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The Development of Fuel Economy Test Method for Heavy Duty Diesel Engine Oil (The First HD Engine Test Method and the New JASO DH-2F Category)

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ABSTRACT

This paper reviews the development of the first fuel economy engine test method for heavy duty diesel oil, as well as the new JASO DH-2F category introduced in April 2017 [1][2][3], which adds a fuel economy requirement to the JASO DH-2 requirements in the JASO M355:2015 standard. Recently, better fuel economy is required heavy duty diesel vehicles as well as gasoline vehicles. Therefore, advanced technologies have been applied to improve diesel engines, as well as diesel engine oils and additives, and achieve better fuel economy. However, the Automotive Diesel Engine Oil Standard (JASO M355) applied in Japan as a standard for diesel engine oils does not include any fuel economy requirements. Consequently, a JASO Diesel Engine Oil Standard Revision Task Force (Task Force) consisting of organizations from related industries, including the Japan Lubricating Oil Society (JALOS), developed an engine test method using a Hino N04C engine equipped with the latest technologies to comply with the 2010 Japanese emissions regulations. The method measures fuel economy performances for fresh and aged oils in JASO-specified engine tests using the N04C engine. The specified test protocol is based on the governmental test method for heavy duty vehicles and evaluated through comparison with Society of Automotive Engineers (SAE) 30 oil. The new test method can differentiate fuel economy performance for different viscosity properties of SAE 5W-30s. The minimum criterion for the fresh oil fuel economy improvement rate was set to 3.7%, and the sum of the improvement rates for fresh and aged oils was set to 6.8%.

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INTRODUCTION

Growing global concern for environmental protection calls for increasingly more severe standards for diesel exhaust emissions and fuel efficiency (fuel economy), leading to the introduction of the 2016 Japanese emissions regulations adopting the World-wide harmonized Heavy Duty Certification (WHDC) mode and of the 2015 fuel economy standard for heavy duty diesel vehicles. Further discussions for the next standards, which cover global harmonization, are ongoing. Recently, reducing CO_2 has become more important than lowering exhaust emissions. The worldwide trends in emissions regulations and fuel economy standards are shown in Figure 1 and Figure 2.

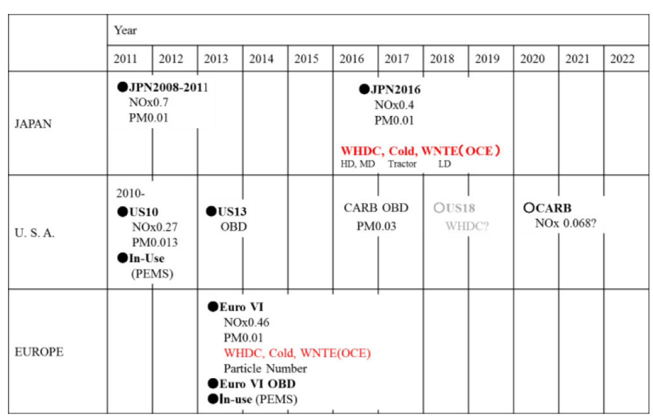

Figure 1. Worldwide trends in emissions regulations.

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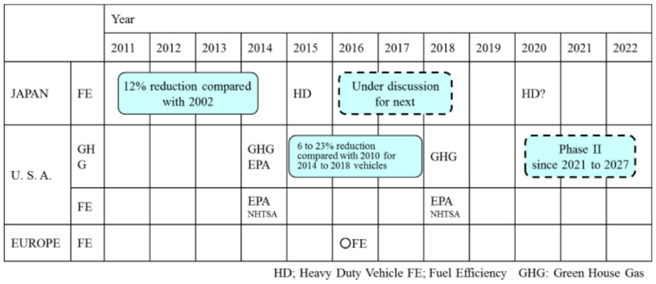

Figure 2. Worldwide trends in fuel economy standards.

Therefore, to achieve better fuel economy, advanced technologies such as downsizing or means of lowering friction etc. in diesel engines have been being developed to comply with the regulations and standards, and technologies for diesel engine oils and additives are also being improved. Based on a 2014 report [4], Figure 3 illustrates the trends in oil quality improvement in Japan. The use of American Petroleum Institute (API) CD oils has decreased considerably in terms of fuel economy and the quantity of disposed oil. In contrast, JASO DH-2 oils are dominant, with a 68% share due to the Diesel Particulate Filter (DPF) spread in Japanese market, and SAE 10W-30 viscosity grade oils for heavy duty engines are popular and widely used in Japan. However, the SAE 5W-30 viscosity grade oils, which provide better fuel economy, started to be used in 2009, as shown in Figure 4. At the present time, the demand for heavy duty engine oils that provide greater contribution to fuel economy, such as SAE 5W-30 is rising.

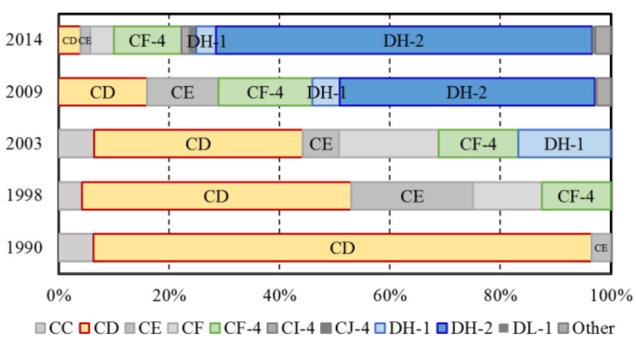

Figure 3. Trends in quality improvement for heavy duty engine oil in Japan. (Source; Japan Automobile Transportation Association (JATA) Report, November 2014)

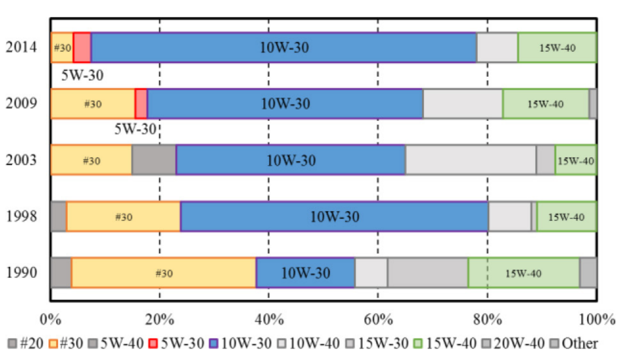

Figure 4. Trends in SAE viscosity grades for heavy duty engine oils in Japan. (Source; Japan Automobile Transportation Association (JATA) Report, November 2014)

The Task Force was established under the Petroleum Association of Japan (PAJ) and Japan Automobile Manufacturers Association, Inc. (JAMA) joint sub-committee, and its members mainly consisted of additive suppliers, along with the Japan Lubricating Oil Society (JALOS). The purpose of the Task Force was to study the scope of the standard, as well as test methods and criteria. In 2016, based on the studies of the Task Force, the Engine Oil Sub-committee of the Society of Automotive Engineers of Japan, Inc. (JSAE) started working on the standard, which covers the fuel economy test method for fuel efficient diesel oils and the new DH-2F category fuel economy requirements as the revised JASO M355:2017.

The JASO diesel engine oil standard (JASO M355) was established in 2001 [5] for Japanese automotive diesel engines in Japan. After a 2005 revision to add JASO DH-2 and DL-1 for engines with after-treatment devices such as DPFs [6][7], the JASO M355:2014 and JASO M355:2015 were revised in 2014 and 2015 to use the N04C engine as an alternative to the previous TD25 engine for JASO M336:2014 (Piston Detergency Test) [8][9] and the 4D34T4 engine for JASO M354:2015 (Valve Train Wear Test) [10][11]. These standards, which consist of four engine tests and seven bench tests, prescribe the minimum performance for engine oils conforming to Japan-made four-stroke diesel engines with after-treatment devices using low sulfur diesel fuel.

The four engine tests specified in JASO M355:2015 are soot dispersancy (ASTM D5967), piston detergency (JASO M336:2014), high temperature oxidation stability (ASTM D6984 or 7320) and anti-wear performance (JASO M354:2015). The seven bench tests specified in JASO M355:2015 are hot surface deposit control, anti-forming, volatility, anti-corrosion, shear-stability, base number and seal compatibility. The limits for chemical elements and sulfated ash are specified.

This paper details the new engine test method for fuel economy heavy duty diesel oils and the new JASO DH-2F fuel economy oil category, which are based on the results of the round robin tests by six laboratories in the Task Force. With the development of this new test method and new category, the JASO M355:2015 diesel engine oil standard was revised to a 2017 version.

Table 1 shows an extract of the engines and requirements specified in JASO M355: 2017. The same N04C engine and the same test conditions are specified in JASO M336, M354, making it especially significant that both tests can be run at one time in a single engine. Furthermore, at this time the new JASO standard with a new oil category specifies the same N04C engine, leading to expectations of reductions in the cost and time needed to develop the oils. And the new oil category JASO DH-2F will have fuel economy benefit without the sacrifice of engine durability performance.

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Table 1. Extract of the engines and requirements specified in JASO M355:2017.

Item		Unit	Standard value					Test method
			DH-1 -17	DH-2 -17	DH-2F -17	DL-0 -17	DL-1 -17	
Viscosity grade			-				XW-30, XW-20	SAE J300
Piston detergency [a)]	WTD (Weighted Total Demerit)	-	740 or less					JASO M336
	TGF (Top Groove Fill)	Mass fraction, %	Report					
	Piston ring sticking		All free					
	Ring land deposit	Merit rating	Report					
Valve train wear protection performance [a)]	Tappet wear	µm	11.3 or less					JASO M354
Soot dispersal performance	Kinematic viscosity increase (100°C, 100 h - 150 h)	$mm^2/s/h$	0.2 or less					ASTM D5967
High temperature oxidation stability	Kinematic viscosity increase (40°C, 60 h) or	%	295 or less				-	ASTM D6984
	Kinematic viscosity increase (40°C, 100 h)		150 or less					ASTM D7320
	Kinematic viscosity increase (40°C, 80 h) or kinematic viscosity increase (40°C, 100 h)	%	-				275 or less 150 or less	ASTM D6984 ASTM D7320
Fuel economy improvement [b)]	Average fuel economy improvement (Fresh oil)	%	-		3.7 or more	—		JASO-MXXX
	Sum of average fuel economy improvement (Fresh oil + Aged oil)	%	-		6.8 or more	—		
	Fuel economy improvement	%	-				2.5 or more	CEC-L-054 -96
Hot surface deposit control	(280°C)	Merit rating	7.0 or more					JPI-5S-55

FUEL ECONOMY TEST METHOD

Test Engine Specifications

Fuel economy performance shall be evaluated using the N04C engine manufactured by Hino Motors, Ltd. The N04C engine is also specified by JASO M336 (Piston Detergency) and M354 (Valve Train Wear). The engine specifications-in-line 4 cylinders with a 4-liter displacement, direct injection turbo inter-cooled-are shown in Table 2 and Figure 5. The general properties of the fuel are summarized in Table 3. The sulfur content of fuel is below 0.005%.

Table 2. N04C engine specifications

		N04C-VH
Engine type		Water cooled 4 cycle diesel
Number of cylinders		In-line 4
Type of combustion		DI turbo inter-cooled
Total displacement	L	4,009
Fuel		Diesel fuel
Fuel injection system		Common-rail
Rated power(Net)	kW/(r/min)	120/2,800
Max. torque (Net)	N・m/(r/min)	430/1,600
Capacity of oil-pan	L	8.0
Total oil quantity	L	9.6

Figure 5. Photograph of the N04C engine.

Table 3. General properties of the fuel.

Item		Property Value	Measuring method	Reference: The quality requirements for Class 2 light gas oil specified in the JIS K 2204: 2007, Clause 3 (Type)
Density	(15 deg. C) g/cm^3	0.820 to 0.845	JIS K 2249-1,2,3,4	0.86 or lower
Distillation characteristics	(10 volume fraction % initial distillation point) deg. C	180 to 245	JIS K 2254	-
	(50 volume fraction % initial distillation point) deg. C	250 to 300		-
	(90 volume fraction % initial distillation point) deg. C	310 to 350		350 or lower
Flash point	(Pensky-Martens closed cup method) deg. C	50 or higher	JIS K 2265-3	50 or higher
Pour point	deg. C	-7.5 or lower	JIS K 2269	-7.5 or lower
Plugging point	deg. C	-5 or lower	JIS K 2288	-5 or lower
Carbon residue of 10 % residual oil	Mass fraction %	0.1 or lower	JIS K 2270-1,2	0.1 or lower
Cetane index		50 or higher	JIS K 2280-4,5	45 or higher
Kinematic viscosity	(30 deg. C) mm^2/s	2.5 to 5.0	JIS K 2283	2.5 or higher
Sulphur content	Mass fraction %	0.005 0 or lower	JIS K 2541-1,2,6,7	0.001 0 or lower

Typical Properties of Candidate Engine Oils

The specifications of the candidate engine oils for the development of the fuel economy test method are shown in Table 4. The four types of oil used in round robin tests by the Task Force in 2015 to develop the test method were DBL1, DFE1, and the on-file JASO DH-2 commercial oils A and B specified as the reference oils. These oil types were discussed to establish the performance criteria for both fresh and aged oils. DBL1 is a diesel base line oil with an SAE #30 viscosity grade equivalent to JASO DH-2 and DFE1 is a diesel fuel efficiency oil with an SAE 5W-30 viscosity grade equivalent to JASO DH-2, while commercial oils A and B are the on-file JASO DH-2 oils. DBL1 was selected to have distinct separation of fuel economy performance between DBL1 and test oil. DFE1 is same as the reference oil of JASO M354 valve train wear testing. And CO A and CO B was selected from commercial oil of DH-2 with 5W-30.

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Table 4. Specifications of candidate engine oils.

		REO		Commercial Oil		Test method
		DBL1	DFE1	A	B	
JASO Grade		DH-2 Equivalent	DH-2 Equivalent	DH-2	DH-2	
SAE Viscosity Grade		30	5W-30	5W-30	5W-30	
Kinematic Viscosity	40°C mm^2/s	93.37	49.72	56.49	59.10	JIS K2283-2000.5
	100°C mm^2/s	11.57	10.58	10.70	10.59	
Viscosity Index		113	210	183	171	JIS K2283-2000.6
HTHS Viscosity	100°C mPa・s	9.68	6.68	7.03	7.07	JPI-5S-36
	150°C mPa・s	3.53	3.20	3.01	3.19	
Acid Number	mgKOH/g	2.65	1.48	2.57	2.62	JIS K2501-2003.7
Base Number HCl	mgKOH/g	7.21	5.96	7.06	6.84	JIS K2501-2003.8
Carbon Residue	mass%	1.05	0.76	1.09	0.87	JIS K2270-2000.6

The DFE1, commercial oils A and B aged oils used to develop the fuel economy test method for aged oils were produced through a 200-hour engine-test with full load condition specified in the JASO M336 or JASO M354 standards in Table 1, which specify the same N04C engine as the fuel economy oil test. The kinematic viscosity increase, base number, acid number increase and carbon residue increase properties of the aged oils at 200 hours, obtained from round robin tests repeated 4 to 6 times, are shown in Figures 6 to 9.

The viscosity increase was 20 to 30% at 40 degrees C, and 10 to 30% at 100 degrees C. As seen in Figure 6, commercial oil A exhibited greater variation in viscosity increase than the other oils. The carbon residue increase properties showed similar variation corresponding to that in viscosity increase, as seen in Figure 7.

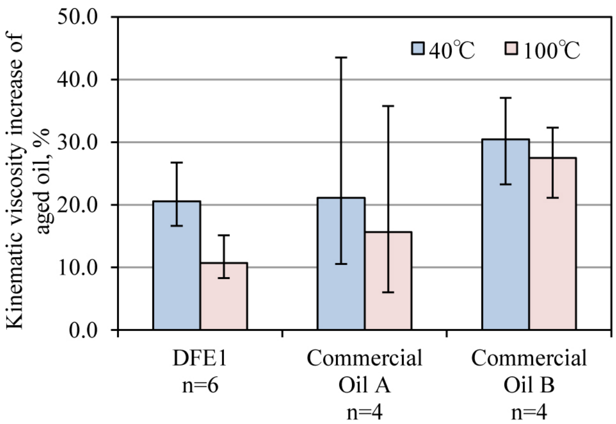

Figure 6. Kinematic viscosity increase of aged oil.

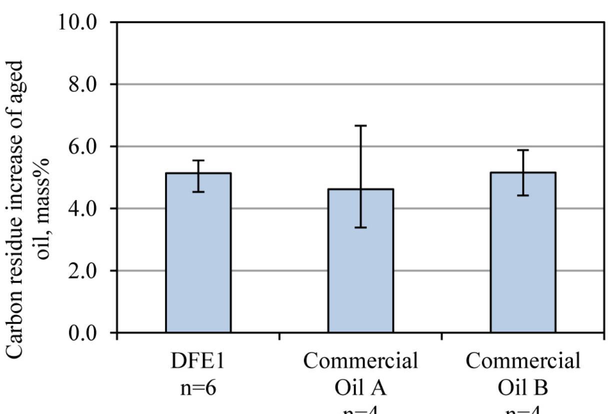

Figure 7. Carbon residue increase of aged oil.

The base number retention at 200 hours, obtained using the HCl method and shown in Figure 8, was 2 to 3 mgKOH/g, compared to the 6 to 7 mgKOH/g value for fresh oil.

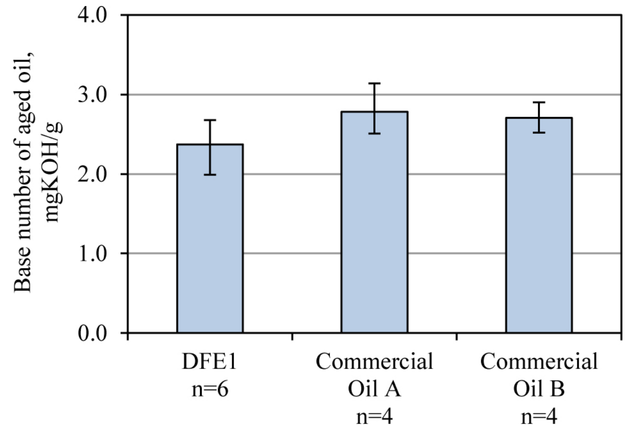

Figure 8. Base number of aged oils.

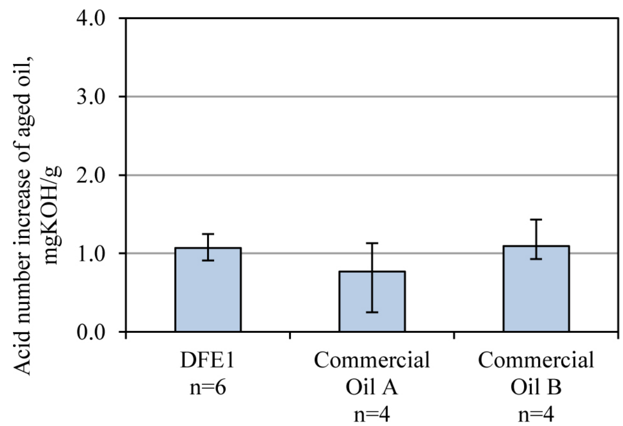

Figure 9. Acid number increase of aged oils.

Engine Operating Conditions for the Developed Fuel Economy Oil Test Method

The specified fuel consumption rate (km/L) shall be calculated based on the governmental Heavy-duty Motor Vehicle Fuel Economy Test Method (TRIAS 5-8-2010) [12], which requires the following engine data: full load conditions, map data for the fuel consumption rate (L/hour), friction torque, and low idling operation obtained from engine dynamo tests. This program is a simulation method for combined city and highway driving for heavy duty vehicles, which is specified as the JE05 mode for the type approval test in Japan.

The engine dynamo tests to measure the fuel consumption rate (L/hour) with DBL1, DFE1, and commercial oils A and B were conducted at engine oil temperatures of 60 and 90 degrees C, which are, respectively, equivalent to winter and summer.

Table 5 outlines the simulation method used to calculate the fuel consumption rate (km/L).

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Table 5. Outline of simulation method used to calculate fuel consumption rate (km/L).

NO.	Item	Remarks
1	Set-up of N04C engine and measurement system Confirmation and adjustment of operating conditions	-
2	Engine dynamo tests ① Full load test (800, 1300, 1800, 2300, 2800, 3300 rpm) ② Motoring friction test (800, 1300, 1800, 2300, 2800, 3300 rpm) ③ Mapping test of fuel consumption in steady-state condition (Total 30 points of 800, 1300, 1800, 2300, 2800, 3300 rpm by each 20, 40, 60, 80, 100% load condition) ④ Low idling operation test (650rpm)	Test with DBL1 and candidate oil (fresh and aged oil) under engine oil temp.: 60 and 90 deg.C
3	Input engine and vehicle specification data and results of engine dynamo test to the simulation program	Web Site; See below
4	Calculating fuel consumption rate (km/L)	Calculating with DBL1 and candidate oil (fresh and aged oil) under engine oil temp.: 60 and 90 deg.C
5	Calculating fuel economy improvement rate (%)	Each 60 and 90 deg.C
6	Calculating average fuel economy improvement rate (%)	Averaging data for 60 and 90 deg.C tests

Figure 6 shows the specific test protocol for the fuel economy test with the DBL1 and candidate fresh and aged test oils at oil temperatures of 60 and 90 degrees C. At the 4th step in Figure 6, the aged oil is tested using the procedure for aged oil specified in JASO M336 or M354 with the specified N04C engine. The calculation method for the average fuel economy improvement rate is shown in Equation (1).

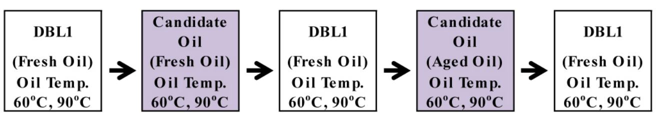

Figure 6. Specific test protocol for the fuel economy test.

$$x = \frac{a + b}{2} \tag{1}$$

x : Average fuel economy improvement rate (%)

a : Fuel economy improvement at 60 deg.C (Oil temp.)(%)

b : Fuel economy improvement at 90 deg.C(Oil temp.)(%)

Design of Engine Testing Matrix for Test Precision and Oil Differentiation

Four laboratories in the Task Force evaluated repeatability, reproducibility, and differentiation of fuel economy performances for the fuel economy test method. A matrix of engine oil tests was designed to determine testing precision for the four oils, including DFE1 and both fresh and aged oils at engine oil temperatures of 60 and 90 degrees C in accordance with the specific test protocol shown in Figure 6. The test matrix is presented in Table 6. The columns indicate reproducibility and the rows indicate repeatability and differentiation of fuel economy performance.

Table 6. Test matrix for round robin tests.

Lab	Repetitions	Test Protocol and Test Oil								
		1	2	3	4	5	6	7	8	9
		DBL1	Candidate Oil	DBL1	Candidate Oil	DBL1	Candidate Oil	DBL1	Candidate Oil	DBL1
1	#1	DBL1	DFE1	DBL1	DFE1	DBL1	DFE1	DBL1	---	---
	#2	DBL1	Co B	DBL1	Aged Oil Co A	DBL1	---	---	---	---
	#3	DBL1	DFE1	DBL1	Aged Oil DFE1	DBL1	Aged Oil DFE1	DBL1	---	---
2	#1	DBL1	DFE1	DBL1	Co B	DBL1	Aged Oil Co B	DBL1	---	---
	#2	DBL1	DFE1	DBL1	Co B	DBL1	Aged Oil Co B	DBL1	Aged Oil Co B	DBL1
	#3	DBL1	DFE1	DBL1	Aged Oil DFE1	DBL1	---	---	---	---
	#4	DBL1	DFE1	DBL1	Aged Oil DFE1	DBL1	---	---	---	---
3	#1	DBL1	DFE1	DBL1	DFE1	DBL1	Aged Oil DFE1	DBL1	---	---
	#2	DBL1	Co A	DBL1	Aged Oil Co A	DBL1	Aged Oil Co A	DBL1	---	---
	#3	DBL1	DFE1	DBL1	Aged Oil DFE1	DBL1	---	---	---	---
4	#1	DBL1	Co B	DBL1	Aged Oil DFE1	DBL1	Aged Oil DFE1	DBL1	---	---

Remarks:
DBL1: diesel base line oil, DFE1: diesel fuel efficiency oil, Co A: commercial oil A, Co B: commercial oil B,
Aged Oil: 200-hour engine-test oil produced according to JASO M336 or M354
Red frame: specific test protocol shown in Figure 6

RESULTS AND DISCUSSIONS

Results of the Engine Matrix Testing for Fresh Oil

Figure 7 shows the results of comparing the 11 fresh oil test repetitions for DFE1 and DBL1, which yielded an average improvement rate of 4.43%, a standard deviation (SD) of 0.27, and a coefficient of variation (CV) of 6.0% under 60 and 90 degrees C engine oil temperature conditions. The range of the 95% Confidence Interval was 3.90 to 4.97%. Therefore the repeatability of the fresh oil results is validated as the test method is acceptable. Furthermore, the fuel economy test method has excellent differentiation performance between DBL1 with an SAE 30 viscosity grade and DFE1 with an SAE 5W-30 viscosity grade. Therefore both the DBL1 and DFE1 oils were set as reference oils.

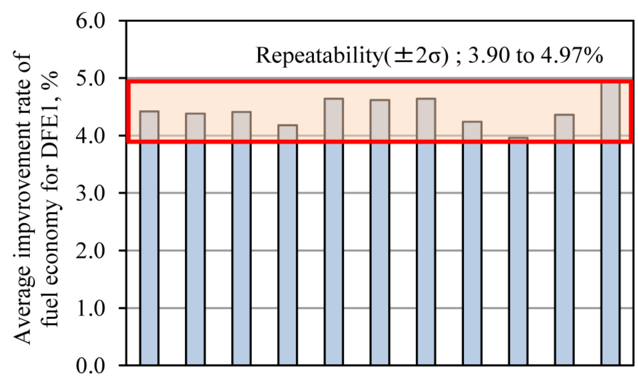

Figure 7. Repeatability of fuel economy test for DFE1and DBL1.

Figure 8 shows the test results for commercial oils A and B, with an SAE 5W-30 viscosity grade for fresh oil. The tests were repeated 18 and 4 times, respectively, including the results of the 11 repetitions for DFE1. The error bars indicate the minimum and maximum values for each oil test repetition.

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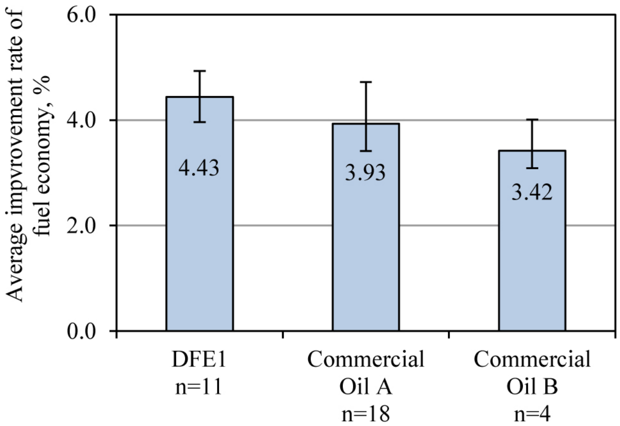

Figure 8. Fuel economy test results for fresh oils.

Each average improvement rates of fuel economy (%) of three types of SAE 5W-30 oil exhibit significant difference with 0.05 of significance level. In other words, the reliability level of these results was 0.95. Even for the 5W-30 viscosity grade, the developed test method can differentiate between changes in the fuel economy performance of individual oils through the differences in their viscosity properties. For example, as seen in Table 4, DFE1 has lower kinematic viscosity (40 degrees C) than the other oils, while commercial oil A has lower HTHS viscosity (150 degrees C).

Results of the Engine Matrix Testing for Aged Oil

Figure 9 shows the DFE1 and commercial oils A and B aged oil test results for 4 to 6 repetitions conducted at the 4 laboratories compared to DBL1. The DFE1 aged oil tests were conducted 6 times at the 4 laboratories, yielding an average improvement rate of fuel economy of 3.88% under 60 and 90 degrees C conditions, with an SD of 0.15 and a CV of 3.8%. The test precision for these results was similar to that of the previously discussed fresh oil tests.

The Task Force also discussed the retention rate (%) of the average fuel economy improvement rate in the specified aged oils compared with the specified fresh oils, referred to as the "fuel economy retention rate (%)" for the specified aged oil in this paper. The average fuel economy retention rate in aged DFE1 was 88.1%, as shown in Figure 10.

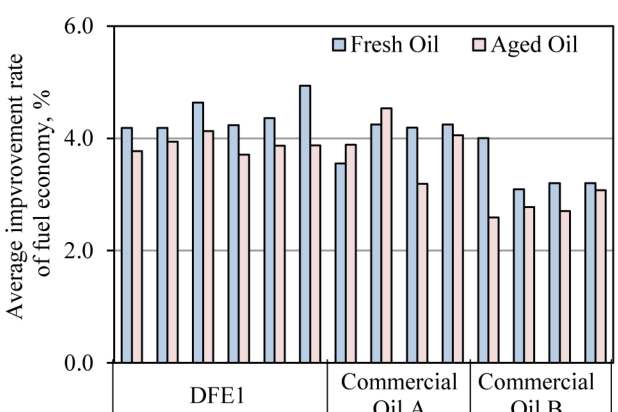

Figure 9. Fuel economy test results for aged oils.

The test results variation for the specified aged Commercial Oil A was much wider than for the specified aged DFE1, exhibiting an SD of 0.56 and a CV of 14% compared to an SD of 0.15 and a CV of 3.8%. This difference in the test results variation for the aged oil fuel economy retention rate between DFE1 and commercial oil A may be caused by the changes of aged oil properties such as kinematic viscosity and carbon residue increase shown in Figures 6 and 7. There were also significant reverse results for commercial oil A, where some of the improvement rates of fuel economy in aged oils were higher than those in fresh oils. Therefore there is a need to further study how the variation of aged oil properties affects fuel economy.

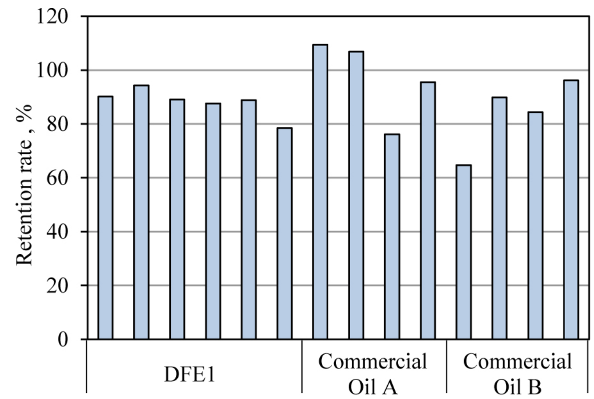

Figure 10. Retention rate (%) of the average fuel economy improvement rate for the specified aged oils

Summarized Test Results for Precision Matrix Testing in the Developed Test Method

The summary of the test precision results for the round robin tests are listed in Table 8. The CV values (%) for the average fuel economy improvement rate and the fuel economy retention rate are acceptable since, at 6% to 14%, the range of the CV values is low.

Table 8. Summary of the precision matrix testing results.

Tested Oil		Repetitions	Average Fuel Economy Improvement			Standard Deviation (SD)	Coefficient of Variation (%)
			Ave. (%)	Max. (%)	Min. (%)		
Reference Oil DFE1 (Fresh Oil)		11	4.43	4.93	3.96	0.27	6.1
Commercial Oil A (Fresh Oil)	2015	17	3.91	4.72	3.41	0.30	7.7
	Round Robin Test	18	3.93	4.72	3.41	0.30	7.6
Commercial Oil B (Fresh Oil)		4	3.42	4.01	3.09	0.41	12.0
Reference Oil DFE1 (Aged Oil)		7	3.79	4.13	3.25	0.27	7.1
Commercial Oil A (Aged Oil)	2015	2	3.53	3.89	3.19	0.49	13.9
	Round Robin Test	4	3.92	4.54	3.19	0.56	14.3
Commercial Oil B (Aged Oil)		4	2.79	3.08	2.59	0.21	7.5
Fuel Economy Retention (%) in Aged Oil (Based on Average Fuel Economy Improvement (%))		14	89.39	109.44	64.70	11.60	13.0

For reference, the following items are summarized briefly as the criteria to check the validity of the test with an engine dynamo in addition to the specified test conditions based on results of the round robin tests.

1. Fuel economy improvement rate in the reference oil; DFE1
2. Fuel economy test results with PC calculation in the reference oil; DBL1

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PASS CRITERIA FOR FUEL ECONOMY OIL PERFORMANCE IN THE NEW JASO DH-2F CATEGORY (JASO M355:2017)

Criterion for Fresh Oils

The Task Force discussed the pass criterion for fuel economy oil performance for the new category in the JASO M355 based on the above results from the round robin tests. First, in order to specify the pass criterion for fresh oils, commercial oil A, which exhibited acceptable mid-level fuel economy performance among the three types of oil, as shown in Figure 11, was selected as a baseline. The results for commercial oil A were therefore analyzed statistically (n=18 repetitions) to fix the performance criterion. The performance criterion for the average fuel economy improvement rate was set to a minimum of 3.7%, which was the rounded value for the 3.77 lower limit of the 95 % confidence interval.

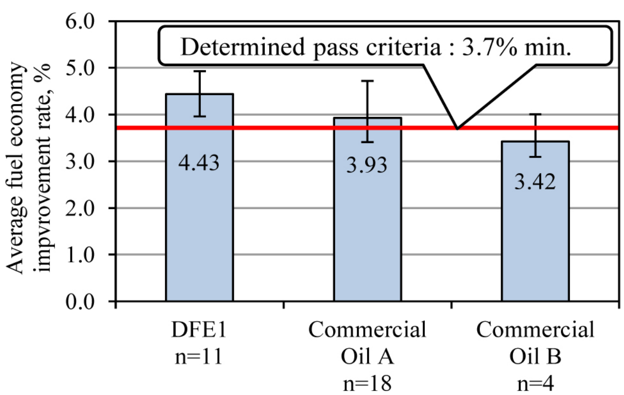

Figure 11. Average fuel economy improvement rate pass criterion determined for fresh oils.

Criterion for Aged Oils

Next, the fuel economy performance criterion for aged oils was discussed based on the fuel economy retention rate (%) for the three types of aged oil in Figure 12. A statistical analysis (n=14 repetitions) yielded an average fuel economy rate of 89.4%, a standard deviation (SD) of 11.6, and a coefficient of variation (CV) of 13%, giving a rounded value of 83.5% for the lower limit of the 95% confidence interval. Based on the 83.5% fuel economy retention rate and the 3.7% fresh oil criterion, which means 3.1% in aged oils, the Task Force, selected the latter value as one of the candidate criteria for aged oils after extensive discussion. However, data and knowledge concerning the fuel economy performance relationship between fresh and aged oils is insufficient, so in addition to the 3.7% fresh oil criterion; the sum of that criterion and the 3.1% aged oil criterion, 6.8%, was set as the minimum criterion for aged oils, as shown in Figure 13.

The revised JASO M355:2017, which add the new DH-2F category of oil fuel economy for heavy duty diesel engines was released in April 2017.

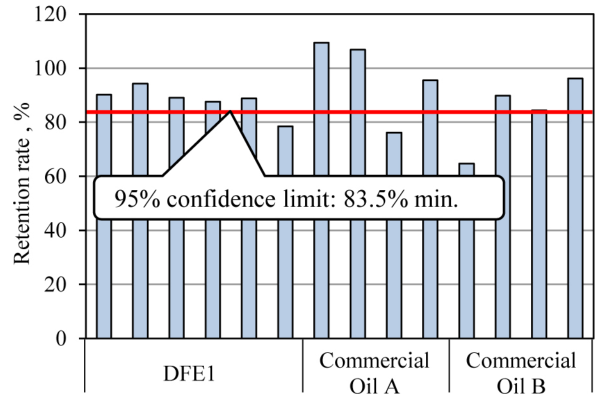

Figure 12. Retention rate in aged oils.

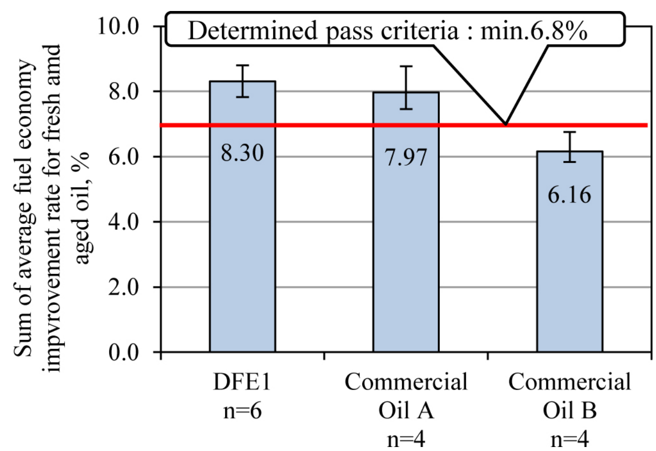

Figure 13. Pass criterion determined as the sum of fresh and aged oil criteria.

CONCLUSIONS

1. The first fuel economy engine test method for heavy duty diesel oil and the new JASO DH-2F category were developed and released in April 2017, with the new standards to be introduced in the market from October 2017 in conformity with the on-file system prescribed by the JASO engine oil standard implementation panel [13].
2. The test method specifies the use of a Hino N04C engine equipped with the latest technologies for compliance with the 2010 Japan emissions regulations, and the new category includes fuel economy requirements in addition to the JASO DH-2 requirements in the 2005 JASO M355 revision.
3. The repeatability and reproducibility of both the fresh and aged oils was acceptable, and test method exhibits excellent differentiation performance between SAE 30 DBL1 and SAE 5W-30 DFE1, which were specified as the reference oils.
4. The performance criterion for fresh oil was set to a minimum of 3.7 % for fuel economy diesel engine oil. In addition, the criterion for aged oil was set to a minimum of 6.8%, which is the sum of the 3.7% fresh oil criterion: and the 3.1% aged oil criterion. The fuel economy performance in-use is extremely important for customers in terms of lowering vehicle operation expenses, as well as for the reduction of CO_2 emissions to improve ambient air quality.

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5. Further study of how the variation of aged oil properties such as kinematic viscosity and carbon residue increase affect fuel economy are needed.

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