

Influence of Ca-, Mg- and Na-Based Engine Oil Additives on Abnormal Combustion in a Spark-Ignition Engine

Kenta Miura, Kento Shimizu, Norikuni Hayakawa, and Tomomi Miyasaka
 Nihon University Graduate School

Akira Iijima and Hideo Shoji
 Nihon University

Toshimasa Utaka, Kazushi Tamura, and Hideki Kamano
 Idemitsu Kosan Co., Ltd.

ABSTRACT

One issue of downsized and supercharged engines is low-speed pre-ignition (LSPI) that occurs in the low-speed and high-load operating region. One proposed cause of LSPI is the influence of the engine oil and its additives. However, the effect of engine oil additives on pre-ignition and the mechanism involved are still not fully understood. This study investigated the influence of engine oil additives on abnormal combustion in a spark-ignition engine. A four-stroke air-cooled single-cylinder engine with a side valve arrangement was used in conducting combustion experiments. The research methods used were in-cylinder pressure analysis, in-cylinder visualization and absorption spectroscopic analysis. Engine oil additives were mixed individually at a fixed concentration into a primary reference fuel with an octane number of 50 and their effect on knocking was investigated.

CITATION: Miura, K., Shimizu, K., Hayakawa, N., Miyasaka, T. et al., "Influence of Ca-, Mg- and Na-Based Engine Oil Additives on Abnormal Combustion in a Spark-Ignition Engine," *SAE Int. J. Engines* 9(1):2016.

INTRODUCTION

Technologies for further improving the fuel economy of automotive engines have become necessary in recent years. In this regard, rapid progress has been made in high-compression engines and in technologies for supercharging and downsizing engines so as to reduce the total displacement. These technologies offer advantages for improving fuel economy in that the engine can operate more frequently in the lower speed range where mechanical losses are smaller and the reduced displacement allows vehicle weight reductions. However, abnormal combustion in the form of low-speed pre-ignition (LSPI) that occurs under low-speed, high-load operating conditions becomes a problem and the ability to increase the engine load is also limited. One cause proposed for the occurrence of LSPI is that oil droplets entering the combustion chamber through the clearance between the piston rings and the cylinder wall are diluted by the fuel to become sources of autoignition. Another suggested cause is that deposits peel off the cylinder wall and become sources of autoignition. Moreover, it has also been reported that changing the composition of the additives included in the engine oil can affect the occurrence of knocking [1, 2, 3]. In studies conducted to date, the authors have mixed calcium (Ca)-, zinc (Zn)- and molybdenum (Mo)-based additives individually into the test fuel in the same proportions as these principal additive components are actually used

in engine oils. Our experimental results have shown that the Ca-based additive, which is used as an engine oil detergent, has the largest effect on autoignition [4-5].

In the present study, the Ca-based additive, which our previous research results have shown tends to promote LSPI, and magnesium (Mg)- and sodium (Na)-based additives that also serve as engine oil detergents were separately mixed into the test fuel. Combustion experiments were conducted to identify the influence of these engine oil additives on the occurrence of autoignition. The resultant combustion characteristics were compared on the basis of in-cylinder pressure analyses and in-cylinder visualization of the combustion flame.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

Experimental Equipment

Table 1 shows the specifications of the test engine and the experimental conditions used. The configuration of the cylinder head and the measurement equipment is shown in Figure 1. A four-stroke air-cooled single-cylinder engine with a side valve arrangement was used in the experiments because it facilitated easy in-cylinder combustion flame visualization and absorption

spectroscopic measurement. The engine temperature was raised under each fuel condition to induce a transition from normal to abnormal combustion. The spark plug washer temperature T_{SP} was measured as a representative engine temperature because the test engine was air-cooled.

In-Cylinder Visualization

As shown in Figure 1, the cylinder head was modified to allow the installation of a quartz window for optical access above the piston in order to visualize combustion in the cylinder. A portion of the combustion chamber was photographed with a high-speed camera at a frame rate of 40,000 frames/sec. and a resolution of 512×128 pixels.

Spectroscopic Measurement

Small quartz windows were provided in the end zone of the combustion chamber where autoignition tends to occur in order to facilitate absorption spectroscopic measurements as shown in Figure 1. Light from a xenon lamp was projected into the combustion chamber on one side and the transmitted light on the opposite side was sampled and introduced into a monochromator via an optical fiber cable.

Table 1. Engine specifications and experimental conditions

Four-stroke Air Cooled Single-cylinder Spark Ignition Engine	
Displacement	397 cm ³
Bore × Stroke	85 × 70 mm
Valve Arrangement	Side Valves
Compression Ratio	8 : 1
Engine Speed: N	1400 rpm
Boost Pressure: P_b (abs)	100 kPa (NA)
Intake Air Temperature	303 ±2 K
Ignition Timing	5 deg. BTDC
Mixture Ratio	Stoichiometric

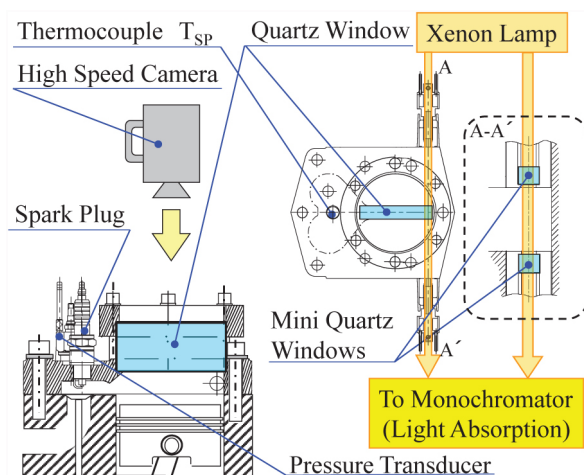


Figure 1. Configuration of test engine

Table 2. Test fuel

Test Fuel (Test Fuel + Additive)
PRF 50 Only
PRF 50 + Ca 2000 ppm
PRF 50 + Mg 2000 ppm
PRF 50 + Na 2000 ppm

The monochromator separated the light at a wavelength of 293.1 nm, corresponding to the absorption wavelength of formaldehyde (HCHO), which is an important species that is produced by low-temperature oxidation reactions [6]. The separated light was introduced into a photomultiplier tube and converted to an electric signal. The average value of the absorbance of the transmitted light prior to the occurrence of low-temperature oxidation reactions was defined as E_0 [A.U.] and used as the baseline. The absorbance of HCHO A_{HCHO} was calculated from the transmitted light intensity E [A.U.] at any arbitrary crank angle.

$$A_{HCHO} = \frac{E_0 - E}{E_0}$$

(1)

Test Fuel

The test fuel used in the experiments is shown in Table 2. A primary reference fuel with an octane number of 50 (PRF 50) was used as the baseline fuel under the assumption of autoignition of a mixture of engine oil and gasoline. As mentioned earlier, Ca-, Mg- and Na-based additives used as engine oil detergents were individually mixed into PRF 50 in a quantity of 2000 ppm to create the test fuel containing each additive.

EFFECT OF ENGINE OIL DETERGENT ADDITIVES ON COMBUSTION

The effect of the Ca-, Na- and Mg-based engine oil additives on the time of autoignition was investigated in combustion experiments.

Figures 2 and 3 present the measured waveforms and the visualized images of the combustion flame obtained at a spark plug washer temperature $T_{SP} = 470 \pm 2$ K with PRF 50 only and with the Ca-based additive mixed into the fuel. From the top the vertical axis shows the in-cylinder pressure P [MPa], heat release rate HRR [J/deg.] and HCHO absorbance A_{HCHO} in the end zone in relation to the crank angle θ [deg.] along the horizontal axis. The visualized images show the condition in the combustion chamber at intervals of 1 crank angle degree. The waveforms in this part were measured in every each cycles. The measured waveforms and visualized flame images show that the fuel containing the Ca-based additive advanced the time of autoignition compared with the results seen for PRF 50 only. This indicates that the Ca-based additive has the effect of promoting autoignition, as was seen in our previous research [4].