

1000 Hour Durability Evaluation of a Prototype 2007 Diesel Engine with Aftertreatment Using B20 Biodiesel Fuel

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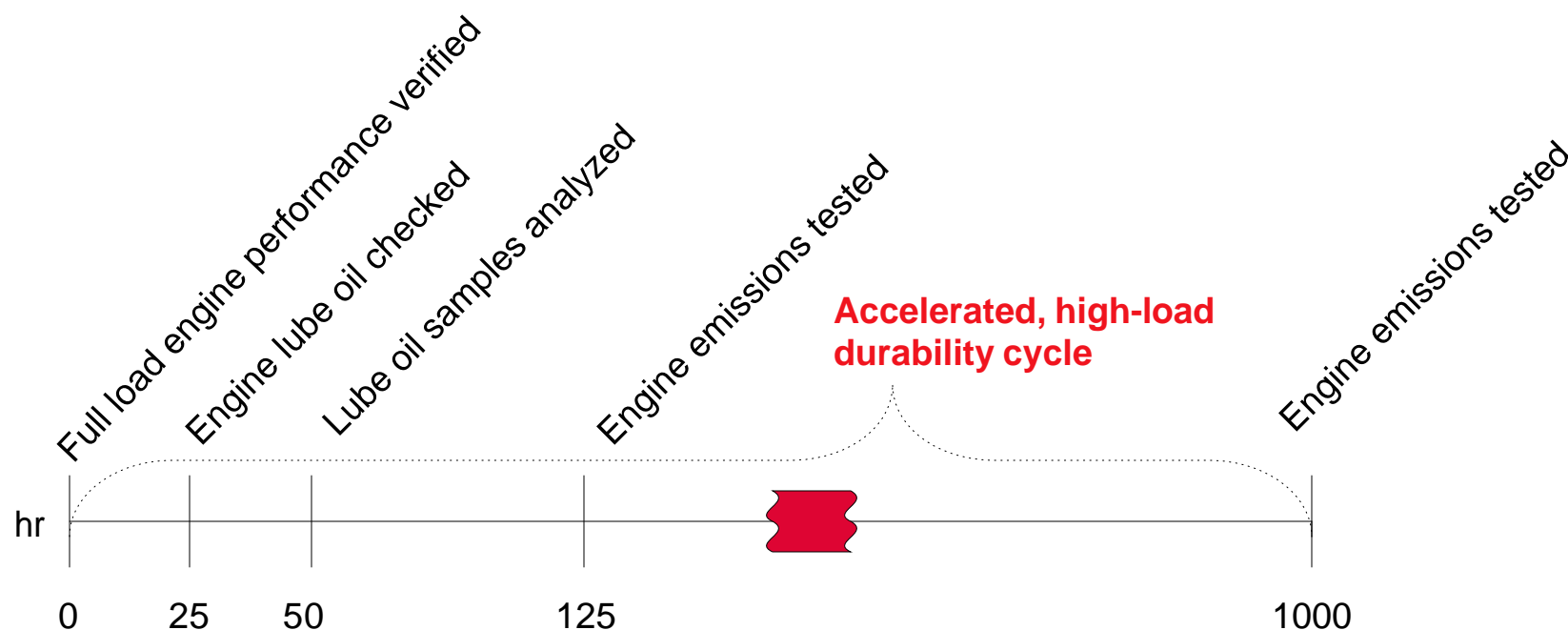
Introduction

- ❑ A prototype 2007 ISL engine was built at Cummins Technical Center and shipped to Southwest Research Institute (SwRI).
- ❑ The National Biodiesel Board contracted SwRI to perform durability and emission testing on the prototype engine.
- ❑ The testing was performed by the Department of Engine and Vehicle Technology in the Engine, Vehicle, and Emissions Research Division at SwRI.
- ❑ SwRI procured the fuel from suppliers, and performed fuel analyses.



Test Plan

- The objective was to operate the engine for 1000 hr using B20 biodiesel fuel, and do a comparative analysis with engines that have operated under the same type of conditions using #2D diesel fuel.





Test Engine

- Cummins prototype 2007 ISL
- Six cylinder 8.9 liter
- Rated power of 330 BHP
- Peak torque of 1150 ft•lb at 1300 rpm
- Diesel Oxidation Catalyst (DOC)
- Diesel Particulate Filter (DPF)
- Post injection (in-cylinder) for active regeneration
- Variable geometry turbocharger
- Exhaust gas recirculation (EGR) with cooler
- Cummins fuel injection system

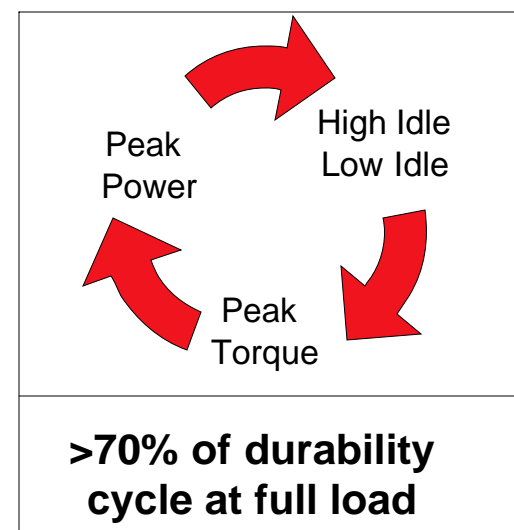
Test Cycles

Durability Testing

- Accelerated
- High-load
- Transient cycle
- Varying load and speed
- Cycle repeated for 1000 hr

Emissions Testing

- Federal Test Procedure (FTP)
 - One cold start transient FTP test
 - Three hot start transient FTP test
 - One SET Ramped Modal Cycle





Test Fuels

	Fuel Type	Description
A	Neat biodiesel	B100 soy-based biodiesel from Sun Coast Resources, Inc.
B	2007 certified ULSD	Emission grade #2D ULSD (<15ppm sulfur) which met 2007 EPA specs from Haltermann Products.
(A+B)	Emission -Grade B20	Blend of 2007 cert. ULSD and Neat biodiesel blended by SwRI used only during emissions testing
C	Durability -Grade B20	B20 blend of neat soy-based biodiesel and commercially available ULSD blended by Sun Coast Resources, Inc.

Sequence of Events		
Hr	Test	Fuel
0-125	Durability	C
125	Emissions	B
125	Emissions	(A+B)
125-1000	Durability	C
1000	Emissions	B
1000	Emissions	(A+B)



Results



Oil Analysis

- ❑ CJ4 Valvoline Premium Blue
- ❑ Soot, viscosity, TBN and elemental analysis were found to be within normal range.
- ❑ Oil dilution, which measures amount of fuel in the oil, was conducted by NREL.

Percent Amount of Biodiesel Measured from Engine Lube Oil Samples at Different Hour Intervals			
Sample (hr)	Biodiesel (wt %)	Sample (hr)	Biodiesel (wt %)
50	0.83	600	0.77
150	1.48	650	1.15
200	1.64	700	1.70
300	0.37	750	1.98
350	1.04	800	0.46
400	1.28	850	0.73
450	1.47	900	1.22
500	1.45	950	1.68
550	0.51	1000	1.84



Durability & Emission Results

- ❑ Approximately 17,000 gallons of B20 biodiesel fuel was used during the durability test.
- ❑ Test went well and was successful. There were no biodiesel related failures during the test, and no reported significant changes in performance of the engine.
- ❑ Engine performance was essentially the same when tested at 125 & 1000 hr of accumulated durability operation.
- ❑ Emission results indicate that THC, CO, and PM levels were not significantly different between the B20 and ULSD.
 - ❑ the emission-grade B20 test resulted in 6% higher NOx (within expected range)
- ❑ Fuel consumption was observed to be 3% higher than the 2007 certified ULSD test (within expected range).



Overhead Components

**Top of cylinder head
No sludge deposits**



**Bottom of cylinder head
Deposits comparable to #2D**



Intake Valves



Exhaust Valves

**Results are typical for this type
of test with #2D diesel fuel**

Power Transfer Components

Component	Comments
Crankshaft Gear	Meets rebuild spec
Cam Gear	Meets rebuild spec
Cam Bushing	Meets rebuild spec
Fuel Pump Gear	Meets rebuild spec
Crankshaft	Meets rebuild spec
Lower & Upper Bearings	Normal wear
Connecting Rod	Meets rebuild spec
Connecting Rod Bushing	Meets rebuild spec

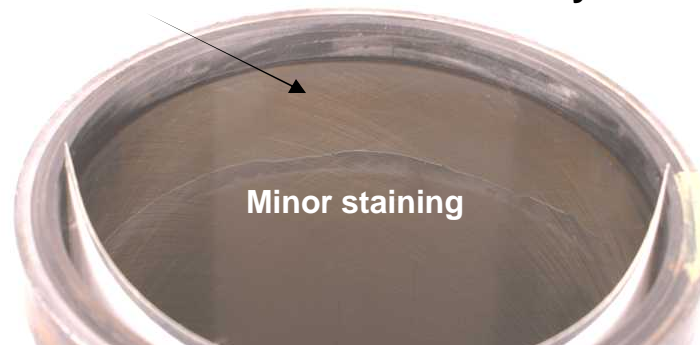


During teardown, the crankshaft was found to be in very good condition, and results were comparable to #2D diesel fuel test.

Power Cylinder Components

Component	Comments
Piston	Normal light wear and deposits.
Cylinder Liners	Normal light wear.
Top rings	Normal uniform face wear. Top and bottom side look typical.
Middle rings	Normal face wear. Top and bottom sides OK, and light carboning.
Oil rings	Looked good. Very little wear.

Crosshatch visible in all six cylinders.



Results comparable to #2D diesel fuel test.

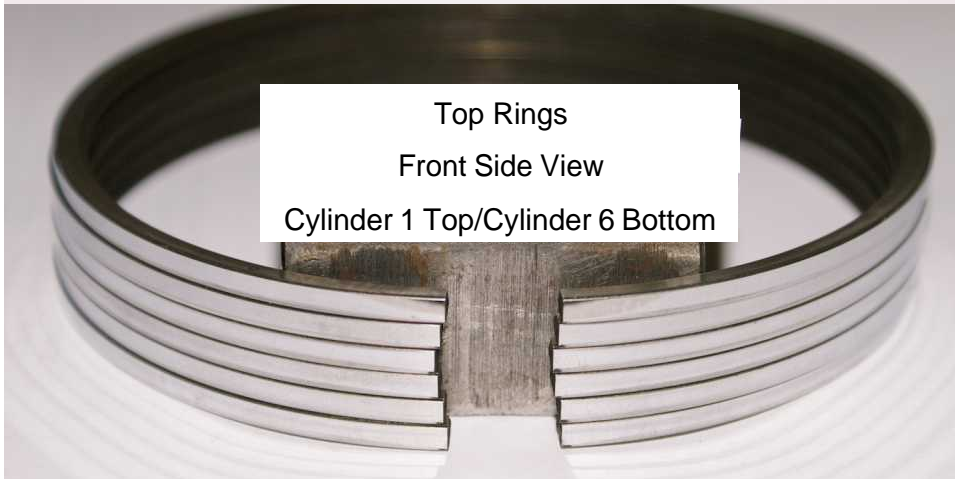
Top Piston Rings



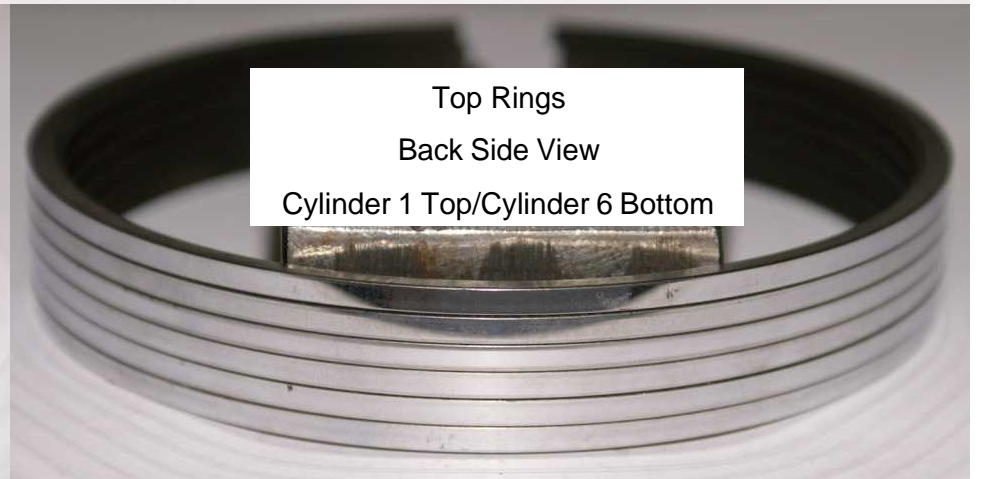
Top Rings
Top Side
Cylinder 1 Top/Cylinder 6 Bottom



Top Rings
Bottom Side
Cylinder 1 Top/Cylinder 6 Bottom



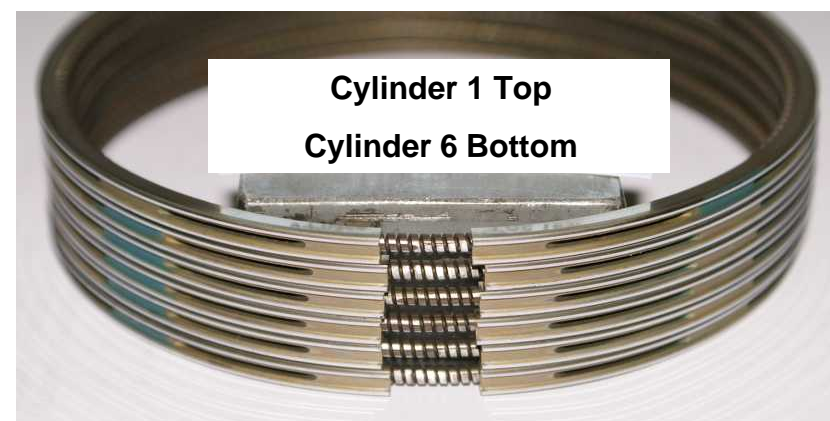
Top Rings
Front Side View
Cylinder 1 Top/Cylinder 6 Bottom



Top Rings
Back Side View
Cylinder 1 Top/Cylinder 6 Bottom

Cooling and Lube Components

Component	Comments
Oil pump	No issues
Oil cooler head	No issues
Oil cooler cover	No issues
Oil pressure regulator/bypass	No issues
Piston cooling nozzles	No problems due to B20.
Oil Pan	Normal
Oil suction tube	Gasket showed good imprint of seal
Turbo coolant/oil lines	Normal



Bottom (Oil) Piston Rings

There were no failures found on the cooling and lube components. The wear and deposits found on the parts were normal and consistent with findings found on parts that ran with #2 diesel fuel in similar tests.

Air Handling Components

Component	Comments
Exhaust Manifold	No issues.
EGR Cooler	No cracks, light coating of soot on inlet and outlet tubes. No soot in inlet diffuser. Findings good overall.
EGR Valve	Looked good. Normal soot accumulation.
EGR gaskets, hoses, tubes, shield, mounting plate, crossover	No issues found due to running with B20.



Carbon deposit layer was generated on the passage and inside parts of the **EGR valve**, but thickness was very thin and condition was dry which is normal for this durability test.



Aftertreatment Components

Component	Comments
Diesel Oxidation Catalyst (DOC)	Looked good. No face plugging. Blockages found appeared like debris and substrate material. Debris was analyzed under Electron Dispersive Spectroscopy (EDS), and all debris found is expected in a typical DOC after 1000 hr of operation, whether fueled with ULSD or biodiesel.
Diesel Particulate Filter (DPF)	Inlet face showed signs of ash build up, but similar to diesel fuel for this type of test. Outlet looked good with no signs of soot. No failure found.
Inlet and outlet section	Looked good.
Gaskets	Looked good.

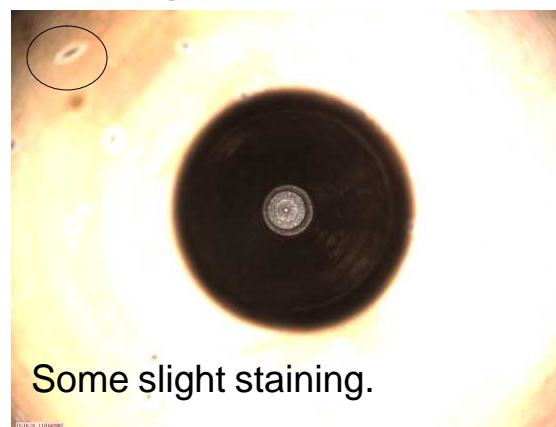
Fuel System Pictures

Stage 1 Plunger Needle

No marks on needle surface or the edge.

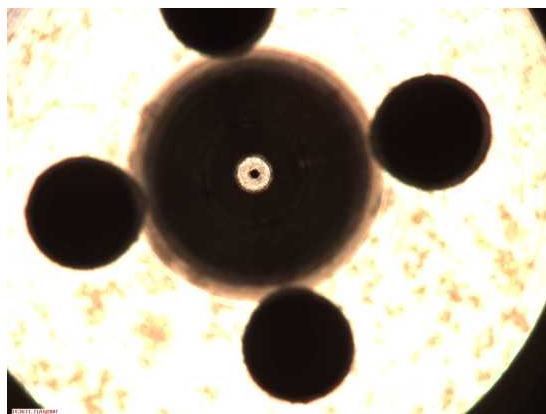


Plunger Needle – Top View

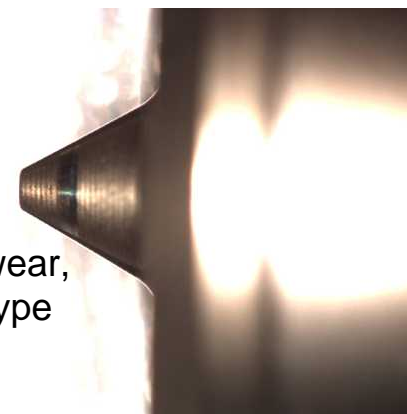


Some slight staining.

Plunger Orifice
not clogged with
oil sludge or
deposits



Stage 2 **Plunger Needle** has some wear, but normal for this type of aggressive test.





Fuel System Components

Rail and fuel lines	<p>Rail – No abnormal wear.</p> <p>End Fitting – No unusual wear.</p> <p>HP Fuel Lines – No visible structural deterioration or cracks observed.</p>
Mechanical Dump Valve (MDV)	<p>No unusual wear, deterioration or sludge buildup observed on plungers, plunger seats or orifice.</p> <p>1) Stage One Plunger – No wear visible on the needle surface or the edge. Some slight staining seen on plunger base.</p> <p>2) Stage Two Plunger – Some wear, but normal. Plunger orifice not clogged with oil sludge or deposits.</p>
Injectors	<p>Injector performance test and photos indicate that the injectors were consistent with injectors that ran with #2D diesel fuel.</p>
Soft Lines	<p>No visible damage to any section of the internal wall of the used fuel tubes indicating that the tubing liner material is resistant to the B20 temperatures and pressures during the engine performance test.</p>
Overall	<p>There were no signs of severe or aggressive corrosion pitting damage on any of the surfaces.</p>



Summary

- ❑ A Cummins 2007 prototype 8.9 liter ISL diesel engine equipped with DOC, DPF, VGT, and EGR with cooler was operated successfully at SwRI using a high-load accelerated durability cycle for 1000 hr with a B20 blend of soy-based biodiesel and ULSD.
- ❑ During the durability testing, no biodiesel related failures occurred.
- ❑ Engine performance was essentially the same when tested at 125 and 1000 hr of accumulated durability operation. Emissions measurements indicate the HC, CO, and PM were not significantly different between the B20 and ULSD tests, and NOx increased with B20 fuel. Fuel consumption also increased with B20 fuel.
- ❑ A thorough engine teardown evaluation of the overhead, power transfer, cylinder, cooling, lube, air handling, gaskets, aftertreatment, and fuel system parts was performed.
- ❑ There were no failures found on the engine components that were directly attributable to running biodiesel B20.
- ❑ The wear and deposits found were normal and consistent with findings from parts that ran with #2 diesel fuel in similar tests.



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