

Feasibility of Using Full Synthetic Low Viscosity Engine Oil at High Ambient Temperatures in Military Vehicles

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ABSTRACT

The US Army is currently assessing the feasibility and defining the requirements of a Single Common Powertrain Lubricant (SCPL). This new lubricant would consist of an all-season (arctic to desert), fuel efficient, multifunctional powertrain fluid with extended drain capabilities. As a developmental starting point, diesel engine testing has been conducted using the current MIL-PRF-46167D arctic engine oil at high temperature conditions representative of desert operation. Testing has been completed using three high density military engines: the General Engine Products 6.5L(T) engine, the Caterpillar C7, and the Detroit Diesel Series 60. Tests were conducted following two standard military testing cycles; the 210hr Tactical Wheeled Vehicle Cycle, and the 400hr NATO Hardware Endurance Cycle. Modifications were made to both testing procedures to more closely replicate the operation of the engine in desert like conditions. These modifications included operation at elevated oil sump (nominally 127°C) and water jacket (nominally 96°C) temperatures. Test engines completed an initial tear down, inspection, and metrology process prior to being built to manufacturer supplied specifications for testing. After completion of testing all engines were again disassembled and underwent a complete metrology and component rating process to determine overall engine wear and deposits. Results to date have shown promising data for use of low viscosity crankcase lubricants utilized at high temperatures in US Army diesel engines.

INTRODUCTION

The US Army has a desire to consolidate multiple lubricant specifications into a single specification, or Single Common Powertrain Lubricant (SCPL). The application of this fluid would range from engine lubrication to power shift transmission operation, and must be designed to operate in ambient conditions ranging from low temperature arctic to high temperature desert type conditions. By achieving these goals, multiple specifications could be reduced into a SCPL that could be used in all tactical or combat vehicles, despite the seasonal or geographical location. The development of this fluid would reduce the logistical burden on the military's supply chain by only requiring one lubricant to be procured and distributed throughout its worldwide operations. Due to the extreme application requirements, it is likely that this SCPL will be formulated from higher cost synthetic base stocks as compared to traditional petroleum derived lubricants. [Table 1](#) below shows the chemical and physical property targets identified by the Army for potential SCPL candidates.

To offset the increased cost of using synthetic lubricants, several performance goals must be met such as increased fuel efficiency and extended drain intervals. Current research has shown the potential reduction in fuel consumption with the use of low viscosity lubricating fluids. (1,2,3) This reduction in fuel consumption is attributed to the reduction in mechanical losses within the system including frictional, pumping, and churning losses. Although these reductions in fuel consumption are expected to be relatively small, when multiplied over a large fleet such as the military's combat and tactical fleet, the cost savings can be substantial. In addition,



the use of synthetic base stocks will provide increased resistance to oil degradation allowing the extension of time between required drain intervals, also increasing the cost effectiveness of the SCPL.

Table 1. SCPL Candidate Chemical & Physical Property Targets

Property	ASTM Method	Units	Required	Target
Kinematic Viscosity @ -40°C	D445	cSt	16000	12000
Kinematic Viscosity @ -48°C	D445	cSt	55000	45000
Pour Point	D97	°C	-55	-60
Low Temp. Cranking	D5293	cP	4700	4400
Low Temp. Pumping	D4684	cP	14000	12000
Brookfield Viscosity	D2983	cP	13000	10000
NOACK Volatility	D5800	%	11	10
Shear Loss	D7109	% loss	8	6

One major aspect of the SCPL development is the verification of compatibility with legacy, current, and potential future engines utilized by the military's tactical and combat fleet. This paper will focus on SCPL engine testing completed to date, as this task represents a key portion in the development and implementation of a SCPL. Preliminary engine testing has been completed using the currently approved MIL-PRF-46167D OEA-30 (4) arctic engine oil as a developmental starting point to determine synthetic low viscosity oil performance when utilized at high oil sump temperatures expected during desert type operations. [Table 2](#) below shows how the MIL-PRF-46167D OEA-30 performs against the target SCPL chemical and physical property goals as defined by the Army.

Table 2. MIL-PRF-46167D Chemical & Physical Properties

Property	ASTM Method	Units	MIL-PRF-46167D OEA-30
Kinematic Viscosity @ -40°C	D445	cSt	10054.2
Kinematic Viscosity @ -48°C	D445	cSt	52548.1
Pour Point	D97	°C	-60
Low Temp. Cranking	D5293	cP	4200
Low Temp. Pumping	D4684	cP	13400
Brookfield Viscosity	D2983	cP	14497
NOACK Volatility	D5800	%	10.7
Shear Loss	D7109	% loss	14.4 (@90 passes)

This oil was chosen as the preliminary SCPL candidate for testing, despite its shortcomings in the chemical and physical properties, since it is currently approved in the military system for use in arctic operation and has low viscometric properties consistent with the initial framework of the SCPL. The primary goal of testing the OEA-30 oil was to determine if required minimum oil film thickness could be achieved within the engine to properly protect critical engine parts when using such low viscosity fluids at elevated temperatures. Military applications are unique compared to their commercial counterparts, as expected total accumulation of operating hours for military equipment is generally much shorter than for typical commercial vehicle. Due to this, military applications could potentially tolerate a higher rate of engine wear than most commercial applications, but must still be able to retain adequate engine protection and function over its intended life cycle. To verify OEA-30 performance at these conditions, testing was completed using modified versions of two standard military test cycles, the 210hr Tactical Wheeled Vehicle Cycle (TWVC) (5) used for the

Table 3. Baseline and Candidate Fresh Oil Chemical & Physical Properties

		MIL-PRF-2104G	MIL-PRF-46167D
Viscosity	SAE J300	15W-40	0W-30
HTHS Viscosity (cP)	D4683	4.18	3.05
Kinematic Viscosity @ 100°C (cSt)	D445	14.8	10.7
Total Base Number (KOH/g)	D4739	8.1	10.1
Total Acid Number (KOH/g)	D664	1.9	2.7

development of military fuels and lubricants, and the 400hr NATO Cycle (6) used for verification of hardware endurance. OEA-30 oil results were compared to previously acquired baseline data (7, 8, and 9) using petroleum based MIL-PRF-2104G OE/HDO 15W-40 (10) to determine changes in high temperature performance. Table 3 below shows fresh oil properties for the baseline and candidate oil.

APPROACH

DETERMINING OIL PERFORMANCE

To determine oil performance several procedures were completed before, during, and after each engine test to generate a basis of comparison between baseline and candidate lubricants. Prior to testing, each engine was completely disassembled and underwent a comprehensive metrology process. Upon completion, each engine was built back to manufacturer recommended specifications in preparation for testing. This was used to generate a baseline data set to use during post test inspections to determine engine wear experienced during testing. As indicated, upon completion of testing each engine was again disassembled and sent through the metrology process, as well as receiving ratings of the piston deposits, valve deposits, and cylinder bore polish. This allowed for a direct comparison of physical engine changes from each lubricant over the test duration.

In addition to the engine measurements, used oil samples were collected regularly to monitor engine oil degradation throughout testing. The following tests were completed on

each used oil sample to track the changes in lubricant properties as a function of total test time:

Table 4. Used Oil Analysis Test Procedures

ASTM Test Procedures	
D4739	Total Base Number
D664	Total Acid Number
D445	Kinematic Viscosity @ 100°C
API Gravity	API Gravity
D4052	Density
TGA Soot	Soot Content
E168	Oxidation & Nitration
D5185	Wear Metals by ICP

During post test data analysis, it was noted that the primary distinguishing factor between the performance of each oil was used oil condition as opposed to the physical engine wear. Small variations in engine wear were noted between the baseline and candidate oil, but no major changes were documented that would impact overall engine performance.

longevity. Conversely, large changes in the rate at which the oil degrades were noticed between baseline and candidate lubricants, and were thus focused on during testing. It was observed that engine wear was highly dependent on the overall oil condition, and therefore, oil condition as a function of test time was determined to be the driving factor for SCPL candidate engine compatibility.

TEST ENGINES

Three high density military engines were selected for initial testing as a way to determine SCPL impact on a large portion of the current military fleet. The test engines were selected to be representative of light, medium, and heavy-duty military vehicles, and consisted of the: General Engine Products 6.5L(T), Caterpillar C7, and Detroit Diesel Series 60 engine.

General Engine Products 6.5L(T)

The General Engine Products (GEP) 6.5L(T) is a 6.5 L V8 non-intercooled turbocharged diesel engine. This engine is from the same family of engines as used in the API CI-4 GM 6.5L roller follower test, but differs since it is turbocharged as opposed to naturally aspirated. Its valvetrain consists of a cam in block arrangement with roller followers, pushrods, and overhead rockers actuating 2-valves per cylinder. The indirect (pre-chamber) fuel injection system utilizes a fuel lubricated rotary style injection pump in a pump line nozzle configuration. It is rated at 190 hp @ 3400 rpm, and 380 lb*ft of torque @ 1800 rpm using diesel fuel. The GEP 6.5L(T) and its 6.5 L and 6.2 L naturally aspirated counter parts are commonly used in all variants of the High Mobility Multipurpose Wheeled Vehicle (HMMWV). Figure 1 below shows the GEP 6.5L(T) test stand installation.

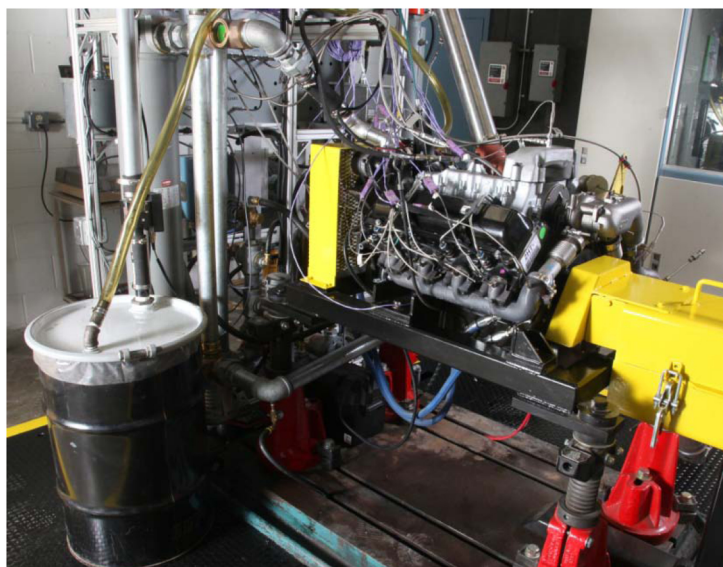


Figure 1. GEP 6.5L(T) Test Cell Installation

Caterpillar C7

The Caterpillar (CAT) C7 ACERT engine is a 7.2 L direct injected turbocharged intercooled diesel engine. Its valvetrain consists of a cam in block arrangement with roller followers, pushrods, and overhead rockers with valve bridges to actuate the 3-valves per cylinder. It uses a hydraulically actuated electronically controlled unit injection (HEUI) fuel system that consists of an oil lubricated high pressure oil pump for hydraulic power. The engine is rated at 330 hp @ 2400 rpm, and 860 lb*ft of torque @ 1440 rpm using diesel fuel. The CAT C7 engine is commonly used in the Family of Medium Tactical Vehicles (FMTV), the IAV Stryker, some Mine Resistant Ambush Protected (MRAP) variants, and the MRAP All Terrain Vehicle (M-ATV). Figure 2 below shows the CAT C7 test cell installation.

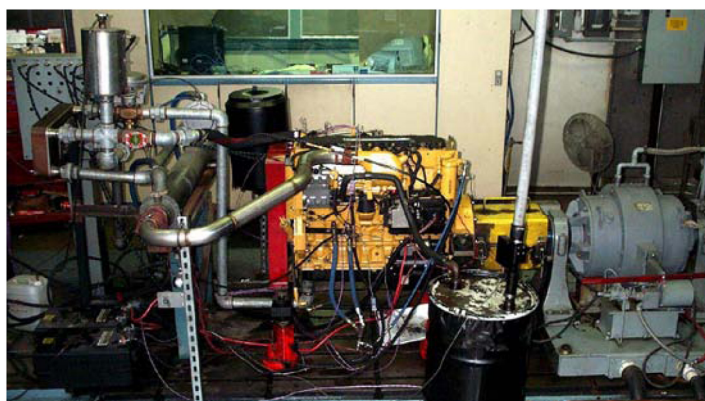


Figure 2. Caterpillar C7 Test Cell Installation Detroit Diesel Series 60

The Detroit Diesel Corporation (DDC) Series 60 DDEC III engine is a 12.7 L direct injected turbocharged intercooled diesel engine. Its valve train consists of an overhead camshaft actuating roller rocker arms that actuate 4-valves per cylinder. It uses electronically controlled unit injectors that are actuated from the overhead camshaft by roller rocker arms. The engine is rated at 375 hp @ 2100 rpm, and 1350 lb*ft of torque @ 1200 rpm using diesel fuel. The engine was from the family of Heavy Tactical Vehicles (HTV), including the Army M915, M916, and M917 trucks, and equipped with an air compressor and Jake Brake assembly. The Jake Brake assembly was physically installed but was electrically deactivated for this testing. Figure 3 below shows the DDC Series 60 test stand installation.