

Engine Oil Development for Preventing Pre-Ignition in Turbocharged Gasoline Engine

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ABSTRACT

Gasoline engine downsizing combined with a turbocharger is one of the more effective approaches to improve fuel efficiency without sacrificing power performance. The benefit comes from lower pumping loss, lower mechanical friction due to 'downsizing' of the engine displacement and 'down-speeding' of the engine by using higher transmission gear ratios which is allowed by the higher engine torque at lower engine speeds. However abnormal combustion referred to as Low-Speed Pre-ignition (LSPI) is known to be able to occur in low-speed and high-torque conditions. It is a potential restriction to maximize the engine performance and its benefit, therefore prevention of LSPI is strongly desired for long-term durability of engine performance.

According to recent technical reports, auto-ignition of an engine oil droplet in a combustion chamber is believed to be one of major contributing factors of LSPI and its formulations have a significant effect on LSPI frequency. Toyota has reported that the oxidation stability of engine oil can be a dominant factor of its auto-ignition, which is a function of its base oil and additive components, of which an example was found that calcium-based detergents significantly increase LSPI frequency.

Based on these findings, we have developed a new engine oil product which can reduce LSPI frequency to less than 10% of that of conventional ILSAC certified gasoline engine oils. High quality base oils (Group III, Group IV) and optimized additive components were formulated in which the amount of calcium-based detergent was reduced to levels lower than general ILSAC oils, and a sufficient amount of anti-oxidants were added. This newly developed engine oil is scheduled to be introduced for Toyota's new turbocharged gasoline engine vehicles. The new engine was released in July 2014 in the Japanese market. Toyota plans to subsequently launch the engine in Europe and the rest of the world.

CITATION: Fujimoto, K., Yamashita, M., Hirano, S., Kato, K. et al., "Engine Oil Development for Preventing Pre-Ignition in Turbocharged Gasoline Engine," *SAE Int. J. Fuels Lubr.* 7(3):2014, doi:10.4271/2014-01-2785.

1. INTRODUCTION

Automotive companies have been developing technologies to reduce CO₂ emission in an effort to be more environmentally conscious and to meet strict CO₂ emission standards. Gasoline engine downsizing by turbocharging and direct-injection systems is one of more effective approaches to improve fuel efficiency of vehicles without sacrificing driving performance. The concept behind this engine type is to achieve driving performance equivalent to a large-displacement engine in a small-displacement engine. The benefit comes from lower pumping loss, lower mechanical friction due to 'downsizing' of the engine displacement and 'down-speeding' of the engine by

using higher transmission gear ratios which is allowed by the higher engine torque at lower engine speeds. The image of low-speed torque improvement is shown in [Figure1](#).

One issue that may occur in low-speed and high-torque conditions is abnormal combustion that starts before the spark ignition timing. Known as low-speed pre-ignition (LSPI), this phenomenon has the potential to damage the engine if it occurs too frequently. Finding a solution for LSPI has been a major challenge for automotive companies. In 2010, a consortium was established at the Southwest Research Institute with the aim of preventing LSPI. Featuring participation by a number of OEMs and companies in the

lubricants industry, this consortium has been addressing the issue of LSPI through the cooperation of related companies in automotive area.

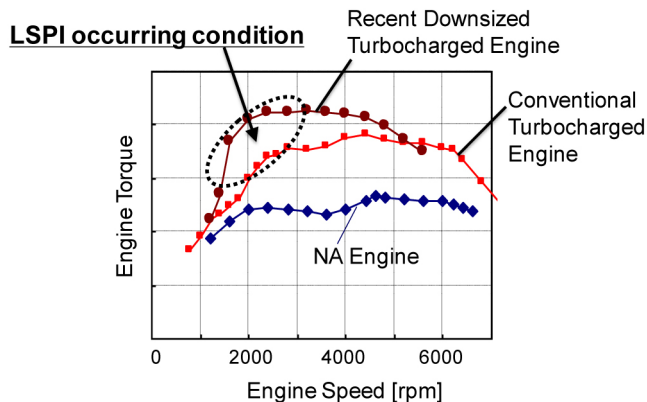


Figure1. LSPI occurring condition in engine operation

2. LSPI MECHANISM AND DEVELOPMENT CONCEPT

Recently many technical papers have been issued regarding LSPI observed in turbo-charged downsized gasoline engines. Dahnz from the Karlsruhe Institute of Technology (KIT) reported that the origin of LSPI is from the auto-ignition of engine oil droplets, which accumulate in piston crevices and become scattered inside the combustion chamber [1]. Zahdeh from General Motors reported that the type of engine oil has an effect on the LSPI frequency [2]. Based on above reports, auto-ignition of engine oil droplets can be illustrated as shown in Figure2.

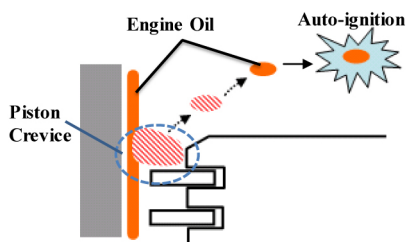


Figure2. Oil Droplet Auto-ignition in Combustion Chamber

The theory of Amann, M from Southwest Research Institute was that some liquid substances released from piston crevice is likely to be a source of LSPI since the volume of piston crevice had a significant impact on LSPI frequency [3]. This agrees well with the theory in Figure 2. Amann, M also referred to fuel composition effects in another technical paper [4].

Dingle, S from Brunel University clarified, by utilizing visualization inside the combustion chamber, that deflagration was consistently initiated from engine oil itself and the phenomenon were observed at specific location where the higher proportion of engine oil and oxygen existed [5]. This result also agrees with the mechanism which is suggested in Figure2.

According to the report from Toyota, Nippon Soken and Denso [6], solid particulate substances was identified as pre-ignition source, which was observed by visualization techniques inside the combustion chamber. According to this report, engine oil/fuel mixture may change to a solid substance with a short ignition delay time compared to engine oil itself.

In summary, it can be concluded that there are many factors which can affect LSPI phenomena; engine oil, deposit (solid substances), temperature, pressure, A/F ratio, and of course hardware design such as an injection system. The purpose of this study is to focus on engine oil formulation impact on LSPI and propose a solution to suppress LSPI phenomena.

Although LSPI frequency can be reduced by controlling the condition of engine operation and the behavior of engine oil within the combustion chamber through engine design based on the above findings, it would be impossible to completely prevent LSPI as far as oil is present. This research aimed to further reduce the LSPI frequency by focusing on the oil itself.

Since it was a new technical area and there was no previous research describing the effect of each engine oil component on LSPI, it was difficult to determine an initial direction for this development. Therefore, it was decided to verify the basic principles of the mechanism leading to the auto-ignition of oil, and to develop new engine oil capable of minimizing LSPI while maintaining the fundamental performance required for engine oil. The development target was reduce the LSPI frequency to 10% of that of conventional API certified gasoline engine oils (API SM, 0W-20).

3. TEST METHOD

A turbocharged prototype engine was used to evaluate the LSPI frequency with different oils. The specifications of tested engine are shown in Table 1.

As shown in Figure 3, the LSPI frequency was measured after an operation (preconditioning) to clean up the inside of the combustion chamber. The purpose of the cleaning process was to eliminate the effect from carbon deposits inside the combustion chamber. Carbon deposits are a known ignition source and may cause errors when measuring the LSPI frequency with different oil types.

The LSPI frequency was measured at wide-open throttle (WOT) and an engine speed of 1,800 rpm. The combustion pressure was monitored and the number of LSPI was recorded for one hour in which a pressure of 9 MPa or above counted as a single LSPI event.