STUDY OF AUTOMOTIVE LUBRICANTS CONTAMINATED BY BIOFUEL, IN DIFFERENT CONCENTRATIONS, THROUGH VIBRATION AND WEAR ANALYSIS

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Abstract. *Attention to biofuel has greatly increased in the whole world in the last two years, following a tendency which encourages the use of energy produced by bio renewable resources in cleaner mechanical processes. However, the consequences and the effects of utilization of bio fuel are more important than those introduced during its production. As an example, the biodiesel produced in a castor-oil plant is very corrosive to internal combustion engines. In this context, investigation on possible lubricant contamination by biodiesel, in machine elements has still to be carried out, mainly in what concerns lubrication power and changes in lubricant properties. This work studies the effect of biodiesel as a lubricant contaminant in ball bearings, which simulates a situation that could actually occur in biodiesel internal combustion engines. A biodiesel, of animal origin, was used as lubricant contaminant in three different concentrations. The tests were carried out with a specific load on the bearings and with three shaft speeds using three specified automotive lubricants. In this study, vibration and oil analysis were collected and analyzed in order to verify if these are reliable techniques in identifying problems originated from some possible lubricant contamination by biodiesel fuel.*

Keywords*: Biofuel, oil analysis, vibration analysis, lubricant, predictive maintenance*

1. INTRODUCTION

Erroneously, the mean of transportation which expanded the most in Brazil was the highway. This type of transportation is the least efficient when compared to railway and waterway transportation. Like the first, the last ones also use the diesel as the main fuel. This fuel normally used in cargo and passengers transportation is imported in a high proportion because of the Brazilian limited refining capacity.

The idea of using liquid fuels as an alternative to diesel, obtained from plants, started in the 70's during the oil crisis. Several research efforts had focused on studying the production of fuel that could be an alternative to diesel, which used various raw materials of plant origin. Thus, it was born the experiment with the tranesterification in Brazil (Parente, 2003). However, the priority was given, at that time, to the program for the development of alcohol (Proálcool), which had its peak in the mid-80th.

The complexity of building a program for production, processing and distribution of an alternative fuel, without official support, was determinant that throughout the oil crisis, a program for alternative fuels for the diesel was not established.

Only nowadays, the use of transesterified vegetable and animal oils as fuel is being introduced on a large scale in order to strengthen the country's energy independence (Anastapoulos et al., 2001). Studies about the biodiesel production and the environmental politics can be found in [(Costa Neto et al., 2000), (Crwkouvic et al. 2005), (Ferrari et al., 2005), (Freitas and Fredo, 2005) and (Oliveira and Costa, 2002)].

The new fuel can be mixed with diesel, in any proportion, or can be used in its pure form. Its use can be applicable in a large scale with some adaptation. One can mention small thermoelectric power plants, in very distant locations from the commercial circuits, which consume large volumes of fuel where the pure biodiesel can be applied.

With its wide deployment, it becomes necessary to study its effect on internal combustion engines. Also, studies on the tribology problems caused through lubricants contamination by the biodiesel must be implemented to validate the various biodiesel that are being made before their distribution to consumer market. In these topics we can quote [(Schumacher et al., 2001), (Agarwal et al., 2003), (Crnkovic et al, 2006), (Rakopoulos et al., 2006)].

Vibration and oil analysis are two very useful techniques for those purpose as can be seeing in (Gonçalves et al, 2006, Gonçalves et al, 2007, Maru[a] et al, 2005, Maru[b] et al, 2005, Maru[a] et al, 2007 and Maru[b] et al, 2007).

In the fourth last works mentioned above, the authors found out that vibration analysis through the root mean square (rms) value was able to show that particle size and the concentration of solid contaminant affect the dynamical response of the bearing in the low frequency range.

This work contributes to the matter by trying to identify problems related to some possible lubricant contamination by biodiesel through the analysis of a rolling bearing lubricated with automotive lubricants contaminated with biodiesel.

2. METODOLOGY

In this experiment three types of commercial automotive lubricant for compression internal combustion engine were used with the properties shown in the Tab. 1 below.

Table 1. Properties of the lubricants used in this experiment

Properties		Lubricant type		
		Shell	Texaco	Castrol
Viscosity at 40 ^{0}C (cSt)	ASTM D 445	139.3	157.2	233.5
Viscosity at 100 ^{0}C (cSt)	ASTM D 445	18.72	14.94	22.7
Viscosity index	ASTM D 2270	152	94	120
TBN (mg KOH/g)	ASTM D 4739	8.5	8.4	8.5
Flash poin (^{0}C)	ASTM D 92	220	258	not provided
Classification	SAE J 300	15W50	40	25W60
	API	CF/SL	CF/SF	CF

The biodiesel used as contaminant was of animal (fat) origin, transesterified with methanol and with viscosity of 5,36 cSt. Each lubricant type was contaminated with two concentration of the biodiesel, that is, 3 % by volume and 5% by volume. This kind of contamination represents a real situation that could occur in a engine. After contaminating the lubricant with the respective biodiesel concentration it was obtained nine viscosity grades that were tested.

The tested ball bearings were of 6205 type, with internal diameter of 25 mm, external diameter of 52 mm and with width of 15 mm. Figure 1 shows the equipment used for the tests. The tested ball bearing was vertically loaded and oil bath lubricated. A radial load was applied in the tested bearing through a lever and a load cell with a screw system.

A system with pulleys transmitted the power from an electric motor to the bearing shaft. Two ball bearings were used to support the shaft. A frequency inverter controlled the shaft speed.

Two piezoelectric accelerometers attached in the bearing housing measured the bearing radial vibration. One at vertical position (PCB 353 B2, 0–7 kHz useful range, sensitivity of 20 mV/g or 2.04 mV/ (m/s²) with an ICP sensor signal conditioner model 480 E9) and other in the horizontal position (PCB 603 C1 0–10 kHz useful range, sensitivity of 100 mV/g or 10.2 mV/(m/s²) with the ICP sensor signal conditioner model 482 A22).

The measured signal was amplified and filtered with low band pass filter at a 7 kHz cutoff frequency. The signal was then acquired through an acquisition board at sampling rate of 20 kHz. In the tests, each acquired signal had a number of 200,000 data, corresponding to 10 s acquisition time. A computer program in MatLab divided two signal of 10 seconds in ten parts each one, added the twenty parts and gave the mean value. All stored data were analyzed with respect to the signal energy Es value. Vibration signals were acquired at every 30 min, during 2 h of testing. The applied load was set to 800 N. A sketch of the equipment used is illustrated in Fig. 1.

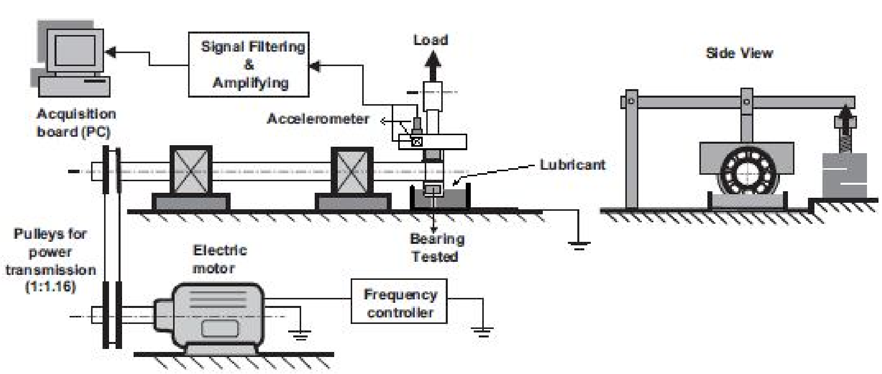


Figure 1. Sketch of the equipment used for the test

After temperature stabilization, vibration signals were acquired for three shaft speeds (30, 35 and 40 Hz), in order to verify if the trends in vibration behavior with the tested viscosity grades would be kept constant when the speed changed. The trend was tried in ranges that could give better results. Experiments with every lubrication condition were repeated several times to check repeatability.

After the test the lubricants were collected and analyzed through atomic absorption spectrography, total base number, magnetic particle index, viscosity and flash point in order to compare one to each other. For that it was used an atomic absorption equipment, an Automatic digital burette, an automatic ferrous debris monitor, Cannon Fenske viscometers, and Cleveland apparatus.

3. RESULTS AND DISCUSTION

Table 2 presents some measured lubricant properties for the nine conditions related to the contamination ratio and lubricant type after the tests and Tab.3 shows the result for the atomic absorption spectrography.

Table 2. Lubricant properties without and with contamination

Lubricant	Properties				
	Viscosity at 40 ^{0}C (cSt) ASTM D 445	Viscosity at 100 ^{0}C (cSt) ASTM D 445	Flash point (^{0}C) ASTM D-92	TBN mgKOH/g ASTM D 95	PQA Magnetic particle index
SHELL 15W50 (5%)	111.47	16.52	165	8.27	10
TEXACO 40 (5%)	116.32	13.59	205	9.19	14
SHELL 15W50 (3%)	123.84	17.57	190	8.05	10
TEXACO 40 (3%)	129.37	14.05	230	9.04	14
SHELL 15W50 (0%)	135.21	18.53	210	8.55	10
TEXACO 40 (0%)	148.66	14.98	250	9.21	14
CASTROL 25W60 (5%)	168.28	18.38	190	7.97	10
CASTROL 25W60 (3%)	201.46	20.67	215	8.18	10
CASTROL 25W60 (0%)	233.00	21.94	230	8.58	14

Table 3. Atomic absorption spectrography obtained with the lubricant after the test

Lubricant	Element (ppm)						
	Cu	Si	Al	Fe	Pb	Cr	Ni
SHELL 15W50 (5%)	0	3	2	0	0	0	0
TEXACO 40 (5%)	13	14	0	5	0	3	0
SHELL 15W50 (3%)	0	0	1	0	0	0	0
TEXACO 40 (3%)	12	14	0	5	0	3	0
SHELL 15W50 (0%)	0	0	2	0	0	0	0
TEXACO 40 (0%)	12	11	0	5	0	3	0
CASTROL 25W60 (5%)	3	2	0	0	0	1	0
CASTROL 25W60 (3%)	2	1	0	0	0	0	0
CASTROL 25W60 (0%)	3	5	0	5	0	1	0

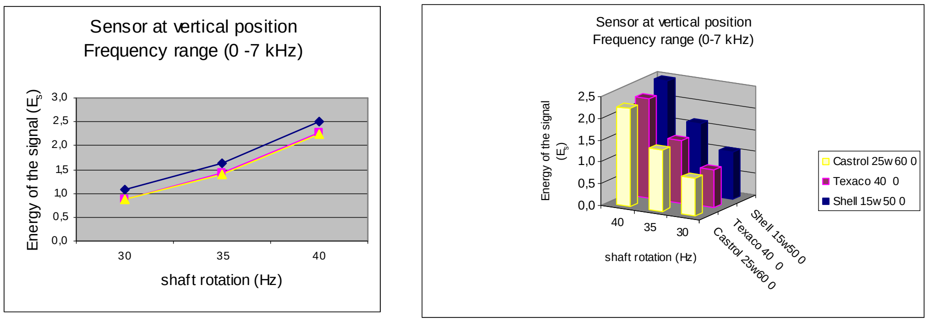
From Table 2 above it can be seen that the flash point and the viscosity obviously decrease with the contamination grade for the three lubricant brand. TBN decreases, but not proportionally, with the contamination grade for the three lubricant brand.

From the Table 3 it can be seen that the Si was presented in greater amount for the Texaco brand. That element could be originated from anti foaming package but it can be seen that the amount of Cu, Fe and Cr was greater for the other lubricant brands. If it is also taken into account, the PQA index for Texaco lubricant brand, it is shown in Table 2 that the result points to a a little bigger wear, even though in an amount compatible for a normal wear.

Bellow, it is presented a sequence of Figures for vibration results in some frequency ranges. Figure 2 and Figure 3 are result for the complete range in both positions.

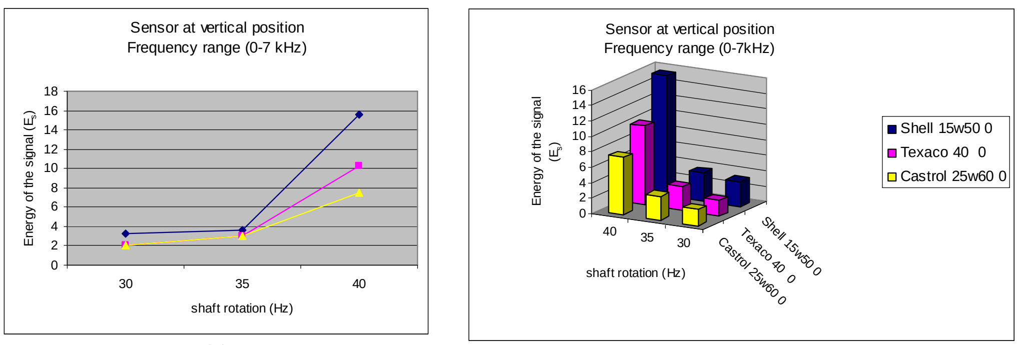
In this paper, the information carried out by the signal s(t) was described by the energy of it, and is defined, in a given time duration T and frequency range by:

$$Es = \int T.s(t)^2\, dt \qquad (1)$$



(a) (b)

Figure 2. Energy of the Signal for the Lubricants without contamination from 0 to 7 k Hz in the vertical position. (a) Linear representation, (b) bar representation

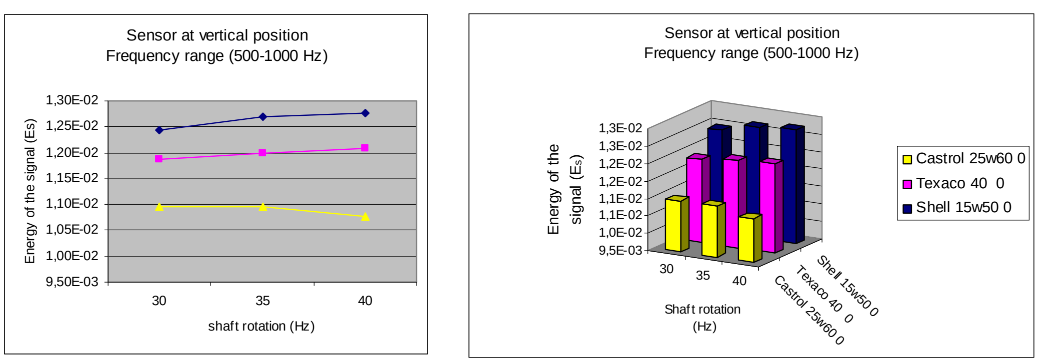


(a) (b)

Figure 3. Energy of the Signal for the Lubricants without contamination from 0 to 7 k Hz in the horizontal position. (a) Linear representation, (b) bar representation

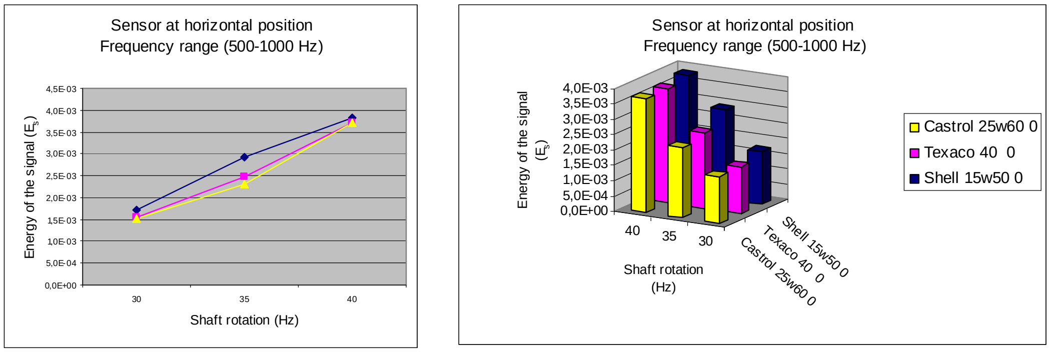
As it can be seen in Fig. 2 and Fig. 3, the signal energy increases from the lower viscosity to the larger ones. The difference between the energies is related to different excitations that are presented in the horizontal and vertical position of both sensors. The energy also increases from the small shaft rotation to the larger ones.

The following two Figures present the Energy of the signal in a different range of frequency.



(a) (b)

Figure 4. Energy of the Signal for the Lubricants without contamination from 550 to 1000 Hz in the vertical position. (a) Linear representation, (b) bar representation

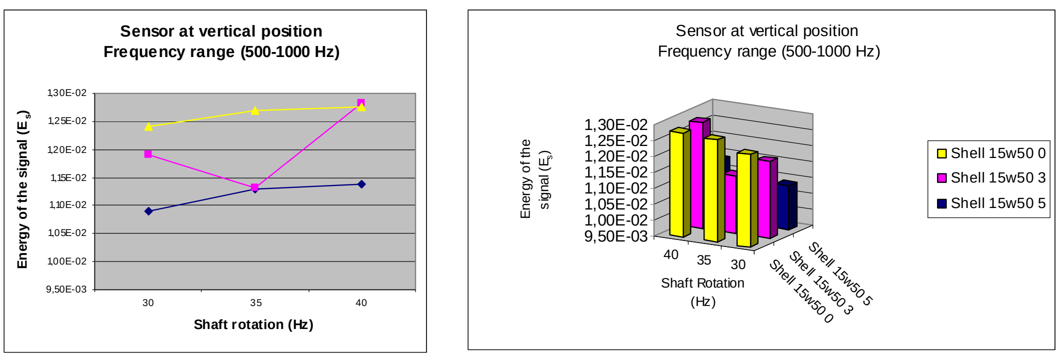


(a) (b)

Figure 5. Energy of the Signal for the Lubricants without contamination from 500 to 1000 Hz in the horizontal position. (a) Linear representation, (b) bar representation

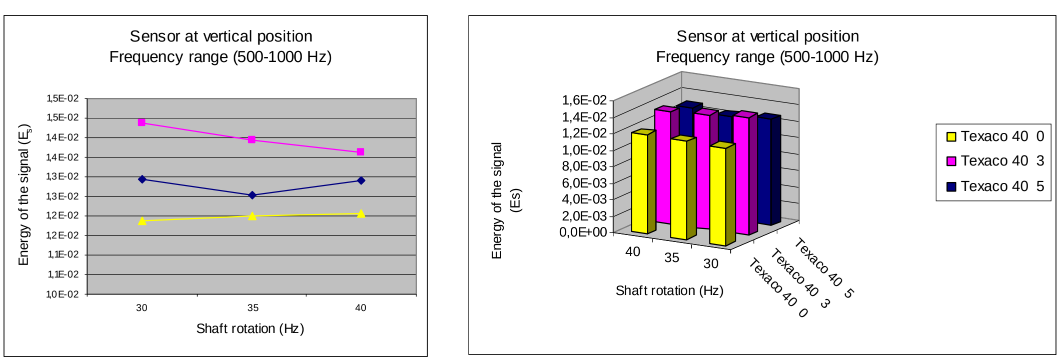
From the Fig. 4 and Fig. 5 it can be seen that the result is better seeing by separating the signal in range of frequency (500-1000 Hz), even though not every range gives better result.

The following Fig. 6, Fig. 7 and Fig. 8 show the difficulty of getting information when viscosity values are very close. For the vertical position in the first two figures, where the viscosity change was small, it was difficult to observe the results by varying the contamination grade that caused a small variation in the viscosity values. For the Fig. 8, where the change in viscosity were larger the result was more visible.



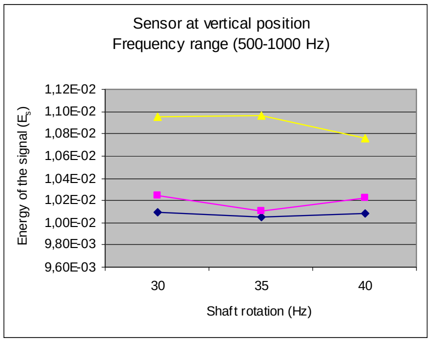
(a) (b)

Figure 6. Energy of the Signal for the Shell lubricants without and with two contamination grades from 500 to 1000 Hz measured in the vertical position. (a) Linear representation, (b) bar representation

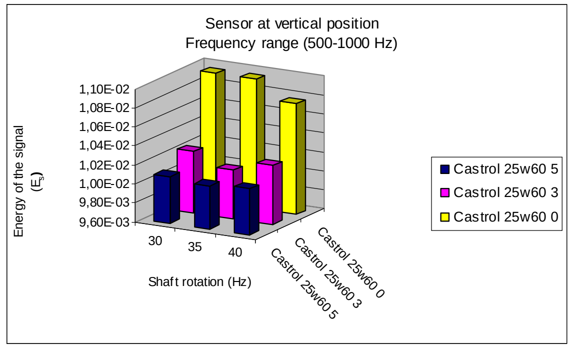


(a) (b)

Figure 7. Energy of the Signal for the Texaco lubricants without and with two contamination grades from 500 to 1000 Hz measured in the vertical position. (a) Linear representation, (b) bar representation



(a)



(b)

Figure 8. Energy of the Signal for the Castrol lubricants without and with two contamination grades from 500 to 1000 Hz measured in the vertical position. (a) Linear representation, (b) bar representation

Figure 9, Fig. 10 and Fig. 11 summarizes the results for the three lubricant with and without contamination, in the frequency range of 500-1000 Hz, for the three shaft rotation

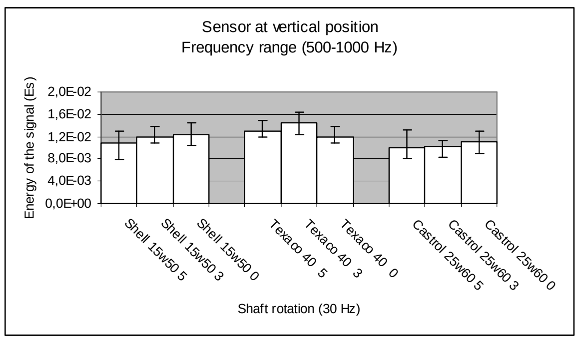


Figure 9. Energy of the signal for the three lubricant brands with and without two contaminant grades from 500-1000 Hz measured in vertical position at 30 Hz

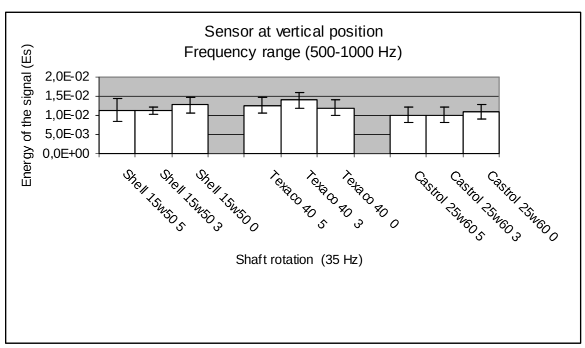


Figure 10. Energy of the signal for the three lubricant brands with and without two contaminant grades from 500-1000 Hz measured in vertical position at 35 Hz

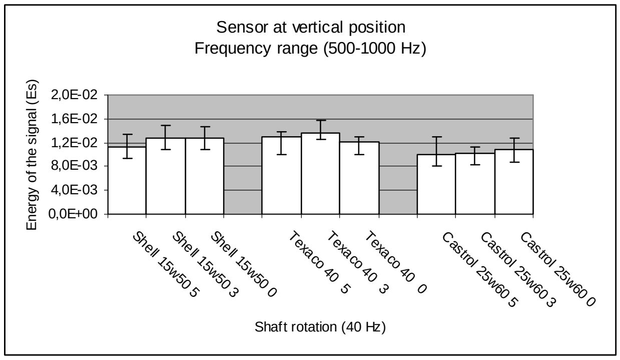


Figure 11. Energy of the signal for the three lubricant brands with and without two contaminant grades from 500-1000 Hz measured in vertical position at 40 Hz

From Fig. 9, Fig. 10 and Fig. 11 it is clear that the fewer the viscosity variations the more difficult is the capacity of detecting this variations.

4. CONCLUSION

Machines have inherent vibrations signature that characterize the baseline of their dynamical behavior. The baseline dynamics certainly affects the vibration characteristics of any monitored component. The vibrations measured by the accelerometers were affected by the overall dynamical response of the equipment, including all the component parts like the shaft and the structure. The results presented in this paper were related to the changes in the vibration of the equipment with respect to its baseline vibration, as a function of the lubricant type and contamination ratio tested in the ball bearing.

Variations caused by either, the use of different lubricant type or different biodiesel contamination ratio, affected the bearing vibration signal and were better observed between the range of 500-1000 Hz.

Changes in lubrication of the ball bearings due to contamination of the three lubricant types with the biodiesel of animal fat origin may be partially detected by vibration monitoring. If the change in viscosity was small it was almost impossible to detect it by vibration analysis.

For that purpose it is advised the use of coupled vibration and oil analysis technique nowadays because one complements the other. Each technique has its own advantage and disadvantage. As an example it can be seen at Table 2 that the lubricant of Shell brand without contamination has almost the same viscosity as the lubricant of Texaco brand contaminated with 3% by volume of the biodiesel tested. Due to the similarity in their viscosities, the vibration signal does not capture the problem. On the other hand if one observes the variations in flash point or in the alkaline reserve the problem is quickly observed.

5. ACKNOWLEDGEMENTS

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