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Influence of Engine Oil Aging on Low-Speed Pre-Ignition (LSPI) Behavior

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Low-Speed Pre-ignition (LSPI) is well known as an abnormal combustion phenomenon in downsized turbocharged gasoline direct injection engine operation. Because lubricant was found to exhibit an impact on LSPI behavior, many studies on effects of engine oil formulation have been conducted, resulting in introduction of Sequence IX test in specific API service categories for passenger car engine oils. Many studies have investigated the formulation impact and revealed several valuable formulation impacts on LSPI events frequency, such as LSPI events increased with calcium (Ca) detergents content, and Zinc Dialkyldithiophosphate (ZnDTP) and molybdenum dithiocarbamate (MoDTC) suppressed LSPI. However, many of those studies tested engine oils without any aging procedures, so durability of LSPI capable engine oils has been considered only recently. In this study, engine oil aging effects on LSPI behavior were evaluated in a Ford 2.0L EcoBoost engine using oils with various formulations, and synchrotron X-ray absorption spectroscopy was carried out to understand local electronic structure of molybdenum LSPI inhibitors before and after aging procedure.

Four different fully formulated 0W-16 gasoline engine oils were prepared as test oils using dispersant, detergent, ZnDTP, anti-oxidant, foam inhibitor, MoDTC, viscosity modifier, and base oil. Detergent system in the test oils comprised of only Ca detergents. Those additives were formulated constant among the test oils except Ca detergents and MoDTC. Ca and Mo contents of the test oils are summarized in Table 1.

A Ford 2.0L EcoBoost TGDI engine weas used to evaluate LSPI performance and age test oils. Typical operation parameters in aging procedure are summarized in Table 2. This aging procedure was considered to correspond to approximately 4,000 miles in vehicle testing. After 72 hours of the engine operation, almost all of base from detergents was neutralized, indicating all test oils were significantly aged. Almost all ZnDTP and MoDTC formulated into the test oils, which have been considered as strong inhibitors of LSPI event in fresh oils, were decomposed into other chemical compounds.

LSPI tests were conducted for each test oil before and after aging, named Fresh and Aged, respectively (Figure 1). Lower Ca content oils, Oil-1 and Oil-2 exhibited excellent LSPI performance even after aging. These results are consistent with previous studies, indicating lower Ca content formulations should have good LSPI performance and durability even without larger amount of MoDTC. On the other hand, the aging procedure clearly increased LSPI events in higher Ca content oils. LSPI events decreased with increasing MoDTC amount, and surprisingly more effective suppression was observed after aging procedure in higher Ca content oil. (Table 3). The synchrotron X-ray absorption spectroscopies revealed MoDTC was oxidized into Mo(VI) oxysulfides, which has been shown to suppress LSPI in Sequence IX.. These findings are expected to provide new engine oil formulation technology to give high LSPI durability.

Table 1. Elemental description of test oils

Formulation	Oil-1	Oil-2	Oil-3	Oil-4
Ca content (wt%)	0.14	0.14	0.20	0.20
Mo content (wt%)	0.10	0.05	0.10	0.05
P content (wt%)	0.77	0.77	0.77	0.77

Table 2. Engine operation condition of aging procedure

Parameter	Condition
Engine Speed	2500 rpm
Torque	128 Nm
Oil Gallery Temp.	100°C
Coolant Out Temp.	85°C
Lambda	1
Blowby	65-75 L/min
Duration	72 hr

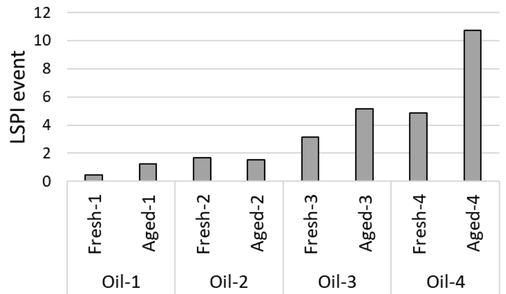

Figure 1. Number of LSPI events of Oil-1, -2, -3, and -4 before and after aging procedure, Fresh and Aged, respectively.

Table 3. LPSI suppression effects of MoDTC in different Ca content oils.

Ca content (wt%)	LSPI Change per Mo content (event/wt%)[a]	
	Fresh	Aged
0.14	-25	-6
0.20	-34	-112

[a] Derived from the equation below,

$$\frac{[\text{No. of events at Mo=0.05wt\%}] - [\text{No. of events at Mo=0.10wt\%}]}{[\text{0.10wt\% of Mo content}] - [\text{0.05wt\% of Mo content}])}$$

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