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BIOGAS AS A FUEL FOR DIESEL ENGINES

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Abstract

The pursuit of reduced greenhouse gas emissions, as well as the increased share of renewable fuels in the overall energy balance has led to a search for alternative energy sources. One of the fuels on which great hopes are set as fuel for engines is biomethane or biogas, whose main component is methane.

Biogas can be obtained from different products by using different technologies, so that it has potential as a widely-available fuel, which is quite easy to produce. The percentage of methane in biogas depends on the technology for obtaining biogas and ranges from 35% to around 75%. The largest biogas sources can be animal farms, where it is obtained from animal excrement. Another source is sewage treatment plants and rubbish dumps, where substantial quantities of biogas are obtained as a result of natural processes occurring in waste dumping sites or sewage. Biogas can also be acquired from waste obtained from fruit and vegetable processing as well as waste from meat plants.

This paper examines the possibility of using biogas as a fuel for diesel engines. In these engines, the combustion of biogas (methane) requires the application of a dual-fuel supply system in which liquid fuel initiating gas fuel self-ignition will be injected into the combustion chamber along with methane. The paper also contains example results showing the effect of the methane dose on the course of the combustion process in diesel engines.

***Keywords**: biogas, methane, diesel engine, dual-fuel supply system*

1. Introduction

Reducing greenhouse gas and toxic compound emissions to the atmosphere is currently one of the major problems facing humanity. In recent years, a number of rigorous standards and laws have been introduced in the world aimed at promoting new, eco-friendly technical solutions in industry, particularly in the automotive industry [6, 9, 11].

The search for new alternative and eco-friendly fuels is favoured not only by a growth in ecological awareness and concern for the environment, but also shrinking oil reserves and a substantial increase in its prices in world markets. Additionally, interest in the use of alternative fuels is favoured by substantial subsidies provided by state governments for companies investing in power engineering based on alternative, renewable energy sources [5, 7, 9-11].

Currently, great emphasis has been placed on increasing the share of so-called "second-generation" renewable fuels in the economy. Such fuels are considered to be fuels from products that cannot be used as food for humans or animals, thus these are fuels produced mostly from waste of all kinds and acquired from rubbish dumps and sewage treatment plants. After around fifteen years of interest in fuels originating from cultivated plants, e.g. rape, there has been a departure from these fuels due to the fact that the cultivation of energy plants is quite energy intensive and artificial fertilizers and pesticides are also used to enhance their yield. This not only has an adverse environmental effect, but considerable quantities of energy are consumed and other harmful compounds form during such production. Fuels obtained from energy crops are considered first-generation renewable fuels. It should also be noted that the production of energy crops also adversely affects food production because their cultivation limits the surface areas of other crops, reducing food production and contributing to a noticeable increase in food prices [2, 4, 9].

It should also be mentioned that research is currently underway on the production of third-generation biofuels. These are considered to be fuels obtained from the processing of algae. These organisms need essentially only carbon dioxide and access to solar energy for growth. They absorb carbon dioxide during their development and release pure oxygen to the atmosphere. Several research projects in which a method for the cheap acquisition of biofuels from algae is being developed are currently underway in the world. However, it should be noted that, at present, the technology for obtaining fuels from algae is quite expensive. However, because of the fact that agriculturally non-utilised land, and even deserts, can be used for algal production as well as the fact that even 30 times more biofuel can be obtained from a unit of surface area than from energy crops, further intensive research is being carried out in this direction [3].

The literature on the subject has also begun to discuss fourth-generation fuels. According to some geneticists, it is possible to create bacteria in the near future, which will absorb carbon dioxide from the air, turning it into eco-friendly fuel. Geneticists are also currently studying the possibility of creating microorganisms, which will be able to produce hydrogen by using sunlight in the photolysis process [2].

2. The process of obtaining biogas and its properties

One of the second-generation fuels is biogas, which can be obtained from different raw materials using different technologies and also, in many cases, appears spontaneously as a result of on-going chemical processes, e.g. landfill gas [2-4, 6].

Because biogas can be obtained using different production technologies, its composition is not constant. The basic and most desired biogas component is methane, which is the simplest CH_4 hydrocarbon. The percentage of methane in biogas depends on the technology for obtaining biogas and ranges from 35% to around 75%. Another combustible compound, which can contain biogas, is hydrogen, although its percentage share is much smaller and typically amounts to 1-5%. The other biogas components are non-combustible compounds and constitute the ballast. The basic non-combustible biogas components are carbon dioxide and nitrogen. Besides the above-mentioned compounds, biogas contains trace quantities of other chemical compounds whose percentage share is low. Tab. 1 presents the approximate biogas compositions, including the method of its obtaining, yet it should be noted that the biogas compositions given in some literature diverge significantly from that provided in Tab. 1 [2].

Tab. 1. Composition of biogas, depending on its origin [2]

Component	Content		
	agricultural biogas	treatment plant biogas	landfill biogas
Methane CH_4	45–75%	57–62%	37–67%
Carbon dioxide CO_2	25–55%	33–38%	24–40%
Oxygen O_2	0.01–2.0–2.1%	0–0,5%	1–5%
Nitrogen N_2	0.01–5.0%	3.4–8.1%	10–25%
Hydrogen sulphide H_2S	10–30 000 ppm	24–8 000 ppm	15–427 ppm

As mentioned above, biogas forms in a biological process, from different sorts of substrates, the most important sources used for its production include:

- waste from agricultural production, including animal excrement,
- biomass grown for energy purposes (e.g. grasses, maize, sugar beet),
- municipal and organic waste (e.g. sewage treatment plants and rubbish dumps),
- waste from the agricultural and food industries (plant and animal waste).

The process of natural gas formation is multi-stage. First, complex chemical compounds such as fats, proteins and carbohydrates decompose hydrolytically. As a result of hydrolysis, thanks to bacteria and the enzymes they release under anaerobic conditions, much simpler chemical compounds form, such as sugars, fatty acids and amino acids. The simple chemical compounds formed this way are acidified thanks to acid-forming bacteria, which results in the formation of fatty acids, small quantities of milk acid and alcohol. Next, acetic acid forms from these compounds and biogas is released from this acid with the participation of acetobacters and methane bacteria [2, 3, 6].

As earlier mentioned, substantial quantities of biogas are released spontaneously from all sorts of rubbish dumps. According to some data, biogas emission from dumps situated inside Poland amounts to ca. 80,000 m^3/h. It should be noted that, in this way, methane is released to the atmosphere, which is over 20 times more harmful to the ozone layer than carbon dioxide.

Currently, to improve the chemical composition of biogas, it is often cleaned in order to increase its percentage of combustible components, particularly methane. The gas obtained this way is called biomethane because it can contain up to 99% of methane. However, it should be noted that the biogas purification process is quite expensive, which is why costly biogas cleaning is typically applied only if biomethane is introduced into the gas network. If biogas is used in the place of its production, much simpler methods for its cleaning are typically applied, which reduces the costs of its obtaining. However, it should be remembered that, in such a case, the mixture obtained in the engine combustion chamber contains substantial quantities of non-combustible compounds, which has a negative effect on using total engine capacity, which causes a decrease in the power generated by the combustion engine [5].

The properties of biogas as engine fuel closely depend on the content of individual compounds. Methane, the main combustible component, has the greatest effect on biogas properties. The basic parameter characterising fuels is the calorific value, which amounts for methane to around 35.8 MJ/m^3 (50 MJ/kg). Therefore, depending on the methane content, the calorific value of uncleaned biogas ranges from 15 to 27 MJ/m^3. Another important parameter for biogas as engine fuel is the methane number, which is the equivalent of the octane number for liquid fuels. This number, similar to the calorific value for biogas, depends on the chemical composition of biogas – for methane this number is 100 and for hydrogen it is 0. However, because of the substantial content of non-combustible compounds in biogas such as nitrogen and carbon dioxide, which increase the methane number, this number typically amounts to around 130 for biogas [2, 4].

3. Biogas as fuel for diesel engines

Because of its properties, biogas is mostly used as fuel for spark-ignition engines. This way of using biogas is most often applied in sewage treatment plants and rubbish dumps, where biogas forms spontaneously as a result of chemical processes occurring there. These engines mostly power electricity generators or cogeneration units [6, 9].

The relatively high self-ignition temperature of methane (the main combustible component of biogas) of ca. 640 °C, limits the use of this fuel as a power feed source for diesel engines. Nevertheless, because of diesel engines' higher efficiency and lower sensitivity to fuel quality, research is carried out on the use of biogas or methane as a fuel for these engines [7, 9-11].

To ensure the proper operation of diesel engines using gas fuel, it is necessary to modify the engine or its supply system. Three methods of adapting a diesel engine to gas fuel supply are currently being used [5, 7, 9, 11]:

- reducing the diesel engine's compression ratio and replacing the fuel injection system with an ignition system, which requires modification of the diesel engine into a spark-ignition engine,
- application of a dual-fuel supply system, thanks to which gas fuel is supplied to a suction manifold, in which a air-gas mixture is formed and is then sucked into the engine combustion chamber. During the compression stroke, a small dose of liquid fuel initiating gas fuel self-ignition is injected into the combustion chamber. In such a system, gas is supplied under small overpressure to the suction manifold, which does not require the application of complex gas

installations. Such an engine supply method is a solution which is relatively simple in design, does not require significant interference in a standard installation and allows simultaneous engine operation in both single- and dual-fuel systems,

- application of special two-way injectors enabling independent injection into the combustion chamber of both gas and the liquid fuel dose initiating self-ignition. In such a case, it is necessary to apply more complex gas installations because of the need to inject gas fuel under a pressure in the order of 25 MPa.

This paper examines the possibility of using biogas as fuel for spontaneous ignition engines. Despite work on third- and fourth-generation fuels, the important role, which second-generation fuels will play, must not be ignored. These fuels, as earlier mentioned, form as a result of waste product processing and it is difficult to imagine any agricultural or food production not resulting in the formation of waste, which can be used for biogas production.

Work on the use of methane for supplying large marine engines is the most advanced. This is connected with the fact that currently large ships have been built (so-called "LG carriers") for the transport of liquid methane (LNG). During the transport of this fuel, up to 0.3% of the carried fuel volume evaporates in the course of one day. Therefore, substantial quantities of methane are released naturally on these ships and it should naturally be managed. Because of the size of these engines, special two-way injectors are typically used in them, injecting both methane and liquid fuel into the combustion chamber [5].

Currently, intensive research is being carried out in many research facilities in Poland and abroad on the use of gas fuels, particularly methane, as fuel for diesel engines applied to power vehicles and machines as well as to power cogeneration units.

The results of this research indicate that the operation of these engines with a dual-fuel supply is possible, yet because of the different methane properties, the course of the combustion process in this engine changes. The course of gas fuel combustion in a self-ignition engine depends, above all, on the following parameters [7, 9-11]:

- the proportion between gas and liquid fuel in the overall supply dose,
- the pilot dose injection parameters, particularly injection pressure, pilot dose injection start angle.

Figure 1 presents example pressure courses obtained for an HATZ 1B40 engine at 40% of a nominal load and different diesel oil and methane percentages.

Figure 2 presents the effect of the injection lead angle for the dose initiating self-ignition for a diesel oil dose equivalent to 22% of the dose for diesel oil supply alone. The next Fig. 3 shows the effect of the injection lead angle for the initiating dose for different proportions between individual fuels on changes of maximum pressure in the combustion chamber.

The effect of the methane share in the dose supplying the engine on its efficiency is presented in Fig. 4. It is clear from the data presented in this graph that an increase in the methane share in the dose supplying the engine causes much higher consumption of this fuel than its calorific value would indicate. This shows a decrease in the overall engine efficiency with the growing methane share in the supply dose. It should be noted that the presented results refer to a constant diesel oil injection lead angle.

4. Conclusions

The discussion on biogas and the example results concerning methane supply to a diesel engine presented above indicate that there is a possibility of supplying these engines with biogas. A complex installation supplying gas fuel is not required to supply these engines. However, if high gas fuel doses are used, a substantial engine power decrease is to be expected.

Consequently, it seems appropriate to use relatively low biogas doses (ca. 40-60%, depending on the load) which will obtain relatively high engine power and reduce the operating costs for vehicles and machines.

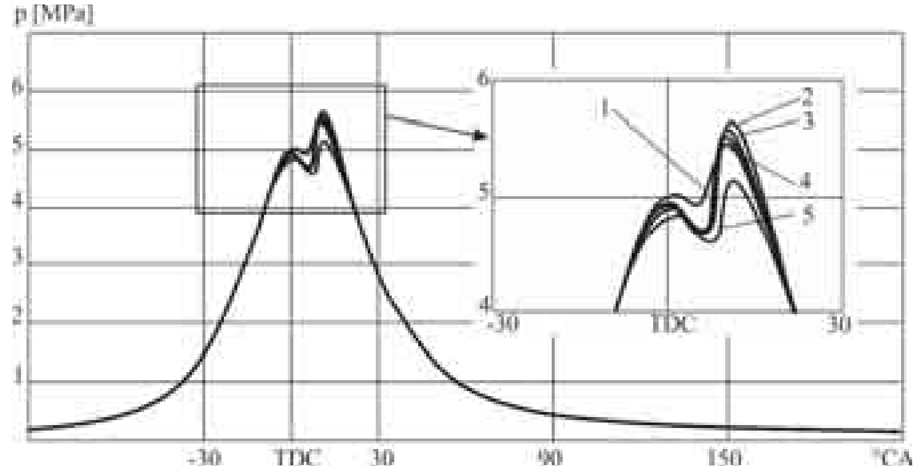

Fig. 1. Average changes of pressure in the combustion chamber at double-fuel engine fuelled with diesel oil (DO) at a varied constant angle of pilot dose injection of 20°CA, at Ne=2kW, N=3000 rpm, and various shares of methane in the dose powering the engine: 1 – 100% DO, 2 – 50% DO+CNG, 3 – 33% DO+CNG, 4 – 22% DO+CNG, 5 – 12% DO + CNG

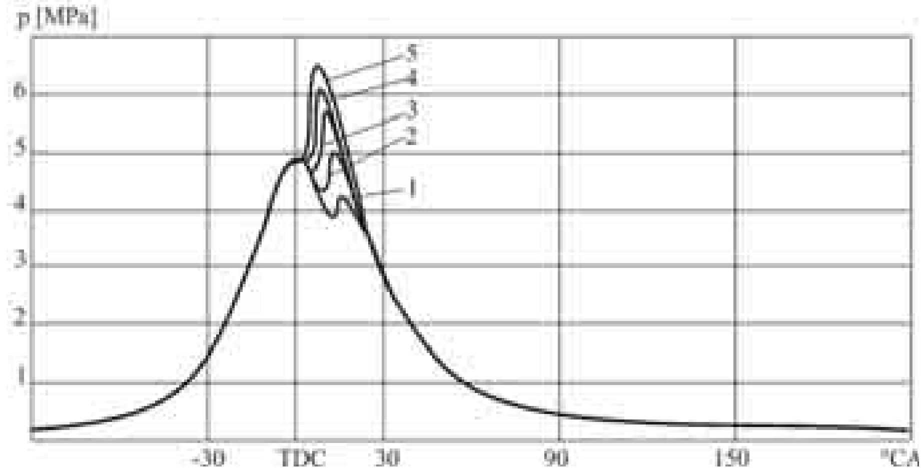

Fig. 2. Average changes of pressure in the combustion chamber at dual fuel engine supply with diesel oil at varied pilot dose injection angle, at Ne=2k, N=3000 rpm, a dose of diesel oil of 22%: 1 – 16°CA, 2 – 18°CA, 3 – 20°CA, 4 – 22°CA, 5 – 24°CA

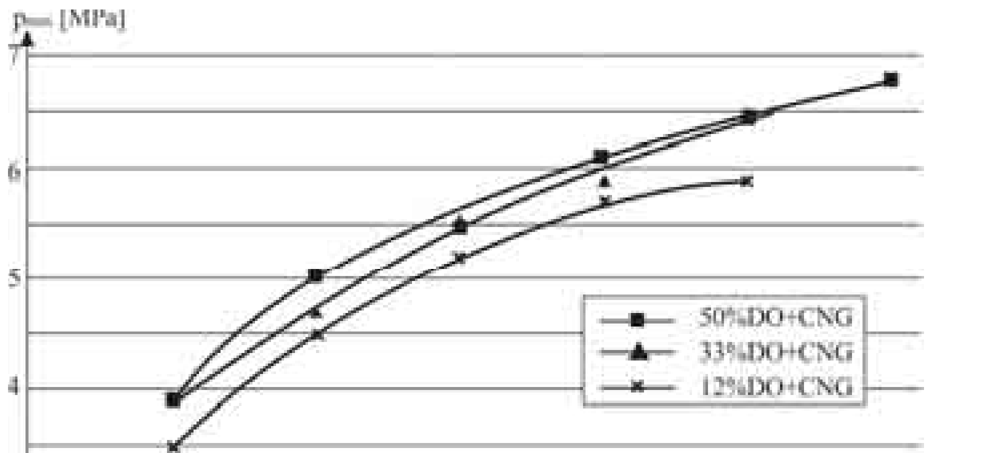

Fig. 3. The effects of advance angle of the pilot dose injection on the maximum pressure of combustion, at various proportions of diesel oil and CNG

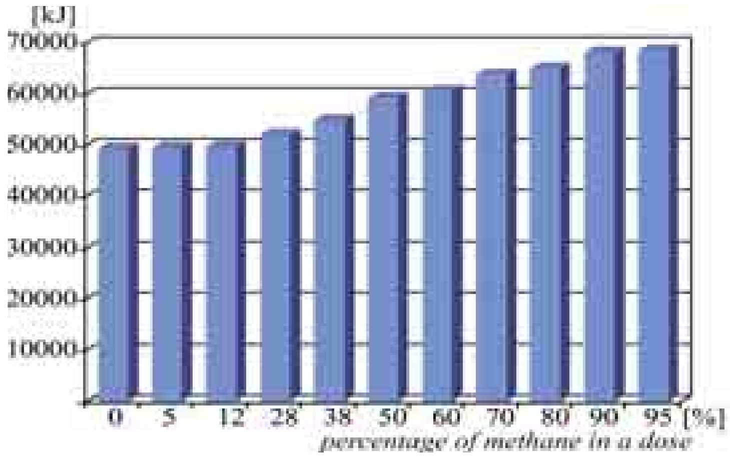

Fig. 4. Power demand of a dual-fuel self-ignition engine supplied with a mixture of methane and diesel oil

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