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The Effects of Base Oil Quality on the Performance of GF-3 Engine Oil

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Abstract : The International Lubricant Standardization and Approval Committee (ILSAC) GF-3 passenger car engine oil specification has been introduced commercially in July 2001. The new specification oil provides superior performance in terms of fuel economy, control of high temperature deposits, and oil consumption. These enhanced performances of GF-3 engine oil need high quality base oil as well as a better additive system. In this paper, the effect of base oil on various performances of ILSAC GF-3 engine oil was investigated. From the GF-3 sequence engine tests, Group III base oil shows better performance in fuel economy retention, oxidation and varnish control than combination of group III and group II or group III and group I.

Keywords : Base oil, GF-3, fuel economy, oxidation, sludge

Introduction

The ILSAC GF-3 passenger car engine oil specification has been introduced commercially in July 2001. The ILSAC GF-3 specification was designed to meet the OEMs needs for high performance engine oil.

In January 1996, the American Automobile manufacturers Association (AAMA) initiated the development of the new specification. Carmakers recognized that lubricants meeting the ILSAC GF-2 specification would not be adequate to protect engines expected to be on the market shortly after year 2000 [1]. The original time schedule for the new specification was that the definition of new specification would be completed by December 1998 and in January 2000, new specification would be used. However, the uncertainties associated with developing new tests and the time needed to understand new requirements delayed the timeframe [1].

The new specification oil provides superior performance in terms of fuel economy in new and used oil, emission system protection, control of high temperature deposits, foaming/oil aeration, and oil consumption. In addition to meeting the above requirements, control of sludge, varnish, corrosion, wear, and oxidation was not to be diminished, compared with GF-2 [1].

All of the engine tests required for ILSAC GF-3 were changed from those required for ILSAC GF-2. The new tests incorporated more current engine technology and unleaded fuel [2]. Table 1 shows the comparison of GF3 and GF2 engine tests.

These enhanced performances of GF-3 engine oil need high quality base oil as well as a better additive system. By the late 1980s, additives played key roles in improving engine oil quality. The engine oil problems observed in the field had the specification be changed [3]. In order to solve the problems, new additives were used and the treat rate of some additive was increased, while base stocks were not significantly changed.

However, recent requirements for engine oil will not be met by only advanced additive system without improved base oil. Severe emission and fuel economy regulations need improved base oil quality. For example, one way to improve fuel economy through oil is to use low viscosity grade oil. However, the use of low viscosity oil will increase oil consumption and induce engine wear. In order to minimize oil consumption, it is necessary to use low volatile base oil. The ILSAC GF-3 standard requires that oil volatility must be lower than 15% Noack, as compared to 22% in the GF-2 oil. (Table 1)

In this paper, the effect of base oil on various performances of ILSAC GF-3 engine oil was investigated. The results are organized into sections based on major performance characteristics such as fuel economy, oxidation and deposit control, and sludge and varnish control.

Table 1. Comparison of ILSAC GF-2 to GF-3

Attribute	GF-2	GF-3
Corrosion Protection	CRC L-38 Sequence IID	Sequence VIII Ball Rust Test
Oxidation Control	Sequence IIIE	Sequence IIIF
Sludge Control	Sequence VE	Sequence VG
Wear Protection	Sequence VE Sequence IIIE	Sequence IVA Sequence IIIF
Fuel Economy	Sequence VIA	Sequence VIB
Deposit Control	Sequence IIE TEOST	Sequence IIIF TEOST MHT-4
Emission Protection P contents, %	0.10 max	0.10 max
Volatility(Noack), %	22 max	15 max
High Temp. Foam, ml	200/50	100/0
Shear stability	CRC L-38	Sequence VIII

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Table 2. Physical properties of test oil

Test	Procedure	Oil A	Oil B	Oil C
Base oil blend		Group III	Group II /Group III	Group I /Group III
KV @ 40°C, cSt	D445	58.07	63.70	59.70
@ 100°C, cSt	D445	10.19	10.55	10.25
CCS @ -30°C, cP	D5293	4,630	5,860	5,120
CCS @ -35°C, cP	D5293	4,630	12,085	11,180
MRV @ -35°C, cP	D4684	17,000	23,100	28,500
HTHS @ 150°C, cP	D4683	3.03	3.08	2.95
Evaporation loss NOACK, wt. %	D5800	12.0	13.1	14.7

Experiment

All test lubricants are blended to SAE 5W30 viscosity grade. Three base oil blends were used for making 5W30 engine oil. The first is API group III base oil only, the second is API group II/group III base oil, and the third is the combination of API group I/group III base oil. All oils use the same treat of DI and friction modifier, but small amount of antioxidant and detergent, if necessary, are added to meet the GF-3 specification. Olefin copolymer type Viscosity Index Improver (VII) was used for all three type of oil.

Physical properties of test oil are measured in accordance with the procedure written in Table 2. All engine tests are conducted in accordance with the standard ASTM Sequence procedure.

Table 2 shows the base oil blend and the physical properties of three types of oil. OIL A using API group III base oil shows good low temperature properties compared with OIL B and OIL C using API group II/group III and API group I/group III. OIL A has also the lowest volatility. These features are mainly contributed by using group III base oil. API Group III base oil has inherently high viscosity index, low volatility, and excellent low temperature fluidity.

Results and Discussion

The base oil influences various performance of passenger car engine oil. According to the Sequence engine test results, the features that are mainly affected by base oil are fuel economy, oxidation and deposit control, and sludge and varnish control. Anti-wear characteristic and the performance of corrosion inhibition and rust prevention was found to be mainly influenced by additive.

Fuel Economy

Fuel economy and its retention is OEM's key concern in the GF3 specification. The fuel economy requirement for the ILSAC GF-3 specification is measured through the Sequence VIB engine test which is a replacement of the Sequence VIA test of ILSAC GF-2 (Table 1). Features of the Sequence VIB include five operational stages and measurements taken before and after an extended aging period to evaluate fuel economy retention [4]. A 1997 Ford 4.6L spark ignition, V-8 cylinder design, 4-cycle engine is used as a test apparatus. The Sequence VIB test incorporates a flush and run type procedure. Each test consists of two 5-stage fuel economy measurements on baseline oil (BC), one at the beginning of the test and one at the end. The test oil is evaluated in between the two baseline runs. The test oil is initially aged during sixteen hours of engine operation at 1500 rpm and 125 oil temperature. After the initial aging, a 5-stage fuel economy measurement is taken. The test oil is then aged an additional eighty hours at an engine speed of 2250 rpm and 135°C oil temperature. Following this final aging, the test oil again goes through a 5-stage fuel economy measurement. The two fuel economy measurements taken on the baseline oil (BC) and a final value for Fuel Economy Improvement is calculated for the test oil.

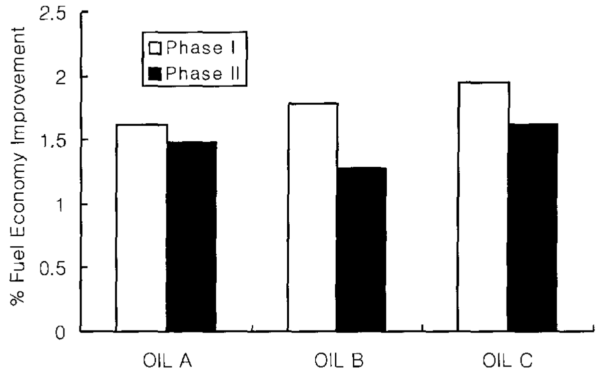

Fig. 1. Comparison of sequence VIB performance of test oil.

Test results of fuel economy are given in Fig. 1. The results show that OIL C using group I and group III base oil has the largest fuel economy improvement, while OIL A using only group III base oil shows the smallest fuel economy improvement. On the other hand, OIL A is smallest in the differences of fuel economy improvement between phase I and phase II.

The effects of engine oil on the Sequence VIB fuel economy are reported by Boffa and Hirano [4]. They showed that both HTHS and base oil viscosity is major impacts on Sequence VIB fuel economy. Because three oils have the same DI and friction modifier, the factor that can lead to these results is considered as the effect of base oil. Fig. 2 shows the relationship between base oil viscosity and fuel economy improvement. Better fuel economy of OIL C and OIL B is due to lower base oil viscosity relative to OIL A.

The difference of the fuel economy between phase I and phase II is very interesting. OIL A shows the smaller difference than OIL B and OIL C. The higher fuel economy retention of OIL A is related the base oil. Higher oxidation stability and lower volatility of group III base oil can retard the increase of base oil viscosity.

Oxidation and deposit control

Oxidation stability of engine oil is very important for longer drain interval and fuel economy retention. The long drain

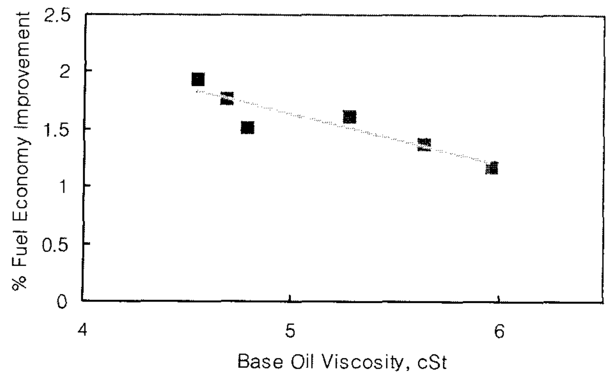

Fig. 2. Relation between fuel economy improvement and base oil viscosity.

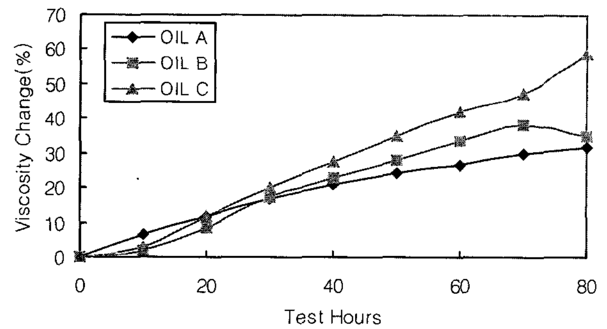

Fig. 3. Viscosity increase of test oil in sequence IIIF.

interval of engine oil has been emphasized for environmental protection and conservation of resources. The oxidation requirement for the ILSAC GF-3 specification is measured through the Sequence IIIF engine test which is a replacement of the Sequence IIIE test of ILSAC GF-2 (Table 1). The Sequence IIIF test is used for evaluating automotive engine oil for certain high-temperature performance characteristics, including oil thickening, varnish deposition, oil consumption, and engine wear. The Sequence IIIF test utilizes a 1996 model Buick 3800 engine as test apparatus. The Sequence IIIF Test consists of a 10-minute operational check, followed by eighty hours of engine operation at moderately high speed, load, and temperature conditions.

The change of viscosity in the Sequence IIIF is shown in Fig. 3. All of the test oil satisfied the GF-3 standard, but the pattern of viscosity increase varies with oils. Oil A has the least increasing rate while oil C has the biggest increasing rate.
Oxidation performance measured by viscosity increase varies with base oil blends. This difference of oxidation is presumed to come from the type of base oil, because of using the same DI. T. Yoshida, J. Igarashi and H. Watanabe reported that the performance of base oil in automotive and industrial applications can be adversely influenced by very small quantities of bad acting molecules such as multiring naphthene, polyaromatic compounds and basic nitrogen [5]. Table 3 shows the composition of base oil blend. According to base oil composition, OIL C is apt to be oxidized because of its low portion of saturate and high ratio of nitrogen compound

Table 3. Composition of base oil

	OIL A	OIL B	OIL C
Saturate %	99.60	98.90	87.05
N %	<0.0002	0.0029	0.0040
S %	<0.0001	0.0009	0.1350

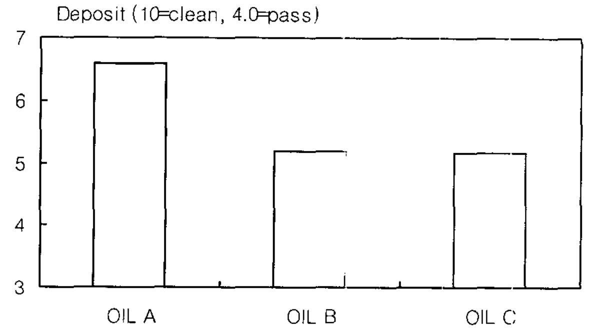

Fig. 4. Weighted piston deposit ratings in the sequence IIIF.

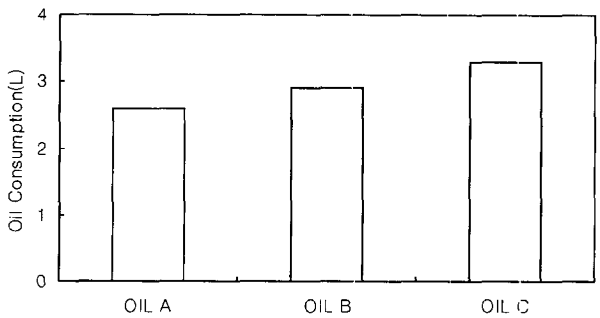

Fig. 5. Oil Consumption in the sequence IIIF.

compared to OIL A and OIL B.

OIL A using group III base stock gave the best deposit control ability in the Sequence IIIF (Fig. 4). This result for OIL A is possibly due to oxidation stability and low volatility of base oil. As shown Fig. 5, oil consumption of OIL A in the Sequence IIIF is the lowest.

Sludge and Varnish Control

The Sequence VG replaces the sludge and varnish evaluation portion of the Sequence VE test. The Sequence VG is designed to evaluate the ability of oil in preventing excessive sludge and varnish deposits in short trip/low temperature driving conditions. The Sequence VG cycles between cold and hot operation to promote the generation of acid and fuel in the oil [3].

Engine ratings for all of the tests are shown in Fig. 6, 7. Even though all three oil passed the requirement of GF-3, there is a little variation on average engine sludge, rocker cover sludge, and oil screen clogging. Good performance of OIL A on above three items is related to the type of base oil. Base oil effects on the Sequence VD and VE has been studied in several papers [6,7]. Roby *et al.* reported that high base oil saturate content was desirable for oxidation control while nitrogen, sulfur, olefins and aromatics were undesirable [6].

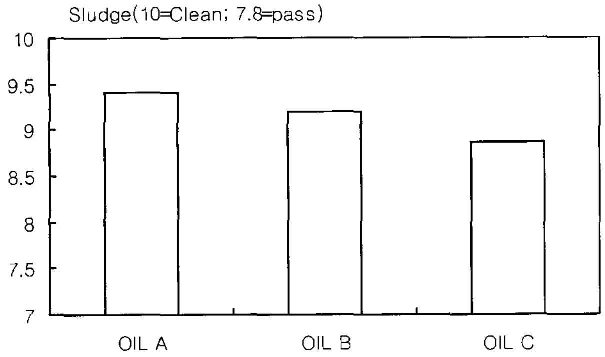

Fig. 6. Average engine sludge ratings in the sequence VG.

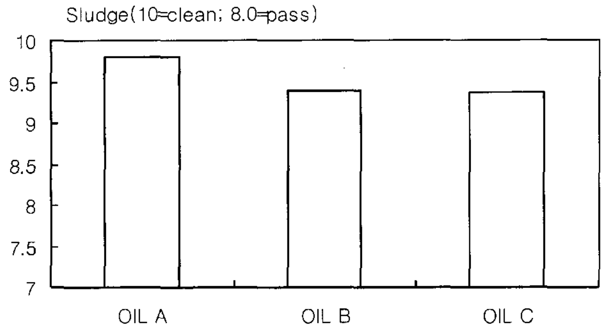

Fig. 7. Rocker cover sludge ratings in the sequence VG.

Base oil variables are most important to sludge and deposit formation in the Sequence VE [7]. Therefore, the best performance of OIL A in the Sequence VG is due to the highest saturate content and the lowest sulfur and nitrogen content of base oil.

Conclusions

The base oil effect on the performance of GF-3 engine oil are studied through bench tests and engine tests. From the GF-3 sequence engine test, specially finding have shown that:

Fuel economy in the Sequence VIB is correlated to the base oil viscosity. The lower viscosity, the better fuel economy improvement.

Group III base oil shows better performance in fuel economy retention, oxidation and sludge control than the combination of group III/group II or group III/group I.

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