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MODELLING OF PROCESS OF INJECTION AND COMBUSTION IN TWO-CYCLE ENGINE

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Abstract

Article presents simulated research and visualization of combustion process of four-cylinder test engine based on the spark ignition engine Toyota Yaris 1.300 cm^3, equipped with two systems of power supply i.e.: fundamental and ignition. Two methods of initiating the combustion process were applied in the engine, that is: from spark ignition and after it has turned off – the combustion is initiated by means of the injection of the ignition dose. The conducted research was aimed at revealing the differences in the combustion process and the engine performance, especially the changes of pressure in the cylinder for that kind of dual-fuel power engine supply. The ignition dose injected to cylinder was equal to about 5% of the general mass of the fuel given to the engine. The mass of the fuel injected to the infold manifold determined the remaining part, and direct injection of fuel took place for several dozen rotation degrees of the crankshaft before TDC (Top Dead Centre).

A spatial grid of the engine's model (preprocessor) was created as well as the modification of the source KIVA 3V program was executed, consisting of taking into account two systems of injection. It is necessary to mention, that KIVA 3V program contains only one source of fuel's injection as a default.

On two-dimensional graphs, the courses of changes of pressure and temperature are presented as well as the change of the mass of the injected ignition dose. A simulation was conducted for chosen rotation angles of the crankshaft, for the purpose of a radical analysis of thermodynamic parameters along with an analysis of the toxic components of the exhaust fumes. The conclusions of the conducted simulated research confirm the reduction of fuel consumption with a simultaneous reduction of the emissions of toxic exhaust fumes components.

Keywords: *two cycle engine, two fuel injection systems.*

1. Introduction

For the purpose of radical analysis of gas-dynamic phenomena occurring in the cylinder of a combustion engine, advanced numerical methods enabling the virtual modelling of complex power supply systems are applied. To meet the correct working parameters of the combustion engine, with a simultaneous realization of the more and more rigorous criteria of cost-effectiveness and greenness, it is necessary to design and study new systems of power supplies with unconventional solutions, enabling a combustion engine to work in two thermodynamic circulations. The uniqueness of this solution is in the new model of flame propagation which is applied by the injection of the ignition dose to the pre-prepared homogeneous load, during the indirect injection to the infold manifold. The numerical analysis by means of KIVA 3V program consists of developing a model of the injection process course and the combustion of a homogeneous load, which is initiated by means of the injection of the ignition stream (ignition dose). On the basis of the results of the simulation research, graphs of the thermodynamic parameters course were created, showing: pressure, temperature in the cylinder for a virtually designed two-cycle engine during its operation with the so-called ignition dose initiated ignition. The mathematical models applied in the calculations which are describing the processes occurring inside of the engine cylinder allow, in a satisfying manner, to take into account their real life conditions. The accuracy of the simulation study results is determined by the quality of the input data, which is obtained by means of real research. The analysis of the process of the fuel-air mixture combustion in a two-cycle engine with the combustion initiated from the ignition dose requires the application of complex calculation methods used in specialist numerical programs [1, 5-7]. The conducted research aimed at revealing the differences in the combustion process and the engine performance, mainly the changes of the pressure in the cylinder, for that kind of two-fuel engine power supply.

2. Modelling and simulation research

The simulation research was executed on one of the 4-stroke test engine cylinders working at rotational speed of 2,000 [rpm], separately for the combustion process initiation from the spark ignition, and the ignition dose. The angle of the approach valve opening was set to calculation at the piston location of 4 degree before TDC, and its closing at the piston location of 46 degree CA after DMP. Additionally, the following were applied in the engine: the mechanism of timing-gear with four valves in each cylinder, two head camshafts driven by means of chain as well as the system of changeable phases of the timing gear of the approach valves shaft.

The simulation of the fuel injection processes as well as the combustion processes in the test engine was enabled by the application of KIVA 3V program working in the 64-bit Linux environment, developed by National Laboratories in Los Alamos [2-4, 9]. The program is in the main intended for thermodynamic calculations of piston combustion engines with automatic spark ignition taking into account of the complex geometry of power supply systems. The modelling and the numerical simulation required maintaining real geometrical dimensions in the engine calculation grid, and specifically: the shape of the combustion chamber, the shape of the approach and escape system, the geometry of the piston bottom. The modelling of opening and closing of the valves were also essential in the simulation process.

The engine cylinder consists of 28,600 nodes and the approach ducts in the cylinder head have 2,100 nodes, while escape ducts have 1,980 nodes. The total number of nodes in the system, when piston is located in the bottom dead position, is 28,980.

Figure 1 shows the general view of the calculation grid of the two-cycle engine including the approach and escape system. Fig. 2 shows the section view of the grid along the valves axes at the piston location of 156^o CA after TDC.

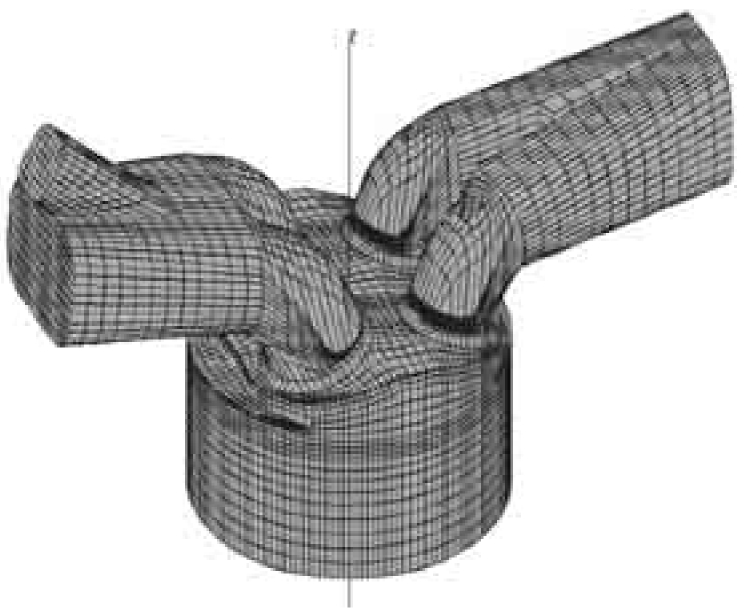

Fig. 1. Calculation grid of test engine

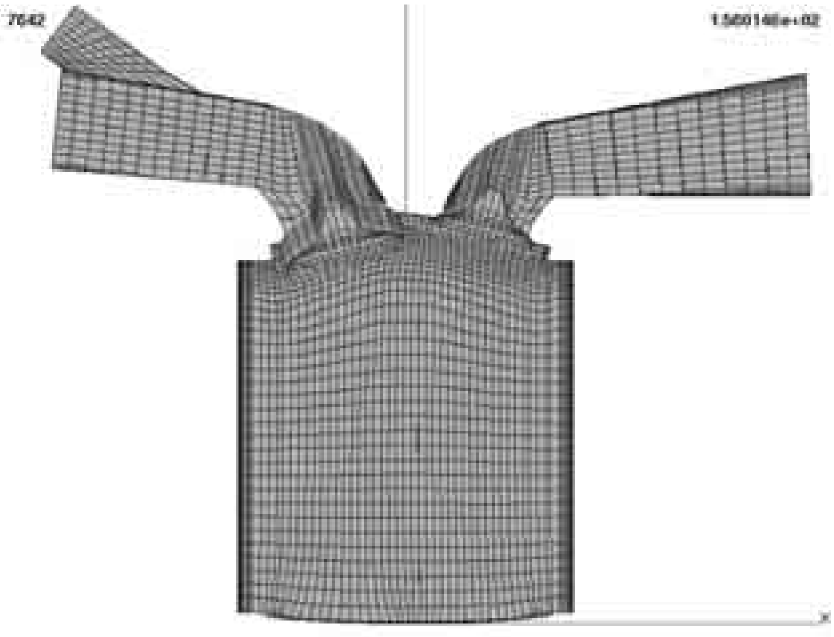

Fig. 2. Calculation grid of test engine (section through valves)

2.1. Initial and boundary conditions

The simulation of the total engine circulation was conducted at the same fuel dose per cycle, however, for the two-phase fuel injection they were divided into two stages.

Fuel dose for *ZI + DZ* system:

General fuel dose for ZI:	0.02195 [g/cycle],
a) ZI (petrol):	0.02085 [g/cycle],
b) DZ (ignition dose):	0.001125 [g/cycle],
Beginning of injection of fuel for ZI:	TDC,
Duration of injection of fuel for ZI:	80 [^{o}CA],
Beginning of injection of fuel for DZ:	28^o CA before TDC,
Duration of injection for DZ:	3.2 [^{o}CA] ,
Rotational speed:	2000 [rpm],
Beginning of ignition (for ZI only):	18^o CA before TDC,
Duration of ignition:	1 [ms] about 10.8 [°CA],
Location of spark plug:	central,
Pressure on escape:	0.1 [MPa],
Pressure on for system ZI:	0.115 [MPa],
Pressure on approach for system ZI + DZ:	0.115 [MPa],
Location of injection's system DZ:	under angle 68^o in relation to vertical axis of cylinder.

2.2. Comparison of working parameters of the two-cycle engine

For the evaluation of the working parameters of the two-cycle engine, which was executed by means of computer simulation in KIVA 3V program, the comparison of the obtained results was executed. Fig. 3 shows the course of the pressure change in the engine cylinder working in both work modes for the rotational speed n=2000 [rpm].

From the course of the pressure change it can be observed that its value increases to about 0.6 [MPa] for the work mode with the combustion initiation from the ignition dose, in relation to the spark ignition. Due to the complexity of the combustion process, the accurate regulation of the mass of the fuel injected to the engine cylinder is necessary. The increased combustion initiating

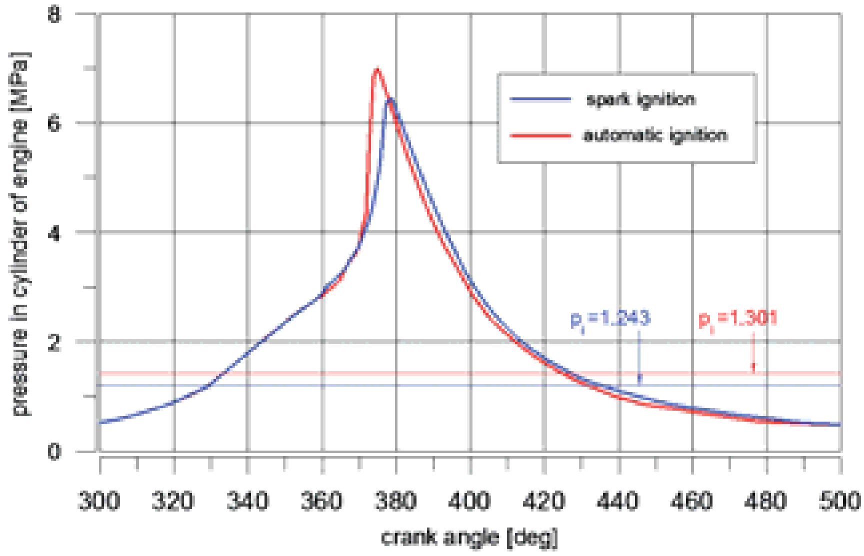

Fig. 3. Comparison of pressure in the cylinder of a two-cycle engine working in two work modes in the function of the crankshaft rotation angle

dose causes extended combustion, producing of big amount of carbon monoxide CO, and in addition decreasing the maximal pressure of combustion. The combustion process is optimum at the fuel dose of 0.02085 [g/cycle] injected to the infold manifold as well as the ignition dose of 0.001125 [g/cycle], with a small total surplus of the air ($\lambda \approx 1.09$). For that kind of settings for the injection systems working in the ignition dose mode, the maximal combustion pressure obtains the value about 6.9 [MPa]. Additionally the induced pressures values, which were obtained on the basis of the presented courses, were presented.

Figure 4 shows the comparison of the courses of the temperature inside the test engine cylinder, and the moment of the combustion's process beginning was marked.

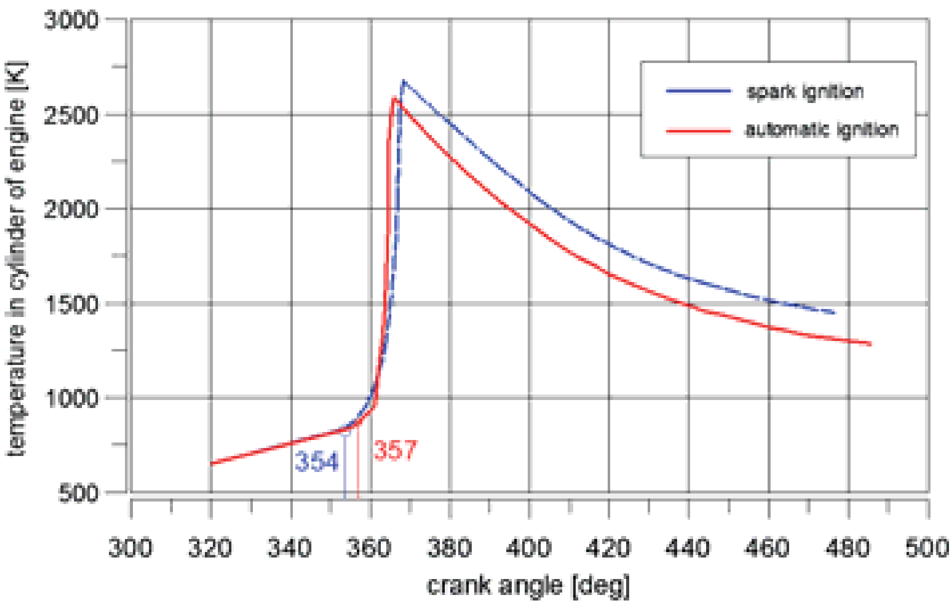

Fig. 4. Comparison of temperature in the cylinder of a two-cycle engine working in two work modes in the function of the crankshaft rotation angle

As a result of the analysis of the temperature courses in the process of simulation for two work modes it is claimed that the higher temperature of about 2,600 [K] is obtained during the load combustion for the combustion process initiated from the spark of the spark plug. Due to the injection of the ignition dose and the occurrence of the automatic volume ignition on the principle of the detonated autoignition occurring in the engine cylinder, the obtained maximal temperature is smaller and it is obtained a few degrees earlier than for the spark ignition. It is also related to the beginning of the combustion process, which begins later than for spark ignition, due to the slight lowering of the load temperature, which consequently leads to the obtaining of smaller maximal temperatures.

2.3. Simulated research of two-cycle engine

To execute the computer simulation of the injection and combustion process in an engine working on the automatic ignition initiated by means of the ignition dose, the PISA module (Piston Engine Simulator) was applied in Phoenics program, which is based on KIVA 3V program. Fig. 2 shows the geometrical grid section of an engines cylinder for Toyota Yaris of the displaced volume equal 1.298 [dm3] with the full geometry of the approach and escape system. The simulation initial parameters for that kind of power supply were presented in point 2.1.

The figures given below (Fig. 5 and 6) show the disintegration of the temperature inside the engine cylinder during its work with the combustion initiation from the injected ignition dose.

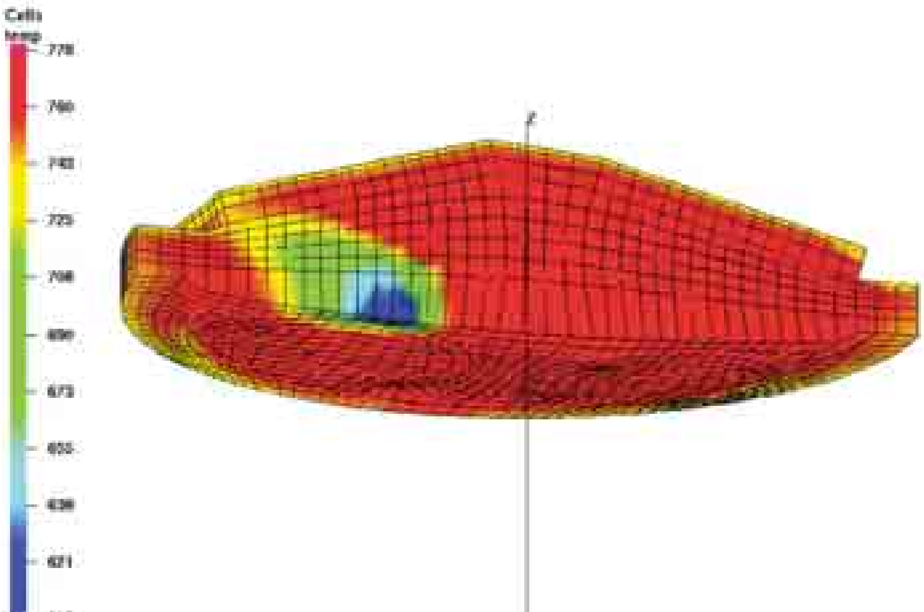

Fig. 5. Disintegration of temperature in the cylinder for 20 [ºCA] before TDC

Figure 5 presents the disintegration of the temperature in the combustion chamber at the location 20 [^{o}] rotation angle of crankshaft before TDC is obtained. The section has visible areas of different temperature of ignition dose, where the beginning of injection took place at 28 [^{o}] rotation angle of crankshaft before TDC. There are distinct propagations of the fresh mass of the ignition dose with visible non-evaporated nucleus in its front part. As a result of the evaporation of the ignition load, it is possible to notice the reduction of the temperature of fundamental load in the combustion chamber by taking the heat by the ignition dose from the fuel-air mixture located in the engine cylinder. Fig. 6 presents the beginning of the load autoignition process. Autoignition is here located around the most evaporated mixture around the ignition load in the vicinity of the piston bottom.

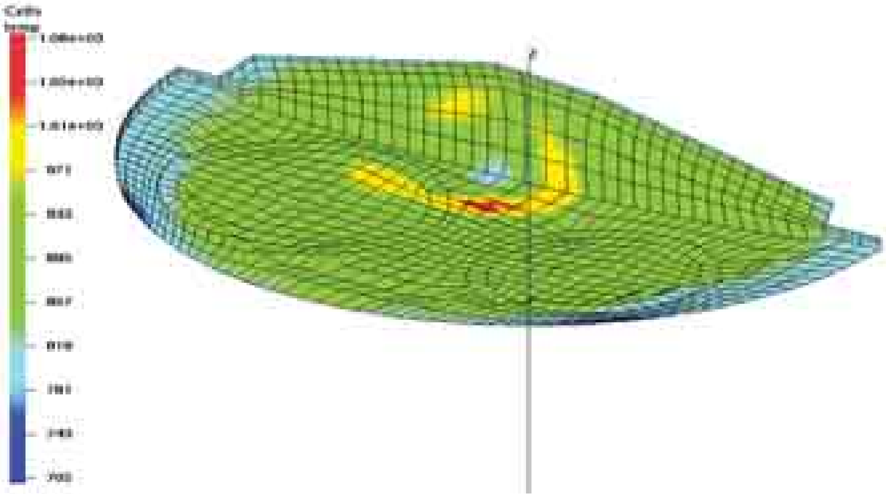

Fig. 6. Disintegration of temperature in the cylinder for 3 [^{o}CA] before TDC (automatic ignition)

3. Analysis of the exhaust fumes components in the cylinder of a two-cycle engine

The mass participation of the analysed components of the exhaust fumes in the cylinder is calculated on the basis of the number of moles of these components [2]. As a result of keeping of the chemical equilibrium, the combustion process is running in accordance with the principle of the molar equilibrium of the particular air and fuel components.

Figures 7-14 show the simulation of the capacity of toxic components for the location of 4 [^{0}] rotation angle of the crankshaft (left column) as well as in function of rotation angle of the crankshaft (right column), respectively for hydrocarbons, carbon monoxide, carbon dioxide as well as nitrogen oxide.

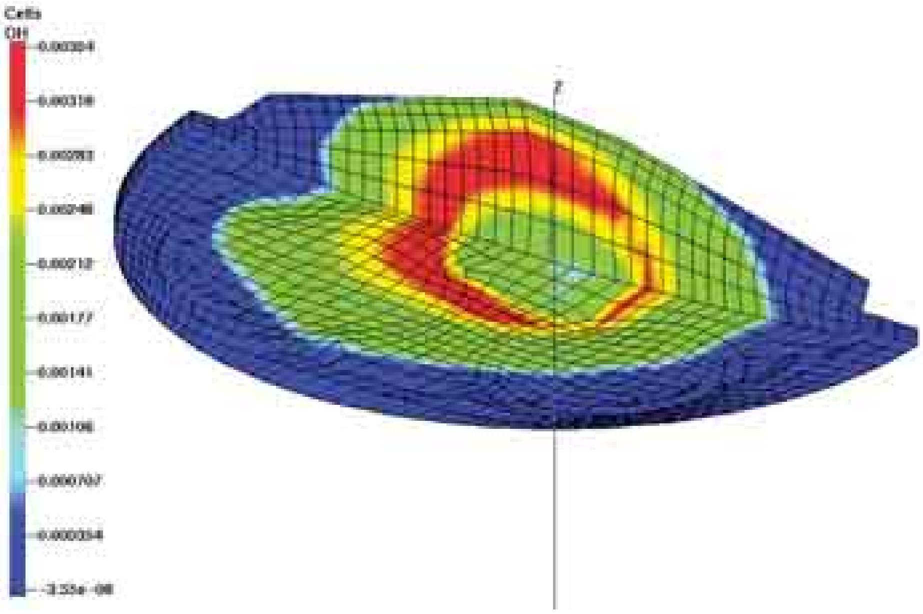

Fig. 7. Mass participation of hydrocarbons in cylinder for 4 [^{o}CA] after TDC

The mass participation course of hydrocarbons for the initiation of the combustion process from the ignition dose is similar to the course for the mode of the ignition from the electrical discharge between the electrodes of a spark plug (Fig. 7 and 8). In the total range of rotation angle of the crankshaft it is not possible to observe the distinct differences between the two courses, only in end period of the combustion's process it is possible to observe a slight increase in the hydrocarbons contents due to the injected ignition dose. During the work of the engine in the mode of the combustion initiation from the ignition dose, the decrease of carbon monoxide contents in engine cylinder can be noticed (Fig. 9 and 10). That process is caused due to the injection of the ignition dose causing the virtually total combustion of the load in engine cylinder, which is related directly to the decrease of carbon monoxide. As a result of such combustion course, there are more profitable conditions for the accurance of the oxidation reaction, which cause the production of carbon dioxide.

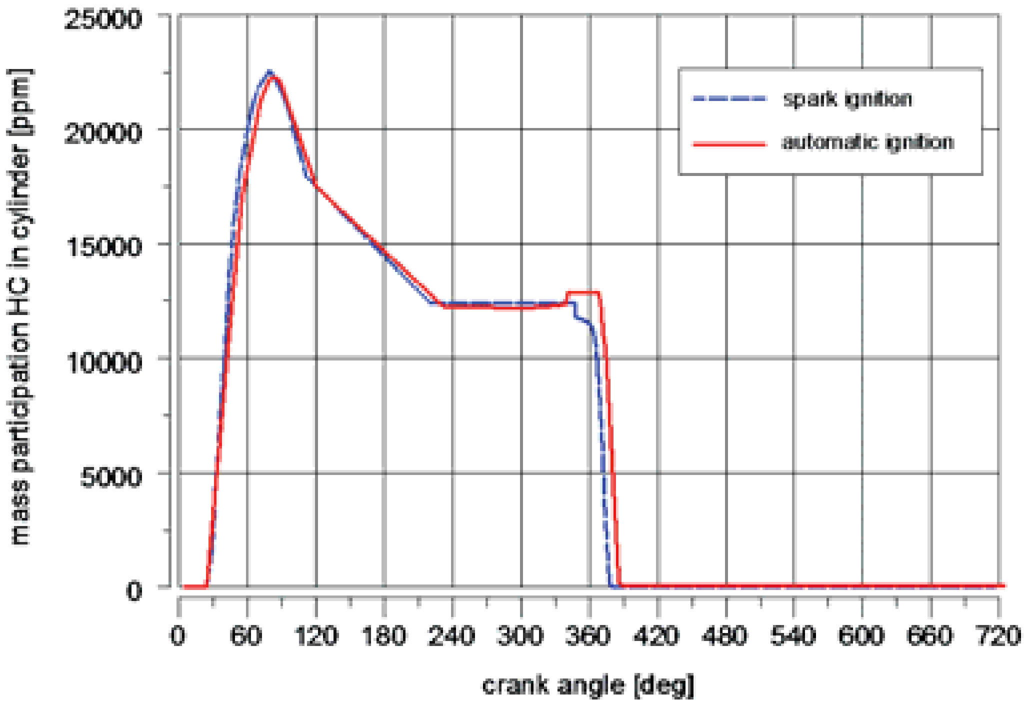

Fig. 8. Mass participation of hydrocarbons in cylinder in function of rotation angle of crankshaft

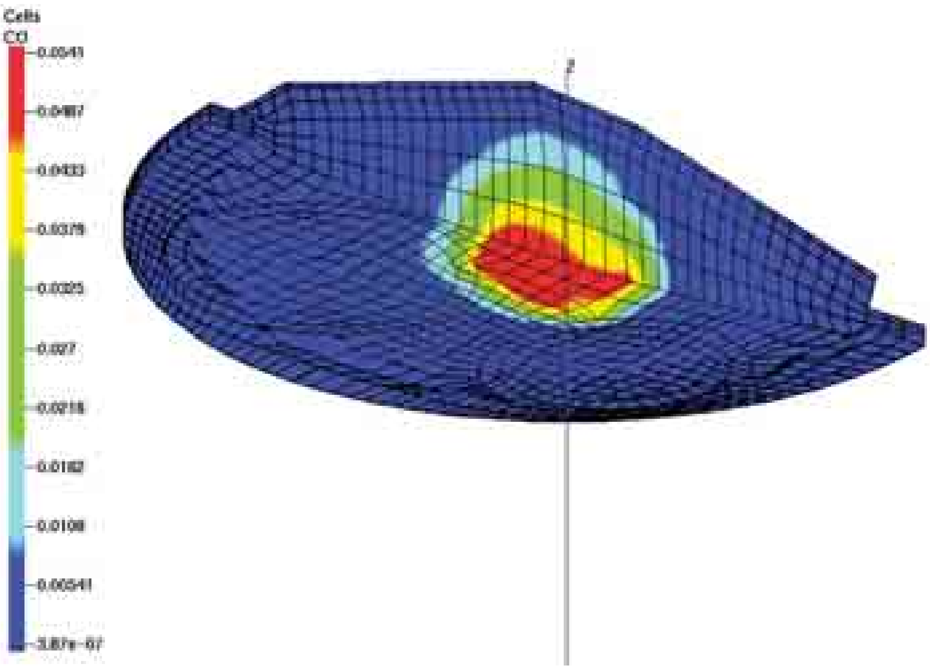

Fig. 9. Mass participation of carbon monoxide in cylinder for 4 [°CA] after TDC

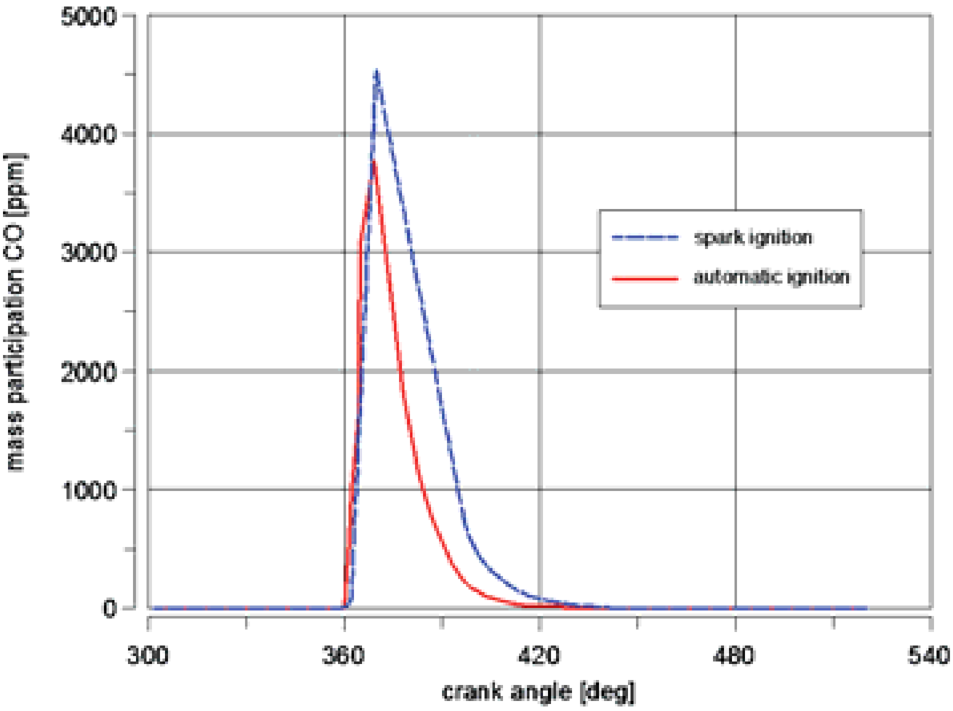

Fig. 10. Mass participation of carbon monoxide in cylinder in function of rotation angle of crankshaft

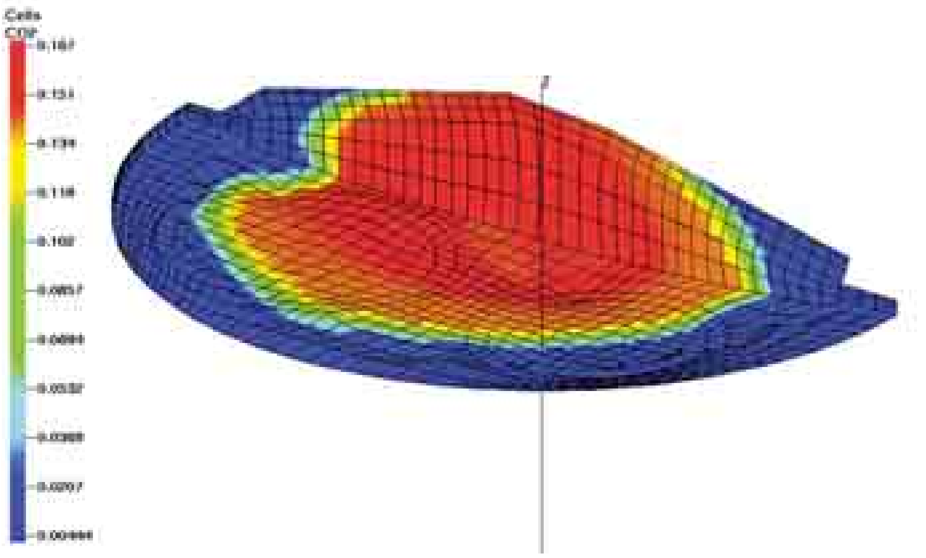

Fig. 11. Mass participation of carbon dioxide in cylinder for 4 [°CA] after TDC

Due to the same character of power supply fuel in the beginning period up to the dozen degrees before TDC during the compression where the injection occurs of the combustion process initiating dose (the mode of ignition dose), it is not possible to observe any greater differences in the mass participation of carbon dioxide (Fig. 11 and 12). In the course of the combustion process it is possible to notice a slight decrease in CO_2 emission for the work mode of an engine with the combustion process initiated from a spark plug. The total mass participation of carbon dioxide is related to the oxygen contents in the load and depends on the air surplus coefficient. Due to the course of the temperature during the load combustion inside the engine cylinder at work with the spark ignition, the increase of nitrogen oxide contents occurs in the exhaust fumes. It is already noticeable in moment of the initial stage of the combustion process and the dispersing of the flame due to character of the injection process, which is definitely different in both work modes. The ignition dose injected to the engine cylinder during the compression stroke and its evaporation slightly decrease the load temperature, which causes the decrease in the maximal value of the combustion temperature, and consequently to the decrease in nitrogen oxide contents by about 5,000 [ppm] in relation to the work mode of spark ignition. In figures 13 mass participation of nitrogen oxide in cylinder was presented.

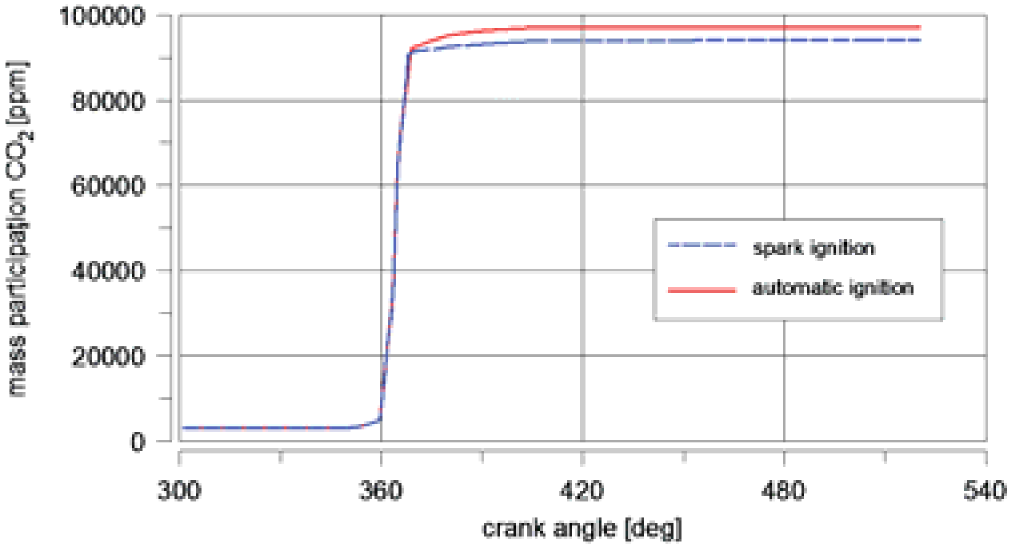

Fig. 12. Mass participation of carbon dioxide in cylinder in function of rotation angle of crankshaft

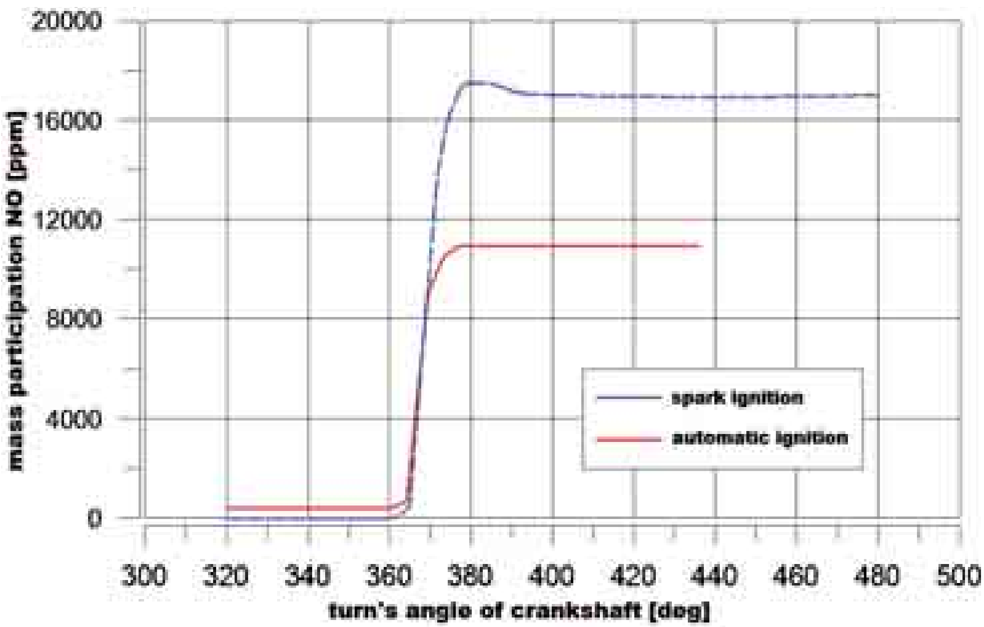

Fig. 13. Mass participation of nitrogen oxide in function of rotation angle of crankshaft

4. Summary of simulated research

The conducted simulations of the circulation within the work of the two-cycle engine reveal the possibility of the petrol-air mixture autoignition by means of a stream of the ignition dose injected directly to the cylinder.

The simulation of the physical processes in the cylinder was conducted for geometrical and boundary conditions like in a real engine, from which the following conclusions result:

1. At the set location of the injection system of the ignition dose of a homogeneous composition of air and petrol load, the ignition of the mixture occurs in the order of TDC.
2. The maximal combustion temperature for the work mode with the ignition dose reaches the value of about 2,600 [K] and is lower by about 100 [K] for the work of the engine in the spark ignition mode.
3. The automatic ignition of the petrol-air mixture occurs on the periphery of the injected stream of the ignition dose.
4. As a result of the delay in reaching the maximal temperature during the combustion process as well as its faster reduction for work mode with combustion initiated from the ignition dose, the mass participation of nitrogen oxide NO in the cylinder is in the order of 11,000 [ppm], which testifies about the decrease in nitrogen oxides in relation to the work of the test engine in the spark ignition mode.
5. The set fuel dosing is a result of the lack of CO at the end of combustion process.
6. The combustion process is very short and for range of 10-90% of the burnt fuel dose it proceeds only through 15 [°CA].

5. References

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