

Introduction of Fuel Economy Engine Oil Performance Target with New SAE Viscosity Grade

Masami Ishikawa, Kazuo Yamamori, and Satoshi Hirano
Toyota Motor Corporation

Teri Kowalski
Toyota Technical Center USA, Inc.

James Linden
Linden Consulting, LLC

ABSTRACT

Fuel economy improvement has been one of the most important challenges for the automotive industry, and the oil and additive industries. The automotive, oil, and additive industries including related organizations such as SAE, ASTM, and testing laboratories have made significant efforts to develop not only engine oil technologies but also engine oil standards over decades. The API S category and ILSAC engine oil standard are well known and widely used engine oil specifications [1] [2].

The development of an engine oil standard has important roles to ensure the quality of engine oils in the market and encourage industries to improve the engine oil performance periodically. However, the progress of technology advancement can go faster than the revision of engine oil standard. An introduction of new viscosity grades, SAE 0W-16 and 5W-16 is one good example. The 16 grade was added into the SAE J300 standard that defines viscosity grades for engine oils in April 2013 [3]. The addition of SAE 0W-16 and 5W-16 has opened up an opportunity to improve engine oil fuel economy performance further. The API Publication 1509 was revised to include SAE 0W-16 and 5W-16 in the API SN category in October 2014, but the fuel economy criteria could not be set due to a lack of sufficient data.

Since the earlier introduction would deliver more benefit to the market, it was decided to run a statistically designed matrix to define the fuel economy improvement that could be delivered by SAE 0W-16 compared to SAE 0W-20 and propose it to related industries.

CITATION: Ishikawa, M., Yamamori, K., Hirano, S., Kowalski, T. et al., "Introduction of Fuel Economy Engine Oil Performance Target with New SAE Viscosity Grade," *SAE Int. J. Fuels Lubr.* 9(2):2016, doi:10.4271/2016-01-0896.

INTRODUCTION

Engine oil is an important element of engine design in terms of its robustness and fuel economy performance. Its viscosity properties must be incorporated in the consideration when designing the engine. The SAE viscosity grade is widely used to categorize engine oils by their viscosity properties. It makes both engine design work and engine oil selection in the market easier. On the other hand, the API specification and ILSAC specification have been used to define engine oil performance by engine tests, laboratory tests, and physical and chemical properties. For example, a series of Sequence VI tests has been used to measure the fuel economy improvement of engine oils. The Sequence VID (ASTM D7589) [4] is the current fuel economy engine dyno test for ILSAC GF-5 and API SN/RC that are both latest engine oil specifications.

The Sequence VID test measures engine oil performance as fuel economy improvement (FEI) value compared with a baseline oil (SAE 20W-30). The baseline oil is defined and supplied by ASTM Test Monitoring Center (TMC) as a part of the Sequence VID test procedure. The Sequence VID test consists of the phase 1 fuel economy measurement (FEI1), the oil aging phase, and the phase 2 fuel economy measurement (FEI2). FEI Sum is the summation of FEI1 and FEI2 and is one of pass/fail criteria for the ILSAC and API SN/RC specifications. FEI2 is also required as pass/fail criteria.

Although API SN covers a wide variety of SAE viscosity grades including mono-grades, ILSAC GF-5 specifies only 0W, 5W, and 10W multigrade oils. The majority of marketed ILSAC GF-5 products are formulated in either one of 0W-20, 5W-20, 0W-30, 5W-30, and 10W-30 because of the fuel economy requirement in GF-5. For the case of API SN, the fuel economy performance is not necessary. Only products that meet both API SN requirements and

additional requirements including fuel economy performance defined as “Resource Conserving” (RC) can claim API SN/RC. API SN/RC is equivalent to ILSAC GF-5 at the SAE viscosity grades listed above.

The 0W definition appeared in the SAE J300 revision as of September 1980. The SAE 0W-20 viscosity grade became available in theory. However, it took almost 2 decades until one of Japanese OEMs developed it under ILSAC and API specifications [5]. Both engine hardware and engine oil required technical advancements and time period to utilize the 0W-20 viscosity grade and make it available as a mass-production product.

A recent revision was made in a different direction. Addition of lower viscosity grades was proposed by industries based on technical data to show feasibility to formulate SAE 0W-16 and lower viscosity grade engine oils. As a result, 16 grade was added in the SAE J300 as an April 2013 revision, and introduction of a few SAE 0W-16 products followed it soon in the Japanese market. The development speed of engine hardware and engine oil technologies are much faster than that of the past. It becomes obvious that the revision of engine oil specifications cannot keep up with the rapid change of engine hardware and engine oil technologies.

The ILSAC GF-5 specification was not designed to incorporate new viscosity grades in the middle of its period. Thus, as an agreement among related industries (auto, oil, and additives), API SN/RC revision to incorporate xW-16 was proposed. JAMA desired to have the fuel economy target defined by the Sequence VID test. It was rejected due to an objection that the industry had not seen enough data to support the proposed Sequence VID criteria. API SN was revised without RC for xW-16.

As the next generation of ILSAC specification, ILSAC GF-6 development has started and GF-6B category has been proposed for viscosity grades lower than SAE 0W-20. xW-16 grades will be a part of GF-6B. The timing of ILSAC GF-6 was originally aimed at 2015, but the latest schedule has been delayed to April 1st, 2018 as the first license date due to delay of test developments. The industry has to renew most of existing engine tests due to the hardware availability and needs to develop two new engine tests, a chain wear test and a Low Speed Pre-Ignition (LSPI) test. This has been quite a challenge to the industry and caused some delay despite of industry-wide efforts.

This is probably the first case that the engine oil technology went further than establishing engine oil specification in terms of SAE viscosity grades. In order to mitigate the delay of ILSAC GF-6 introduction and utilize the SAE 0W-16 grade to contribute to the fuel economy improvement of vehicles compatible with it as soon as possible, the authors decided to propose a new fuel economy performance criteria for the SAE 0W-16 based on a matrix test work of Sequence VID. Industry-wide engine oil specifications such as ILSAC and API specifications are the best way to ensure minimum quality level and availability of engine oil products in the market.

MATRIX DESIGN

It is important to choose appropriate test oils that represent engine oil technologies in the market, in order to set an industry specification to facilitate technology developments toward the right direction. From that viewpoint, each of following items were carefully reviewed and decided.

Additive Technologies

There are four additive suppliers that can provide fully formulated additive packages. It is preferable to choose at least 3 additive technologies to represent the majority of the market. All four suppliers provided their market general GF-5 additive packages, appropriate viscosity index improvers (VIIs) and pour point depressants (PPDs) to support this matrix work. “Additive technology” means the total formulating technology including additive package, VII, and PPD in this paper.

Base Stock

Group-III base stocks are widely used to formulate SAE 0W-20 viscosity grade. Since its SAE 0W-16 version can be made as a modification of the SAE 0W-20 formulation, a group-III base stock was selected. [Table 1](#) shows the physical properties.

Table 1. Physical properties of base stock

Test	Method	Unit	Result
Kinematic Viscosity @ 100°C	ASTM D445	mm ² /s	4.3
Kinematic Viscosity @ 40°C	ASTM D445	mm ² /s	19.5
Viscosity Index	ASTM D2270		130
NOACK	ASTM D5800B	wt% loss	14.0

Viscosity grades

SAE 0W-20 and SAE 0W-16 were selected. As 16 grade, SAE 5W-16 is possible to blend. However, it does not make good sense to formulate SAE 5W-16, since SAE 0W-20 has been widely used as ILSAC and API products in the market. It was decided to focus on the comparison and discrimination between SAE 0W-16 and SAE 0W-20 to confirm whether there is a statistically significant difference between the two viscosity grades..

Test Laboratories and Engine Test Stands

The Sequence VID test can be run at both independent laboratories, such as Southwest Research Institute (SwRI) and Intertek Automotive Research (IAR), and dependent laboratories, such as additive suppliers’ and oil companies’ laboratories. Two independent laboratories were chosen to avoid any potential conflicts among additive suppliers. Each test laboratory dedicated one calibrated test stand for this matrix work.

Number of Repeat Tests

2 repeat tests were conducted per test oil per test laboratory. In other words, 4 repeat tests were conducted on each of the test oils.

Final Design

Table 2 shows the summary of the matrix design. The total number of tests is 24 runs. Data size of the matrix is comparable to industry matrices, such as a precision matrix. It contains the majority of technologies in the market (3 out of 4), 2 test laboratories, 2 repeats/ test oil/laboratory, and 2 viscosity grades.

Table 2. Factors and Levels in the Matrix Design

Factor	Level	Description
Additive Technology	3	Market General GF-5 Technologies, 3 out of 4 suppliers.
Base Stock	1	Group-III stock
Viscosity Grades	2	0W-16 and 0W-20
Test Laboratory	2	IAR, SwRI
Repeat tests	2	per laboratory per oil
Total Test Number	24	

TEST OIL PREPARATION

The purpose of this matrix work is to understand the fuel economy improvement performance difference between SAE 0W-16 and SAE 0W-20 as a representation of the current market. There is no intention to compare technologies of additive suppliers. Thus, a double blind method was applied to assign test oil codes. Authors received additive samples and transferred them to a test oil blender after renaming sample codes. The blender renamed finished oil samples again. In this way, additive supplier names were kept anonymous to test laboratories and related industries.

At the blender, blending studies were carried out to meet following criteria. A VII treat rate was adjusted for each test oil formulation to meet the HTHS viscosity at 150°C as primary parameter. The exact same base stock was used for all formulations to compare the influence of viscosity grade. Thus, CCS and MRV viscosities were not adjusted.

Table 3. Target Blend Properties and Blend Check

	Method*	Unit	SAE 0W-16	SAE 0W-20
Additive Package			Recommended Treat Rate	
VII			Adjust	Adjust
PPD			Recommended Treat Rate	
Base Stock			Balance	Balance
Blend Check				
KV@100°C	D445	mm ² /s	6.1 ≤, < 8.2	6.9 ≤, < 9.3
KV@40°C	D445	mm ² /s	report	report
HTHS Vis @ 150°C	D4683	mPa-s	2.3 ≤, ≤ 2.4	2.6 ≤, ≤ 2.7
HTHS Vis @ 100°C	D6616	mPa-s	report	report
CCS @ -35°C	D5293	mPa-s	≤ 6,200	≤ 6,200
MRV @ -40°C	D4684	mPa-s	≤ 60,000	≤ 60,000
Viscosity		Pa	< 35	< 35
Yield Stress				
NOACK	D5800B	wt% loss	≤ 15	≤ 15

* All test procedures are ASTM test procedures.

As a random selection, additive technology 2, 3, and 4 were selected for the matrix. Table 4 shows the viscosity properties of test oils. SAE 0W-16 formulation with the technology 2 was coded as “Oil 200”. SAE 0W-20 formulation with the technology 2 was coded as “Oil 201”. All blends met all viscosity requirements by the SAE J300 and the blend targets for the matrix work.

Table 4. Test Oil Viscosity Properties

Test Oil Code			Oil 200	Oil 201	Oil 300	Oil 301	Oil 400	Oil 401
Additive Technology			Technology 2		Technology 3		Technology 4	
Performance Level			ILSAC GF-5		ILSAC GF-5		ILSAC GF-5	
SAE Viscosity Grade			0W-16	0W-20	0W-16	0W-20	0W-16	0W-20
Test	Method	Unit						
KV@100°C	D445	mm ² /s	7.07	8.43	7.17	8.56	7.02	8.37
KV@40°C	D445	mm ² /s	36.1	44.4	36.5	44.7	35.4	43.4
VI	D2270		162	170	164	173	164	173
HTHS@150°C	D4683	mPa-s	2.3	2.7	2.3	2.6	2.3	2.6
HTHS@100°C	D6616	mPa-s	4.9	5.6	5.0	5.7	4.9	5.5
CCS @ -35°C	D5293	mPa-s	4,830	5,180	5,140	5,560	4,590	5,070
MRV @ -40°C	D4684							
Viscosity		mPa-s	11,600	15,600	16,400	21,100	23,700	28,500
Yield Stress		Pa	< 35	< 35	< 35	< 35	< 35	< 35
NOACK	D5800B	wt% loss	13.6	13.6	13.1	13.0	13.5	13.9

SEQUENCE VID ENGINE TEST RESULTS

Two independent test laboratories installed new engine units and calibrated by ASTM TMC reference oils in accordance with the test procedure. The Sequence VID test is a flush and run type engine test. The same engine unit can be used for 3 or 4 thousands hours of test operation, as far as the engine can meet ASTM LTMS targets by calibration tests with reference oils. It is known that the Sequence VID test has aging effect on the fuel economy test result. The test procedure applies engine hour correction to adjust the aging effect. In this test matrix, the test run order was randomized to make sure not to be biased by the run order. For the analysis, the final FEI results including the LTMS severity adjustment and the engine hour correction were utilized.

It was expected to run all 12 tests on one engine at each test laboratories. However, one of two engines showed high oil consumption result at the 7th test out of 12 tests. It forced the test laboratory to change the engine unit and calibrate another new engine unit to complete the matrix.

TEST RESULT ANALYSIS

Figure 1 shows the FEI Sum results by SAE grades and the oil codes. Since there are a few data points that are apart from other data points, they were tested by the Studentized residuals. No data point was judged as an outlier.