

Additive Formulation Technology for Fuel Economy Passenger Car Motor Oil and Development of Sequence VID Screener

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ABSTRACT

Fuel economy is one of the most essential performance requirements for Passenger Car Motor Oil because of fuel economy regulations in many countries and increasing fuel prices. The ILSAC GF-5 specification was issued on December 22, 2009 and requires better fuel economy performance based on the Sequence VID (Seq. VID) Test and higher weighted piston deposit merits based on the Sequence IIIG Test, compared to the ILSAC GF-4 specification. Fuel economy performance is affected by viscosity, friction modification and the lubricant additive chemistries. However, fuel economy engine tests under combustion mode introduce high variability into a fuel economy measurement. Screening by bench testing is complicated by the difficulty to reproduce friction conditions of all of engine parts. A motored friction torque test using an engine is one of the better solutions for fuel economy screening. As such, various additive chemistries were evaluated on this test using the latest model engine, and it distinguished the differences in additive chemistries, in addition to those in viscosity and friction modifiers. A correlation between the motored friction torque test and the Seq. VID for Fuel Economy Improvement (FEI 1) was also studied. The impact of phosphorus contained in Zinc Dithiophosphate was also evaluated for fuel economy in the Sequence VIB (Seq. VIB). Lower phosphorus formulations showed better fuel economy improvement.

INTRODUCTION

Global warming is one of the most important environmental issues. Carbon dioxide (CO₂) is well known as a greenhouse effect gas which is one of the factors of global warming. Most industries have been taking various actions to reduce CO₂. In the automotive industry, the fuel economy regulations¹⁻³ as well as engine oil specifications were applied in major countries. To satisfy such regulations, automobile makers have been working to develop new technologies to achieve less fuel consumption. They have been introducing new products equipped

with new technologies aimed at reducing CO₂ production. The engine lubricant can also play an important role for reducing CO₂ production because fuel economy performance is affected by lubricant oils⁴⁻¹¹. Therefore, lubricant manufacturers and additive companies have been working to develop "Fuel Economy" lubricants. They have been using motored engine friction tests for their studies and reported lower viscosity oil yielded higher friction reduction¹²⁻¹⁷. In addition to fuel economy regulations, consumers are interested in fuel economy performance due to recent increases in fuel prices. This demand is also driving the need for vehicles with better fuel efficiency. In this paper, the development of motored modern engine friction torque test and various lubricant formulation technologies for fuel economy are investigated and report an excellent correlation between the developed motored engine friction torque test and Sequence VID.

EXPERIMENTAL

ENGINE SPECIFICATION USED FOR FUEL ECONOMY MEASUREMENT ON CHASSIS DYNAMOMETER

Details of engine specification used for fuel economy measurement on Chassis Dynamometer are shown in Table 1.

Table 1 Description of Engine

Engine Type	L-4
Aspiration	Natural Aspiration
Valvetrain System	16-valve, DOHC
	Slide Type

MOTORED FRICTION TORQUE TEST

Two types of motored engine friction torque tests were developed and used to screen fuel economy performance of engine lubricant. Details of engine specifications are shown in Table 2.

Table 2. Description of Motored Friction Torque Test

	Motored Friction Torque Test	
	Fully Assembled Engine	Cylinder-head
Engine Type	L-4	L-4
Aspiration	Natural Aspiration	Natural Aspiration
Valvetrain System	4-valve, DOHC	4-valve, OHC
	Roller Rocker Arm	Sliding Rocker Arm
Min/Max Engine Speed/ rpm	550-2,000	375-1,000
Oil Gallery Temperature/ °C	25-100	60-120

Motored Engine Friction Torque Test

The motored engine friction torque test uses all engine parts such as cylinder-head, pistons and crankshaft and so on. The valvetrain system employs roller type. The motor is connected with the crankshaft through a torque meter. The ignition plugs were removed to release cylinder compression pressure. The oil temperature is controlled by an electric heater and the test oil is circulated by oil pump as shown in Figure 1. The friction torque was measured and % increase was determined using that of SAE 0W-20 reference oil without friction modifier.

Motored Cylinder-head Friction Torque Test

The motor is connected with the camshaft through a torque meter. The driving torque of camshaft and rocker arm is measured as the friction. Sliding type valvetrain system was employed in this test stand.

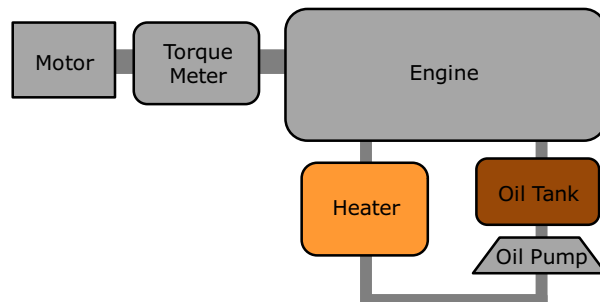


Figure 1. Design of Motored Friction Torque Test

RESULTS AND DISCUSSION

IMPACT OF VISCOSITY AND FRICTION MODIFIER FOR FUEL ECONOMY

It is generally assumed that there are two major factors which affect fuel economy: One is viscosity and the other is friction modifiers. The viscosity is determined by viscosity modifiers (VM) and base stocks. First, effect of viscosity on fuel economy performance was evaluated. Three test oils were prepared by blending them at between 2.6 cP and 3.7 cP High Temperature High Shear (HTHS) viscosity at 150 °C. Vehicle fuel consumption using each of the test oils was measured on a Chassis Dynamometer test under the 10-15 mode¹⁸, which is the Japanese fuel economy measurement method. Fuel consumption was calculated by the carbon balance method. All oils were run 5 times each and an average

was used as the fuel consumption. Fuel economy improvement was determined using averaged fuel consumption of 2.9 cP HTHS viscosity oil without friction modifier as the baseline for comparison. As shown in Figure 2, the lower HTHS viscosity oil gave better fuel economy improvement. This is the reason why Sequence VI test requires higher pass limit for lower viscosity grades. Friction modifiers also significantly contribute to improving fuel economy. Historically, both organic and inorganic friction modifiers are used in engine oil formulations. The organic friction modifiers have been found to be most effective in mixed and hydrodynamic conditions while the inorganic friction modifiers have been found to be most effective in boundary type conditions. For this study, the performance of an inorganic friction modifier was examined by Chassis Dynamometer test under the 10-15 mode¹⁸, as also shown in Figure 2. The benefit of the friction modifier was over 0.5% under the 10-15 mode.

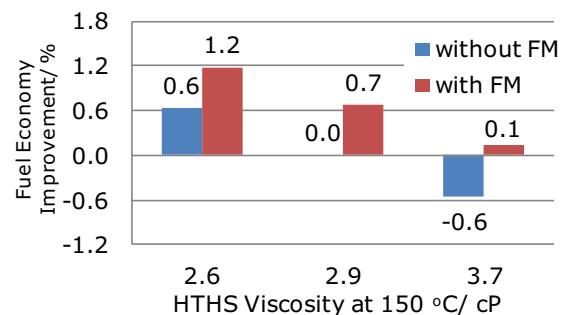


Figure 2. 10-15 Mode Fuel Economy Test on Chassis Dynamometer

EVALUATIONS ON MOTORED ENGINE FRICTION TORQUE AND SEQUENCE VID TESTS

The impact of viscosity on our motored engine friction torque test was studied at high and low temperatures. The impact of different HTHS viscosities was also evaluated. The HTHS viscosity of the test oils at 150 °C range from 2.3 cP to 3.6 cP and friction torque change was determined using friction torque of 3.5 cP HTHS viscosity oil as the baseline for comparison. No friction modifier was formulated in any of the tested oils and physical properties are shown in Table 3.

Table 3. Physical Properties

HTHS Viscosity @ 150 °C	cP	2.3	2.5	2.7	2.9	3.5
KV100	mm ² /s	7.4	8.2	9.1	9.9	13.3
KV40	mm ² /s	41.0	46.7	52.6	58.8	82.2
Viscosity Index		146	152	155	153	163

The results at steady engine speed are shown in Figure 3. Friction reduction was observed at the lower HTHS viscosity at 40 °C. However, at 80 °C, increase of friction torque was observed at 2.3 cP. This is considered a typical indication that the friction conditions have changed and shifted to more boundary conditions because of thinner oil film by higher temperature and gave higher friction torque^{11,13,14,16,17}.