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AN INFLUENCE OF CORRECTION OF THE IGNITION ADVANCE ANGLE ON THE COMBUSTION PROCESS IN SI ENGINE FUELLED BY LPG WITH THE ADDITION OF DME

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Abstract

The paper presents the results of tests of the SI engine fuelled by LPG with the addition of DME in the form of a mixture of gaseous fuels. Experimental tests were carried out on a chassis dynamometer in the full range of engine loads, at a fixed rotational speed: 2000, 2500 and 3000 rpm. The use of dimethyl ether (DME) as a fuel component makes it possible to exploit its important advantages. DME can be produced as a renewable fuel, which is important from the point of view of ecology. Another important fact is the presence of oxygen in this fuel, which has a positive effect on the engine volumetric efficiency. During the tests, the ignition timing was also adjusted due to the very good DME flammability. Two additional correction levels were applied, increasing the ignition advance by 3 and 6 CA degrees, compared to the factory settings of the driver. The analysis of the obtained results allowed determining the dependence of the basic engine parameters, in the function of the correction of ignition advance angle. In the summary, attention was also paid to the possibility of determining corrected maps of the ignition advance angle taking into account the variable proportions of fuel components.

Keywords: *Dimethyl ether, DME+LPG, fuel blend, SI engine*

1. Introduction

The According to the analysis of published results of scientific research conducted in recent years, dimethyl ether (DME) is gaining more and more important applications in the automotive industry. The main ones assume its use as motor fuel, but it is more and more often pointed out that it is a very good carrier of hydrogen [1]. One DME molecule contains 6 atoms of hydrogen, and the conversion process to obtain hydrogen is cleaner and cheaper than for natural gas conversion. As a DME fuel, it is perceived mainly as a substitute for diesel fuel due to its high cetane number (about 55) and it is used on an increasing scale in truck fleets [2, 3]. Among the companies, developing applications of this type in Europe is the Volvo group, and in the USA the Oberon group [5]. The technology of storing and distributing this fuel is not currently a major technical problem.

By popularizing the use of DME as a fuel, the main focus is [4]:

– the possibility of reducing total CO_2 emissions by up to 68% when using bioDME, which is a renewable fuel; the level of emissions depends on the raw material used to produce the fuel,
– fuel with a simple molecular structure, which translates into cleaner and quieter combustion process and easier control of NO_x emissions,
– no solid particles in combustion products,
– fuel not contaminated with sulphur compounds.

The physical and chemical properties of DME are similar to LPG, which is why it can also be used as fuel in SI engines. One of the applications is the LPG / DME blend [6, 7]. An additional utilitarian aspect is the use of existing LPG fuel systems. As indicated by the results of the conducted tests [8, 9], the DME share may be above 20% of the fuel mass. However, to date, it is considered the most effective mixtures with the addition of DME from 10 to 17%. Such fuel does not require correction of engine control parameters and ensures similar dynamics, comparable to LPG.

In the conducted research, an attempt was made to assess the improvement of the main operating parameters of the SI engine fuelled by the LPG / DME blends with variable proportions of components, by correcting the ignition advance settings.

2. Experimental studies

2.1. Measurement set-up

The popular passenger car powered by 1.6 litre engine naturally aspirated with a compression ratio of 9.6-port fuel injection, two valves per cylinder, flat pistons and without external EGR was used in the experiments. The experiments were performed on a BOSCH FLA 203 chassis dynamometer. Main features characterizing the engine installed on the tested vehicle have been listed in the Tab. 1. Engine performance has been estimated on the basis of acquired dynamic characteristics, defining the power on wheels in function of vehicle speed. Test stand has been equipped with various transducers and sensors allowing the identification of engine operating conditions. Basic measurements and control systems allowed continuous acquisition of engine operating conditions, through registrations of:

- in-cylinder pressures, crank angle, with the TDC identification,
- power on wheels,
- manifold pressure,
- inlet air temperature,
- exhaust gases temperature,
- fuel mass flow to the engine.

The in-cylinder pressure was measured by Kistler 6121 piezoelectric pressure transducers and a charge amplifier, Kistler 5011A. The signals were processed in type NI PCI-6143 board in a computer for online pressure measurements. The pressure recording system was also connected to the Kistler 2613B crank angle encoder giving the temporal resolution of the pressure recordings of 0.5 CA. The pressure measurements were recorded and stored on a computer, with recordings performed for 200 subsequent cycles in each test, and was further processed with the help of a script debugged in LabVIEW 7.1 environment.

Tab. 1. Engine specifications

Engine code	X16SZR
Cylinder number and layout	4 R
Maximum power	55 kW@ 5200 rpm
Maximum torque	128 N·m @ 2800 rpm
Displacement	1598 ccm
Bore × stroke	79.0 × 81.5 mm
Compression ratio	9.6

2.2. Methodology of research

The main purpose of the research is to determine the impact of changes in ignition timing on the basic parameters of engine operation with the use of fuels with various DME shares. The change of the ignition advance angle is accomplished by entering into the engine control algorithm a set value correcting the angle determined by the controller. During the tests, two additional degrees of correction were applied, increasing the ignition advance by 3 and 6 degrees of CA compared to the factory controller settings. Three measurements were made for each measuring point, one at the nominal ignition timing (without correction) and two more with the given corrective values. The scope of the tests carried out included measurements in steady state of engine operation at selected rotational speeds and a variable degree of engine load. The following rotational speeds were selected for the tests: 2000, 2500 and 3000 rpm. The degree of engine load is equivalent to the throttle-opening angle. The test was performed for the following engine loads 21, 33, 48, 60, 75, 90 and 100%.

2.3. Preparation of fuel blends

Considering the results obtained in the previous stage [8], fuels with different DME mass content varying in the range of 7-30% of DME mass in the mixture with LPG were prepared for testing. The scheme of the station used for the preparation of gas mixtures of specified mass composition is shown in the figure (Fig. 1). Individual fuel components are stored in separate cylinders. They were provided for testing as technical gases, so that their composition was precisely defined. The cylinders are equipped with pressure reducers and connected to individual solenoids. After opening the solenoid valve, the gas enters the rail, which is connected directly to the tank. The stand is also equipped with pressure gauges controlling the pressure of individual gases and the pressure in the central fuel tank. The tank is connected to the vehicle's fuel system.

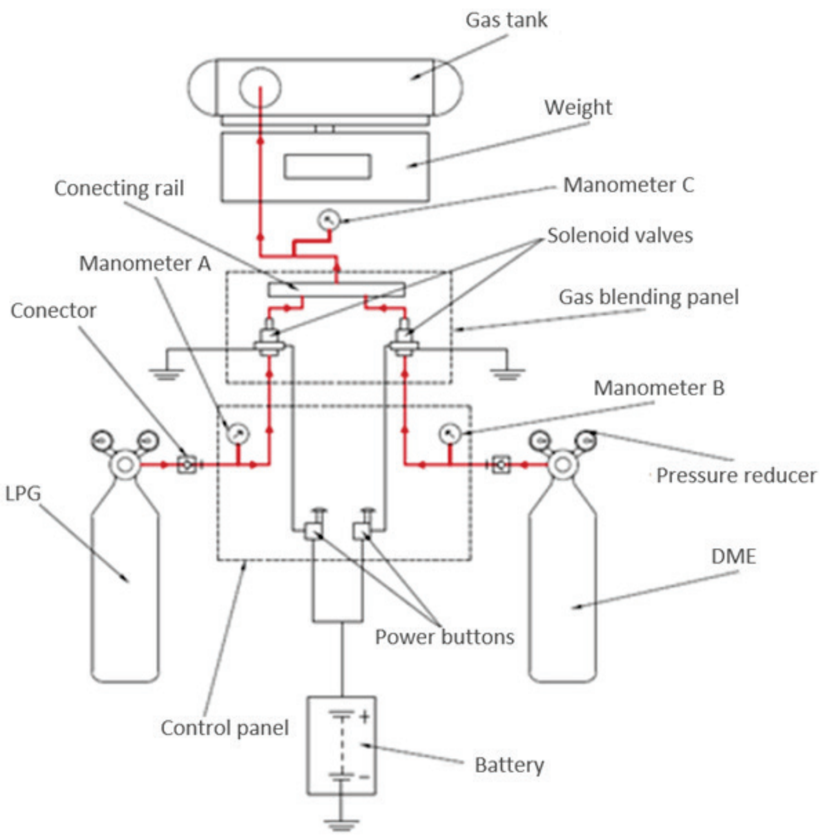

Fig. 1. The scheme of the preparation of blends of gaseous fuels [10]

The procedure for preparing the fuel blend was as follows. A fixed portion of LPG was introduced into the central gas tank, which was placed on the scale, and then refilled with DME. The weight of the recessed portion of DME was calculated each time to obtain the correct composition of the fuel blend. A portion of the one-time blend had such a mass that it would be sufficient to make a series of measurements. The basic parameters of the tested fuel blends are presented in Tab. 2.

Tab. 2. The parameters of fuels prepared for test

Fuel composition [% by mass]		Molecular mass of fuel [kg/kmol]	Stoichiometric air fuel ratio A/F [kg/kg]	Lower heating value [MJ/kg]
LPG	DME			
93	7	50.615	15.30	44.67
89	11	50.397	15.04	43.88
86	14	50.236	14.84	43.33
83	17	50.080	14.64	42.78
79	21	49.86	14.37	42.05
74	26	49.6	14.04	41.14
70	30	49.39	13.77	40.42

3. Results and discussion

3.1. Correction of ignition advance angle

As it was mentioned earlier, the tests were performed at the nominal ignition advance values given by the factory engine controller, and two degrees of correction were applied. The map of uncorrected values that were measured during the tests at the lab is shown in the graph (Fig. 2). Analysing the results of measurements at each of the engine operating points, the ignition angle values at which the engine obtained the highest power were determined. As a result of these actions, a map of the corrected ignition timing was determined for each of the tested engine rotational speeds. A map of corrected values determined using the criterion of generated power at 3000 rpm is shown in the next graph (Fig. 3).

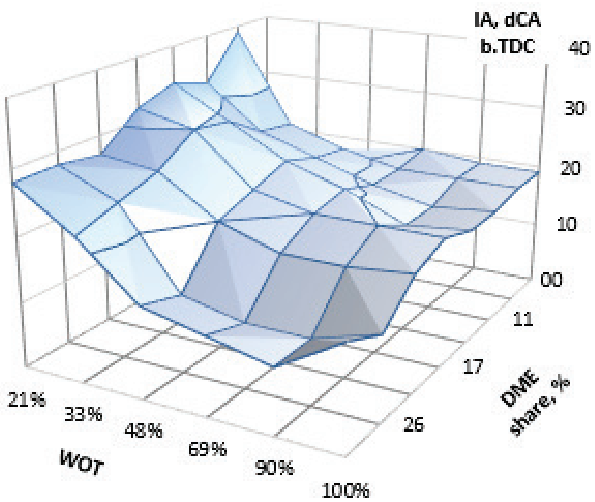

Fig. 2. Map of uncorrected ignition timing values for the tested engine at 3000 rpm

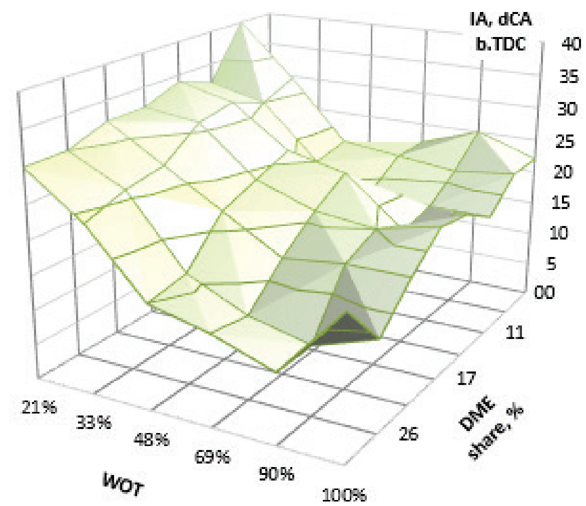

Fig. 3. Map of corrected ignition timing values for the tested engine at 3000 rpm

Comparing the presented graphs, those can be seen that graphs' shapes have not changed significantly, but at most measuring points the ignition advance value has increased, which increases the engine power. Such a relationship was observed for all rotational speeds at which measurements were made.

3.2. Engine power and power on wheel

Observing the graphs of power measured on the wheels of the vehicle (Figs. 4 and 5), it can be seen that the engine achieves the highest power when fed with a blend with a DME share of 17%, only with a load of 21% the highest power was obtained with an increased share of DME up to

21%. These trends were observed at all tested engine speeds. The ignition timing correction applied did not change these trends. However, it caused that in most measuring points an increase in engine power was observed. The magnitude of these changes is presented in the graph (Fig. 6).

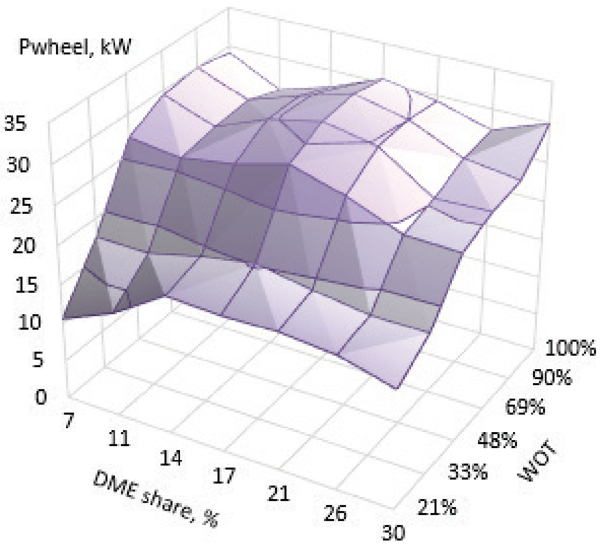

Fig. 4. The values of power measured on the wheels of the vehicle at 3000 rpm, without IA correction

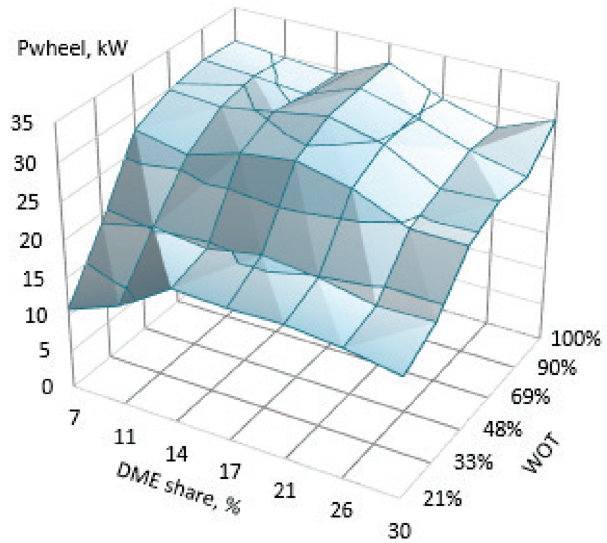

Fig. 5. The values of power measured on the wheels of the vehicle at 3000 rpm, with IA correction

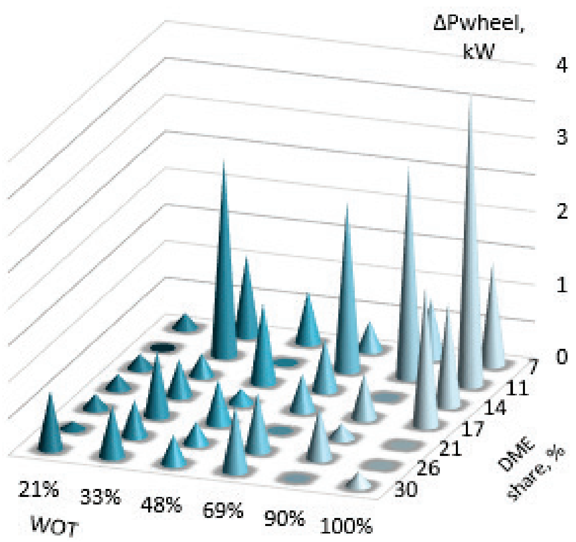

Fig. 6. Changes in the power measured on the wheels of the vehicle as a result of the IA correction at 3000 rpm

The analysis of the indicated power diagrams of the engine confirms these observations. The indicated power was calculated on the basis of the recorded indicated pressure. The graphs (Figs. 7 and 8) show the results obtained at an engine speed of 2500 rpm. It can also be stated that increasing the share of DME in fuel above 17% causes a gradual decrease in the value developed by the engine.

3.3. In-cylinder pressure analysis

The course of pressure changes in the engine cylinder is the best reflection of the changes taking place. In this case, the present closed indicator charts show how the change in the proportion of fuel components affects the operation of the engine (Fig. 9). Increasing the DME proportion gradually, we observe an increase in the maximum pressure, but after exceeding the

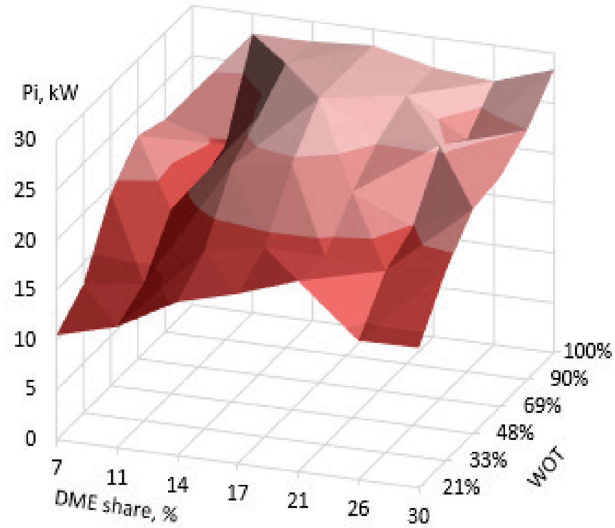

Fig. 7. Indicated power values at 2500 rpm, without IA correction

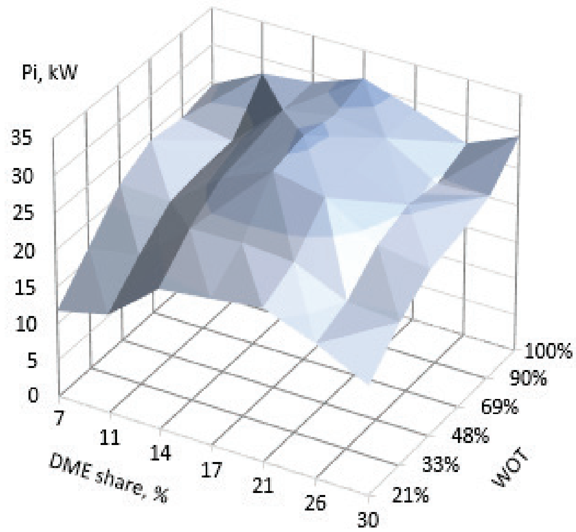

Fig. 8. Indicated power values at 2500 rpm, with IA correction

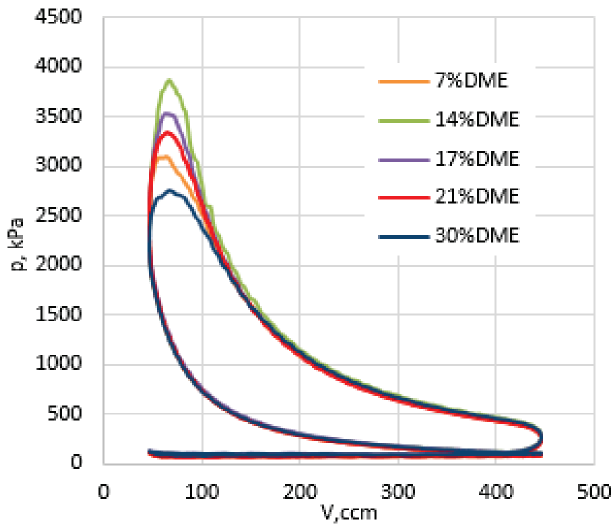

Fig. 9. Impact of DME share on p-V chart, n = 2500 rpm, WOT = 69%

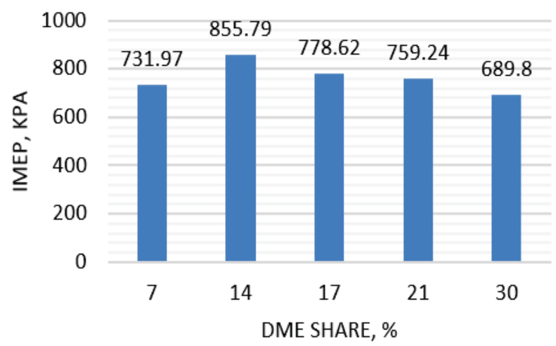

Fig. 10. Impact of DME on IMEP value, n = 2500 rpm, WOT = 69%

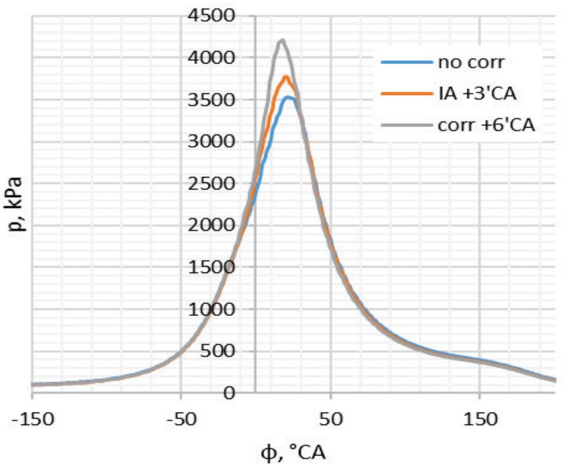

Fig. 11. Impact of ignition timing correction on in-cylinder pressure, n = 2500 rpm, WOT = 69%, DME share = 17%

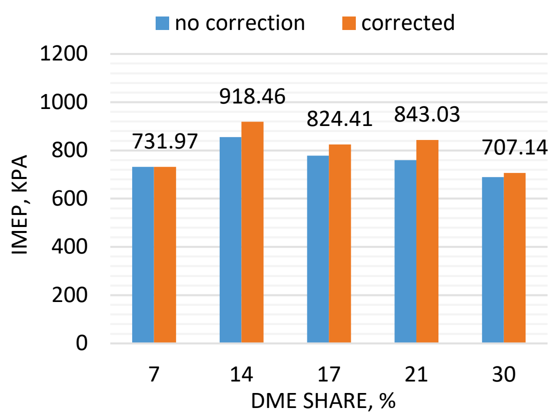

Fig. 12. Impact of DME share on IMEP, including ignition timing correction, n = 2500 rpm, WOT = 69%

proportion of approx. 14%, with the engine load, the combustion process occurs in such a way that the maximum pressure begins to drop. This, of course, will result in a decrease in the value of other engine performance parameters. These changes are visible in the next graph showing the average indicated pressure (Fig. 10).

The introduction of a constant ignition advance correction in the range of + 3°CA and +6°CA causes that the combustion process will be initiated a little earlier. This configuration of control parameters may cause an increase in indicated pressure (Fig. 11). Similar changes are observed in the case of changes in the IMEP value (Fig. 12), where in most cases the introduction of correction causes an increase in the value of this parameter.

3.4. Stability assessment of combustion process

Due to the high cetane number of DME, and hence, the tendency to self-ignition, too much share of this component in the fuel can lead to loss of control over the combustion process. Therefore, in the development of test results, attention was also paid to the assessment of engine stability. The universal parameter used to assess the degree of repeatability of subsequent engine cycles is the covariance factor, determined on the basis of changes in the IMEP standard deviation in subsequent engine cycles (1).

$$COV_{imep} = \frac{COV_i}{\overline{p_i}} \cdot 100\%, \tag{1}$$

where:
COV_i – IMEP standard deviation in subsequent cycles,
$\overline{p_i}$ – average IMEP value for the whole number of cycles.

Observation of this parameter (Fig. 13) shows that the stability of the engine is particularly threatened in the area of low loads and with a DME share of over 25%. Correction of the ignition timing clearly reduces this risk (Fig. 14). Almost in the entire area of the study, the coefficient was obtained at a similar level of approx. 4%.

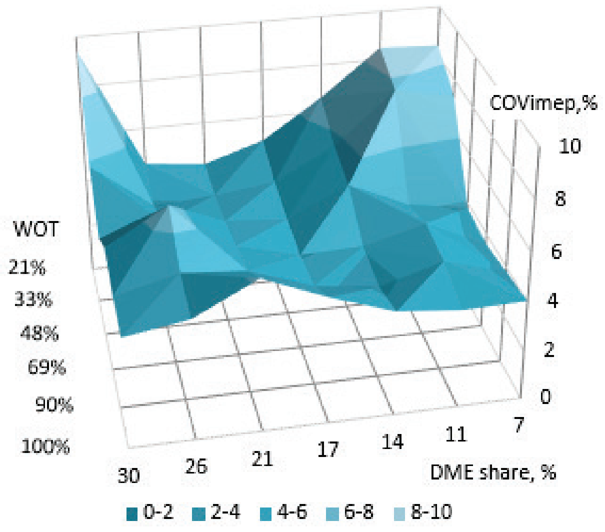

Fig. 13. The value of COV_{imep} at n = 3000 rpm, without ignition advance correction

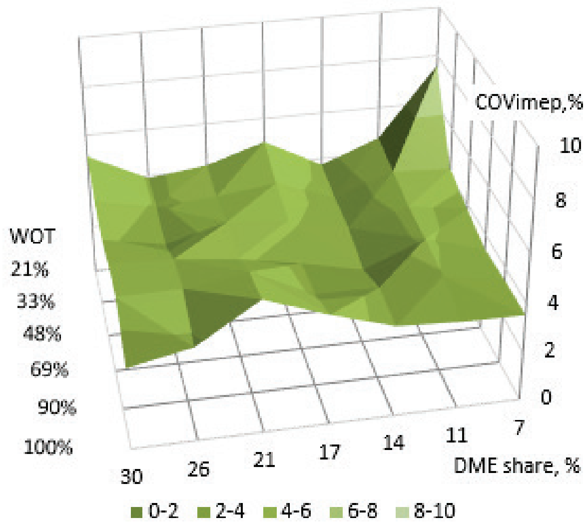

Fig. 14. The value of COV_{imep} at n = 3000 rpm, with ignition advance correction

4. Conclusion

The formulated conclusions resulting from the conducted research show that:

1) DME (BioDME) can be used as a component of a fuel mixture with LPG because it ensures the maintenance of engine performance at a comparable level.

2) The engine achieves the highest power when fed with a mixture with a DME share of 17%, only with a 21% load the highest power was obtained with an increased share of DME to 21%.
3) Increasing the DME share in fuel above 17% is possible, but it gradually reduces the value of the power developed by the engine.
4) The introduced ignition advance correction also has a positive effect on engine stability.

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