OIL ANALYSIS OF INTERNAL COMBUSTION ENGINEE

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Abstract. *All engines must be lubricated in order to preserve the integrity of the system for its designated lifetime. The extreme temperatures in internal combustion engines make lubrication complex. The lubricants that are suitable for use in these engines are expected to reduce friction, dissipate heat from internal parts, minimize deposit formation, and prevent corrosion and wear. Its main function is to reduce friction by forming a film between two moving surfaces. The strength and durability of this film is related to the viscosity of the lubrication and to the speed and load experienced by the moving surfaces. Analyzing the lubricant of an internal combustion engine one can foresee what is happening inside it. For instance, wear between the valve and seat is thought to occur primarily due to relative motion when the valve is seated, due to cylinder pressure that forces the valve into the seat, causing slight deflections of both valve and seat. In order to study the predictive maintenance in an internal combustion engine, through wear particle oil analysis, it was constructed two tests rig composed by an engine coupled to a reducer. This work presents some results in the test rigs working with different lubricant. For analysis it was used analytical ferrography, viscosity measurement, TBN, spectrometry and magnetic particle quantifier. The result showed good agreement with the observed after disassembling the motors.*

Keywords*: Oil Analysis, Ferography, TBN,Predicitive Maintenance*

1. INTRODUCTION

Since the introduction of internal combustion engine in vehicles, monitoring became necessary in order to gain better performance and a larger useful life.

In deluxe vehicle it already exists some type of “on-line” monitoring in motors. Beyond getting the final product expensive this kind of monitoring is made mainly by the analysis of the vibratory signal (Wang et al, 2003).

The current tendency is the motor lubricant monitoring in order to get a better fuel economy, smaller pollutant emission, and a longer motor useful life. That can be done through the measurement of Total Base Number (TBN), viscosity and wear particle inside the lubricant among others (Petrobras, 1999)

This technique is nothing else than a predictive maintenance, that by a simplistic definition, it is a preventive maintenance subordinate to a type of predetermined event, just as the information given by a captor or the measure of a wear that reveal the state of degradation of a part or equipment (Xavier, 1998 and Tavares, 1987).

Being the internal combustion engine a complex machine, it is not possible to do the monitoring of some symptoms as it happens with other machines where the adequate vibrations analysis are made to diagnose the rotation machinery. (Fygueroa, 1997).

The analysis of oil consists of collecting oil samples in a certain period of the engine operation and, later on, evaluating them to determine either the engine or the lubricant state.

2. PROBLEMS AND POSSIBLE CAUSES

The formation of sludge, spall and varnish in the engine can be due to a long period of use, low quality of the oil, oil contamination, over heating or low temperature operation, damaged or non operating thermostatic valve, leaking of gas through ring and valve, oil or gas filtration not efficient, bad gas quality, excessive usage in low speed, non efficient ventilation and inlet and pump deregulated.

It should be made the oil change, independently of the kilometer, when one observes high temperatures and over heating, contamination by fuel, water, coolant or dust, rings in bad conditions and air and oil filtration faulty.

Water in oil can be cause of cracking in the cylinder head, fault or burn in cylinder head joint, leakage in radiator, low temperature operation, exaggerated usage of low speed, external contamination, cracking or porosity in cylinder block or cylinder head, press in cylinder head with inadequate torque and leakage through liner cylinder retainer.

A decrease of viscosity can be consequence of fuel dilution and complementation with lower viscosity oil.

On the other hand an increase in the viscosity can be cause of very long interval between the changes, overload, operation under super heating, ring in bad states, water and/or soot contamination, low quality oil, air filter restriction or not filtered air entrance and complementation with larger viscosity oil.

Wear of rings can be due to bad oil quality, faulty oil and air filtration, long interval between oil changes, insufficient cooling, not filtered air entrance, liner cylinders distortion, wear inside grooves piston, rings and piston with wrong measures, obstructed piston and rotation not allowed.

If in inspection it is observed wear away and journal damage, it can be cause of low oil pressure, excessive load, incorrect injection time (diesel engine), wrong assembly, material fatigue, metallurgical metal fault, missed oil viscosity, water and/or oil leakage, foam and cavitation in the oil, faulty oil and air filtration, and bad oil quality.

The scratching and damage in liner cylinder can be due to lubrication faulty, insufficient cooling, arrested, broken or worn rings, liner piston distortion, faulty during machinering, inadequate burnishing, inadequate's pistons and rings projects, inadequate metallurgy, wrong oil viscosity, wrong assembly, oil and air filtration' faults, problems in running period, overload and excess of slow velocity.

High consumption of fuel together cylinder low pressure, potency loss, increase of dark smoke (emissions), liner scratching, varnish, sludge, piston seizing, excessive deposits of ashes and overload in other cylinders can be due to ring bad state.

Engagements difficulty and premature synchronizer wear away can be due to usage of higher oil viscosity or with different characteristic than that specified, water contamination, oil with long period of change and lack of fluid in hydraulic system.

Wear way and gear breakage in manual transmission box can be consequence of usage of oil with inferior performance than the desired, low level of lubricant, overload, march change without clutch usage and accomplished out of time, water contamination, hooking up reverse speed with vehicle in movement forward.

3. OIL ANALYSIS TECHNIQUES

There are several methods and techniques of oil analysis for fine and precise diagnoses for engine damage. Bellow it is discussed some ones.

3.1 -Spectrometry

Spectrometry gives elementary quantitative analysis of wear particles inside lubricant (Schilling, 1965), for this purpose it is utilized emission and absorption spectrometer.

***Emission Spectrometer*:** It makes usage of atom properties. When an atom is excited it emits a radiation that is function of its electronic configuration and that is composed for longitude of characteristic wave. That makes different materials to emit different radiations.

Atomic Absorption Spectrometer: It takes in count the property that the amount of monochromatic light absorbed by the atoms of an excited element is proportional to its concentration. This relatively simple technique is of low cost.

In the used oil analysis the spectrometer is being used more and more. This test is very receptive and precise in the limit detection and presents the disadvantage of not to detect big particle (bigger than 7µm).

The basic principle of atomic absorption consists of submitting the sample to a high tension that heats up and liberates energy. The specials phenomenons of the radiation are generated when they can differentiate and attribute the radiations to different frequency in the specific elements present in the lubricant. The radiation intensity to a specific frequency is proportional to the concentration of its respective element. Figure 1 presents a schematic drawing of the atomic absorption spectrometer

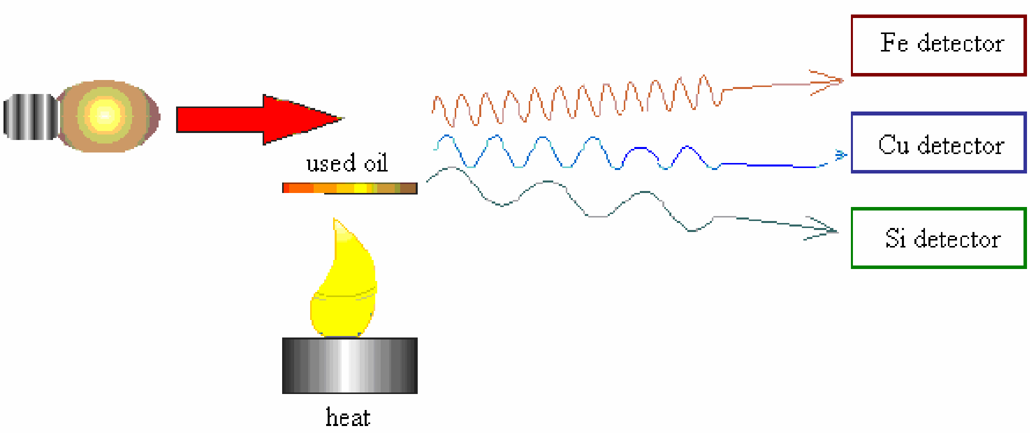


Figure 1 – Schematic of atomic absorption spectrometer.

Some detected elements presents in an internal combustion engine are listed in Table 1.

Table 1 –Elements detected in the oil analysis of an internal combustion engine.

Silicon	Dust, antifoaming addictive
Calcium	Dust, detergent addictive
Barium, magnesium	Detergent addictive
Iron	Gear and rolling
Copper	Metals of journal or rolling spacer
Chromium	Liner Piston ring
Aluminum	Piston
Tin, Cooper, Silver	Rolling
Alloys	Fuel contamination
Vanadium, Sodium	Burned fuel

The oil manufacturer counts with tables with maximum values for elements in the lubricant, in relation to the machine type and to the productive process. The contamination is shown in other part of the report in which one can relate the measured concentration of several elements at the maximum allowed (according to the manufacturer). It should be considered that all the machines are different and their operation conditions, in different regions, are different too.

3.2 - Ferrography

There are two types of ferrography, the direct reading ferrography and the analytical ferrography

The direct reading ferrography consists of a quantitative measurement of the particle concentration in a fluid through the precipitation of this particle in a glass tube under a strong magnetic field. Two rays of transported light by optical fiber shock inside the tube in two positions that correspond to the big and small particles position that were deposited by the magnetic field. The light is reduced in relation to the deposited particle inside the glass tube and that reduction is electronically monitored and measured.

Two reading set are obtained (particle bigger than 5 microns and particle smaller than 7 microns). Generally more than 20.000 particle bigger than 7 microns indicate an alert and particle beyond 40.000 indicate problems in machine ferrous components (Rueda, 2005). Figure 2 illustrates a directing reading ferroscopy.

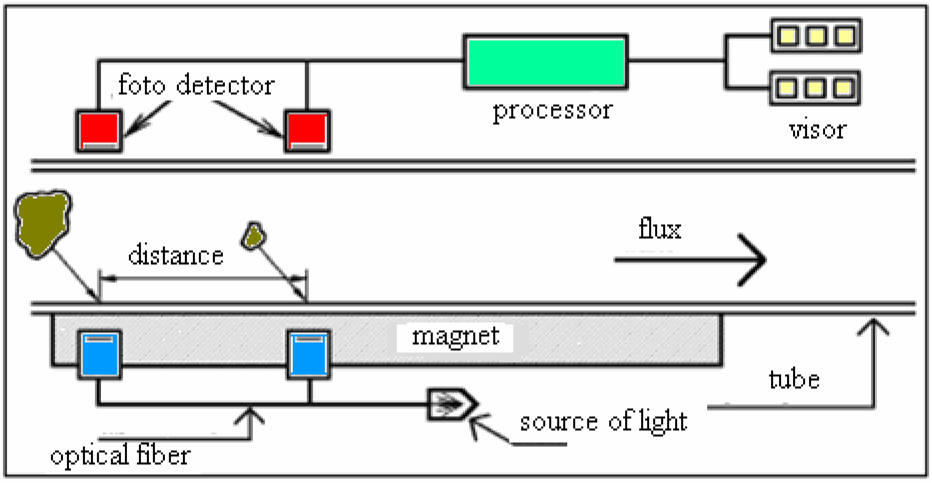


Figure 2 – Direct reading ferrography schematic apparatus

The particle number has a code corresponding to a norm ISO 4406, or others norms, for lubricant analysis. The code is a number that goes from 1 to 24. The lubricant maker recommends the amount of wear particle according to these numbers.

Table 2 – Recommended values by norm ISO 4406

Code	Particle	
	from	to
24	80.000	160.000
23	40.000	80.000
.	.	.
.	.	.
2	0,02	0,04
1	0,01	0,02

The analytical ferrography is the magnetic particle separation that is found in the lubricant. A slid rests in a magnet that attracts the ferrous particles and allows the adhesion of this particle to the slid.

The prepared slid at this away it is named ferrogram. The ferrogram is than ready to optical inspection through a bichromatic microscope.

3.3 – TBN (Total Base Number)

The TBN determine the effectiveness and the control of the acids that appear during the combustion process. As larger the TBN, larger will be the effectiveness in eliminating the contaminant that causes wear and larger will be the reduction of the corrosive effects of acids in a prolonged time period. The measurement linked to ASTM D2896 and ASTM D4739-06 generally varies from 6-80 mg KOH/g in modern lubricant, from 7-10 mg KOH/g for general automotive and from10-15 KOH/g for diesel operation. When TBN is measured in 2 mg KOH/g or less, the lubricant is considered inadequate to engine protection, so corrosion can occurs. A fuel with high sulfur content will decrease TBN quickly due to the increase of sulphuric acid.

3.4 Viscosity

Viscosity is a fluid property corresponding to microscope transportation of movement by molecular diffusion. That is to say, as larger the viscosity, smaller the speed of the fluid movement. It is defined by viscosity Newton's law:

$$\tau = \mu \frac{\partial u}{\partial y} \qquad (1)$$

Where μ is the viscosity coefficient, viscosity or dynamic viscosity and du/dy is the derived of speed in function to the fluid height.

Many fluids, as water or most of gases, satisfy the Newton's law and so they are known as Newton's fluids. The non Newton's fluid has a more complex and non linear behavior.

Viscosity can be understood as the measurement of the resistance of a fluid to the deformation caused by a torque. It is commonly noticed as the "oil Thickness", or the leakage resistance. So, water is "thin" having a low viscosity, while vegetable oil is "thicker", having high viscosity.

4 – MATERIALS AND METHODS

For this work it was built two tests rig composed of internal combustion engine coupled to reducer in order to give power to the engine. The power was given only by the internal friction of the reducer. Firstly an engine of Montgomery brand was used. The potency was 3.5 HP, for stroke, 1300 rpm and with reservoir capacity of 800 ml. The engine was coupled to a reducer from Cestari brand with 5 CV, 1750 rpm capacity, reduction of 1:2. Only one test was made with this test rig because the engine presented some problem during the operation and it was discarded. Figure 3 illustrates the test rig with this kind of engine.

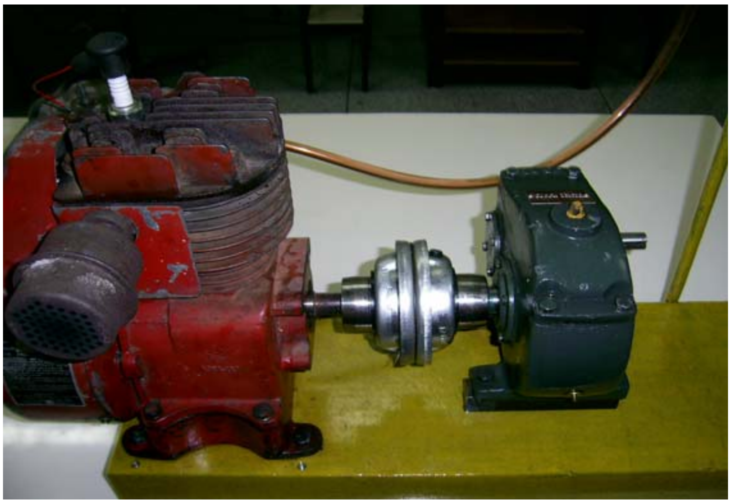


Figure 3 – Test rig built with Montgomery engine and Cestari Reducer brand

A second test rig was built with a new engine of Briggs & Stratton brand. Its power was 8 HP, four strokes, reservoir capacity of 800 ml, 3000 rpm. The engine was coupled to a reducer from Cestari brand with 5 CV, 1750 rpm capacity, reduction of 1:2. Figure 4 illustrates this test rig.

Figure 4 – Second test rig constructed

For experiment in the first test rig it was used SAE 40 API – SF. Initially the experiment should have been tested for 25 hours but, due to engine problem, it was not possible. So the lubricant was analyzed after 605 minutes of experiment.

Then, it was decided to change the engine to be analyzed. So it was constructed the second test rig. The oil was analyzed after 25 hours of experiment. Four kinds of oil were analyzed. The first oil was SAE 30 API-SF. The second oil analyzed was SAE 40 API-SF that was the same used in the first test rig. The third oil analyzed was TIVELA S 150 commercial synthetic oil recommended as gear oil). The fourth oil was o TIVELA S 320 (also commercial synthetic oil recommended as gear oil). The oil specifications are on Table 3.

Table 3 – Lubricant specifications

Properties	Lubricants			
	SAE 40 API SF	SAE 30 API SH	TIVELA S150	TIVELA S320
Flash point [^{o}C]	262	256	280	254
Pour test (^{o}C)	-6	-18	-18	-18
Viscosity (40 ^{o}C) [cSt]	163,5	109	150	320
Viscosity (100 ^{o}C) [cSt]	15,46	11,9	14,2	30,5
Viscosity index	95	97	95	96
Density (20^{o}C)[g/cm^3]	0,8963	0,8941	1,087	1,086

All experiment was done with engine in 2200 rpm. The rotation was measured with a tachometer of Oppama brand, PET-2000DX model.

4.1 – Oil Analysis

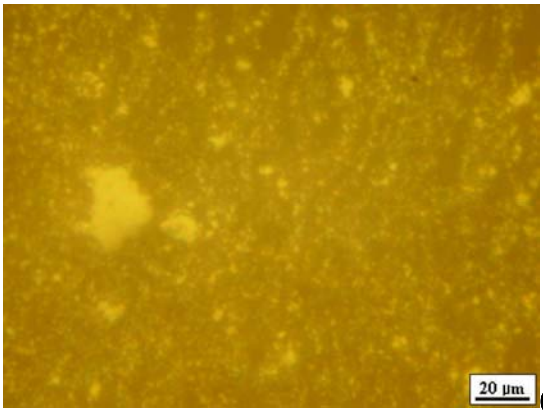
In oil analysis several equipment were used, as rotary particle separator, automatic particle quantifier, optical microscope, and apparatus for Total Base Number, and atomic absorption equipment.

The oil samples were put in the rotary particle depositor – RPD and than analyzed in a Neophot 21 and Jenaval micoscopes. The RPD separates the particles into three concentric rings, depending on the wear particle size. Utilizing the automatic particle quantifier the PQ index (an index that represents the magnetic particles inside the oil) in 1 ml of oil was obtained. It was also obtained the viscosity, the water content, and the chemical components in the oil by atomic absorption.

5 - RESULTS AND DISCUSSION

5.1 – Montgomery internal combustion engine

The Figure 5 shows results obtained in the RPD test of lubricant of this engine through reflected light. Table 4 shows more results obtained by used oil analysis tests



(E)

Figure 5 – Wear particles inside SAE 40 API-SF used oil from Montgomery engine. Reflected light. (E) External ring

Table 4 – Values of tests in SAE 40 API-SF used oil from Montgomery engine

Atomic Absorption (ppm)							ISO 4406	water (%)	TBN (mgKOH/g)	Visc.40°C (cSt)	Visc.100°C (cSt)	PQ new/used
Cu	Si	Al	Fe	Pb	Cr	Ni	23/22/21	0,00	5,24	100,69	11,21	12/13
9	51	22	125	13	10	1						

The medium fuel consumption was 156.13 minutes/liter

The figure 6 presents the piston head of the engine after the experiment.

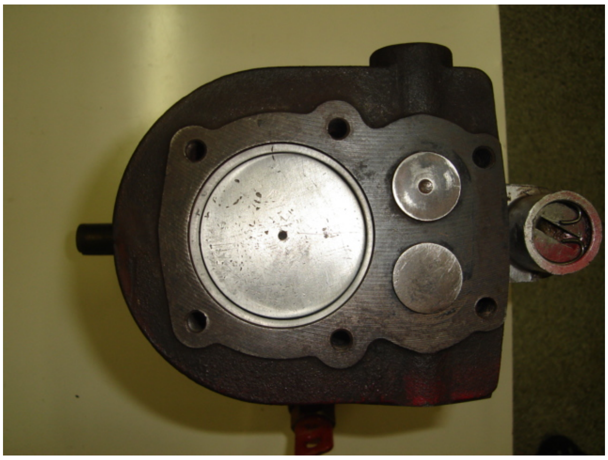
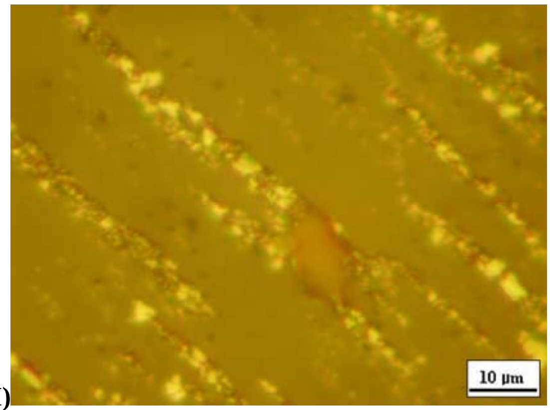


Figure 6 – Piston head of Montgomery engine after the test

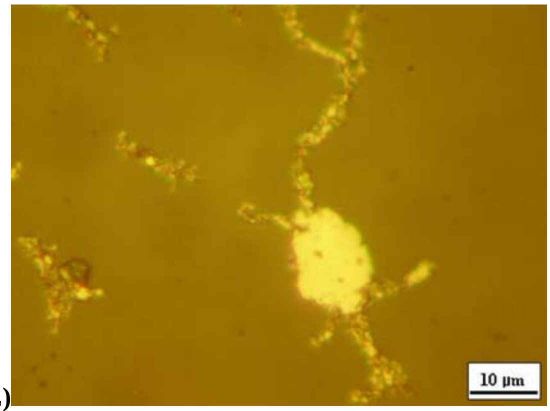
5.2 Briggs & Strator Internal Combustion Engine

5.2.1 With SAE 40 API-SF oil.

The Figure 7 shows results obtained in the RPD test of lubricant of this engine through reflected light. Table 5 shows more results obtained by used oil analysis tests



M)



(E)

Figure 7 – Wear particles inside SAE 40 API-SF used oil from Briggs & Stratton engine. Reflected light. (M) Medium ring and (E) External ring.

Table 5 – Values of tests in SAE 40 API-SF used oil from Briggs & Stratton engine

Atomic Absorption (ppm)							ISO 4406	water (%)	TBN (mgKOH/g)	Visc.40°C (cSt)	Visc.100°C (cSt)	PQ new/used
Cu	Si	Al	Fe	Pb	Cr	Ni	23/22/21	0,00	10,92	130,54	13,76	12/14
9	69	0	33	13	10	3						

The medium fuel consumption was 81.52 minutes/liter.

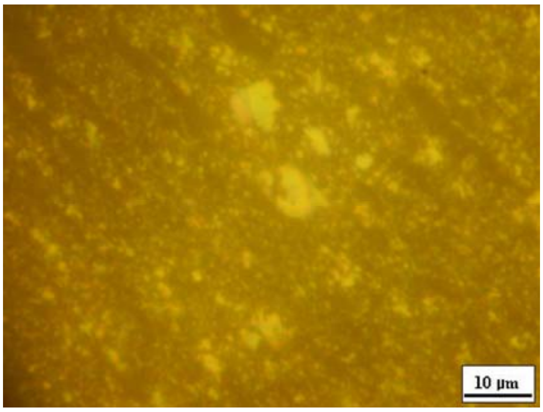
Comparing the two test rigs for the same type of oil one can observe an approximately equal PQ value for both ones. On the other hand the Fe content for the first test rig was very higher than for the second one. This means that small ferrous wear particles were present in the first test rig since the Ni content got approximately the same values.

The higher Al content in the first test rig indicates a higher piston wear. That was confirmed by the picture on the Figure 6 where one can observes the advanced wear in this part.

The wear of cylinder liner and piston rings was high at the two test rigs as indicate by Cr content in the atomic absorption test. The high Si content was due to faulty seal and to contamination with antifoaming additive. The oil viscosity in the first test rig experienced a great falls in relation to the new oil. That happened, probably, due to contamination with fuel. The odor of the used oil, in comparison to the new one, confirmed the observed fact.

5.2.2 With SAE 30 API-SH oil

The Figure 8 shows results obtained in the RPD test of lubricant of this engine through reflected light. Table 6 shows more results obtained by used oil analysis tests



(I)

Figure 8 – Wear particles inside SAE 30 API-SH used oil from Briggs & Stratton engine. Reflected light. (I) Internal ring.

Table 6 – Values of tests in SAE 30 API-SH used oil from Briggs & Stratton engine

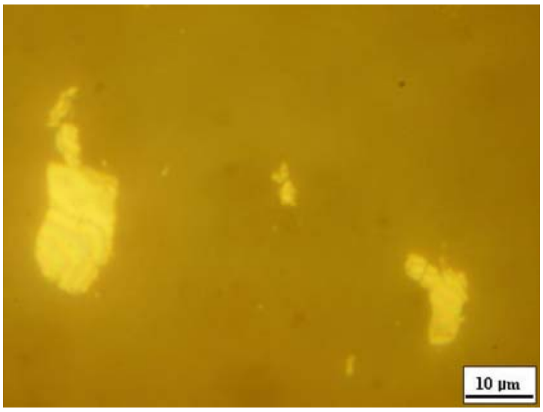
Atomic Absorption (ppm)							ISO 4406	water (%)	TBN (mgKOH/g)	Visc.40°C (cSt)	Visc.100°C (cSt)	PQ new/used
Cu	Si	Al	Fe	Pb	Cr	Ni	23/22/21	0,00	4,30	91,83	10,85	8/9
5	54	17	63	16	11	2						

The medium fuel consumption was 83.33 minutes/liter.

By Figure 8 it can be seen some oxidized particle. The small value of TBN in Table 6 can be the cause of that oxidized particle and indicate a great action of the alkaline source during the test.

5.2.3 With TIVELA S 150 Synthetic oil

The Figure 9 shows results obtained in the RPD test of lubricant of this engine through reflected light. Table 7 shows more results obtained by used oil analysis tests



(I)

Figure 9 – Wear particles inside TIVELA S 150 Synthetic used oil from Briggs & Stratton engine. Reflected light. (I) Internal ring.

Table 7 – Values of tests in TIVELA S 150 Synthetic used oil from Briggs & Stratton engine

Atomic Absorption (ppm)							ISO 4406	water (%)	TAN (mgKOH/g)	Visc.40°C (cSt)	Visc.100°C (cSt)	PQ new/used
Cu	Si	Al	Fe	Pb	Cr	Ni	23/22/21	0,00	2,15	158,46	24,57	26/26
0	41	0	0	2	0	0						

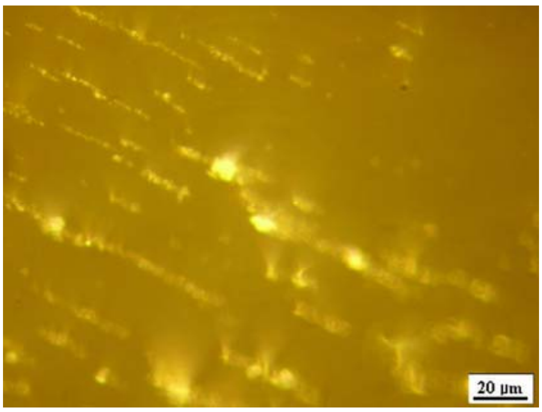
The medium fuel consumption was 87.21 minutes/liter.

As PQ value for new and used oil was the same and Fe and Ni content was equal to zero, one can conclude that Fe was presented in bigger particles and those particles were already inside the non filtered new oil.

By Figure 9 it can be observed a particle with a severe wear color.

5.2.4 With TIVELA S 320 Synthetic oil

The Figure 10 shows results obtained in the RPD test of lubricant of this engine through reflected light. Table 8 shows more results obtained by used oil analysis tests



(I)

Figure 10 – Wear particles inside TIVELA S 320 Synthetic used oil from Briggs & Stratton engine. Reflected light. (I) Internal ring.

Table 8 – Values of tests in TIVELA S 320 Synthetic used oil from Briggs & Stratton engine

Atomic absorption (ppm)							ISO 4406	water (%)	TAN (mgKOH/g)	Visc.40°C (cSt)	Visc.100°C (cSt)	PQ new/used
Cu	Si	Al	Fe	Pb	Cr	Ni	23/22/21	0,00	1,46	334,37	38,96	24/33
0	43	4	22	5	0	0						

The medium fuel consumption was 87.21 minutes/liter.

Looking at Table 8 we can see a PQ value for used oil well higher than for the new one and Fe content with a value of 22. One can conclude that the wear debris contain mainly Fe in the big and small wear debris.

The oils Tivela S caused minor ring and liner piston wear. This fact was observed by the lesser Cr content in the atomic absorption test.

6 – CONCLUSION

Wear particle analysis for automotive engines provides important information regarding engine condition.

During sliding of piston rings and cylinder liners, scuffing can be considered the major type of wear caused by the breakdown of oil film separating the sliding surfaces.

A linear relation of the viscosity with the fuel consumption was not observed.

Although not recommended for internal combustion engine the Tivela S synthetic oils presented better fuel economy for the tested engine. That does not imply that this type of oil is the indicated one for the type of tested engine.

Tivela S 320 presented a higher PQ value than Tivela S 150 and higher Fe content in the atomic absorption test. That could be an indicative of gear and rolling element bearing wear. After disassembled the engine that was really observed.

It is impossible to compare the total wear since each experiment was done after the preview ones.

7 – ACKNOWLEDGEMENT

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