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ANALYSIS OF THE LUBRICATING OIL'S LIFE OF BIOGAS POWERED GENERATORS

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Abstract. *The economic development of the western region of Paraná is vastly based on livestock, due to this we must promote initiatives that reduce the negative effect of this activity on the environment. The swine herd, dairy, cattle and poultry million head confined in various farms in the region add jobs and income for thousands of families but generate organic wastes that require a single treatment in order to prevent environmental pollution. A likely alternative to this problem is the installation of biodigesters, which stores the gas released by bacteria in anaerobic digestion process of wastes, and electricity generators. This generators use the heating from the oxidation of the gas, named Biogas, rich in methane to generate electricity and to fuel the properties. The sludge resulted from fermentation of organic material can still be used as a biofertilizer, closing the cycle of the sustainable process. The biogas has high levels of* H_2S *and* H_2O *and this represents an obstruction for the lubricating oil of the engine where the gas is burned, because this contaminates the oil and then accelerates its oxidation, reducing its life and increasing the frequency of their exchanges for new oil. The object of this work is an attempt to increase the time between oil and oil filters exchanges from gas engines MWM 6.12T determined by the manufacturer, seeking to extend the life of the lubricant and reduce costs with lubrication . The defense of this work was based on the study of the production of biogas, the use of biodigesters and operating characteristics of gas engines MWM 6.12T used in electricity generators. It was observed the operating environment to which these engines are unsheltered and the possible sources of oil contamination. Armed with the physic-chemical characteristics of the lubricant, together to its laboratory analysis and considering the presence of main contaminants it can be possible to determine the state of oil degradation in order to support the chosen decision to meet the object.*

Keywords: *biogas;digester;gas engine;lubricating oil;lubrication*

1. INTRODUCTION

The western Paraná's economy is based on farming and agro industry. According to IBGE (2011), the cattle herd was nearly 1.2 million head, the pig exceeded 2.2 million and the chickens passed the 75 million, helping to keep the state as the possessor of the biggest effective of this species (22.3%).

Due to livestock large scale and the processing of the flesh, there is a huge concentration of waste and leavings at farms and industry. The technological development applied to livestock has made it possible to increase the capacity for animal's feedlot and its daily slaughter, fortifying the economy of both sectors. However, this implies an increase in the generation of waste that without appropriate facilities for treatment are dumped into rivers and lakes, causing the deterioration of these environments (Nishimura, 2009). As a sustainable alternative to this impasse economic and environmental, it was suggested to invest in the installation of digesters and motor generators, which should help in saving the environment, reducing the farm's dependence for energy and increasing the profitability of activities performed.

The digesters are structures specially designed for the anaerobic digestion process of waste, performed by bacteria (Magalhães, 1986). One of the byproducts of this process, the Biogas, is a flammable gas, rich in methane (CH_4) and used as fuel in motor generators groups adapted for its use. Generally, it has high concentrations of water (H_2O) and Hydrogen sulfide (H_2S). This in turn, if not removed from the biogas by filtering, can join the power generator's lubricating oil, and due to being highly corrosive, contaminate it and contribute significantly to the oxidation process.

Given that, by analysing the physic-chemical properties of MWM 6.12T engine's oil samples, each one working with different kinds of oil, and based on the operating conditions of each engine, is intended to infer about the possibility of increasing the time between oil changes, thus seeking to extend the lubricant's life and to reduce costs with lubrication.

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1.1 Motivation

The burning of biogas generates electricity that supplies the farms and some facilities of agro industries, thus decreasing the energy dependence of its facilities and it is possible to use the sludge after fermentation as biofertilizer in agriculture.

As all rotating machines, the engines need to have their rotating parts well lubricated to avoid defects or failures. However, the lubricating oil used in these engines also suffer oxidation and need to be exchanged at a period determined by the manufacturer in the program of engine's periodic maintenance. Each exchange is equivalent to 18 litters of oil reset and for a small farm spending on this replacement can mean a generous reduction in profitability of the electricity generation system deployed.

The maintenance program is uncertain as the interval exchanges because it suggests that this depends on the extreme of demands and environmental conditions of operation. Thus, this study aims to analyse the lubrication process currently used in the MWM 6.12T engines and to infer about the possibility of increasing the time between its oil changes.

2. THEORETICAL ANALYSIS

2.1 Biodigester

In general, facilities that hold animals in confinement are cleaned with water and the waste extracted are channeled into treatment ponds or poured in shafts water that goes through the farms. In any case, the excrement is exposed to the environment and that contributes to water contamination in addition to along its fermentation methane releases into the atmosphere. The biodigester is an alternative to avoid these problems.

According to Magalhães (1986), the biodigester is a chamber with varied shape and a bell jar. The chamber operates like a septic tank, into which organic substances are fermented under anaerobic conditions, and it is the digester. Already the bell jar accumulates the gas generated during fermentation and it is the gasometer. This structure is intended to obtain biogas and hence its byproduct rich in nutrients, the biofertilizer.

The substrate, after completely digested, results in an excellent fertilizer applied to the soil, renewing its productive capacity. This create new vegetable waste resulted from leaves, grass, herbs, vegetation, that way creating a cycle of renewable energy.

The volume of the daily load in biodigester needs to be constant to maintain the internal stability. Excess water in the mixture restricts the fermentation and increases the retention time. The concentration of solids around 8% is considered optimal in the solution.

The model of biodigester installed in studied units is the Canadian or Navy or tubular flow. It is horizontal, rectangular masonry base and gasometer built in PVC set over a ditch covered with water that surrounds the base (Steinhauser, 2008). Its main feature is the coupling of several modules in series. As the western Paraná is extremely hot during long periods of the year, the temperature inside the biodigester is maintained in sufficient amounts for fermentation of organic material. The cover is made of PEAD and it is anchored in the ground.

Figure 1. Canadian Biodigester

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2.2 Biogas

A great importance has been given to biogas because it can play the role of "politically correct" fuel. It addresses environmental issues of a legal nature or simply exempts the inputs of the properties and makes them more energy independent and profitable.

Biogas is a gas resulted from the anaerobic fermentation (in privation of free oxygen on air) of organic material, under appropriate conditions of humidity, temperature and acidity. In case of waste, Godinho (1981) explains that the digestion process is the decomposition of waste by methanogenic bacteria which reduce the molecular size of the cellulose in gas particles through anaerobic fermentation, resulting in a biomass and part of it is transformed into methane (CH_4) or methanol (CH_3OH).

Magalhães (1986) even states that the composition of biogas varies according to the composition of substrate (organic material), the temperature inside the digester, fermentation time and even the model and the capacity of the digester because there is the possibility to digest different materials such as manure, feces, leavings, rotting fruit, twigs, leaves and others and the environments and conditions are different for each location. The fuel is methane by excellence and the biogas is as pure as more content of methane. It is odorless and can not be detected unless artificially odorized. When mixed with air in a ratio of 1:5 to 1:15 is detonating.

In usual values, to Magalhães (1986) the gaseous mixture consists of:

Table 1. Composition of biogas mixture

Gas	Formula	%
Methane	CH_4	$55-65$
Carbon Dioxide	CO_2	$35-45$
Nitrogen	N_2	$0-3$
Hydrogen	H_2	$0-1$
Oxygen	O_2	$0-1$
Hydrogen sulfide	H_2S	$0-1$

About the Hydrogen sulfide (H_2S), Magalhães (1986) says that it is the most likely cause for the corrosion of metallic materials and is obtained by reduction of sulfates in water. This gas releases and dissolves in condensed water on the top of the pipes, together the oxygen which comes from ventilation. This ventilation, full of aerobic bacteria, assists in gas oxidation, giving rise to sulfide gas (H_2SO_4), which erodes the internal surfaces of pipes and engines and can also contaminate the lubricant, causing more damage to the engine.

2.3 Combustion Engines

Combustion engines are thermal machines that convert heat generated by burning fuel, in this case a hydrocarbon (CH_4), into mechanical energy (Kimura, 2010). For the engines WMW 6.12T installed in the units studied, the mechanical energy is converted into electricity by a shaft that connects the engine to the electrical generator.

Figure 2. MWM 6.12T Gas Engine

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The MWM 6.12T is a four-stroke engine with six cylinders. In this kind of engine the crankshaft must make two complete revolutions before the camshaft complete one revolution (Taylor, 1988). Technically, this engine has its block and head designed for ignition occurs by compression and Diesel is the original fuel. However, as biogas is admitted into the combustion chamber and its calorific value is lower than the diesel because the carbon dioxide presents, the compression of the air-fuel mixture does not generate its ignition. Thus, it is necessary to include candles in the cylinder head, which generates spark and oxidise the mixture and the engine ignition becomes by spark.

Another change is about the properties of the intake air. As the original engine is Diesel, it only admits air and thus operates in Diesel cycle. But when it undergoes changes and starts to admit air-fuel mixture, it is Otto cycle.

In diesel engines, the insufficient combustion can result in soot, which represents not oxidized products from the combustion of mixture. These products penetrate through the walls and shirts of the cylinder block and reach the oil in crankcase and that affects negatively the performance of the lubricant (Kimura, 2010). It is believed that this can be the mode of crankcase oil contamination with H_2S.

As the methane is the fuel used into studied engine, it is worth noting that this is not over diesel but gas engines. It is included within the generic classification of explosion engines, those in which the gas-air mixture reaches the cylinder and a spark produces an explosion and therefore the dilatation transforms thermal energy into momentum (Taylor, 1988).

2.4 Lubrication Process

Definitely, there is a moment in oil's life that it should be replaced. However, the replacement will be connected directly to the machine type and the nature of the operations involved. In practice, observation and common sense are essential factors for a good evaluation of the oil and equipment condition (Moreira, 1987).

A lubricant would have unlimited life cycle if it could be free of contaminants. The major sources of contamination of sump oil are the combustion products. The operating conditions, type and quality of fuel and the mechanical conditions of the engine, induce the nature and in the quality of contaminants that are found in lubricants (Carreteiro, 2006).

Even when are studied identical equipments in similar services, there will always be different conditions resulting in different performances of the lubricant, thus each case should be treated separately.

For Moreira (1987), the Lubrication Process is much more than the simple application of lubricant. It is the connection between all the steps that concern to the lubricant: choice, buying, transportation, storage, testing, training, instruction, lubrication, cleaning, handling, among others.

As understood, the study of the lubrication process of maintenance units or equipments, which generates a planned lubrication, trends to increase the effectiveness of maintenance. Currently, in the demonstration units of biogas studied, there are no parameters to determine which lubricant should be used in engines, as well there is no concern about its storage, cleaning and the correct procedures for an effective lubrication. There is no training that gives an insight into the lubrication process of such units or equipment. The guidance on performing the management of waste oil is insufficient and there are no standard to justify its replace, leaving the maintenance technician to decide if it is already time to exchange it or not. It is easy to see the disregard for lubrication process steps.

(a) Poorly Covered Container (b) Improper Storage and Dirty Environment

3. MATERIAL AND METHODS

In general, it was necessary to conduct a study regarding the biodigesters, because them provide the necessary conditions for the generation and storage of biogas, a feedstock that is converted into electrical energy by the generators. Another subject discussed was the biogas itself, because is from it that arise the main lube oil contaminants, H_2S and H_2O. Combustion engines also received special attention, as well as the lubrication process dedicated to the engines.

To meet the objectives of this study, it was required to carry out collections and assays for analysis of physic-chemical

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properties of the oil contained in engines previously selected. All tests were performed according to standards, so that data obtained are reliable enough to assist in the analysis of oil condition.

The methodology followed was designed by the authors, and from there it was determined to hold a batch of tests for six oil samples - a sample of new oil and old oil of three MWM 6.12T engines using different lubricants. These engines were put into operation at next periods and have similar operating characteristics.

Table 2. Kinds of oils and times between exchanges

Unit	Engine	Oil	Time Between Exchanges (h)	Cost (R$/liter)
Colombari	MWM01	Lubrax Top Turbo	300 − 350	9,50
UIA-MAT	MWM02	Lubrax Extra Turbo	200 − 300	8,75
UPL-ITA	MWM03	Extravida XV 300	200 − 300	13,50

To evaluate also if the minimum time for exchange is within acceptable limits, it was decided to take the samples shortly before this minimum value and since then to infer about the possibility of using oil for both periods between changes of each engine and for periods longer.

Table 3. Collection times

Unit	Engine	Time of Used Oil (h)	Time of New Oil (h)
Colombari	MWM01	280	0
UIA-MAT	MWM02	180	0
UPL-ITA	MWM03	190	0

To perform the collections, was followed the proceedings recommended for Baroni (2004). The collection must always be done with the engine running or soon after a break to prevent the sedimentation of most particles, and in case of removing from drain, the purge should be performed. The oil must still be hot. It is necessary to remove 50 to 500 mL per sample. It depends on witch assays that needs to be realized and the material used for collection should be disposable and single use for each sample. The bottle should always keep upright and it is very important to identify the sample immediately after collection.

Due to the need for collection equipments, it was drawn up a home kit that contains:

- 1 Litter recipient;
- 1 Graduated 60 mL syringe;
- 0.5 meters of fuel hose.

(c) Kit for Collecting Oil

(d) Identification of Sample

The tests that should determine the most representative parameters to infeer about the oil conditions are:

- Total Bases Number (TBN) - ASTM D2896: is responsible for raising the alkalinity reserve of the oil. It is affected by the operating conditions of the engine and especially the sulfur content of the fuel (Carreteiro, 2006);

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- Viscosity at 40 and 100^{o}C, cSt - ASTM D2270: have their characteristics affected mainly by fuel and solvents (Carreteiro, 2006). A decreasing on viscosity could represent the presence of fuel or the mixing with a different oil (Mobil, 1979);
- Water Content (Karl Fischer) - ASTM D1744 /ASTM D4377: is relevant in this case because it is known that the Biogas has high contents of water in its mixture and is recommended by Carreteiro (2006). The maximum water allowed in engine's oil is 0.2%. For larger values should be performed the drying of oil (drain) before starting the engine. It is good to note that the nature of water may indicates the source of the contamination;
- Demulsibility (Water Separability) - ASTM D 1401: is necessary to see if the water has low or high facility to separate from oil. Water in oil is unwelcome as it speeds up the process of oxidation of the oil (Moreira, 1987);
- Corrosion on Copper Blade - ASTM D130: enables to verify the reativity power of oil;
- Infrared - comparision of peaks in ghaphics - shows the chemical compounds present in the oil. Through this test it is possible to check how the old oil has changed in relation to the new oil (Carreteiro, 2006). The TBN is an assay that can complement the infrared about getting the alkalinity of oil, but with a smaller accuracy;
- Oxidation at rotary pump (RBOT) - ASTM 2272: informs the oil resistence against the oxidation by accelerating this process. It is a very useful test to estimate which should be the time of condemnation oil by simulation of oil operating conditions (Moreira, 1987).

With the test results on hands and from a set of actions, we could infer about the possibility of increasing the interval between lubricant oil changes.

4. RESULTS AND DISCUSSION

The results obtained from the laboratory tests are shown in the tables 4,5 and 6, together the data from Petrobrás (2011a), Petrobrás (2011b) and YPF (2013).

Initially, jumps out the discrepancy among the data provided by the manufacturer and the one founded in the tests. However, the difference between these data is small and does not interfere in the results.

A satisfactory result was the water content found in the samples. The addition of water occurred during the use of each oil load was very small, and the final value of water content for the three samples of used oil was less than 1000 ppm.

Table 4. Results of the assays for the MWM01 Engine

Properties	Tecnical Card	New Oil	Old Oil
Used Time (Hr)	0	0	280
Viscosity @40^{o}C (cSt)	107,2	105,7	-
Viscosity @100^{o}C (cSt)	14,8	14,8	-
TBN ($mgKOH/g$)	11,0	10,94	2,55
Water Content (ppm)	-	234	528
Demulsibility	-	0/03/77	-
RBOT (min)	-	195	-
Infrared ($\%DBPC$)	-	0,01	0,0
Corrosion on Copper Blade	-	1a	4a

Table 5. Results of the assays for the MWM02 Engine

Properties	Tecnical Card	New Oil	Old Oil
Used Time (Hr)	0	0	180
Viscosity @40^{o}C (cSt)	111,9	106,3	-
Viscosity @100^{o}C (cSt)	15,1	14,8	-
TBN ($mgKOH/g$)	9,0	9,39	2,28
Water Content (ppm)	-	237	376
Demulsibility	-	0/03/77	-
RBOT (min)	-	165	-
Infrared ($\%DBPC$)	-	0,04	0,04
Corrosion on Copper Blade	-	1a	4b

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Table 6. Results of the assays for the MWM03 Engine

Properties	Tecnical Card	New Oil	Old Oil
Used Time (Hr)	0	0	190
Viscosity @40^{o}C (cSt)	-	113,1	-
Viscosity @100^{o}C (cSt)	15,4	19,1	-
TBN $(mgKOH/g)$	10,0	10,32	5,47
Water Content (ppm)	-	864	900
Demulsibility	-	0/0/80	-
RBOT (min)	-	215	-
Infrared $(\%DBPC)$	-	0,0	0,0
Corrosion on Copper Blade	-	1a	4c

For the engines MWM01 and MWM02 the water contents found were very close and as the used oil samples had different times of use, justified the difference in values between them. In the case of MWM03 was found water concentration much higher than the other two, but the variation of that concentration over the life of the lubricant is extremely low. The lubricant of all engines showed low abbility to separate from water in the results for the demulsibility tests.

Observing the graphs generated by infrared testing (Figures 3,4 and 5), it was possible to compare concentration of substance considered important for conservation of the characteristics required for oil among new and old oil. This test becomes very important in this case for indicating the variation of sulfonation and oxidation compounds concentration. The observation of the antioxidant additive depletion also helps determine the state of oil's life.

Based on the data found by Mihalcová (2002), it was possible to difference four spectral regions of interest to this work: Antioxidant ($\approx$ 3650 cm^{-1}) Oxidation ($\approx$ 1730 cm^{-1}) Nitration ($\approx$ 1600 cm^{-1}) and Sulfonation ($\approx$ 1150-1200 cm^{-1}). In addition to these, two other regions were able to be differenced: Water ($\approx$ 3350 cm^{-1}) and Soot ($\approx$ 1900 cm^{-1}).

As can be seen, the amplitude peaks at the wavenumber of water in all the graphics are extremely low. Based on this information and finding low levels of water by the Karl Fischer test, it can be inferred that water is not a contaminant in which the decision-making process should be based, as it do not have sufficient concentration to facilitate the corrosion of the engine internal parts. However, it is known that corrosion in those engines is intense; hence the need for having a contaminant with high corrosion power, the analysis turns round to the sulfonation peaks.

Comparing the amplitudes of the sulfonation peaks at new and old oil samples, it gets clear that the concentration of these compounds varies significantly. It can also be observed an amplitude variation of sulfonation compounds related to the TBN, because, by making a comparision among the variation of the TBN (Table 4, 5 and 6) and the amplitude peaks at new and old oil samples, it is possible to infeer an inversely proportional relation among magnitudes. In oder words, when results for sulfonation compounds increases the TBN decreases.

The test of corrosion on copper blade indicated an acidity disproportionate for the oil of engine MWM03 because it still had almost half of its alkaline reserve (TBN), thus the amplitude of the infrared sulfonation was that less varied among the three oils. However, it was also the one that showed the highest acidity. An assumption to this is that the alkalinity of this oil has a smaller neutralizing power than the other two, since the manufacturer is different from theirs and additives cocktails added to the oil are generally different.

Still on TBN, the decrease of this parameter indicates the reduction of the alkaline reserve. When this reserve is depleted, the oil starts to become acid, because there is no more inhibition for the activity of corrosive agents which attacks the engine internal parts (Moreira, 1987). The TBN can be used to determine the oil time service. Thus, there are two commonly adopted policies regarding to oil changes according to the value of TBN obtained:

1) To change the oil when TBN is under half (Petrobrás, 2011a). This is the most conservative method; or

2) Evaluate the TBN observing the type of machine on operation and the importance that the alkaline reserve has for the process, because each equipment must be individually evaluated (Moreira, 1987). This is based on lubricant periodic analysis.

In this particular case, it is preferable to work with the second alternative, since it is completely possible to conduct periodic analysis of the lubricant in order to conduct a follow up characteristics throughout its life. Also because, by the graphs, there is small oxidation of the oil used in reference of new, and this is the parameter that damns the oil.

The curves on graphics acquired for the rotary pump test (RBOT) were atypical. Even so, this test produced significant results but need to be supplemented with results obtained for old oil samples. This suggestion will be taken for further analysis in order to avail as the largest amount of data as possible to decisions of oil changes are as reliable as possible.

It is necessary to underline that the data obtained in the laboratory do not generate results alone; the results are a coronation to the work of data analysis and condition of the equipment within a planned lubrication (Moreira, 1987).

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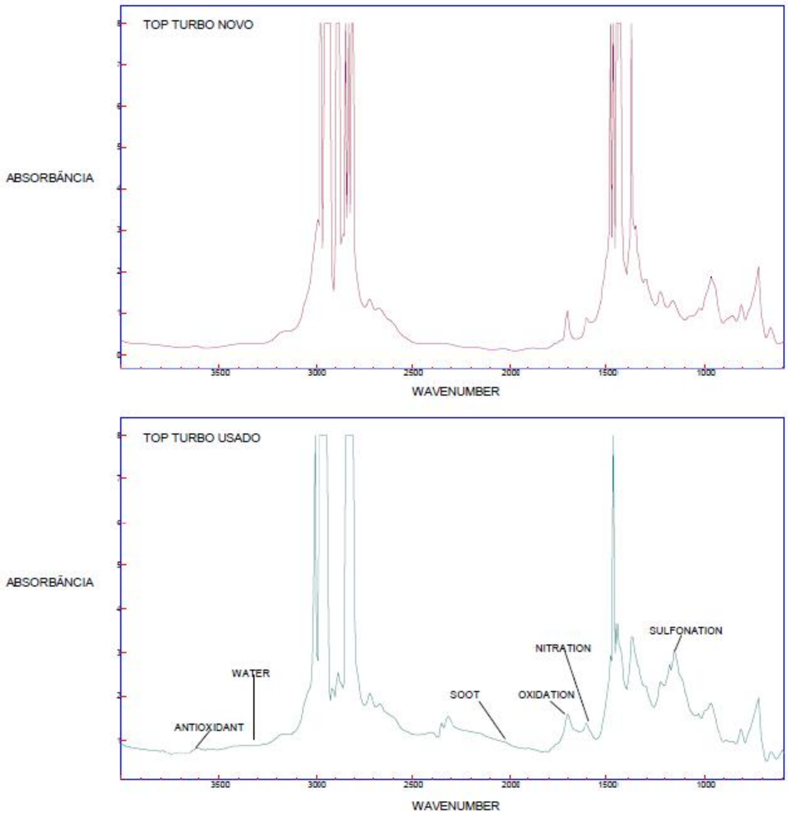

Figure 3. Infrared for the Oil of Engine MWM01

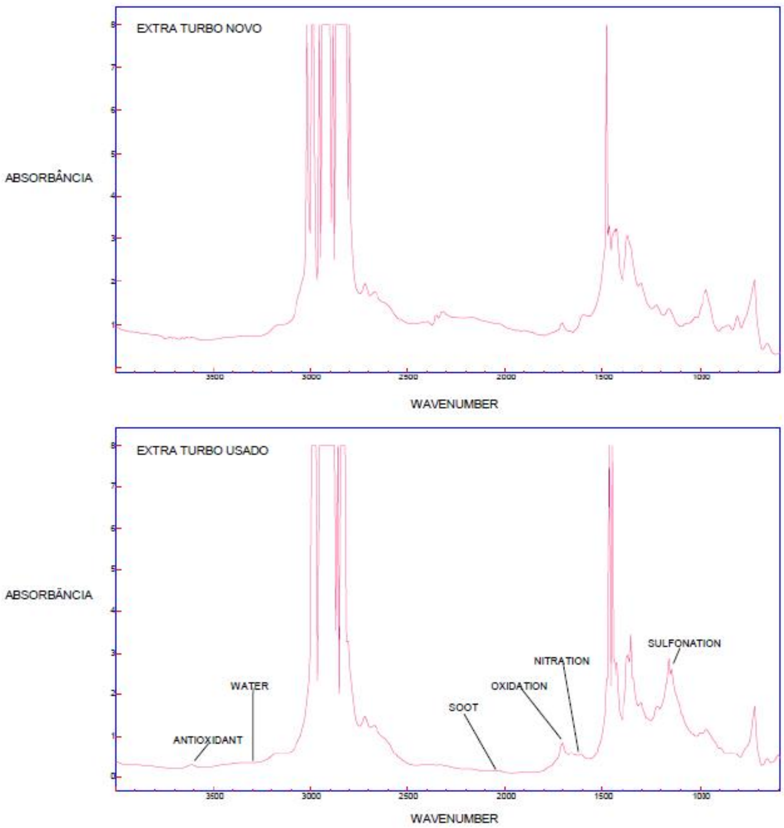

Figure 4. Infrared for the Oil of Engine MWM02

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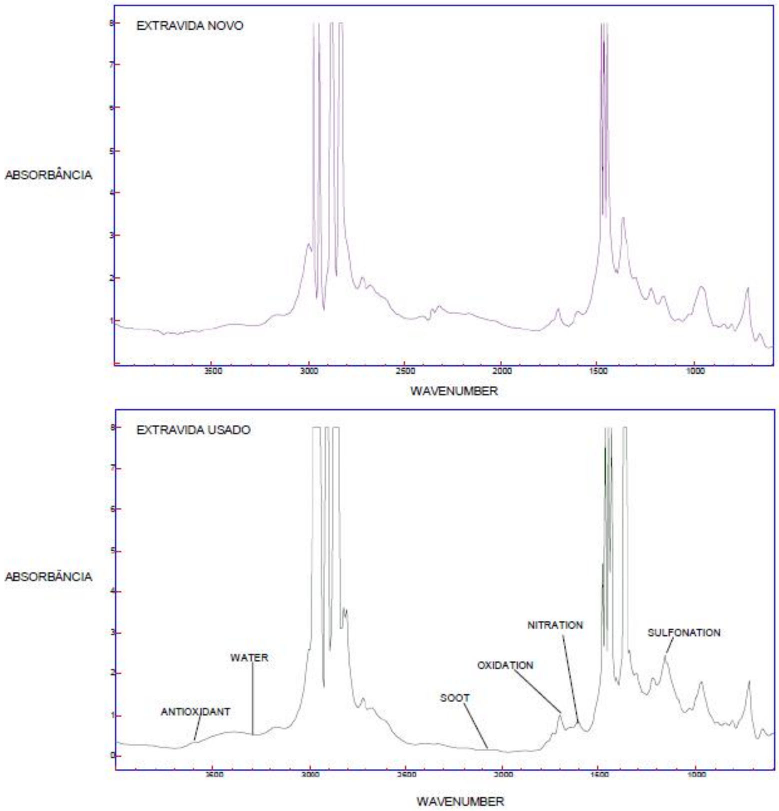

Figure 5. Infrared for the Oil of Engine MWM03

5. CONCLUSIONS

The high amplitude peaks of sulfation compounds are justified by the neutralization of acid products using the alkaline reserve. In addition, the oils of the three engines had low water content and oxidation, however, if the oil start to have higher concentrations of water in the future, must pay attention to its demulsibility. It was also observed some amount of antioxidant additive and alkalinity. With this, we can conclude that these oils still have a remaining useful life, but would require periodic monitoring of the oil loads to which it might be inferred about the lifetime.

To increase the oil's lifetime it is necessary to combat its main contaminants. To do this, the project of a H_2S filter has been deployed and it is being tested in the units where are operating the engines MWM01 and MWM02. It should drastically reduce the formation of acid products based on sulfur.

Another initiative aimed at increasing the lifetime is about the need of organizes a lubrication process in the studied units through the implementation of a systematic maintenance. It must be especially careful with the handling and storage of lubricants, so that water contamination is avoided. Thus, the formation of acids is inhibited, preventing corrosion of the engine and an increase of acidity in lubricant.

The lower time limits for the oil changes listed at Table 2 can be maintained. It is important to underline the importance of monitoring the oil loads performance in future works in order to estimate an upper limit for the oil change. It is advised the oils of engines MWM02 and MWM03 be exchanged due to its high acidity, and start using the same oil of MWM01 engine.

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