CHOICE OF A PILOT DOSE IN DUAL FUEL SELF-IGNITION ENGINE OF A GENERATOR, DEPENDING ON ITS LOAD

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Abstract

One of the basic problems concerning dual fuel powering of self-ignition engines is to determine the minimal dose of diesel oil injected into the combustion chamber in order to trigger self-ignition. Most research conducted to date on double-fuel powering self-ignition has been carried out on engines with mechanical injection systems, which does not ensure the possibility of obtaining very small diesel oil doses initiating self-ignition.

The original system of fuelling the engine with diesel oil was replaced with a laboratory Common Rail system. The basic parameters of injector operation were controlled by a specially-developed system ensuring continuous choice of parameters of injector operation. The examined engine was fitted with a prototypical system of methane-air fuelling and a system for controlling and adjusting the supplied dose of methane

This study presents the results of research aiming at determining the pilot dose injected into the combustion chamber of the engine to ensure the course of combustion in the engine operating under various loads. The results presented in the paper concern tests of a single-cylinder self-ignition engine, HATZ 1B40, operating in a generator adopted for CNG fuelling.

Keywords: *combustion engine, gas engine, dual fuel powering, CNG*

1. Introduction

Limited global resources of petroleum and the need to limit the emission of gases causing the so-called greenhouse effect, have led to the need to look for new, alternative sources of energy, which can be used not only as fuel for powering combustion engines, but also for electricity generation.

One of the possible methods for lowering the discharge of toxic components into the atmosphere is the wider use of methane as a fuel for combustion engines. Methane can originate from fossil fuels – natural gas (CNG), as well as biogas obtained from various sources, first of all such as: waste dumps, municipal waste, post-production waste of the fruit and vegetable processing plants and farm waste [2, 7, 9, 13, 14].

Currently, powering combustion engines with methane is becoming increasingly more popular, which can be seen by the constant increase in the number of stations where filling up with this fuel is possible. In many European towns, municipal buses are powered only by CNG. The application of CNG as a fuel for engines makes it possible to significantly reduce the concentration of toxic compounds and exhaust gas smokiness. The interest in methane results not only from the existence of large resources of this fuel, but it is also dictated by ecological and economic factors. CNG is currently the cheapest fuel widely applied in the economy [3, 5, 7, 9, 13, 14].

A significant limitation in applying methane as fuel for combustion engines is the need to maintain a relatively low temperature of its storage in a liquefied form (-162°C), therefore, fuelling systems applied in practice most frequently use it in a compressed form. Unfortunately, such a solution involves the need to use relatively large fuel tanks of special structure, which significantly increases the weight and limits the range of the vehicle [2, 3, 11-13].

Due to a relatively high self-ignition temperature (about 540°C), methane is used primarily as fuel for spark-ignition engines.

2. Powering the self-ignition engine with gas fuel

Currently, many research centres [3, 4, 7] are carrying out studies on using methane originating from natural gas and biogas for powering self-ignition engines [3, 4, 7]. The example can be prototypical solutions applied in farm tractors manufactured by Steyer and Valtra, in which biogas can constitute up to 80% of the total dose.

A significant impediment in applying gas fuels for powering self-ignition engines is the need to inject a specific dose of liquid fuel into the combustion chamber of the engine in order to trigger self-ignition of the compressed gas and air mixture [1, 4, 12].

In order to adapt self-ignition engines for methane fuelling, various solutions are currently applied, which include, among others [5, 9, 11]:

- engine modernization consisting in lowering its degree of compression and replacing the fuel injection system with the ignition system. This solution involves changing a self-ignition engine into a spark-ignition engine,
- modernization of the inlet system of the engine consisting in supplying fuel in a gas form to the suction manifold. The gas and air mixture is sucked into the combustion chamber, and at the end of the compression stroke, the injection system of the engine supplies a small dose of fuel to initiate the self-ignition of the compressed mixture. Such a method of powering the engine is a relatively simple solution in terms of construction, not requiring any significant interference in standard installation, at the same time allowing engine operation in both single and dual fuel systems,
- the application of two-way injectors, making it possible to inject gas and liquid fuel directly into the combustion chamber.

Most research conducted to date on double-fuel powering self-ignition has been carried out on engines with mechanical injection systems, which does not ensure the possibility of obtaining very small diesel oil doses initiating self-ignition [5, 6, 13]. In that research, one of the main aims was the least possible interference into an existing fuel system. The operation of such a system generally consisted of adjusting the amount of gas supplied to the suction manifold, and the amount of the initiating dose was adjusted by the fuelling system of the engine.

At present, work is also being conducted on dual-fuel engines with the Common Rail system [3, 10, 14]. However, it should be emphasized that in some of this research, e.g. [10], a specific amount of methane was supplied to the suction manifold and a dose of oil to initiate self-ignition was automatically supplemented by the control system.

3. The test stand and research methods

The research carried out in the Department of Mechatronics of the University of Warmia and Mazury in Olsztyn aimed at determining the minimum dose of diesel oil injected into the combustion chamber to ensure proper ignition of the methane-air mixture compressed in the combustion chamber.

The research was conducted on the basis of a HATZ 1B40 single-cylinder, low-power engine driving a three-phase generator (Tab. 1). The examined engine was fitted with a prototypical system of methane-air fuelling and a system for controlling and adjusting the supplied dose of methane. The examined engine was subject to modernization, consisting of supplying gas (CNG) to the mixer in the inlet system. After mixing with air, the gas was sucked into the cylinder. The original system of fuelling the engine with diesel oil was replaced with a laboratory Common Rail

system. With this aim in view, a standard mechanical injector was replaced with an electromagnetic injector with similar nozzle parameters. The basic parameters of injector operation were controlled by a specially-developed system ensuring continuous choice of parameters of injector operation, such as:
- duration of the impulse for injector opening – with 10 μs adjustment,
- fuel injection advance angle – with crank angle adjustment of 0.5°,
- possibility of dividing an injected fuel dose into four parts, with possible individual adjustment of duration and beginning of injection for each of the doses.

Tab. 1. Technical characteristics of the Hatz 1B40 engine

Engine type	HATZ, 1B 40, 4-stroke, air-cooled
Rated power	6.8 kW at 3000 rpm
Number of cylinders	1
Engine displacement	462 cm^3
Cylinder diameter	88 mm
Piston stroke	76 mm
Compression ratio	21
Mixture making system	direct injection

The CR fuelling system was fitted with a controlled fuel pressure regulator in the tank, with the possibility of its continuous adjustment.

During the conducted research, the engine-generator set was put under load of the power take-off system through the three-phase power regulator.

The applied sensors/converters and the control and measuring apparatus enabled control and measurement of the following values:
- a diesel oil dose injected into the combustion chamber,
- instant consumption of CNG,
- engine speed,
- power received from the system,
- temperature of the engine head,
- temperature of engine lubrication oil,
- temperature of exhaust gases in the exhaust manifold,
- signal from the knock sensor installed on the engine head.

During the test, the changes of pressure in the combustion chamber were recorded with the use of the engine indicating system, AVL Indimodul 621.

The research conducted resulted in determining the minimal dose of diesel oil injected to the combustion chamber, ensuring maintenance of initial parameters of the engine (N, n) on the set level.

The tests were carried out for various engine loads, while maintaining the set power received from the current generator during the subsequent measurements. During the measurements, the share of the diesel oil dose was gradually reduced, compensating the energy demand with an increased dose of methane.

In order to determine the consumption of diesel oil and methane, measurements were taken on the test stands to obtain characteristics of the injector output depending on the fuel pressure and the duration of the impulse for injector opening (Fig. 1) as well as characteristics of the output of the methane dosing valve as a function of the valve-opening degree (Fig. 2).

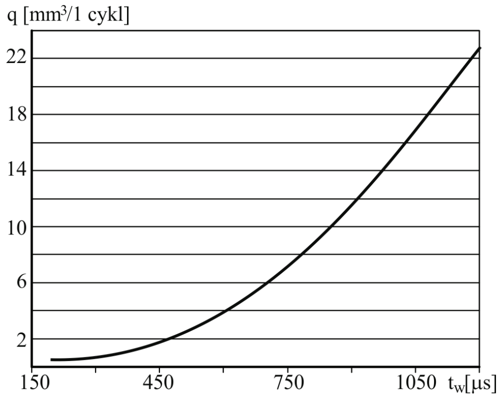

Fig. 1. Characteristics of diesel oil output depending on duration of the impulse for injector opening at injection pressure of pw=40 MPa, for the injector applied on the test stand

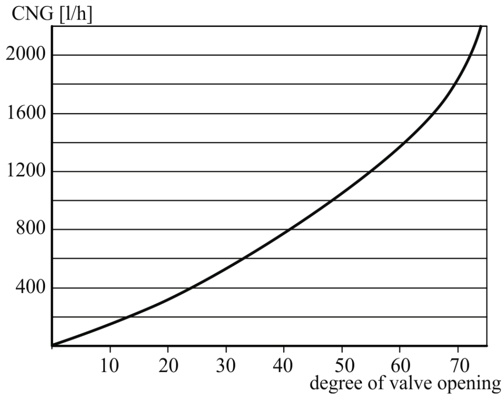

Fig. 2. Characteristics of CNG output depending on the opening degree of a dosing electrovalve used

The view of the complete test stand is presented in Fig. 3. and the injector installed in the engine head is presented in Fig. 4.

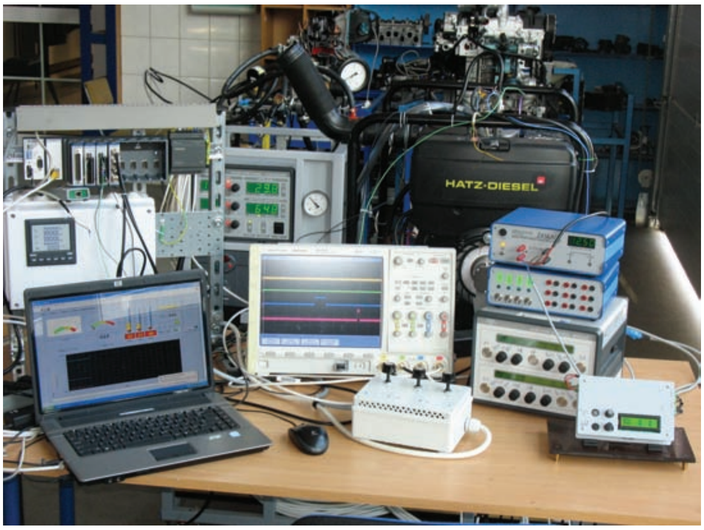

Fig. 3. A view of a HATZ 1B40 engine with a system for controlling, monitoring and fuelling with CNG and diesel oil

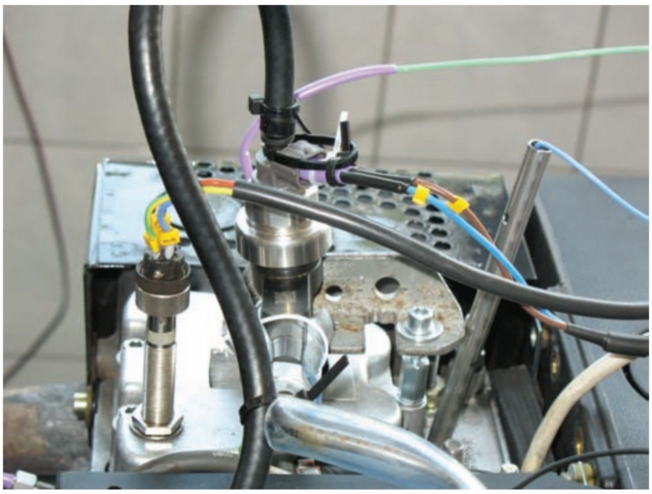

Fig. 4. A view of mounting the applied electromagnetic injector for injecting a pilot dose of diesel oil and of the pressure sensor in the combustion chamber

4. Results

The results of the research described in the further part of the study were obtained after carrying out a series of experiments on the test stand, maintaining the same power received from the generator during each series. The research was carried at:

- constant pressure of diesel oil injection of 40 MPa,
- constant advance angle of pilot dose injection of 14.5 °CA,
- constant engine speed of 3000 rpm.

The measurements were taken for the following values of power received from the generator: 0.6 kW, 1 kW, 2 kW, 3 kW, 4 kW, which corresponds to: 12.5%, 21%, 42%, 63% and 85% of the rated load of the examined system.

For each value of the initial power of the tested system, the measurements began with engine operating on diesel oil only. For subsequent measurements, the share of diesel oil was reduced in a fuelling dose, compensating it with an increased share of CNG. Records was made until the moment of obtaining the lowest possible dose of diesel oil at which the engine operated evenly and no unfavourable phenomena, such as “engine knocking” or an excessive increase in engine or exhaust gas temperatures occurred.

Figures 5-9 presents the consumption of diesel oil and CNG for individual series of measurements.

While analysing the results presented on the above diagrams, it can be established that the effect of an even operation can be obtained until the injection of a pilot dose of about 2.5% of the total dose used for fuelling the engine with diesel oil only. It should also be emphasized that with such low doses of diesel oil, the consumption of methane significantly increases, which proves significant energy losses related to extension of the combustion process in time. It should also be noted that these research results (Fig. 5-9) were obtained at a relatively low advance angle of the pilot dose injection, amounting to 14.5°. During the tests carried out at minimal doses of diesel oil (minimal injector opening times), it was found that the ignition of the combustible mixture began with a dose of diesel oil and self-ignition of gas did not occur.

Respectively, for partial loads of the engine, the minimal pilot dose was about 5.5%. However, it should be noted that under those conditions, it was not possible to inject a lower dose of fuel into the combustion chamber. This resulted from the characteristics of the applied injector and impossibility of obtaining an injection opening time below 170 μs.

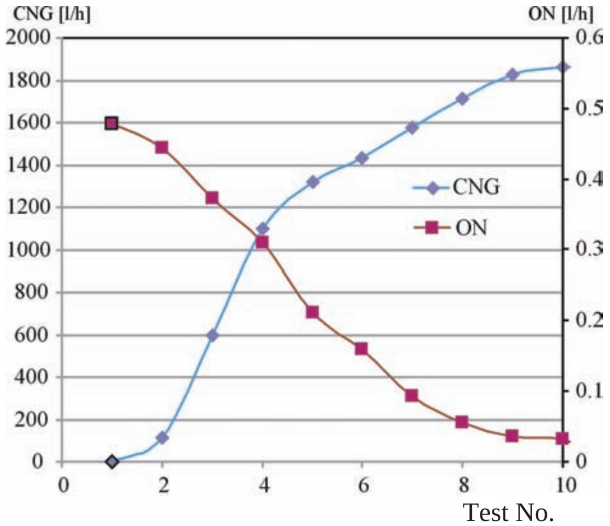

Fig. 5. Consumption of methane and diesel oil for initial load Pe1 = 0.6 kW, at constant advance angle of the pilot dose injection of a=14.5°

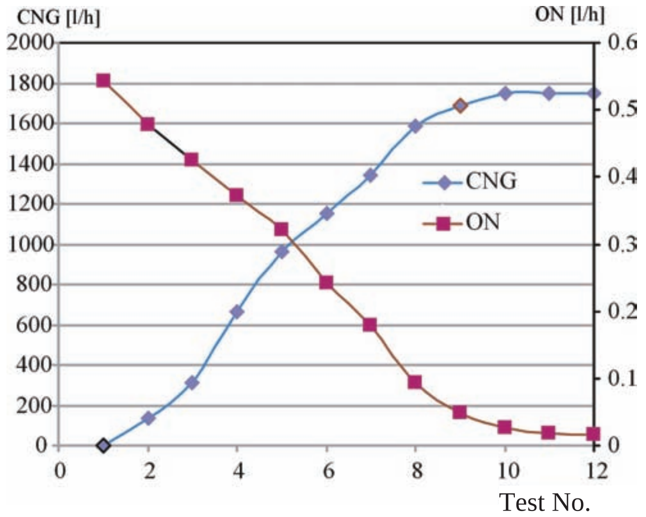

Fig. 6. Consumption of methane and diesel oil for initial load Pe1 = 1.0 kW, at constant advance angle of the pilot dose injection of a=14.5°

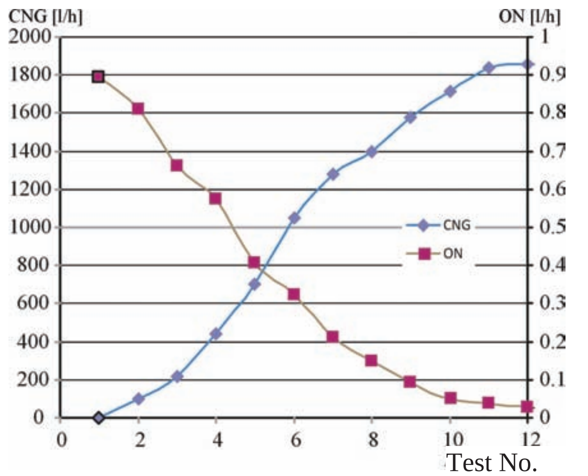

Fig. 7. Consumption of methane and diesel oil for initial load Pe1 =2.0 kW, at constant advance angle of the pilot dose injection of a=14.5°

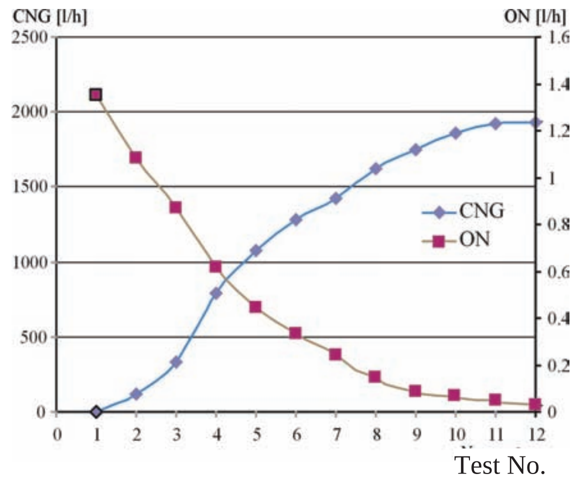

Fig. 8. Consumption of methane and diesel oil for initial load Pe1 =3.0 kW, at constant advance angle of the pilot dose injection of a=14.5°

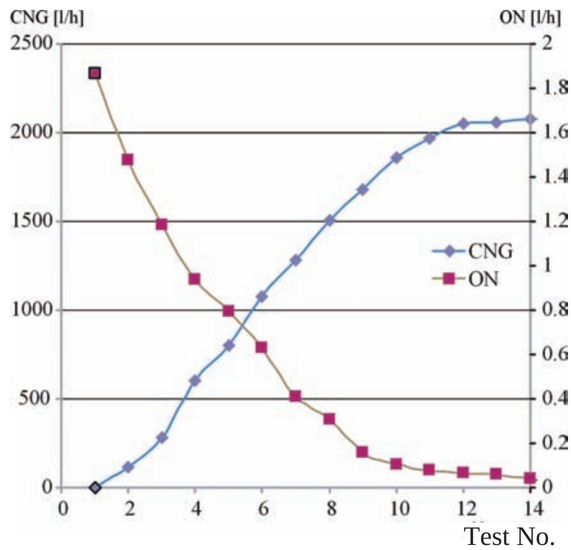

Fig. 9. Consumption of methane and diesel oil for initial load Pe1 =4.0 kW, at constant advance angle of the pilot dose injection of a=14.5°

Figures 10 and 11 present the average sample courses of pressure recorded in the combustion chamber. As can be clearly seen from these diagrams, an increase of the share of methane in the dose fuelling the engine results in delaying the moment at which the maximum pressure occurs in the combustion chamber. As a result of load expansion in the combustion chamber, the value of the maximal pressure is also lowered. During the research presented in this paper, a constant advance angle of the pilot dose injection was maintained, amounting to 14.5° CA.

5. Summary

The obtained results indicate the possibility of fuelling a low-power self-ignition engine with methane, with pilot doses of diesel oil of 2.5% of the dose applied without using gas at full load of the engine and about 5.5% at partial loads. However, the use of such a low pilot dose requires a relatively low advance angle of the pilot dose, which results in a delayed ignition of the mixture and extension of combustion in time. Extension of combustion results in a significant growth of methane consumption, which results in significant energy losses. On the other hand, increasing the advance angle of diesel oil injection results in a significant acceleration of fuel combustion, which is manifested by the rough operation of the engine.

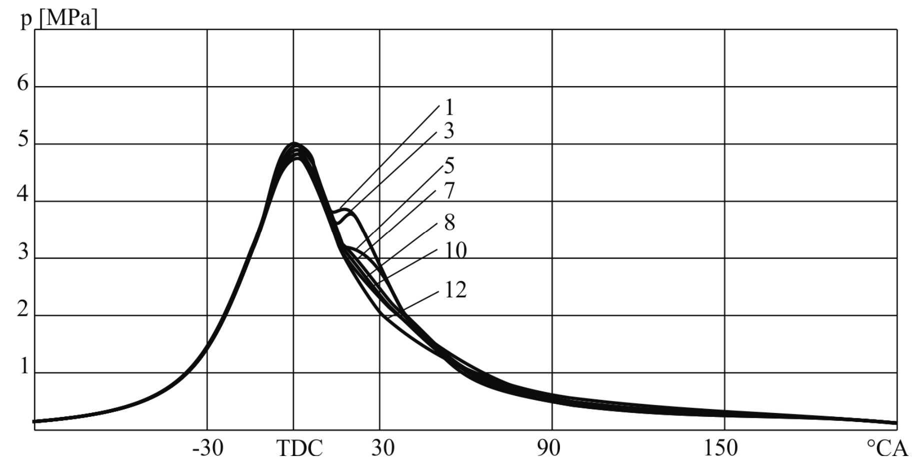

Fig. 10. Selected sample courses of pressure in the combustion chamber recorded for the generator load of 2 kW (selected measurement points according to markings in Fig. 6)

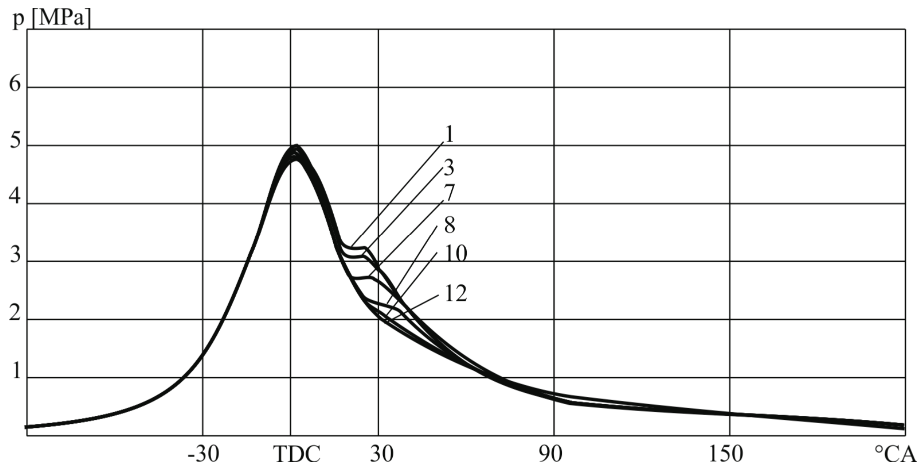

Fig. 11. Selected sample courses of pressure in the combustion chamber recorded for the generator load of 3 kW (selected measurement points according to markings in Fig. 7)

It should be emphasized that the engine used in the tests was a non-supercharged engine, of relatively low power in comparison to engines of a similar cylinder capacity used in motor vehicles. Adjustments of the advance angle of the pilot dose injection are required in order to maintain an appropriate level of maximum values of pressure in the combustion chamber and the moment of its occurrence.

Further research on methane powered self-ignition engines should focus on optimization of the advance angle of the pilot dose injection and take into consideration the emission of toxic compounds into the atmosphere.

Acknowledgement

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