LUBE-TECH

NO.17

WORLDWIDE PERFORMANCE SPECIFICATION FOR DIESEL ENGINE OIL (WWHD-1)

BACKGROUND

The concept of the world as a 'global village' has increased rapidly with the development of the internet and e-commerce. At the same time, large-scale manufacturers of e.g. cars and commercial vehicles have maintained a competitive edge by 'globalising' their operations, as they seek to reduce costs by benefiting from economies of scale-up and also by attracting grants from countries anxious to attract business investment. Computer-designed vehicles are becoming less distinguishable by manufacturer, since there is generally only one optimum package for a given set of requirement criteria. As a result, national differences between vehicles have narrowed, although the US market has been historically somewhat apart from most other areas, being in the main segregated between gasoline passenger cars and heavy duty commercial diesels, with virtually no light-duty diesels as are common in Europe and elsewhere. However, this situation is changing rapidly. Vehicle usage patterns also differ, being influenced by fuel availability considerations, particularly in terms of price and quality, localised legislation including emissions control, the general localised economic situation and population prosperity, and also by local geographical conditions.

The North American diesel engine lubricant market in particular is evolving to a global marketplace as the presence and influence of international companies grows. One example is Volvo, which manufactures engines in Sweden for use in Volvo Truck North America's commercial vehicles. They require that diesel oils be field tested in Volvo engines to gain Volvo VDS or VDS-2 extended drain acceptance. As such collaboration with European partners or parent companies is likely to increase, there is an increasing requirement for lubricants that meet both North American and European performance.

Through their collaboration with MTU, a subsidiary of Daimler-Benz, Detroit Diesel has introduced the Series 2000 and 4000 engines that require Detroit Diesel/MTU Type 1 or Type 2 lubricants. To gain Type 1 approval, a lubricant must meet the requirements of ACEA E2-96 and API CG-4. Type 2 approval requires ACEA E3-96 performance and allows end-users to extend drain intervals. Detroit Diesel and MTU have worked together for a number of years to develop and market diesel engine technology resulting in the development of the Series 2000 and 4000 engines for off-highway application.

As a wholly owned subsidiary of Renault, Mack Trucks is another example of an engine manufacturer that sees a need to have global diesel lubricants.

A positive step towards the first truly globalised lubricant was taken last year. Last June in Paris, representatives from the Society of Automotive Engineers (SAE) and the Coordinating European Council (CEC) attended a presentation from representatives of three diesel engine OEMs, namely Mack Trucks, AB Volvo and Isuzu, in turn representing their national bodies, namely the US Engine Manufacturers Association, the European Automobile Manufacturers Association and the Japanese Automobile Manufacturers Association.

SCOPE

The following specification in its original form was jointly developed by the European Automobile Manufactures Association (ACEA), Engine Manufacturers Association (EMA), and Japan Automobile Manufacturers Association (JAMA) for engine oils to be used in high-speed, four stroke-cycle heavy duty diesel engines designed to meet 1998 and newer exhaust emission standards worldwide.

Although initially described as a 'minimum performance specification', it was later made clear that the use of the term 'minimum performance' was to highlight the requirement that test limits called for minimum performance requirements; the lubricant itself was certainly <u>not</u> a lowest common denominator, bottom-tier product.

Oils meeting this specification are also compatible with certain older engines. Application of these oils is subject to the recommendation of individual engine manufacturers.

Engine oils meeting the minimum performance requirements of WWHD-1 are intended to provide a consistent oil performance worldwide and therefore may be recommended by engine manufacturers to maintain engine durability wherever their engine is being used. This specification identifies engine oil for use under adverse applications that necessitate wear control, high-temperature stability and soot handling properties. In addition, WWHD-1 is expected to provide engine oils with protection against non-ferrous corrosion, oxidative and insolubles thickening, aeration, and viscosity loss due to shear.

Recommendations of this performance specification in manufacturer's maintenance guides, owner's manuals, and related documents to describe the engine oils required for their products is voluntary. Oil marketers may voluntarily choose whether to market engine oils which meet this specification. ACEA, EMA and JAMA make no representation or guarantee as to whether oil marketers have collected sufficient data to support the performance of any of their specific oils.

TERMINOLOGY

HEAVY DUTY

Engine oils formulated to this specification are intended for use in diesel fueled engines used in vehicles with a Gross Vehicle Weight Rating of 8600 pounds (3900 Kgs) or higher.

PERFORMANCE LIMITS

The performance limits for the Worldwide Engine Oil Specification are summarized in tables 2a and 2b. While ACEA, EMA, and JAMA believe that in order to meet the performance limits of WWHD-1 engine oils should undergo a full test program, it is recognized that commercial practice often includes the use of interchangeability guidelines. Therefore the use of interchangeability and read across guidelines in effect for the marketed region is acceptable.

SIGNIFICANCE AND USE OF THE RECOMMENDED PROPERTIES

For the benefit of end-users and other interested parties, the following section summarizes terminology used in this specification, the critical properties of lubricating oils, and where appropriate, the reason for the selection of a particular quality level of that property.

Test Averaging Acceptance Criteria (TAAC)

Any data based approach for evaluation of the performance of an oil formulation where more than one test may be run. When more than one test is run on an oil formulation, the results are to be averaged. If three or more tests are conducted one test may be discarded from the average. All parameters must average to a passing result. TAAC only applies to those performance characteristics that are shown in Tables 2a and 2b with a single limit. Characteristics with more than one limit are based on the number of runs made and reflect the test's test precision without further averaging.

<u>Piston Deposits and Bore Polish</u>

Survey experience has shown buildup of ring belt deposits to cause improper ring operation, which can lead to high oil consumption and cylinder scuffing. This condition generally determines the life to overhaul for most diesel engines and may have an effect on emission levels. Two engine tests have been identified to measure this performance requirement. The Mercedes Benz OM 441LA test is used for evaluating piston deposit control in engines equipped with aluminum pistons, while the Caterpillar 1R test is used for ferrous pistons.

<u>Wear, Ring/Liner</u>

Piston ring and cylinder liner wear are directly related to engine service life. Under conditions of retarded fuel injection timing, used to meet reduced exhaust emission limits, fuel soot induced wear is likely. The capability of an engine oil to protect the piston rings and liner under these conditions is evaluated with the Mack T-9 test.

<u>Wear, Valve train</u>

Increased valve train loading, coupled with higher engine oil soot loading, as a result of engine design intended to meet reduced exhaust emission standards, has created a concern regarding excessive valve train wear. Wear of these components may change engine timing, impacting performance and exhaust emissions. Wear also shortens engine life. Valve train wear mechanisms may be either rolling or sliding depending on design. The Roller Follower Wear Test (RFWT ASTM D5966) is used to measure engine oil performance for its effect on axle shaft wear, indicating roller wear conditions. Sliding follower valve train wear mechanisms wear protection is measured in two tests. The Mitsubishi 4D34T4 measures engine oil performance effects on cam lobe wear and the Cummins M11 evaluates oil performance impact on rocker pad wear.

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Soot Control

High levels of soot in the engine oil can cause sludge formation, wear and filter plugging. Soot accumulates in the engine oil of a diesel engine as a result of engine timing and combustion. Although the engine oil does not typically impact the formation of soot, properly formulated engine oil can reduce the effects of soot on engine durability. The Mack T-8E engine test is used to measure this performance requirement.

Sludge Control / Filterability

Retarded injection timing increases the potential for partial combustion products to reach the cylinder wall and mix with crankcase oil. These resinous materials form sludge deposits can plug oil filters if not adequately dispersed. Ability of an oil to control filter plugging is critical since plugged filters can allow unfiltered oil to circulate through the engine causing excessive wear of bearings. High filter delta pressure can also result in delay in delivery of oil to critical bearings during cold starts. Under severe conditions sludge can accumulate restricting oil flow. Sludge accumulation is often used to judge oil quality at the user level. The Cummins M11-HST measures both sludge and filter plugging.

Oxidation Control

The moving parts of an engine are designed to operate on a lubricating film. The thickness of this film determines the load carrying ability of the engine components. Therefore, to properly perform, the oil must maintain a consistent viscosity not only when new but also during service. Several factors impact an oil's ability to maintain a consistent viscosity. Soot and oxidation typically cause viscosity to increase while fuel contamination and shear typically cause viscosity to decrease. Oxidation may be inhibited with the proper oil formulation. Oxidation control is measured with the ASTM Sequence IIIF test and the CEC L-85-T-99 (PDSC).

Shear Stability

Engine oils, which contain polymers typically, undergo viscosity loss when subjected to high shear conditions. High shear regimes in an engine exist in piston ring and cylinder wall interface, valve train, and other areas of high relative parts velocity, high loading, and/or high temperature. Shear stability is measured by ASTM D3945. Shearing which results in a permanent viscosity loss is evaluated in this test by passing fresh oil through a high shear fixture, followed by measuring kinematic viscosity (D445). An engine oil producing a test result below the prescribed limit may not maintain sufficient oil film thickness in heavily loaded areas of the engine. A "stay in grade" requirement is often viewed as an oil drain requirement.

Foaming / Aeration

Excessive oil aeration can cause low oil pressure; malfunction of hydraulic valve lifters; and in engines with hydraulic-electronic unit injectors, injection timing may be adversely affected, since air is compressible. Oil with an excessive amount of air does not lubricate engine parts properly, potentially leading to abnormal engine wear.

Corrosiveness

Some oil formulations may cause a chemical attack of metals other than iron, which are used in bushings, bearings, and oil coolers of the engine. The High Temperature CBT evaluates corrosion of lead, copper and tin at the higher temperatures found in some engines.

Volatility

This characteristic evaluates the volatility of engine oils at 250°C using a NOACK evaporative tester. Oils which exhibit high evaporative rate (high volatility) tend to have high oil consumption rates in engines. In some engine designs, high oil consumption may increase particulate emissions.

Turbocharger Deposits

Engine lubricants are more or less sensible to form deposits in the turbocharger. These deposits can lead to lower boost pressure. In modern engines, a central engine computer superintends the boost pressure, which manage, among other parameters, the amount of fuel.In order to optimize the emission levels the fuel quantity will be reduced by decreasing boost pressure. This will lead to a lower engine power output than the engine is specified.

DESCRIPTION OF ENGINE TESTS

Table 1 provides a summary of the engine tests used for this recommended guideline. The tests that describe the performance of engine oils which meet these recommendations have been identified by the particular engine manufacturer of each named test as being representative, either through actual field testing or engineering judgment, of the measured characteristic.A brief description of each test follows. The complete engine test procedures described in this section are available from the Engine Manufacturers Association, Association des Constructucteurs Europeens D'Automobilies, and Japan Automobile Manufacturers Association.

MITSUBISHI 4D34T4

Protection performance of soot related valve train wear can be evaluated by this test. Decrease in cam-lobe diameter is used to determine the level of valve train wear. The test engine is the Mitsubishi 4D34T4 engine, a 3.9 litre, in-line, 4-cylinder, with charged-air inter-cooling. In order to obtain better discrimination among oils, nodular cast iron camshaft, which is different from that of the production engine, is used. The engine conditions are set up to produce around 4.5% soot increase at the end of the test. This is achieved by operation at steady state of 3200 rpm with 10% over fueled during the total test duration of 160 hours.

MERCEDES BENZ OM 441 LA

The OM 441 LA is an 11 litre, V6 Heavy Duty Diesel engine that produces 250 kW at 1900 rpm and meets 'Euro 2' exhaust emission standards. The test duration is 400 hours. It consists of alternative 50 hours phases of steady state and constant speed running. During the test the oil temperature rises to above 123°C and coolant temperature is controlled at 106 ± 1°C. Oil samples are taken every 50 hours during the test.

Primary test parameter: Bore Polish

Piston Cleanliness

Turbocharger Deposit (boost pressure loss)

CATERPILLAR 1R

The Caterpillar 1R test evaluates lubricant performance with regard to piston deposits, oil control, and scuffing resistance for ferrous pistons. The 1R test is run in a high-speed four-stroke cycle Caterpillar 1Y3700 single cylinder oil test engine (SCOTE). The 1Y3700 SCOTE represents the latest technology in diesel engine design, and it is equipped with the following features:

- Two piece articulated piston with steel crown and aluminum skirt
- Mid-supported low distortion cylinder liner
- Gear driven overhead cam
- High pressure electronically controlled fuel injection system
- High temperature oil system

Fuel for the 1R is set at 0.05% sulphur to represent diesel fuel used in North America

TABLE 1
WWHD-1 ENGINE TEST SUMMARY

Test Identification	Engine Speed r/min	Test Length Hours	Fuel Flow	Power Output
Mitsubishi 4D34T4	3200	160	96.0 ±1.0 mm^3/stroke cyl.	120 kW
MB OM 441 LA	1900 / 1330 / 1140	400	160 / 181 / 191 mg/stroke	240 / 205 / 185 KW
Caterpillar 1R	1800	504	240 g/min	68 kW
Cummins M11	1600 / 1800	200	117 lb/h	335 / 360 hp
Mack T-8E	1800	300	139.5 1% lb/h	353 hp
Mack T9	1800 / 1250	75 / 425	139.5 / 121.2 lb/h	360 / 425 hp
Navistar 7.3L	3000	20	42 kg/h	153 kW
Roller Follower Wear Test - RFWT	1000	50	9.4 kg/h	32-36 kW
Sequence IIIF	3000	80	N/A	51 kW

after 1994 and in many other densely populated areas of the world. The 1R test is run for 504 hours with the engine operating steady state at full rated speed and load. At the end of the test, the piston deposits and oil consumption are evaluated and the pistons, piston rings, and cylinder liner are analyzed for any scuffing or seizure. The 1R test is designed to evaluate the performance of lubricants for current direct injection high-speed diesel engines operating on low sulphur diesel fuels.

CUMMINS M11

The Cummins M11 test is run in a six-cylinder engine, which has a specially programmed electronic controller to generate soot in the crankcase oil. The test cycles represent conditions, which generate soot, and those, which generate wear in the overhead, valve train.

Test cycle:

50 Hours @ 1800 r/min Soot generating

50 Hours @ 1600 r/min Wear generating

50 Hours @ 1800 r/min Soot generating

50 Hours @ 1600 r/min Wear generating

The Cummins M11 is designed to evaluate an oil's abilities to prevent excessive filter pressure drop, excessive viscosity increase, sliding valve train wear, bearing corrosion and sludge deposits when it is subjected to high levels of soot.

MACK T-8E

The Mack T-8E test is run in an E7-350 six-cylinder engine with mechanical fuel injection. The fuel injection timing is adjusted to give a target level of soot build-up in the bulk lubricant. The Mack T-8E test is designed to evaluate an oil's ability to prevent excessive viscosity increase and filter plugging when it is contaminated with high levels of soot. The test length is 300 hr. (was 250 hr. for CG-4) to accumulate enough soot (4.8 % min.) for pass / fail limit. The limit includes relative viscosity (Visc. @ 4.8 / (0.5* (V new + V Din) which removes the effect of oil shearing during test. The Mack T-8E shears oils to approx. 50 % of the Din (D 3945) viscosity. Excellent correlation between the test and the field has been established.

MACK T-9 (ASTM D 6483)

The Mack T-9 test is run in an E7-350hp V-MAC six cylinder Mack engine with electronic fuel injection control. The Mack T-9 was developed to evaluate ring and liner wear in a modem high-output diesel engine with two-piece ferrous/aluminum pistons. It also evaluates lead corrosion due to loss of total base number (TBN) in oil. It is a 2-stage test

Phase 1 - 75 Hour @ 1800 r/min for soot generation.

Phase 2 - 425 Hour @ 1250 r/min for wear and corrosion.

Good correlation to field has been established.

ENGINE OIL AERATION TEST (ASTM RR:DO2: 1379)

Twenty (20) hour flush and run test, using Navistar 7.3L DIT diesel engine. Engine oil from the oil sump is used to actuate the fuel injectors. The test evaluates the engine oil's resistance to aeration. Excessive oil aeration can adversely impact engine operation. In severe cases, it may prevent a cylinder from firing thus causing a rough engine operation. An oil sample is taken in a 100ml graduated cylinder and aeration is calculated by taking the percent difference between the exact initial volume and final volume. The aeration limit is 8.0 %.

ROLLER FOLLOWER WEAR TEST (ASTM D-5966)

Fifty (50) hour flush and run test, using GM 6.5L diesel engine, in which only the value lifters are replaced between tests. This test is designed to evaluate an oil's ability to prevent wear of the axle shaft in roller follower hydraulic valve lifter assemblies equipped with needle bearings. This test has been correlated with stop-and-go delivery service.

ASTM SEQUENCE IIIF

ASTM Sequence IIIF test is designed to evaluate an oil's ability to resist thickening when subject to high-temperature service. This test replaces the Sequence IIIE Engine Test (ASTM D5533). The thickening measured in this test is not soot related.

GENERAL

Comments on this new specification were invited, with a closing date of last October, with a planned release and use of the new specification from January 2001. The bulk of the comments received were accepted, the revised specification being re-named Global Diesel Heavy Duty-1.

Retention of three separate tests (M-11, Roller Follower Wear Test, Mitsubishi 4D34T4) for valve train wear was argued on the basis that since all the tests and their relative severities differ to some extent, there was insufficient time to identify which test was the most severe. Although it was mandated the all candidate engine oils must undergo the full test programme, conventional base oil and viscosity grade interchangeability is permitted. As expected, although the specification was strongly supported by the OEMs, the concept of this globalised specification has a number of detractors. The American Chemistry Council, for example, has voiced its opposition, preferring to see a move instead towards globalised tests for use in various regions as a way of reducing test and test development costs.However, work is already under way to develop the next issue, Global Diesel Heavy Duty 2, which will be comprised of new tests developed from scratch.

David Margaroni

REFERENCED DOCUMENTS

Interested parties should consult the most recent versions of the documents referenced below.

ASTM Standards:

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance to Specifications

E 178 Practice for Dealing with Outlying Observations

D 892 Test Method for Foaming Characteristics of Lubricating Oils

D 975 Specification for Diesel Fuel Oils

D 3945 Test Method for Shear Stability of Polymer Containing Fluids using a Diesel Injector

Nozzle

D 5533 Sequence IIIE Engine Test

D 5966 Test Method for Roller Follower Wear Test

D 5800 Test Method for Evaporation Loss of Lubricating Oils by the Noack Method

D 5968 Test Method for Evaluation of Corrosiveness of Diesel Engine Oil

D 6483 Test Method for Evaluation of Ring and Liner Wear

Other ASTM Publications:

RR D02-1273 1Y540 Engine 1K Test Procedure

RR D02-1379 Engine Oil Aeration Test

CEC Testing Standards

CEC L-52-T-97 OM 441 LA test for Bore Polish and Piston Deposits

CEC L-85-T-99 Oxidative Induction Time for Oils using Pressure Differential Scanning

Calorimetry

CEC L-39-T-96 Elastomer Compatibility Test

CEC L-36-T-96 HT/HS Viscosity by Ravenfield Viscometer

CEC L-14-A-93 Test Method for Shear Stability of Polymer Containing Fluids using a Diesel

Injector Nozzle Shear

CEC L-40-A-93 Test Method for Evaporation Loss of Lubricating Oils by the Noack Method

JASO Testing Standard

JASO M 354-199 Test Method for Evaluation of Valvetrain Wear Performance

Other Publications:

Caterpillar SCOTE 1R Test Procedure

Cummins M11 HST Test Procedure

Mack T9 Test Procedure

Mack T-8E Test Procedures

Society of Automotive Engineers J300 Engine Oil Viscosity Classification System

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TABLE 2A WORLDWIDE ENGINE OIL SERVICE SPECIFICATION WWHD-1

Characteristic	Test Method*	Test Name	Requirements	Limits
Engine Tests				
Aeration	ASTM D XXXX	Navistar EOAT	Aeration, Vol. %, Max.	8.0
Bore Polish	CEC L-52-T-97	Mercedes Benz OM 441 LA	Bore Polish % Area, Max.	2.0
Corrosion	ASTM D 6983	Mack T-9	Used Oil Lead, ppm Max	15
			TAN Increase at EOT, max.	2.0
Filter Plugging	ASTM D XXXX	Cummins M11	Oil Filter Diff. Press., kPa, Max.	79 / 93 / 100
Piston Cleanliness	ASTM D XXXX	Caterpillar 1R	Weighted Demerits (WDR), Max.	397 / 416 / 440
			Total Groove Carbon, % Max.	40 / 42 / 44
			Top Land Carbon, % Max.	37/ 42 / 46
			Oil Consumption g/hr, Initial Max. / Final Max.	13.1 / 1.5 X Initial
CEC L-52-T-97	Mercedes Benz OM 441 LA	Weighted Merits,	Min.25.0	
			Oil Consumption, kg/test Max.	40
Oxidation	ASTM D XXXX	Seq IIIF, 80 Hrs.	Kv100 Viscosity Increase, % Max.	100
Turbocharger Deposits	CEC L-52-T-97	Mercedes Benz OM 441 LA	Boost Pressure Loss at 400 Hours, % Max.	4
Sludge Control	ASTM D XXXX	Cummins M11	Eng. Sludge, CEC Merits, Min.	8.7 / 8.6 / 8.5
Soot Control	D-5967	Mack T-8E	Relative Viscosity @ 4.8% Soot	2.1 / 2.2 / 2.3
Wear, Valvetrain	JASO M354-1999	Mitsubishi	Cam Lobe Wear,µm	
		4D34T4 160 Hrs	Average	95
	ASTM D 5966-96	Roller Follower Wear Test	Pin Wear, µm maximum	7.6 / 8.4 / 9.1
	ASTM D XXXX	Cummins M11	Rocker Pad Average Weight Loss, Normalized to 4.5% Soot, mg Max.	6.5 / 7.5 / 8.0
Wear, Ring / Liner	ASTM D 6983	Mack T-9	Average Wear Normalized to 1.75% Soot	
			Liner, µm Max.	25.4 / 26.6 / 27.1
			Top Ring Wt Loss, mg Max.	120 / 136 / 144

* Test methods noted ASTM XXXX are under development by ASTM. A numeric designation will be provided when it becomes available.

TABLE 2B WORLDWIDE ENGINE OIL SERVICE SPECIFICATION WWHD-1

Characteristic	Test Method*	Test Name	Requirements			Limits	
Corrosion	D 5968	Corrosion Bench Test	Used Oil Element Content above Baseline, ppm, Max.			Copper 20, Lead 100, Tin 50	
Elastomer Compatibility	CEC-L-39-T-96	Variation after 7 days fresh oil, No pre-aging		RE 1	RE 2	RE 3	RE 4
		Hardness DIDC	points, max.	1/+5	-5/+8	-25/+1	-5/+5
		Tensile Strength	%. max	-40/+10	-15/+18	-45/ +10	-20/+10
		Elongation rupture	%, max	-50/+`10	-35/+10	-20/+10	-50/+10
		Volume variation	%, max.	-1/+5	-7/+5	-1 /+30	-5/+5
Foaming Tendenc	ASTM D892	Sequence I (24°C)	Tendency / Stability, ml Max.			10 / nil	
	W/O Option A	Sequence II (94°C)	After 1 Min. Settling			50 / nil	
		Sequence III (24°C)				10 / nil	
Foaming - High Temperature	ASTM D 6082	Sequence IV (150°C)	Tendency / Stability, ml Max. After 1 Min. Settling			200 / 50	
Oxidation	CEC-L-85-T-99	PDSC	Oxid. Induction Time, min., Min.			35	
Shear Stability	D 3945	Bosch Injector Test	Viscosity after 30 Cycles, measured at 100 oC			Stay in Grade	
Sulfated Ash	ASTM D-874	Sulfated Ash	Mass %, Max.			2.0	
Viscosity HT/HS Rate	ASTM D4624/D 4683 CEC-L-39-T-96	Ravenfield / Tapered Bearing Simulator	High Temperature / High Shear Rate, Viscosity, cP, Min.			3.5	
Volatility	ASTM D 5800	NOACK	% Volume Loss, Max.			15	

* Test methods noted ASTM XXXX are under development by ASTM. A numeric designation will be provided when it becomes available.