Model Studies of Fuel Injection

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Introduction

A model and real scale studies of the process of combustible mixture formation and combustion in low power two-stroke engine are undertaken. An analysis of development tendencies of these engines shows that the direct fuel injection (GDI) may be the promising solution from the point of view of emissions.

For this reason the studies of unconventional system of mixture formation with simultaneous use of jet ignition system were undertaken in two-stroke engine. The objective of these studies is to determine optimum conditions for mixture formation from the point of view of NOx emission as well as combustion of lean mixtures enabling additional decrease of HC and CO emissions.

This paper reports on preliminary stage of the project containing model studies of fuel injection conducted with the use of open space research stand and constant volume chamber.

Experimental

Photographic method developed at KAIST Korean Institute was used in the studies of structure of fuel spray. Schematic of measurement system is shown in Fig. 1.

The system consists of: light source, CCD camera and PC computer with frame grabber software and control system. The test volume was illuminated by light beam from electric spark of very short duration (60 ns). Measurements were performed for fixed distance of injector nozzle exit from light beam axis. The location of system axis plane was varied within the range of 0-20 mm with the step of 5 mm. Due to symmetry of the jet the points of measurements were located only at one side of the axis. Measurements were done changing the delay of light impulse within the range of t_{del} = 2.5 to 7.5 ms with 1 ms step. Fifty frames were done for each measurement point. Every frame was processed by the computer software developed at KAIST in order to determine droplet Sauter mean diameter (SMD).

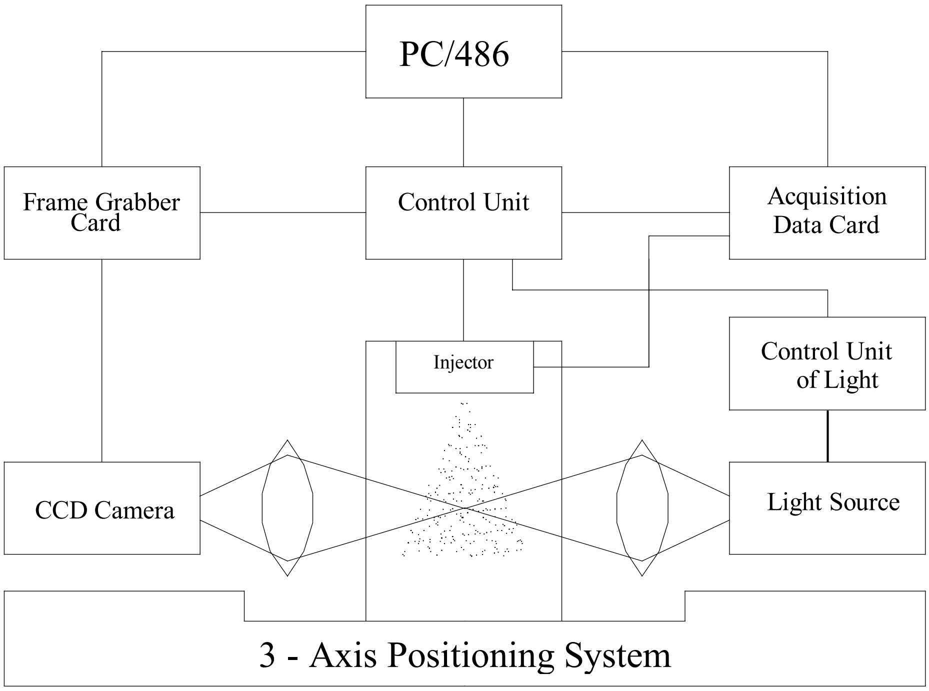

Figure 1. Schematic of fuel spray test unit

The process of combustible mixture formation was studied in cylindrical constant volume chamber. Schematic of research apparatus is shown in Fig.2.

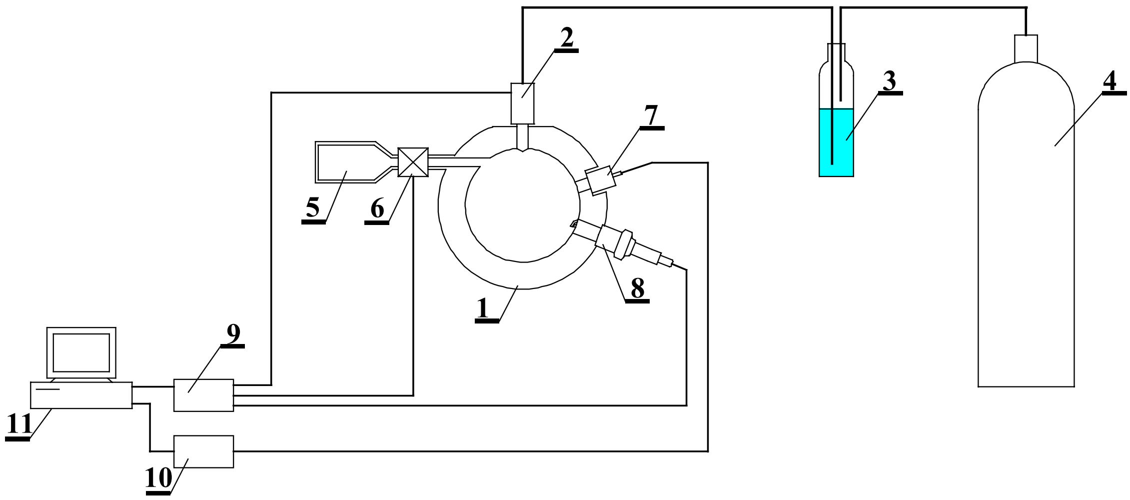

Figure 2. Schematic of research apparatus: 1 – test chamber, 2 – injector, 3 – fuel tank, 4 – nitrogen tank, 5 – compressed air tank, 6 – electromagnetic valve, 7 – pressure transducer, 8 – spark plug, 9 – control unit, 10 – amplifier, 11 – computer with control unit

The chamber of 80 mm in diameter and 80 mm long had two windows made of optical glass enabling for the visualization of the injection process. Typical Schlieren optical system equipped with the high-speed registration system composed of diode light source and high-speed drum camera was used. The diode emitted pulsating light of with the frequency of 2.5 kHz.

The studies of injection process were conducted in research chamber for two cases: fuel injection without initial air vortex, and fuel injection with initial air swirl. In the first case the fuel was injected to the chamber filled with air of atmospheric pressure. In the second case the chamber after evacuation was filled with air under the pressure of tank 5. The air was introduced tangentially to chamber wall in order to create vortex. After defined time the fuel injection occurred.

In result of mixing and vaporization the mixture of fuel vapors and air was formed in the chamber. The process of mixture formation was registered by drum camera. Additionally pressure rise in the chamber was registered with the use of Kistler piezoelectric transducer.

Experiments were conducted for different times of injection delay and for variable time of injection duration in order to form the mixture of defined air excess coefficient λ. The profiles of injection process for different injection parameters and different chamber initial conditions are presented in Figs. 3 to 5.

Figure 3 shows Schlieren pictures of fuel injection process to the chamber without air swirl.

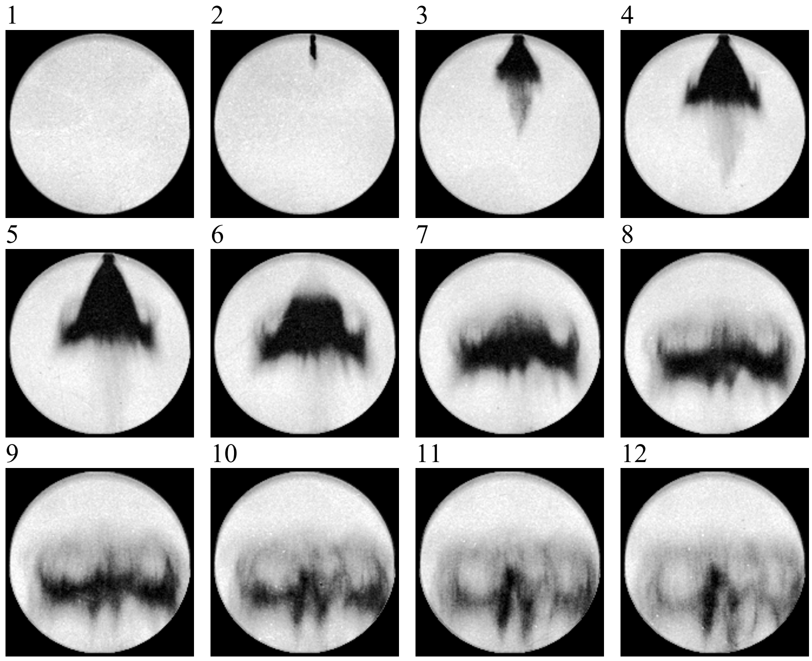

Figure 3. Schlieren pictures of fuel injection process to the chamber without air swirl t_{inj}=2 ms; p_{inj}=70 bar; 2.5 kHz

The narrow cylindrical jet is observed during the first phase of injection process. Not before continuous flow of fuel through injector causes its rotation and the jet takes the conical shape with nozzle divergence angle dependent on injector characteristics. The fuel outflow velocity estimated on the basis of photographs is equal to about 30 m/s. Research chamber of the volume of V_k = 400 cm^3 contains about 500 mg of air under atmospheric pressure. In order to get stoichiometric fuel-air mixture it is necessary to inject about 34.5 mg of fuel (duration of injection is about 6 ms). Duration of injection of t_{inj} = 2 ms provides very lean mixture. Photographs in Fig.3 show relatively fast vaporization of fuel dose without uniform filling of the chamber.

Completely different situation occurs when the air in the chamber is initially swirled. Figures 4 and 5 present photographs of fuel injection process for such case. The duration of fuel injection was 4 ms and 5 ms respectively for two cases. In both cases the progress of the process is similar.

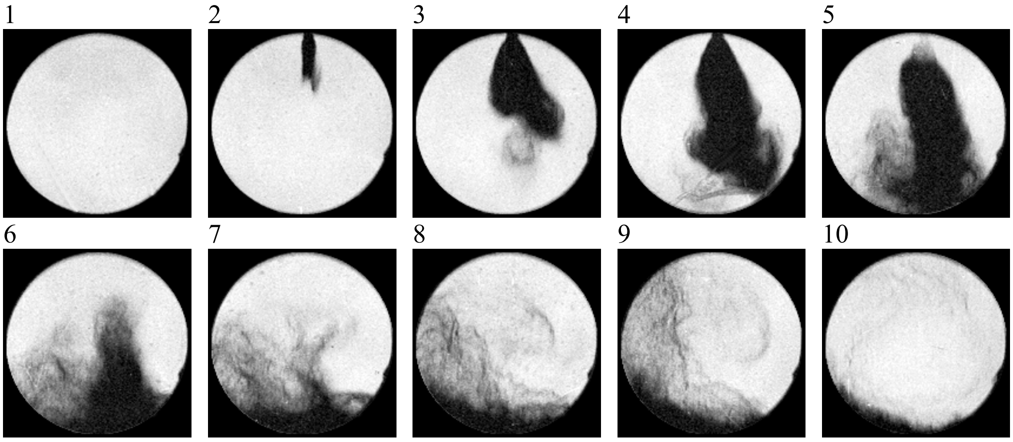

Figure 4. Schlieren pictures of fuel injection process to the chamber with initial air swirl t_v*=40 ms;* t_{id}*=50 ms;* t_{inj}*=4 ms;* p_{inj}*=7 MPa; 1.25 kHz*

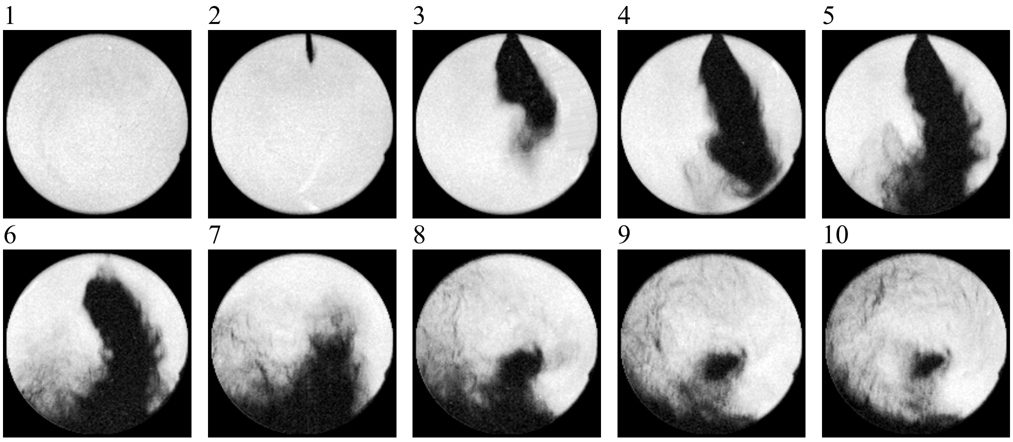

Figure 5. Schlieren pictures of fuel injection process to the chamber with initial air swirl t_v*=40 ms;* t_{id}*=50 ms;* t_{inj}*=5 ms;* p_{inj}*=7 MPa; 1.25 kHz*

Figures show that initial air swirl causes fragmentation of outflowing fuel jet. This leads to the intensification of mixing and vaporization of fuel droplets. Air vortex deflects fuel jet, which results in the formation of zones of variable concentration (different λ). The observed process may be used in model studies of combustion process of stratified charge. After proper selection of ignition point and ignition delay the combustion process of such charge could be realized.

Results

On the basis of the studies performed it can be concluded that the injector used in tests satisfies the assumed parameters and it will be used in the future model studies of ignition and combustion processes.

The application of siphon system with compressed nitrogen and petrol enables for the injection of fuel of the required parameters without using complex and costly high-pressure injection pump. The mixtures from stoichiometric to very lean ($\lambda = 1 - 3$) may be achieved in the test chamber of the volume of 400 cm^3.

The studies have shown that using fuel injection to the chamber with the air of room temperature it is not possible to generate uniform mixture during relatively short time both in the case with and without swirl. However air swirl (before injection) in the chamber enables to get non-uniform mixture but with the visible in Schlieren pictures division into reach and lean The studies have shown that using fuel injection to the chamber with the air of room temperature it is not possible to generate uniform mixture during relatively short time both in the case with and without swirl. However air swirl (before injection) in the chamber enables to get non-uniform mixture but with the visible in Schlieren pictures division into reach and lean mixture regions. This creates conditions for the realization of combustion of stratified mixture in which lean mixtures can be burned. The achieved conditions ease ignition in the region of rich mixture and then cause flame front propagation to the lean mixture zone. The combustion process organized in such a way causes favorable decrease of emissions of harmful gases in combustion products.

References

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