

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%.

CITATION: Hashimoto, K., Tomizawa, K., Nakamura, Y., Hashimoto, T. et al., "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)," *SAE Int. J. Fuels Lubr.* 10(2):2017, doi:10.4271/2017-01-0884.

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 CO₂ 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](#).

	Year											
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
JAPAN	● JPN2008-2011 NOx0.7 PM0.01					● JPN2016 NOx0.4 PM0.01						
						WHDC, Cold, WNT(OCE) HD, MD, Tractor, LD						
U. S. A.	2010- ● US10 NOx0.27 PM0.013 ● In-Use (PEMS)		● US13 OBD			CARB OBD PM0.03		CAUS18 WHDC?		OCARB NOx 0.068?		
EUROPE			● Euro VI NOx0.46 PM0.01 WHDC, Cold, WNT(OCE) Particle Number ● Euro VI OBD ● In-use (PEMS)									

Figure 1. Worldwide trends in emissions regulations.

		Year											
		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
JAPAN	FE	12% reduction compared with 2002				HD	Under discussion for next				HD?		
U. S. A.	GHG				GHG EPA	6 to 23% reduction compared with 2010 for 2014 to 2018 vehicles				GHG	Phase II since 2021 to 2027		
	FE				EPA NHTSA				EPA NHTSA				
EUROPE	FE						OFE						

HD; Heavy Duty Vehicle FE; Fuel Efficiency GHG; Green House Gas

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.

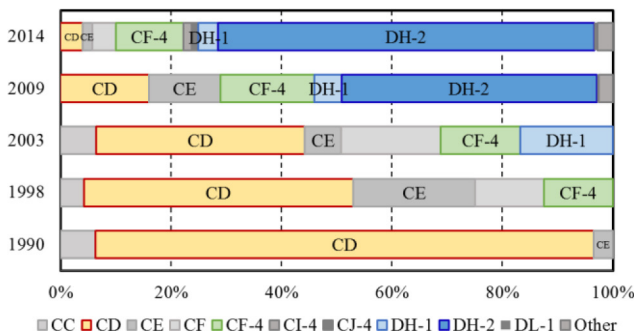


Figure 3. Trends in quality improvement for heavy duty engine oil in Japan. (Source; Japan Automobile Transportation Association (JATA) Report, November 2014)

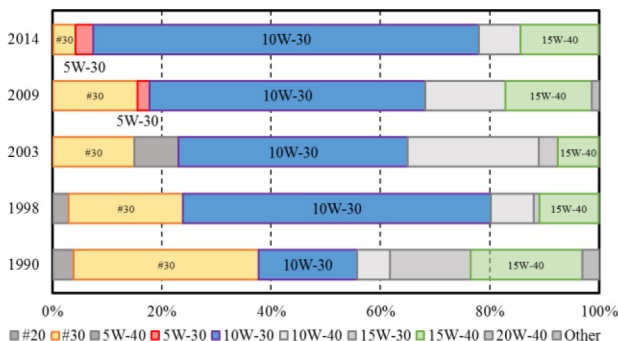


Figure 4. Trends in SAE viscosity grades for heavy duty engine oils in Japan. (Source; Japan Automobile Transportation Association (JATA) Report, November 2014)

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.

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 Kinematic viscosity increase (40°C, 100 h)	%	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
Hot surface deposit control	(280°C)	Merit rating	7.0 or more					JPI-5S-55	



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

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

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.