COMBUSTION TEMPERATURE AND EXHAUST GAS COMPOSITION IN SI ENGINE FUELLED WITH GASEOUS HYDROCARBON FUELS

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Abstract

This paper presents the issues connected with the process of combustion of natural gas and methane-hydrogen blend in SI engine. Enriching methane with hydrogen is the way to make the combustion process more efficient and gives possibilities of CO_2 emission reducing. The detailed analysis focused on changes in temperature profile and their impact on thermal charge and composition of the emitted exhaust gas. All the range of investigation is divided into three parts. First part is dedicated to comparison of combustion temperatures of LPG, CNG and Petrol. In the middle part are presented the results of investigation of influence ignition advance on combustion temperatures of CNG. The third part includes the results of research project aimed at opportunities of efficient combustion of gaseous fuels, whose main constituent is methane. The selected group of fuels included: CNG, and methane-hydrogen blends (with volumetric hydrogen shares – 5%, 10%, 15%, 20% and 30%). The tested engine was an Opel Astra naturally aspirated four-cylinder 1.6 l petrol engine with power output of 55 kW at 5200 rpm and torque of 128 Nm at 2600 rpm. This engine was modified in a way allowing its CNG propulsion without compression ratio variations. The investigations were carried out on chassis dynamometers and were the basis for analysis by means of mathematical simulation model, in this paper. The obtained results were compared to measurements for fuelling with unleaded petrol (95-octane) as a base fuel for this drive unit. Fuelling of engine with blend of methane and hydrogen opens up opportunities for considerable reduction in CO_2. For blend contains 30% of hydrogen the emission of CO_2 was 35% lesser than in petrol case.

Keywords: *transport, road transport, simulation, combustion engines, air pollution, environmental protection*

1. Introduction

Alternative fuelling of SI engines with gaseous hydrocarbon fuels is increasingly popular today. The economic and ecologic benefits of use of this type of fuels are commonly known. Among this group, the most popular fuels include liquefied petroleum gas (LPG) and compressed natural gas (CNG).

However, efficient combustion of these fuels in engines can have some consequences. The negative phenomena include distribution and higher values of temperature of charge during transitions which occur inside combustion chamber. These effects are manifested in two aspects. Firstly, share of NO_x in exhaust gas rises. Secondly, thermal load to components of combustion chamber is increased. These transitions are confirmed with damages to parts closing combustion chamber which occur in some engines after longer use of the engine fuelled with gaseous fuel.

The study attempted to analyse the distribution and changes in temperature inside combustion chamber under different conditions of engine work, fuelled with the selected hydrocarbon fuels.

2. Test stand and procedure

For the purposes of the study, Opel Astra I engine was marked with code X16SZR. Main technical specifications are compared in Tab. 1. This engine, manufactured to be fuelled with unleaded petrol of 95 octane, was equipped with two systems of fuelling:

- with propane-butane blend,
- with natural gas and methane-hydrogen blend.

During tests on chassis dynamometer, the pressure indicated as a function of crank angle and pressure in air intake. The following fuels were used for fuelling the engine: unleaded petrol, LPG, CNG and methane enriched with hydrogen, with volumetric share of 5, 10, 15, 20 and 30%.

All the measurements were taken for air fuel ratio λ=1, with EGR system disconnected. Ignition advance was controlled by in-built controller, with exception of the series when it was used as adjustment parameter and it was corrected with special-purpose system.

The pressure profiles registered inside the cylinder as a function of crank angle, mass of consumed fuel and temperature at air intake and exhaust system and pressure in air intake was the basis for further simulation calculations. Simulation calculations were based on a calculation program, EnComTwo; description, assumptions and equations for mathematical model were presented in author’s previous studies [1, 2].

The tests included 3 measurement series:

1. testing the engine fuelled with petrol, LPG and CNG [5],
2. testing the engine fuelled with CNG at different levels of ignition advance correction [6],
3. testing the engine fuelled with methane with hydrogen addition (variable share 5-30%) [4].

During each series the measurements were taken at steady conditions of engine work i.e.:

- in neutral,
- at higher rpm, without loading the engine,
- at steady rpm with full load.

During analysis of the obtained results, the reference for all stages of the study was the results obtained for petrol, which is a base fuel for this particular engine. Other fuels were treated as alternative fuels.

Tab. 1. Engine specifications

Number and system of cylinders	4 R
Max. engine power /rpm	55 kW at 5200 rpm
Max. torque /rpm	128 Nm at 2800 rpm
Engine displacement	1598 cm^3
Bore	79.0 mm
Stroke	81.5 mm
Compression ratio	9.6

3. Temperature profile during combustion of LPG and CNG

Analysis of tests results registered in chassis dynamometer allowed for determination of profiles for mean temperature of the charge $T_m(\varphi)$ closed in combustion chamber. It is a part of the cycle, which encompasses the process of compression, from the moment of closing intake valve, combustion, decompression of the load until the moment of opening exhaust valve. Through application of two-zone model for calculations, changes in temperatures in exhaust gas zone $T_b(\varphi)$, which accompany the process of combustion of the given fuel were also calculated.

The charts below compare results obtained for LPG, CNG and petrol (Fig. 1). In order to demonstrate the reasons for fundamental differences in mean load temperature profiles $T_m(\varphi)$, temperature increments and profile of heat released during combustion (Fig. 2) were calculated.

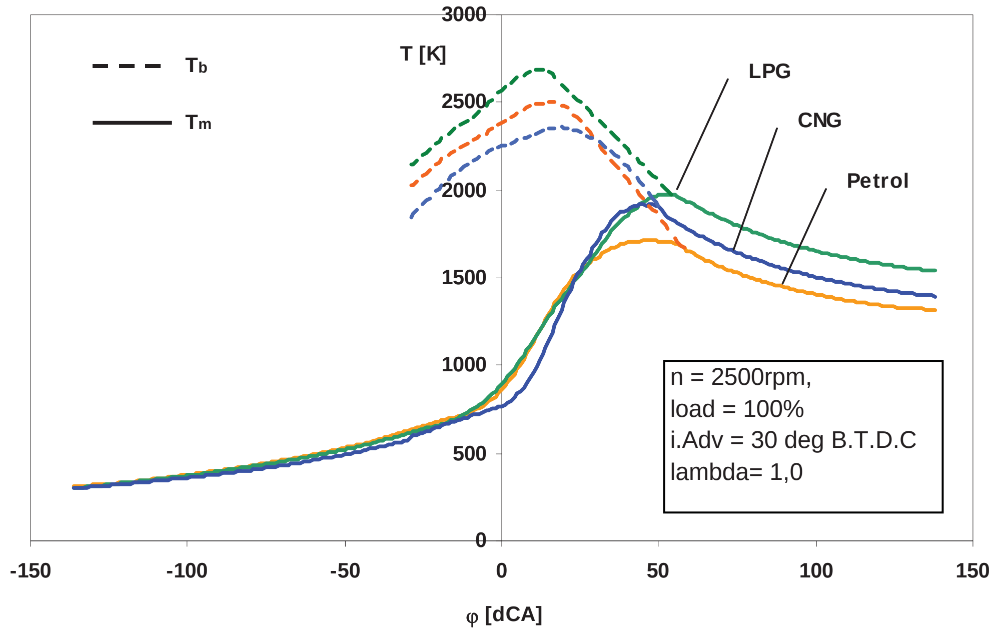


Fig. 1. Temperature profiles T_m and T_b during working cycle obtained for tested gaseous fuels and petrol

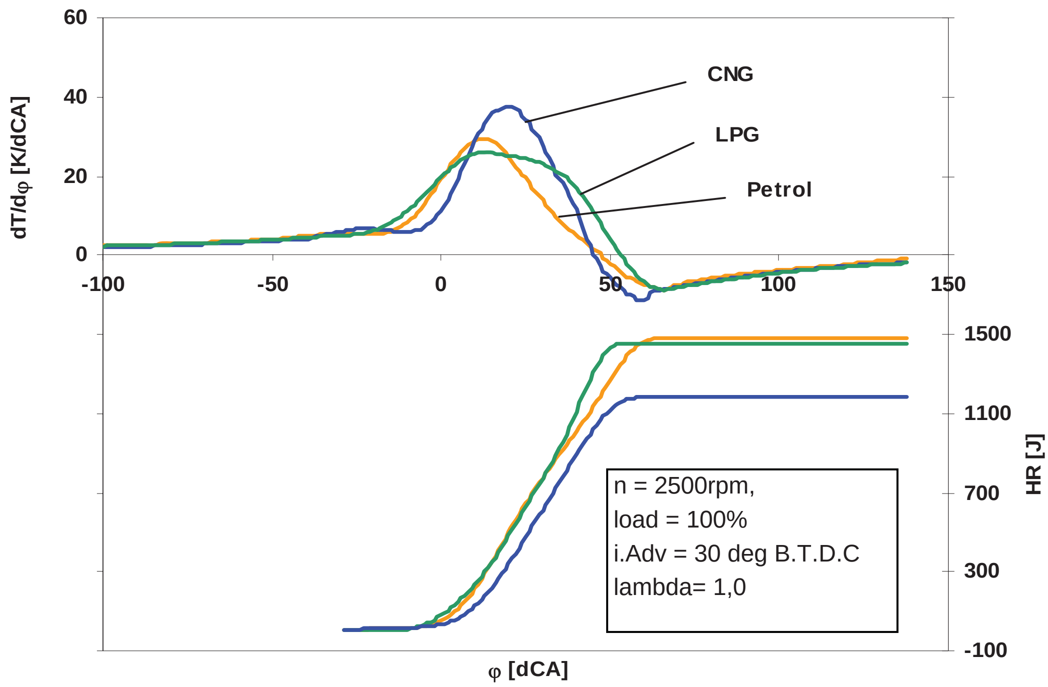


Fig. 2. Rise in temperature and heat released during combustion of tested gaseous fuels and petrol

4. Effect of ignition advance correction on temperature of load during combustion of CNG

Control of the process of CNG combustion by means of ignition advance correction consists in increasing its values. This operation is aimed at improvement in engine working conditions. An unfavourable phenomenon during combustion of natural gas is slower initiation of the process of combustion compared to petrol. This results in slower rise in pressure in cylinders and delay of the moment of reaching maximal pressure in engine working cycle, which negatively affects the obtained indexes [3].

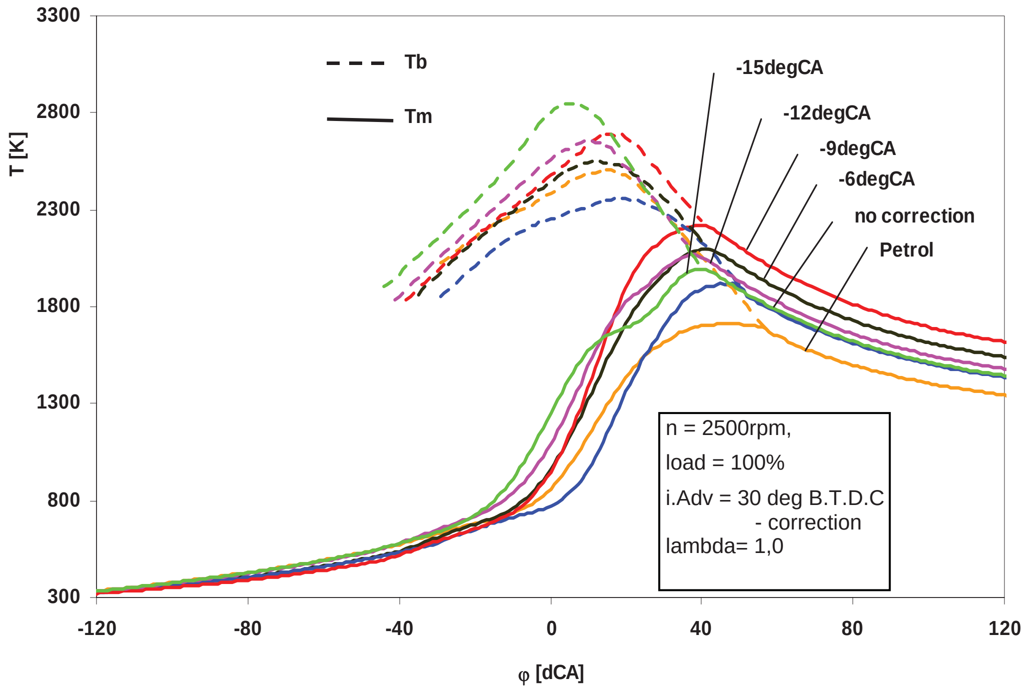


Fig. 3. Temperature profiles T_m and T_b for CNG obtained for variable ignition advance value

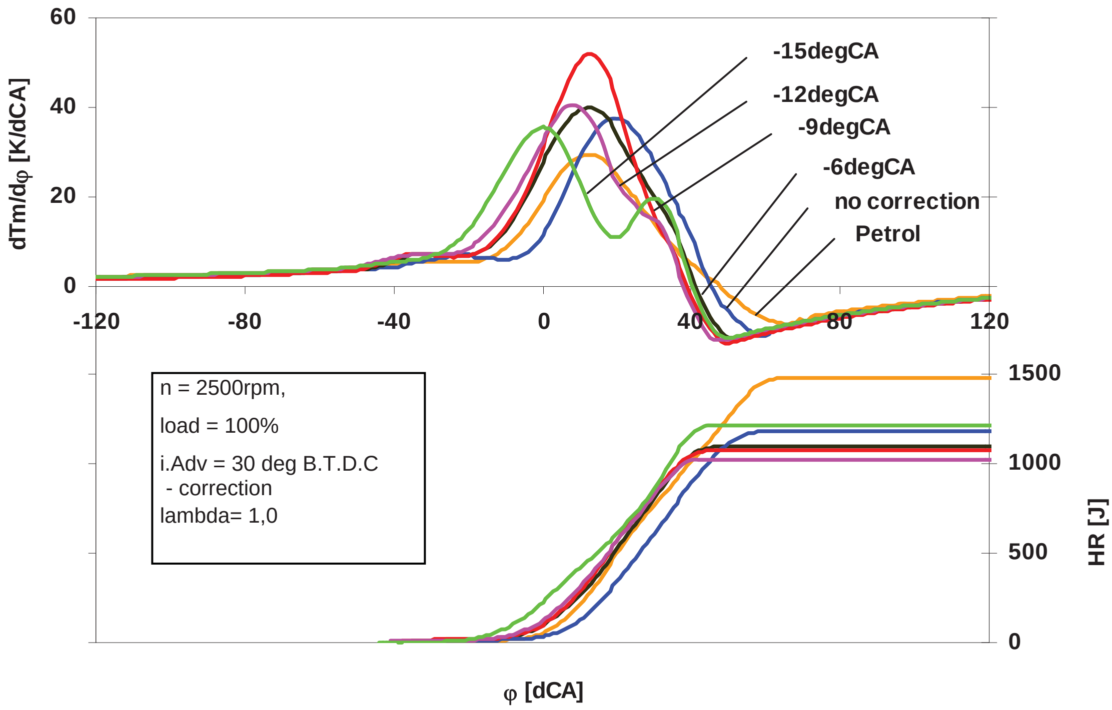


Fig. 4. Rise in temperature and heat released vs. ignition advance angle

One of the methods of levelling these differences is to accelerate the process of combustion through increase in ignition advance; however, this procedure is followed by changes in charge temperature profile. The results demonstrate the impact of correction degree on gas temperature and course of combustion processes (Fig. 3 and 4).

5. Changes in temperature profile during combustion of blends of methane and hydrogen

Another method of improvement in the process of natural gas (CNG) combustion is use of the blend of methane and hydrogen as a fuel. It does not require changes in fuelling system since methane is main component of natural gas and accounts for ca. 90-96% of its share. Enriching this fuel with hydrogen is aimed at:

- acceleration of the process of load ignition, which would shorten initial phase and would produce an improved heat release curve profile,
- higher values of lower heating value for blend, which permits more energy to be released during a single cycle.

Moreover, use of fuel with addition of hydrogen reduces share of coal, which will cause reduction in content of CO_2 in exhaust gas.

Given the results of the investigations of the two fuel blends [7], one can conclude that it positively impacts on the profile of indicated pressure and on final indexes of engine performance. However, as a consequence of these changes, rise in load temperature in cylinder can be observed. The impact of the amount of hydrogen addition on mean temperature of gases in cylinder and profile of heat release are presented in next charts (Fig. 5 and 6).

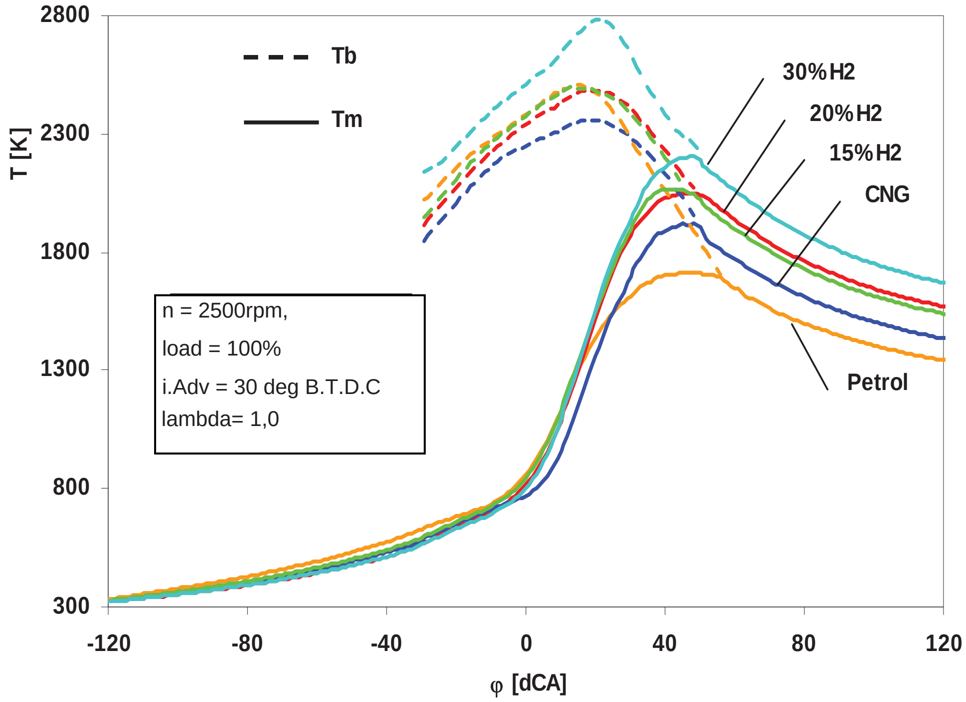


Fig. 5. Temperature profiles T_m and T_b for CNG and methane-hydrogen blends

As a consequence of different fuel, there are observing significant changes in composition of emitted gases. Shares of each constituent of exhaust gas (N_2, CO_2, H_2O) depend directly on fuel composition. The most significant change was observed in the studied group of fuels is a considerable reduction in CO_2 emissions in exhaust gas (Fig. 7). Rise in hydrogen share in fuel blend is followed by the rise in contents of vapour (H_2O) in exhaust gas.

In general, changes in the process of combustion favourable affect emissions of CO, however, rise in emissions of NO_x can be observed (Fig. 8), which is connected with occurrence of higher temperatures of exhaust gas.

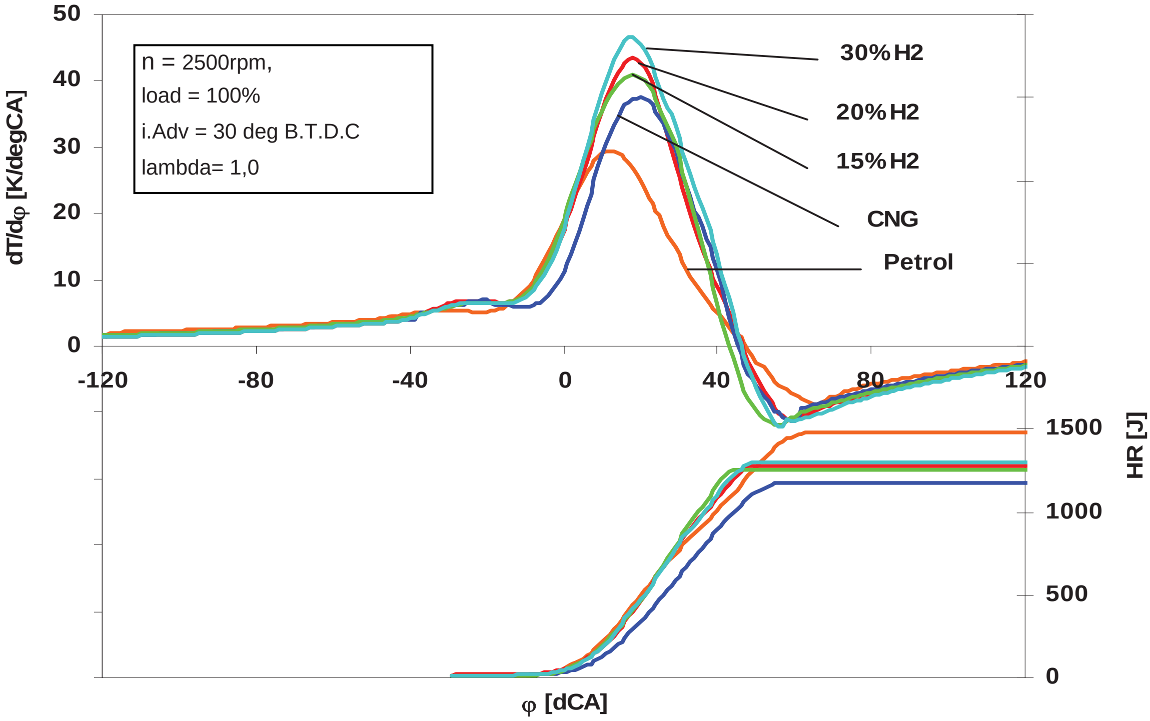
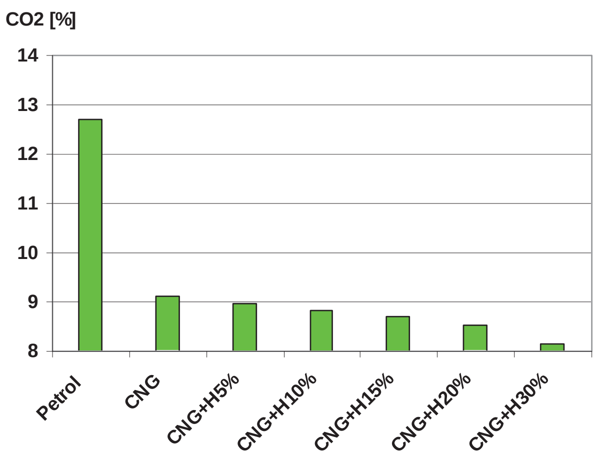


Fig. 6. Rise in temperature and heat released during combustion of CNG and methane-hydrogen blends



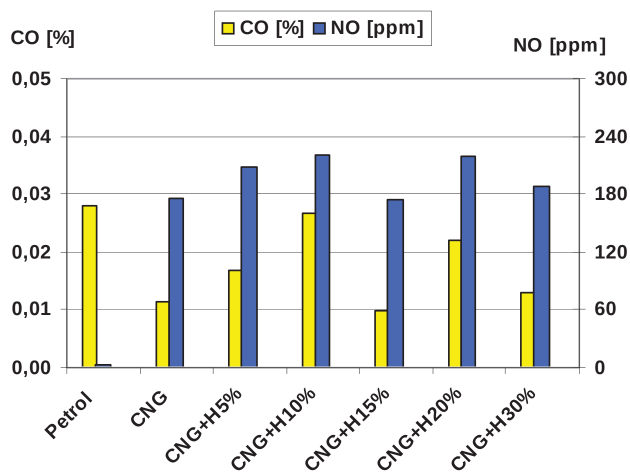


Fig. 7. CO_2 emissions from tested fuels Fig. 8 Emission level for CO and NO_x

6. Summary and conclusions

To sum up the analysed issues, one can conclude that the temperature of load in engine cylinder depends directly on:

- amount of energy released during the process of combustion,
- combustion time,
- location of the process of combustion in engine working cycle.

The amount of the released energy is directly proportional to load temperature and considerable effect is also observed from other factors. Shorter combustion time is characterized by higher elementary portions of released energy (RoHR), which results in accumulation of heat in combustion chamber. Location of the process of combustion in engine working cycle correlates with the process of compression, where concurrent occurrence of these phenomena affects maximal values of both pressure and temperature.

The analyses carried out in the study allow for drawing the following conclusions:

1. Mean temperature of the charged enclosed in cylinder in the studied engine, working under full load, is highest in the case of fuelling with LPG.
2. Enrichment of natural gas with hydrogen causes an increase in temperature and, at the share of hydrogen of 20%, values of mean temperature are similar to fuelling with LPG.
3. Temperature of exhaust gas, during combustion of gaseous fuels in the studied engine, reaches the highest values in neutral compared to full load. In the case of fuelling with petrol, the opposite situation can be observed.
4. Fuelling of engine with blend of methane and hydrogen opens up opportunities for considerable reduction in CO_2 and reduction in the level of CO in exhaust gas. In case of using fuel composed: 70% of methane and 30% of hydrogen the emission of CO_2 is 35% lesser than in petrol case.

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