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Impacts of Biodiesel Fuel Blends Oil Dilution on Light-Duty Diesel Engine Operation

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Impacts of Biodiesel Fuel Blends Oil Dilution on Light-Duty Diesel Engine Operation

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ABSTRACT

Increasing interest in biofuels—specifically, biodiesel as a pathway to energy diversity and security—has necessitated the need for research on the performance and utilization of these fuels and fuel blends in current and future vehicle fleets. One critical research area is related to achieving a full understanding of the impact of biodiesel fuel blends on advanced emission control systems. In addition, the use of biodiesel fuel blends can degrade diesel engine oil performance and impact oil drain interval requirements.

There is limited information related to the impact of biodiesel fuel blends on oil dilution. This paper assesses the oil dilution impacts on an engine operating in conjunction with a diesel particle filter (DPF), oxides of nitrogen (NO_x) storage, a selective catalytic reduction (SCR) emission control system, and a 20% biodiesel (soy-derived) fuel blend. The main focus was on the biodiesel oil dilution levels observed during an accelerated aging protocol and an assessment of the potential impacts on the engine and emissions control systems. For the NO_x storage system (which requires a late in-cylinder fuel injection for regeneration), biodiesel oil dilution levels ranged from 5%–10%. For the SCR system (which used a urea solution as a reductant and late in-cylinder fuel injection for diesel particle filter regeneration), biodiesel oil dilution ranged from <4%–8%. These observations were made over typical oil drain intervals. Despite these observed biodiesel oil dilution levels, there were no observed impacts on the performance of the engine or the emission control systems.

INTRODUCTION

Biodiesel fuel blends are one option currently being researched as a pathway to energy diversity and reduced petroleum dependence in the transportation sector. One of the key factors related to the success of biodiesel fuel blends is their compatibility with vehicle components such as fuel systems, combustion parts, and advanced emission control systems. However, one way that biodiesel fuel blends can create potential problems affecting vehicle operation is through accelerated dilution of the oil by the fuel. This is particularly important for vehicles utilizing advanced emissions control systems that require late in-cylinder fuel injection. Excessive oil dilution has the potential to lead to several problems, such as reduced oil performance and durability (e.g., decreased viscosity or the development of oil sludge) and catalyst poisoning. At a minimum, oil dilution could impact the interval requirements for oil changes, the effectiveness of additive packages, and sump capacity. Acceptable oil dilution limits for original equipment manufacturers (OEMs) range up to 50% [1], but most OEMs want limits to be much lower.

Biodiesel is a renewable fuel derived from vegetable oil, animal fat, or waste cooking oil, and it consists of the methyl esters of fatty acids. It is typically used as a diesel blending component at levels up to 20% by volume. Life-cycle analysis indicates that the use of biodiesel can help displace imported petroleum in the United States, and resource assessments have indicated that biodiesel has the potential to displace 5% or more of petroleum diesel over the next decade [2, 3]. However, because biodiesel has a relatively higher

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A similar paper is published as SAE 2009-01-1790.

distillation temperature and boiling point, when it is present in post-injected fuel it tends to dilute the oil on a level disproportionate to its blend ratio in the fuel [4, 5, 6]. This leads to a concern about oil dilution.

Current research at the National Renewable Energy Laboratory (NREL) on the impacts of biodiesel on emission control systems has provided an opportunity to also evaluate the impact of biodiesel fuel blends on oil dilution and its associated impacts on the performance of the engine and emission control system. As a corollary to a larger research project at NREL on biodiesel impacts on selective catalytic reduction (SCR) with urea and oxides of nitrogen (NO_x) adsorber catalyst (NAC) systems [7, 8], researchers assessed biodiesel's impacts on oil dilution. The purpose of this paper is to document the oil dilution observed in this research project and assess any potential engine or emission control system impacts.

HARDWARE DESCRIPTION

The following sections provide an overview of the hardware components used during the project. The test vehicle and test engines were procured by the U.S. Department of Energy in direct support of this project. All the catalyst hardware, as well as the urea dosing system, was supplied by the Manufacturers of Emissions Controls Association (MECA).

ENGINE HARDWARE – The engine used for this project in the test cell as well as in the vehicle was a 4-cylinder 2.15 L high-speed direct injection (HSDI) diesel engine. The original engine calibration complied with Euro 4 emission standards. The engine utilized a conventional high-pressure exhaust gas recirculation (EGR) loop, a second-generation common-rail fuel injection system (1600 bar maximum injection pressure, solenoid injectors) with all actuators electrically controlled. Table 1 lists the main parameters of the test engine.

Table 1: Engine specifications

Engine Power	113 kW at 4000 rpm
Peak Torque	360 Nm at 2000 rpm
Maximum Engine Speed	4700 rpm
Maximum BMEP	21 bar
Cylinder Arrangement	4-Cylinder Inline
Firing Order	1 – 3 – 4 – 2
Valve Train	4 Valve DOHC
Bore to Stroke Ratio	1.0034
Displacement	2.15 L
Compression Ratio	18:1
Fuel Injection System	2nd Generation Common Rail

The test vehicle was a conventional four-door sedan vehicle in the 1,700 kg class. It met the Euro 4 emission standards and was equipped with a catalyzed diesel particle filter (DPF) as a standard feature. Table 2 lists the relevant vehicle features.

Table 2: Vehicle specifications

Criterion	Unit	Value
Vehicle Mass	kg	1,700
Air Drag Coefficient	-	0.29
Frontal Surface Area	m^2	2.20
Transmission Gear Ratio	1st	4.99
	2nd	2.82
	3rd	1.78
	4th	1.25
	5th	1.00
	6th	0.82
	Axle	2.65
Tires	Rear	205 / 55 R 16 91 H
	Front	205 / 55 R 16 91 H

CATALYST SPECIFICATIONS – Two emission control systems (ECS) were developed and tested separately as part of this project. These included an NAC/DPF system and a SCR/DPF system. The NAC was located in a close-coupled position, directly after the turbine exit with minimal distance to the catalyst to allow for rapid heat-up of this NO_x treatment unit; the DPF was located under the floor. The SCR catalyst was also located under the floor and was followed by the DPF in the same can, with a close-coupled diesel oxidation catalyst (DOC). All the piping between the DOC exit and the SCR inlet was made of dual-wall exhaust pipe to increase heat preservation during operation. MECA provided all the ECS components. Table 3 lists all the catalyst specifications for this project.

Table 3: Catalyst specifications for each component

Component System		Volume [L]	Cell Density [cpsi]	PGM loading [g/ft^3]
NAC System	DOC	0.8	400	150
	DPF	3.3	300	60
	NAC	4.1	400	120
SCR System	DOC	1.23	400	150
	DPF	4.1	300	60
	SCR Fe-ZSM-5	4.43	300	N/A

FUEL AND OIL SPECIFICATIONS – An ultra-low-sulfur diesel fuel (ULSD), also referred to as the base fuel, was used to blend the 20% by volume soy-derived methyl ester. Table 4 lists the fuel specifications for each tested fuel type. The effects on the fuel specifications as a result of the increased amount of methyl ester become particularly noticeable in the heating value, the cetane number, and the oxygen content. The base lube oil used for this study was CJ-4 oil.

Table 4: Fuel specifications

Specification	Unit	ASTM Method	ULSD	B20
Net Heating Value	MJ/kg	D240	42.53	41.52
Cetane Number	-	D6890	41.4	45.6
Density at 15°C	kg/m^3	D4052	847.5	852.9
Viscosity at 40°C	mm^2/sec	D445	2.429	2.685
Carbon	wt%	D5291	87.04	85.01
Oxygen	wt%	By difference	0.00	2.29
Hydrogen	wt%	D5291	12.96	12.70

LATE IN-CYLINDER FUEL INJECTION EVENTS

Oil dilution in diesel engines will occur over time with normal operation, leading to oil degradation and the need for oil replacement. With increased use of advanced emission control devices, oil dilution impacts can also increase as a result of late in-cylinder fuel injection events used in conjunction with some of these devices [4, 6]. The late injection events are used as a regeneration strategy for DPFs as well as NACs. These late injection events increase the opportunity for unburned fuel to reach the cylinder walls and in turn enter the lubricating oil. With conventional diesel fuel it can boil out of the lube oil, minimizing long-term dilution effects. However, this effect is accentuated with biodiesel because of its high boiling point relative to petroleum diesel, which can lead to a disproportionate amount of fuel being retained in the lube oil. Three main late injection events are associated with DPF and NAC operation that can accentuate the oil dilution problem. These include lean-rich modulation used for NAC regeneration, desulfurization used to liberate the NAC from accumulated fuel-borne sulfur, and DPF regeneration used to burn off accumulated soot from the DPF substrate.

LEAN-RICH MODULATION – NAC regeneration is a key component of meeting NO_x emission standards with an NAC system. A short pulse of rich exhaust gas desorbs the NO_x emissions and subsequently reduces them, following the well-known chemistry of the three-way catalyst, described in more detail in the next section. These events occur quite frequently (e.g., every one to two minutes). The goal is to obtain the required rich exhaust conditions with a diesel engine that typically operates under lean conditions. Lean-rich modulation through late in-cylinder fuel injection is used to achieve the rich exhaust conditions required by the NAC, but this also has the potential to lead to increased oil dilution.

Desulfurization – The basic principle of NAC is the adsorption of NO_2 during the lean operating phases of the engine. The NO_2 is adsorbed by alkaline earth oxides forming nitrates such as Ba $(NO_3)_2$. The nitrates become unstable and release the NO and NO_2 at high temperature (thermal release of NO_x) or during rich exhaust conditions. The rich exhaust conditions allow the three-way-catalyst mechanism to be used to reduce the released NO_x into N_2 and CO_2. In addition to their desired functions, NACs exhibit the undesired function of adsorbing SO_3^{-2} and forming $BaSO_4$, which is a considerably more stable compound requiring high temperatures and stoichiometric operating conditions to be released. This release or desulfurization has to occur relatively frequently to avoid catalyst deactivation. The frequency of this event depends on the fuel sulfur level as well as the contribution of the engine lubricating oil. The rich operation required to create these high-temperature desulfurization conditions also requires late in-cylinder fuel injection, and that in turn creates an opportunity for increased oil dilution.

DPF REGENERATION – DPF regeneration is occasionally required in order to oxidize the accumulated soot that collects on the DPF during normal engine operation. As with NAC regeneration and NAC desulfurization, late in-cylinder fuel injection is used to create the high temperatures over the DPF required to burn or oxidize the accumulated soot. This provides another opportunity for increased oil dilution, and it would be the case for both NAC systems and SCR systems.

AGING TEST CYCLE

Both systems were aged to an equivalent of 120,000 miles, or full useful life, and the oil was sampled at regular intervals during this aging. In order to simulate the appropriate aging conditions, the engine and ECS were exposed to an equivalent useful lifetime of fuel in the engine dynamometer test cell. To keep the aging time at a reasonable level, the aging duration for each ECS was set to be accomplished in approximately 700 hours. The following assumptions were used regarding fuel consumption for the system:

- Highway Fuel Economy Test (HFET) fuel economy of 55 mpg
- Urban Dynamometer Driving Schedule (UDDS) cycle fuel economy of 33 mpg
- Split of ¾ HFET and ¼ UDDS

These assumptions resulted in an average fuel economy of 49.5 mpg. At 120,000 miles, this equates to 2,424 gallons or 7,708 kg of fuel. Given the 700 hours of aging time, an average fuel consumption of approximately 11 kg/hr was established. Three operating phases were established to reflect real in-use operating modes:

1. NAC operation using the systems efficiency control algorithms to determine the frequency of regeneration events
2. DPF regeneration (300 for full useful life, 20 minutes each)
3. Desulfurization (25 for full useful life for the NAC system only, 20 minutes each)

Table 5 shows detailed operating conditions and durations for the chosen durability cycle. In phase 1, the engine operating conditions are changed between two operating points (OP1 and OP2) for 120 minutes and repeated 300 times. In phase 2, the system transitioned into the DPF regeneration mode with a DPF inlet temperature set point of 650°C. Once the DPF regeneration was completed, approximately 20 minutes, the system returned to phase 1 operation. This sequence was repeated until the total runtime of 28 hours was achieved. After 28 hours, the system was forced into the phase 3 desulfurization mode with a set point temperature of 700°C and frequent lean-rich transitions, as discussed in the desulfurization section. The entire sequence of (phase 1 plus phase 2) x 12 plus phase 3 was repeated 25 times to add up to the total run time of just over 700 hours. Phase 3 was run only with the NAC system as desulfurization was not required for the SCR system. In addition to the operating points, the following table also contains the fuel flow rates for each state.

Table 5: Durability cycle operating conditions

Operating Point	Operating Condition	Duration	Reps	Fuel Consumed
	[rpm or Nm]	[min.]		[gallons]
OP 1	2000 rpm, 210 Nm	5		0.262
OP 2	2600 rpm, 160 Nm	5		0.287
Phase 1	(OP 1 + OP 2) x 12	120	300	6.234
Phase 2	DFP regeneration 2600 rpm, 110 Nm	20	300	1.062
Total per Cycle	Phase 1 + Phase 2	140	300	7.296
Phase 3 (NAC only)	Desulfurization 2200 rpm, 75 Nm	20	25	0.668

OIL ANALYSIS METHODOLOGY

The fatty acid methyl ester (FAME) content in the vehicle's lube oil was determined using a modified version of ASTM D7371, which covers FAME content in diesel fuel oil. Infrared spectroscopy was performed using a Thermo Scientific Nicolet 4700 Fourier transform infrared (FTIR) instrument equipped with a zinc-selenide (ZnSe) 60^{o} attenuated total reflectance (ATR) cell. Samples were prepared by diluting the lube oil 50% by volume in heptane, which helped to make the sample cleanup of the ATR cell easier. The FTIR was calibrated with six standards made from a typical soy-derived biodiesel and the unused lube oil from the project. The standards ranged from 0%–9%. The calibration and samples were analyzed by comparing biodiesel specific peak intensities over the ranges of 1188-1340 cm-1 and 1724-1751 cm-1. A partial least squares (PLS) calibration was developed using the TQ Analyst software package, version 7.2 Each sample was collected using 32 scans and a 2 wave-number resolution. Four standard checks were performed to verify calibration from both soy- and animal-derived FAMEs. Recoveries of these checks averaged 106%. Repeatability was acceptable; each of the 19 samples was run twice, and all showed an average variation of 5%. Sample matrix spiking done on 19 different samples showed an average recovery of 88%. The JPI5S23 method was used to measure the petroleum diesel fuel oil dilution in each sample.

Additionally, the used oil samples were tested for viscosity at 100°C (D445), total base number (TBN via D4739), total acid number (TAN via D664), and metals by inductively coupled plasma (ICP) (D5185).

OIL DILUTION RESULTS

The following section describes the oil dilution observations made at several points during the aging of each ECS; the oil was sampled and analyzed during each oil change. The biodiesel oil dilution figures in this section are based on measurements made using the methodology described above.

For the NAC systems, the oil sample/change interval started at ~50 hours at the start of aging (approximately every 10,000 miles) and then changed to ~100 hours toward the end of aging (approximately every 20,000 miles). This was done to better understand the impact of extended oil change events. Table 6 shows the oil dilution measurements for the NAC systems along with the sample/change interval and the total ECS age.

Table 6: Oil dilution measurements for the NAC system

Sample #	Oil Age (hours)	System Age (hours)	Biodiesel Oil Dilution (%)	Diesel Oil Dilution (%)
1	48	48	4.7	2.9
2	92	140	6.6	3.4
3	65	205	5.2	4.2
4	90	295	5.7	–
5	67	362	5.3	2.0
6	65	427	6.8	3.0
7	65	492	5.9	2.7
8	100	592	8.3	3.5
9	158	750	10.1	4.1

As Table 6 shows, biodiesel oil dilution levels for the NAC system ranged from less than 5% to 10%; the highest measurements were associated with longer oil change intervals that occurred at the end of the aging. Each oil sample was exposed to numerous late in-cylinder fuel injection events for NAC and DPF regeneration and NAC desulfurization. NAC regeneration events were the most frequent, ranging from 605 to 2,010 events per oil change. The DPF regeneration events ranged from 21 to 65 per oil change event, and the desulfurization events occurred only a few times per oil change. Figure 1 shows the number of late in-cylinder fuel injection events by category. A comparison of this figure with Table 6 shows that biodiesel oil dilution levels track with the frequency of late in-cylinder injection events, but also with oil age.

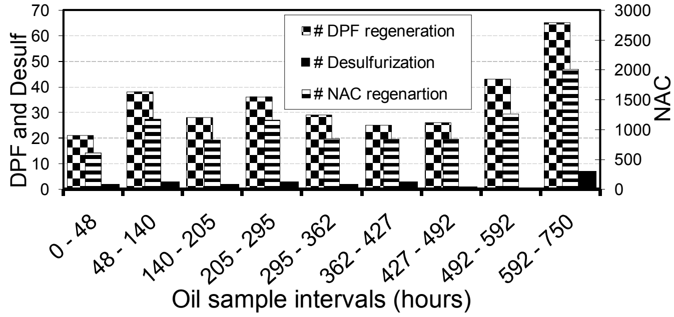

Figure 1: Late in-cylinder fuel injection events by category as a function of ECS age

Viscosity decreased with increasing oil age and increasing diesel fuel dilution, but it never went below 11 cSt. TBN decreased sharply with oil age, getting as low as 2.44 mg KOH/g for 150-hour oil, while TAN increased slightly to 2.26 mg/KOH/g. Iron in the oil increased with age, reaching a level of 55 ppm at 150 hours. Lead was below detection except for samples exceeding 100 hours in age, where it was 3 ppm.

For the SCR systems, the oil sample/change interval started at ~50 hours and remained at that interval for the entire aging process (approximately every 10,000 miles). Table 7 shows the oil dilution measurements for the SCR systems along with the oil sample/change interval and the total ECS age.

Table 7 shows that the biodiesel oil dilution levels for the SCR systems range from less than 4% to 8%. As shown in Figure 2, the biodiesel oil dilution levels for the SCR system, relative to oil age, are similar to those associated with the NAC system. This result was observed despite the fact that the SCR system was exposed to far fewer late in-cylinder fuel injection events. The SCR system was exposed to only 16 to 27 late in-cylinder fuel injection events, depending on the oil change sample/interval. These events were associated with the DPF regeneration. It appears that oil age, and not late in-cylinder fuel injection events, is the driving factor in determining biodiesel oil dilution levels.

Used oil age never exceeded 80 hours for the SCR system. Viscosity was approximately constant for the used oils, at about 13.9 cSt. TBN decreased slightly with oil age, reaching a low value of 4.54 mg/KOH/g at 75 hours, while TAN was essentially constant at about 2 mg/KOH/g. Iron in the oil increased with oil age but never exceeded 12 ppm; other wear metals were below detection limits.

The main observations are a significant reduction in TBN for the lubricant in both systems and a higher level of iron in used lubricant for the NAC system. The researchers anticipate that biodiesel in the lubricant will oxidize to produce acids, causing a reduction in TBN. Biodiesel content in the oil increases with oil age for both the NAC system and the SCR system. Figure 3 shows that the rate of TBN decrease with oil age is identical for the SCR and NAC systems, indicating that the main factor affecting TBN loss is simply lubricant age, not biodiesel content. TAN never exceeds TBN, indicating that even up to 150 hours the lubricant service interval had not been exceeded.

Table 7: Oil dilution measurements for SCR system

Sample #	Oil Age (hours)	System Age (hours)	Biodiesel Oil Dilution (%)	Diesel Oil Dilution (%)
1	65	65	8.0	4.6
2	76	141	7.6	4.0
3	54	195	6.5	3.1
4	65	260	7.0	3.3
5	59	319	4.1	1.6
6	63	382	4.7	1.8
7	58	440	4.1	1.6
8	64	504	3.7	1.0
9	64	568	3.6	1.0
10	45	613	3.7	1.4

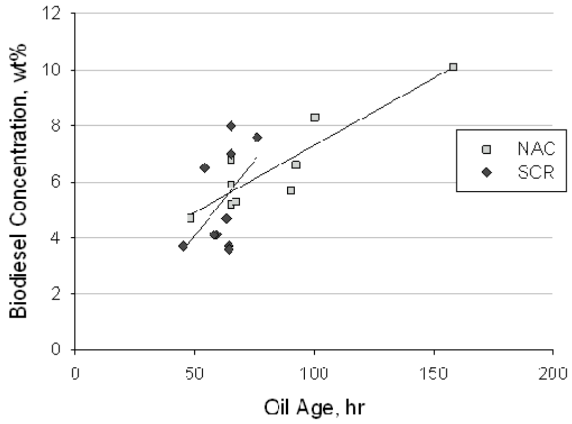

Figure 2: Lubricant biodiesel content as a function of lubricant age

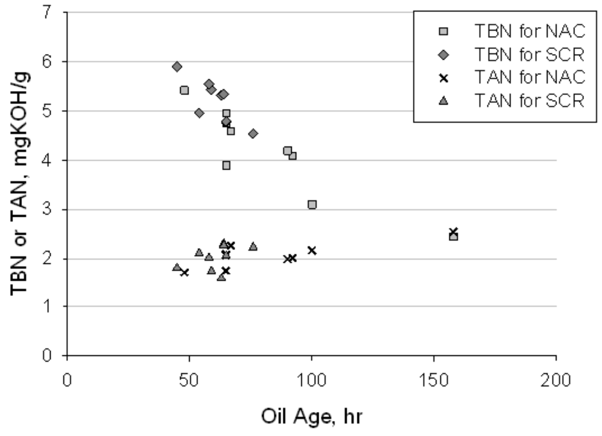

Figure 3: TBN and TAN as a function of lubricant age for both systems

EMISSIONS IMPACTS

At two points, during and after the completion of the durability testing with each ECS, the components were installed in the project vehicle and underwent emissions testing. All of the following vehicle tests were conducted at EPA's National Vehicle and Fuel Emissions Laboratory. The vehicle was tested using a 48-inch-diameter, single-roll, electric chassis dynamometer. The tests showed that Tier 2 Bin 5 emission levels could be met with the NAC ECS. However, the performance of the SCR system degraded to a point at which Tier 2 Bin 5 limits could not be met. Figure 4 and Table 8 show the system performance in the course of the aging process for both ECS.

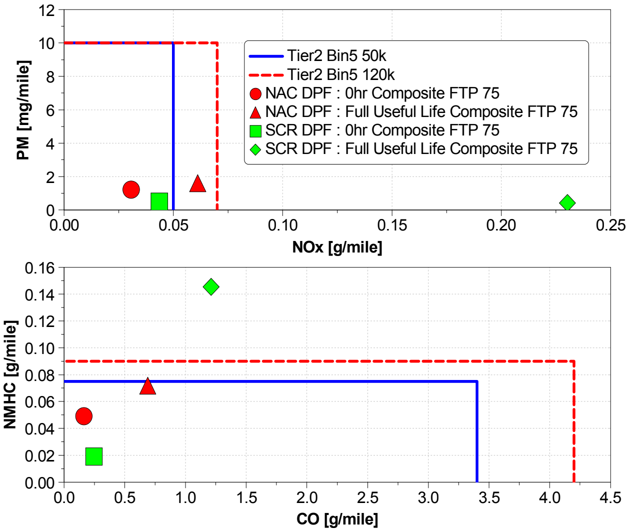

Figure 4: Emission results with new and useful life aged components

Although the desired NO_x and NMHC emission levels for the SCR system were not met, the researchers believe that this was the result of degradation of the SCR catalyst from thermal shock due to hydrocarbon (HC) adsorption and loss of cold start performance, and not a result of fuel or fuel oil dilution impacts. The Tier 2 Bin 5 emission levels could be met with the SCR system for PM and CO.

Table 8: Emission results with new and useful life aged components, FTP 75 (g/mi)

System	NO_x	PM	CO	NMHC
NAC 0 hr	0.031	0.0012	0.163	0.149
NAC 700 hr	0.061	0.0016	0.690	0.072
SCR 0 hr	0.044	0.0005	0.247	0.019
SCR 700 hr	0.230	0.0004	1.212	0.145

ENGINE COMPONENT IMPACTS

After the completion of the durability tests for the NAC and the SCR system, the engine had undergone an accelerated aging schedule representative of twice its useful life, or approximately 240,000 miles. At the conclusion of the project, the engine was disassembled and each component was carefully analyzed. All moving parts such as bearings, pistons, and piston rings were inspected and measured. None of the components of the engine, including the injectors, showed signs of excessive wear or other signs of deterioration as a result of the extended biodiesel operation. The flow characteristics of the injectors remained comparable to levels noted before the start of the durability study. Figure 5 shows several engine components after the disassembly.

The cylinder bore in the upper left corner of Figure 5 shows the honing pattern, which indicates that there was no loss in oil control for this engine. The main bearing shown below the cylinder bore showed no sign of deterioration or wear. This component is prone to wear caused by oil dilution and the resulting loss in lubricity of the engine oil. On the main journal as well as one cam, shown on the right side of the figure, no visible signs of wear were detected.

CONCLUSION

The completed project included an evaluation of two emission control systems tested in conjunction with a biodiesel blend fuel. The focus of this paper was on the biodiesel oil dilution levels observed for both systems utilizing a 20% biodiesel blend. For the NAC system (which requires a late in-cylinder fuel injection for regeneration), the biodiesel oil dilution level ranged from 5%–10% for oil samples ranging in age from ~50 to ~150 hours. For the SCR system (which used a urea solution as a reductant and required only late in-cylinder fuel injection for DPF regeneration), biodiesel oil dilution ranged from <4%–8% for oil samples ranging in age from ~50 to ~75 hours. The rate of biodiesel accumulation in the oil as a function of oil age was similar for both ECS, despite the fact that the SCR system saw fewer late in-cylinder fuel injection events. There were no obvious biodiesel specific effects on used lube oil properties, and most changes appeared to be consistent with normal lube oil aging. Based on a comparison of TBN and TAN, oil service life was never exceeded in these tests. Despite these biodiesel oil dilution levels, no impacts were observed on the performance of the engine or the emission control systems.

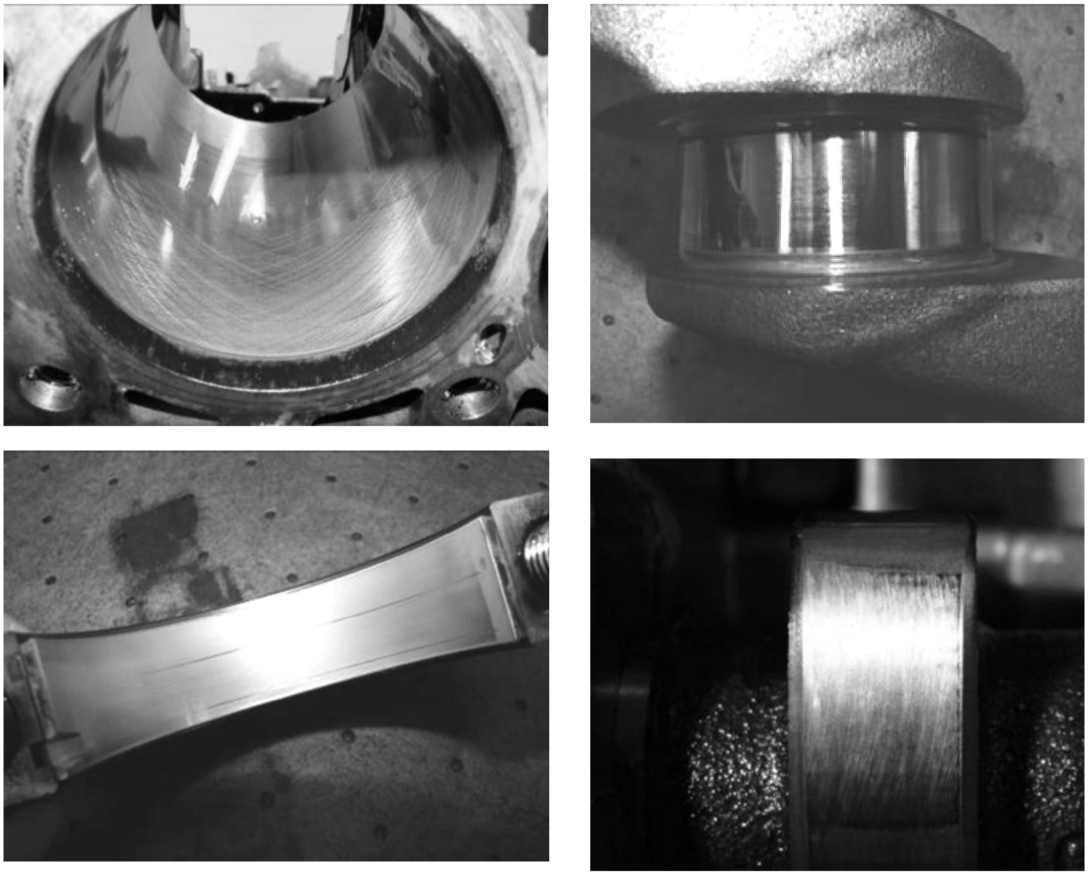

Figure 5: Selected engine components

Durability tests with both emission control systems [8] demonstrated that the NAC system provides sustainable conversion efficiencies over its useful life. However, the SCR system did experience performance degradation, which was attributed to the deactivation of the iron-zeolite through thermal shock.

Finally, no biodiesel-related wear and engine mechanics deterioration were found after the hardware was exposed to an accelerated aging protocol of twice the engine's useful life.

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REFERENCES

1. R. Kotrba, "Understanding the Post-Injection Problem," *Biodiesel Magazine*, Vol. 5, No. 5, May 2008.
2. John Sheehan, Vince Camobreco, James Duffield, Michael Graboski, and Housein Shapouri, *An Overview of Biodiesel and Petroleum Diesel Life Cycles*, NREL/TP-580-24772, May 1998.
3. K. S. Tyson, J. Bozell, R. Wallace, E. Petersen, and L. Moens, *Biomass Oil Analysis: Research Needs and Recommendations*. NREL/TP-510-34796. Golden, CO: National Renewable Energy Laboratory, June 2004.
4. Andrea Morgan, Howard Fang, and Bhandary Kirtan, "Biodiesel on Fuel Dilution of Engine Oil," SAE 2007-01-4036.
5. Cathy C. Devlin, Charles Passut, Tze-Chi Jao, and Bob Campbell, "Biodiesel Fuel Effect on Diesel Engine Lubrication," SAE 2008-01-2375.
6. Howard Fang, Shawn Whitacre, Elaine Yamaguchi, and Maarten Boons, "Biodiesel Impact on Wear Protection of Engine Oils," SAE 2007-01-4141.
7. Marek Tatur, Harsha Nanjundaswamy, Dean Tomazic, and Matthew Thornton, "Biodiesel Effects on U.S. Light-Duty Tier 2 Engine and Emission Control Systems," SAE 2008-01-0080.
8. Marek Tatur, Harsha Nanjundaswamy, Dean Tomazic, and Matthew Thornton, "Biodiesel Effects on U.S. Light-Duty Tier 2 Engine and Emission Control Systems-Part 2," SAE 2009-01-0281.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

ATR:	attenuated total reflectance
Ba:	Barium
BMEP:	brake mean effective pressure
B20:	biodiesel with 20% renewable fuels content
CO:	carbon monoxide
CO_2:	carbon dioxide
cpsi:	cells per square inch
DOC:	diesel oxidation catalyst
DOE:	U.S. Department of Energy
DOHC:	double overhead camshaft
DPF:	diesel particle filter
ECS:	emission control system
EGR:	exhaust gas recirculation
EPA:	Environmental Protection Agency
EURO:	European
FAME:	fatty acid methyl ester
FTIR:	Fourier transform infrared (spectroscopy)
FTP:	Federal Test Procedure
HC:	hydrocarbon
HFET:	Highway Fuel Economy Test
HSDI:	high-speed direct injection
MECA:	Manufactures of Emission Controls Association
NAC:	NO_x adsorber catalyst
NMHC:	non-methane hydrocarbons
NO:	nitric oxide
NO_2:	nitrogen dioxide
NO_x:	oxides of nitrogen
NREL:	National Renewable Energy Laboratory
O_2	oxygen
OEM:	original equipment manufacturer
PM:	particulate matter
PGM:	platinum group metal
RPM:	revolutions per minute (engine speed)
SCR:	selective catalytic reduction
TAN:	total acid number
TBN:	total base number
THC:	total hydrocarbon
UDDS:	Urban Dynamometer Driving Schedule
ULSD:	ultra-low-sulfur diesel (here, the base fuel)

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This paper assesses the oil dilution impacts on an engine operating in conjunction with a diesel particle filter (DPF), oxides of nitrogen (NOx) storage, a selective catalytic reduction (SCR) emission control system, and a 20% soy-based biodiesel fuel blend. The focus was on biodiesel oil dilution levels observed during an accelerated aging protocol and an assessment of the potential impacts on the engine and emissions control systems. For the NOx storage system, which requires a late in-cylinder fuel injection for regeneration, biodiesel oil dilution levels ranged from 5% to 10%. For the SCR system, which used a urea solution as a reductant and late in-cylinder fuel injection for DPF regeneration, biodiesel oil dilution ranged from <4% to 8%, as observed over typical oil drain intervals. Despite observed biodiesel oil dilution levels, no impacts were observed on engine performance or emission control systems.

15. SUBJECT TERMS
biodiesel fuel; diesel engine; fuel oil dilution; diesel emissions; diesel particle filter; selective catalytic reduction; emission control system

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