SIMULATION OF INJECTION AND COMBUSTION PROCESSES IN 4-STROKE SPARK IGNITION ENGINE WITH CNG DIRECT INJECTION

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Abstract

The paper presents results of simulation conducted as a first step of 4-stroke spark ignition experimental engine testing. The simulations were performed in a KIVA-3V software, which is intended to carry out a 3-D simulations of engine's processes. The source code of the software has been modified in order to apply it for gas injection. Original version of the software has been designed to simulate liquid fuel injection only. The simulation of direct CNG injection and combustion has been done for stratified and homogenous modes in order to check the assumed injection, ignition and charging parameters. Important assumption is that the injector had only one nozzle with flow area equal to 2 mm^2. Two different cases of fuel direct injection for stratified charge have been analysed. In the first case fuel jet was almost vertical. In the other one fuel jet was nearly horizontal. Further testing has been performed using one-cylinder motorcycle 4-stroke SUZUKI DR-Z400S engine adapted to CNG fuelling. Such an engine has a suitable high compression ratio for CNG fuelling. The simulation has confirmed assumed parameters and has shown that one nozzle injector doesn't provide required fuel stream dissipation and piston crown modification is needed to direct fuel stream in spark plug area. However doing simulation requires some effort this example has shown than this is very important step before conducting experimental tests which provides crucial information and helps to avoid expensive mistakes which can be made during experimental engine preparation.

***Keywords**: injection process, combustion process, simulation ,modelling, alternative fuels, CNG*

1. Introduction

It is rational to perform simulation of injection and combustion processes to initially examine an engine chosen for hardware testing prior to these tests. Knowledge gathered during simulation allows checking assumed setup parameters like injection, ignition and charging parameters and helps to understand behaviour of the examination subject. Because of ease of adjustment, SUZUKI DR-Z400S engine has been chosen for testing purpose. This is one-cylinder 4-stroke spark ignition motorcycle engine where desired modifications like increasing compression ratio and installation of CNG injector can be easily achieved. This modern engine with capacity of 400 cm^3, bore/stroke ratio equal to 90 mm/62.6 mm and compression ratio $\varepsilon = 12$ can be easily equipped with gas injector located between two inlet channels because there is enough space to locate it. The cylinder with a pent-roof combustion chamber and four valves has the spark plug located in the middle of the cylinder head. The assumed parameters of CNG injection are presented in Tab. 1.

The simulation results help to make final decisions regarding setup during experimental engine testing and identify potential problems which may occur later on.

2. Simulation mesh description

The simulation of injection, ignition and combustion processes which take place in the engine has been performed in 3-dimensional space using KIVA3V software. The source code of the software has been modified in order to apply it for gas injection. Original version of the software has been designed to simulate liquid fuel injection only. Geometry of the engine and cross section through the valves are shown in Fig. 2 and Fig. 3 respectively. The mesh consists of 62838 vertices and 62811 cells. Important assumption is that the injector had only one nozzle with flow area equal to 2 mm^2.

Tab. 1. Injection parameters

	Stratified charge	Homogenous charge
Dose of CNG fuel	0.0098 g/cycle	0.045 g/cycle
Beginning of the injection	105 deg CA BTDC	55 deg CA ATDC
Duration of injection	40° CA	120° CA
Ignition point	9° CA BTDC	9° CA BTDC
Cone of fuel jet	50°	50°
Number of nozzles	1	1

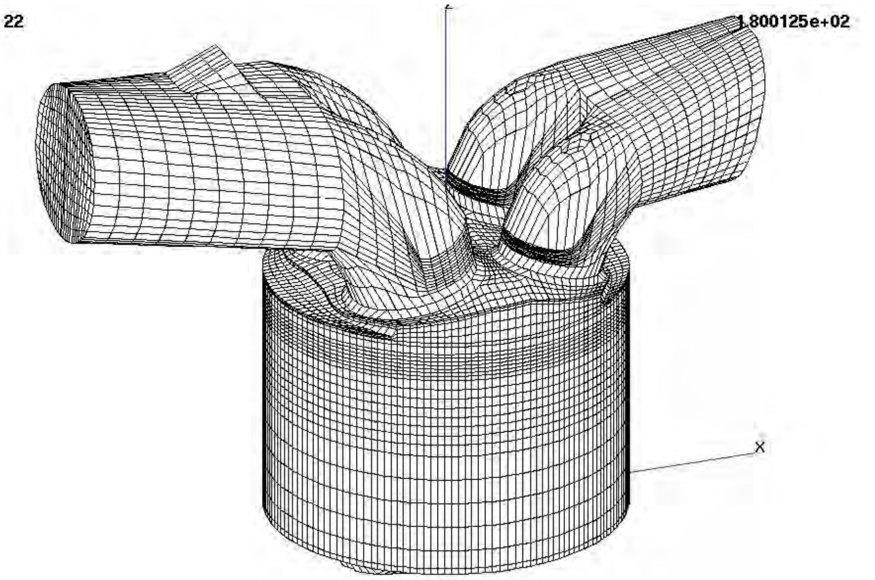

Fig. 2. Calculation mesh of motorcycle engine SUZUKI DR-Z400S

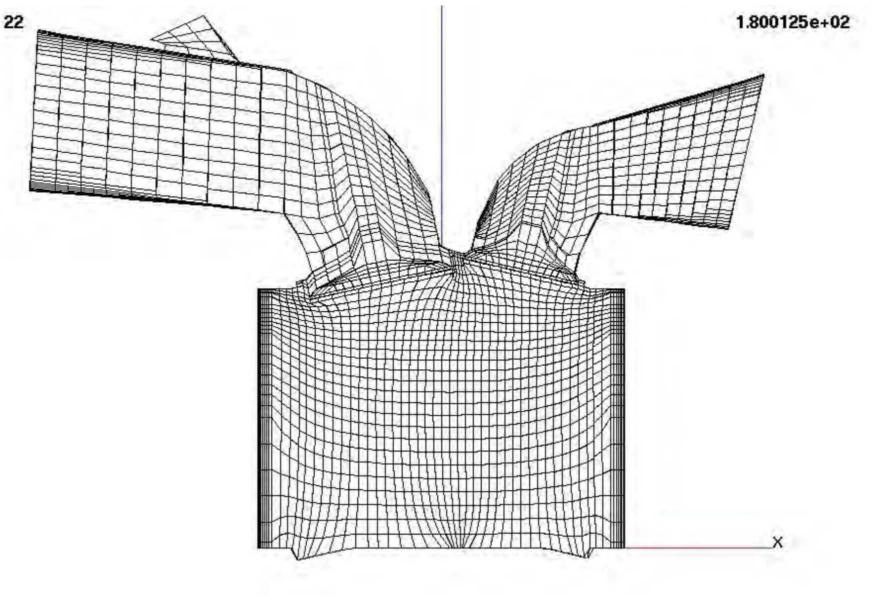

Fig. 3. Cross-section through the valves on calculation mesh of motorcycle engine SUZUKI DR-Z400S

3. Mass of injected fuel

The injection of CNG during compression stroke (stratified mode) was simulated with injector to cylinder wall inclination angle of 70°. Changes of CNG mass injected to the cylinder are shown in Fig. 4. Because of small dose of injected fuel kinetic reaction during combustion process takes place very quickly. The rest of fuel located in wall regions burns very slowly and this process takes place until the exhaust valves open. For homogeneous charge fuel injection takes place during induction stroke and assumption in simulation for this case is that all mixture components are distributed evenly.

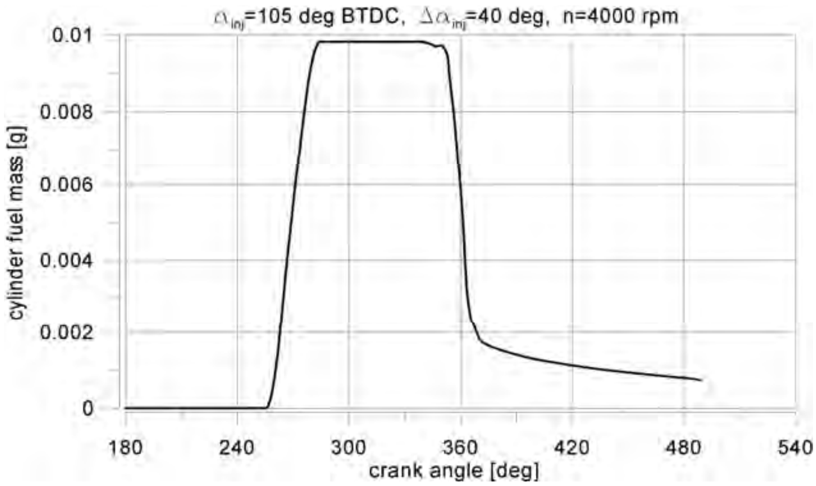

Fig. 4. Mass of CNG in the cylinder for injection fuel dose equal to 0,0098 g/cycle at 4000 rpm

4. Propagation of fuel stream

Two different cases of fuel direct injection for stratified charge have been analysed:

a) with almost vertical fuel jet (26° of injector to cylinder axis inclination angle),

b) with parallel fuel jet (70° of injector to cylinder axis inclination angle).

In the first case fuel reaches piston head very quickly (Fig. 5 and Fig. 6) and only small amount of it gets close to the spark plug.

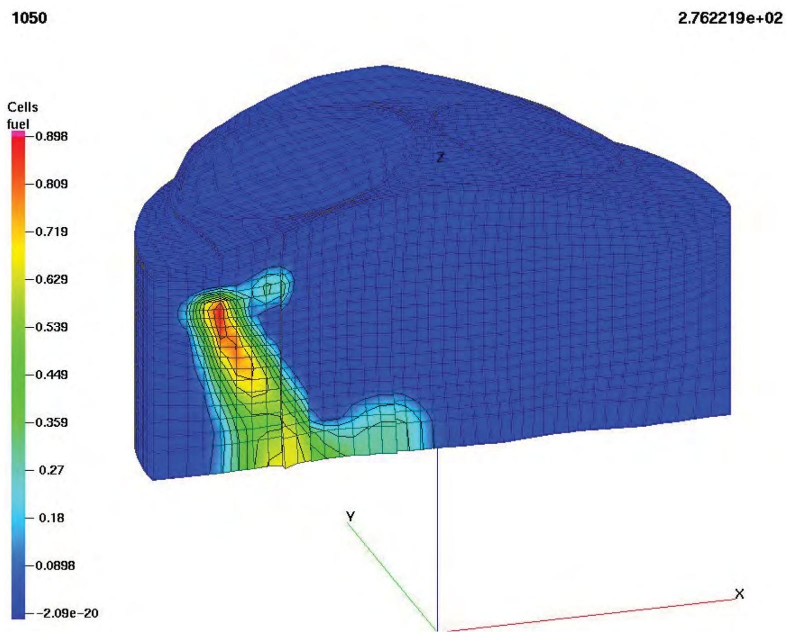

Fig. 5. Distribution of CNG during injection at 84° BTDC with injector to cylinder axis inclination angle of 26°

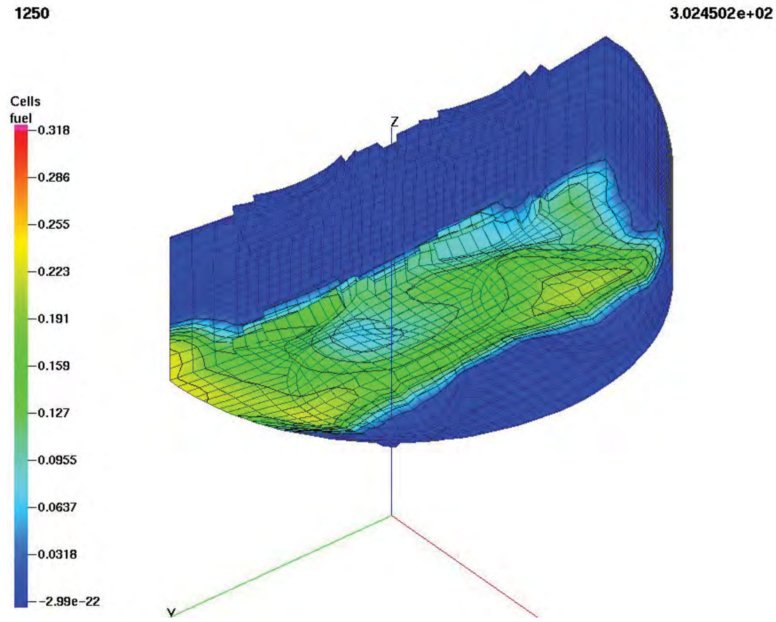

Fig. 6. Distribution of CNG during injection at 58° BTDC with injector to cylinder axis inclination angle of 26°

With the parallel direction of the injected fuel stream most of the fuel flows through the combustion space and after reaching the opposite wall reflects from it (Fig. 7 and Fig. 8). After that gaseous fuel washes the cylinder head and reaches the spark plug.

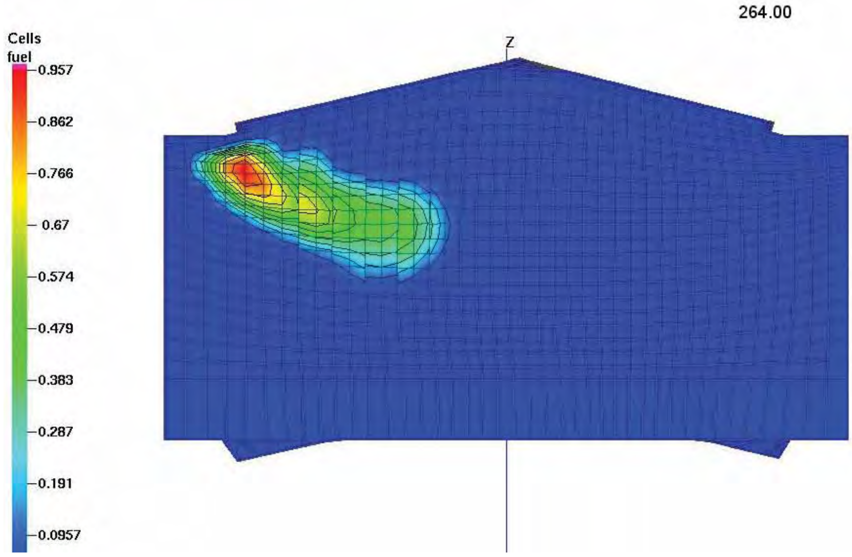

Fig. 7. Distribution of CNG during injection at 96° BTDC with injector to cylinder axis inclination angle of 70°

The injector with one nozzle does not provide sufficient dissipation of fuel inside the combustion chamber. A bowl in the piston crown is needed to direct fuel stream in spark plug region. Beginning and duration of the injection together with proper fuel dose are critical parameters which should be carefully chosen and set up during tests on the experimental engine working in stratified injection mode.

5. Engine parameters

Cylinder pressure in a naturally aspirated CNG fuelled engine in a stratified mode is on the same level as in a gasoline engine. Pressure and mass of cylinder charge are shown together in Fig. 9. Mass of the cylinder charge decrease takes place at the end of inlet valve opening by about

7% and increases after CNG injection as a result of gaseous fuel inflow. Combustion of natural gas is a long process and in the described case takes place until the exhaust valves open.

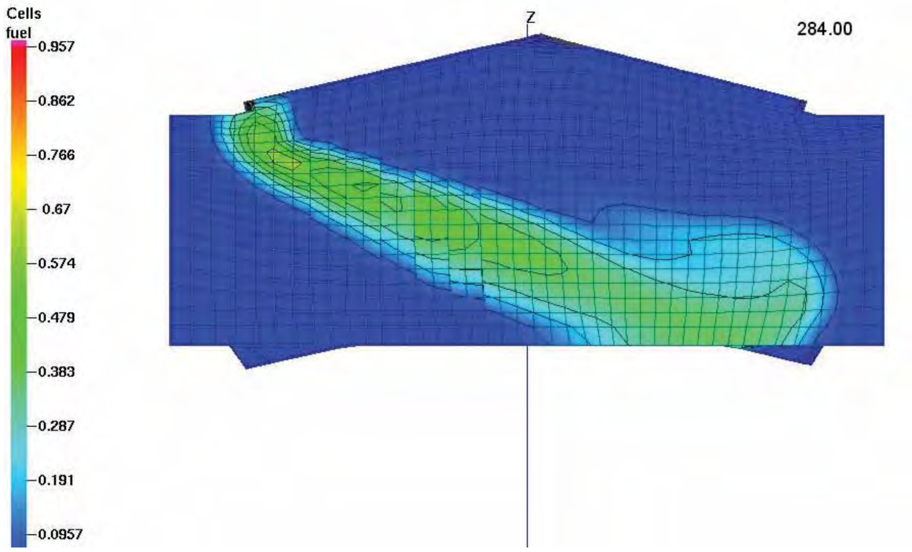

Fig. 8. Distribution of CNG during injection at 76° BTDC with injector to cylinder axis inclination angle of 70°

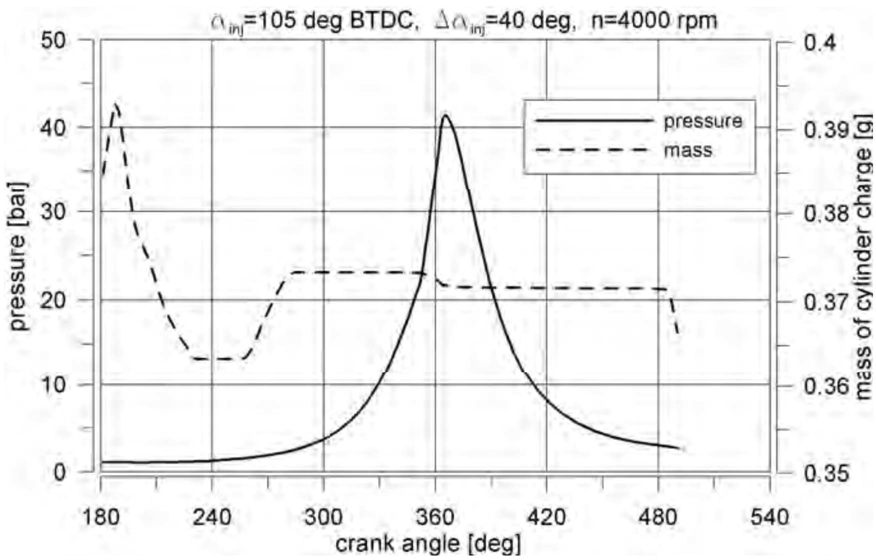

Fig. 9. Cylinder pressure and charge mass in the naturally aspirated engine working in stratified charge mode

In the engine with high charging ratio ($\gamma = 2.0$) working in homogeneous mode maximum combustion pressure reaches 130 bar and the whole fuel charge is burnt during 30° CA (Fig. 10). Because of pressure fluctuation in the inlet pipe the charge in the cylinder decreases and the maximum pressure also has a lower value than expected taking into account theoretical considerations only.

6. Remarks and conclusions

This article presents results of the simulations carried out to initially examine and gather information regarding one–cylinder 4–stroke motorcycle engine SUZUKI DR-Z400S fuelled with CNG under stratified and homogenous operation modes. The simulation gave answer to important questions how to set up experimental engine during further tests and what changes are necessary to engine construction to obtain required experiment conditions (bowl in piston crown). The critical parameters are beginning and duration of injection and fuel dose. The simulation has provided this crucial setup information. Conclusion is that without having a bowl in piston crown and using one-nozzle injector it won't be possible to achieve desired combustion conditions. However doing simulation requires some effort this example has shown than this is very important step before conducting experimental tests which provides crucial information and helps to avoid expensive mistakes which can be made during experimental engine preparation.

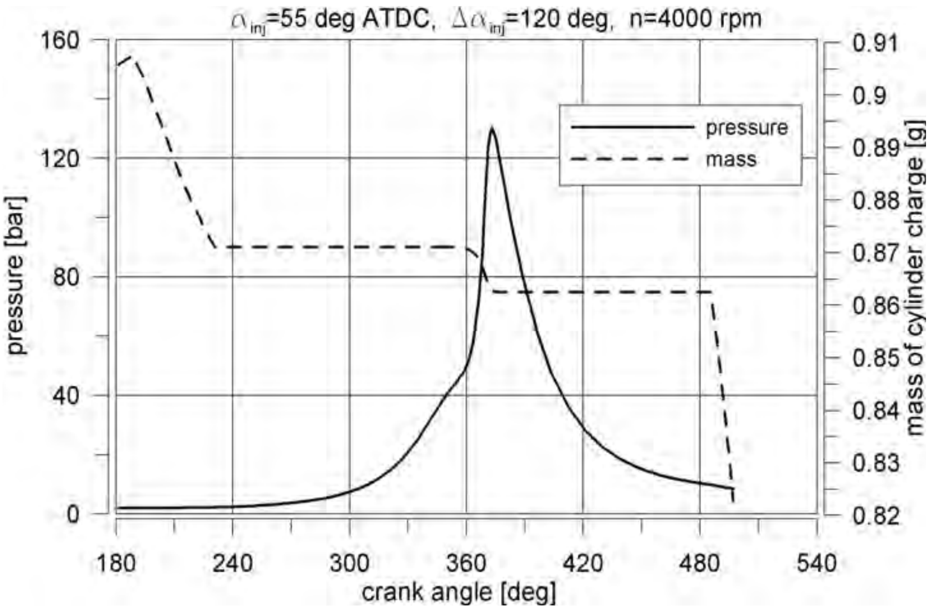

Fig. 10. Cylinder pressure and charge mass in the high-charged engine working at homogenous charge mode

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