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Analysis of lubricant oil contamination and degradation and wear of a biogas-fed otto cycle engine

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ABSTRACT. The increasing deployment of biodigesters for the treatment of waste on farms and the use of the biogas generated in the production of energy have highlighted the need for knowing the influence of this fuel on internal combustion engines. This study aimed to analyze the influence of filtrated biogas on lubricant oil contamination and degradation, as well as on engine wear and corrosion. Lubricant oil samples were collected every 75 engine operating hours (EOH) and then correlated between each other and with a sample of new oil, determining the elements present in the biogas that contribute to lubricant oil contamination and degradation, as well as lubricant oil performance in the course of EOH and engine wear. The results demonstrate that hydrogen sulfide affects the performance of the lubricant oil and engine wear. Among the metals, we observed that the copper concentration exceeded the maximum limit recommended in the literature. As for the additives, the variation in concentrations of magnesium impacted on lubricant performance. By monitoring lubricant oil quality were able to extend the engine oil change interval of this study by 50%, what resulted in a savings of 33.3% in the cost of lubricant per hour worked.

Keywords: contaminants, biogas, biodigester, biomethane, corrosion.

Análise da contaminação e degradação do óleo lubrificante e desgaste de um motor ottolizado alimentado por biogás

RESUMO. A crescente implantação de biodigestores para tratamento de resíduos nas propriedades rurais e a utilização do biogás gerado na produção de energia mecânica evidenciaram a necessidade de conhecimento da influência de utilização deste combustível nos motores de combustão interna. Este trabalho teve como objetivo analisar a influência da utilização do biogás filtrado na contaminação e degradação do óleo lubrificante, desgaste e corrosão do motor. Amostras de óleo lubrificante foram coletadas a cada 75 hM (horas de funcionamento do motor), e após correlacionadas dentre elas e com uma amostra de óleo novo, determinando os elementos presentes no biogás que contribuem para a contaminação e degradação do óleo lubrificante, como também o desempenho do lubrificante no decorrer das hM e o desgaste do motor. Os resultados demostraram que o gás sulfídrico influencia no desempenho do óleo lubrificante e no desgaste do motor. Dentre os metais, foi identificado que a concentração de cobre excedeu o máximo recomendado pela literatura, e a elevação da sua concentração teve relação com a elevação de chumbo e estanho, principalmente após as 375 hM. Em relação aos aditivos, foi a variação das concentrações de magnésio que impactou no desempenho do lubrificante. Por meio do monitoramento da qualidade do lubrificante é possível estender o intervalo de troca de óleo do motor do presente estudo em 50%, resultando em uma economia de 33,3% no custo do lubrificante por hora trabalhada.

Palavras-chave: contaminantes, biogás, biodigestor, biometano, corrosão.

Introduction

Biogas, which mainly consists of methane and carbon dioxide, is a compound that also presents in its composition impurities and other gases such as hydrogen sulfide, sulfur dioxide and water vapor in amounts that vary according to the biomass used, climatic factors, digester dimensions and other circumstances (Cervi, Esperancini, & Bueno, 2010). Internal combustion engines that do not have gas cleaning processes suffer especially from their rapid degradation due to the presence of water vapor and hydrogen sulfide gas. These gases can cause corrosion in several parts of the engine, wear of moving parts and possible lubricant oil contamination. Another gas typically present in biogas and detrimental to engine performance is carbon dioxide, which acts as an anti-knock agent during the combustion. The reduction of its contents can be performed with a biogas wash (in solvents or water) and subsequent drying, also acting in the reduction of water vapor content.

The calorific value of natural biogas ranges from 5,000 to 7,000 Kcal m^{-3}, whereas biomethane (highly filtered biogas) can reach up to 12,000 Kcal m^{-3} (Silva & Albino, 2015). Biomethane with 90% methane has characteristics similar to CNG (Souza & Schaeffer, 2010). According to Mannarino (2005), natural gas, when used in cars, buses and trucks, is named natural vehicle gas and is advantageous in regard to the cost per mile. As it is dry, it does not cause carbon deposits on the internal parts of the engine, increasing its life cycle and the interval of oil change, significantly reducing maintenance costs.

Biogas can be used as a fuel for diesel and Otto cycle engines. The use of biogas in diesel cycle engines is achieved by using two technologies: the conversion from diesel to Otto cycle and bi-fuel conversion (diesel and biogas). Al-Qarallah (2014) states that in dual-fuel operation in diesel cycle engines biogas is introduced along with air at the intake stage, and ignition is effected by a small diesel pilot injection to provide compression ignition, thus initiating the combustion of the gas that is admitted into the cylinder through the intake manifold. It is advantageous for not requiring any engine modifications.

The process of conversion from diesel to Otto cycle consists of replacing the entire diesel injection system with a gas carburetion system to the intake air and also an electrical system with spark plugs for ignition, which occur by electric spark. Due to the necessary changes in the process of conversion from diesel to Otto cycle, loss of power and engine performance may occur (Souza, Pereira, Nogueira, & Pavan, 2004). But even if this is the most complicated method, Suzuki, Fernandes, Faria, and Vidal (2011) believe this is the most suitable type of engine for the use with biogas.

Lubricant oils are responsible for the decrease in friction and consequently in the wear of the engine, as well as for the cleaning of combustion residues and residues caused by component wear. The efficiency of the lubricant might be diminished by the severe use of the engine and by contaminants, such as water, dust (silica), fuels and combustion residues. The periodic analysis of the lubricant serves to track both its normal deterioration and that caused by different types of contamination, working as an indicative of preventive maintenance (Corrêa, Maziero, & Storino, 2011).

As the engine lubricant is an indicator of wear caused by work conditions and quality of the fuel and oxidizer, the present study aims to assess the influence of the use of filtered biogas on lubricant oil contamination and degradation as well as on engine wear and corrosion.

Material and methods

The experiment was carried out on a poultry farm located in the city of São Miguel do Iguaçu, Parana state, Brazil. The generator set used is made by the Fockink Group and consists of a converted Otto cycle engine by MTU Onsite Energy of Brazil Ltda. (Mercedes-Benz), model OM447, 6 cylinders, 117.8 kw power, coupled to a WEG generator, model GTA251ALHD, 139 kVA power, operating at 1800 RPM, 220 volts tension, 292 Amperes current, 60 Hz frequency and φ 0.80 cos. The average biogas consumption of the engine is 60 m^3 $hour^{-1}$ at full load. The total volume of lubricant in the system of the engine is 28.5 L.

Biogas was previously filtered in order to reduce the concentrations of carbon dioxide, hydrogen sulfide, sulfur dioxide, water vapor and other impurities. The filters are also made by the Fockink Group and are filled with iron dust.

We used a Petrobas lubricant, model Extra Turbo 15w40, which meets the criteria of the API CG-4/SJ and MB 228.1 specifications. The Fockink Group and MTU Onsite Energy recommended the change of the lubricant and filter for this engine at 250 EOH.

Because of the benefits of the use of natural vehicle gas and its similarity with purified biogas we proposed the possibility of extending the interval of lubricant oil change when biogas is used as fuel, with sampling in intervals of 75 EOH for a total period of 525 EOH for the first sampling stage. The choice of this interval was motivated because of the necessity in indentifying any deterioration presented by the lubricant, what could be improved with more interval time. This period establishes a trend of several important parameters of oil performance, mainly viscosity, TBN, oxidation, nitrates and sulfates.

For the sampling, the engine was started until the operating temperature was reached and the lubricant oil homogenized. Sampling was performed by means of a vacuum pump that was inserted into the dipstick tube at medium depth in order to avoid sucking dirt and sludge from the surface of the lubricant or from the bottom of the crankcase, and to counter the problem of lubricant decantation and bottom accumulation. The samples of 0.1 L of lubricant oil taken from the engine were replaced with new oil after each sampling.

The analysis performed on the lubricant oil consisted of:

- Moisture determination by the Karl Fischer method (ASTM D1744 - American Society for Testing and Materials [ASTM], 2013a);
- Morphological study of the particles by means of macroscopy – NAS 1638 (National Aerospace Standard [NAS], 2001), ISO 4406 (International Organization for Standardization [ISO], 1999) and SAE AS 4059 (Society of Automotive Engineers [SAE], 2013);
- Kinematic viscosity at 100°C - NBR 10441/ ASTM D445 (Associação Brasileira de Normas Técnicas [ABNT], 2007, American Society for Testing and Materials [ASTM], 2015);
- Infrared spectrometry (ASTM E2412-10 - American Society for Testing and Materials [ASTM], 2010) to indentify oxidation, glycol, soot content, nitrates and sulfates;
- Total Base Number - TBN - ASTM D4739 (American Society for Testing and Materials [ASTM], 2011);
- Plasma optical emission spectrometry (ASTM D5185 - American Society for Testing and Materials [ASTM], 2013b) identifying 19 chemical elements (Ag, Cr, Cu, Fe, Mo, Ni, Pb, Sn, Ti, Al, K, Na, Si, B, Ba, Ca, Mg, P, Zn).

Biogas samples were collected together with lubricant oil samples. The sampling was performed in the engine admission valves, before the air/fuel mixer, with a sampling bag. The gas was analyzed with a biogas analysis kit developed by the partnership between Embrapa and Alfakit, following the methodology of Kunz, Oliveira, and Piccinin (2007), with quantitative and qualitative results of the biogas composition. The technique for the analysis of ammonia as well as hydrogen sulfide consists in boiling biogas in a solution and performing the colorimetric analysis right after. As for the analysis of methane and carbon dioxide, biogas is also boiled in a solution; however, the concentration is given by the difference between the initial and final gas volume. All analyses were performed in triplicate.

Results and discussion

Lubricant analysis

Table 1 shows the results of the lubricant oil analysis.

The variation of viscosity in the first and second stages was 12.69 and 16.42% lower than the viscosity analysis of the new oil. The lowest viscosity found was 12.98 cSt. Thus, all results obtained are in accordance with the limits in of Nédic, Peric, and Vuruna (2009).

Total base number (TBN) is a measure of reserve alkalinity of a lubricant that represents its capacity in neutralizing acids. Biogas suffers an elevated influence of hydrogen sulfide, and as cited by Macin, Tormos, Sala, and Ramirez (2006), a significant proportion of gases generated at combustion get past the piston rings and contaminate the crankcase oil causing different adverse effects.

Table 1. Results of the lubricant oil samples analyzed.

Samples	Replication Sampling stage	New oil	1st sampling stage							2nd sampling stage							
	Oil EOH	0	75	150	225	300	375	450	525	75	150	225	300	375	450	525	600
Wear	Silver	0	2	2	1	0	0	0	0	0	0	0	2	0	0	0	0
	Chromium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Copper	0	22	34	42	47	52	59	76	12	18	23	32	36	53	80	103
	Iron	1	7	10	14	15	20	28	32	6	10	15	20	20	23	27	29
	Molybdenum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Nickel	0	0	1	1	1	1	1	1	0	0	0	1	1	1	1	1
	Lead	0	2	2	2	2	2	3	4	1	1	2	2	2	3	5	6
	Tin	0	1	2	3	3	3	3	5	0	0	0	1	2	3	6	8
	Titanium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Aluminum	3	4	4	5	5	6	6	7	3	3	4	4	4	4	5	5
Contamination	Potassium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sodium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Silicon	7	2	2	2	3	3	3	3	2	2	2	2	3	2	3	3
Additives	Boron	1	1	3	1	1	0	0	0	1	2	3	9	1	1	1	0
	Barium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Calcium	1321	1347	1382	1397	1459	1430	1488	1479	1333	1342	1353	1380	1370	1446	1404	1453
	Magnesium	880	958	1006	1014	1069	1049	1095	1081	917	939	953	975	950	1017	989	1013
	Phosphorus	1086	1078	1085	1067	1093	1076	1078	1028	1054	1037	1014	992	990	969	936	931
	Zinc	1370	1361	1331	1327	1378	1363	1399	1373	1336	1324	1316	1316	1321	1363	1312	1340
Infrared	Oxidation	6	8	9	9	10	10	10	11	7	8	9	10	10	11	11	12
	Glycol	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
	Soot	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0	0	0	0	0	0	0	0
	Nitrates	5	8	8	8	8	8	8	8	7	7	8	8	8	8	8	8
	Sulfates	15	18	19	20	21	21	23	25	17	19	21	23	23	25	26	28
TBN	TBN (mg KOH g^{-1})	7.713	6.57	5.26	5.12	5.37	5.37	5.13	5.2	7.32	6.77	5.42	5.79	4.44	6.7	5.11	6.13
V100ºC	Viscosity at 100ºC (cSt)	15.53	14.2	13.8	13.5	13.7	13.6	13.6	13.6	13.9	13.3	13.4	13	14.1	13.7	13.4	13.2
Physical Tests	Water (%)	0	0	0	0	0	0	0	0	0	0	0.31	0	0	0	0	0

Thus, it is necessary to verify if hydrogen sulfide or by-products of its burning reach the lubricant oil and if they act as degrading agents of the TBN.

Corrêa et al. (2011) state that for diesel engines the total base number must be higher than 2.5 mg KOH g^{-1}. Nédic et al. (2009) and Naegele et al. (2013) states that the total base number must be higher than 50% of the value of the new oil only if this value is higher than 2.0 mg KOH g^{-1}. The lowest total base number found in the experiment was 4.443 mg KOH g^{-1} at 375 EOH of the second stage and it represents the highest variation, 42.4% in relation to the new oil, although the total base number increased after this sampling with a variation of 20.54% at 600 EOH.

The titrimetric method was used for the analysis of the total base number, so the lowest values found on both stages might be considered errors because of the accuracy of the method or of the reading of the results, as in subsequent samples the total base number is usually higher. This behavior of variation (increase and decrease) of the total base number and of the viscosity at 100°C was also verified in the experiment of Naegele et al. (2013), in which an MTU engine was assessed, model MDE MB 3066 L4, operating on rigorously filtered biogas (approximately 0 ppmv of hydrogen sulfide); however, there was an increase in oil viscosity in that engine. As for the experiment of Nédic et al. (2009), using an engine similar to the one of this study, operating only on diesel, the behavior of the total base number was of continuous decrease, without the sharp reduction in the first hours of oil utilization that occurred in the present study.

With the results of the first and second stages, in which the values of variation of the last samples in relation to the new oil were 32.57 and 20.54% respectively, we can affirm that the oil was still capable of neutralizing acidic by-products at 600 EOH generated by biogas combustion and resulting from the oxidation of oil during its aging process.

Nitrates, sulfates and oxidation are contaminants generated by the combustion process that reduce lubrication properties, increasing viscosity and causing sludge to deposit, besides blocking the filters. Glycol is generally originated from leaks in the cooling system, whereas soot originates from leaks in the intake system or irregular burning of liquid fuels.

Oxidation and nitrate values did not exceed the recommended limits. Soot and glycol results were not significant.

The highest sulfate values, 26 and 28 A cm^{-1}, were found on the second stage at the sampling at 525 and at 600 EOH. Oelcheck (2010) recommends 36 A cm^{-1} as the maximum value, whereas Naegele et al. (2013) recommend 25 A cm; thus, the value on the second stage after 525 EOH is 12% higher than the limit recommended by Naegele et al. (2013) although it is within the limit recommended by Oelcheck (2010).

Spectrometry showed no evidence of chromium and titanium in any of the samples. The values of molybdenum, nickel, silver, lead and tin were not significant and were under the limit values in all samples.

Singh, Agarwal, and Sharma (2006) stated that copper is not added to the lubricant oil as an additive, and the presence of this metal in samples of lubricant oils usually occurs due to the wear of the valve guides, piston rings, mounting points, etc. Copper values must range from 40 to 60 ppm, which was reached at 450 EOH of the first stage. An increase of copper quantity in the lubricant oil was observed after 375 EOH. On the second stage, from 75 to 375 EOH, the average increase rate was 32.35%, whereas from 375 to 600 EOH the rate was 42.30%.

The iron concentration values (Figure 1) were similar to those of copper. All samples showed results below the 100 ppm limit value according to the parameters established by Nédic et al. (2009).

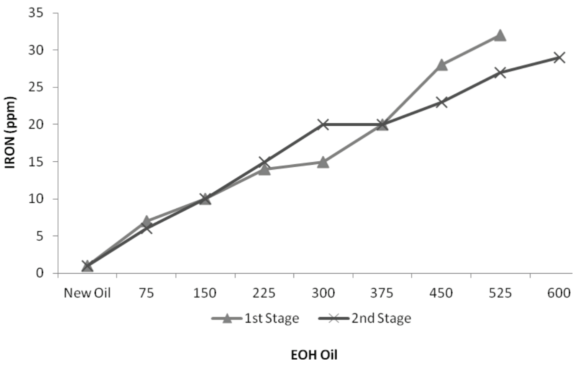

Figure 1. Variation of iron concentration in the lubricant oil as a function of engine operating hours.

The contaminant agents we found were aluminum and silicon. None of the samples analyzed showed the presence of potassium and sodium. The values of aluminum and silicon were higher in the first stage, decreasing in the others. Aluminum is not added to lubricants as additive, so its presence in the sample of the new lubricant oil (3 ppm) must have come from the own oil used or caused by some type of contamination, possibly during transportation, storage or sampling. The limit value of aluminum for Otto cycle engines and gas Otto cycle engines listed in Naegele et al. (2013)

is 10 ppm; as for diesel cycle engines the value is 40 ppm. Therefore, all samples were under the limit for both specifications.

The limit value of silicon for Otto cycle engines and gas Otto cycle engines in Naegele et al. (2013) is 7 ppm, in Oelcheck (2010) as for diesel cycle engines this value is 20 ppm. Thus, all samples were under the limit for both specifications. The samples of the new oil were equal to the limit value of 7 ppm for Otto cycle and gas Otto cycle engines due to the presence of silicon as anti-foaming additive.

Additives, calcium, zinc and phosphorous presented variation inferior to the limit described in Naegele et al. (2013) (± 20% new oil). No trace of barium was detected and the concentration of boron was not significant.

The variation of magnesium concentration in the lubricant oil in the first and second stages was 24.43 and 15.57% higher than that in the new oil. According to the allowed variation described in Naegele et al. (2013) (± 20% new oil), we can affirm that only the results of the second stage are under the limit of utilization recommended. As for the first stage, the value is inferior to the limit recommended until the sampling at 375 EOH, with a variation of 19%. Therefore, the limit value for the substitution of the lubricant due to magnesium variation is 375 EOH.

Physical test results showed 0% water content in the lubricant oil, with the exception of the sample at 225 EOH in the fourth stage, in which 0.31% water was found. This possibly happened because of the low temperature of the oil when sampling occurred or some type of contamination from outside the engine, as other samples did not present any sign of glycol, what would represent the passage of coolant onto the crankcase.

Biogas analysis

The results of the biogas samples are described in Table 2. No trace of ammonia was detected.

Figure 2 shows data referring to methane production, in which a variation ranging from 70 to 80% was verified during the analysis period. The variation may have occurred because of different variables, such as waste characterization (that varies according to the age of the animal), temperature and climatic changes, washing of the installation with detergents, inlet supply lines partially covered and covering tarps with leaks. Wastewater and rain dilute the waste content in the biodigester and the presence of detergents inhibits the biological activity, what impacts methane production.

Table 2. Biogas analysis results.

Stage	Sample (EOH)	Hydrogen Sulfide (ppmv)	Methane (%)	Ammonia (ppm)
1st Stage	75	640	74	0
	150	560	73	0
	225	255	78	0
	300	305	73	0
	375	586	72	0
	450	543	70	0
	525	331	76	0
2nd Stage	75	305	74	0
	150	178	80	0
	225	407	78	0
	300	357	75	0
	375	357	74	0
	450	408	74	0
	525	383	72	0
	600	300	70	0

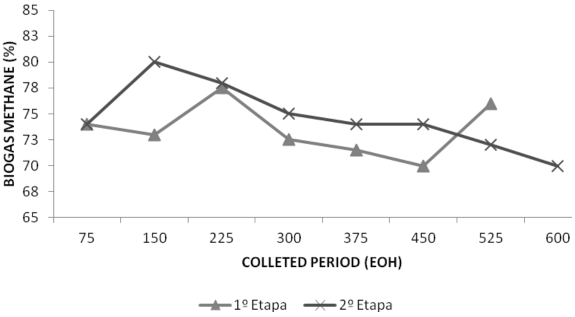

Figure 2. Biogas methane (CH_4) concentration.

Pereira (2005) states that it is necessary to take all precautions at the moment the waste enters the biodigester, eliminating, for example, rainwater penetration and reducing the use of antibiotics, detergents and disinfectants in the livestock production system. When well operated, the system yields biogas with up to 70% methane. Cervi et al. (2010) report that when the necessary environmental conditions for the processing of the waste by microorganisms are met, the biogas obtained must be composed of a mixture of gases with approximately 60 to 65% of the total volume consisting of methane. Even with all adversities, and confronting the cited literature, we were able to verify good biodigesters managing and production, with yields over 70% in the research period.

Figure 3 shows the results of the analysis of hydrogen sulfide. We verified a correlation between methane production and the presence of hydrogen sulfide. In the first stage, as the presence of methane in the samples decreased, the presence of hydrogen sulfide increased. In the second stage, the behavior was similar until 225 EOH, however, from 300 to 600 EOH, while methane concentration decreased, the presence of hydrogen sulfide remained unaltered.

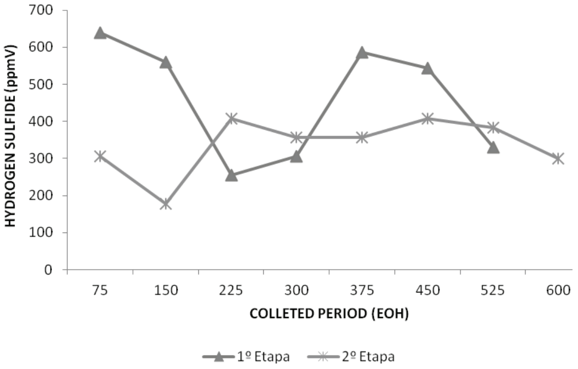

Figure 3. Biogas hydrogen sulfide (H_2S) concentration.

After the sampling at 375 EOH in the first stage, the substitution of the iron dust of the biogas filter was performed and there was a decrease in hydrogen sulfide concentration until the sampling at 150 EOH in the second stage, however, after that the values increased again and remained unaltered after the sampling at 225 EOH in the second stage until the end of the experiment. Before the substitution of the iron dust, the average hydrogen sulfide value was 469 ppmv, and after it, 357 ppmv, proving that there was a reduction in hydrogen sulfide. However, these values are elevated for the use of biogas in engines because the recommendation is that values should be inferior to 50 ppmv. This behavior during filtering might have occurred because of the quick filter saturation and due to the filter's lack of iron sponge regeneration through a controlled oxygen stream. Its performance was not satisfactory.

Comparison of Biogas and lubricant oil results

As for the sulfate content, we could observe a relationship with the utilization of biogas with high levels of hydrogen sulfide. When compared to the data of Naegele et al. (2013), in which biogas presented sulfate levels close to zero, the increase of sulfates was inexistent, however, in this study, because of the elevated concentrations of hydrogen sulfide there was an increase in sulfates that limited the oil change to 450 EOH. According to Souza et al. (2016), contents of hydrogen sulfide in biogas must be minimized by filtration processes in order to avoid engine wear and contamination. Thus, for the utilization of biogas in engines, an efficient filtration is necessary, with as much reduction of hydrogen sulfide content as possible, as this action will have a direct impact on lubricant oil durability and also on engine durability because of the degrading power of this gas.

Copper, lead and tin data reveal an increase in the engine's levels of wear after 375 EOH. Copper is the metal most sensitive to corrosion when hydrogen sulfide is used, and it is found in important engine parts, mainly bushings and bearings (Singh et al., 2006). The increase in tin concentration might be directly related to the increasing copper rate, as the addition of both results in bronze, which is found in bearings. Tin is also used in metals of rings, pistons and bushing stops, and its presence in the lubricant indicates wear of the parts. Lead and copper may fuse, composing an alloy present in bearings and bushings (Nédic et al., 2009). The oil samples in the study of Silveira, Coelho, Motia Neto, Moura, and Moura (2010) also presented a trend of increase in the concentration of all metals analyzed compared to the new oil, further suggesting that this increase is related to the quality of the parts composing the engine and the types of paths where the vehicle has been.

As for magnesium, the limit value recommended by the literature was reached after 375 EOH. This additive with dispersant/detergent properties is greatly important to the engine, mainly when biogas with hydrogen sulfide is used, because it acts in the neutralization of the acids generated and controls the oxidation process.

According to the data exposed, it is possible to increase the lubricant oil change intervals of the engine herein mentioned in 50%, from 250 to 375 EOH. In relation to the lubricant filter, based on its efficiency verified herein, the substitution can be done along with the lubricant oil change at 375 EOH.

Based on this new period and considering the lubricant oil cost of R$ 8.50 (U$ 3.62) per liter (pricing for Cascavel, State Paraná, January, 2014), the oil cost per EOH of the engine used in this study will decrease from U$ 0.42 to 0.28, an economy of U$ 505.53 a year (10 engine operating hours daily), which is equivalent to 33.3% of the previous cost. If we consider the cost of the filter, which had its life cycle increased, the cost of labor and the period the equipment is not operating for oil change, the economy will be evidently higher. Besides the economic advantage, there is also an environmental advantage as less oil consumption generates a lower volume of waste for posterior destination and recycling.

Conclusion

The values of viscosity, total base number (TBN), oxidation and nitrates did not exceed the limits standardized in the literature, even when the lubricant was used for 600 EOH.

We identified a relationship between the high concentration of hydrogen sulfide and the increase in sulfate concentration in the lubricant oil, with results superior to those found in the literature, what resulted in lubricant oil change intervals of a maximum of 450 EOH.

Among the other metals, only copper showed values over the recommended limit after 450 EOH.

Among the additives, only magnesium presented variation over the limit standardized. Due to its dispersant/detergent properties, its excessive variation might have occurred because of the intense oil oxidation, reaching its recommended limit at 375 EOH.

The limit value for the lubricant oil load change in the engine studied, according to the limits found in literature, is 375 EOH, a value 50% higher than the manufacturer's recommendation.

The analysis of the results and its confrontation with the literature demonstrated that the controlled maximization of the oil change intervals did not harm the performance of the system. That results in the economy of maintenance and operating costs and improves the attractiveness of the use of biogas in engines. Moreover, we highlight the anticipated identification of component faults by monitoring the oil lubricant analysis, what allows previous scheduling of maintenance operations and reduces the inactivity period of the engine in case of component fault.

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