TRIBOLOGYCAL EVALUATION OF OGR BIODIESEL USE IN DIESEL ENGINES

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Abstract. *To become technically viable the large-scale use of this biodiesel, some technical aspects deserve a special attention, within them it can be highlighted its use consequences on the engine lubricant oil. This study is important because of the presence of biodiesel in lubricant oil degrades its quality, directly interfering on the engine mobile parts lubricating conditions. This way, this research has as objective to evaluate which is the effect of the biodiesel produced from OGR – residual fats and oils- on the engine lubricant oil as well as the wearing caused on the engine components by its use. The OGR biodiesel physical chemistry properties used were evaluated and indicated that the biodiesel was within the patterns of the National Petroleum Agency. To the evaluation of the lubricant oil degradation, it was used the OGR biodiesel in a diesel stationary engine, working at constant speed of 1800rpm, under variable load condition. The engine, a Tramontini model TR 22, with mechanical pump and direct injection system has a nominal power of 22CV to 1800 rpm and was coupled to a 12,5 kVA Kolbach generator. During the tests, the engine-generator set met the energy demand of the electrical engines of a 1000 liter-day capacity biodiesel production plant. The tests lasted 300 hours, with lubricant oil sampling each 50-hour use. The results showed significant variation on the kinematics and dynamic viscosities and presence of biodiesel in the lubricant oil on the early 100-test hours, indicating the passage of the biodiesel to the crankcase from a combustion chamber, through the tribologycal piston rings system – cylinder jacket. Also, ICP - MS analyses were performed to verify the contamination of the lubricant oil by metals. The results showed a constant increase of oil contamination by Al, Cu, Mn, Fe, Pb and Cr. A visual and metrological evaluation of the engine's internal conditions was performed at the end of the tests. It was observed an accented deterioration of the compression piston ring in its upper face. Also, it has been noticed variation on the cylinder jacket roughness by the end of testing. Its conicity and the ovalization were also measured and their values meet the producer's specifications. The pressure of the injection nozzle was 170bar, within the established by the manufacturer and it was not observed any formation of significant deposits inside the engine. Considering that the manufacturer recommends changing lubricant oil every 100 hours-use and that the tests have lasted 300 hours, it can be concluded that OGR biodiesel may be used in stationary diesel engines since the lubricant oil change occurs periodically.*

Keywords*: biodiesel, lubricant oil, diesel engine*

1. INTRODUCTION

The use of vegetal origin fuel recalls to the diesel engine cycle development period, in 1897, when the Mechanical Engineer Rudolph Diesel elaborated and patented an engine by internal combustion through pistons with oil injection in a container with oxygen, causing an explosion when mixing. At that moment, Rudolph Diesel used the oil of pure peanut as combustible. However, because the market expansion of oil in the following decades, such engine was projected and commercially used with oil diesel proceeding from the extraction of petroleum, what has relegated the vegetal oil use for second plane. In such a way, during all century XX, some research had continued to be developed on the subject, attempting to especially adapt the vegetal oil to the diesel engine, which got being projected to work with a fluid of lightly different properties, especially in terms of viscosity. In 1922, Mailhe used acid catalysers to assist the vegetal oil transformation in hydro-carbons and, in 1924, Wattermann and Perquin had applied the Bergius process of hydro-carbons synthesis for high pressure hidrogenization of coal to the vegetal oil and had gotten an almost total conversion of these hydro-carbons. Although, only in middle of years 70, in the scene After World War II and, more specifically, after the oil crisis, in 1973, is that the research in the biofuels area became to receive considerable incentives again. In these conditions, Brazil, already in decade 80, started to increase these research through the Pro-alcohol, a federal program that allowed the development of an alternative biofuel (ethanol) for use in spark ignition engines, or Otto cycle. In the current decade, because of economic and environmental questions, the biofuels use came back to be an interesting alternative in the world-wide market, of form that, in Brazil, since 2006, a small percentage of biodiesel is already added to diesel commercialized in all the country, with increasing values in the composition of this fuel which arrive, today, 5%. So, many alternatives are being evaluated as sources for biodiesel production, in a way that different cultures of oil plants can supply the market, depending on the geographic region in which if it is found. Moreover, the environmental appeal is also a strong partner in the development of these technologies, not only because the question of the reduction of the particulate emissions of material and sulphur composites for engines diesel, but also because the question of the recycling of oils and residual fats (OGR), thus reducing its environmental impact. It is appropriate to point out, however, that the biofuels use in engines can cause differentiated wearing on the parts of the engine, as well as intervening with the performance of the lubricant oil that, in a full analysis, compromises the performance of the engine as a whole. In such a way, many companies of the private sector, as well as the Ministry of Science and Technology, through the National Program of Production and Use of Biodiesel, are promoting researches and studies in short, medium and long run through its module of Technological Development. One of the areas in study refers to the tribologycal issues associated to the biodiesel use in diesel engines (MCT, 2009), which point to the necessities of modifications and adjustments with respect to optimum exploitation of this technology.

2. THEORETICAL REFERENTIAL

2.1 Use of biodiesel in engines

The lubrication deficiency in mechanical systems of the motor cause inestimable damages, mainly with respect to premature wearing, efficiency loss, reduction of the components useful life and, in the most serious cases, the blocking of the engine. Aiming to reduce costs, the lubricant oil analysis becomes an important technique for the predictive maintenance of engines, that is, through a series of analytical techniques of the used oil it can be evaluated where and when the probable problems will appear.

Corrêa et al (2008), had evaluated the sunflower biodiesel and diesel use in the performance of a diesel engine with direct fuel injection, in dynamometer for mixtures B5, B10, B20 and B100, during 96h of use. The results had shown that, in terms of lubricant oil contamination for biodiesel, even after the use of B100, it had been detected acceptable alterations, being the water presence and the text of iron the more expressly parameters modified. The same authors had tested sunflower rude oil in a diesel engine MWM 229,3, 46kw of power and they had identified that the lubricant oil degradation occurred already in the first 60h of engine use. This contamination was identified by the lubricant viscosity increase, by the raised presence of oxidation products, by the accented fall of the alkaline reserves and by the raised text of copper, chromium, iron and lead.

About mixtures diesel/biodiesel, Silva (2006), in its research, evaluated the effect of biodiesel on the lubricant oil properties, when used in the B10 ratio in a diesel engine, inhaled, with indirect fuel injection. The assays had lasted 30h and shown that the use of 10% in volume of biodiesel combined with metropolitan diesel did not cause significant variation in the concentration of metallic elements or the physical - chemical properties of the lubricant oil. It had been evaluated in this work the contamination for diverse metallic elements, being that the most relevant values had been found for Fe, Al, V, Sn, Pb, Ni, Cr and Cu and they had not exceeded 1,45ppm, that can be considered a degree of contamination for new lubricant oils. Moreover, the properties of percentage of water, viscosity and density of the lubricant oil had been also monitored. The values found for each one of these variable after the assays had remained inside of the limits established by the ANP.

In terms of performance of diesel engines using biodiesel or mixtures diesel/biodiesel, Juliato (2006), tested B2 mixtures, B5, B10 and B20 of soybean and turnip oil in a monocylindrical engine, Yanmar, with power of 7,7kW 2400rpm. The engine was mounted in a dynamometer, where it was assayed for verification of the torque, power and brake specific fuel consumption curves for each used mixture. The results had shown not to have significant differences in the values of the engine torque and power, when working with mixtures biodiesel/diesel comparatively to diesel standard. However, a sensible increase in the specific consumption of the fuel, proportional to the percentage of biodiesel added in the mixture was evidenced. This result agrees to the observed one for Porte (2008), who evaluated, during his research, a monocylindrical engine Toyama, with normal rated power of 4kW 3000rpm and relation diameter x course equal to 78 x 62mm, with regard to the brake specific fuel consumption. The assays had understood B2, B10, B20, B50 and B100 mixtures of sunflower oil and the results had also shown an increase of proportional the brake specific fuel consumption to the addition of biodiesel in the mixture.

Puhan et al (2005), had tested biodiesel produced by transesterification using sulfuric acid as catalyst in a diesel engine with direct fuel injection. The tests were carried through by a constant speed of 1500rpm and the results showed that the thermal efficiency of biodiesel produced was comparable to the diesel one (26.36% for diesel and 26.42% for biodiesel used).

Assays of fleet had been also carried through with stimulate of the Ministry of Science and Technology, in Brazil (MCT, 2009). During the years of 2008 and 2009, they had been evaluated diesel engine supplied with B5 mixtures, for periods of use superior to 10.000h. The used engines in the tests had been chosen randomly, being of different marks, submitted to the different applications (load transport, passengers, agricultural implements), in such a way that the systems of fuel injection Common Rail, UIS, UPS, and rotary press were tested. The tests had the participation of many companies of different sectors of the biodiesel chain, such as fuels producers (Petrobras), vehicles manufacturers (Ford, Fiat, Volkswagen), injection systems manufacturers (Bosch) and of physical-chemical analyses laboratories (Ladetel, Tecpar). The results had shown that the conditions of wearing for engines supplied with B5 and engines supplied with metropolitan diesel did not present significant differences between it. The only exceptions made during the assays were referring to the use of biodiesel of mamona in engines, in function of that many injection systems had presented fails that had disabled the accomplishment of the tests for the same period that the engines supplied with biodiesel of oil soybean.

2.2 Tribology applied to the engines

It is consensus that the biggest amount of lost energy occurs in the friction between the piston rings and the cylinder jacket (Bhatt et al, 2009). In such a way, when the efficiency of a lubricant is evaluated, it is important to measure the thickness of the lubricant film at this tribologycal system. This thickness can vary between 2,5 and 8 micron with SAE 10W50 oil at 1600rpm and without load, as prescribed for Harigaya et al.

Takiguchi et al (1988), had measured the friction forces until a speed of 5000rpm and its results had shown that the present friction in the region is provoked, basically, by the lubrication hydrodynamics in high rotation of the engine. The same authors had measured the thickness of the lubricant film in piston rings under real conditions of operation of a diesel engine. Their results had shown that the thickness takes care the hydrodynamics lubrication theory if there is enough oil in the region. Moreover, the thickness of the oil film of the piston ring under real conditions was measured for the same motor (D x S = 140 x 152 mm). As result, it was also observed that the measured thickness film, although agreed to the hydrodynamics theory, presented always a real value inferior to the theoretical one and that the upper ring always varied its inclination against the wall of the cylinder, affecting the formation of the lubricant film.

Miltsios et al (1989) had assumed that the ring has a circular profile in the direction of the movement and had assumed that the piston is elliptical. The ring inclination is also considered. When the oil film is thick enough to not have contact between the surfaces, the lubrication is hydrodynamics. When the oil film does not have this minimum thickness, there is contact between the surfaces and the lubrication is mixing because the film supports a part of the load and another part is supported by the surfaces roughness. The oil film thickness beyond which the hydrodynamics lubrication exists cannot be determined with precision. It depends on the surfaces topography and the heights of the roughness.

Wakuri et al (1992), had assumed that the oil film pressure in the oil entrance is equal to the ambient pressure and that the oil film breaks in the exit according the Reynolds boundary conditions. After the oil film breakdown, the oil is carried to the cavitated region. The pressure in this region is constant in relation to the ambient. When the piston rings are used in set, the oil supplied to each ring is dependent of the amount of oil left for the preceding ring. The subsequent rings vain operate in a condition of oil imbalance, where the region of the entrance of the ring incompletely is filled with oil, even if the main ring is working with the ideal amount of lubricant. In such a way, the analysis that the oil is supplied adequately to the rings in the entire time interval is not true. The interaction between rings in a set of rings is determined by the condition of continuity of the draining of the oil if this to flow in or flow out the volume of control.

3. METODOLOGY

To perform this research, the assignments were divided in four steps, described bellow.

3.1. Biodiesel production from OGR

Afubra collected the OGR used in the production of biodiesel from schools, restaurants and residences of the region of Rio Pardo Valley, and it was stored in PET bottles, these oils pass trough an initial process of filtering for withdrawal of solid material. Following, it is prepared the mixture for production of biodiesel in the ratio of 200 liters of oil for 34 liters of methanol and 8 liters of methoxide of sodium, that produce 198,6 liters of biodiesel and 43,4 liters of glycerol. The conversion ratio, for OGR, is about 92,5% (m/m). The mixture passes then for a heating process at 60° for a period of 30 minutes, followed by a time of reaction of 45 minutes. The decantation of glycerol is then preceded for a period of 2h, followed by filtering and burnishing of biodiesel, in a continuous process at 185 liters per hour.

3.2. Characterization of OGR biodiesel

In order to characterize biodiesel of OGR during the tests, the norm ANP 07/2008 was obeyed. The samples of biodiesel were collected and sent for analysis in an accredited laboratory.

3.3. Tests with diesel engine fulled by biodiesel of OGR

The diesel engine used was a motor Tramontini, TR 22, with power of 22CV at 1800rpm, water-cooled, electric start, with direct injection by mechanical pump. The engine was connected to a three-phase generator Kolbach, 220/380V with capacity of 12,5kVA. The set engine-generator was acquired new, reason by which has not been done any initial procedure of maintenance. The engine was supplied directly by biodiesel of OGR previously produced in the AFUBRA's production plant, after a storage period of 45 days. The lubricant used in the engine, as recommended by manufacturer, was oil SAE 15W40, whose regularity of exchange also recommended by the manufacturer, is 100h. From this value, it was stipulated that, for the purpose of this research, the engine would work with biodiesel of OGR during a period of 300h without oil exchange, so exceeding in 200h the recommendation of the manufacturer for lubricant exchange. Samples of new lubricant oil had been collected and in intervals of 50h of use of the engine, obeying the following cares:
- The samples had been collected with the engine running, at least, 20 minutes;
- All the samples had been removed from the crankcase;
- The bottles used in the sampling were new, manufactured in polypropylene;
- The bottles had not been completely filled during the collection in order to guarantee its homogenization and expansion for the temperature.

After 300h of use of the engine, it was opened for measurement of its internal components and verification of the degree of observed wearing. The following parameters had been analyzed:
- Wearing and ovalization of the cylinder jacket. For measurement of the wearing on the cylinder jacket, it had been considered the measurement of its superficial roughness with a Suftest 211 - Ra scales. For measurement of the ovalization of the cylinder jacket, it was used a comparing clock Starret, model 452. The measurements of superficial roughness of the cylinder jacket had been carried through in the new jacket and after the assays, in a total of 10 measurements in the Top Dead Center (PMS) and 10 measurements in the half of the piston course;
- Gap between ring tip;
- Wearing in the rings faces, with aid of optical microscope;
- Gap between rings and narrow channels using a calibrador de folgas Starret;
- Contamination, leakage and pressure of injection in the injector peak, with aid of an appropriate group of benche;
- Wearing of the injection piston in the mechanical pump, by means of visual analysis, with aid of optical microscope;
- Contamination of the fuel filter, by means of visual inspection;
- Contamination of the centrifugal lubricant oil filter, by means of visual inspection.

During the assays, all power generated by the set engine-generator was unloaded in the electric equipment of the biodiesel production plant: four electric engines of 0,5HP, an electric engine of 0,25HP, an electric engine of 1,75HP 2 electric engines of 1HP, an electric resistance of 7500W and 3 light bulbs of 150W that it composes the cell of energy production, totalizing a demand of energy of approximately 17kW.

3.4. Methodology for lubricant oil analysis

The analyses of the lubricant oil had consisted of a accompaniment, in approach intervals of 50h of use of the engine, of the following variables: specific weight, acid value, viscosity kinematics, dynamic viscosity and flash point, in accordance with respective norms ASTM. Also the biodiesel contamination was evaluated through the method for Attenuated Total Reflection in the Infrared ray with Transformed of Fourier (ATR-FTIR). The results had been acquired, in third copy, in spectrophotometer PERKI ELMER using an internal accessory of universal attenuated total reflectance, in the interval 4000 to 400cm^{-1}, with resolution of 4 cm^{-1} and 32 sweepings. Finally, also the contamination of the lubricant oil by metals was monitored, where the samples had been submitted to a procedure of acid digestion attended by microwaves radiation (Multiwave 3000, Anton Paar, Austria), with capacity for 8 simultaneous decompositions. About 200 mg of sample had been transferred to the quartz pipes with the aid of a syringe. They had been added, immediately afterwards, 6 mL of 14 HNO_3 mol L^{-1}.

After the stage of digestion, the samples had been augmented at 30 mL in polypropylene bottles and later diluted 5 and/or 10 times, when necessary. The samples had been analyzed by ICP OES equipped with a "cross-flow" pneumatic vaporizer (Spectro Analytical Instruments), vaporizer chamber of double step and torch with 2,5 mm of internal diameter quartz injector. The plasma was generated from argon (99.996% of pureness). The analysis conditions are shown in Table 1.

Table 1: Operational conditions of ICP OES.

CONDITION	ICP OES
Generating power RF (W)	1400
Main Ar outflow (L min-1)	20
Ar outflow auxiliary (L min-1)	1
Ar outflow of the vaporizer (L min-1)	0,9

In Table 2, the used wavelengths for each element are shown.

Table 2: Wave lengths (nm) chosen for each element.

Element	ICP OES (nm)
Al	396,152
Cd	214,438
Cr	205,552
Cu	324,754
Fe	238,204
Mg	280,270
Mn	259,373
Ni	231,604
Pb	220,353
Si	288,158
Zn	213,856

4. RESULTS AND DISCUSSION

After analysis of biodiesel in laboratory, the results (table 3) had shown that the water content present in the samples was much higher then estabilished by ANP, what can bring serious damages to the engine. According Fox et al, the waters content compromises the lubricant capacity of biodiesel. This factor can speed up the wearing in some componentes where the lubrication is done just by biodiesel, like the mechanical pump piston in the injection system. Besides that, it’s verified that as older the oil is, more susceptible it’s become to degradation by the water. (Fox at al, 1990 and Bormio, 1995).

Table 3 – Characterization of biodiesel used in the tests

Parameter	Method	Standard	Measure	Unit
Aspect	visual	LII	LII	-
Specific mass at 20°C	ASTM D 1298	850 -900	884,2	kg/m³
Kinematic Viscosity at 40°C	DIN EN ISO 3104	3,0 – 6,0	5,6924	mm²/s
Water content (max)	ASTM D 6304	500	2800	mg/kg
Total contamination (max)	DIN EN 12662	24	63	mg/kg
Flash point (min)	ASTM D 93	100	20	°C
Ester content (min)	DIN EN 14103	96,5	81,40	% (m/m)
Carbon residue (max)	ASTM D 4530	0,05	0,12	% (m/m)
Ashes (max)	ISO 3987	0,02	0,04	% (m/m)
Sulphur (máximo)	DIN EN ISO 20884	50	10,2	mg/kg
Sodium + potassium (max)	DIN EN 14108/109	5	<0,5	mg/kg
Calcium + magnesium (max)	DIN EN 14538	5	<0,5	mg/kg
Phosphor (max)	DIN EN 14107	10	0,7	mg/kg
Corrosivity (Cu), 3h at 50°C (max)	DIN EN ISO 2160	1	1a	corrosion degree
Cetanes	DIN EN ISO 5165	-	55,8	-
Cloud point (max)	DIN EN 116	19	-7	mg KOH/g
Acid number (max)	DIN EN 14104	0,5	0,55	% (m/m)
Free glycerin (max)	DIN EN ISO 14105	0,02	0,02	% (m/m)
Monoglicerides		-	0,57	% (m/m)
Diglicerides		-	1,90	% (m/m)
Triglicerides		-	12,52	% (m/m)
Total glycerin (max)		0,25	1,73	% (m/m)
Metanol (min)	DIN EN 14110	0,2	1,90	% (m/m)
Iodine number	DIN EN 14111	-	110	g/100g
Oxidation stability 110°C (min)	DIN EN 14112	6,0	0,7	h

Besides that, can be also noticed that the biodiesel presented low oxidation stability and high values for contamination, ashes and glycerin, which also compromise the contamination inside the engine.

In terms of wearing of the engine components, it was observed that the bushings had presented marks of wearing by abrasion, provoked, possibly, for strange particles they had incrusted in the surface of the bushings, and wearing by erosion. In assays carried through in-group of benches, it was observed that the injection pressure was 170bar and that there was fuel dripping when the set was not set in motion. This would send to the wearing in the needle of the injection peak, but what can be observed in optical microscope was irregularities in its surface, probably deriving of its manufacturing process, once that did not have signals of wearing in the element. Also, no blockage in the orifices of peak injection was observed.

In accordance to the manufacturer information of the engine used in the assays, the cylinder jacket is made of cinereous casting iron with addition of Ni, Cr, Cu and Mo. Such component still presented the stoning after 300h of assay throughout its entire surface, except in the region corresponding to the compression chamber. Considering only the region of the jacket corresponding to the cylinder course, the measurement of the superficial roughness showed a bigger wearing in the region of the PMS (table 4). This is justified by the fact of that, in function of the high accelerations gifts in these regions, the hydrodynamics layer of the lubricant film reaches critical values, having at certain moments its disruption and the consequent material remove of the surfaces in relative movement.

Table 4 – Measurements of roughness after 300h in the cylinder jacket

Measurements of roughness after 300h	Roughness in the PMS (μm)	Roughness in the middle of the cylinder course (μm)	Roughness in the new jacket (μm)
Average of 10 readings	0,363	0,497	0,740
Standard deviation	0,113	0,230	0,121

It was observed that the ovalization of the cylinder, made from the average of 5 measurements of the difference between two diameters unbalanced of 90°, was of 0,005mm. Also the coning of the shirt was measured, whose average value for three readings was of 1 ' 37 ' 'of coning. Such values do not represent inconveniences for the functioning of the engine, being inside of the acceptable limits defined by the manufacturer of the equipment. The segment rings, in special, the first fire ring, had presented marks in the form of risks in the direction of the piston movement, as figure 1.

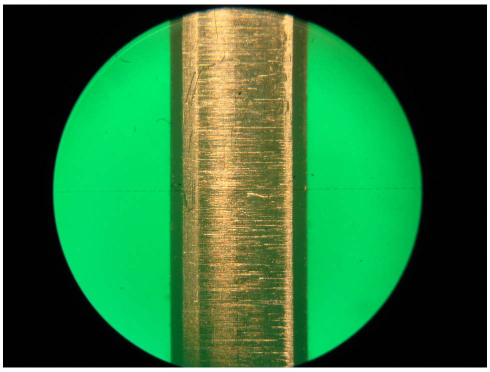
Figure 1 – Fire Ring (external face)

Such marks point to an abrasive wearing, caused by the breakdown lubricant film present in the tribologycal system ring/shirt. This wearing was provoked, probably, by cyclical form, once that the jacket indicates minor roughness in the region of the PMS. One gives credit that great part of the marks gifts in rings had been provoked while the piston reached this point of the jacket, where the tribologycal conditions are more unfavorable.

No significant formation of splodges, soap or points of corrosion in the fuel filter was identified, just as no significant wearing in the fuel pump was identified.

The spectroscopy in the infrared ray did not identify the presence of biodiesel in the lubricant oil even at 300h of use, as that was not identified the carbonyl composite presence, characteristic of the band of 1500cm^{-1}. However, the assay also showed the carboxylic composite presence (band of 3000cm^{-1}) and alterations in the band of 1370cm^{-1}, characteristic of ν (C – O), that indicates the oxidation of the lubricant oil throughout the time, as shown in figure 2.

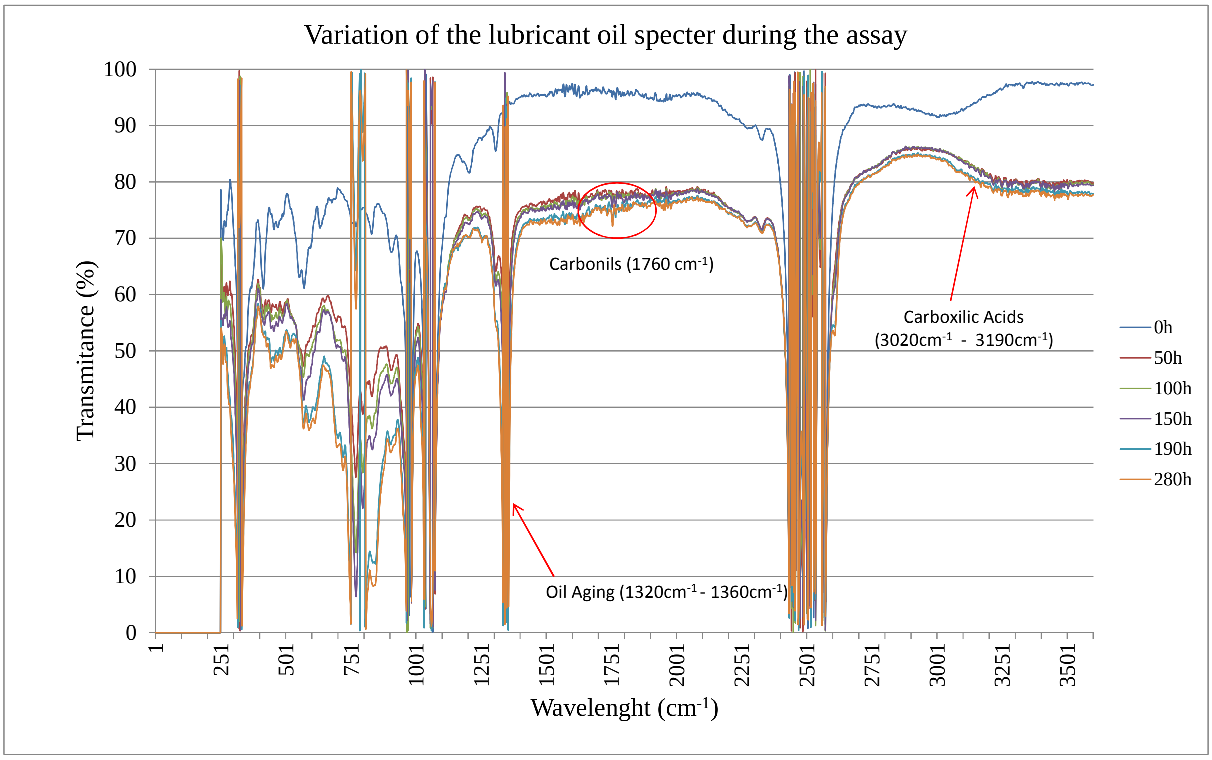

Figure 2 – Specter of the lubricant oil during the use

These results are according to the reduction of viscosity of the lubricant oil, as Figure 3 shows. This can have favored the wearing of the engine, especially in the region between rings and the cylinder jacket, where the tribologycal conditions are more severe.

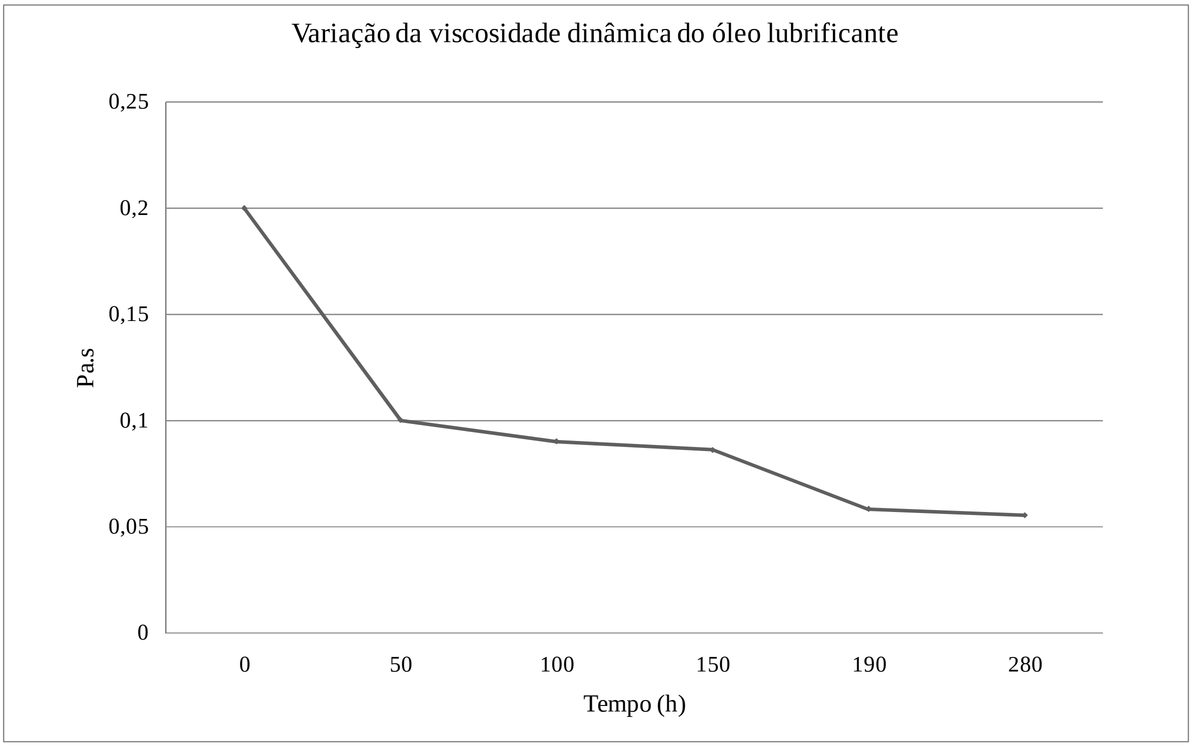

Figure 3 – Dynamic viscosity of the lubricant oil variation trough the time of using

It was noted yet that there was an increase in the acidity of the lubricant oil, provoked by the contamination and degradation of biodiesel, as shown in Figure 4.

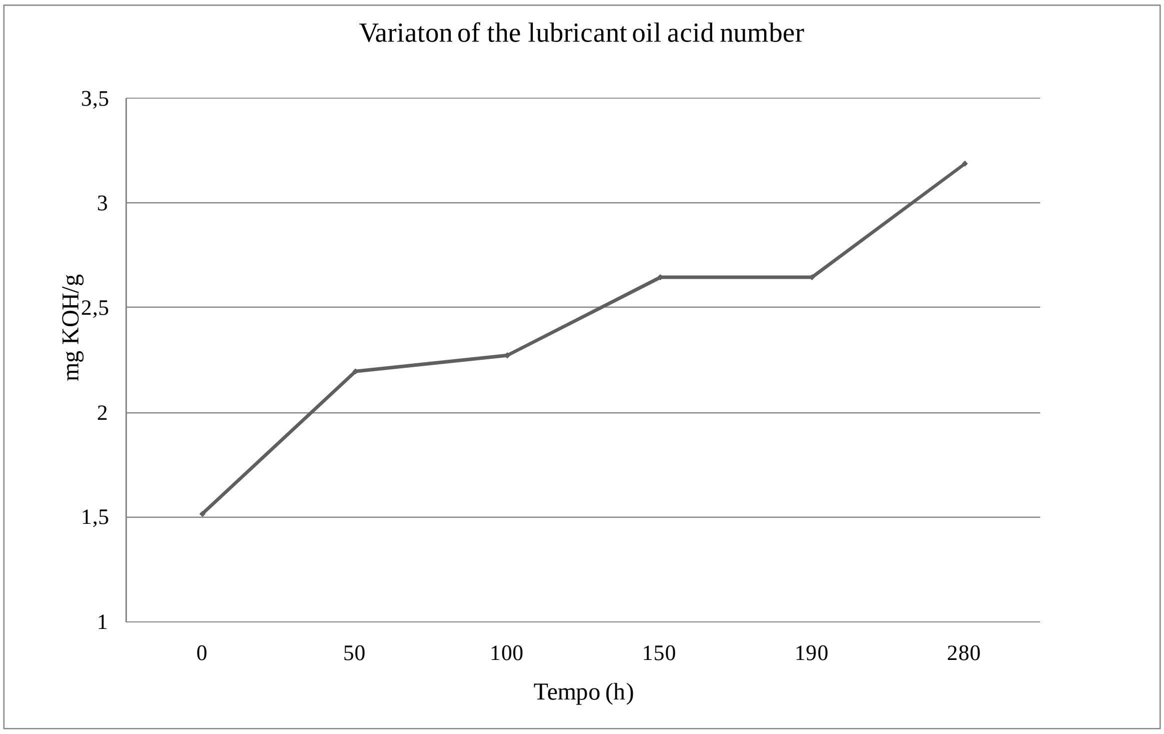

Figure 4 – Acid value of lubricant oil variation through the time of using

An equation can be got from this analysis to monitor the increase of the acid value and, for consequence, the contamination of the lubricant by biodiesel in function of the time:

$$y = 1,2047.e^{0,1903.x} \quad (1)$$

$$R^2 = 0,809 \quad (2)$$

Where y corresponds to the acid value of the lubricant and x corresponds to the time of use of the lubricant in the engine. The results had shown despite the specify weight of the lubricant oil did not vary and that the reduction in its flash point can be considered worthless for practical works, therefore was inferior to 2% to the end of the assays.

The analysis of contamination by metals showed a continuous increase of aluminum, chromium, cooper, iron, manganese and lead. The chromium, lead and cooper are proceeding, probably, from piston rings, in accordance with its composition and signals of wearing. The manganese is proceeding from the jacket and the iron can in such a way be deriving from the jacket or from the rings, whereas the aluminum must be deriving from the piston. Table 5 shows the variation of the lubricant oil contamination by metals throughout the assays.

Table 5 – Lubricant oil contamination by metals during the tests – mg g^{-1}

	Al	Cd	Cr	Cu	Fe	Mg	Mn	Ni	Pb	Si	Zn
0h	3,86	<0,11	<0,25	<0,4	<1,7	266	0,34	<0,75	<3,32	<360	1136
50h	<3	<0,11	1,11	8,02	35,8	218	1,27	<0,75	<3,32	<360	1152
100h	7,19	<0,11	1,38	9,95	70,13	211	1,57	<0,75	3,61	<360	1093
190h	7,72	<0,11	1,4	13,26	80,69	170	1,87	<0,75	9,97	<360	875
280h	7,54	<0,11	2,29	9,57	86,64	172	2,02	<0,75	13,78	<360	864

Based on the table results, the following equations and respective correlation coefficients are proposed for each one of metals in question:

Aluminum: $y = 3,4321.\ln(x) + 1,9757$ (3)

$$R^2 = 0,4267 \quad (4)$$

Chromium: $y = 1,2346.\ln(x) + 0,0538$ (5)

$$R^2 = 0,9114 \quad (6)$$

Cooper: $y = 6{,}9384.\ln(x) + 1{,}5165$ (7)

$R^2 = 0{,}7951$ (8)

Iron: $y = 56{,}649.\ln(x) + 0{,}4105$ (9)

$R^2 = 0{,}9813$ (10)

Magnesium: $y = 0{,}1667.x^3 + 3{,}2143.x^2 - 47{,}952.x + 308{,}4$ (11)

$R^2 = 0{,}9469$ (12)

Manganese: $y = 0{,}04.x^3 - 0{,}4714.x^2 + 2{,}0086.x - 1{,}226$ (13)

$R^2 = 0{,}9951$ (14)

Lead: $y = -0{,}5133.x^3 + 5{,}3607.x^2 - 12{,}806.x + 8{,}022$ (15)

$R^2 = 0{,}9982$ (16)

Zinc: $y = 23{,}5.x^3 - 226{,}71.x^2 + 563{,}79.x + 769$ (17)

$R^2 = 0{,}9645$ (18)

Where y represents the metals in each equation, x represents the time of using and R^2 represents the correlation coefficient.

One strong positive correlation is observed between the time of use of the lubricant in the engine and its contamination by the metals chromium, cooper, iron, manganese and lead. Amongst these, salient that iron, manganese and lead present R^2 superior to 95%. It is justified by the following facts:
a) The iron is the metal present in bigger amount in all the existing tribologycal systems in the engine, in such a way that its wearing throughout the time becomes more salient;
b) Lead is a soft material present in the tribologycal system rings and the cylinder jacket;
c) The manganese is present in the great majority of steel. In the engine in study, one not only meets present in the jacket and rings, but also in the proper cylinder of the engine, manufactured in aluminum alloy.

Magnesium and zinc present a strong and negative correlation, superior to 90%. This can be justified because of the new lubricant oil presents high texts of these elements in its composition that, during its use, are agreed with other elements of the metallic surfaces of the engine. For example, the magnesium can agree with oxygen at high temperatures in the region of the combustion chamber forming the magnesium oxide, or still, to combine with the walls of the jacket, being formed composites of Fe - Si - Mg. Yet, the zinc, by its characteristic of material of sacrifice in corrosion situations, can agree with the atmospheric oxygen at high temperatures to form oxide of zinc in the surfaces of the jacket or rings, being thus formed a superficial oxide layer or basic carbonate that isolates the metal and protects of the corrosion.

A moderate positive correlation is still noticed between the time of use of the lubricant oil and its contamination by aluminum. The fact of this correlation not to be so strong as the previous ones are justified by the fact of that the biggest amount of aluminum present in the diverse tribologycal systems in question meets in the piston of the engine, that does not suffer a wearing so accented as rings or jacket. Ahead it said, concludes that biodiesel of OGR in study can be used in the Tramontini engines since that the regularity of exchange of the lubricant oil recommended by the manufacturer is kept, in intervals of 100h.

5. ACKNOWLEDGMENTS

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