EFFECT OF THE PARAMETERS OF PILOT DOSE INJECTION IN A DUAL FUEL DIESEL ENGINE ON THE COMBUSTION PROCESS

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Abstract

The paper presents the effect of the main parameters of pilot dose ignition: injection pressure, injection advance angle and injector opening time on the combustion process in a dual fuel diesel engine. The study continues the research conducted at the Department of Mechatronics of the University of Warmia and Mazury, Olsztyn, on optimisation of dual fuel self-ignition engines with CNG as the main fuel dose. The results presented in the paper were obtained with a single-cylinder engine HATZ 1B40, adapted to methane combustion.

The results presented in the paper show the recorded changes of pressure in the combustion chamber with a constant fuel pilot dose and different ignition advance angles. Scheme of fuelling and measurement systems, view of engine indicating system, average changes of pressure in the combustion chamber, average changes of pressure in the combustion chamber and average changes of pressure in the combustion chamber at dual fuel engine supply with diesel oil at varied pilot dose injection angle, effects of advance angle of the pilot dose injection on the maximum pressure of combustion, at various proportions of diesel oil and CNG, average changes of pressure in the combustion chamber at double-fuel engine fuelled with diesel oil and various shares of methane in the dose powering the engine, CNG consumption as a function of the advance angle of the pilot dose injection for various shares of the pilot dose are presented in the paper.

Keywords: *diesel engine, injection pressure, injector opening time, fuel injection advance angle, course of combustion*

1. Introduction

The need to reduce the emission of greenhouse gases, as well as the limited resources of petroleum, has been a driving force for searching for new, alternative sources of energy which can be used for powering combustion engines.

The current regulations concerning the use of renewable fuels, e.g. Directive No. 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market has required the generation of at least 7.5% of electricity obtained from renewable sources since 2010 and the share of this energy must amount at least to 20% by 2020. Another document imposing an obligation to reduce the emission of greenhouse gases is the Kyoto Protocol, the signatories of which, including Poland, agreed to reduce their own emissions to negotiated values by 2012, presented in the annex to the protocol (at least 5% of the emission level of 1990), e.g. carbon dioxide, methane, nitric oxides – gases emitted by engines and causing the greenhouse effect [1, 3, 5, 7].

Currently, one of the fuels which are constantly increasing in consumption is methane, originating mainly from fossil fuel (the main component of natural gas). Methane can be also acquired from other sources, such as: municipal waste, treatment plants and waste dumps and also as a result of the processing post-production waste of the fruit and vegetable processing plants, or it can be as obtained from the processing of agricultural crops. The main advantage of methane as a fuel for combustion engines is the lower emission of waste gases and its availability, which makes it a relatively cheap fuel [2, 6, 9, 10, 12].

Methane as fuel for combustion engines is increasingly often used for powering spark ignition combustion engines, which is confirmed by the continuously expanding networks of methane filling stations. A serious impediment in applying methane as an engine fuel is its low condensation point –162°C. Nowadays, technologies have been developed for constructing special tanks to store methane in a liquid form (LNG), but the time of this storage is limited. Therefore, in practice, it is most often used in a compressed form (CNG). The application of methane in a compressed form requires the use of relatively large fuel tanks, which increases the weight of the entire vehicle, makes it difficult to install them on a vehicle and significantly reduces the range of the vehicle [3, 5, 8, 12, 13].

Unfortunately, the application of methane as a fuel for diesel engines is impeded by a relatively high self-ignition temperature of about 540°C. Therefore, in order to use methane as a fuel for diesel engines, it is necessary to adapt the engine to work in a dual fuel system. In such a solution, methane is supplied to the engine manifold, where it is mixed with air making a mixture, then after being sucked into the combustion chamber and being compressed, a specific dose of fuel is injected by the fuel system to the chamber in order to trigger self-ignition of the methane-air mixture. Another solution of using methane as a fuel for diesel engines is the application of special two-way injectors, facilitating injection into the combustion chamber of both the pilot dose and methane, although this is applied only in high-power engines [2, 4, 6, 9, 12].

2. Test stand and the aim of the research

This study presents selected test results of the diesel engine powered in a dual fuel system. The tests described in this paper were carried out on a single cylinder diesel engine with direct injection into the combustion chamber, engine rating of 462 cm^3 and rated power of 6.8 kW at a rotational speed of 3000 rpm. Methane was supplied to the suction manifold through a special system making it possible to control the dose of the supplied gas and to measure its consumption.

The pilot dose of diesel oil was injected into the combustion chamber by an electromagnetic injector controlled by the Common Rail system. The pilot dose was controlled through a special system enabling a precise control over the following parameters:

- fuel injection pressure,
- fuel injection advance angle,
- amount of the pilot dose injected.

During the tests, the engine was put under the load of a three-phase generator, with a rated power of 4.7 kW and the system ensuring adjustment of the power received. The scheme of the fuelling system of the test engine is presented in Fig. 1.

During the tests, the following parameters were measured:

- a dose of diesel oil injected into the combustion chamber,
- instant consumption of CNG,
- engine speed,
- power received from the system,
- course of pressure changes in the combustion chamber as a function of the crank angle.

Additionally, the following parameters of engine operation were controlled during the tests:

- 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.

The system of engine indicating was used, AVL Indimodul 621 (Fig. 2), was used for recording pressure in the combustion chamber. This set consists of a charge amplifier – FlexIFEM Piezo 2P2E AVL, a crank angle encoder – 365C AVL, a piezoelectric sensor for measuring dynamic pressure in the cylinder – GM 12D AVL. During operation, the IndiModul system was controlled by the IndiCom computer software suite. The pressure values in the combustion chambers were recorded at every crank angle of 0.5°.

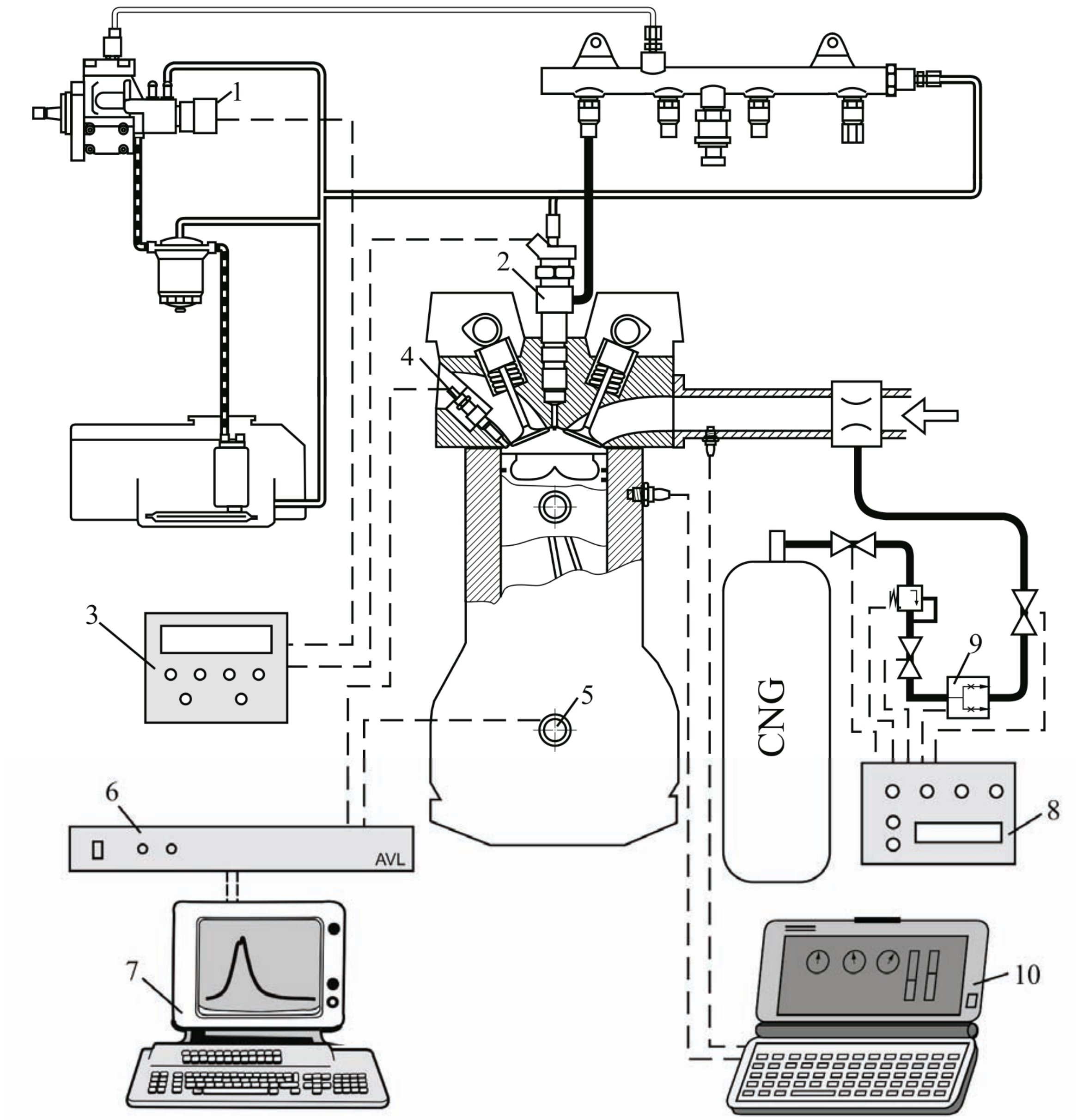

Fig. 1. Scheme of the fuelling and measurement systems: 1 – fuel pressure regulating valve, 2 – electromagnetic injector, 3 – rate control system of diesel, 4 – AVL GM 12 D piezoelectric cylinder pressure sensor, 5 – 365C AVL crankshaft rotation angle marking gauge, 6 – AVL Indimodule 621 engine indicating system, 7 – program IndiCom AVL, 8 – CNG feed control system, 9 – two-way gas flow controller, 10 – measurement system: received power, engine and exhaust gas temperature

3. Results

The results of measurements presented in this study were obtained after carrying out a series of experiments on the described test stand, preserving the following constant operation parameters for the tested engine-generator set:

- constant engine speed of 3 000 rpm;
- constant power received from the generator, 2 kW (40% of the nominal load);
- pressure of diesel oil injection of 40 MPa.

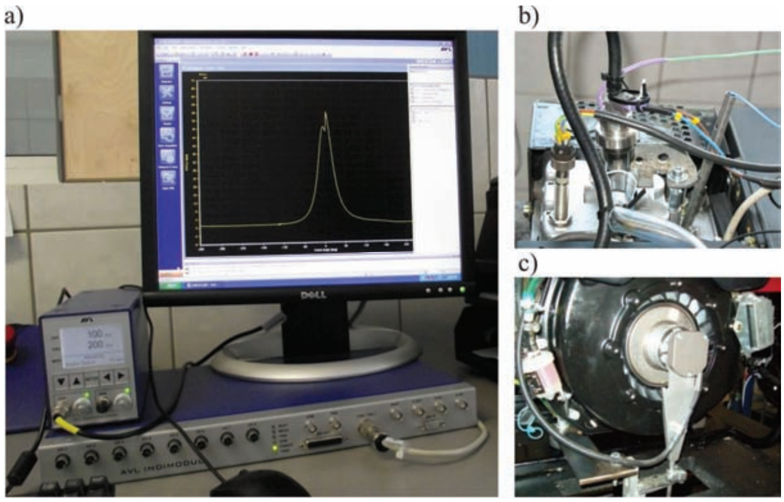

Fig. 2. The view of the engine indicating system: a) charge amplifier – FlexIFEM Piezo 2P2E AVL and IndiCom software, b) piezoelectric sensor GM 12D AVL, c) crank angle encoder – 365C AVL

First, the quantity of the diesel oil dose was determined along with its changes while powering the engine with diesel oil only, at a variable angle of the first fuel injection. Next, the subsequent measurement series was carried out, in which the share of diesel oil in the dose supplied to the engine was reduced and replaced with methane. Fig. 3-6 presents pressure changes in the combustion chamber averaged from 50 measurements, for the following shares of diesel oil in the total dose: 100%, 50%, 22%, 12%. On the other hand, Fig. 7 presents the effects of an advanced angle of diesel oil injection on the value of maximum pressure in the combustion chamber, for subsequent proportions of fuels powering the engine during the tests.

While analysing the recorded pressure changes in the combustion chamber, it can be claimed that the share of methane in the dose powering the engine, at diesel oil doses up to 20%, results in increasing the maximum pressure in the chamber, with the growing rate of its increase. At lower doses of diesel oil initiating self-ignition, the maximum pressure in the combustion chamber decreases in comparison to fuelling the engine only with diesel oil. However, it should be emphasized that, in this case, combustion is extended over time, which results in a high increase of methane consumption.

The diagrams clearly demonstrate a strong effect of the advanced angle of diesel oil injection on the course of the pressure increase in the combustion chamber. At an injection angle of the piloting dose lower than 22°CA before TDC, the pressure graph has two maxima: the first related to the compression of the mixture and the second resulting from the delayed self-ignition of the diesel oil - methane - air mixture.

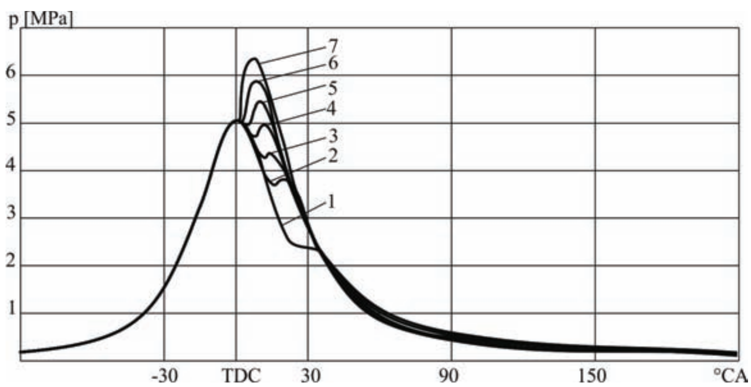

Fig. 3. Average changes of pressure in the combustion chamber while supplying the engine with diesel oil at varied fuel injection beginning angle, at Ne=2kW, n=3000 rpm:1 – 12.5°CA, 2 – 14.5°CA, 3 – 16.5°CA, 4 – 19 °CA, 5 – 21°CA, 6 – 23°CA, 7 – 25°CA

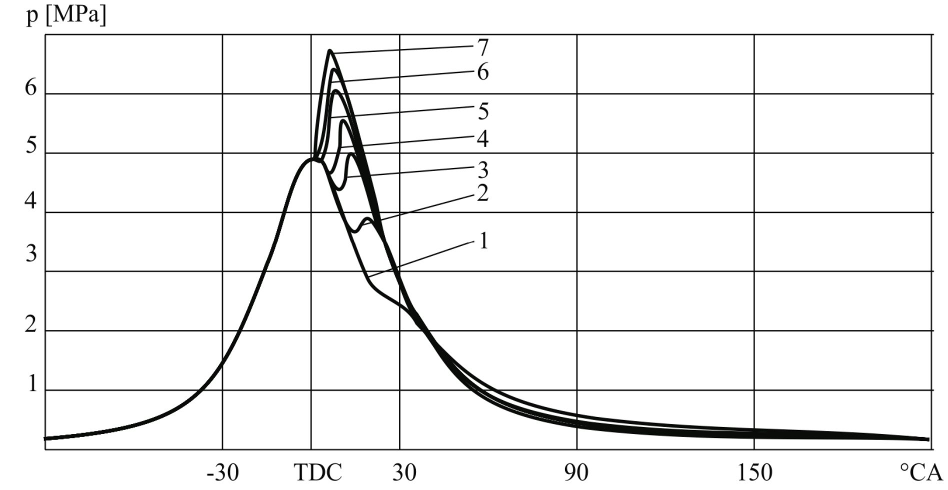

Fig. 4. Average changes of pressure in the combustion chamber at dual fuel engine supply with diesel oil at varied pilot dose injection angle, at Ne=2k, N=3000 rpm, a dose of diesel oil of 50%: 1 – 14°CA, 2 – 16°CA, 3 – 18°CA, 4 – 20°CA, 5 – 22°CA, 6 – 24°CA, 7 – 26°CA

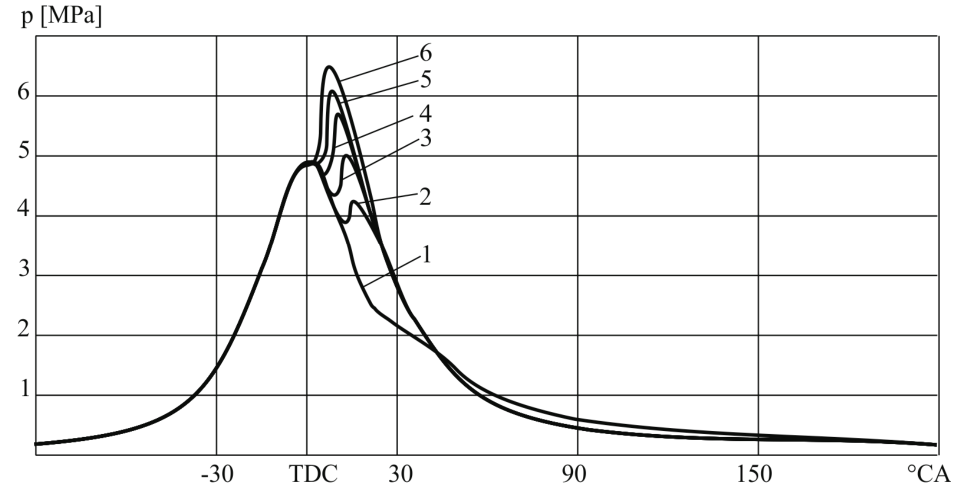

Fig. 5. Average changes of pressure in the combustion chamber at dual fuel engine supply with diesel oil at varied pilot dose injection angle, at Ne=2k, N=3000 rpm, a dose of diesel oil of 22%: 1 – 14°CA, 2 – 16°CA, 3 – 18°CA, 4 – 20°CA, 5 – 22°CA, 6 – 24°CA

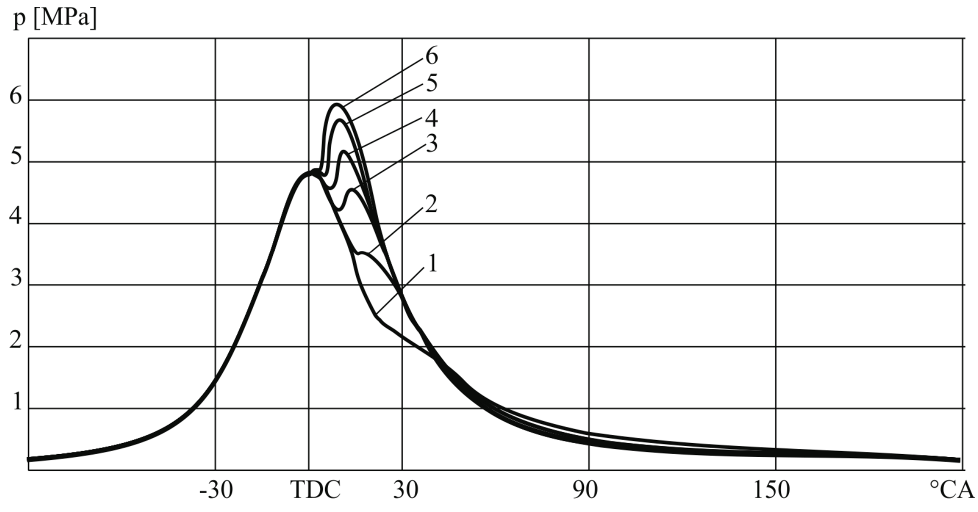

Fig. 6. Average changes of pressure in the combustion chamber at dual fuel engine supply with diesel oil at varied pilot dose injection angle, at Ne=2k, N=3000 rpm, a dose of diesel oil of 12%: 1 – 14°CA, 2 – 16°CA, 3 – 18°CA, 4 – 20°CA, 5 – 22°CA, 6 – 24°CA

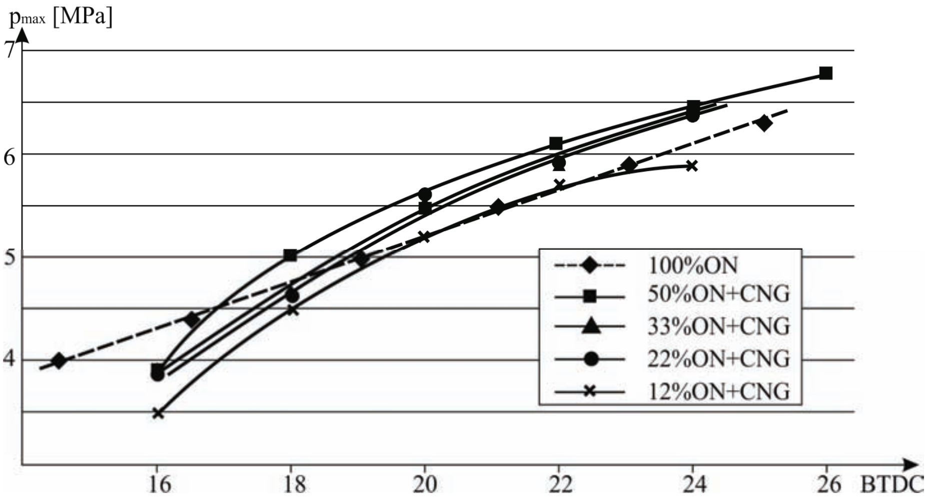

Fig. 7. The effects of advance angle of the pilot dose injection on the maximum pressure of combustion, at various proportions of diesel oil and CNG

The effect of the share of methane in the dose powering engine the course of pressure changes at constant advance angle diesel oil injection is presented in Fig. 8. As results from this figure, the delay of the self-ignition of the mixture increases along with the growth of the methane share in the powering dose, after the ignition of the mixture, the rate of the pressure increase in the combustion chamber significantly grows, which result in rough engine operation. With the increase of the methane share in the powering dose, the maximum pressure of combustion also increases. However, it should be emphasized that at about a small share of the diesel oil in the powering dose, the maximum pressure is lower than when the engine operates on diesel oil only, but combustion in this case is extended in time, which results in high energy losses.

The effect of the advance angle of the constant diesel oil pilot dose injection on methane consumption is presented in Fig. 9. As can be clearly noted in this diagram, a late injection of the dose initiating self-ignition requires increasing the share of methane in the dose powering the engine.

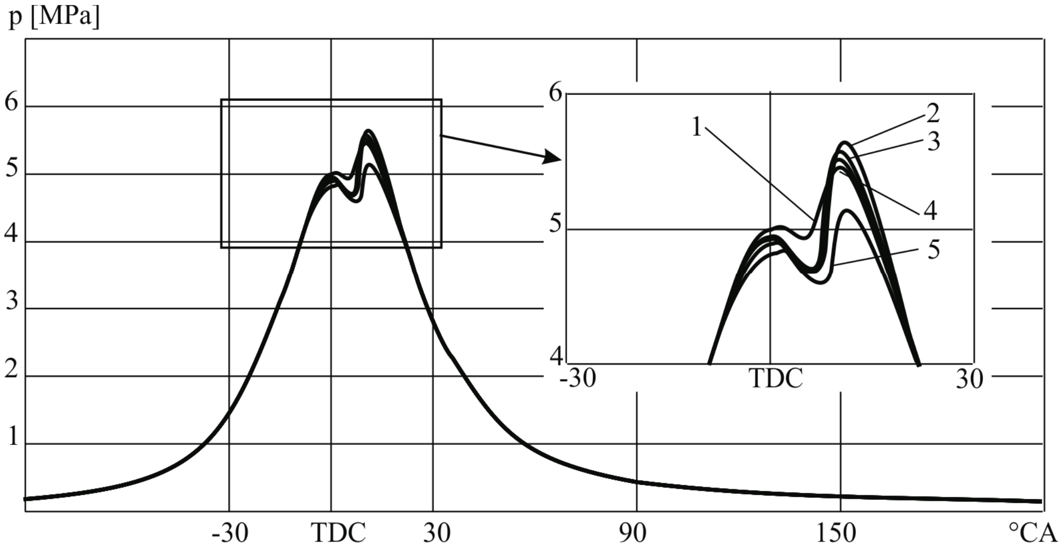

Fig. 8. Average changes of pressure in the combustion chamber at double-fuel engine fuelled with diesel oil (DO) at a varied constant angle of pilot dose injection of 20°CA, at Ne=2kW, N=3000 rpm, and various shares of methane in the dose powering the engine: 1 – 100% DO, 2 – 50% DO+CNG, 3 – 33% DO+CNG, 4 – 22% DO+CNG, 5 – 12% DO + CNG

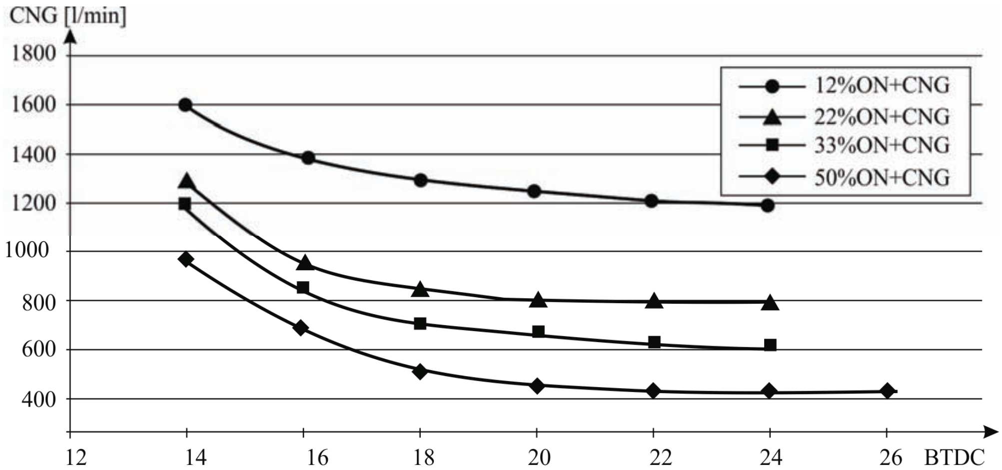

Fig. 9. CNG consumption as a function of the advance angle of the pilot dose injection for various shares of the pilot dose at n=3,000 rpm, Pe=2kW

4. Summary

The results presented above demonstrate the effects of basic parameters of injection of the pilot dose of diesel oil, i.e. the amount of the dose, its injection advance angle and the course of pressure changes in the combustion chamber of the dual fuel diesel engine. The results obtained demonstrate the effect of those parameters on the course of combustion in those engines. On the basis of these results, it can be concluded that in the case of small, unloaded diesel engines of relatively high rotational speed, the best course of combustion is ensured by the percentage of the methane dose not exceeding 80% of the total dose. At higher shares of methane in the supplied dose, fuel combustion is extended over time, which results in high energy losses.

The obtained preliminary results comply with press reports concerning prototypical solutions for engines applied in farm tractors manufactured by STAYER and VALTRA, powered by the dual fuel system with diesel oil and methane supplied in the form of biogas.

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