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EVALUATION OF LUBRICITY FUELS BY SOUND PRESSURE ANALYSIS IN RECIPROCATING MOTION USING FOURIER TRANSFORM

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Abstract. *The lubricity is an important property of diesel and biodiesel fuels because it produces a protecting layer on the metal surface to prevent wear of engine moving parts, such as fuel injectors and pumps. According to ASTM D6079, the HFRR (High Frequency Reciprocating Rig) tribometer is used to characterize the lubricity fuels, considering only wear scar diameter (WSD) in lubricated contact. On the order hand, this information is not sufficient to characterize the tribological behavior of fuel, so others tribological parameters can be analyzed, such as coefficient of friction and film formation. Furthermore, there are others non-intrusive parameters that can be used to evaluate the tribological behavior in a dynamic regime as sound pressure signals. The characterization of these signals can be made by Fourier Transform Analysis. In this context, the present work evaluated the effect of biodiesel addition on the diesel lubricity using sound pressure signals and the application of Fourier Transform. HFRR tests were carried out by lubricated steel ball-on-disc contact using diesel pure (B0), soybean biodiesel (B100) and blend (B20) of diesel S50 with soybean biodiesel. A sound pressure sensor attached to the system permitted to obtain the signals during the test. These signals were analyzed using Fourier Transform and they were associated with parameters supplied by ASTM D6079. These analyses allowed capturing the small fluctuation of sound pressure signals, and it can be associated with the wear evolution during lubricated contact as well as WSD values.*

Keywords: *lubricity, biodiesel, sound pressure signal, FFT.*

1. INTRODUCTION

Fuels lubricity is the term that defines the ability of a fuel to prevent friction and wear between metal surfaces in rotary motion under load (Gomes and Oliveira, 2005). In this way, diesel fuel has the function of lubricating certain mechanical parts of engines and fuel injection systems. The decrease of the lubricity causes premature wear of components.

With the global efforts to decrease pollutants, the use of diesel has been restricted due to the high concentration of sulfur. The process of removing sulfur from diesel by HDT (hydrotreating) causes harmful effects, which has led to the development of several standards to ensure acceptable levels of fuel lubricity. The inclusion of biodiesel on low-sulfur diesel (LSD) was important to restore the lubricating properties through the use of diesel-biodiesel blends. Knothe and Staidley (2005) showed that the addition of 1% (v/v) biodiesel on LSD improves significantly its lubricity.

The method HFRR (High Frequency Reciprocating Rig), established by ASTM D6079, evaluates the lubricity of the fuels considering the wear scar diameter (WSD) originated by ball-flat disc contact. It consists in reciprocating sliding the ball under a flat surface disc, immersed in the lubricant. A load is applied on the ball through a trapped mass. During the test happens the formation of the wear scar (WSD), wherein its diameter, in nm, measured in the x and y-axis are an indicative used for wear evaluation.

The demand worldwide for the acoustic comfort and to control SPL (Sound Pressure Level) grows increasingly. It demands real engineering solutions, materials and processes to remedy the problems with the noise produced by motors, shafts, bearings, gears, among others tools.

Currently, the signals generated in mechanical contact (vibration, acoustic emission, temperature and forces) have been used as a data source for monitoring the operating conditions of machines and others mechanical equipment. In practice, the representation of signals in the time domain can hide the most important information, and the analysis of frequency spectrum can enhance it (Souza, 2011).

According to Zhu *et al*. (2007), the friction signals contain much information that can reflect characteristics and behaviors of the tribological system. The acoustic emission signals are obtained in the current process, and it can be analyzed by several signal processing techniques, which can be used to complement the lubricity evaluation. The analysis in the frequency domain is used to provide complementary information for these signals, which can reveal the signal frequency components. Passos *et al.* (2010) analyzed the vibration and acoustic emission signals for damage identification (spalling) in the contact track of a bearing. They concluded that both signals showed sensitivity in detecting changes in the wear track, causing a significant increase in the reliability in the use of these tools.

This paper proposes a new lubricity evaluation method, establishing comparison between the wear and sound pressure levels by the frequency analysis of LPS using FFT techniques and its correlation with the evolution of wear derived by WSD analysis.

2. MATERIALS AND METHODS

This work used LSD diesel (B0S50 until 50 ppm of sulphur donated by ALESAT Combustíveis S.A. from Natal/ RN - Brazil), biodiesel (B100SB obtained in Chemistry Laboratory of ECT/ UFRN) and their B20-SB blends (prepared by the addition of 20% (vol.) biodiesel to diesel).

The AISI 52100 steel materials used to evaluate the lubricity of fuels are composed of the ball (ø = 6 mm, Ra = 0.05 µm and hardness HRC = 62) and a flat disc with a hardness HV_{30} = 190, which were assigned by INA Rolamentos (São Paulo/ SP - Brazil). The flat disc was machined with a dimension of 10 mm in diameter and a thickness of 3 mm; after, it was sanded and polished with alumina abrasive solution (ø = 0.3 µm) with a final roughness Ra of ≈ 0.008 µm.

The tribological tests were carried out in triplicate using the HFRR (PCS Instruments®), illustrated in Fig. 1, equipped with a data acquisition board of National Instruments (NI CDAQ-9172) available at Laboratory of Tribology and Dynamics/ UFRN. The tests consisted of reciprocate sliding (1 mm to 10 Hz, 0.02 m/s) of the ball with a 10N load on the flat disc, both immersed in 2 mL of fuel and heated at 60°C. Table 1 shows the test conditions labeled by the parameters N1, N2 and N3, which are related to the test time, cycle number, and displacement distance.

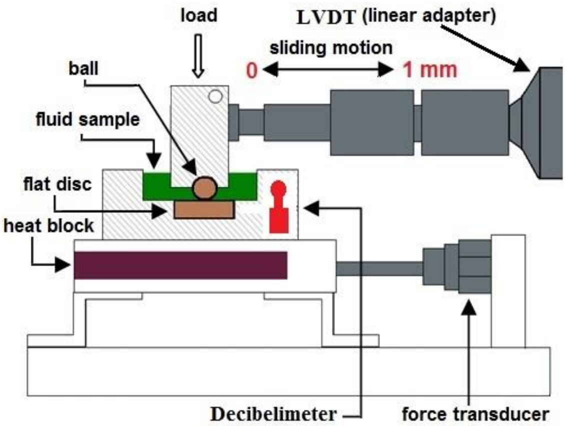

Figure 1 – Schematic HFRR lubricity test

Table 1 – Set parameters of HFRR lubricity test

Parameter	N1	N2	N3
Test time (second)	4500	7200	10800
Megacycle number	0.045	0.072	0.108
Displacement distance (m)	90	144	216

During the experiment, the SPL was acquired using a Decibelimeter Digital (Minipa MSL-1352C), used on the amplitude range of 30-130 dB. The measurement of sound pressure level (SPL) was made setting the sensor in front of the ball-flat disc contact at a distance of 10 cm and it was connected with the modulus (NI 9205) of National Instruments. The signal acquisition was made by LabView® software and imported to Matlab® where it the FFT algorithm was implemented.

3. RESULTS AND DISCUSSIONS

The wear scar diameter measured after the tests in N1, N2 and N3 conditions (Tab. 1) and using the HFRR equipment are illustrated in Fig. 2. As can be seen, WSD increases as a function of N1, N2 and N3 but its value was reduced with the increase in biodiesel content observed in the blend. Hence, the rise in the biodiesel content influenced the lubricity positively, providing scars lower than those generated by B0S50. Therefore, it was considered that soybean biodiesel fuels (B100SB and B20SB) had a greater ability to protect the metal surfaces than B0S50 fuel. However, the condition of dry contact in the ball-flat disc was considered the most severe because the wear values are approximately one order of magnitude higher than in the lubricated condition.

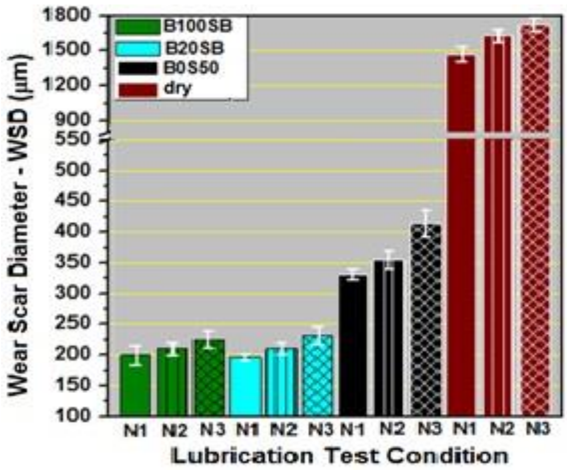

Figure 2 – Wear scar diameter as a function of N1, N2 and N3 conditions.

Figure 3 presents the maximum depth (μm) and the scar area (μm^2) measured in the longitudinal direction of the sliding, which has increased in function of the reduced biodiesel content and with the time test. This characteristic was also mentioned in studies made by Sulek *et* al. (2010) and Farias *et al*. (2012), in which scars profiles decreased with the use of blends with high biodiesel content or pure biodiesel. Thus, the lowest values were attributed to the use of B100SB, while the use of low fuel lubricant (B0S50) reaching extreme values of depth and scar area, except the dry condition.

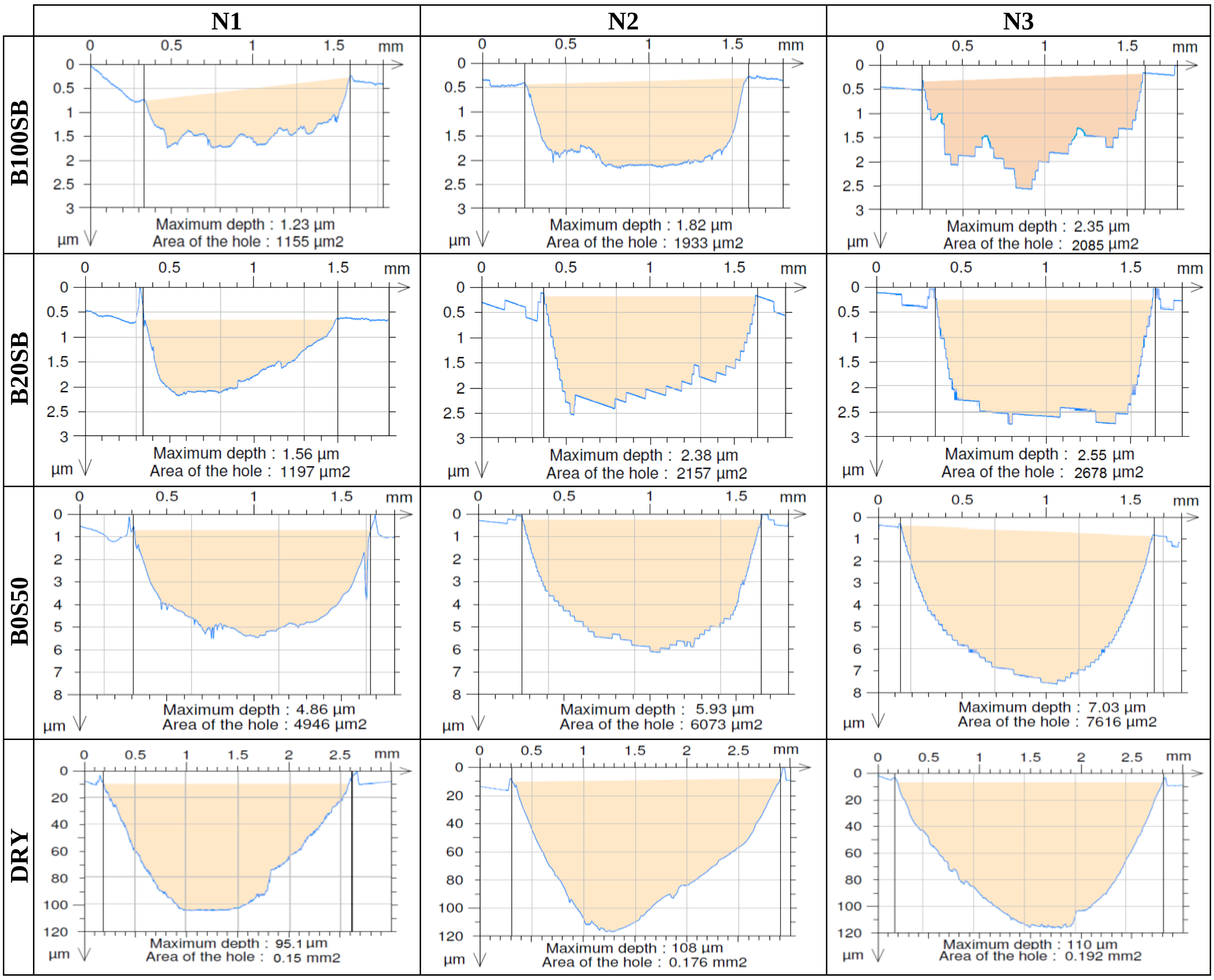

Figure 3 – Sequence of longitudinal profiles presents the evolution of disc wear scar as a function of fuel and N1, N2 and N3 conditions.

The analysis of physical system can be made from the temporal representation of SPL (dB). Since changes in amplitudes indicate that the system under friction is not linear. According to Dautzenberg and Kals (1986), the shape of the theoretical signal is different from the experimental signal that can be attributed to the different distribution of obstacles found on the contact surfaces.

The SPL signal (dB) obtained during the experiment were processed to generate graphs in time at Fig. 4 and frequency domains in Fig. 5 using a window of 0.1 s, after the first hour to test. The illustrations in Fig. 4 showed an increase in the SPL for diesel pure, for the B20 blend and B100 remained constant in a function of N1, N2 and N3 conditions. The condition of dry contact ball-flat disc was considered the most severe condition with values higher than in the lubricated condition. Related to biodiesel content and the wear scar, it was observed that for blend, the increase in biodiesel content promotes a decrease in the wear scar, producing grooves of small diameter and depth and decreasing the SPL along the test. However, the not addition of biodiesel for the B0S50 and the condition of dry contact showed large wear scars, both on flat disc and in the ball, grooves of high depth, leading to an increase in SPL as a function of N1, N2 and N3 conditions. Chen *et al*. (2002) attributed the fluctuation of friction due to plowing in the surface that increases the roughness, which handle noise generation.

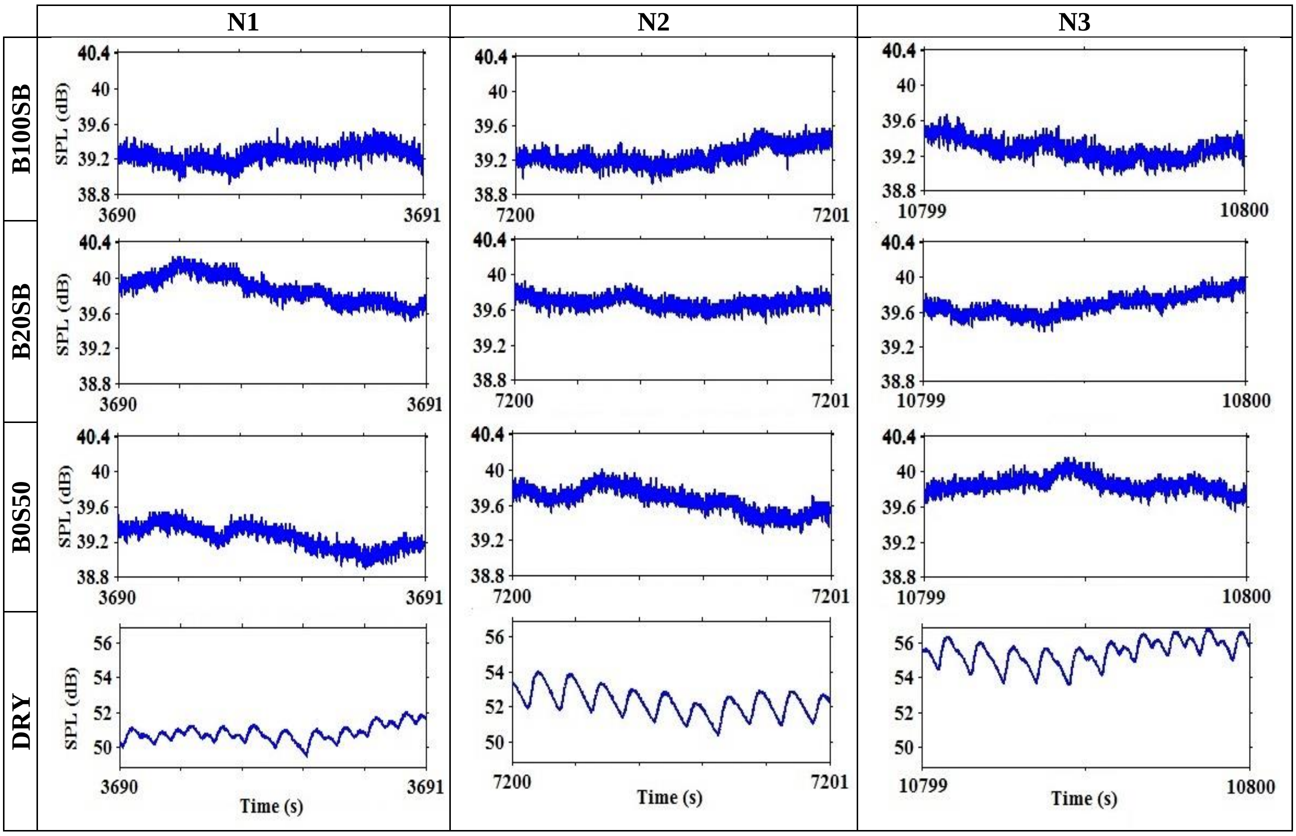

Figure 4 – Sound pressure level signals in the time domain as a function of fuel and N1, N2 and N3 conditions.

From the image analysis of the SPL in the time domain shown Fig. 5, it is found that these results corroborate those found in various literature on the relationship of the noise and wear process. However, it is not possible evaluate what the best fuel from the analysis of the curves shown in the time domain to the lubricated conditions, being necessary the application of the FFT to highlight the main components of the spectra of signals frequency captured during the 10800 s.

In Fig. 5, the frequency amplitudes obtained by contact with the B100SB and B20SB exhibited similar behavior, but the B20SB presented a greater number of variations during the test. In them, the components have peaks whose amplitudes were for 0.8 $x10^{-4}$ and 1.5 $x10^{-4}$. Already at dry condition and lubricated with B0S50, the components are greater and with frequencies, close to 900Hz. Also in dry test it was perceived audible noise more intense than in the lubricated trials.

The fuels and dry condition have a specific frequency component with the largest magnitude in comparison to the others, and it shifts in a positive direction, for all conditions. This magnitude increases with the biodiesel content and in the dry state. As also it increases as a function of N1, N2 and N3. That is, the biodiesel content and the number of cycles influence the frequency spectra. The rise in biodiesel content in high cycle conditions corresponds to an increase in the amplitude of the high-frequency sound pressure level (SPL).

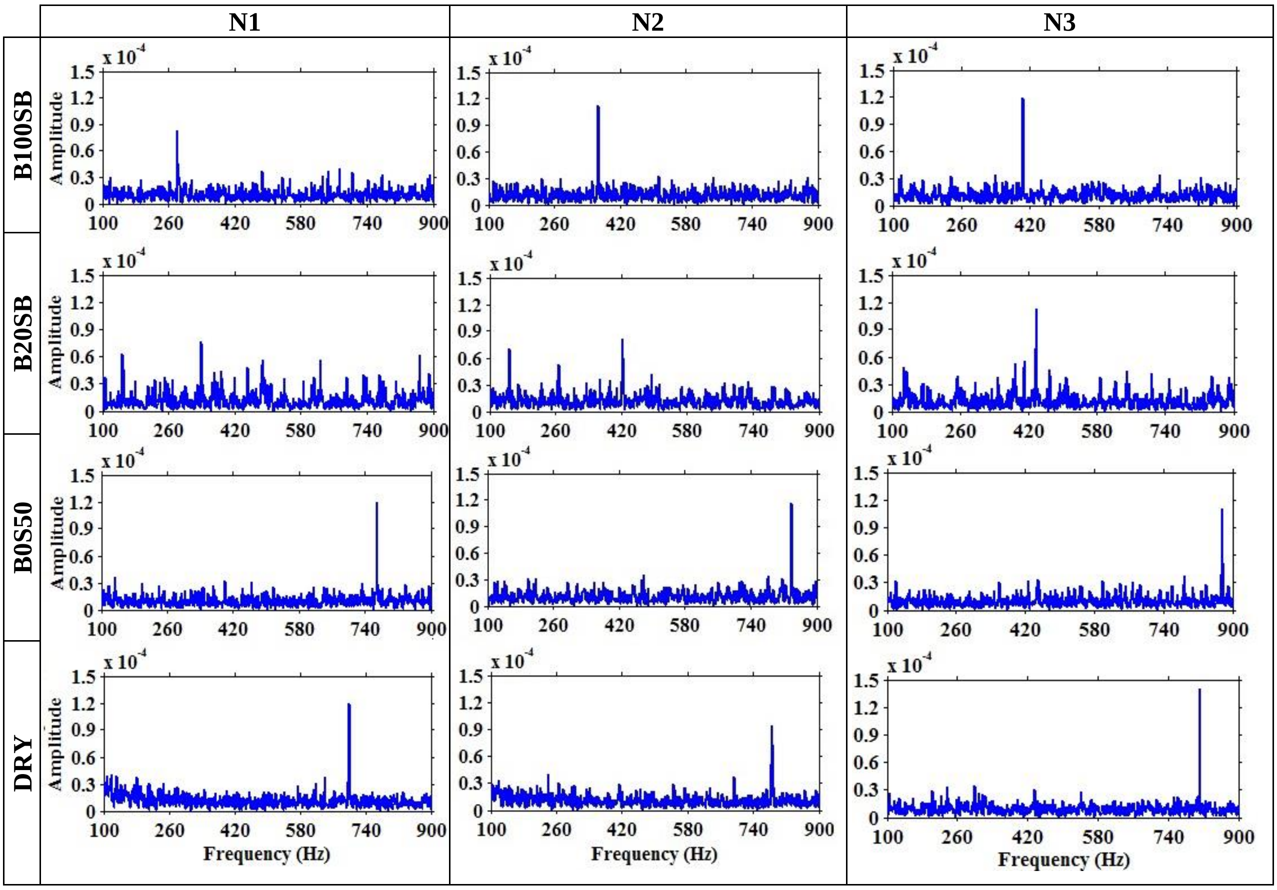

Figure 5 – Frequency spectrum of SPL signals as a function of fuel and N1, N2 and N3 conditions.

It was perceived there is an inverse correlation between the lubricity with the SPL signal in both time and frequency domains. It can be inferred that the increase in SPL and WSD is a consequence of changes in metallic contact topography, depending on the lubricating capability of each fuel.

These results can be related to the morphology of the worn surface. To Qian *et al*. (2013), noise-induced friction is classified into low frequency (10-500 Hz) and mid (500-18000 Hz). According Dang *et al.* (2013), the increase of SPL has a directly proportional relationship with the rise on surface roughness. This fact occurs because the wear process increases the worn out area, WSD and the number of roughness, providing more collisions between these asperities. Thus, the dry condition generated roughest surfaces that contributed to the generation of components with large amplitudes (between 700 Hz and 900 Hz), when compared to lubricated surfaces with less rough.

4. CONCLUSION

From the analysis of the experimental results, it can be concluded:

(1) The SPL analysis by FFT technique can be correlated with the lubricity of B0S50, B100SB, and B20SB fuels.

(2) B100SB and B20SB fuels have a higher lubricity than B0S50. This fact could be proved by the formation of the wear scar.

(3) Through the profile analysis of the disc wear scar, it was observed that the wear has evolved with test time established by N1, N2 and N3 conditions, and it was affected by biodiesel content. This observation confirmed the low performance of B0S50.

(4) The analysis in time and frequency domains of sound pressure level signals showed that there is a inverse relationship between SPL and lubricity. It led to minor variations in time and different frequencies in SPL spectrum for various fuels and at dry condition.

5. ACKNOWLEDGEMENT

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