

A Study on the Effect of a Calcium-Based Engine Oil Additive on Abnormal SI Engine Combustion

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ABSTRACT

Supercharged direct-injection engines are known to have a tendency toward abnormal combustion such as spontaneous low-speed pre-ignition and strong knock because they operate under low-speed, high-load conditions conducive to the occurrence of irregular combustion. It has been hypothesized that one cause of such abnormal combustion is the intrusion of engine oil droplets into the combustion chamber where they become a source of ignition. It has also been reported that varying the composition of engine oil additives can change susceptibility to abnormal combustion. However, the mechanisms involved are not well understood, and it is not clear how the individual components of engine oil additives affect autoignition.

In this study, abnormal combustion experiments were conducted to investigate the effect on autoignition of a calcium-based additive that is typically mixed into engine oil to act as a detergent. The experiments were performed with a single-cylinder 4-cycle gasoline engine using a primary reference fuel (PRF 50) into which the calcium salicylate (CaSa)-based detergent was mixed at various ratios.

The experimental results showed that autoignition occurred increasingly earlier with a higher concentration of the CaSa-based engine oil additive, giving rise to severe abnormal combustion. This indicates that the addition of a CaSa-based detergent to engine oil tends to promote autoignition and abnormal combustion.

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INTRODUCTION

Gasoline automotive engines have been required to provide higher fuel economy in recent years owing to various environmental issues such as global warming. Attention has been focused on direct-injection, supercharged, downsized engines as one approach to improving fuel economy. Downsizing reduces the engine displacement while supercharging boosts the mean effective pressure of the engine, thereby achieving high power output equal to that of conventional engines even in the low speed range. At the same time, the ratio of mechanical losses is reduced to improve fuel economy. However, increasing the mean effective pressure in the low-speed range creates a condition conducive to the occurrence of abnormal combustion. It is well known that this can result in spontaneous low-speed pre-ignition and strong knock (1)-(2). As one cause of such abnormal combustion events, it has been hypothesized that an engine oil film formed on the piston rings and near the cylinder wall peels off as oil droplets that disperse throughout the combustion chamber to become sources of autoignition, as illustrated in Fig. 1. It has also been reported that changes in the composition of engine oil additives may make it more conducive for abnormal combustion to occur (3)-(4).

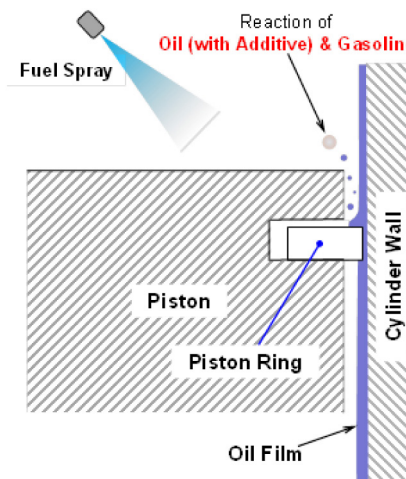


Fig. 1. Conceptual representation of pre-ignition caused by oil droplets in combustion chamber



The principal engine oil additives include calcium salicylate (CaSa)-based additives used as oil detergents and molybdenum dithiocarbamate (MoDTC)-based additives and zinc dithiophosphate (ZnDTP)-based additives used to form an oil film on metal surfaces. It has also been reported that Ca-based additives influence the frequency of autoignition.

This study focused on a CaSa-based additive used as an oil detergent and investigated its effect on abnormal combustion. Abnormal combustion experiments were conducted using a single-cylinder, four-stroke gasoline engine and a primary reference fuel (PRF50) into which the CaSa-based additive was mixed at various concentration.

TEST EQUIPMENT AND PROCEDURE

Specifications of Test Engine

Table 1 shows the test engine specifications and the experimental conditions, and the configuration of the test equipment used is shown schematically in Fig. 2.

Table 1. Engine specification and experimental conditions

Four-stroke Single Cylinder Spark Ignition Engine	
Bore×Stroke	85×70 mm
Displacement	397 cm ³
Compression Ratio	8 : 1
Engine Speed	1400 rpm
Air-fuel Ratio	Stoichiometric
Ignition Timing (IT)	-5 deg. ATDC
Valve Arrangement	Side Valves
Test Fuels (Fuel + ppm)	PRF 50
	PRF 50 + Ca 110 ppm
	PRF 50 + Ca 550 ppm
	PRF 50 + Ca 1100 ppm
	PRF 50 + Ca 2200 ppm

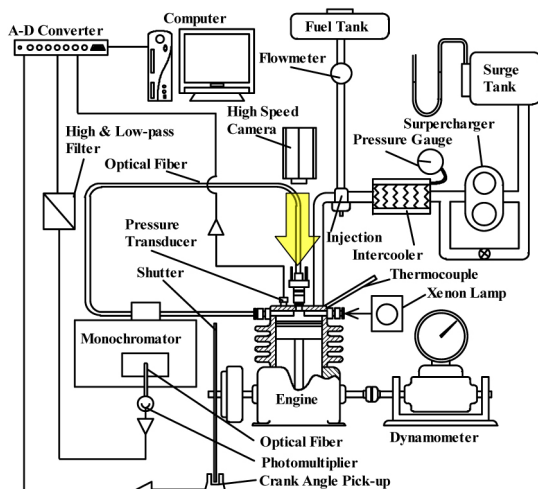


Fig. 2. Configuration of test equipment

Combustion experiments were conducted using a four-stroke single-cylinder gasoline engine with a side valve layout that allowed easy attachment of the measurement instruments. Figure 3 shows the cylinder head and the positions where the measurement instruments were attached. The engine temperature was varied to induce a transition from a state of normal combustion to one of abnormal combustion. As the test engine was air-cooled, the spark plug washer temperature T_{SP} [K] measured with a thermocouple installed at the position labeled X in Fig. 3 was used as a typical engine temperature. The temperature of the fresh intake air was adjusted with an intercooler to be approximately 300 K. A quartz crystal pressure transducer was used to measure the pressure in the combustion chamber.

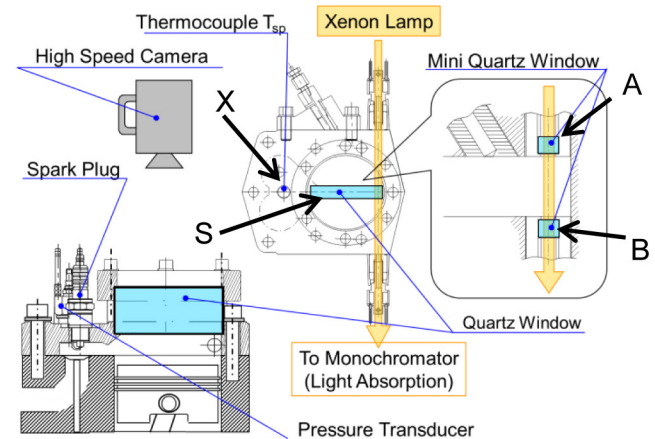


Fig. 3. Cylinder head and measurement positions

Test Fuels

The test fuel was used PRF50. We prepared 'additized fuels' by adding engine oil additives into PRF50 to simulate formation of the mixture of fuel and engine oil additives in the combustion chamber. The model illustrated in Figure 1 led us to assume the maximum possible concentration of additives in the droplet as the concentrations of additives in the engine oils. Typical calcium concentration of gasoline engine oils is about 2200 ppm. We mixed Calcium additive into PRF50 at calcium concentration of 110 ppm, 550 ppm, 1100 ppm and 2200 ppm. Introduction of these additized fuels into combustion chamber realized continuous formation of the mixture of fuel and engine oils in the combustion chamber. Fuel was supplied to the engine using a port injection system with the injector installed in the intake pipe in order to obtain a homogeneous air-fuel mixture in the cylinder.

Visualization Measurements

A quartz window (84 × 40 mm) was provided in the top of the cylinder head for visualizing and photographing combustion. A high-speed camera was positioned above the portion labeled S in the Fig. 3 for capturing combustion images at a frame rate of 40,000 frames/sec. and a resolution of 512 × 128 pixels. All of the visualized images were obtained at the same camera settings with regard to brightness and contrast.

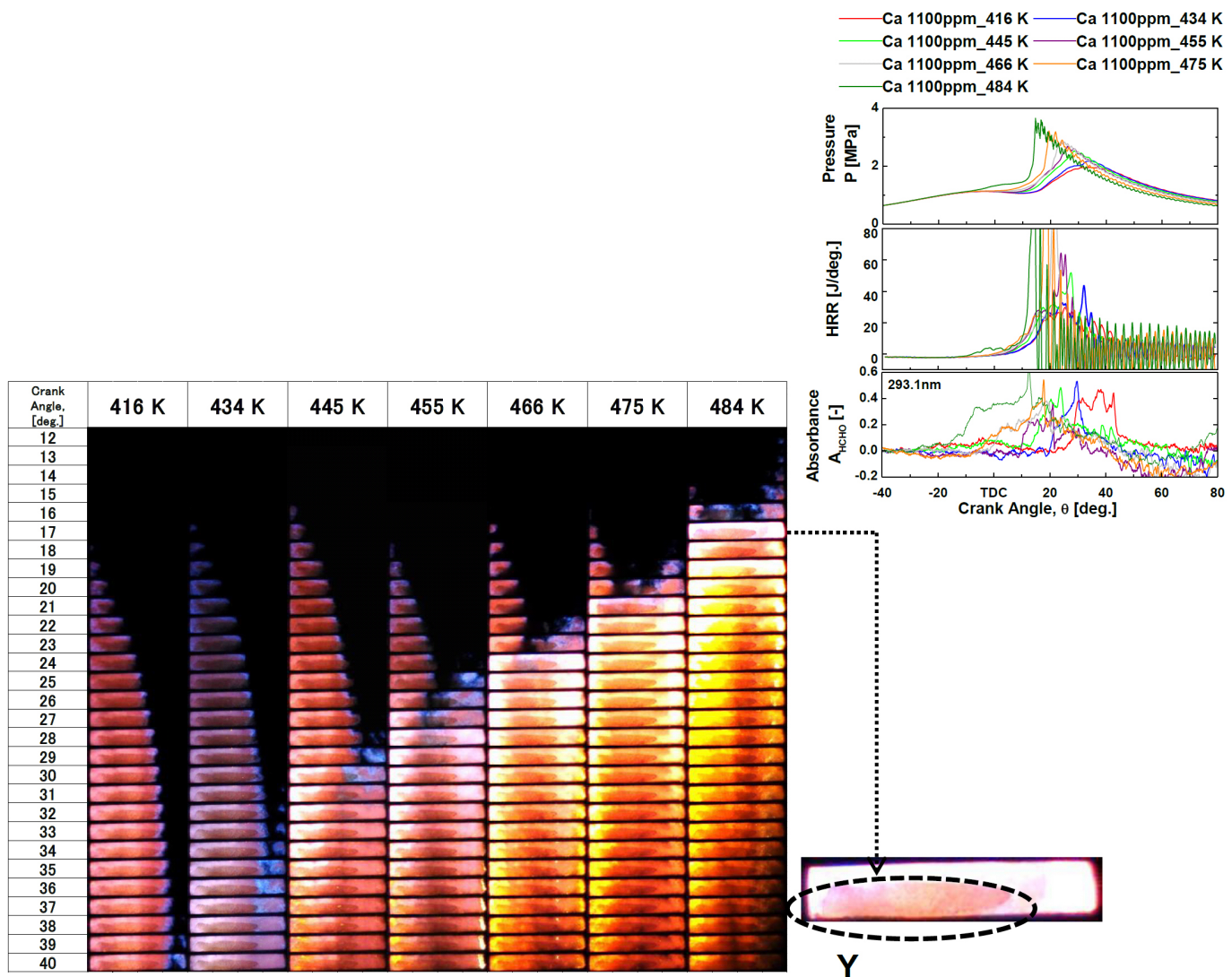


Fig. 4. Measured waveforms and visualization results

Spectroscopic Measurements

Spectroscopic measurements (5) of light absorption were obtained by irradiating the combustion chamber with parallel light from a xenon lamp through a quartz observation window (labeled A) provided in one side of the cylinder head and extracting the transmitted light through a quartz observation window (labeled B) on the opposite side. The extracted light was passed through an optical fiber cable into a monochromator that separated the light at a wavelength of 293.1 nm (6). This wavelength is where strong light absorption by formaldehyde (HCHO) occurs. HCHO is a key chemical species that is produced during low-temperature oxidation reactions.

The separated light was introduced into a photomultiplier tube and converted to an electric signal. The output voltage thus measured was regarded as the transmitted light intensity. Letting E_0 [A.U.] represent the transmitted light of the baseline state before the occurrence of any low-temperature oxidation reactions, light absorbance of formaldehyde A_{HCHO} was defined as shown in Eq. (1) below using the transmitted light intensity at any arbitrary crank angle E [A.U.].

$$A_{HCHO} = \frac{E_0 - E}{E_0} \quad (1)$$

EXPERIMENTAL RESULTS AND DISCUSSION

Measured Waveforms and In-Cylinder Visualized Images

Figure 4 presents the measured waveforms and visualized combustion images obtained with the test fuel containing 1100 ppm Calcium concentration on the additive when the spark plug washer temperature T_{SP} was varied over a range of $T_{SP} = 416$ –484 K. From the top of the figure, the vertical axes show the measured waveforms for the cylinder pressure P [MPa], heat release rate HRR [J/deg.] calculated from the measured cylinder pressure data, and HCHO absorbance A_{HCHO} in the end zone of the combustion chamber. The visualized images were obtained at increments of 1 crank angle degree from 12 deg. to 40 deg. after top dead center (ATDC).



Documents

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