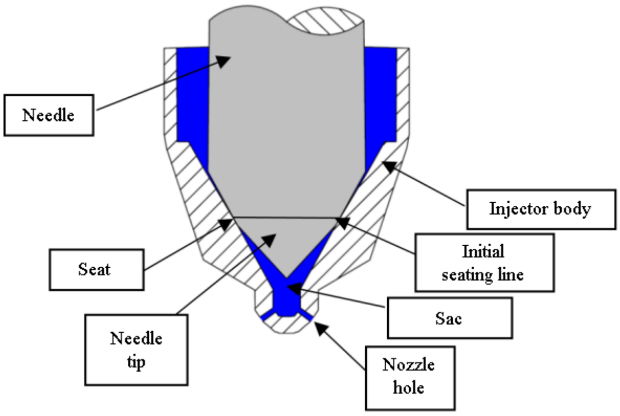


Figure 1. Needle tip seated on nozzle

This study has the purpose to evaluate qualitatively the wear occurred on the surface of the nozzle's needle when working with biodiesel B6 and B6 additivated during 150 h, for each fuel, on a stationary diesel engine.

2. EXPERIMENTAL

2.1 Engine tests

The tests were performed using a 4 stroke 5 hp stationary diesel engine, coupled on a dynamometric rig as outlined on the Fig. 2.

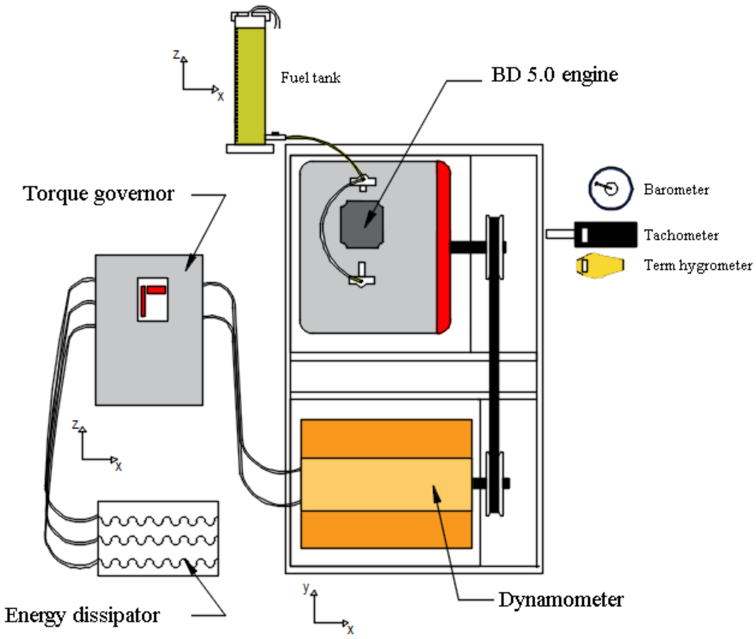


Figure 2. Scheme of the test rig

Two types of biodiesel were tested. Firstly, the engine ran with biodiesel B6 with a sulfur content of 10 mg/kg, it was acquired in a Brazilian gas station and then, after an overall of 150 h, it was changed: piston, piston rings, piston pin, connecting rod, engine's joints and nozzle; and then, the engine ran with the same biodiesel plus an additive (B6a) for more 150 h. Since the engine was unused before the tests, at the first 20 hours of tests it was running without load and with a constant rotation of 1300 rpm (running in), according to the manufacturer indications. After the running in period,

Table 1. Engine technical specifications

Brand	Branco Diesel BD 5.0
Type	Horizontal, single-cylinder, air-cooled
Combustion system	Direct injection
Injection system	Mechanical
Diameter x stroke	70 mm x 55 mm
Cylinder capacity	211 cm^3
Compression ratio	20:1
Maximum power	5.0 hp at 3600 rpm
Continuous power	4.2 hp at 3600 rpm
Maximum torque	1.25 kgfm at 2500 rpm
Lubrication system	Forced through oil pump
Lubricant	Petrobras SAE 15W-30 Semi-synthetic oil
Oil capacity	0.75 L

the rotation was kept constant at 3500 rpm and a constant load of 333 W was applied through transmission belts coupled with the dynamometer.

Table 2. Parameters monitored during the tests

Monitored parameters	**B6**	**B6a**
Engine rotation	3500 rpm	3500 rpm
Number of cycles	16×10^6	16×10^6
Average environmental temperature	35.3 °C	36.7 °C
Average relative humidity	61.2 %	56.7 %
Atmospheric pressure	1.013 bar	1.013 bar

2.2 Fuel tests

To determine the lubricity of the fuels, it was used the High Frequency Reciprocating Rig (HFRR) that consists in a ball-on-disc test, based on the standard ASTM D-6079. For each fuel there were made three tests with the pair ball-disc fully immersed in the fuel and it was measured: film formation percentage, coefficient of friction and average wear scar diameter (WSD) in μm, formed in the ball surface due to the reciprocating sliding movement against the disc, it was analyzed on an optical microscope with magnification of 100 times.

Table 3. HFRR parameters

Fuel volume	2.0 ± 0.2 mL
Normal load	1.96 ± 0.01 N
Frequency	50 ± 1 Hz
Stroke length	1.00 ± 0.02 mm
Temperature	60 ± 2 °C
Time	4500 s
Ball material	AISI 52100 steel
Disc material	AISI 52100 steel

3. RESULTS

3.1 Fuel chemical characterization

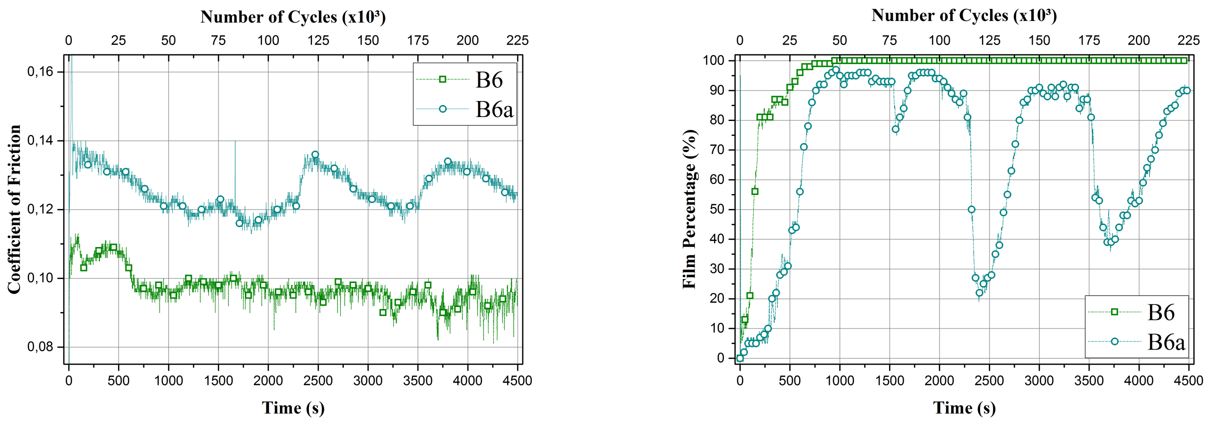
Both fuels were chemically characterized in the Fuels and Lubricants Lab (LCL-UFRN) according to the ASTM standards.

As outlined in Tab. 4, the additivated biodiesel (B6a) did not present a considerable difference of the physico-chemical parameters compared to the B6. The difference of approximately 8% at the viscosity can have influence in the fuel atomization in the combustion chamber (Capana, 2008).

Table 4. Fuel properties

Property	Standard	Limit	Samples	
			B6	B6a
Density at 20 °C, $\mathrm{kg/m^3}$	ASTM D4052	815 to 853	830.4	836.7
Flash point, °C	ASTM D93	38.0	65.5	67.0
Kinematic viscosity at 40 °C, $\mathrm{cSt(mm^2/s)}$	ASTM D445	2.0 to 4.5	2.564	2.772
Cetane index, min	ASTM D4737	45	52.3	49.7
Sulfur content, mg/kg	ASTM D5453	15	8.1	8.7
Volatility, °C	ASTM D86	180	172.2	162.4
Corrosiveness to Copper	ASTM D130	N/A	3 h/50 °C, 1b	3 h/50 °C, 1b
Acidity index, mg KOH/g	ASTM D664	0.5	0.3569	0.2702
Calorific value, MJ/kg	ASTM D3588	42.80	45.96	44.49

3.2 Fuel lubricity test



(a) Coefficient of friction of B6 and B6a

(b) Film percentage of B6 and B6a

Figure 3. Lubricity of the fuels evaluated using the HFRR

At the beginning of the tests it can be observed that the film percentage raises and the friction coefficient decreases. According to Farias (2010), the fluctuation of the interfacial film of the analyzed fluids presents in each time interval has a direct link with the friction values and wear rates.

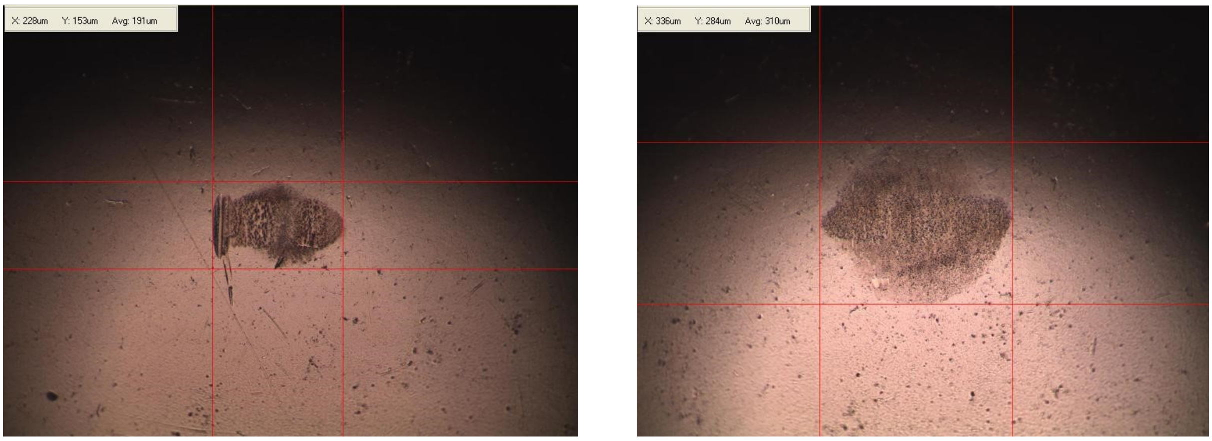
Around 40 thousand cycles it is observed that the fuels reach the stability, forming a constant film. However, after 75 thousand cycles the B6a presents a cyclic behavior of the film formation with an approximate period of 1000 s and, once the film reduces, the contact of the metals' asperities occurs, what can be observed in the friction coefficient increasing in the same time intervals. The instability of the modified biodiesel can be assigned to the tensoactive in its composition, considering that the anfifilic molecules of the additive are responsible to form the adsorption surface in the interface fuel-metal.

Analyzing the wear scar diameter, measured in Fig. 4, the fuel B6a presented a bigger WSD than the B6, what means that the additive decreased the lubricity of the biodiesel. Furthermore, the average coefficient of friction of B6 was 0.099 against 0.126 of the B6a.

3.3 Optical microscopy

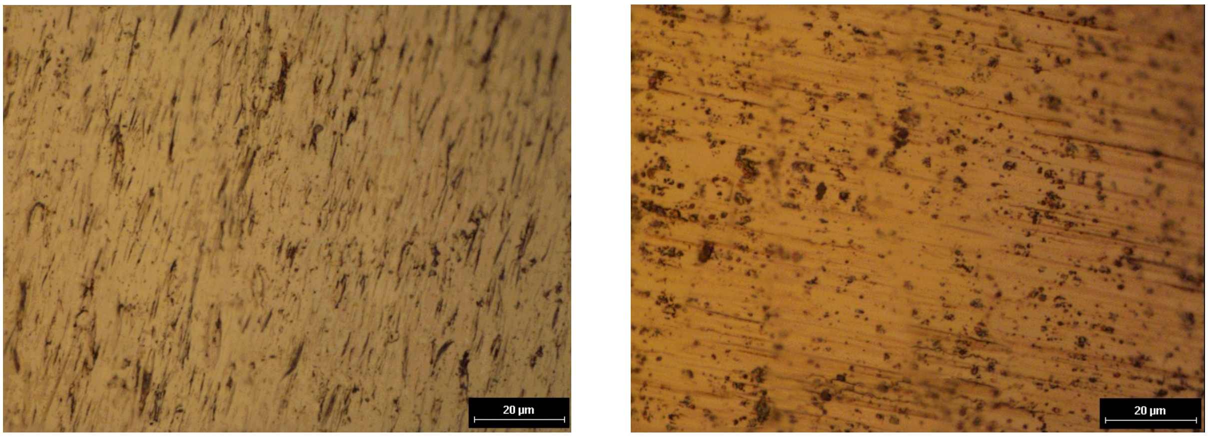
Each needle was analyzed after 150 h of tests on the engine. To analyze the surface of the needles, it was used an optical microscope with magnification of 1000x. The images, outlined on the Fig. 6a and Fig. 6b, evidenced different mechanisms of wear in the surface of the needle that ran with B6 to the one used with B6a.

The needle that ran with the B6 presented non-continuous risk marks evidencing the presence of a third body that could have caused the abrasive wear on the needle's surface, this may also be related to the low capacity of the fuel to form a film that could reduce the surface contact between the tribological couple. The needle that ran with the B6a presented pits on the surface, an evidence of corrosion, that could have been intensified by the presence of oxygen in the additive used on this biodiesel. In this case, the fuel was capable to form a film that reduced the occurrence of the abrasive wear evidenced by the horizontal marks, originated from the manufacturing process of the component, that were kept, an



(a) WSD B6 (b) WSD B6a

Figure 4. Wear Scar Diameter



(a) 1000x B6 (b) 1000x B6a

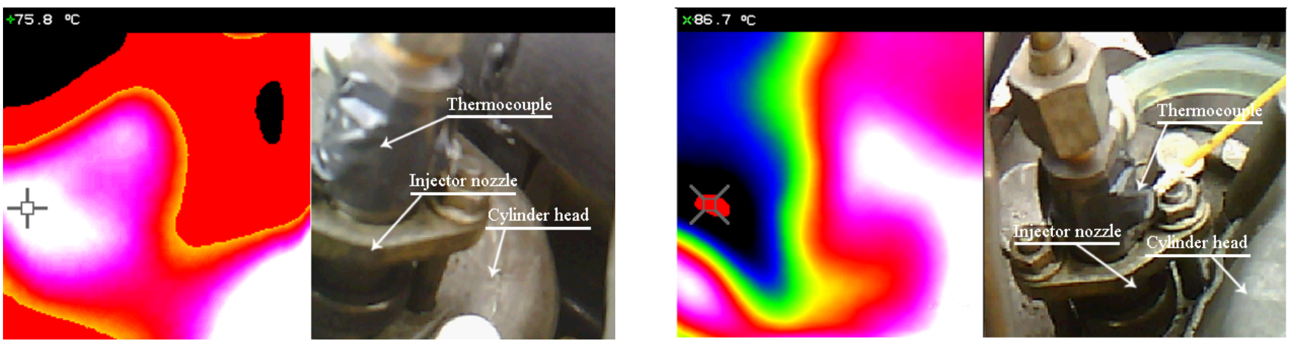
Figure 5. Optical microscopy of the needles

indicative of lower loss of material on its surface compared to the needle of B6.

Once the data obtained from the HFRR presented a different result for lubricity compared to the result of the optical microscopy analysis, it is possible to conclude that, for this study, the lubricity tests do not represent reliably the working conditions of the needle.

3.4 Nozzle's temperature

The temperature of the nozzle was measured with the engine running in the same test period for each fuel, using both thermocouple and a thermographic camera.



(a) Thermographic B6 (b) Thermographic B6a

Figure 6. Thermographic images

Both the camera and the thermocouple indicated that the additive present on the B6a induced a higher temperature in

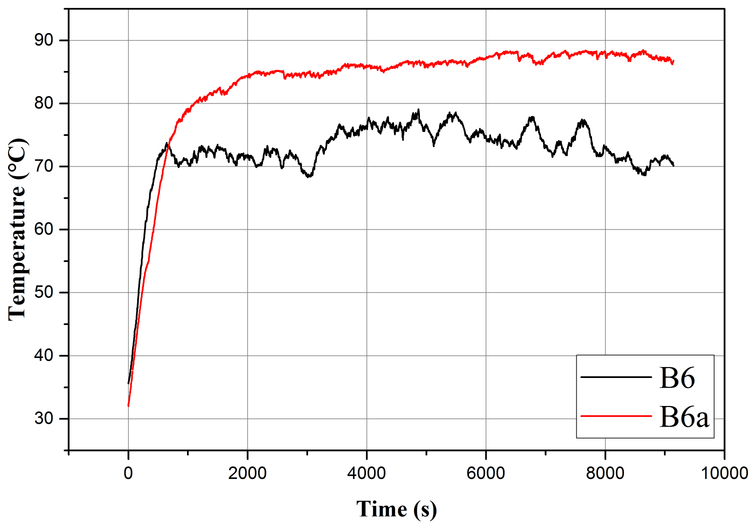


Figure 7. Thermocouple data

service to the diesel injector. This can be related to the combustion of a long carbonic chain and the presence of oxygen in the additive, what causes the fuel to deliver a higher quantity of heat in the combustion chamber when burned.

4. CONCLUSIONS

With the tests performed and the acquired data, it was possible to verify that the additive present on B6a provided a best film formation on the needle's surface in the working conditions of the engine, avoiding a higher loss of material and the increase of the backlash between the needle and the nozzle.

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