

Development of Low Viscosity API SN 0W-16 Fuel-Saving Engine Oil Considering Chain Wear Performance

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ABSTRACT

A low viscosity API SN 0W-16 engine oil was developed to achieve a 0.5% improvement in fuel efficiency over the current GF-5/API SN 0W-20 oil. Oil consumption and engine wear are the main roadblocks to the development of low viscosity engine oils. However, optimization of the base oil and additives successfully prevent oil consumption and wear. First, it was confirmed in engine tests that NOACK volatility is still an effective indicator of oil consumption even for a low viscosity grade like 0W-16. As a result of base oil volatility control, the newly developed oil achieves the same level of oil consumption as the current GF-5/API SN 0W-20 oil. Second, it was found that the base oil viscosity and molybdenum dithiocarbamate (MoDTC) had a significant effect on chain wear in rig testing that simulated silent chain wear. For the same base oil viscosity, the new oil maintains the same oil film thickness under high surface pressure. The same base oil as that of the current GF-5 0W-20 oil was selected to obtain that oil film thickness. Viscosity was adjusted by reducing the viscosity modifier content. Additionally, the anti-wear performance of MoDTC was confirmed not only with fresh oil, but also with aged oils that were collected after actual vehicle tests. MoDTC reduced friction and wear with fresh oil, but aged oils showed high friction and low wear. This indicates that some MoDTC decomposition products do not have a friction reduction effect, but they reduce wear. As a result of optimizing the base oil and additives, the anti-wear performance of the new oil was assured.

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INTRODUCTION

Powertrain systems with good energy efficiency like those of hybrid electric vehicles (HEVs) and electric vehicles (EVs) are being put on the market mainly in Japan, America, Europe and China for the purpose of improving fuel economy. Globally, however, vehicles fitted only with an internal combustion engine (ICE) still account for the vast majority of the overall vehicle population. Accordingly, from the standpoint of reducing CO₂ emissions, improving the fuel economy of ICE-equipped vehicles remains a critical issue.

Ways of improving ICE fuel economy include increasing thermal efficiency, reducing pumping losses and lowering friction. In this connection, progress has been made in various areas related to lubricating oils. For example, molybdenum friction modifiers are being used to reduce friction of sliding engine parts [1, 2, 3]. Low friction surface treatments have been developed such as hydrogen-free diamond-like carbon (DLC) coatings [4], and engine oils optimally suited to such surface treatments have also been developed [5, 6]. In recent years, much work has been done especially on approaches for improving fuel economy by using low viscosity engine oils to reduce viscous resistance. This trend is most salient in the Japanese market. Low viscosity engine oils are being put on the market for compact cars, including minivehicles, and HEVs.

Low viscosity engine oil grades have been newly established in the SAE J300 viscosity classification such as SAE 16 in 2013 and SAE 12 and 8 in 2015. With regard to SAE 16 in particular, the American Petroleum Institute (API) established a new engine oil specification designated as API SN in 2015 and added the Resource Conserving category in 2016 [7]. Before the API SN specification was added to SAE 16, there were no general API/ILSAC (International Lubricant Specification Advisory Committee) specifications for other viscosity grades. Each company implemented its own original criteria for confirming quality. Low viscosity grade oils below the level of SAE 20 and complying with the specification are being studied and applied to specific engines [8, 9].

However, from the standpoint of improving fuel economy by popularizing and promoting the use of fuel-saving engine oils, it is necessary to have oils that can be applied without making any major changes to engine specifications. For that reason, there is a need for engine oils having qualities conforming to the SN specification that applies to the 0W-20 fuel-saving oils already in general use. In general, reducing the viscosity of engine oils has two principal adverse effects: (1) oil consumption increases due to greater oil vaporization; (2) wear increases owing to the reduction of the oil film thickness.

This paper describes the development of a new 0W-16 oil that conforms to the SN specification. First, the base oil was optimized to inhibit oil consumption. Second, anti-wear performance was maintained and improved by optimizing the base oil and adding a molybdenum dithiocarbamate (MoDTC) additive. Third, friction was reduced by applying an ashless friction modifier (FM) for which good results have been reported [10, 11] in combination with a DLC coating that is a proven friction reduction technique.

EXPERIMENTAL

Motored Silent Chain Wear Test

Table 1. Motored chain wear test mode

Chain type	Silent chain
Speed	6000 rpm
Oil temperature	100 ± 1 or 110 ± 1 °C
Oil supply	Splash
Oil	Oil with 0.4mass% carbon black DIA CONTAMINANT SD-R Mitsubishi Chemical Average particle size from 0.1 to 0.3 μm



Figure 1. Silent chain wear test

Figure 1 shows the test equipment that was used to simulate silent chain wear. Two adjustable shafts equipped with sprockets enabled the chain to be rotated under arbitrary levels of tension, temperature and speed. The timing chain length was measured with designated measurement equipment before installation on the wear test equipment and it was measured again after the chain wear test. Chain elongation was calculated from the difference between the initial and final chain length. In this study, oil evaluations were conducted under high tension and high temperature operating conditions in consideration of the fact that the oil film thickness of low viscosity oils is reduced.

Carbon black was added to the engine oil to simulate actual engine conditions. Pre-diluted DIA CONTAMINANT SD-R was used. The carbon black content was adjusted to 0.4mass% by adding fresh oil.

Fired Chain Wear Test

The chain wear test was a fired engine dynamometer lubricant test, which evaluates the ability of a test lubricant to reduce timing chain wear. It was proposed as an ILSAC GF-6 chain wear test. It is conducted as a cyclic test, with a total running duration of 216 hours. A water-cooled, 4-cycle, in-line cylinder, 2.0-liter direct injection Ford engine was used in the chain wear test. The engine had a dual overhead cam, four valves per cylinder, and a direct-acting mechanical bucket lifter valve train. The timing chain was replaced in each test. The chain length was measured prior to installation, after break-in and at the end of the test. The test sequence was repeated for 54 test cycles. Each cycle consisted of two stages and ramps as outlined in Table 2.

Table 2. Fired chain wear test condition

Parameter	Stage 1	Ramp 1 → 2	Stage 2	Ramp 2 → 1
Duration min.	120	30	60	30
Engine speed rpm	1550	-	2500	-
Engine torque N·m	50	-	128	-
Oil gallery temperature °C	50	-	100	-
Engine-out coolant out temperature °C	45	-	85	-

Engine Motoring Torque Test

Table 3. Motoring torque test conditions

Engine type	2.0L L4
Valve train type	Bucket type DOHC
Valve lifter type	Hydrogen-free DLC coating
Engine speed	550-2800 rpm
Oil temperature	50±0.1 °C, 80±0.1 °C
Coolant temperature	50±0.1 °C, 80±0.1 °C

The equipment used to measure friction in the engine is shown schematically in Figure 2. The spark plugs, exhaust manifold, and intake manifold were removed from the test engine. The flywheel was modified to attach a torque meter. The engine oil was heated with an electrical heater in the oil pan. The coolant temperature was controlled with an external temperature controller. A 30-minute flushing operation was performed twice at 1600 rpm before each friction measurement. Engine friction was measured from idling speed to 2800 rpm. The contribution of the oil to fuel economy improvement was calculated based on the reduction in friction torque. The change in torque was confirmed before and after each test with a reference oil. Based on the friction torque measured in motoring torque tests, the main

improvement in fuel economy under Japan's JC08 emission test mode was calculated by using the proportionality constant. The engine and test conditions used in the motoring torque tests are shown in Table 3.

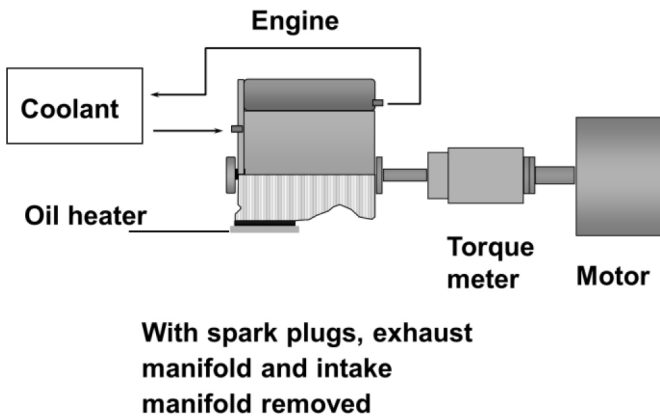


Figure 2. Engine motoring torque test

SRV Reciprocating Friction and Wear Test

Friction tests that simulated silent chain wear and friction were conducted using an SRV reciprocating friction test machine made by Optimol. The cylinder test piece was made of the same carburized high carbon steel with vanadium carbide as the chain pins. The disk test piece was made of the same materials as the chain plates. The center of the disk piece was in 5.0 mm in width. The other area was 0.45 mm in height. An SRV test specimen is shown in Figure 3. The SRV test conditions are shown in Table 4.

Table 4. SRV test conditions

Cylinder test piece	3 mm dia. Carburized high carbon steel with vanadium carbide
Disk test piece	24 mm dia. × 7.9 mm Material JIS G 4051 S55C C:0.52-0.58 mass% Si:0.15-0.35 mass% Mn 0.6-0.9 mass% P:0.030 mass% max. S:0.035 mass% max.
Load	600 N
Stroke	3.0 mm
Wear width	5.0 mm
Frequency	50 Hz
Oil temp.	80 °C
Oil volume	100 µL
Test time	120 min.

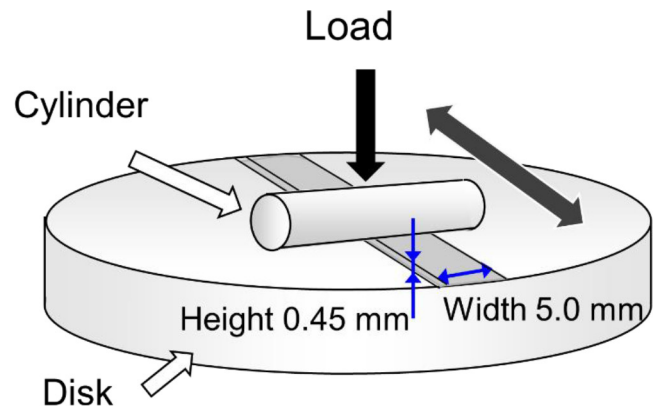


Figure 3. SRV test specimen

XPS Analysis Test Condition

Disk test pieces were analyzed to confirm the molybdenum compounds formed on the surface. The analysis conditions are shown in Table 5.

Table 5. XPS analysis conditions

X-ray source	Al Ka (hv=1253.6 eV)
X-ray spot size	400 µm
Pass energy	50 eV
Step size	0.1 eV
Dwell time	50 msec.
Number of scans (Mo3d)	50

RESULTS AND DISCUSSION

Investigation of Oil Consumption

As one index of oil consumption, the API SN specification requires that the NOACK volatility (i.e., mass loss) of an oil should be no more than 15% when tested at 250°C for one hour. Oil consumption tests were conducted using a 2.0L L4 engine to confirm whether an allowable level of oil consumption could be guaranteed when the same index was applied to oils having lower viscosity than that of SAE 20. The amount of oil consumption was found by weighing the test oil after 4 hours of engine operation under a 6000-rpm full load mode.

The properties of the oils used in the tests are shown in Table 6. Based on the use of the same performance additives, the NOACK volatility of the test oils was adjusted by varying the base oil. The viscosity of the test oils was adjusted by varying the content of the viscosity modifier (VM) that was added. The viscosity of Oil B was reduced to that of 0W-16 and volatility was maintained by changing the base oil and reducing VM. The high shear rate and high temperature (HTHS) viscosities of Oil C and Oil D were the same as the values of Oil B. Lower viscosity base oil than Oil B was added to Oil C to increase NOACK and VM was added to adjust the