

0W-16 Fuel Economy Gasoline Engine Oil Compatible with Low Speed Pre-Ignition Performance

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ABSTRACT

It has been long established fact that fuel economy is a key driving force of low viscosity gasoline engine oil research and development considered by the original equipment manufacturers (OEMs) and lubricant companies. The development of low viscosity gasoline engine oils should not only focus on fuel economy improvement, but also on the low speed pre-ignition (LSPI) prevention property. In previous LSPI prevention literatures, the necessity of applying Ca/Mg-based detergents system in the engine oil formulations was proposed. In this paper, we adopted a specific Group III base oil containing Ca-salicylate detergent, borated dispersant, Mo-DTC in the formulation and investigated the various effects of Mg-salicylate and Mg-sulfonate on the performance of engine oil. It was found that Mg-sulfonate showed a significant detrimental impact on silicone rubber compatibility while the influence from Mg-salicylate remains acceptable. The newly developed 0W-16 engine oil in this paper showed 1.0% fuel economy improvement (FEI) compared to typical GF-5 0W-20 engine oil. In addition, adequate fuel economy retention property of the 0W-16 engine oil was demonstrated in the ageing process. This newly developed engine oil also passed LSPI test and all of the bench and engine tests required by GF-5, which implied that this oil could provide good protection for engines.

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1. INTRODUCTION

The evermore stringent regulations on exhaust emission and fuel consumption prompt the continuous upgrading of engine oil. As shown in Table 1 [1], similar to the trends in EU, US and Japan, the fuel economy limit in China will be lowered from 6.9L/100km in 2015 to 5.0L/100km. Thus, automakers and oil companies are focusing more on devising new strategies to improve the fuel economy of vehicles.

On the one hand, fuel economy improvement is achieved by the downsized design of engines and the introduction of turbocharger to engines. However these designs may cause the abnormal pre-ignition phenomenon in the engine at low speed also known as low speed pre-ignition (LSPI) [2], which leads to extreme heavy-knocking and consequentially, results in severe engine damage. On the other hand, engine oil is playing a greater role in improving fuel economy of vehicles for its lower cost compared to other fuel saving strategies. From the Stribeck curve presented in Fujimoto et al.'s article [3], it shows that fuel economy improvement can be achieved by lowering

the friction coefficient in both boundary and hydrodynamic lubrication conditions through the introduction of friction modifier and lower viscosity of engine oil[4,5,6].

For low-viscosity engine oils, LSPI prevention property should be taken into consideration. Fujimoto et al. (2012) introduced an empirical equation about the relationship between LSPI frequency and the elements content in engine oil as shown in equation (1) in their previous study [2].

$$\text{LSPI frequency} = 6.59 \times \text{Ca}[\text{Wt. \%}] - 26.6 \times \text{P}[\text{Wt. \%}] - 5.12 \times \text{Mo}[\text{Wt. \%}] + 1.69 \quad (1)$$

According to this equation, calcium content in engine oil should be decreased. In order to maintain the deposit control capability, magnesium-based detergents are usually added to engine oil formulations. According to another study [7], Kaneko et al. (2016) found that Mg-sulfonate detergent-based formulations resulted in a higher friction coefficient compared to Ca-salicylate-based

Table 1. Projected FE limits for new vehicles

Counties /Region	2015	2020	2025	Degree of Reduction -2020	Degree of Reduction -2025
	Limits	Limits	Limits		
China	6.9L/100km	5.0L/100km	—	5.5%	—
EU	130g/km (5.2L/100km)	95g/km (3.8L/100km)	75g/km (3.0L/100km)	5.4%	4.2%
America	36.2mpg (6.5L/100km)	44.8mpg (5.3L/100km)	54.5mpg (4.3L/100km)	3.7%	3.4%
Japan	16.8km/L (5.9L/100km)	20.3km/L (4.9L/100km)	—	3.3%	—

formulations, which implied a detrimental impact on the fuel economy of vehicles. This negative impact was counter balanced by the introduction of borated dispersant. Nevertheless Kaneko et al.'s study did not probe the different influence of Mg-salicylate and Mg-sulfonate on the engine oil performance.

Based on all of the above, this paper would like to probe the various effects of Mg-salicylate and Mg-sulfonate on the performance of engine oil, and developed new 0W-16 low viscosity engine oil compatible with low speed pre-ignition performance, which also passed all of the bench and engine tests required by GF-5.

2. STRATEGY OF LOW-VISCOSITY ENGINE OIL DEVELOPMENT

In the development of the oil, fuel economy improvement is the most essential criteria being focused on. Hence, viscosity index improver (VII) with better friction reduction and viscosity-temperature properties was selected primarily.

For more attention would like to be paid to the various effects of Mg-salicylate and Mg-sulfonate on the all-round performance of engine oil, including fuel economy, we adopted a specific Group III base oil containing specific Ca-salicylate detergent, borated dispersant, Mo-DTC in the formulation. Finally, we conducted LSPI test and the entire bench and engine tests required by GF-5 on the developed oils and guaranteed well durability property of the newly-developed oil.

3. TEST METHODS

A high frequency reciprocating rig (HFRR) and mini-traction machine (MTM) were used in the evaluation of three selected viscosity index improver (VII). A viscosity index improver with better friction reduction property will be chosen in the formulation.

3.1. Mini-Traction Machine (MTM)

MTM works as a screening test method for measuring friction and wear behavior of lubricants in both boundary friction and hydrodynamic friction condition. The friction coefficient curves of three 0W-16 candidate oils were tested by MTM with different PMA VIIs. The test conditions are shown in [Table 2](#).

Table 2. MTM test conditions

Mini-traction Machine	
Materials	AISI 52100 steel ball and disk
Sliding rolling ratio	50%
Load	30N
Contact pressure	1.0Gpa
Speed	10~3000mm/s
Test duration	6sec/step
Temperature	80℃

3.2. High Frequency Reciprocating Rig (HFRR)

High-frequency reciprocating rig, as described in ASTM D6079-99, is usually used to evaluate the lubricity of diesel fuels, while it is also used to check the performance of low viscosity lubricants. In this paper, HFRR was adopted to check the friction reduction properties of the selected VIIs, as a supplementary of MTM test. The test conditions are shown in [Table 3](#).

Table 3. HFRR test conditions

HFRR	
Stroke	1mm
Load	400g
Temperature	100℃
Reciprocating frequency	50Hz

3.3. Engine Fuel Economy Test

Fuel economy improvement was evaluated using a 2ZR-FE, 1.8L, linear 4-cylinder engine with roller rocker arm type valve train system [2]. The test procedure was consisted of 9 typical engine conditions with different engine speeds, loads, oil temperatures and coolant temperatures, and each condition was assigned a weighting factor according to their contribution to the fuel consumption. The final fuel consumption was calculated by the amount of fuel consumption multiplied by corresponding weighting factors. In order to avoid the fluctuation caused by different engine tests, the engine fuel economy test of the GF-5 0W-20 reference oil was conducted prior to and after the test of the candidate oil. Final fuel economy improvement index was achieved with the normalized fuel consumption of candidate oil dividing the average fuel consumption of the reference oil.