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AN INFLUENCE OF METHANE/HYDROGEN PROPORTION IN FUEL BLEND ON EFFICIENCY OF CONVERSION ENERGY IN SI ENGINE

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Abstract

The relations between methane/hydrogen proportions in fuel blend are presented in this paper. The research cycle carried out contains results of dynamometer chassis tests complemented with mathematical model calculations. An object of X16SZR engine installed in Opel Astra I was investigation. The engine has been equipped with additional CNG feeding system where fuel is being injected into intake manifold under low pressure. 8 fuel blends were tested with variable methane/hydrogen volume proportion (%): 100/0, 95/5, 90/10, 85/15, 80/20, 70/30, 60/40 and 50/50. The feeding and ignition systems were controlled by nominal drivers. In every measuring series engine was tested in the following steady states: on idle, high speed without load and full power at discrete variable speed in range 1500…3500 rpm. The main aspect of the analysis was to identify the influence of hydrogen share on engine parameters such power, fuel consumption, in-cylinder pressure, temperature and exhaust gas composition. Very significant ecological fact possibility of CO_2 emission reduction has been identified. Result of increasing content of hydrogen in fuel mixture is engine knocking. Analysis carried out on the basis of results allowed it to the point on methane/hydrogen proportion in fuel blend considering a total efficiency, emission and heat flux in parts of combustion chamber in engine.

Keywords: *methane/hydrogen blend, low-carbon fuel, total efficiency, SI engine*

1. Introduction

Application of methane blended with hydrogen as a fuel in SI engine can be considered a next step toward implementation of universal clean energy sources. In terms of the low emission hydrogen is a perfect fuel, however many mechanical problems still exist. In the current situation of energy-fuel industry natural gas is very important fuel. Significant economic-ecological advantages of this fuel are stimulating constant progress, both in the area of its application as an alternative fuel considering together the infrastructure and feeding system. However, in SI engines the natural gas is still considered an alternative. The engine construction and operating parameters nominally are being designed for petrol. Differences in the combustion cause certain disadvantages in case of feeding with the natural gas. A basic difference is extension of the period of flame development. However, in the second phase the speed of energy release is increasing while air/petrol mixture combustion is proceeding in this period rather evenly (Fig. 1). The second important difference is a lower calorific value (in relation to petrol) of air/methane mixture. In a consequence of these differences in-cylinder pressure course changes (IMEP and engine power are lower), the temperature of exhaust gases is rising (NO_x emission is greeter). Presented results are based exactly on the existing agreement, that methane is a main component of natural gas (usually more than 96%). The addition of hydrogen is giving the possibility of obtaining to the higher efficiency of the conversion energy, and the considerable reduction of CO_2 emission. Preliminary tests conducted by authors [2-4], as well as in other research centres [5-9], confirmed the rightness of this thesis.

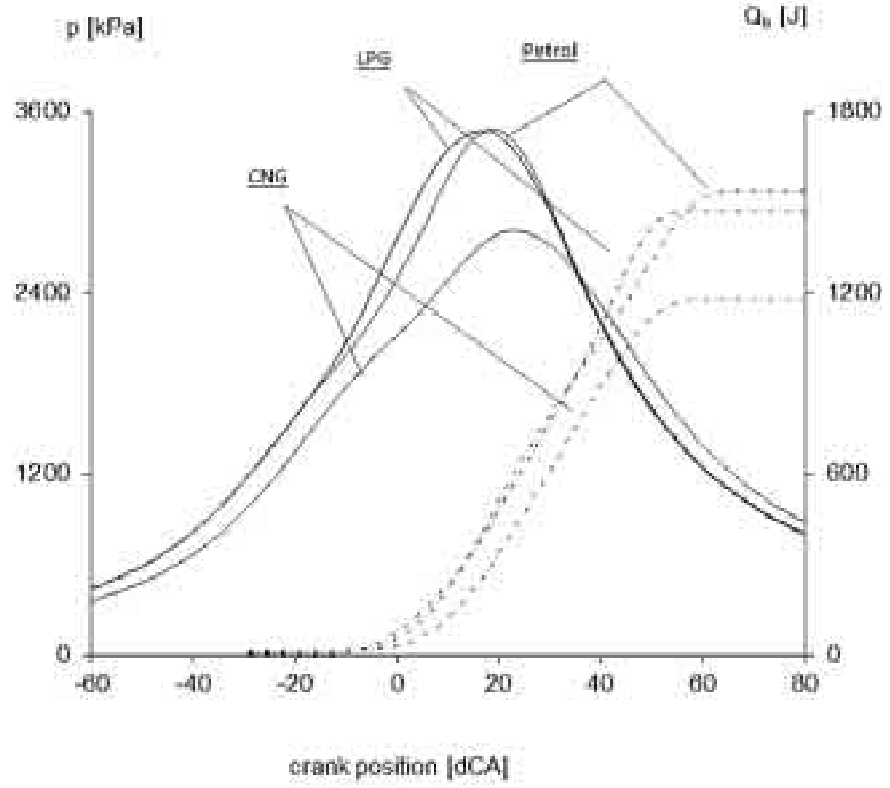

Fig. 1. Sample differences in the course of the in-cylinder pressure and the function of heat release for petrol and gas fuels. Engine speed - 2500rpm, WOT – 100%

2. An investigation

2.1. Object and range of research

A 1600ccm 4-in line cylinder X16SZR engine was the object of investigation. The engine has been equipped with multipoint simultaneous CNG injection system. A car with tested engine has been placed on dynamometer chassis. The test-bench has been additionally equipped with the in-cylinder pressure measurement and the registration system. Nominal engine regulation parameters remained unvaried during the tests, except for the EGR system, which has been disabled.

Conducted tests included measurement series of engine performance parameters, individual for each of the fuels. Each series included examinations of engine working at steady conditions: on idle, without load with speed c.a. 4000rpm and at full load with speed varying from 1000 to 3500rpm, increasing discretely about 500rpm.

2.2. An influence of the hydrogen share on the quantity of energy delivered in the filling process

Stream of energy delivered to the cylinder, in case of applying different fuels, depends on the calorific value and the density of A/F mixture, which determines mass of charge in the given cycle/cylinder.

Primary data of fuel blends prepared for tests has been shown in the Tab. 1. Whereas change of the lower calorific value of fresh charge *Wu,* depending on the hydrogen share, presented in the form of a graph (Fig. 2), was calculated according to the following relation:

$$W_u = \frac{W_d}{1 + \lambda \times L_a} \,. \tag{1}$$

Tab. 1. Characteristic parameters of tested fuels

CH_4 / H_2 mass proportion [%]	W_d [MJ/kg]	L_a [kgA/kgF]	ρ [kg/m^3]
100/0	50.050	17.482	0.717
95/5	50.430	17.596	0.685
90/ 10	50.910	17.720	0.653
85/ 15	51.435	17.860	0.622
80/ 20	52.016	18.010	0.590
70/ 30	53.388	18.370	0.526
60/ 40	55.137	18.826	0.463
50/ 50	57.442	19.424	0.400

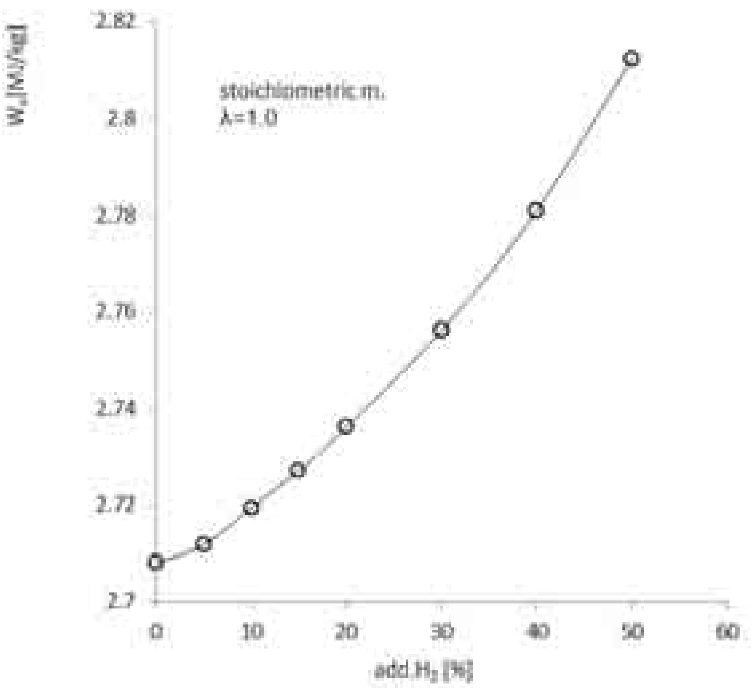

Fig. 2. Lower heating value of A/F mixture in function of hydrogen share

2.3. Transformations inside engine cylinder

Results registered during stand tests were used for calculation with the application of the mathematical model of combustion. The model calculations are based on equations of energy balance in a closed combustion chamber and were done on the base of the registered in-cylinder pressure course.

The model calculations are supplementary to conducted measurements. Graphs presented below (Fig. 3) show the influence of the hydrogen content in the fuel on basic parameters, which describe the combustion process in the investigated engine.

2.4. The results of power on wheels measured

Power measured on wheels P_w is one of main functional parameters. The measurements were made on chassis dynamometer at the engine set speeds for WOT (Fig.4). For the purposes of engine output power estimation, it is necessary to take into consideration transmission efficiency. For configuration of transmission in the investigated car a correction ratio of k=0.946 (according to EEC standard) has been assumed.

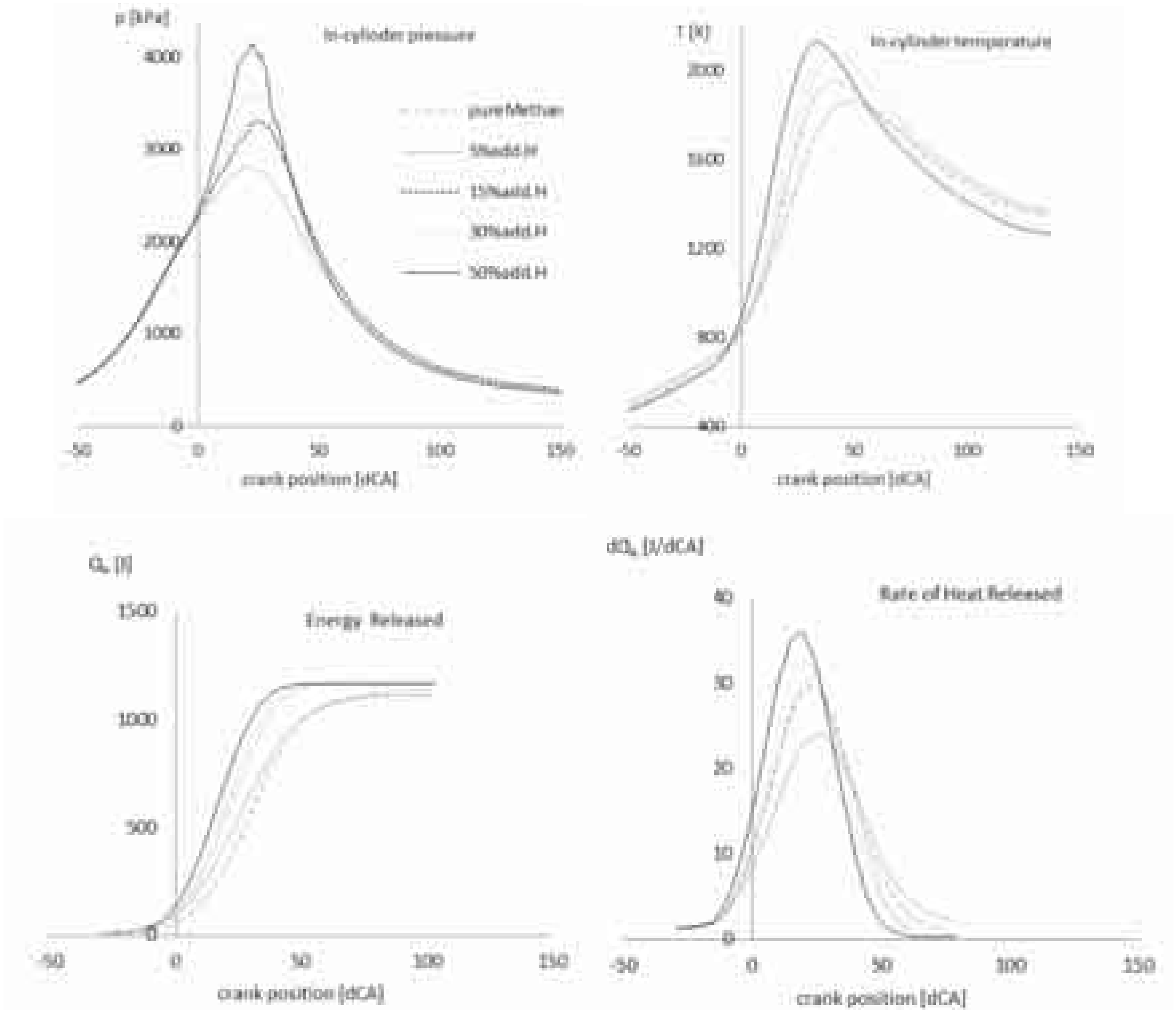

Fig. 3. The characteristic parameters of energy conversion in depend of variable methane /hydrogen proportion. Engine speed - 2500rpm, WOT – 100%

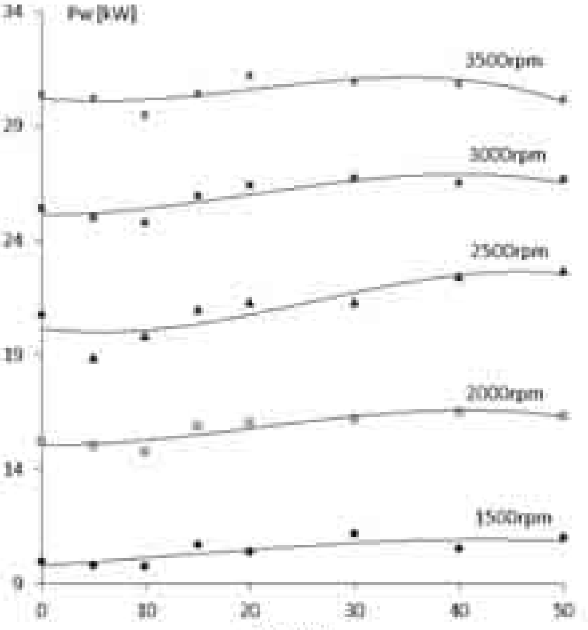

Fig. 4. Power on wheels measured in steady operating, in relation to variable hydrogen share

3. Discussion

3.1. Differences in heat release process

A chemical energy of the charge closed in a combustion chamber is released during combustion process. The speed and the energy profiles are closely dependent on the fuel type. General aim of adding hydrogen to methane is to minimize disadvantageous occurrences, which are accompanying the combustion of A/F mixture created on the basis of the natural gas or pure methane. Because of the differences of selected properties of methane and hydrogen, an improvement of the conditions for the initiation of a flame and shortening the period of charge heating are expected. Minimum ignition energy of hydrogen is 0.02 mJ; and of methane 0.28 mJ. It can also be noticed that, speed of flame spread of hydrogen is 2.9 m/s; and of methane 0.38 m/s [1]. Taking into consideration the increase of lower calorific value of fresh mixture (Fig. 2) also an overall quantity of the energy released in combustion process increases. Changes of the duration of the combustion period depending on the amount of the hydrogen share were appointed on the basis of tests results obtained at fixed speeds. The chart below (Fig. 6) presents the duration of the main phase of the combustion process (10 %< MFB<90%).

3.2. Temperature and exhaust gas composition

The basic factors that significantly influence the composition of the exhaust gases are the fuel composition as well as temperature of the combustion process and physico-chemical transformation occurring right after. A very significant fact related to the use of methane/ hydrogen blends is the possibility of a significant CO_2 emission reduction (Fig. 5) [3]. This is due to the reduced share of the carbon in the fuel through the introduction of the hydrogen. In tests that have been carried out an additional simulation has been completed, which led to appointing the course of the temperature of the gas in a closed combustion chamber, from the moment of the intake valve closure until exhaust valve opening. The temperature of the gas at that point (open of the exhaust valve) marked T_{ex}, and named temperature of the exhaust gases leaving the combustion chamber. Direction of changes of this temperature allows forecasting the change of shares of individual elements in the emitted exhaust gases, including emission of NO_x. Obtained T_{ex} values have been shown in the graph (Fig. 7). Analysis of presented relations shows the possibility to reduce exhaust gas temperature for a certain proportion of the composition of fuel blend.

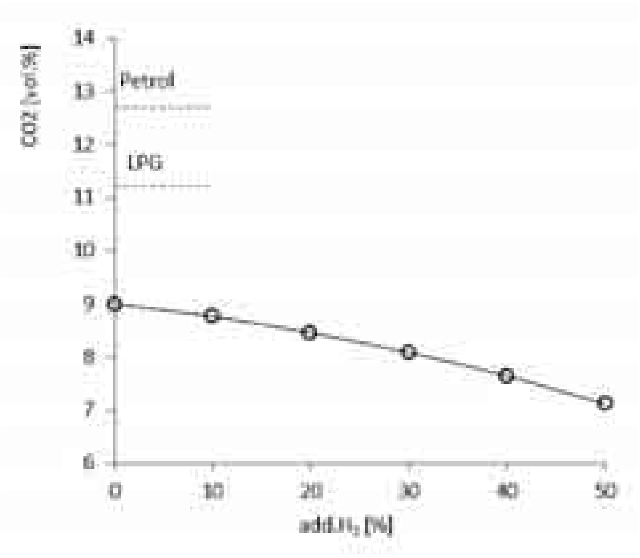

Fig. 5. The level of emission CO_2 in depend on H_2 share, compared with Petrol and CNG

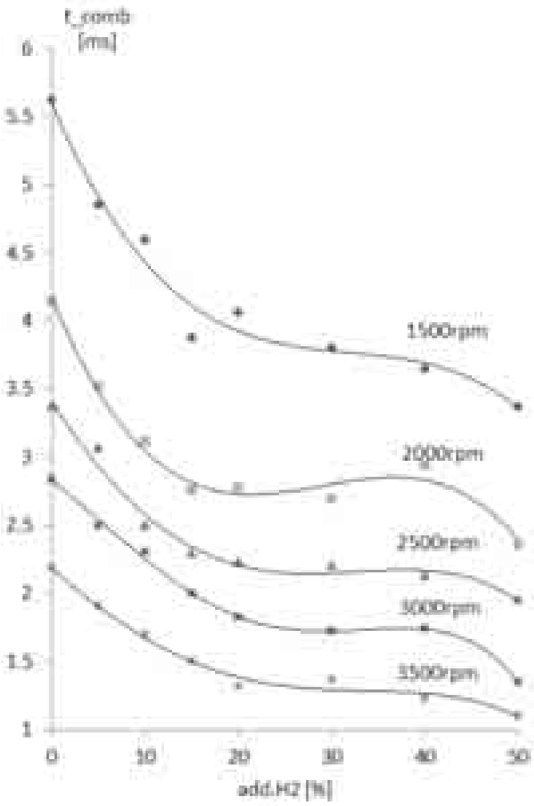

Fig. 6. Combustion duration (10%<MFB<90%) in function of H_2 share for fixed engine speed

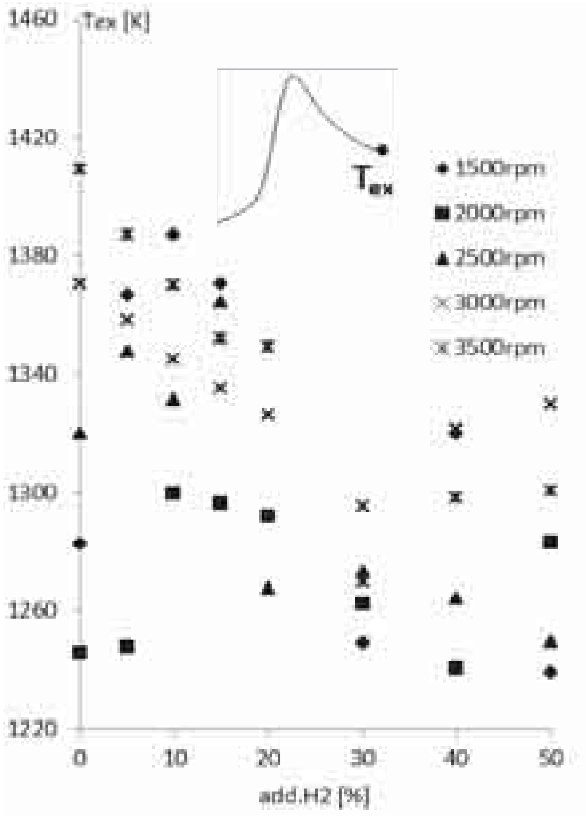

Fig. 7. An influence of H_2 share on temperature of the exhaust gases leaving the combustion chamber

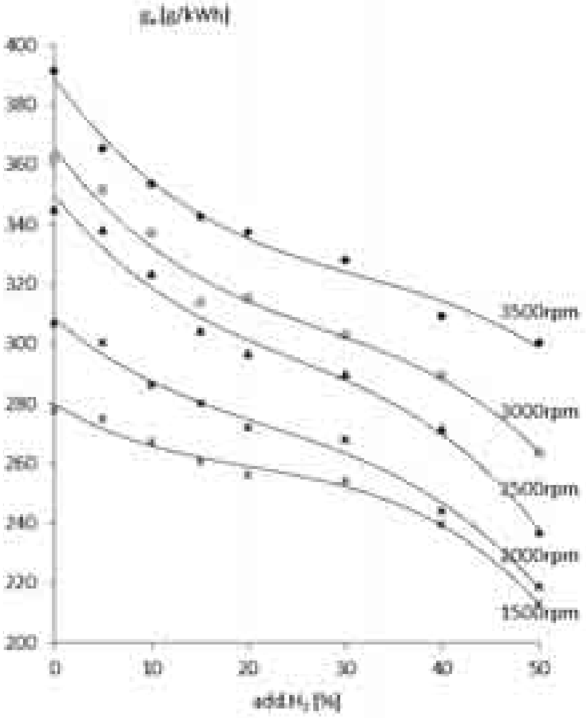

Fig. 8. Changes of g_e obtained for variable fuel composition and speed of engine

3.3. Efficiency of energy conversion

An individual fuel consumption g_e [g/kWh] is one of universal indicators representing the level of the efficiency of energy conversion in the IC engine. The value of this indicator has been calculated on the basis of the results of the measurements of fuel consumption and engine power obtained in the course of executing stand tests. Measurements of fuel consumption were done in a weight analysis mode, with the use of an external fuel tank placed on an electronic weight platform. Registration of fuel mass loss was made in the engine steady operating point, with the time coordination. Obtained results made it possible to estimate g_e in function of fuel composition (Fig. 8). Presented results show that g_e decreases with the increase of hydrogen content in the fuel, thus increases the effective efficiency of engine, and therefore becomes inversely proportionate.

3.4. Limitations of hydrogen in the fuel

Limitations of methane enrichment with hydrogen are connected with knocking combustion. The presence of this phenomenon is visible in recorded signal of the in-cylinder pressure and becomes audible in emitted sound. What can also be noticed is variation in the rate of pressure rise during the combustion process. The sudden increase in the maximum value of this parameter can be observed at maximum engine power and speed above 3000rpm, for blends with more than 30% of hydrogen (Fig. 9).

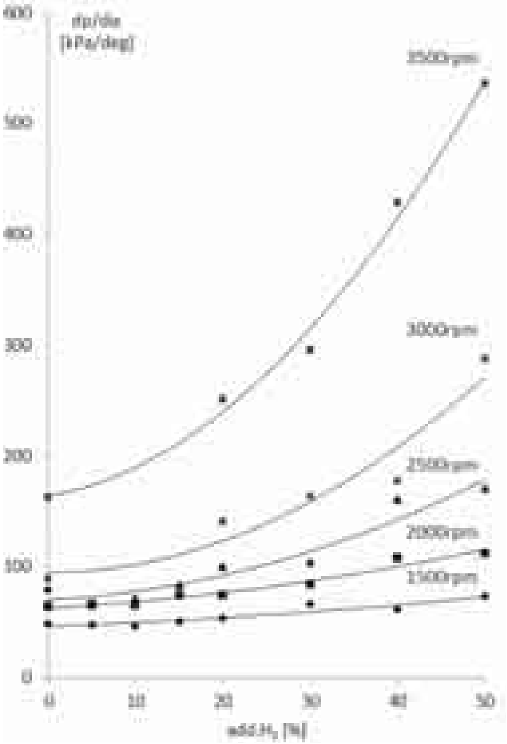

Fig. 9. The maximum value of the rate of pressure in function of the H_2 share in the fuel, λ=1.00

4. Conclusions

In the summary of the research process and analysis of the obtained results, it can be concluded that:

1. Increasing the content of hydrogen in a hydrocarbon-originated gas fuels (e.g. methane, natural gas), significantly affects the improvement of the efficiency of energy conversion in the SI engine, without interfering with the original feeding and ignition systems algorithms.
2. Basic changes in the course of the heat release function are ensued the shorten period of burning initiation and increase the amount of energy supplied to the cylinder in the filling process, due to the higher calorific value of charge.
3. As a result of these changes higher engine power and reduction of ge can be achieved. An effective increase in power on wheels has been measured for fuel blends containing: 30% and 40% of hydrogen, which ranged from 11% (1500 rpm) to 3% (3500 rpm). While ge decreased respectively from 16% to 8% in this range of speed.

4. Moreover, because of the necessity of global reduction of the greenhouse gas emissions, it is important to significantly reduce CO2 emission. In comparison with the petrol, the level of emissions has been reduced by 37%, for a blend of 70%CH4/30%H2.
5. The changes of course and the duration of combustion process, caused by a greater hydrogen share in fuel, influence as well the temperature of charge. It has been proved that earlier occurrence of maximum value, lowers exhaust gases temperature, which determines the content of toxic components.
6. Further increasing of hydrogen share in the fuel, at nominal settings, is limited because of the presence of signs of knocking combustion at full load of engine. Therefore, further research should be primarily oriented on estimation of a reasonable proportion of methane and hydrogen, and then on the optimization of settings, in order to eliminate negative phenomena's.

Abbreviations

g_e	Individual fuel consumption;
IC	Internal combustion;
CNG	Compressed Natural Gas;
IMEP	Indicated Mean Effective Pressure;
λ	Air excess ratio;
W_u	Mass heating value of stoichiometric mixture;
W_d	Mass heating value of fuel;
L_a	Stoichiometric air to fuel ratio;
ρ	Density of fuel;
P_w	Wheel power measured;
T_{ex}	Temperature of exhaust gases at opening exhaust valve;
MFB	Mass Fraction Burned;
WOT	Wide-open throttle.

References

[1] Collier, K., Hoekstra, R. L., Mulligan, N., Jones, C., Hahn, D., *Untreated exhaust emission of a hydrogen-enriched CNG production engine conversion*. SAE Paper 960858, 1996.

[2] Flekiewicz, M., Kubica, G., Flekiewicz, B., *Hydrogen enriched CNG - a tool for dual fuel engine overall performance improvement,* SAE Paper number 09FFL-0205, San Antonio, US 2009.

[3] Flekiewicz, M., Kubica, G., Flekiewicz, B., *The possibility of the SI engine CO_2 emission reduction with the application of CNG-Hydrogen blends*, Journal of KONES, Vol. 15, No. 3, pp. 139-146, 2008.

[4] Flekiewicz, M., Kubica, G., Wilk, K., *The analysis of heat release process in SI engine fed on natural gas and methane-hydrogen blends*, SAITS – FISITA, 12th EAEC European Automotive Congress, Bratislava, SK 2009.

[5] Karim, G. A., Wierzba, I., Al-Alousi, Y., *Methane-hydrogen mixtures as fuels*, Int. J. Hydrogen Energy, 21 (7), 1996.

[6] Moreno, F., Muñoz, M., Magén, O., Monné, C., Arroyo, J., *Modifications of a spark ignition engine to operate with hydrogen and methane blends*, International Conference on Renewable Energies and Power Quality (ICREPQ'10), Granada, Spain 2010.

[7] Pede, G., Rossi, E., Chiesa, M., Ortenzi, F., *Test of blends of hydrogen and natural gas in a light duty vehicle*, SAE Technical Paper 2007-01-2045, doi:10.4271/2007-01-2045, 2007.

[8] Szwaja, S., *Hydrogen rich gases combustion in the IC engine,* Journal of KONES, Vol. 16, No. 4, pp. 447-454, 2009.

[9] Wallner, T., Ng, H., Peters, R., *The Effects of Blending Hydrogen with Methane on Engine Operation*, Efficiency, and Emissions, SAE Technical Paper 2007-01-0474, doi:10.4271/2007-01-0474, 2007.