ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1216491

EXPERIMENTAL TESTS ON A DUAL FUEL COMPRESSION-IGNITION ENGINE POWERED BY BIOGAS WITH A VARYING CHEMICAL COMPOSITION

Sławomir Wierzbicki, Michał Śmieja, Michał Kozłowski

University of Warmia and Mazury in Olsztyn
Faculty of Technical Sciences
Oczapowskiego Street 11, 10-710 Olsztyn, Poland
e-mail: slawekw@uwm.edu.pl, smieja@uwm.edu.pl, michal.kozlowski@uwm.edu.pl

Aleksander Nieoczym

Lublin University of Technology
Faculty of Mechanical Engineering
Nadbystrzycka Street 36, 20-618 Lublin, Poland
e-mail: a.nieoczym@pollub.pl

Zbigniew Krzysiak

University of Life Sciences in Lublin
Department of Mechanical Engineering and Automation
Głęboka Street 28, 20-612 Lublin, Poland
e-mail: zbigniew.krzysiak@wp.pl

Abstract

Biogas is among the fuels whose significance in the general energy balance will increase. These results from the fact that it may be produced from various kinds of waste materials, and it is therefore considered a renewable fuel of the second generation. Because of its properties, biogas may be used directly to power spark-ignition engines. Nonetheless, numerous tests are underway involving the possibility of using biogas to power compression-ignition engines. In order to use biogas, whose main combustible component is methane, in compression-ignition engines, it is necessary to use a dual fuel power supply system. With such a system supplying power to the engine, the gas and air mixture in the cylinder is ignited by a small dose of liquid fuel.

This paper presents a fragment of the research on the use of biogas with a varying chemical composition for powering compression-ignition engines. The described tests were conducted using a one-cylinder compression-ignition engine mounted on an engine test stand. The fuel gas consisted of a mixture of natural gas and carbon dioxide; the share of each individual component was regulated from the station, which controlled the operation of the whole test stand. The developed control system also enabled the adjustment of the operating parameters of the engine test stand and the parameters of the injection of liquid fuel, such as the injection pressure, the timing angle of injection and the size of the dose. The results presented in the paper show the impact of the individual control parameters of the engine on the value of the engine's torque and the amount of toxic compounds in the exhaust fumes.

Keywords: *biogas, dual fuel compression-ignition engine, emission of toxic compounds*

1. Introduction

The struggle against global warming is currently one of the biggest challenges for mankind. In recent years, more emphasis has been put on increasing the share of renewable energy in the general energy balance. Particular attention is paid to second-generation renewable fuels. An important feature of this type of fuel is the use of products originating from the group of crops for non-food purposes, or of inedible by-products for its production, due to which the creation of such fuels does not compete with the production of food [2, 4, 6, 7].

One such fuel, among others, is biogas, which is generated spontaneously as a result of natural processes occurring in nature, e.g. in landfills, and can also be created from various kinds of organic materials in biogas plants [2, 7, 8].

Biogas produced in this manner contains considerable amounts of methane (40-75%), the main combustible component, as well as incombustible carbon dioxide (25-55%), which is a filler. Additionally, depending on its origin, biogas may contain minor shares of other components, such as hydrogen, carbon monoxide, nitrogen and oxygen, as well as trace amounts of hydrogen sulphide and other chemical compounds [1, 2, 7, 11].

Biogas is characterised by a high methane number (above 100), due to which it is used mainly as fuel for SI engines. This method of supplying power by means of biogas is most frequently used to power stationary engines propelling power generators, e.g. in wastewater treatment plants and biogas plants [6, 7].

Another possible method of utilising biogas is using it to power compression-ignition engines. Unfortunately, due to the high autoignition temperature of methane (840 K), the main combustible component of biogas, it is not possible to obtain the conditions necessary for its autoignition in a combustion chamber. It is therefore necessary to utilise a dual fuel power supply system in order to enable the use of biogas with this type of engine. It involves supplying the engine with fuel gas along with air during filling, injecting a small dose of liquid fuel into the cylinder near the end of the compression stroke, which is meant to trigger the ignition of fuel gas [3, 5].

2. The purpose of the tests and the description of the test stand

The examinations of the possibility of using biogas to power compression-ignition engines were conducted using an L100N6 engine from the YANMAR Company. Load was applied to the tested engine by means of an AMX211 engine test stand from the AUTOMEX Company. Fig. 1a presents a view of the complete test stand. The method of communication between the individual elements of the stand is presented in Fig. 1b. The detailed design of the test stand has been described in [9, 10, 12].

Tab. 1. The basic technical parameters of a YANMAR engine

Engine type	L100N6CA1T1CAID
No. of cylinders	1
Engine displacement	435 cm^3
Compression ratio	20
Piston diameter/stroke	86 / 75 mm
Max. power	7.4 kW
Max. torque	27 N·m
Max. rotational speed	3600 rpm
Injection type	direct
Cooling system	air

In order to fully implement the assumed research programme, a system was developed, capable of supplying the engine with fuel gas of a specified chemical composition, produced artificially in a laboratory. Based on the information available in the literature, it was assumed [1, 2, 11] that the fuel which the engine was to be supplied with during tests would be a mixture of two basic components of agricultural biogas, which are methane (CH_4) and carbon dioxide (CO_2). The remaining chemical compounds of biogas produced in agricultural biogas plants are present in trace amounts, usually not exceeding 1%, and therefore their share in the tested fuel was omitted. High-methane type E natural gas, available in urban networks, with a methane content of 97.8%

was used as the source of methane.

In accordance with the assumptions, apart from methane, which was its main combustible component, the produced fuel gas also contained carbon dioxide. Compressed carbon dioxide, with a purity class of 2.2, and therefore with a CO_2 content amounting to 99.2%, was used as the source of this gas during tests. This was a typical technical gas, used commonly for welding purposes.

A layout of an installation supplying fuel gas of a specified chemical composition is presented in Fig. 2.

In order to produce fuel gas having a particular chemical composition, the abovementioned gases were fed to the engine manifold via an installation designed specifically for the needs of the tests, ensuring the predetermined flow of the individual components of the fuel gas. A general layout of the fuel gas supply installation is presented in Fig. 2 [9, 10, 12, 13].

a) b)

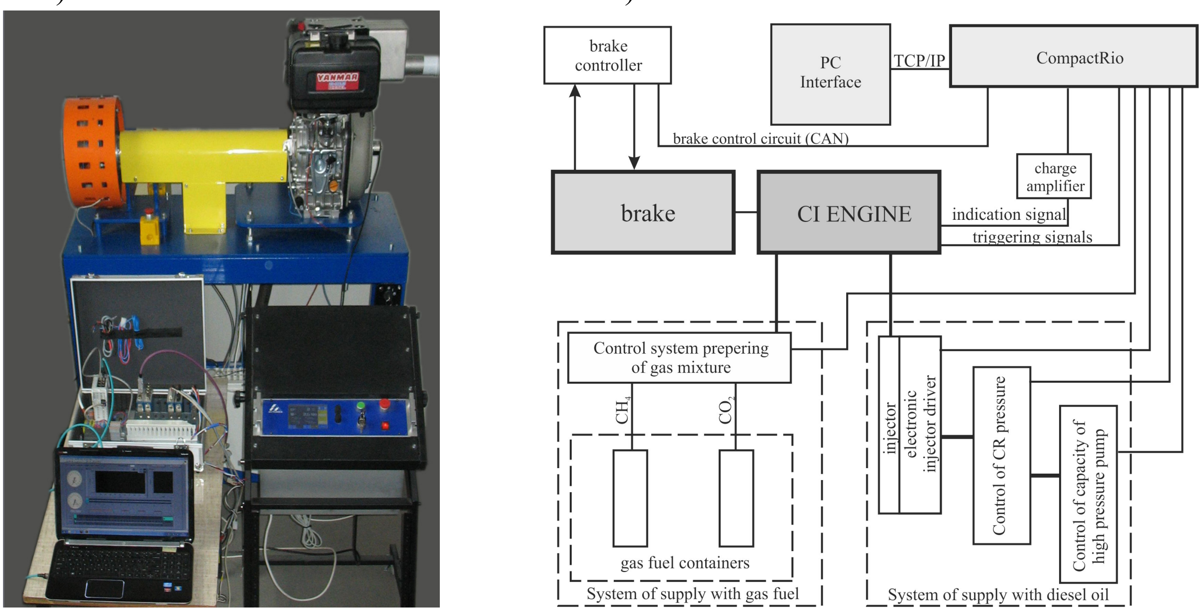

Fig. 1. A view of the test stand (a) and a layout of communication between the elements of the test stand (b)

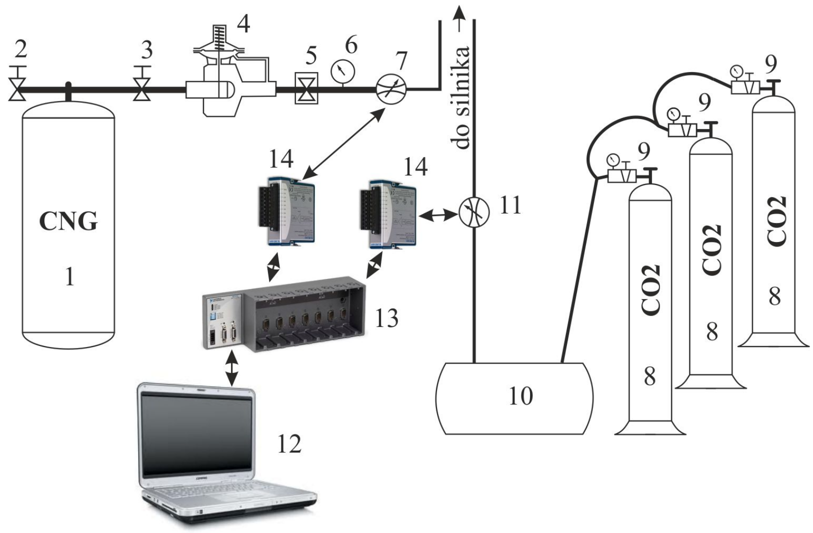

Fig. 2. A block diagram of the fuel gas supply installation: 1 – a CNG cylinder, 2 – a fill valve, 3 – a stop valve, 4 – a two-stage regulator, 5 – a solenoid valve, 6 – a pressure gauge, 7 – a MasStream mass flow regulator, 8 – CO2 cylinders, 9 – regulators with pressure gauges, 10 – an expansion tank, 11 – a Bronks mass flow regulator, 12 – a PC, 13 – a programmable CompactRio controller, 14 – input-output cards controlling the flow regulators

3. Test results

During the tests conducted on the stand described above, the engine was supplied with constant doses of liquid fuel, amounting to 10 and 15% of the dose of liquid fuel consumed by the engine during mono-fuel operation at n = 3000 rpm and with a load of 25 Nm. The liquid fuel injection pressure and the timing angle of injection were changed during the tests. Additionally, the engine was supplied with variable doses of fuel gas having a specified chemical composition.

Figure 3 presents the impact of the injection pressure and the timing angle of the injection of a constant dose of liquid fuel on the engine's torque, with constant doses and a stable chemical composition of fuel gas. Fig. 4, on the other hand, presents a sample impact of the timing angle of injection and the amount of fuel gas in a dose with a stable chemical composition on the engine's torque, with a constant dose of fuel. The impact of the timing angle of the injection of liquid fuel and the injection pressure on the emission of toxic compounds is presented in Fig. 5.

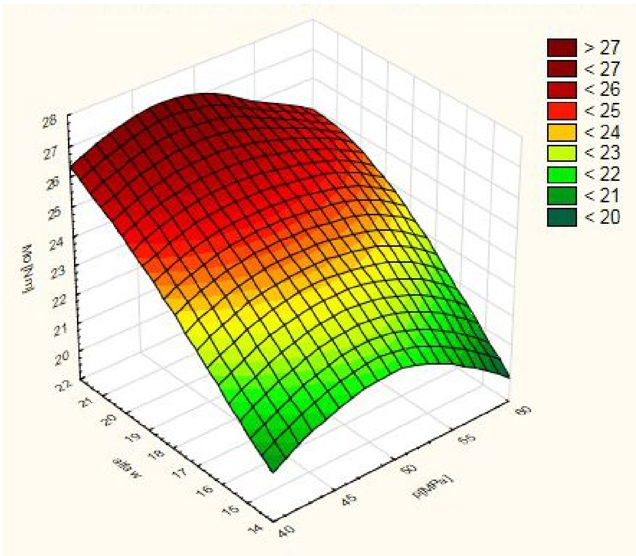

Fig. 3. The impact of the injection pressure and the timing angle of the injection of liquid fuel on the engine's torque at n = 3000 rpm, with a 15% dose of diesel fuel and a 108 l/min dose of fuel gas having a 50% methane content

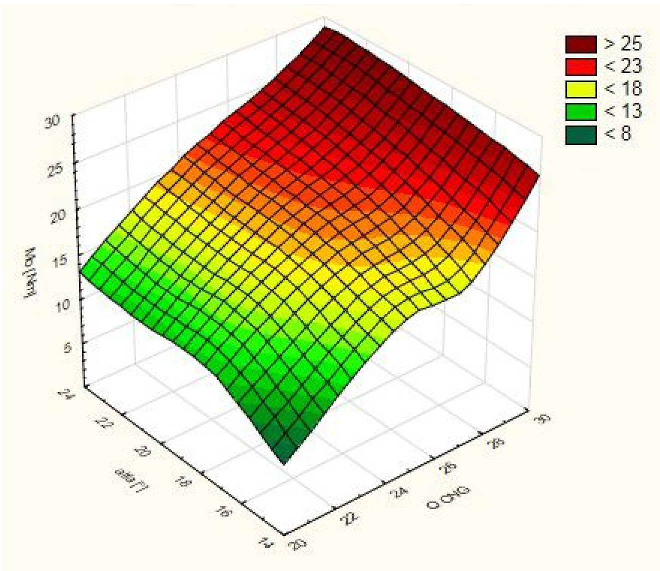

Fig. 4. The impact of the dose of fuel gas and the timing angle of injection on the engine's torque at n = 3000 rpm, with a 10% dose of liquid fuel, p_w=50 MPa, and the CNG content of fuel gas amounting to 50%

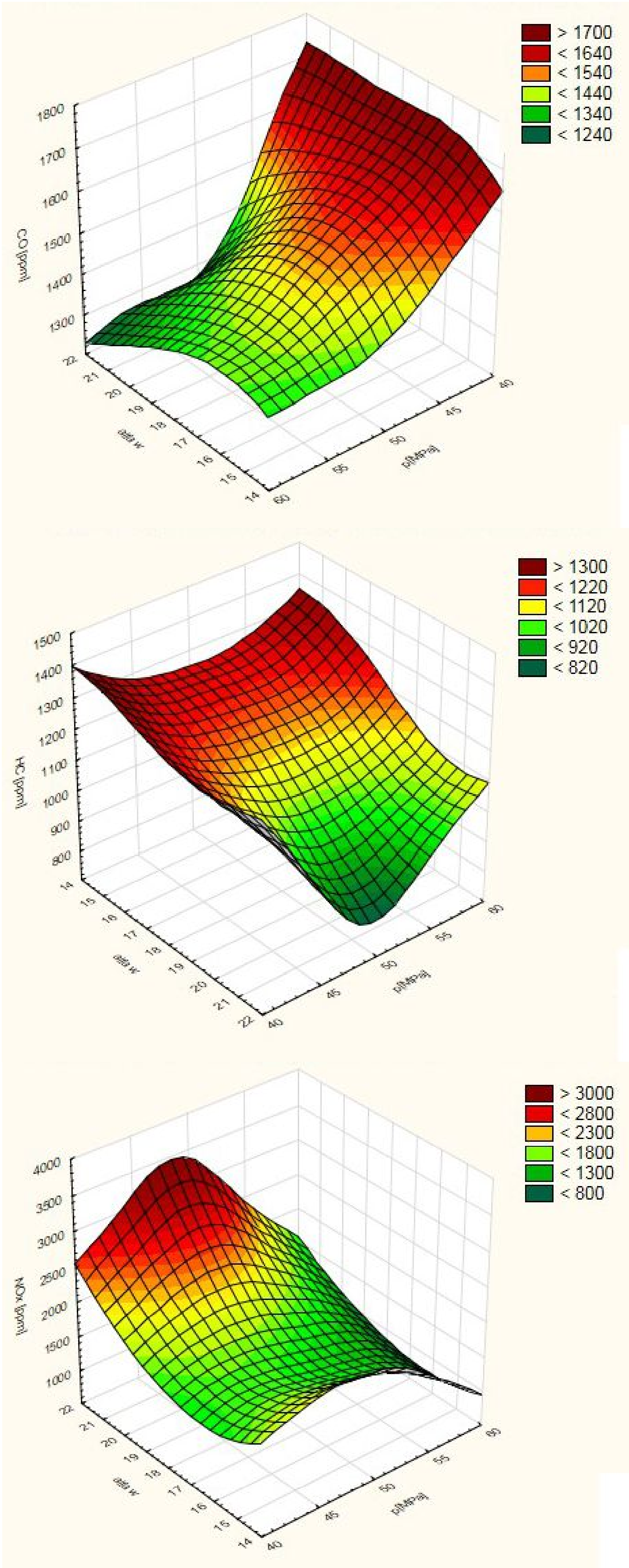

Fig. 5. The impact of the injection pressure and the timing angle of the injection of liquid fuel on the amount of toxic compounds in the exhaust fumes at n = 3000 rpm, with a 15% dose of diesel fuel and a 108 l/min dose of fuel gas having a 50% methane content

4. Summary

The tests presented above confirm the possibility of using biogas to power dual fuel compression-ignition engines. The primary parameters controlling this type of engine are the dose of liquid fuel and the parameters of its injection, such as the injection pressure and the timing angle of injection.

When analysing the impact of the injection pressure of the dose initiating autoignition, the best performance of the engine was recorded at a pressure of 50 MPa. At lower injection pressures, the dose of liquid fuel is stretched in time, which considerably prolongs the burning of the load in the combustion chamber. On the other hand, at too high pressures (short fuel injection time) there is a high penetration of the stream of liquid fuel in the combustion chamber, which initiates the combustion of a gas and air mixture within a larger volume of the combustion chamber. This favours quicker burning of the load in the combustion chamber, which thus favours the rough operation of the engine.

Another significant parameter controlling a dual fuel compression-ignition engine is the timing angle of the injection of liquid fuel. Too high values of this angle result in the premature initiation of the ignition of fuel gas, which also favours the rough operation of the engine.

It should also be emphasised that both the timing angle of the injection of liquid fuel as well as the injection pressure greatly affect the concentration of toxic compounds in the exhaust fumes. The presented results clearly indicate that the proper operation of a dual fuel compression-ignition engine requires the right selection of injection parameters for the pilot dose of liquid fuel.

References

[1] Cebula, J., *Biogas purification by sorption techniques*, ACEE Journal, 2, 2009.

[2] Gis, W., Jakóbiec, J., Żółtowski, A., *Biogas as engine fuel,* Silniki spalinowe, 1(148), 2012.

[3] Kowalewicz, A., *Adaptacja silnika wysokoprężnego do zasilania gazem naturalnym*, Czasopismo Techniczne. Mechanika, R. 105, Z. 7-M, pp. 67-78, 2008.

[4] Merkisz, J., Gis, W., Żółtowski, A., *Biogas as vehicle fuel*, Silniki Spalinowe, Vol. 50, No. 3, pp. 1-16, 2011.

[5] Mikulski, M., Wierzbicki, S., Śmieja, M., Matijošius, J., *Effect of CNG in a fuel dose on the combustion process of a compression-ignition engine*, Transport, 30(2), 162-171, 2015.

[6] Mustafi, N. N., Raine, R. R., Verhelst, S., *Combustion and emissions characteristics of a dual fuel engine operated on alternative gaseous fuels*, Fuel 109, pp. 669-678, 2013.

[7] Stelmasiak, Z., *Studium procesu spalania gazu w dwupaliwowym silniku o zapłonie samoczynnym zasilanym gazem ziemnym i olejem napędowym,* Rozprawy Naukowe, Wydawnictwo ATH, 2003.

[8] Stelmasiak, Z*., Dwupaliwowe silniki o zapłonie samoczynnym*, ITE, Radom 2013.

[9] Szczurowski, K., Radkowski, S., Walczak, D., Zieliński, Ł., *The effect of addition of LPG and camelina oil esters on noise and vibration in a dual fuel CI engine*, Diagnostyka, 15(4), pp. 53-58, 2015.

[10] Śmieja, M., Wierzbicki, S., *The concept of an integrated laboratory control system for a dual-fuel diesel engine*. Journal of KONES, Vol. 19, No. 3, pp. 451-458, 2012.

[11] Śmieja, M., Wierzbicki, S., Mamala, J., *Sterowanie dawką wtryskiwanego paliwa w układzie Common Rail z wykorzystaniem środowiska LabView,* Combustion engines, 154(3), pp. 542-548, 2013.

[12] Wierzbicki, S., *Biogas as a fuel for diesel engines,* Journal of KONES, Vol. 19, No. 3, pp. 477-482, 2012.

[13] Wierzbicki, S., Śmieja, M., Grzeszczyk, R., *Zintegrowane sterowanie stanowiskiem badawczym silników o ZS w środowisku fast prototyping,* Combustion engines, 154(3), pp. 536-541, 2013.