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# Evaluation of Using Biogas to Supply the Dual Fuel Diesel Engine of an Agricultural Tractor

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**Abstract:** It is known that biogas without prior purification to biomethane is a commonly used fuel only for the stationary internal combustion engines but not for vehicle engines. The current study evaluates the use of biogas without its prior upgrading to biomethane as fuel for tractor engines. The following tests were carried out: biochemical methane potential tests, dynamometer engine tests, and field tests with the use of a tractor. The average methane content in biogas obtained from vegetable wastes exceeded 60%. The tests performed on the engine dynamometer showed that the engine powered by dual fuel worked stably when diesel was replaced by 40% biogas (containing 50% of $CO_2$) or 30% methane. Dual fuel supplying of the engine caused an increase in the concentration of hydrocarbons and carbon monoxide in the exhaust gases and a decrease or no effect in the concentration of particulate matter and nitrogen oxides. It did not significantly affect the dynamics of the vehicle and its useful properties. Biogas that contains a maximum of 50% $CO_2$ and from which $H_2S$, moisture, and siloxanes have been largely removed, is suitable as a fuel for tractors. Such biogas can be obtained in biogas plants from different substrates, e.g., vegetable or agriculture wastes as well as biodegradable municipal wastes.

**Keywords:** biogas; dual fuel engine; knocking combustion; exhaust gas emissions

## 1. Introduction

Biogas is produced by microorganisms from organic raw materials during the methane fermentation process. Its main components are methane ($CH_4$) and carbon dioxide ($CO_2$) as well as small amounts of nitrogen ($N_2$), hydrogen ($H_2$), oxygen ($O_2$), hydrogen sulphide ($H_2S$), water vapour ($H_2O$), carbon monoxide (CO), hydrocarbons (HC), ammonia ($NH_3$), volatile organic compounds (VOC), and siloxanes [1,2]. For biogas production, different substrates such as organic waste from agricultural, industrial, or food sources, the biodegradable fraction of municipal wastes are used [3,4]. Also, in several research institutions, work on the use of other substrates, e.g., microalgae for biogas production, has been conducted [5,6].

Biogas, biomethane, and natural gas (CNG—compressed natural gas, LNG—liquefied natural gas) are classified as methane fuels. Biogas is mainly used for the production of heat and electricity in cogeneration systems [7,8]. This gas, after appropriate purification to biomethane quality, can be pressed into the natural gas distribution network or used as fuel to power spark ignition (SP) and self-ignition (SI) engines of vehicles [9–11]. It is also possible to use biogas in fuel cells [12,13] or to produce syngas [14,15], which is an intermediate product in the production processes of different chemicals, e.g., dimethyl ether (DME) [16] or hydrogen [17,18].

The studies on the use of methane fuels to power vehicle engines have been undertaken by various research units around the world for years. These studies have concerned mainly natural gas [19] and its applications in the transport sector. Research in this area is focused on, among others:

- the impact of the type of gas fuel (CNG, LPG) on engine operation parameters, compared to the conventional fuel [20,21];
- the evaluation of the natural gas combustion process in the engine, with the addition of another gas, e.g., hydrogen [22,23];
- the impact of the change in initiation of fuel ignition of the mixture, from diesel oil to, e.g., biodiesel [24,25], biodiesel with ethanol [26,27], or diesel with ethanol [28];
- emission of toxic components in exhaust gases from the engine [29] and environmental impact throughout the life cycle of gaseous fuel (from obtaining the raw material, through production, to its use in the engine) [30,31];
- economic effects of fuelling the engine with CNG [32].

Apart from natural gas, there is research work on biomethane. This work is mainly concentrated on environmental benefits resulting from the use of biomethane to power the engine of vehicle, instead of natural gas or fossil fuel. It was shown, among others, that biomethane, in relation to these fuels, is characterized by lower greenhouse gas emissions in the whole life cycle [33–35]. In addition to road vehicle applications, some works were also carried out on discovering the possibility of biomethane use for powering of tractor and agricultural machinery engines. The main result of the research was the production of tractors equipped with biomethane engines (or alternatively natural gas), among others, by AGCO Valtra [36], Same Deutz-Fahr [37], or New Holland [38].

On the other hand, there is a lack of research focused on the use of untreated biogas to power vehicle engines. In the area of its use, the only research was carried out on the possibility of supplying stationary engines (SP or SI), which are part of a cogeneration installation [39,40]. These engines differ from the vehicle engines because their design is adapted to the steady state working conditions. The conducted research concerned, among others, the effect of methane content in biogas on the amount of energy produced and on the process of its combustion in the engine. It was found that with increasing methane concentration in biogas, the amount of energy [41], adiabatic combustion temperature, laminar combustion speed, ignition delay, calorific value of the mixture, and the methane number [42] would also increase. The effect of biogas on thermal efficiency, engine performance, as well as the emission of exhaust components was also investigated. In this work [43] it was shown that with the compression ratio of 15.5:1 and various engine loads, the engine works normally (without knocking combustion) when it was supplied with a mixture containing 50% biogas and 50% methane. It was also found that changing the ignition system from SI to SP resulted in the reduction of CO, $CH_4$, and nitrogen oxides ($NO_x$) emission levels. On the other hand, in the work [44] it was found that with the increase in the share of $CO_2$ in the biogas, the volume of hydrocarbons (HC) and CO emissions increase, while the emission of nitrogen oxides decreases. These results were confirmed by the studies presented in [45,46]. According to the authors [44], due to thermal efficiency and engine power, the content of carbon dioxide in the biogas should not exceed 40%. In [47], it was additionally found that the 40% concentration of $CO_2$ in biogas does not significantly affect the deterioration of the performance of a two-cylinder, dual engine, compared to its supply with natural gas containing 96% methane. On the basis of the literature study, it can be stated that both the amount of carbon dioxide in biogas and its role in the fuel combustion process are not clearly defined. However, these works show that biogas is successfully used as fuel for the supply of stationary internal combustion engines. The aim of this article is to evaluate the use of biogas as agriculture tractor fuel, without prior purification to biomethane.

## 2. Materials and Methods

Empirical studies were divided into three stages. In the first stage, biochemical methane potential (BMP) research was carried out on raw materials of various origins and on a laboratory scale. In the second stage, the influence of dual fuel supply mode on the self-ignition engine parameters was studied. The tests were carried out on the engine dynamometer, while the engine was supplied with diesel fuel and biogas. In the third stage, operational tests were carried out in a field conditions.

### *2.1. Stage 1*

Biochemical methane potential tests were carried out under mesophilic conditions (35 °C), for seventeen mixtures of different substrates used in various ratio. The BMP tests were performed in digesters of 0.8 L working volume in duplicate for all samples. The digesters were connected to gas collectors (scaled plastic containers, approximately 1 L of volume each, filled with saturated NaCl water solution) and buffer tanks. The volume of the produced biogas was monitored daily compared to the reference sample (inoculum with the water). Gas analyser with pressure and temperature sensors (GMF 416, GAS DATA Ltd) was used to analyse the pressure and composition ($CH_4$, $CO_2$, $H_2$, $H_2S$, $NH_3$) of the biogas. The tests were run until the bacteria stopped to produce biogas (approximately 45 days). The substrates used in the research were: maize silage (MS), grass silage (GS), whey (W), cattle manure (CM), pig manure (PM), distillery decoction (DD), biodegradable vegetable wastes (BVW), biodegradable municipal wastes (BMW), drain from municipal waste composting plant (D), sewage sludge concentrated by flotation (SSF), sewage sludge concentrated by gravitation (SSG), and a mixture of sewage sludge (MSS). Based on the results of that stage, the best biogas composition for the engine tests was selected.

### *2.2. Stage 2*

The engine tests were carried out on the engine dynamometer with the use of a turbocharged Cummins CDC 6T-590 diesel engine from a CASE MX 135 tractor. The engine was adapted to dual fuel supply with diesel oil and biogas, through just a simple modification without interfering in the construction of the engine. This solution avoided the introduction of a complicated management system or construction modification of the engine. The detailed scheme of the gas supply and gas injection systems in the tested engine is presented in Figure 1.

The engine was supplied with commercial diesel oil (denoted as ON), high methane content natural gas denoted as $CH_4$ (containing 97.8% of methane, 0.2% of carbon dioxide, and the remaining 2.0% were other typical components of natural gas such as: ethane, propane, butane, and nitrogen) and synthetic biogas. The process of combustion of the test fuels, including the knocking combustion phenomena, was examined on the engine dynamometer using the IndiSmart engine control system from AVL List GmbH. To measure the concentrations of exhaust gas components (carbon monoxide, carbon dioxide, oxygen, total hydrocarbons, and nitrogen oxides), the AVB CEB II analyser was used. The analysis of the particulate matter concentration was carried out using the AVL 415 analyser. The engine was loaded by the Schenck W 450 electro-rotor brake device. Tests were carried out in the mono (by diesel oil) and in the dual fuel (by ON/biogas or ON/$CH_4$) supply modes, at two characteristic crankshaft rotation speeds of the engine: maximum torque n = 1400 rpm and maximum power n = 1800 rpm, for: 100%, 75%, 50%, 25%, and 10% engine loads.

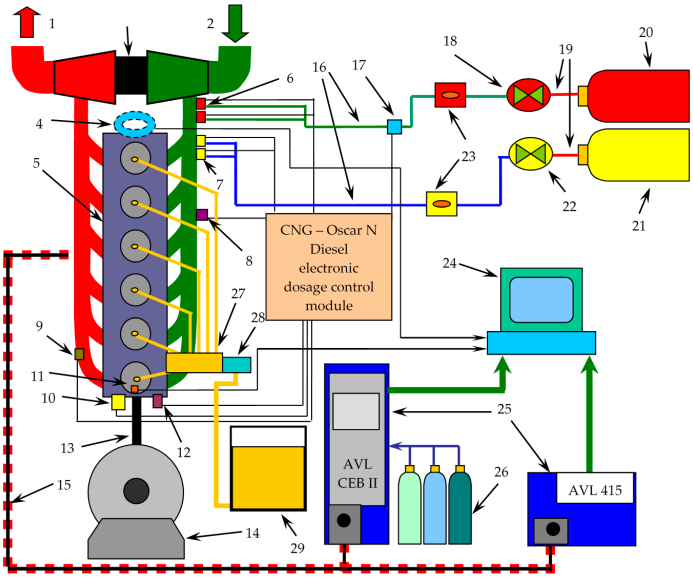



**Figure 1.** Scheme of the test bench with the Cummins 6T-590 engine adapted for dual fuel supply with diesel oil and biogas, where: 1—exhaust outlet, 2—air inlet, 3—turbocharger, 4—crankshaft angle sensor, 5—tractor engine, 6—$CH_4$ injectors, 7—$CO_2$ injectors, 8—boost pressure sensor, 9—thermocouple, 10—knocking combustion sensor, 11—cylinder pressure sensor, 12—engine temperature sensor, 13—drive shaft, 14 - Schenck W450 eddy-current dynamometer, 15—heating pipes supplying exhaust gas to the analysers, 16—low pressure gas pipes, 17—low pressure shut-off valve, 18—200/2.5 bar gas pressure reducer, 19—high pressure gas pipes, 20—compressed $CH_4$ storage, 21—compressed $CO_2$ storage, 22—adjustable gas pressure reducer, 23—$CH_4$ and $CO_2$ flowmeter, 24—PC computer integrated with the IndiSmart module with the registration and data acquisition system, 25—exhaust gas analysers, 26—reference gases, 27—injection pump with injector system, 28—fuel dose correction system, and 29—liquid fuel tank.

### 2.3. Stage 3

Prior to operational testing, the Cummins 6T-590 engine and the dual fuel supply system were mounted on a Case IH MX 135 tractor (Figure 2). Four cylinders with a total capacity of 160 L, which were filled with biogas under the pressure of 125 bar, were mounted on the top of the tractor. In order to protect the engine against operation in destructive conditions, a knock sensor was also installed.

**Figure 2.** View of the Case IH MX 135 agricultural tractor.

As part of the study, tractor tests were carried out to determine its dynamics (acceleration of the tractor from the idle speed to maximum speed on the selected gear ratio) and the level of fuel consumption during mono and dual fuel engine supply. As a next step, the research was carried out in the biogas plant, using realistic conditions of the vehicle operation. The engine was supplied in dual fuel mode with diesel and real biogas, obtained from the agricultural biogas plant with a capacity of 946 kWe/1004 kWth (located in the Pomeranian Province in Poland). This gas contained from approximately 50% to approximately 60% methane, depending on the substrates used (different ratio of pig manure, maize silage, and glycerine). After leaving the digestion chamber, the biogas was subjected to a biological treatment (Thiobacillus and Sulfolobus species were used) from hydrogen sulphide (up to a maximum concentration of 20 ppm). Then the biogas was pressurized to a maximum pressure of 13 MPa (due to the possibility of carbon dioxide condensation in the compressed biogas), and it was directed to the drying system and then the gas fuel storage.

During the field works, the fuel consumption was recorded and the engine operation parameters were analysed. Additionally, the changes in the physicochemical properties of the lubricating oil, the degree of engine pollution, and the wear of its components were assessed. Due to the specific nature of gas fuel combustion, the engine was lubricated with commercial engine oil of SAE 15W/40 viscosity class and API CI-4 quality class, with increased resistance to oxidative changes. Engine oil samples were taken from the oil sump every 40 moto hours. According to standards presented in Table 1, the following parameters were investigated: kinematic viscosity, basic number, sulphated ash content and total sediments, coking residues, ignition temperatures, fuel content, and content of metallic elements originating from engine construction elements. Operational tests were carried out for 200 moto hours.

**Table 1.** Analytical methods used for engine oil analysis.

| Parameter | Analytical Method |
|---|---|
| Kinematic viscosity at 40 °C and 100 °C | PN-EN ISO 3104 |
| Basic number | PN ISO 3771 |
| Total sediments | own method |
| Coking residues | PN-EN ISO 10370 |
| Fuel content | PN/C-04083 |
| Sulphated ash content | PN-ISO 3987 |
| Ignition temperatures | PN-EN ISO 2719 |
| Content of metallic elements | ASTM D 5185 |

## 3. Results

### 3.1. Stage 1

Figure 3 shows the results of biochemical methane potential for different substrates. It shows the average yield for biogas and methane per 100 g of substrates used for the tests or their mixtures in different ratio of particular substances.

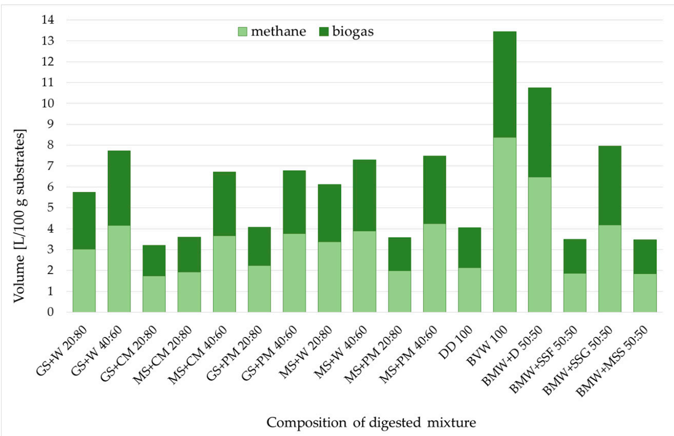



**Figure 3.** Average biogas and methane yields from biochemical methane potential (BMP) tests of different substrate mixtures.

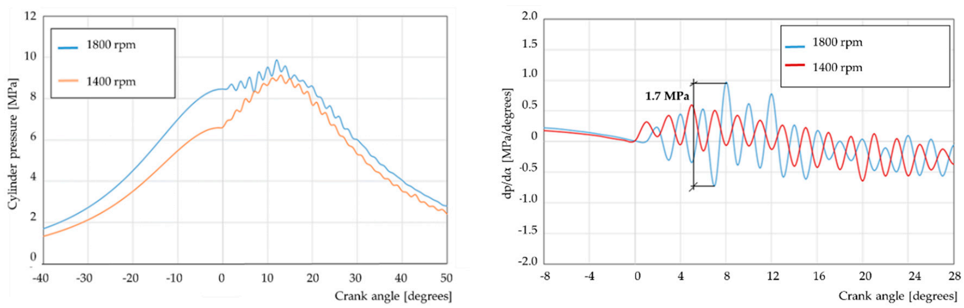
Based on the results from BMP tests (Figure 3), it can be stated that the higher productivity of biogas and methane was observed for biodegradable vegetable waste (13.45 L of biogas and 8.76 L of methane per 100 g of BVW). Additionally, this sample was characterized by the highest methane concentration in the biogas (62.2%) among all the tested samples. The smallest volume of biogas was obtained from the mixture of maize silage with pig manure (MS+PM, ratio 20:80) and it was 3.20 L/100 g substrates. However, the lowest methane yield was found for the mixture of biodegradable municipal waste (BMW) and sewage sludge concentrated by flotation (SSF) used in ratio 50:50, and it was 1.04 L/100 g substrates. Depending on the type of fermented feedstock, the average methane content in the biogas was within the range between 52.2% and 62.2%, while carbon dioxide was within the range between 28.3% and 45.9%.

The $H_2S$ content ranged from 0.06% to 1.86% $v/v$. The most hydrogen sulphide was found in a mixture of biodegradable municipal wastes with a mixture of sewage sludge (18,640 ppm $H_2S$), while the smallest amount was characterized by: distillery decoction (628 ppm $H_2S$); maize silage mixture with pig manure (785 ppm for the share of 40:60 substrates and 2570 ppm $H_2S$ for the share of 20:80); and biodegradable vegetable wastes (4080 ppm $H_2S$).

Differences in the biogas productivity, obtained from particular substrates and their mixtures, are the result of different physicochemical properties of these materials, i.e., the dry matter content, organic matter content, and organic load characterized by the chemical oxygen demand parameter.

### 3.2. Stage 2

Taking into account the results of the Stage 1 tests, synthetic biogas composed of 60% $CH_4$ and 40% $CO_2$ was prepared for the engine tests. The engine was supplied in the dual fuel with diesel and various methane or biogas contents. Based on the analysis of the combustion process of these fuels in the engine, it was found that knocking combustion symptoms and unstable engine operation occurred when replacing the diesel fuel with about 40% biogas or slightly more than 30% methane. This phenomenon was manifested by temporary fluctuations (oscillations) in the pressure of the working medium in the combustion chamber, greater than 0.7–0.8 MPa. The abovementioned levels of pressure were set as a limiting factor for the maximum acceptable methane fuel concentration in the mixture with diesel fuel due to the possibility of engine damage [48]. The occurrence of pressure peaks during the combustion process was accurately determined based on indicator diagrams. These diagrams show the change of the working medium pressure in the combustion chamber as a function of the crankshaft rotation angle ($dp/d\alpha$). The determined instantaneous maximum amplitude of pressure fluctuations of the working medium in the engine combustion chamber was 1.7 MPa/°CA when the engine was supplied with a diesel fuel mixture with 40% biogas share, under the same speed and load conditions. Figure 4 shows examples of engine test results when supplying with diesel and 40% of biogas.




(**a**) (**b**)

**Figure 4.** The course of changes: (**a**) The pressure in the combustion chamber along with the knocking combustion symptoms; (**b**) oscillation of pressure $dp/d\alpha$ of the working medium resulting from knocking combustion in the combustion chamber; when the engine was powered by diesel oil and 40% of biogas, for 80% load of engine and two rotational speeds of the engine crankshaft (1400 and 1800 rpm). **Reproduced from [48], Polish Scientific Society of Combustion Engines: 2015.**

The conducted research has shown that replacing diesel fuel with 30% of gaseous fuel (methane or biogas), would help to avoid knocking combustion. Therefore, the combustion process in the engine was investigated for this composition of fuel mixture. The tests were carried out in the entire engine load range at two rotational speeds of the crankshaft. It was observed that the pressure values for both mono and dual fuel mode, under the same speed and load conditions of the engine operation, were similar. However, the initiation of self-ignition of diesel fuel blends with methane or biogas was earlier by approximately 2–3°CA, in relation to the engine fueled with diesel only.

Figure 5 presents results of exhaust gases emission during supply the engine with diesel oil and diesel oil with 30% of methane fuels content.

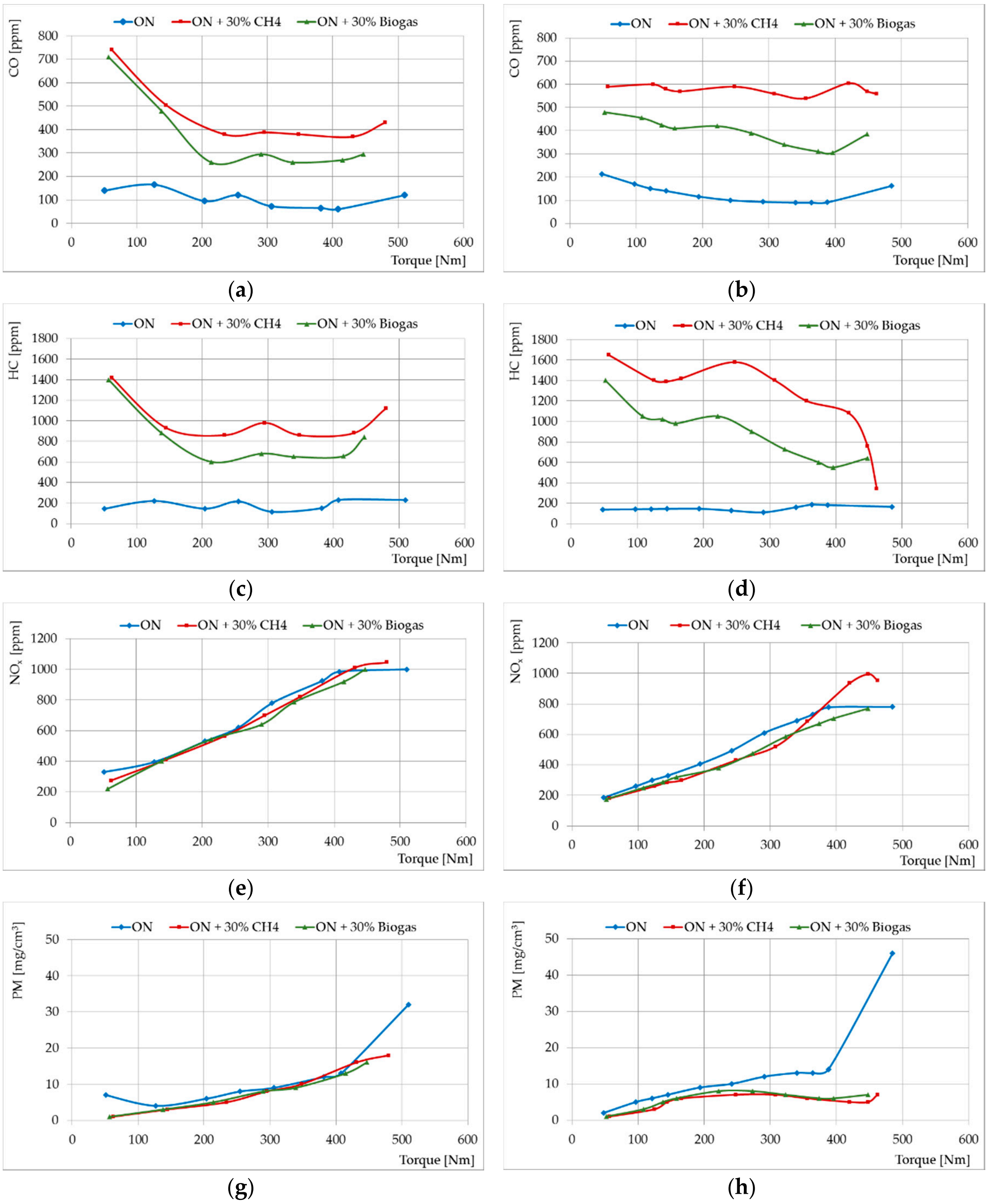



**Figure 5.** Emission versus torque under two crankshaft rotational speed for: (**a**) CO at 1400 rpm; (**b**) CO at 1800 rpm; (**c**) HC at 1400 rpm; (**d**) HC at 1800 rpm; (**e**) $NO_X$ at 1400 rpm; (**f**) $NO_X$ at 1800 rpm; (**g**) PM at 1400 rpm; (**h**) PM at 1800 rpm; on the base of [49–51].

The results presented in Figure 5 show that replacing diesel fuel with methane or biogas doses in quantities of 30%, regardless of the operating conditions of engine, resulted in an increase in HC and CO emissions in the exhaust gases. But at the same time such change of supply mode did not have a significant influence on the concentration of nitrogen oxides. In the case of solid particles, their concentration in the exhaust gases was lower during the dual fuel supply, especially in the high engine loads. It has also been found that higher concentrations of solid particles were generated when the engine was supplied with diesel, especially at a higher engine crankshaft rotation speed. On the other hand, replacing methane with the same biogas dose resulted in a significant reduction of hydrocarbons and carbon monoxide emission levels. These differences were particularly visible for a rotational speed of 1800 rpm and a torque above 200 Nm. The substitution of methane with biogas did not significantly affect the emission of nitrogen oxides and particulates, practically in all the examined range.

The research engine was factory designed for mono fuel operation with diesel oil. The increase in carbon oxide and hydrocarbon concentrations, when supplying the engine with diesel oil with 30% methane fuels share, could be a result of the lack of changes in the factory settings of operating parameters of the engine used for the tests. This could affect incomplete fuels combustion. Optimizing these can change the course of the combustion process and, as a result, reduce CO and HC emissions.

### *3.3. Stage 3*

On the basis of the results of Stages 1 and 2 of the tests, biogas and diesel fuel dosing maps were developed and the electronic system controlling the time of gas injectors opening was programmed, depending on the speed of the tractor engine and its load. At high loads, the engine was mainly fed with liquid fuel (ON), while at lower loads with a mixture of liquid fuel and biogas. In order to avoid knocking combustion, the maximum dose of biogas was 30% in relation to liquid fuel.

During field tests, the tractor worked 200 moto hours, consuming 280 L of diesel and 63 L of biogas (containing approximately 50% carbon dioxide). In operational tests, there was no excessive fuel consumption, problems with starting the engine, smoke during the start-up, or a negative impact on the noise level. It was found that the average value of the maximum acceleration was 1.89 m/s when the engine was powered by only ON and 1.56 m/s when the dual fuel ON/Biogas system was used. The average value of the maximum speed reached by the tractor during mono fuel tests was 20.5 km/h and 18.7 km/h during dual fuel supply.

Changing the power supply of tractor did not negatively affect the cleanliness of the lubrication system of the engine. The examples of analytical tests of engine oil samples are presented in Table 2.

**Table 2.** Results of engine oil analysis.

| Parameter | Fresh Oil | Sample after 140 mth | Sample after 200 mth |
|---|---|---|---|
| Kinematic viscosity in 40 °C, $mm^2/s$ | 111.7 | 104.7 | 102.6 |
| Kinematic viscosity in 100 °C, $mm^2/s$ | 14.77 | 13.56 | 13.69 |
| Basic number, mg KOH | 11.40 | 11.95 | 12.02 |
| Total sediments, %, m/m | - | 0.08 | 0.03 |
| Coking residues, %, m/m | 1.39 | 1.38 | 1.47 |
| Fuel content, %, v/v | - | 0.6 | 0.8 |
| Sulphated ash content, %, m/m | 1.35 | 1.33 | 1.34 |
| Ignition temperatures, °C | 200 | 206 | 204 |
| Content of Fe, ppm | - | 3.0 | 5.6 |
| Content of Cu, ppm | - | 0.9 | 1.4 |
| Content of Pb, ppm | - | 0.8 | 1.2 |

The results presented in Table 2 indicated that there was no significant effect of dual fuel mode on acceleration of aging of engine oil during the tested tractor operation period [52]. There were also no failures or incorrect functioning of the storage system, gas fuel injection characteristics, and the tractor itself.

In terms of usability, the use of dual fuel supply did not increase the failure rate when using the tractor in its real operation conditions. During the entire operational tests, there was no interference from the anti-knocking combustion system. It indicates that the correct selection of the proportion of diesel oil and biogas during the variable working conditions of the agricultural tractor engine was done.

## 4. Conclusions

The authors evaluated the possibility of using biogas without prior upgrading to biomethane as fuel for an agriculture tractor engine. The physicochemical properties of biogas and its availability are key prerequisites for its use as an alternative engine fuel, affecting the reduction of dependence on fossil fuels, and the diversification of energy sources. Such biogas should contain at least 50% methane and it ought to be cleaned from hydrogen sulphide, water, and siloxanes. This gas can be obtained in typical biogas plants from various types of biodegradable raw materials. The BMP tests have shown that a good substrate for its production can be: biodegradable vegetable wastes (BVW) and a mixture of biodegradable municipal wastes (BMW) with drain from municipal waste composting plant (D). The average methane content in the biogas obtained from these substrates exceeded 60%. For these samples the higher amounts of biogas were also obtained compared to other tested mixtures (13.45 L from 100 g of BVM and 10.76 L from 100 g of BMW+D). Additionally, the biogas produced from BVM contained smaller amounts of hydrogen sulphide (4080 ppm) compared with e.g., a mixture of biodegradable municipal wastes with mixture of sewage sludge (18,640 ppm). Generally, the $H_2S$ content in biogas obtained during BMP tests was in range from 0.06% to 1.86% v/v.

Biogas without prior purification to biomethane quality is used as fuel for stationary internal combustion engines. At present, its use for powering vehicle engines involves the necessity of performing complicated and expensive refining processes (removal of carbon dioxide, hydrogen sulphide and water). The study showed that it is possible to use biogas with at least 50% methane content to power an agriculture tractor engine. The tests performed with the use of an engine dynamometer showed that an engine powered by dual fuel (diesel oil and biogas) worked stably when replacing the diesel fuel with about 40% biogas or slightly more than 30% methane. Higher amounts of methane fuels caused knocking combustion symptoms in the engine. The results of the engine load characteristics tests showed that tested dual fuel solution caused a decrease in PM concentration, especially at higher values of torque and during higher engine crankshaft rotation speed (1800 rpm) in comparison to mono fuel supplying. Replacing diesel with methane or biogas doses in quantities of 30%, regardless of operating conditions of the engine, resulted in an increase in HC and CO emissions in the exhaust. Such increase can be reduced by optimizing engine performance or using a catalytic converter. Dual fuel supply of the engine did not have a significant influence on the concentration of nitrogen oxides in exhaust gases.

In field tests conducted during 200 moto hours, the tractor engine was supplied with real biogas containing approximately: 50% methane, 50% carbon dioxide, 20 ppm of hydrogen sulphide, and without water and siloxanes. Results showed that the change of tractor engine power from single to dual fuel did not significantly affect the dynamics of vehicle and its useful properties. During these tests there was no excessive fuel consumption (the tractor engine consumed 280 L of diesel and 63 L of biogas). Problems with starting the engine, extra smoke emission during the start-up phase, as well as negative impact on the noise level were not noticed. Moreover, no negative impact on the lubrication system of the engine was found. The replacement of 30% diesel oil with biogas caused negligible deterioration in maximum acceleration of agriculture tractor from 1.89 m/s to 1.56 m/s and in maximum speed from 20.5 km/h to 18.7 km/h.

The dual fuel self-ignition engine is a solution that makes it possible to implement the idea of using of biogas (without the need to purify it to biomethane quality) as fuel for vehicles. Such biogas can contain up to approximately 50% of carbon dioxide and it should be purified from water and siloxanes. It is also important to purify the gas from hydrogen sulphide due to its corrosive effect. However, the authors stated that a small amount of $H_2S$ (20 ppm) had no negative effect on the engine. An unquestionable disadvantage of the solution is the relatively small share of biogas in relation to diesel oil. The use of larger amounts of biogas requires significant changes in engine construction in aim to its decompression. Due to the high concentration of $CO_2$ in biogas, it is not possible to compress it (without its condensation) to pressures such as CNG. This is an additional disadvantage which has influence on the amount of refuelled fuel and the driving range of the vehicle.

The concept of a dual fuel engine is known, but the innovative possibilities related to the supply of the engine with biogas and its operation control give hope for widespread adoption of this solution, not only in the stationary but also the traction versions. Nevertheless, this solution requires further research and optimization work.

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