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Selection and evaluation of degradation intensity indicators of gas combustion engine oil

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Abstract. The paper is focused on the analysis of data obtained during the operation of gas combustion engines running on biogas. The observed engines were running continuously in cogeneration units of biogas plants. The long-term operational monitoring of engines operating on biogas was carried out using tribotechnical diagnostics methods focused on oil properties. Each of individual indicators was determined in obtained time series. As critical indicators oils were identified oxidation, sulfation, nitration and total acid number. The prerequisite for correct selection of the oil change interval is knowledge on evolution of critical indicators over time. In the reference case, oil oxidation was identified as critical indicator. This knowledge allows to optimize intervals of oil sampling and oil change interval on the basis of time series evaluation.

Key words: biogas, engine oil, oxidation, sulfation, oil change.

INTRODUCTION

Long-term monitoring of oil filling and diagnostic of engine together with monitoring of particles content creates conditions for sustainable and reliable operation of engine during whole service life (Novacek, 2015).

The first prerequisite in order to correctly diagnosis is proper sampling of engine oil. During oil sampling those basic rules must be maintained: a) avoid external contamination of a sample; b) sampling should be done with the engine running or as soon as engine is stopped; c) sampler should be immediately marked with both sample and engine identification data (Novacek, 2015).

During the last decade, the tribological analysis of industrial lubricants was done by using well-known tests. Those tests provided early warnings of possible problems, so there was sufficient time to take proactive action. According to the American Petroleum Institute (API), base oils fall into five main groups (Group I–V). This breakdown is based on the refining method and the base oil's properties in terms of, among other things, viscosity and the proportion of saturates and sulfur content. Transition of actual oils from Group I to Group II and III was accompanied with general changes in oil composition. Oils belonging to Group II and III have inferior natural oxidation stability in comparison with oils of Group I. This is main reason why those kinds of oils are highly doped with antioxidants (Novacek & Novak, 2013; Cerny, 2015). Antioxidants are not able to stop the process of oxidation, but this process can be significantly slowed down. Antioxidants are consumed and if their amount in the oil drops below a certain threshold, there is an appreciable acceleration of oxidation of the oil, as is shown in Fig. 1.

Biogas is produced by processing of organic waste and biomass in bio-gas stations and then is burned using gas engine cogenerations units. Gas combustion engines of cogeneration units are operated continuously at constant speed but under variable load. This load depends mostly on requirements of electricity distribution network and on actual composition of used biogas. Because of the forced breaks, load variation or gas composition variation, the thermal load of engines and oil fillings varies. This operational mode has extremely high requirements on engine oils (Posta et al., 2016).

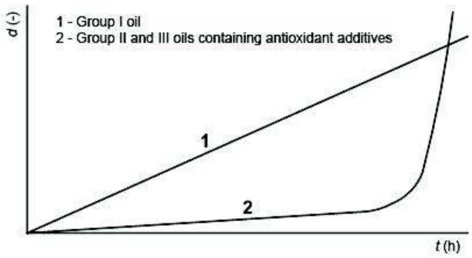

Figure 1. Progress of oil degradation.

Engine oils specified for gas engines belongs to most challenging products of his kind. The progress and level of degradation of those oils was long-term monitored in order to full utilization of their potential. Scientific problem can be presented as verification of hypothesis assuming that for given type of engine and specific working conditions can be expected similar progress as is shown in Fig. 1. Therefore, results from earlier analyses can be used for determination of a limit value of critical indicators and corresponding operating time.

MATERIALS AND METHODS

Long-term monitoring of operation and condition of engine oil of two identical engines of cogeneration units was carried out. Both engines was supplied with biogas from the same fermenter. Cogeneration units, shown in Fig. 2, was marked as KJ3 a KJ4. Units KJ1 and KJ3 was not monitored due to their different operational mode. Monitored units consist of Scania-Schnell ES 2507 combustion engine and Stamford HCI434F2 generator. Basic parameters are shown in Table 1. Engines was filled with engine oil with zero content of zinc and medium content of sulphated ash, specified for use in all kinds of stationary gas engines running at sewage gas, biogas or woodgas. Basic oil parameters are shown in Table 2.

Figure 2. Cogeneration units.

Table 1. Basic technical parameters of cogeneration unit

Engine		Generator	
Model	Scania-Schnell ES 2507	Model	Stamford HCI434F2
Cylinder volume	12,000 cm^3	Voltage	400/230 V
Rated power	250 kW	Rated power	280 kW
Oil capacity	41 l	Frequency	50 Hz

Table 2. Basic technical parameters of engine oil used in cogeneration units

Property	Units	Value	Testing standard
Density at 15°C	kg m^{-3}	866	DIN 51 757
Fire point	°C	260	DIN ISO 2592
Pour point	°C	-35	DIN ISO 3016
Kinematic viscosity at 40 °C	mm^2 s^{-1}	105.00	DIN 51 562-1
Kinematic viscosity at 100 °C	mm^2 s^{-1}	13.40	DIN 51 562-1
Sulphur ash	% of mass	0.7	DIN EN ISO 6245
TBN	mg KOH g^{-1}	8.9	DIN ISO 3771

Condition monitoring of oils was performed using tribotechnical diagnostics by independent and certified laboratory. Standards used for analyses are described in Table 3. Oil samples were acquired by authorized employee according to methodology given by laboratory. At the time of sampling, the overall operation time of engine was read from the control unit of engine. Procedure of oil sampling for analysis has to follow certain order. The sample should be extracted so that the concentration of information is consistent and representative. During the sampling process, it is essential to make sure that the sample does not become contaminated (dust, debris, water, etc.). It is important to take sample always from the same spot of crankcase immediately after turning off the engine.

Table 3. Standard test methods

Method	Standard
Determination of elements in oil using OES-ICP	ASTM D 5185
Oxidation, sulfation, nitration, water and glycol content	ASTM E 2412
Acidity number TAN	ČSN ISO 6619
Base number TBN	ČSN ISO 3771
Viscosity	ČSN EN ISO 3104

RESULTS AND DISCUSSION

In the period of years 2014–2016 there was performed 30 analyses (approximately 1 sampler per month) of engine oil for each of monitored engine. List of mostly exceeded thresholds values is shown in Table 4. In all cases when threshold of sulfation and nitration was exceeded, threshold of oxidation was also exceeded. Therefore, it is evident that the critical indicator of oil condition in the monitored engine is oxidation.

Table 4. Exceed count for selected threshold parameters in period of years 2014–2016

Parameter	Treshold	KJ3	KJ4	Total /%
Oxidation	20 Abs·cm^{-1}	29	26	55 / 92
Sulfation	20 Abs·cm^{-1}	7	9	16 / 27
Nitration	20 Abs·cm^{-1}	8	3	11 / 18
Viscosity 100°	16.4 mm^2 s^{-1}	7	6	13 / 22
TAN > TBN	mg KOH g^{-1}	17	18	35 / 59

Relation between values of oxidation and oil filling uptime in case of monitored engines is shown in Fig. 3, using calculation according to Formula 1.

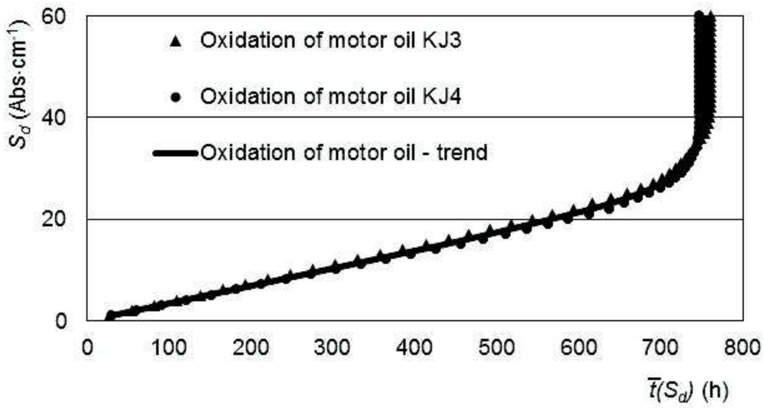

Figure 3. Oxidation of engine oil.

$$\bar{t}(S_d) = \frac{1}{n}\left[\sum_{i=1}^{m(S_d)} t_i(S_d) + \sum_{j=1}^{n-m(S_d)} t_j(S_d)\right] \quad (1)$$

where: n – the range of the entire sample of monitored elements; $m(S_d)$ – the number of elements operating at certain value of diagnostic signal S_d; $t_i(S_d)$ – operating time of i-th element, which is functional at certain value of diagnostic signal S_d; $t_j(S_d)$ – operating time of j-th element, which is in failure mode at certain value of diagnostic signal S_d.

Speed and mode of degradation process of engine oil can be affected by fuel used in combustion engine. As states (Vesela et al., 2014) when is used fuel E85 containing 85% of ethanol and 15% of BA95 petrol, the significant degradation index is reduction of viscosity. While monitoring, in case of this study, the progress of degradation of engine oil in gas engines burning biogas, viscosity was in either case an indicator excessing critical value and therefore does not lead to oil change, as shown in Table 4. Exceeding of viscosity, TAN/TNB indicators was (with single exception) accompanied with significant exceed of oxidation.

As shown by the results of the performed operational monitoring of engines operating on biogas, the significant degradation index of engine oil is oxidation or sulfation.

Results of performed operational monitoring can be also used to set the value of diagnostic signal, which corresponds with optimal time of change of oil filling.

Method of determining the normative diagnostic signal and determining optimal time for preventive maintenance gives (Teringl et al., 2015; Legat et al., 2017). Principle of such as determination process is presented by specific samples of data collected during operation monitoring in Fig. 3.

Analogously, we can determine the optimal time for an oil change for each of additional diagnostic signal. First diagnostic signal, which exceeded limit value, will be used as decisive for real oil change.

Results of carried operational monitoring, shown in Fig. 3, confirms the hypothesis that for specific engine in specific working conditions course as shown in Fig. 1 can be expected.

In particular case of monitored oils, the appropriate procedure is further described. Oil service time will be monitored and in the moment of optimal time, oil filling will be either changed or the oil sampling followed by analysis has to be done. If the analysis confirms reached or exceeded limit values, oil change will be performed immediately or the deadline of oil change will be resolved. Values given by oil analysis will be added to data history, so next time will be included again both in optimization process of oil change interval and in process of adjusting of threshold value of diagnostics signal.

CONCLUSIONS

Modern engine oils are highly doped with antioxidants additives. Oil degradation continues rapidly after depletion of additives. This moment can be captured using frequent tribotechnical analyses, or can be estimated from early service periods reached before the breakpoint of degradation curve. Using execution of qualified estimation, the preventive maintenance of oil fillings including oil analysis can be driven.

Results of monitoring of engine oils demonstrate that in this particular case, the reason of oil degradation is mainly oxidation, which led to execution of 98% of oil change events.

Recommendation for operators of referenced kinds of gas engines:

- Monitoring of oil service interval and oil sampling at that time, when limit value of selected parameter is close to his threshold, based on acquired knowledge (respecting shape of time progress of critical parameter) of this research it is possible to predict remaining service interval of oils belonging to Group II and Group III in similar operation conditions.
- According to results of obtained analysis, either perform of oil change or set its deadline.
- Add the values given by oil analysis to data from earlier analyses, so they will be included again in optimization process of both setting of oil change interval and adjusting of threshold value of diagnostic signal.

By this approach, the highest possible utilization of the potential of engine oil without excessive risk of shortening the technical life of the engine can be achieved.

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