

Engine Oil Fuel Economy Testing - A Tale of Two Tests

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ABSTRACT

Fuel economy is not an absolute attribute, but is highly dependent on the method used to evaluate it. In this work, two test methods are used to evaluate the differences in fuel economy brought about by changes in engine oil viscosity grade and additive chemistry. The two test methods include a chassis dynamometer vehicle test and an engine dynamometer test. The vehicle testing was conducted using the Federal Test Procedure (FTP) testing protocol while the engine dynamometer test uses the proposed American Society for Testing and Materials (ASTM) Sequence VIE fuel economy improvement 1 (FEI1) testing methodology. In an effort to improve agreement between the two testing methods, the same model engine was used in both test methods, the General Motors (GM) 3.6 L V6 (used in the 2012 model year Chevrolet™ Malibu™ engine). Within the lubricant industry, this choice of engine is reinforced because it has been selected for use in the proposed Sequence VIE fuel economy test. Results indicate that agreement between methods does exist for some oils. However in the case of ultra-low viscosity oils and oils containing high levels of friction modifier (FM) additives, the engine dynamometer test gave results much lower than those obtained in the chassis dynamometer testing. The consequence of this is that oils which may significantly improve vehicle fuel economy on the road may not be commercialized since the same benefit is not observed in the engine dynamometer test. Since the chassis dynamometer test uses a complete vehicle, is based on an actual drive cycle, and includes dynamic events such as transient operation and cold start, it is believed to be more representative of actual on-road vehicle performance than the engine dynamometer test. Further, chassis dynamometer testing provides a means to validate the relevance of the proposed Sequence VIE engine test results, including the benefits from highly friction modified and low viscosity oils.

CITATION: Michlberger, A., Morgan, P., Delbridge, E., Gieselman, M. et al., "Engine Oil Fuel Economy Testing - A Tale of Two Tests," *SAE Int. J. Fuels Lubr.* 10(2):2017, doi:10.4271/2017-01-0882.

INTRODUCTION

Fuel economy is inherently difficult to measure with a high degree of precision. This is especially the case when evaluating an engine oil's impact on fuel economy. As a result, many different tests have been developed to investigate friction and fuel economy. Some tests evaluate individual aspects of fuel economy such as friction in specific tribocouples like valve train contacts, power cylinder components, bearings, etc. These types of tests are commonly referred to as bench tests. Other tests measure engine friction by monitoring the torque necessary to spin a non-fired, electric motor-driven, engine. These types of tests are commonly known as Friction Torque Tests (FTTs).

Both bench tests and FTTs have the advantage of being relatively inexpensive and take minimal time to run, however one must be careful not to over-interpret the applicability of results. For example,

just because a particular engine oil or chemical additive performs well in a friction, wear, or corrosion bench test, does not guarantee that performance will translate to an actual vehicle. This is a result of the many simplifications and assumptions inherent to the small-scale tests. Because of these simplifications, it is imperative that engine oils and their chemical additives be evaluated in actual fired engines. This is not only the opinion of the authors, but also that of the industry (1, 2, 3, 4), and is further supported by the fact that the industry has made considerable investments in the development of fired engine and vehicle test procedures. For engine oil certification in North America, oils must meet minimum standards in fuel economy improvement (FEI) in the industry standard Sequence VI engine dynamometer test. The Sequence VI test procedure is re-evaluated and updated in conjunction with engine oil category upgrades. At the time of writing this paper, the industry is currently updating this test

from the Sequence VID, to the proposed Sequence VIE. The International Lubricant Standardization and Approval Committee (ILSAC) and the American Petroleum Institute (API) have both included minimum performance criteria in this test.

To ensure compliance with greenhouse gas (GHG) emissions and fuel economy standards, the United States Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) have adopted vehicle testing standards. These tests utilize complete vehicles on chassis dynamometers to determine emissions and calculate fuel economy. Though there are many standardized and custom drive cycles, two of the most common are the Federal Test Procedure 75 (FTP-75) and Highway Fuel Economy Test (HwFET). For the purposes of this paper, unless otherwise noted, the acronym FTP or Combined FTP testing is defined as the weighted combination of the FTP-75 and HwFET procedures.

The Sequence VI fuel economy test and the FTP testing procedures are designed to be linked, as the test conditions and stage weighting factors of the Sequence VI test were developed to represent conditions experienced during the FTP tests, this work was conducted during the development of the Sequence VID test (5). Engine test conditions from the Sequence VID were carried over to the Sequence VIE test. Therefore, the proposed Sequence VIE test uses the same conditions for evaluation as the Sequence VID but a new engine (the GM 3.6 L Chevrolet™ Malibu™ engine). The objective of this paper is to investigate the similarities and differences between these two procedures, which again, use the same engine. A matrix consisting of five (5) engine oils was developed for testing. The matrix allows for the independent comparison of the impact on fuel economy from lubricant viscosity and from presence and amount of friction modifying additive chemistry.

MECHANICAL TESTS

Two mechanical tests were used to evaluate engine oils' impact on fuel economy, one engine dynamometer test and one chassis dynamometer vehicle test. Engine dynamometer testing was conducted on a 2012 model year, GM, 3.6 L V6 engine using the test conditions from the proposed Sequence VIE fuel economy test. This test consists of several different segments, including fuel economy (FE) evaluations and oil aging periods. FE evaluations are conducted on both candidate and baseline oils. The proposed Sequence VIE baseline oil is an industry-standard oil, which is used to determine the fuel economy improvement (FEI) of the candidate oils. The exact composition of this baseline oil is not known but it is blended to an SAE 20W-30 viscosity grade. Conducting baseline testing before and after the candidate oil evaluations allows for compensation of irreversible hardware drift over the course of the test. Table 1 describes the Sequence VIE test progression, with baseline and candidate oil testing stages. Note: While the proposed Sequence VIE engine test evaluates both fresh and aged oil fuel economy, only fresh oil fuel economy will be discussed in detail. This is because chassis dynamometer testing was conducted on fresh oil only, therefore a comparison between aged oil fuel economy in both tests cannot be made.

Table 1. Sequence VIE Test Progression

Step	Oil	Segment	Data
1	Baseline	FE Evaluation	BLB1
2	Baseline	FE Evaluation	BLB2
3	Candidate	16 hour Aging	-
4	Candidate	FE Evaluation	CA1
5	Candidate	109 hour Aging	-
6	Candidate	FE Evaluation	CA2
7	Baseline	FE Evaluation	BLA

From the data generated in individual FE evaluations, fuel economy improvement is calculated with the following equation 1.

$$FEI1 (\%) = \frac{(0.8 * BLB2 + 0.2 * BLA) - CA1}{(0.8 * BLB2 + 0.2 * BLA)} * 100 \quad (1)$$

This value represents fresh oil fuel economy. A similar calculation (Equation 2) is used to determine the candidate oil's fuel economy improvement after aging:

$$FEI2 (\%) = \frac{(0.1 * BLB2 + 0.9 * BLA) - CA2}{(0.1 * BLB2 + 0.9 * BLA)} * 100 \quad (2)$$

The aging period is intended to represent approximately 6500 miles of on-road driving. Thus, the proposed Sequence VIE quantifies both fresh oil and aged oil fuel economy.

Each FE evaluation is composed of a weighted sum of the fuel consumed in each of six discreet speed and load stages. Weighting factors are applied to each stage and were developed to help improve correlation to the FTP testing (5). Test conditions and weighting factors for each test stage can be seen in Table 2.

Table 2. Sequence VIE Fuel Economy Evaluation Stages

Stage	Engine Speed (RPM)	Torque (Nm)	Oil Temp. (°C)	Coolant Temp. (°C)	Weighting Factor
1	2000	105	115	109	0.300
2	2000	105	65	65	0.032
3	1500	105	115	109	0.310
4	695	20	115	109	0.174
5	695	20	35	35	0.011
6	695	40	115	109	0.172

The test conditions were designed to force the engine into various regimes of lubrication including boundary, mixed, and hydrodynamic, while still being reasonable approximations for the speeds and loads experienced in the FTP-75 and HwFET tests. It is important to note that each tribocouple within the engine may operate in a different

regime of lubrication at any particular condition set. Gross simplifications are made by describing certain condition sets as boundary or hydrodynamic. In this manner, assignment of a macroscopic lubrication regime is much more qualitative than quantitative. A detailed discussion of lubrication regimes is beyond the scope of this paper, but one good resource is (6).

In this study, chassis dynamometer testing was conducted with the FTP-75 and HwFET driving schedules. Plots of these driving schedules can be seen in Figures 1 and 2. To improve test precision, many improvements were made to the standard test procedure, including a robotic driver, dedicated dynamometer tires, laser vehicle alignment and more. A full explanation of these improvements can be obtained in previous publications (7, 8). Fuel economy was calculated using the carbon balance method as described in (9). The FTP-75 procedure consists of three phases. Fuel economy and emissions are evaluated independently for each phase. A weighted average is then used to calculate total cycle fuel economy (9). The HwFET consists of only one phase and represents highway driving.

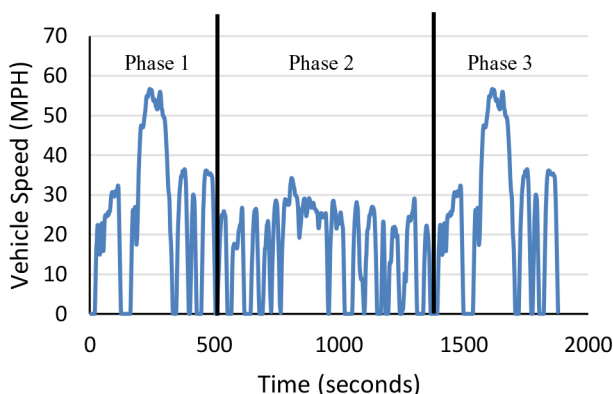


Figure 1. FTP-75 Driving Schedule

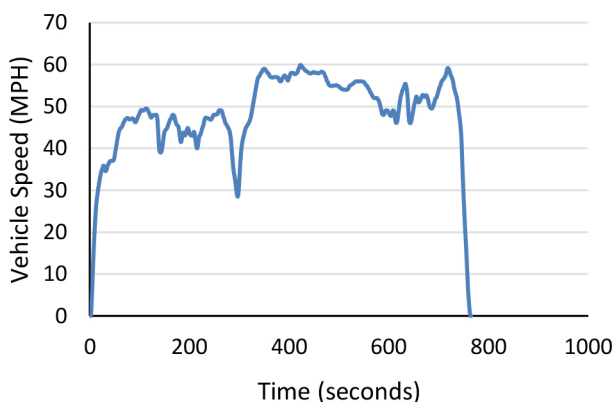


Figure 2. HwFET Driving Schedule

The vehicle used for testing was the 2012 model year Chevrolet™ Malibu™, powered by GM's 3.6 L, port fuel injected, V6 engine. This vehicle was specifically chosen as it is the same model engine used in the proposed Sequence VIE test. The authors believe that use of the same hardware for both engine dynamometer and chassis dynamometer testing will increase chances of agreement between the two methods. To generate enough data for statistical robustness,

all FTP testing was conducted in triplicate, with the exception of the GF-5 Baseline oil that was evaluated in triplicate, twice for a total of 6 tests.

TEST OILS

Test oils were carefully developed to represent relevant formulations and isolate the two variables being studied, oil viscosity and additive chemistry. Indeed, each oil uses the same Group III oil base stocks, same viscosity modifier (VM) type, and same base additive package. To achieve different viscometrics, different viscosity base stocks and VM treat rates were used. To minimize variability, all base stock cuts came from the same oil slate. Additionally, while the VM treat rate was altered for each viscosity grade, the VM type was held constant. Similarly, the exact same additive package was used for each oil, with the exception of the friction modification chemistry used to evaluate FM as a variable. This careful approach to test oil formulation was done to minimize any potential confounding. The additive package used for all oils was based on an ILSAC GF-5 licensed product. More information about the test oils can be seen in Table 3.

Table 3. Test Oils

Test Oil	Description	SAE Grade	D4683 HTHS Viscosity (cP)	FM
1	GF-5 Baseline	5W-30	3.1	Standard
2	High Viscosity	10W-40	3.7	None
3	Mid Viscosity	5W-30	3.1	None
4	Low Viscosity	0W-16	2.3	None
5	Mid Viscosity + High FM	5W-30	3.1	High

The two variables studied are oil viscosity and friction modifier presence and treat rate. In this manner, differences in fuel economy can be isolated as a function of viscosity or friction modification, or considered together. A graphic which represents each test oil can be seen in Figure 3.

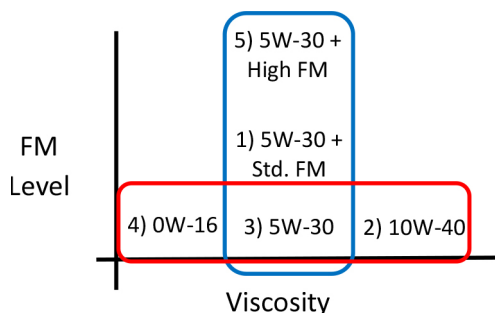


Figure 3. Test Oil Graphic

RESULTS

The results from the proposed Sequence VIE fuel economy test can be seen in Table 4. This table includes both fresh oil fuel economy (FEI1) and aged fuel economy (FEI2).