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Fuel Economy Durability - A Concept to be Considered for Motorcycle Oils

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ABSTRACT

Motorcycle manufacturers have recognized that highly friction modified passenger car oils can be deleterious to clutch performance, leading to clutch slippage. To address this issue, a JASO specification for four-stroke motorcycle oils was developed in 1999, categorizing oils into high friction oils termed JASO MA and low friction oils termed JASO MB. The high friction oils were preferred for most motorcycles where the engine oil also lubricates the clutch and gears. New motorcycle transmission technologies have increased the number of dry clutch applications which has led to an increased demand for JASO MB oils to improve fuel efficiency. While JASO MB oils contain friction modifiers to improve initial fuel economy, the motorcycle specifications have not addressed the fuel economy durability of motorcycle oils. This paper will investigate the fuel economy durability of JASO MB quality oil in various ways in order to determine if the fuel economy benefit is maintained throughout the time the oil spends in the engine.

INTRODUCTION

The fuel efficiency of vehicles has been an important issue over the last 25 to 30 years due to concerns over the conservation of natural resources and the protection of the environment (1). One way to improve the fuel efficiency of vehicles is to utilize energy conserving motor oils that reduce engine friction. The first industry standard for energy conserving motor oils was established in 1983 by the American Petroleum Institute (API). Various tests such as the Sequence VI and Sequence VIA were utilized from 1983 until 2000 to evaluate the fuel efficiency of engine oils. In 2000, the Sequence VIB test was introduced, which for the first time evaluated not only initial fuel economy, but also fuel economy durability. This test was utilized for the International Lubricant Standardization and Approval Committee (ILSAC) GF-3 and GF-4 specifications. It has recently been replaced by the Sequence VID test (2), which measures fuel economy durability for the ILSAC GF-5 specification in a General Motors 3.6L V6 engine. Fuel economy durability therefore has been a key performance parameter engineered into passenger car oils for the past 10 years. During this timeframe, different types of friction modifiers have been developed and higher levels of friction modifiers have been added to engine oils in order to meet the more stringent fuel economy and fuel economy durability targets.

As highly friction modified passenger car oils became common in the market, motorcycle manufacturers found that they can be deleterious to clutch performance, leading to clutch slippage. To address this issue, a JASO T903 specification for four-stroke motorcycle oils was developed in 1999, categorizing oils based on clutch friction performance into high friction oils termed JASO MA and low friction oils termed JASO MB. The JASO MA category was divided into JASO MA1 and MA2 in 2006. The JASO T903:2006 classification of oils is shown in table 1 (3).

Table 1. Classification of JASO Oil Quality

	DYNAMIC FRICTION INDEX (DFI)	STATIC FRICTION INDEX (SFI)	STOP TIME INDEX (STI)
MA2	≥1.80 and <2.50	≥1.70 and <2.50	≥1.90 and <2.50
MA1	≥1.45 and <1.80	≥1.15 and <1.70	≥1.55 and <1.90
MB	≥0.50 and <1.45	≥0.50 and <1.15	≥0.50 and <1.55

The high friction oils are preferred for most motorcycles where the engine oil also lubricates the clutch and gears. New motorcycle transmission technologies have increased the number of dry clutch applications which has led to an increased demand for JASO MB oils to improve fuel efficiency. While JASO MB oils contain friction modifiers to lower friction and improve fuel economy, no industry standard tests exist to evaluate the fuel economy durability of motorcycle oils. The focus of this study is to evaluate fuel economy durability of JASO MB oils using various techniques.

OIL SELECTION

In order to investigate the fuel economy durability of JASO MB quality oil, a high quality JASO MB oil was purchased from the Japanese market. Analysis of this oil is shown in table 2.

Table 2. Viscometric and Elemental Analysis of Purchased JASO MB Oil

VISCOMETRIC ANALYSIS	
VISCOSITY @40 cSt	68.57
VISCOSITY @100 cSt	10.68
VISCOSITY INDEX	145
HTHS 150 cP	3.13
ELEMENTAL ANALYSIS	
BORON %	0.018
CALCIUM %	0.184
MOLYBDENUM %	0.049
NITROGEN %	0.111
PHOSPHORUS %	0.094
SULFUR %	0.654
ZINC %	0.112

The oil was found to have been formulated to conventional 10W-30 viscometrics and to contain a high level of molybdenum, indicative of a high treat level of a friction modifier.

FUEL ECONOMY MEASUREMENTS – EVALUATION 1

Since there is no motorcycle test available to measure the fuel economy durability of a JASO MB oil, a Sequence VID test was utilized (2). The Sequence VID test is a standardized ASTM test (D7589) used to measure a lubricant's ability to improve the fuel efficiency of a passenger car engine. The test incorporates a flush and run procedure using a General Motors (2008 Cadillac) 3.6L V6 engine. The test method involves measuring the fuel required to run the engine at various operating stages. The operating conditions shown in table 3, in combination with weighting factors were designed to correlate to the EPA's FTP cycle which is used to quantify fuel efficiency.

Table 3. Sequence VID Test Conditions

FE Stage	Speed (rpm)	Load (Nm)	Oil Temp (°C)
1	2000	105	115
2	2000	105	65
3	1500	105	115
4	695	20	115
5	695	20	35
6	695	40	115
Aging	2250	110	120

The test begins with a six-stage evaluation of a baseline or reference oil. The candidate oil is then flushed into the engine and after 16 hours of aging, which represents approximately 1500 miles of driving, the candidate oil is evaluated using the same six-stage procedure. This provides a measure of the initial fuel efficiency of the oil. The oil is then aged an additional 84 hours for a total of 100 hours which represents 6500 miles of driving. The six-stage evaluation is then repeated. This second evaluation provides a measure of the fuel economy durability of the lubricant. After flushing the engine with a high detergent oil, a fresh charge of reference oil is again introduced into the engine and evaluated, thus bracketing the candidate oil at beginning and end with a baseline or reference oil test.

Test results are reported as a Fuel Economy Improvement (FEI) and are calculated as a percent improvement over baseline for the initial evaluation after 16 hrs of aging (FEI 1) and after 100 hours aging (FEI 2).

The commercial JASO MB oil was evaluated in the Sequence VID test. The fuel consumption of the baseline oil as well as the commercial JASO MB test oil are shown in figure 1. Clearly when the engine is run on the test oil after aging, much more fuel is consumed than when the test was run on the new oil. This indicates a drop in fuel efficiency as the oil ages.

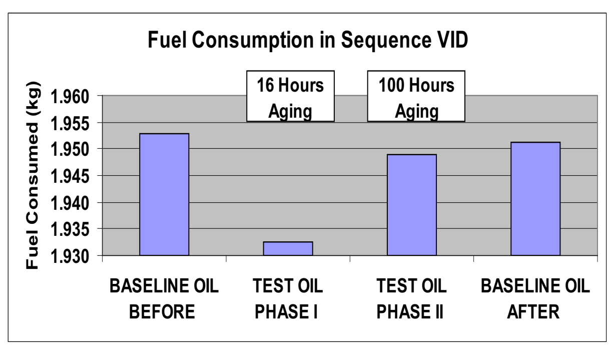

Figure 1. Commercial JASO MB OIL

The fuel consumption results are used to calculate the fuel economy improvement results which are shown in table 4. This commercial JASO MB oil had outstanding initial fuel economy (FEI 1) as might be expected with a highly friction modified oil. However, the fuel economy improvement dropped rapidly with aging as seen in the fuel economy durability (FEI 2).

Table 4. JASO MB Oil Sequence VID Results

JASO MB Oil	
% FEI 1	1.0
% FEI 2	0.2

Of course the Sequence VID is run in an automobile engine, and it would be useful to know if such a large drop in fuel economy performance is seen after aging in a motorcycle engine.

FUEL ECONOMY MEASUREMENTS – EVALUATION 2

Fuel efficient motorcycle oils are defined as MB quality based on JASO T904:2006 SAE#2 clutch friction test (4). To meet JASO MB, at least one of the indices measured must fall within the JASO MB range shown in table 5. The purchased JASO MB oil was evaluated in this test and found to easily meet these criteria, indicating it should be a very fuel efficient oil.

Table 5. Evaluation of Commercial JASO MB Oil

	JASO MB OIL	MB CRITERIA
DYNAMIC FRICTION INDEX (DFI)	1.29	≥0.50 and <1.45
STATIC FRICTION INDEX (SFI)	1.06	≥0.50 and <1.15
STOP TIME INDEX (STI)	1.35	≥0.50 and <1.55

In order to evaluate fuel economy durability in a motorcycle, the JASO MB oil was aged in a Honda single cylinder 250cc motorcycle engine. This is an air and oil cooled four stroke off-road motorcycle sold in the United States and sourced from the Honda XR 250. It was chosen for this experiment because its size and architecture are similar to engines commonly found in Asia and smaller-displacement engines that can be found in the United States and Europe. Although the Honda 250cc motorcycle engine is a wet-clutch motorcycle, operating conditions believed to impact fuel economy durability are similar in both wet and dry clutch motorcycles. The engine uses an external oil system that circulates oil through the motorcycle's frame for cooling. When this engine was installed in a test stand, the frame was replaced with a heat exchanger for more precise control over oil temperature. This heat exchanger provided the necessary cooling to maintain an oil temperature of 140°C throughout the test. The addition of this heat exchanger and associated piping allowed the use of a larger than stock oil charge (2300 ml). This large oil volume was necessary to produce enough used oil for additional testing after the oil age evaluation. To reduce or eliminate any variability caused by wear during the test, top-end engine parts including the cylinder, piston, and piston rings were replaced before each 192 hour test.

To approximate a typical urban/suburban motorcycle driving cycle, a two-stage test was developed. The first stage simulates driving at moderate speed and load, approximately 50% of rated power. Engine speed for this stage is maintained at 6000 rpm. The second stage simulates low speed and load operation, approximately 25% of rated power. During the second stage, the engine speed is maintained at 4500 rpm.

The test engine is operated at the first stage (50% load) for one quarter of the total test time, then at the second stage (25% load) for the remaining three quarters of total test time. To further simulate a realistic drive cycle by eliminating long periods of steady-state operation, the test engine alternates between high and low conditions every four hours. Therefore, one complete four hour testing cycle consists of one hour at the higher speed/load condition set followed by three hours at the lower speed/load condition set. This dual-stage cycle is repeated until the desired test length is reached.

Equivalent distances were calculated by determining the distance the vehicle would travel in fourth gear during the first condition set, and second gear in the second condition set, with respect given to stock tire diameter and final drive ratio. It was determined that during the first condition set (6000 RPM and 4th gear) a vehicle speed of approximately 45 MPH (72 KPH) would be attained. Similarly, during the second condition set (4500 RPM and 2nd gear) the vehicle would be traveling approximately 20 MPH (32 KPH). Table 6 contains operating conditions, test hours and equivalent simulated distances.

Table 6. Conditions for Oil Aging

Condition Sets

Stage 1 Simulate 45 MP

Gear (Simulated)	4th	#
Engine Speed	6000	RPM
Load	50	% of Rated
Oil Temperature	140	° C
Time of Test	25	%
Stage Time (per cycle)	1	Hour
Stage Time (total)	48	Hours
Simulated Distance	2182	Miles

Stage 2 Simulate 20 MP

Gear (Simulated)	2nd	#
Engine Speed	4500	RPM
Load	25	% of Rated
Oil Temperature	140	° C
Time of Test	75	%
Stage Time (per cycle)	3	Hours
Stage Time (total)	144	Hours
Simulated Distance	2825	Miles

*Stages are repeated until test completion

Total Simulated Distance	**5007**	**miles**
Total Test Hours	**192**	**hours**

The initial test duration was set at 192 hours, which simulates approximately 5000 miles (8045 km) of on-road driving. This is shorter than the Sequence VID duration, but was chosen because it represents a reasonable oil change interval for a modern on-road motorcycle. At the end of the oil aging evaluation, the drain oil was collected. This used oil was evaluated in the JASO T904:2006 SAE#2 test and found to be no longer of JASO MB quality as seen in table 7. In fact, this aged oil falls within the JASO MA2 criteria, the highest friction oil category.

Table 7. Conditions for Oil Aging

	AGED MB OIL	MB CRITERIA
DYNAMIC FRICTION INDEX (DFI)	1.97	≥0.50 and <1.45
STATIC FRICTION INDEX (SFI)	1.79	≥0.50 and <1.15
STOP TIME INDEX (STI)	1.98	≥0.50 and <1.55

This experiment demonstrated that the JASO MB oil did not maintain fuel efficiency throughout the time in the engine. As a follow-up it was decided to repeat the experiment several times, collecting oil at various intervals in order to determine how long the JASO MB quality of the original oil is maintained. In successive experiments, the test duration was shortened to 96 hours which simulates 2500 miles (4023 km), 48 hours, simulating 1250 miles (2011 km), and finally to 24 hours which simulates 625 miles (1006 km). Each of these aged oils was evaluated in the JASO T904:2006 SAE#2 clutch friction test in order to determine oil quality and the results are shown in table 8.

Table 8. Evaluation and Classification of Used Oils

	Miles of Aging				
	0	625	1250	2500	5000
DFI	1.29	1.38	1.65	1.97	1.97
SFI	1.06	1.29	1.51	1.76	1.79
STI	1.35	1.51	1.72	1.95	1.98
Oil Classification	MB	MA1	MA1	MA2	MA2

A simple graph of this dataset, shown in figure 2, may be used to determine how long a good quality JASO MB oil maintains performance and by inference its fuel efficiency.

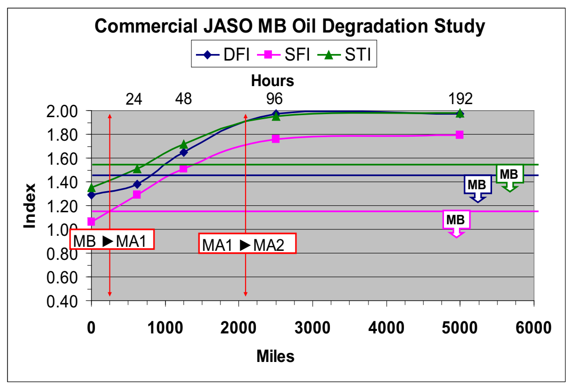

Figure 2. Oil Classification as Function of Time

An oil maintains JASO MB quality as long as one of the indices meets the MB criteria. From the graph shown in figure 2, it is apparent that the oil maintains JASO MB quality for only about 10 hours or 250 miles of use in the motorcycle engine. The oil further deteriorates to a JASO MA2 quality oil by about 90 hours or 2000 miles. It should also be stated that the conditions used to age the oil may be conservative relative to many actual motorcycle drive cycles.

In summary, using various test methods it has been shown that a high quality JASO MB oil lost its ability to deliver fuel efficiency very rapidly. It was then decided to try to develop a motorcycle oil with enhanced fuel economy durability and validate the performance using these testing approaches.

ENHANCED FUEL ECONOMY DURABILITY STUDY

Many studies have evaluated fuel economy durability in passenger car oils over the last 10 years. In order to determine if these approaches have applicability in motorcycles, an experimental 10W-30 motorcycle oil was formulated to meet JASO MB while utilizing friction modifiers and other components known for enhanced fuel economy durability. This experimental motorcycle oil differs from typical passenger car oils in that it is formulated with supplemental chemistry to deliver gear oil protection as well as a very shear stable viscosity modifier not typically used for automotive applications. The viscometric and elemental properties of this oil are shown in table 9.

Table 9. Viscometric and Elemental Analysis of Experimental Oil

VISCOMETRIC ANALYSIS	
VISCOSITY @40 cSt	73.29
VISCOSITY @100 cSt	10.91
VISCOSITY INDEX	138
HTHS 150 cP	3.20
ELEMENTAL ANALYSIS	
BORON %	0.000
CALCIUM %	0.135
MOLYBDENUM %	0.000
NITROGEN %	0.086
PHOSPHORUS %	0.097
SULFUR %	0.262
ZINC %	0.106

In order to validate the experimental oil quality, it was evaluated in the JASO T904 2006 SAE# 2 clutch friction test and was shown to be JASO MB quality as seen in table 10.

Table 10. Evaluation of Experimental JASO MB Oil

	EXPERIMENTAL OIL	*JASO MB CRITERIA*
DYNAMIC FRICTION INDEX (DFI)	1.52	≥0.50 and <1.45
STATIC FRICTION INDEX (SFI)	0.55	≥0.50 and <1.15
STOP TIME INDEX (STI)	1.50	≥0.50 and <1.55

The experimental JASO MB oil was then evaluated in the Sequence VID test. The fuel consumption of the baseline oil before as well as the experimental JASO MB test oil are shown in figure 3.

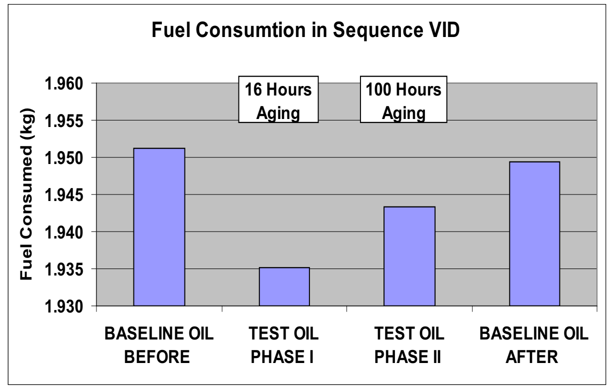

Figure 3. Experimental JASO MB Oil

The difference between the new and used oil in terms of fuel consumption is not as large with the experimental JASO MB oil as was seen with the commercial JASO MB oil. This is evident in the calculation of fuel economy improvement for the Sequence VID shown in table 11.

Table 11. Experimental Oil Sequence VID Results

Experimental Oil	
% FEI 1	1.0
% FEI 2	0.6

Comparing the Sequence VID results in figure 4, the experimental JASO MB oil has similar initial fuel economy to the commercial JASO MB oil but much better fuel economy durability. While there remains room for additional improvement, it should be recognized that all oils will degrade in use. In the ILSAC GF-5 specification for current passenger car oils, the Sequence VID FEI 2 requirement is 0.6% for a 10W-30 engine oil

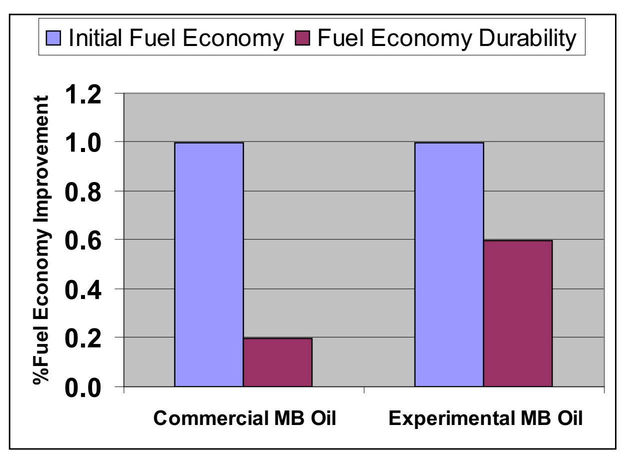

Figure 4. Sequence VID Fuel Economy Comparison

This experimental JASO MB oil which demonstrated enhanced fuel economy durability in the Sequence VID was then subjected to the same aging in the Honda single cylinder 250cc motorcycle engine as the commercial JASO MB oil. This experiment was conducted in order to evaluate if the enhanced fuel economy durability observed in the Sequence VID would be evident when the oil was aged in a motorcycle engine. The oil was aged for various periods of time and then evaluated in the JASO T904:2006 SAE#2 clutch friction test to determine how long the oil maintained JASO MB quality. The results may be seen in table 12.

Table 12. Classification of Used Oils

	Miles of Aging				
	0	625	1250	2500	5000
DFI	1.52	1.66	1.66	1.71	1.68
SFI	0.55	0.94	1.14	1.35	1.39
STI	1.50	1.72	1.73	1.82	1.76
Oil Classification	MB	MB	MB	MA1	MA1

A simple graph of this dataset, shown in figure 5, may be used to determine how long this experimental JASO MB oil maintains its performance and by inference its fuel efficiency.

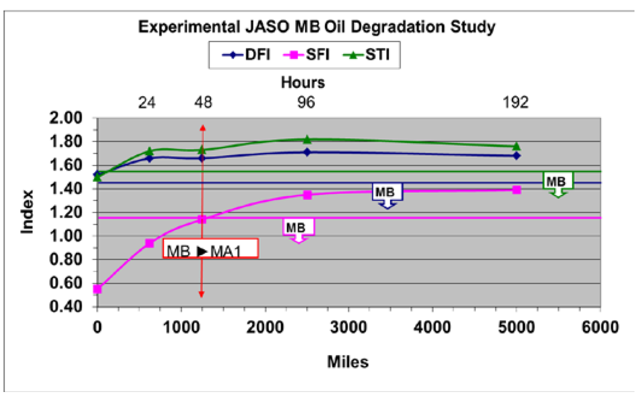

Figure 5. Oil Classification as a Function of Time

An oil maintains JASO MB quality as long as one of the indices meets the MB criteria. From the graph shown in figure 5, it is apparent that the experimental JASO MB oil maintains MB quality for at least 48 hours of use in the motorcycle engine. At 48 hours or 1250 miles, this is more than four times as long as the commercial JASO MB oil maintained performance. Interestingly in 192 hours or 5000 miles of evaluation, this experimental JASO MB oil never deteriorates further to an MA2 quality oil as did the commercially purchased JASO MB oil.

CONCLUSION

Fuel economy durability has been a feature engineered into passenger car oils for the past 10 years, but this feature has not been evaluated in terms of motorcycle oils. A high quality JASO MB oil was purchased in the Japanese market to use for fuel economy durability evaluations. This oil was initially evaluated in the Sequence VID used for testing passenger car lubricants and found to have excellent initial fuel economy, but poor fuel economy durability. A Honda 250cc motorcycle engine was then used to age the oil for various periods of time, and the JASO T904:2006 SAE#2 clutch friction test was run on the used oils. It was found that the high quality commercial oil only maintained JASO MB quality for the first 10 hours of use in a motorcycle engine. The oil further deteriorated from MA1 to an MA2 quality oil after about 90 hours of use.

An experimental JASO MB motorcycle oil was then developed based on knowledge of fuel economy durability. This experimental oil demonstrated similar excellent initial fuel economy in the Sequence VID, but much better fuel economy durability than the commercial oil. The experimental oil was then aged in the Honda XR-250 motorcycle engine for various periods of time, and the JASO T904:2006 SAE#2 clutch friction test was run on the used oils. In this case the JASO MB quality was maintained for 48 hours of use, and the oil never deteriorated to a JASO MA2 oil.

This study demonstrates that fuel economy durability can be evaluated and can be improved for motorcycle oils. This attribute should be considered for future motorcycle oils for the environmental benefits as well as to deliver the maximum fuel efficiency over time for the motorcycle rider.

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