

SOME PROBLEMS WITH OPERATION OF ENGINES FUELLED WITH LANDFILL BIOGAS

Maciej Ziółkowski

Gdansk University of Technology, Faculty of Mechanical Engineering
Narutowicza Street 11/12, 80-952 Gdansk, Poland
tel.: +48 58 3471174, fax: +48 58 3471174
e-mail: mziolkow@mech.pg.gda.pl

Abstract

In the article has been described some problems associated with the production of biogas and using it as a fuel in internal combustion engines. In Poland biogas is mostly generated from deposits from sewage treatment plants, agricultural waste and from landfills. The biogas chemical composition depends on the organic matter as a source of biogas on used fermentation technology. One of the forms of biogas utilization is burning it in internal combustion engines. Engines producers offer a range of models designed to be fuelled with biogas. However there are some significant problems with operation of such engines that appear in the case of using landfill biogas as a fuel. This kind of biogas is characterized by considerable variability in methane content, which dynamically changes throughout the period of landfill usage. In the article there is some information about the impact of changes in the methane content on operation of internal combustion engines fuelled with landfill biogas. Rapid increase in the methane content may be the purpose of knocking and engine damage. There also presented the analysis of control systems applied in gas engines. The analysis is made for purpose of determining the ability of described control systems to maintain with rapid changes in methane content in fuel gas. On the basis of this there are described some requests for features that should be characterized by the gas engine control system adapted to the combustion of landfill biogas. In summary are presented some guidance to facilitate the correct selection of engine fuelled with landfill biogas.

Keywords: power plants, internal combustion engines, gas engines, landfill biogas

1. Introduction

In Poland in recent years there has been observed a significant growth of number of local stationary power plants, mostly used as CHP (Combined Heat and Power) systems. These objects have different applications: from the typical peak power plants or emergency power systems and local CHP systems to mine gases and various types of biogas utilisation systems [6, 7]. Such objects are elements of a distributed power system, which is complementary to the national energy system. Local, independent power plants and CHP systems can increase reliability of electricity supply and stabilize voltage in the power grid. The increase of popularity of power plants based on reciprocating internal combustion engines fuelled by natural gas or biogas is connected with the introduction of the Energy Law in 1997 in Poland [10], which sets the principles of shaping energy policy, terms of supply and use of fuels and prime energy sources. The Act also contains mechanisms to support the high efficiency generation of electricity using renewable energy sources. The supporting mechanisms are in form of certificates which can be obtained in certain condition and sold. The main impact on development of energy sector based on internal combustion engines have yellow certificates (CHP systems fuelled by natural gas) and green (biogas fuelled power plants and CHP systems). In addition, strict restrictions in free methane emissions from landfills and sewage treatment plants disposals forced to use systems of utilisation of methane free emissions in biogas. Utilization is based on burning biogas in gas flare, or in internal combustion engines those driving power generators. Seamless operation of engines fuelled with gaseous fuel mostly depends on the type of used fuel gas. In Polish energy sector mainly are used two types of gaseous fuels: natural gas and biogas. Combustion of natural gas in an engine

adapted to operate with this fuel makes no operational problems. Natural gas is a very clean fuel, with a constant chemical composition which greatly facilitates the design of the engine control system. In addition to developed natural gas piping systems it is easy to supply the gas from the pipeline directly to the engine, eliminating the need of having fuel storage systems. Experiences from operating power plants fuelled with natural gas indicate no significant problems connected with usage this fuel [9]. In the case of using biogas as the fuel it looks quite different. Due to the large variability in the composition of biogas, and pollutants there are a number of problems in engines operation. Some of those problems will be presented in this article.

2. Landfill biogas

Biogas is gas naturally generated in the process of anaerobic digestion of organic matter. It is a mixture of gases, which has the largest share of methane and carbon dioxide. The composition of biogas - methane content and hence the calorific value depends mainly on the substrate used to gas production and on the conditions of the fermentation process. Usually it contains 40-80% methane, 30-55% carbon dioxide, 0.1-5.5 hydrogen sulphide and trace amount of hydrogen, carbon monoxide, nitrogen.

In Poland there are three main sources of biogas, which may be used as a fuel in gas combustion engines. These are landfills, deposits from sewage treatment plants and agricultural waste. Technology of biogas production from sewage treatment plants deposits and agricultural waste are similar. Biogas production is realised in digesters. The composition of generated biogas depends on the kind of substrates supplied to the digester and the fermentation process controlled by temperature of digester batch [3]. Diagram of this type of biogas plant is shown in Fig. 1.

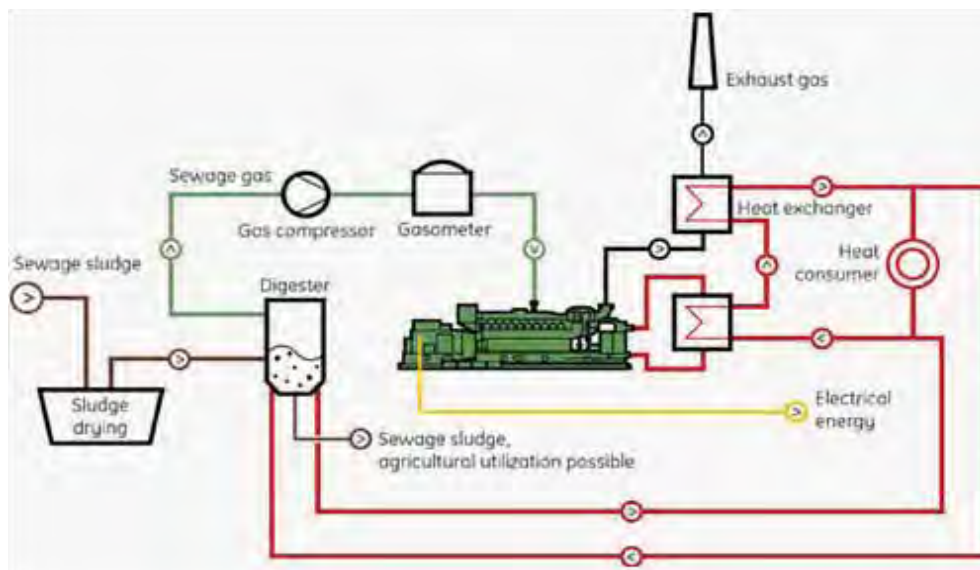


Fig. 1. The scheme of biogas production plant [12]

In this kind of biogas plant the fermentation process takes about 30 days and there is a possibility to ensure such fermentation parameters to achieve a stable composition of produced biogas [3].

In the case of biogas generated from landfills, the situation is somewhat more complicated. The composition of the captured biogas is also dependent on the substrate, i.e. the type of material stored in a dump. In Polish conditions, when there is no rubbish sorting, dumps have very diverse content. There are both organic materials, which can be used for process of biogas formation, as well as other materials that are not subject to fermentation and can affect the process of natural fermentation. Natural fermentation process on landfill takes about 20 years and consists of several

stages. Each stage of fermentation is characterized by different methane contents in the produced biogas. The range of methane content is from 0 to about 70% [11].

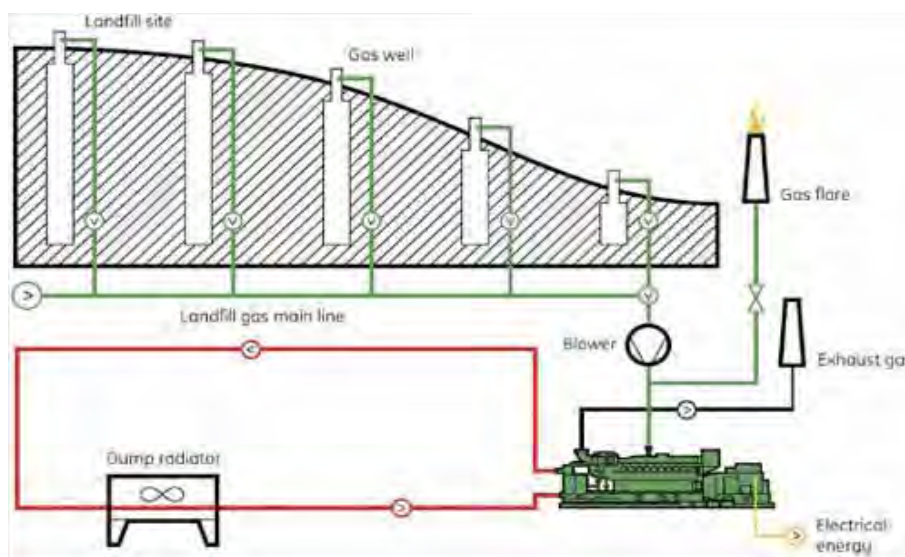


Fig. 2. The scheme of biogas plant on landfill [12]

In addition, the course of these phases does not always take place simultaneously throughout the volume of dump. All of that that causes that the composition of biogas captured throughout the period of landfill degassing is quite changing. These changes may have static course - as the result of the conduct of the subsequent phases of fermentation, or dynamic - when it comes to release of biogas captured under impermeable layers of the dump for example during heavy rainfall. In addition, the results of investigations [9] suggest that the rapid changes in the composition of biogas are also influenced by atmospheric pressure.

In Figure 3 and 4 there are presented investigation results of the composition of the biogas in the landfill in Gdansk Szadólki [9]. The graph shows the percentage content of methane in the biogas in the first five years of landfill biogas plant operation. The results confirm the high variability of methane content in biogas, which value during investigated period ranged from about 40 to 80%.

An important aspect that must be taken into account during investigating of the composition of biogas is the dynamics of methane content change. In case of investigated landfill quite big changes of methane content in biogas occurred fairly quickly. Within selected month of landfill operation, the methane content changes exceed 25% during a few days (Fig. 4). Such situation causes a major difficulty in proper settings of engines fuelled with such fuel.

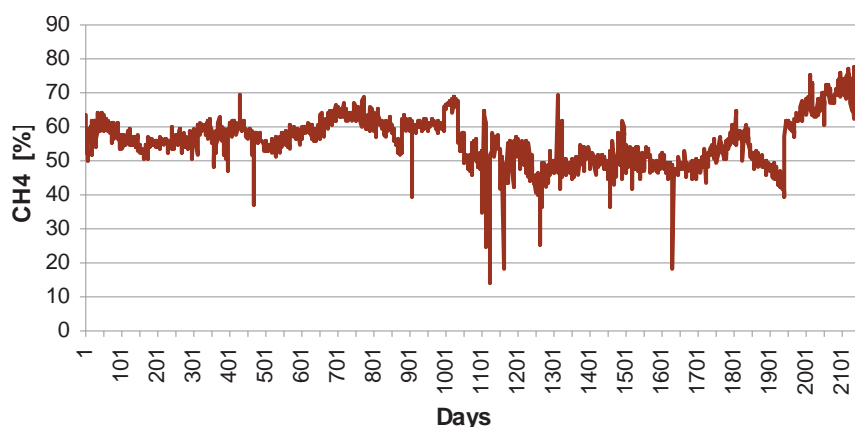


Fig. 3. The methane content in biogas [9]

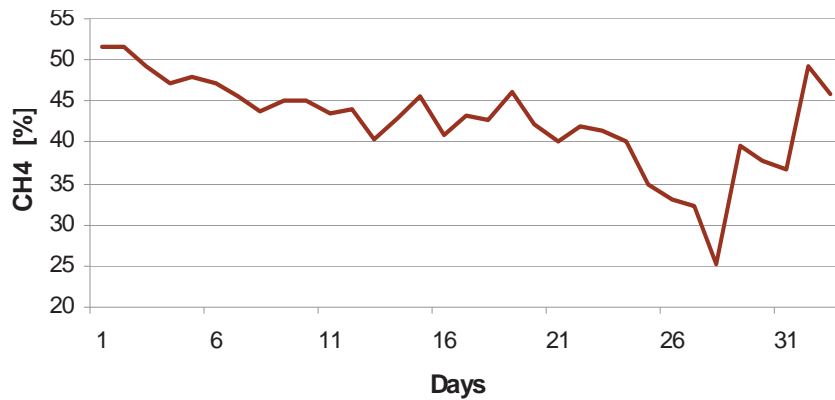


Fig. 4. Example of dynamics of methane content change [9]

Another important aspect of biogas powered engines operation is the content of sulphur, fluorine compounds, chlorine and solid contaminants in biogas. These are substances that affect the durability of engine components and usually are removed from the biogas in the relevant installations. Especially great difficulty makes the removal of silicates, which due to their small size, are not filtered even by the $5\mu\text{m}$ gas filters.

3. Operation of biogas fuelled engines with variable content of methane in the biogas

The kind of used fuel has significant impact on engine performance [8]. The operation of biogas fuelled engines with highly variable methane content is very difficult. Especially if the changes of methane content are occurring in short period of time. Change in biogas methane content causes a change of calorific value of biogas, and thus there is a need to change the amount of fuel needed for combustion in the same mass of air. Gas engines fuel systems, in most cases, are controlled in view of maintaining a constant air/fuel ratio coefficient - λ . Theoretically, the value of air/fuel ratio coefficient should be 1, but in order to reduce the fuel consumption, engines used for power generating usually work with an increased ratio of λ , which according to the design of the engine can have values in the range between 1.2 to 2.2. Change of the methane content in the biogas determines also change of λ coefficient. The decrease of methane content in the air/fuel mixture causes the impoverishment of the mixture and growth of λ coefficient, which is manifested by a decrease in engine power. The consequence of this situation is the decrease of engine speed. The speed controller responds for that by increasing the dose of fuel to maintain the preset speed. The consequence of a large decrease in methane content in the fuel can be stopping the engine, when the regulator will not be able to maintain the speed required to synchronize the generator to the network. In case of a significant increase of methane content in the fuel situation is reversed. Enrichment of the mixture causes a growth of engine speed. Speed controller to maintain a constant engine speed will limit the dosage of fuel. However, in the case of a large and rapid increase in methane content in biogas the regulator may reach its maximal position in which the mixture may be still too rich. As the result of this situation the λ coefficient can reach such value when the engines start knocking. Combustion with knocking in the engine results in rapid destruction of the pistons and cylinder heads due to high temperatures and combustion pressures.

Author's experiences in the operation of biogas fuelled engines indicate that the frequent cause of engine damage is also silicates contained in the biogas. Particles of silicates, during combustion, generate deposits on combustion chamber and piston crown surfaces. Those deposits are partially scrubbed into lubricating oil, which reduces its lubricating properties and accelerating wear of engine moving elements. Deposits in combustion chamber also can cause appearing of knocking.

4. Control system of gas fuelled combustion engines

Control systems of internal combustion engines driving generators are optimised to maintain a constant engine speed regardless of load in order to maintain proper frequency of generated current. The diagram of such a system is shown in Fig. 5.

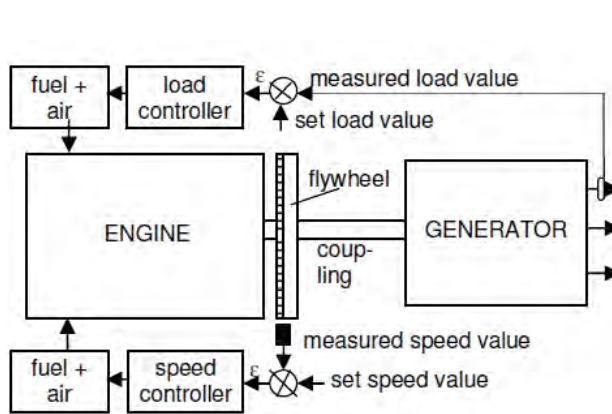


Fig. 5. Basic control system of generating set [4]

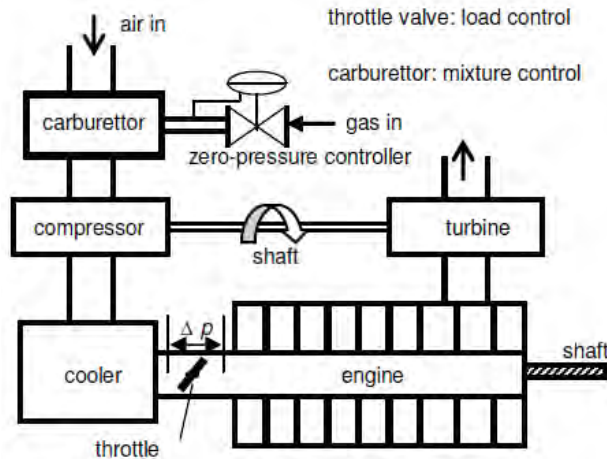


Fig. 6. Engine control system with carburettor and throttle valve [4]

This control system is maintaining constant engine speed by means of fuel dosage change. This is a standard procedure used in power generators of most manufacturers. Implementation of such control system requires an appropriate control system for fuel dosage, which is particularly important in gas engines controlled quantitatively. The simplest and most widely used systems use the throttle to control engine power and the carburettor combined with a reducing valve on the gas supply line to control the composition of an air/fuel mixture (Fig. 6). The primary control parameter in such a control system is a measurement results from λ sensor that indicates the oxygen content in the exhaust gases. On the basis of this measurement the control system is checking the correctness of air/fuel mixture and if it is needed corrects this value by changing of the fuel quantity amount. This type of control system supplemented with a simple ignition system with fixed ignition timing is characterized by low production cost and high reliability. However, due to the large inertia and a relatively small range of adjustment of the air/fuel mixture this system is also very sensitive to the change in methane content in biogas. In case of most engine manufacturers the tolerance range for changes in the biogas methane content is about 10 to 20%. Such control technology is enough for engines fuelled with natural gas or biogas produced in the digesters, where gas composition is very stable. In the case of biogas from landfills this type control system is usually insufficient. Using such a control system together with ignition control system with constant ignition timing causes that engines are running with low power or getting damaged due to the knocking. In addition, because of the engine power is the function of methane content, rapid growth of methane content in fuel causes the growth of engine power. Increase of engine power makes the boost pressure growth. When the boost pressure is higher the total mass of air and fuel, mixed before turbocharger, is also bigger. As you can see it can quickly lead to uncontrolled enrichment of the air/fuel mixture that can cause knocking. Described control system sometimes is too slow to prevent knocking in case of rapid growth of methane content. Moreover the absence of the knock sensor simply leads to engine failure. High exhaust gases temperature measurement is also not enough quick mean of preventing engine from knocking especially in case installing only few temperature sensors which are measuring mean value of exhaust gases temperature. Mean exhaust gases temperature value can be proper even in case of knocking in one or two of several cylinders.

An extension of the control system shown in Fig. 7 is a system with similar structures, but with no λ sensor. The engine in this case is controlled by the use of a linear relationship between the air/fuel ratio, engine power, boost pressure and temperature of the air/fuel. In this case the mixture is determined by measuring the required engine power, boost pressure and temperature of the mixture after the turbocharger. Adjustable settings are: the amount of gas supplied to the mixer, the throttle position, and the position of turbocharger bypass valve. This control system, presented in Fig. 7, accomplishes much more rapid and comprehensive response to the control parameters. Use of bypass valve allow to control of boost pressure, which assures better control of engine power in case of rapid changes in the methane content in biogas. However still remains the problem of limited range of methane content tolerance and constant ignition timing.

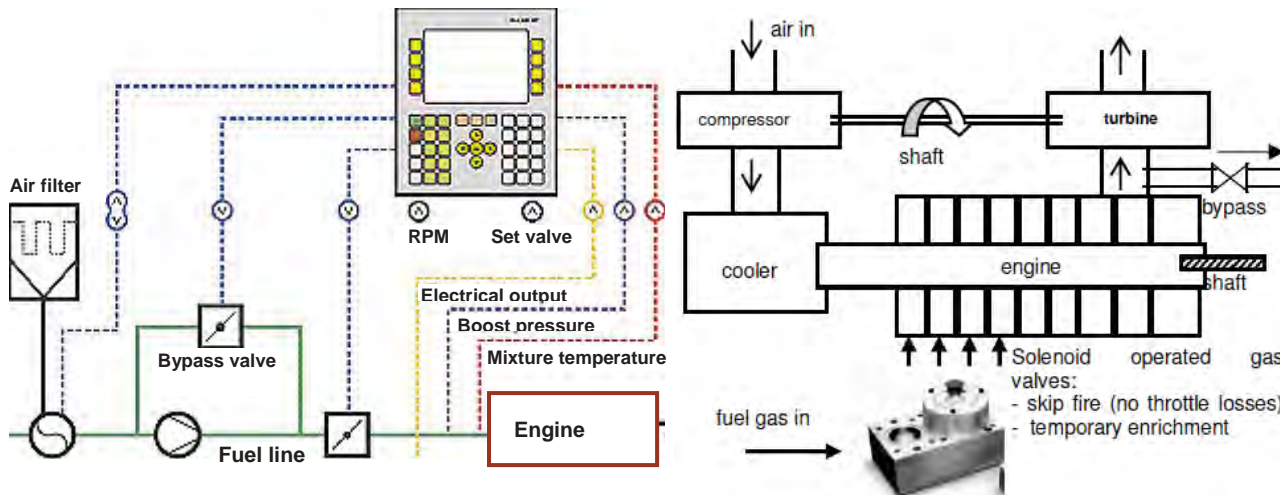


Fig. 7. Engine control system with boost pressure control [12] Fig. 8. A gas engine with fuel admission per cylinder and air-to-fuel control with a turbo bypass [4]

Modern gas engines, especially those adapted to be fuelled by gas with a variable composition, have installed technical solutions that enable precise control of composition of the air/fuel mixture. Schematic example of such control system is shown in Fig. 8. In this case, controlling the composition of the mixture takes place on the basis of the same parameters as before, but this system allows for precise measuring quantities of gas to be supplied individually to each of the cylinders. This is possible according to installing the individual gas admission valve before each of cylinders. Next difference is that the fuel gas is supplied to the engine under a pressure of several bars. Controlling the composition of the air/fuel mixture takes place by controlling the valve opening time. In the case of sudden changes in the methane content of the fuel gas, the air/fuel mixture can be further adjusted by changing the pressure of fuel gas, which greatly expands the range of methane content tolerance. Power control in this case is not realised by use of throttle but by controlling the bypass valve of a turbocharger, which can change the mass of fresh air supplied to the cylinders.

This engine control system solution allows for much wider range methane content changes in biogas, more over feeding the fuel directly in front of each of the cylinders enables their individual control which is very serious matter in high power engines. Because of the fuel gas is not mixed with air before the turbocharger it allows to avoid deposition of pollutants from the gas in the charge air cooler and eliminate the defect air/fuel mixture self enrichment in case of the sudden methane content growth described before. In this case the growth of boost pressure can't enlarge the fuel dosage by itself. Such engine control system supplied with the ignition system with variable ignition timing allows not only the for optimal use of fuel energy and engine capacity but also in case of knocking detection allows for stopping knocking through a rapid change in the air/fuel mixture ratio (ex. by dropping the fuel pressure) and changing ignition timing settings. So new control parameters are automatically set to achieve maximal engine performance simultaneously avoiding knocking.

Unfortunately, this solution has also an important drawback, which is the high price. This reason significantly limits the scope of these solutions to high-power engines, where the high price of the control system has a smaller share in the price of the entire unit.

The greatest tolerance of the fuel gas composition assures control systems of dual fuel engines. Adding diesel oil to the air/gas mixture can solve almost all problems with changes in the methane content in biogas. Only Wartsila currently offers engines for power generating of this type, but their nominal power of several MW eliminates their use in polish market. Moreover, use of such engine is restricted with their high process, need of preparing tanks of diesel oil and difficulties in obtaining green certificates due to the diesel oil combustion with biogas. Nevertheless it is carried out a series of research in case of using these types of engines [1, 5].

5. Summary

The operation of biogas fuelled engines with a variable content of methane; particularly with landfill biogas is difficult and requires a suitably equipped engines. Most manufacturers of gas engines have in their offer engines prepared to be fuelled with biogas. However, in case of landfill biogas, it appears that most of them are not adapted to operate on fuel with such variable methane content. This is due to some misunderstandings made during engine ordering:

- on the one hand - before contracting the engine there are usually carried out some measurements of chemical composition of biogas. The results provided to the engine manufacturer are in most cases the average values and does not include information about possible changes of the content of individual components of the biogas. There should be carried out a series of measurements of gas composition at various points of the landfill and at different weather conditions. In case of not having such an opportunity there should be carried out investigations on other landfills with a similar structure which should give a better knowledge about biogas composition;
- on the second hand – the supplier of the generating set gives to the engine manufacturer estimated composition of the biogas based on information from the customer. Supplier usually is not investing under what exactly conditions will work the delivered engine, thereby in most cases the engines are adjusted to the specific parameters of biogas with small tolerance for changes in its composition.

Such situation rapidly leads to engine operational problems. Engines can not cope with rapid and large changes in gas composition, which resulting in reduced operational power in the event of decrease of methane content, or falling into the knock in the case of a large increase of methane content. In such situation the engine service are changing the position of methane content tolerance range (although its width is constant, the change is to move the range toward higher or lower methane content), which due to high variability in the methane content in biogas appears to be very ineffective. Most often it turns out that in order to protect the engine from knocking the service is limiting engine maximum power, to have bigger buffer for methane content growth. Such solution causes less generated power and extension of the period of return on investment cost. Moreover, described problems with silicates in landfill biogas and an unwillingness to buy expensive purification systems, makes that the persistence of elements of the engine significantly decreases. This increases the cost of engine maintenance, which affects the profitability of investment. Operational experiences indicate that up to the first major overhaul of the engine maintenance cost often reaches 50% of engine initial cost [2].

Summing up a large part of the problems in the operation of engines fuelled with biogas with a high variability of methane content are due to mistakes made during engine selection. Often this is due to ignorance or negligence on both the client and supplier which effects in selection of insufficient engine or engine control system, which is unable to adapt to the actual parameters of supplied fuel. Supplying the engine equipped with a proper control system, that allows for a wide range of changes in the biogas composition, with the knock sensor and ignition system with

variable timing is possible but in most cases much more expensive. Similarly ordering an installation for methane content in biogas enrichment and stabilization and fuel filters preventing engines from silicates is also possible but even more expensive. However, looking from the perspective of 20 years operation of the landfill and having the opportunity to save on the maintenance costs and operating engines with higher power level leads to conclusion that the proper selection of engine with the customized control system should have minor influence for period of investment costs pay back and quantity of achieved profits.

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