The impact on the manner of loading the engines powered with biogas and natural gas on the selected parameters of the motor oil

J Kaszkowiak¹ and M Markiewicz-Patalon¹
¹Faculty of Mechanical Engineering, UTP University of Science and Technology, Bydgoszcz, Poland

e-mail: kaszk@utp.edu.pl

Abstract. The article presents the results of testing four engines working in two groups. The first group was powered by natural gas, the second was biogas. In each of the groups, one of the engines was loaded constant at the level of about 80% of the maximum power (with a variation of ± 5%) the other in a variable manner (in the range of 40-70%). After the cycle, the viscosity, acid number, base number, chloride content, silicon content and calcium and phosphorus content were tested in the oil. It was found that the acid number for all examined cases did not differ significantly. Like the content of calcium and phosphorus. The content of silicon in the oil was higher for the engine that was permanently loaded but produced more energy in the tested period (132 MWh) regardless of the type of fuel. The higher viscosity value was found in the oil of the engine loaded in a variable manner but producing less energy (66 MWh). The value of the basic number of oil had a higher value for the engine loaded in a uniform manner.

1. Introduction

Combustion engines powered with gas fuel, constitute a constantly increasing group of working units. Apart from the engines powering automotive vehicles, in which there are mainly used LPG, CNG or hydrogen, there also operate stationary units powered with natural gas or with biogas. That last group of engines is used mainly for cooling generators’ drives or for power generators. The use of biogas as the fuel for supplying combustion engines’, allows for its management and its processing into easier to transpose energy’s types. Quite often, apart from engines powered with biogas, enterprises use engines constructionally identical but differing most often only in controlling software, powered with natural gas. It allows to ensure the power’s generation continuity in situations of biogas’ deficiency, or to supplement the generated power’s volume.

The natural gas is the fuel of composition depending mainly on the source of its acquiring, in practice is not subject to any serious changes.

However, it is the composition of biogas that is differentiated and which is subject to changes depending on the raw material used for its generations. The lowest changeability there shows the biogas generated in agricultural biogas plants using the homogenous raw-material for its generations. In the Western Europe’s conditions, these are most often bets and corn, and in Poland – corn in the fresh form or as silage, which are such raw material [2]. The raw materials for biogas’ generation are also other substrates: liquid manure, wastes from food processing enterprises, past the date foodstuffs and algae...
Using of material acquired at the time of the municipal waste treatment plant’s operation, is a unique manner of biogas’ generation. However, due to its changeability, the volume of CH\textsubscript{4} contained in it and the volume of pollutions, in particular of sulphur compounds, are subject to substantial fluctuations. A typical composition of biogas generated from the typical substrates, is presented in the table 1.

**Table 1.** Approximate biogas’ composition depending on the source of origin (own study)

| Type of gas           | Agricultural biogas plants (corn, beets) | Municipal wastes | Waste water treatment plants |
|-----------------------|------------------------------------------|------------------|----------------------------|
| Methane               | 45-75%                                   | 45-55%           | 64-75%                     |
| CO\textsubscript{2}   | 25-55%                                   | 25-30%           | 20-35%                     |
| CO                    | ≤0,2%                                    | ≤0,2%            | ≤0,2%                      |
| H\textsubscript{2}S   | 10-30000 ppm                            | ≤8000 ppm        | ≤8000 ppm                  |
| N\textsubscript{2}    | 0,01-5%                                  | 10-25%           | 3-4%                       |
| O\textsubscript{2}    | 0,01-2%                                  | 1-5%             | 0,5%                       |

The contents of pollutions in substrates, and the degree of their size reduction have an impact on the biogas’ composition and its efficiency [8,9]. The efficiency of a biogas plant depends also on the fresh or previously ensilaged material. The use of the material subject to the correct silaging process, positively influences the volume of the generated biogas and levelling of its composition [3]. Differentiated raw materials influences the cost of biogas’ generation, and as an effect – the operating costs of engines powered with biogas.

Assuring of the most favourable operating conditions at the simultaneous costs’ minimization, is one of the aspects of such engines’ operation. Apart from the costs resulting from the defect’s removal and inspections, the expenses connected with the engine oil’s change, are a significant position. Extending of the periods of time between the oils’ changes results in these expenses’ lowering, however simultaneously in case of the lubrication properties’ worsening, there may occur an engine or its sub-assemblies’ breakdown, what generates much higher costs. In many cases, the enterprises using engines powered with biogas, practice periodical inspections of the oil level and on its basis, they make decisions on further use of the engine oil or its changing. Some enterprises, most often using these types of engines in smaller quantities, basing on a record of hours worked assuming as a criterion of oil change the number of hours worked by a unit from the time of its change. As shown by the tests, the time of oil exposure as compared to the time of operation, influences to a slight degree the lubrication oil’s property [4]. According to different authors, also the biogas’ quality has an impact on the level of oil. In case of correctly purified oil, its adverse impact is minimized [6] and similar to the influence of the natural gas [7]. As shown by the conducted researches, also enrichment with oxygen of air powering engines, is an effective manner of lowering the negative oil impact on the oil level’s [1].

The purpose of the conducted studies was to find out, whether it would be possible to determine the necessity of the oil’s change based on the operating factors, such as conducted work, time of operation or the number of hours after the oil’s change irrespective of the number of the working hours.

### 2. Methodology and materials

The tests were conducted on the group of four engines powering electric power generators. Two of them were powered with biogas, the remaining two ones were powered with natural gas. The tested units had an identical construction with 12 cylinders placed in the V system. The engines were equipped with turbo-charging of a constant geometry. The engine cubic capacity amounted to approximately 12000cm\textsuperscript{3}, and their power quoted by the producer amounted to 380 kW. The engines were in a very good technical condition, till the tests’ commencement they had been exploited for not longer than 2 years from the moment of their production or conducting the general overhaul. Prior to commencement of the tests’
cycle, in all the engines there were conducted the changes of the engine oil, oil filters and air filters. The view of one of the engines presented in fig. 1.

Combustion engines powered the electric power generators of the maximum power 340 kW. Biogas, with which engines were powered, was generated from the wastes from the municipal waste water treatment plant. Its composition was controlled with the use of the biogas analyser BIOTEX MultiPoint.

Figure 1. View of one of the engines on which the tests were conducted

The generated biogas was subject to purification (removal of mechanical impurities, de-watering and elimination of sulphur and silica compounds).

The share of the selected compounds in biogas, prior to and after purification, is presented in the table 2.

Table 2. Average values of the selected compounds in biogas in the period of the conducted tests

| Components of biogas         | Average contents prior to purification | Average contents after purification |
|------------------------------|----------------------------------------|------------------------------------|
| Methane                      | 65,15%                                 | 65,15%                             |
| Hydrogen sulfide             | 57 ppm                                 | 11 ppm                             |
| Carbon dioxide               | 34%                                    | 34%                                |
| Ammonia                      | 0 ppm                                  | 0 ppm                              |

The natural gas used for combustion engines’ powering, was supplied to the engine only after its purification from mechanical impurities, its parameters were assumed in accordance with the supplier’s declaration and they were not examined. The composition of the natural gas is presented in the table no 3.

Table 3. Contents of the natural gas (as per supplier’s data)

| Contents of the natural gas | Average contents  |
|-----------------------------|-------------------|
| Methane                     | 97,8%             |
| Nitrogen                    | 1,0%              |
| Propane, butane, ethane     | 1,0%              |
| Other ones                  | 0,2%              |

Pursuant to the producer, the oil’s exchange in engines should be conducted after each 1000 operating hours.

The lubricant used was synthetic low viscosity oil SAE 40. It is dedicated to spark-ignition engines fueled with natural gas or biogas. It is especially recommended for engines fed with biogas produced from municipal waste and sewage (including increased acidity). The oil met the following specifications:
GE-Jenbacher 6 (F) 4 (C), Caterpillar for acid gas and biogas engines, MWM gas engines, and Waukesha. The oil, according to the classification, the oil used in the tests came from one production series.

For the period of the tests, in each group of engines, one of them was loaded in a continuous manner, evenly on the level of about 330 kW, with variability of ±5%, and the other engine operated with loading within the power range of 30-75% (at the average loading of approximately 40%).

The loading method corresponded to the amount of work carried out and amounted to 66 MWh for variable load engines. For engines loaded in a uniform manner, the amount of work performed was about 132 MWh.

The research cycle was terminated after the production of a certain amount of electricity (66 MWh and 132 MWh) as a measure of the amount of work done by the engine. It was equivalent to 1000 hours of work for each engine group. The oil samples were then sampled and analysed. The samples taken were: viscosity (100°C), acid value and basic number, assuming that they can be indicative of oil degradation. The content of silicon and chlorides as indicators of oil contamination as well as the content of calcium and phosphorus, acting as refining additives, were also measured. The test cycle was repeated three times.

The obtained results were subject to statistical analysis, conducting the analysis of variance in the Statistica programme.

3. Results of the tests

Comparing the obtained results for the time of engines’ operation within the scope of up to 1000 hours it was found, that in the engines powered both with biogas as well as with the natural gas, occurring of essentially statistically differences in the engine oil’s viscosity depended only on the mode of loading.

For engines powered with biogas, the oil’s viscosity in case of uniform loading, had an average value for 1,5% lower, than for the engine loaded in a variable mode. A reverse regularity was observed for the engines powered with the natural gas, where the viscosity at the variable loading had the average value lower for about 2,3%, than for the engine of a constant load and it did not significantly differ statistically.

The acid number of oil did not differ significantly in the conducted examinations (the average value was 2.8), where the base number showed to be significantly differentiated only on case of engines powered with biogas, reaching the value higher for about 28% for the variable value of the engine’s load.

The contents of improvers did not differ statistically significantly both due to the mode of the engine’s load and the time of operation, both for the engines powered with biogas as well as with the natural gas. The contents of the examined impurities in oil for the engines powered with biogas differed significantly depending on the mode of their loading.

Regardless of the type of fuel, the silicon content in the oil was significantly lower for the variable load.

In the engine powered with biogas, the contents of silica in oil was significantly lower for the variable load for about 23% in the engine operating under the constant load. However, in case of an engine powered with the natural gas, the contents of silica was for about 36% than for the engine loaded in a variable mode. The contents of silica in oil, depending on the mode of the engine’s loading, is presented in the fig. 2. The differences statistically significant at the level of 0.05 are marked with the letters a and b.

It was found in the tests, that the contents of chlorides in oil for engines powered with biogas, was not significantly statistically diversified, however for engines powered with the natural gas loaded in a variable mode, it had the significantly statistically lower value for about 14% than for engines loaded in a constant mode.

Many results were obtained in the tests considering the volume of the performed by the engines’ work. It was found, that viscosity of oil of the engines powered with biogas, differed significantly depending on the volume of the performed work. The value of viscosity is presented in fig. 3.
Figure 2. Dependency of the contents of silica on the loading mode

Figure 3. Viscosity values depending on the loading mode for engines powered with biogas

For the engines powered with the natural gas, the differences in the engine oil’s viscosity proved to be statistically insignificant irrespective on the volume of the performed work. The value of the acid number for all the examined cases (volume of the performed work, type of fuel) also proved to be statistically insignificant.

The base number for the engines powered with biogas increased together with the increase of the performed work’s volume. However, for the engines powered with the natural gas, no significantly statistical differences were found in the tested period of time. The value of the base number for the engines powered with biogas is presented in fig.4.

Figure 4. Value of the base number (TBN) depending on the loading mode of an engine powered with biogas

For all the cases (value of the performed operation and the type of fuel) occurrence of statistically essential differences in the contents of improvers (calcium and phosphor) was not found. Within the examined scope, also the differences occurring in the contents of silica and chloride proved to be statistically insignificant in all the examined cases.
4. Conclusions

For the engines powered with biogas it may be found, that one of the criterion allowing for the engine oil condition’s evaluation is the viscosity, the value of which decreases together with the volume of work performed by the engine. Such a criterion cannot be assumed for the engines powered with the natural gas, where occurrence of dependency between the viscosity and the volume of the performed work was not found. For the engines powered with biogas there was also found the change in the base number’s value, which increases together with the volume of the performed work, what may be the next indicator of the engine oil’s consumption level.

The obtained results of the tests conducted for the engines powered with biogas show, that the listed parameters may be the alternative for the time of an engine’s work, as the oil’s consumption measure.

In case of engines powered with the natural gas, within the examined scope occurrence of changes in the evaluated engine oil’s properties were not found, thanks to what the oil’s condition could be examined. Continuation of the researches on the first and the second group of engines with widening of the scope of the controlled oil parameters shall be appropriate. The conducted researches show, that the change of the contents of chlorides in the oil of engines powered with the natural gas may be such a parameter.

References
[1] Cacua K, Amell A, Cadavid F (2012) Effects of oxygen enriched air on the operation and performance of a diesel-biogas dual fuel engine Biomass and Bioenergy Vol 45 pp 159-167
[2] Czekała W, Bartnikowska S, Lewicka A, Bugała A, Zbytek Z, Lewicki A (2016) Economic and energy efficiency of the solid biofuels produced from digested pulp 3RD International Conference on Chemical and Biological Sciences Amsterdam
[3] Dulcet E, Kaszkowiak J, Borowski S, Mikolajczak J (2006) Effects of microbiological additive on baled wet hay Biosystem Engineering Vol pp 379-384
[4] Janosova M, Petrovic A, Vozarova V, Hujo L, Csillag J, Malinek M (2016) Analysis of the physico-chemical properties of the hydraulic fluids in order to modify change intervals Procedings of International PHD Students Conference (MENDELNET)
[5] Mussgnug J H, Klassen V, Schlüter A, Kruse O (2010) Microalgae as substrates for fermentative biogas production in a combined biorefinery concept Journal of Biotechnology Vol 150 / 1.
[6] Roubaud A, Favrat D (2005) Improving performances of a lean burn cogeneration biogas engine equipped with combustion prechambers, Fuel Volume 84, Issue 16 pp 2001-2007
[7] Subramanian K A, Vinaya C, Mathad K, Vijay V, Subbarao P (2013) Comparative evaluation of emission and fuel economy of an automotive spark ignition vehicle fuelled with methane enriched biogas and CNG using chassis dynamometer Applied Energy Volume 105, pp 17-29
[8] Zastempowski M, Borowski S, Kaszkowiak J (2013) New Solutions in Harvesting Plants for Power Purposes (5th International Conference on Trends in Agricultural Engineering Prague, Czech Republic
[9] Zastempowski M, Bochat A (2016) Innovative Constructions of Cutting and Grinding Assemblies of Agricultural Machinery 6th International Conference on Trends in Agricultural Engineering Prague 2016 pp 726-735