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Biodiesel Effects on Diesel Particle Filter Performance

A. Williams, R.L. McCormick, R. Hayes, and J. Ireland

Milestone Report
NREL/TP-540-39606
March 2006

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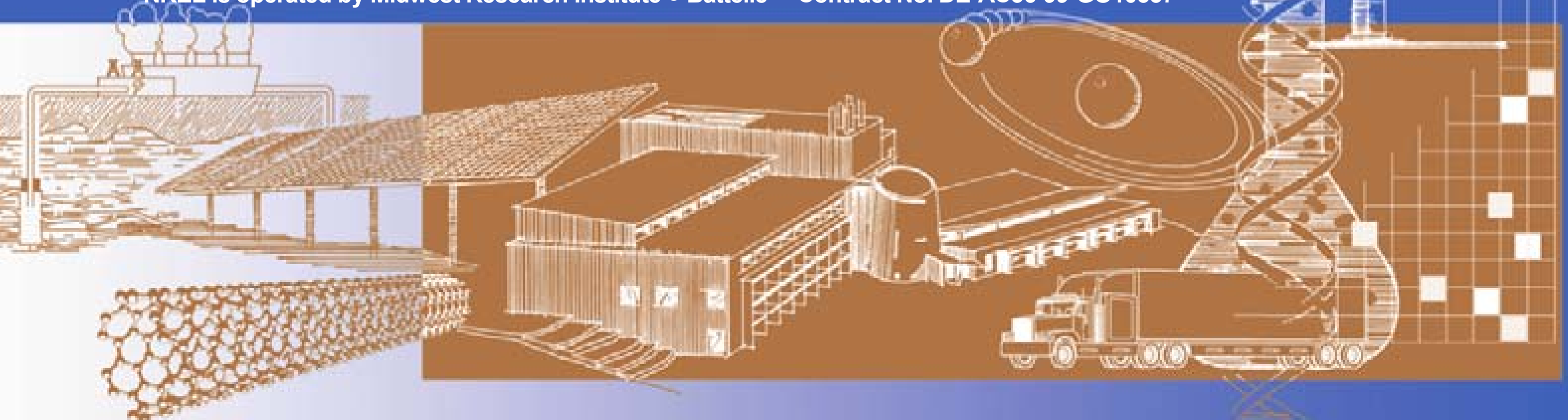

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Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
BSFC	Brake specific fuel consumption, g/bhp-hr
B100	100% biodiesel
B20	20% biodiesel, 80% petrodiesel
B5	5% biodiesel, 95% petrodiesel
BPT	balance point temperature
CCRT	Catalyzed Continously Regenerated Technology
CO	carbon monoxide
DPF	diesel particle filter
g/bhp-hr	grams per brake horsepower hour
NO	nitrogen monoxide
NO_2	nitrogen dioxide
NO_x	oxides of nitrogen
NREL	National Renewable Energy Laboratory
PM	Particulate matter
ReFUEL	Renewable Fuels and Lubricants facility
rpm	rate per minute
ULSD	Ultra-low sulfur diesel (petrodiesel having 15 ppm or less sulfur)
THC	Total hydrocarbon

Executive Summary

This document reports results of research on the performance of biodiesel and biodiesel blends with ultra-low sulfur diesel (ULSD) and a diesel particle filter (DPF). In particular, tests were conducted using a 2002 model year Cummins ISB engine (with exhaust gas recirculation or EGR) that had been retrofitted with a Johnson-Matthey catalyzed DPF, a passively regenerated filter. Tests were conducted from August 2005 through January of 2006 in NREL's ReFuel facility. This report also documents completion of the National Renewable Energy Laboratory's Fiscal Year 2006 Annual Operating Plan Milestone 10.2, which is also Corporate Planning System Milestone 24050. These milestones support the U.S. Department of Energy, Fuels Technologies Program Multiyear Program Plan Goal of identifying fuels that can displace 5% of petroleum diesel by 2010.

The impact of biodiesel and biodiesel blends on DPF performance was assessed by making the following measurements:

- Balance point temperature (BPT, the DPF inlet temperature at which the rate of particle oxidation approximately equals the rate of particle collection)
- Filter regeneration rate (assessed by monitoring DPF back pressure as a function of time after pre-loading with particles and ramping to high exhaust temperature)
- Transient emissions testing with and without the DPF installed.

Tests were conducted using 2007 certification diesel, a commercial ULSD known as BP-15, and biodiesel derived from soybean oil.

Results show that on average, the BPT is 45°C and 112°C lower, respectively, for B20 blends and neat biodiesel, than for 2007 certification diesel fuel. Filter regeneration rate measurements indicate that biodiesel causes a significant increase in regeneration rate, even at the 5% blending level. Transient emissions tests show a 25% particulate matter (PM) reduction for B20 without the DPF installed. Installation of the DPF caused PM emissions to drop by more than a factor of 10 for petrodiesel. Use of B20 with the DPF produced an additional PM reduction of 67% as compared with the petrodiesel plus DPF configuration. The use of B20 caused a 2.9% increase in fuel consumption, consistent with the lower energy content of this fuel. Installation of the DPF caused a nearly 2% fuel economy penalty for both ULSD and B20.

Overall the results suggest significant benefits for the use of biodiesel blends in engines equipped with DPFs. The significant lowering of BPT and increase in regeneration rate might allow passive DPFs to be used in lower temperature engine duty cycles, avoiding the need for actively regenerated filters and their associated fuel economy penalty. Actively regenerated systems might require less frequent regeneration, also resulting in a lower fuel economy penalty. These hypothetical fuel economy benefits have yet to be demonstrated, and this will be the subject of future research.

Introduction

This document reports results of research on the performance of biodiesel and biodiesel blends with ultra-low sulfur diesel (ULSD) with a diesel particle filter (DPF). In particular, tests were conducted using a 2002 model year Cummins ISB engine (with exhaust gas recirculation or EGR) that had been retrofitted with a passively regenerated Johnson Matthey catalyzed diesel particle filter.

Biodiesel is a renewable fuel derived from vegetable oil, animal fat, or waste cooking oil and consists of the methyl esters of fatty acids. It is typically used as a diesel blending component at levels of 20 volume percent or lower. A resource assessment indicates that biodiesel has the potential to displace 5% or more of petroleum diesel use over the next decade [1]. A life cycle analysis indicates that biodiesel is a highly renewable fuel, and that use of B20 results in a 19% reduction in life cycle petroleum consumption [2]. The U.S. Environmental Protection Agency has reviewed biodiesel emissions data for heavy-duty engines published up through about 2000 [3]. For engine dynamometer testing the average emission changes for B20 versus petroleum diesel were +2.0% for oxides of nitrogen (NO_x), -10.1% for particulate matter (PM), -11.0% for carbon monoxide (CO), and -21.1% for total hydrocarbons (THC). More recently the National Renewable Energy Laboratory (NREL) tested two newer engines equipped with EGR and meeting the 2004 emission standards. This study found, on average, a 25% reduction in PM emissions for B20 [4]. Thus, PM emission reductions are touted as a significant advantage for B20 over conventional diesel fuel.

In 2007, new certification emission standards for heavy-duty diesel engines will significantly reduce PM emissions as compared with earlier heavy-duty standards. Most relevant to this work, beginning with the 2007 model year the PM emission standard will be lowered from 0.1 g/bhp-h to 0.01 g/bhp-h. This lowering of PM emissions by a factor of 10 is enabled by the introduction in June 2006 of diesel fuel containing a maximum of 15 ppm sulfur (ultra-low sulfur diesel or ULSD) and also forces the use of DPFs. In a DPF, soot particles are trapped on a ceramic filter. In catalyzed DPF systems, such as that described in this report, the soot is then burned by reaction with nitrogen dioxide (NO_2). The role of NO_2 as an oxidant is critical to catalyzed DPF performance, and DPFs typically contain a precious metal catalyst upstream of the ceramic filter where nitrogen monoxide (NO) is converted to NO_2. NO_2 is a more aggressive oxidizer of soot at low temperatures than oxygen, and thus can control the soot oxidation rate. Therefore, the small increase in NO_x emissions (mainly NO) observed for B20 may have significant consequences for the performance of B20 with DPFs.

Some published information is available on the performance of DPFs with biodiesel and biodiesel blends. Frank and coworkers [5] tested B20 and several other fuels at Environment Canada with several different aftertreatment and engine configurations. The use of a catalyzed DPF produced a factor of 10 reduction in PM emissions relative to the base case. No PM emission advantage was observed for B20 with a DPF installed. No engine-out emissions were reported for B20 in this study. Additionally, 2007 compliant procedures for PM emission measurement do not appear to have been used.

However, researchers at Pennsylvania State University [6] have recently shown that blending of 20% biodiesel into diesel fuel can significantly lower balance point temperature (BPT). They present results showing that this is not caused by increased availability of NO_2, but by inherent differences in soot reactivity for different fuels. This was confirmed by thermogravimetric analysis wherein soot produced in an engine from different fuels was burned under identical conditions. Soot characterization by electron microscopy suggested that the cause of this increased reactivity is a more highly disordered soot nanostructure for B20 blends, such that the soot is more reactive or reactive at lower temperatures. More recent results from the Penn State group [7] suggest that changes in nanostructure are not the cause of increased reactivity, but rather the introduction of highly reactive surface oxygen sites when the soot is produced from B20.

This report examines the impact of biodiesel and biodiesel blends on BPT, filter regeneration rate, and transient emissions using a fully modern engine and state-of-the-art (2007-compliant) emissions measurement system.

This report also documents completion of the NREL's Fiscal Year 2006 Annual Operating Plan Milestone 10.2, which is also a Corporate Planning System Milestone 24050. These milestones support the U.S. Department of Energy, Fuels Technologies Program Multiyear Program Plan Goal of identifying fuels that can displace 5% of petroleum diesel by 2010.

Experimental Setup

The test setup consisted of a 2002 model year 5.9L Cummins ISB, equipped with a DPF. Properties of the test engine are shown in Table 1. The engine is direct injection, inter-cooled with cooled high-pressure EGR; and employs a variable geometry turbocharger, electronic control, and high-pressure common rail fuel injection. The 300hp engine is designed to meet the 2004 U.S. heavy-duty emissions standards. The lubricant employed was Valvoline 15W-40.

Table 1. Test Engine Specifications

	Cummins ISB
Serial Number	56993170
Displacement, L	5.9
Cylinders	6
Rated Power, kW	224 at 2500 rpm
Rated Torque	895 N-m at 1600 rpm
Bore x Stroke	10.2x12 cm
Compression Ratio	16.5:1
Fuel System	Common Rail
Intake Restriction, kPa	4.47
Exhaust Back Pressure[a], kPa	7.95

[a]Without DPF installed.

The DPF is a 12 L catalyzed passively regenerated system, employing Catalyzed Continuously Regenerating Technology (CCRT™), provided by Johnson Matthey. The CCRT™ filter is a diesel oxidation catalyst followed by a wall-flow catalyzed soot filter. It is used in applications with exhaust temperatures as low as 200°C-250°C. The DPF is mounted 152 cm from the engine turbo flange outlet. The DPF was instrumented for inlet and outlet temperatures and pressures as well as differential pressure. Temperatures were measured with K-type thermocouples mounted 8 cm from the face of the pre-catalyst on the inlet side and 8 cm from the face of the DPF on the outlet side. Inlet and outlet pressures as well as differential pressure were measured from the same location. The overall setup and relative location of all instrumentation is illustrated in Figure 1. In addition, engine and emissions sampling system were instrumented for measurement of all other critical temperatures and pressures.

The engine was mounted to a DC electric engine dynamometer at NREL's Renewable Fuels and Lubricants (ReFUEL) facility. ReFUEL's engine dynamometer is part of a fully functional test cell capable of steady-state or transient testing for emissions and fuel consumption. The ReFUEL emission measurement system is based on the full-scale dilution method with constant volume sampling for mass flow measurement. Gaseous emissions—including carbon dioxide, NO_x, THC, and CO—are measured continuously. PM emissions are measured based on a gravimetric system, in which samples are collected onto 47 mm Teflon filters then weighed with a microbalance in a clean room environment.

Test fuels included 2007 certification diesel, a commercial ULSD known as BP-15, and various biodiesel blends made from a soy biodiesel feedstock. The properties of the ULSD fuels are listed in Table 2. The soy biodiesel was S15 grade and met the requirements of ASTM D6751. Through out the study fuels were stored in-doors in a heated and air conditioned environment. With the exception of transient emission testing, all experiments were conducted with the 2007 certification diesel and the soy biodiesel. Transient testing was conducted with the commercial ULSD and the soy biodiesel.

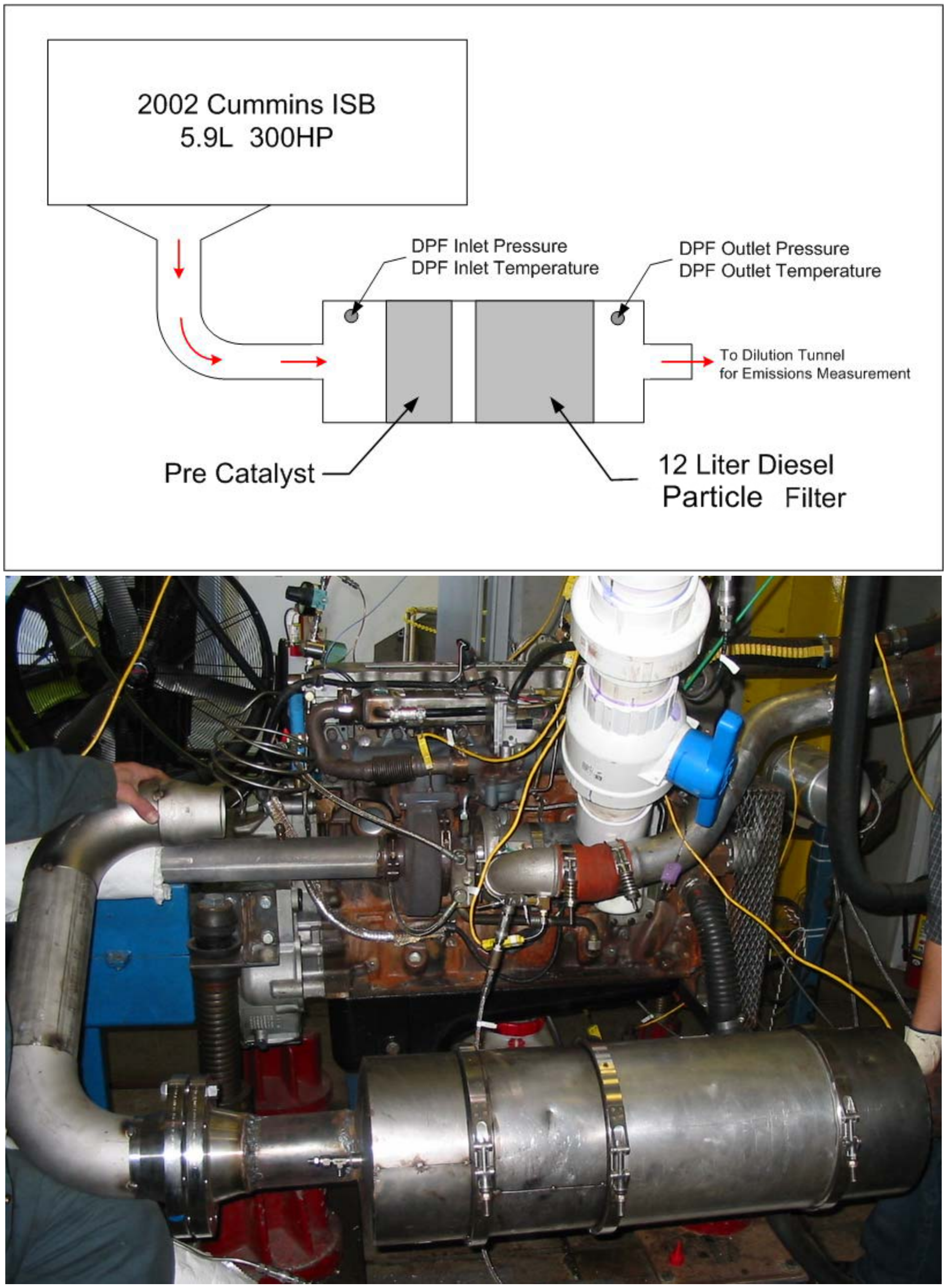

Figure 1. Experimental setup

Table 2. Properties of Diesel Test Fuels

Property	Method	Units	Commercial ULSD (BP-15)	2007 Certification Diesel
Cetane Number	D613		51	41
Kinematic Viscosity 40C	D445	mm2/s	2.5	2.3
Cloud Point	D2500	ºC	-12	--
Flash Point	D93	ºC	64	82
Total Sulfur	D5453	ppm	13	12
Ash Content	D482	wt%	0.000	
Specific Gravity	D4052		0.8371	0.858
Carbon Residue	D524	wt%	0.04	--
Corrosion, Copper strip	D130		1A	--
Water and Sediment	D2709	vol%	0	--
Carbon	D5291	wt%	86.04	--
Hydrogen	D5291	wt%	13.48	--
Aromatics	D1319	%vol	29	28.8
Distillation T90	D86	ºC	322	299

Procedures and Results

Balance Point Temperature

The BPT is determined as the DPF inlet temperature at which the rate of particle oxidation approximately equals the rate of particle collection. At the BPT, the DPF should not experience a net gain or loss of PM, and consequently the differential pressure across the DPF should not change. A series of BPT tests were conducted to compare the operation of a DPF on a modern engine with 2007 certification diesel, biodiesel, and a B20 blend. The BPT was determined with the following test sequence and is illustrated in Figure 2:

- The DPF was completely regenerated by operating at near rated power (2500 rpm and 575 ft-lbs) for 120 minutes.
- The DPF was preloaded with PM at 2000 rpm and 20 ft-lbs over the appropriate amount of time to achieve an approximate 1.5 g/L loading of PM on the DPF.
- The preloaded DPF was operated at 1700 rpm while torque was increased to achieve a stepped increase in exhaust temperatures. The DPF pressure drop is monitored continuously to determine slope of the increase or decrease of the differential pressure across the DPF at a given inlet temperature.
- This sequence was repeated for 2007 certification diesel, B100 and B20 (soy) fuels for determination of BPT at 1700 rpm.

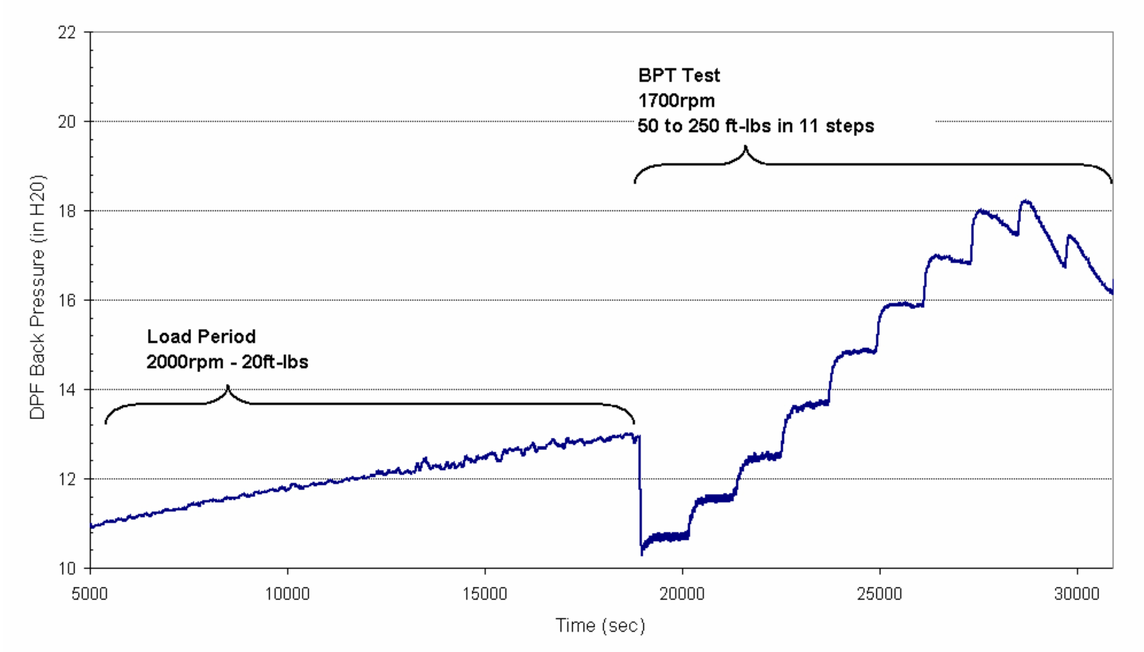

Figure 2. DPF differential pressure during balance point temperature test

The BPT is determined by analyzing the slope of the differential pressure for each of the 11 temperature steps. If the slope is positive (back pressure is increasing), then it is assumed that the DPF is collecting PM. Once the slope becomes negative (back pressure is decreasing), that temperature is above the balance point temperature, as previously defined. The BPT determination is made by plotting the slope of the back pressure versus the DPF temperature for each of the 11 steps. A linear curve fit is made between the two steps where back pressure slope transitions from a positive to a negative value. The point where the curve fit crosses the Y-intercept is determined as the best estimate of the BPT. In order to understand variability of the testing method, two repeats of the BPT test were completed for 2007 certification diesel and B20, and three repeats for B100. In the case of 2007 certification fuel, three additional torque steps were added in order to move sufficiently beyond the BPT. Figure 3 shows the resulting BPT windows for each of the fuels. On average, the BPT is 45°C lower than 2007 certification diesel for B20 blends and 112°C lower for neat biodiesel. These results do not allow an assessment to be made of the relative importance of the increased availability of NO_2 (caused by the higher NO_x emissions from biodiesel) versus increased reactivity of soot as concluded by Penn State [6].

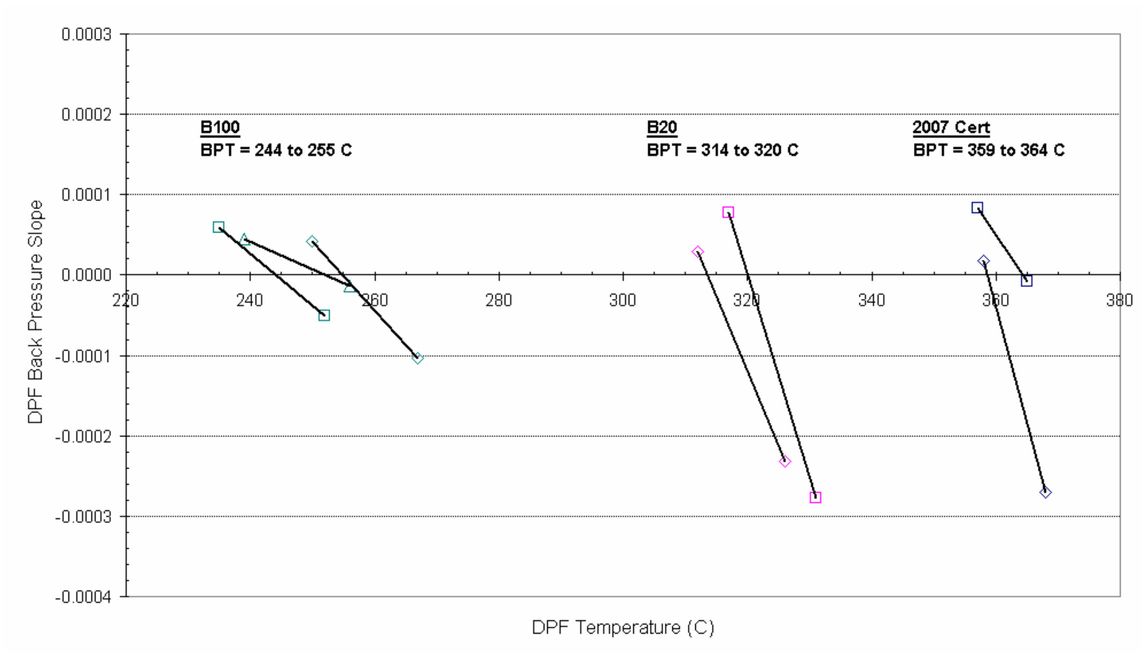

Figure 3. BPT test results for B100, B20, and 2007 certification diesel

Regeneration Rate

The regeneration rate testing is similar to BPT testing in that the DPF is fully regenerated and preloaded to approximately 1.5 g/L. However, rather than stepping through different torques at 1700 rpm, the engine moves directly to a single, relatively high-torque (high-temperature) operating point, which simulates an active regeneration event. This test method is illustrated in Figure 4. This method provides a potential advantage of comparing regeneration behavior between fuels at the same approximate DPF preload conditions (grams/Liter). This contrasts with the BPT measurement method, which allows for different loading to occur during the 'steps' following preload and prior to reaching the BPT.

Testing was conducted with 2007 certification diesel, B5, and B20 with two repeats for each fuel. Once the DPF had been preloaded, the engine was then operated at the chosen higher temperature point (1700 rpm and 250 ft-lbs) for 60 minutes. This allows enough time for DPF temperature to stabilize. In each case the DPF temperature at the active regeneration point stabilized between 348°C and 357°C. In general, DPF inlet temperatures were lower with higher blend ratios of biodiesel. DPF back pressures also varied from test to test, either as a consequence of the slight temperature differences or relative differences in the amount of particle loading. At the stabilized regeneration point, DPF back pressures ranged between 48.3 cm of H_2O and 52.1 cm of H_2O.

Results for regeneration rates are shown below in Figure 5. This plot shows the normalized DPF back pressure for the final 15 minutes of steady-state operation at the active regeneration point. DPF back pressures are normalized to show relative differences in performance for each of the fuels. As can be seen, the back pressure slope for 2007 certification fuel is slightly positive for repeated runs at the 1700 rpm, 250 ft-lb operating condition with temperatures around 354°C. This is consistent with previous testing that showed a BPT somewhere between 359°C and 364°C for this fuel. The plot also illustrates that both biodiesel blends at the B5 and B20 level show measurable decreases in DPF back pressure at the same operating condition with similar amounts of DPF preloading. The slope of the back pressure decrease increases with biodiesel content. These test results show that PM from biodiesel blends (even down to the B5 level) appears to measurably oxidize more quickly than particles from certification diesel fuel. Increased levels of biodiesel in the fuel appear to increase the rate of DPF regeneration at a given engine operating condition. Again, these results do not allow an assessment to be made of the relative importance of the increased availability of NO_2 (caused by the higher NO_x emissions from biodiesel) versus increased reactivity of soot.

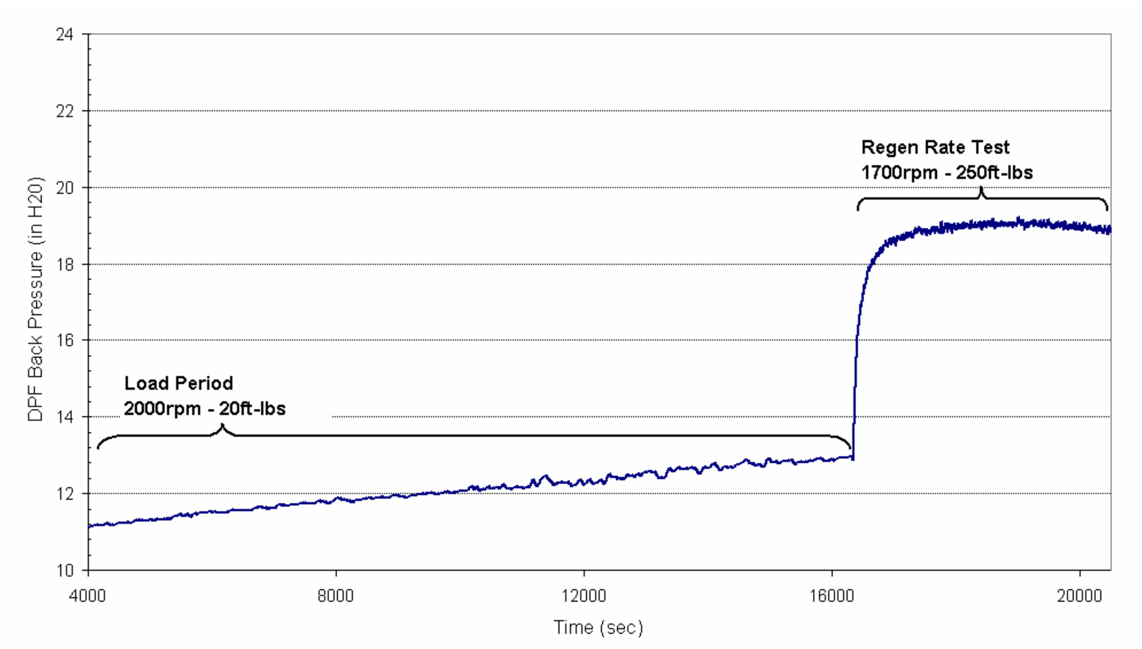

Figure 4. Regeneration rate test DPF differential pressure

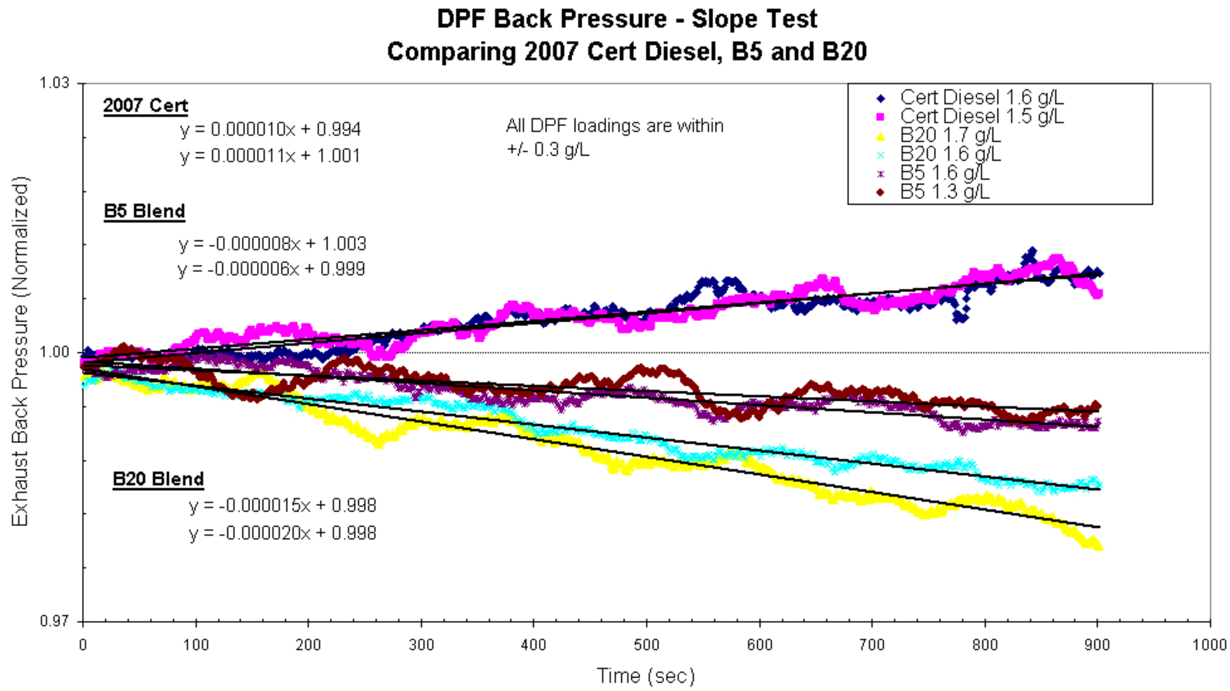

Figure 5. Regeneration rate test results for B5, B20, and 2007 certification diesel

Transient Emissions Testing

Baseline emissions over three hot-start, heavy-duty transient tests were measured for a commercial ULSD fuel, and a B20 blend prepared from the ULSD and a soy-biodiesel. These tests were conducted with and without the DPF for both fuels to confirm operation of the filter and to determine reduction efficiencies of all regulated pollutants. The results for each repeated run are shown in Table 3.

Before installation of the DPF, the B20 blend yielded a 25% PM reduction relative to ULSD, as shown in Figure 6. Following DPF installation, PM emissions were reduced by 94% for ULSD and 97% for B20. This slightly higher reduction in PM for B20 is statistically significant ($p<0.01$) and is actually a 67% reduction in PM for B20 with DPF versus ULSD with DPF.

Without the DPF, biodiesel reduced emissions of both THC and CO by 12%. In the case of both fuels, the catalyzed DPF reduced THC and CO emissions by 98% to 99% to almost undetectable levels. NO_x emissions increased for the biodiesel blend by 6% without the DPF. DPF installation caused NO_x emissions to increase by 1% ($p<0.05$) for ULSD but did not cause a significant change in NO_x for B20. NO_x emissions for B20 were 5% higher than emissions for ULSD after DPF installation.

The biodiesel blend produced a 2.9% ($p<0.001$) increase in fuel consumption without the DPF installed, consistent with the known lower volumetric energy content of biodiesel

[8]. Installation of the DPF produced a nearly 2% fuel economy penalty for both fuels (P<0.001).

Table 3. Heavy-Duty Transient Emission Test Results[a,b]

Fuel	Run #	NO_x g/bhp-hr	THC g/bhp-hr	CO g/bhp-hr	PM g/bhp-hr	BSFC g/bhp-hr
Without DPF:						
ULSD	945	2.04	0.216	1.21	-	184.2
ULSD	946	2.06	0.211	1.23	0.0925	183.7
ULSD	947	2.05	0.198	1.20	0.0888	182.9
ULSD	948	2.06	0.184	1.18	0.0868	181.7
ULSD	959	2.05	0.145	1.16	0.0820	186.2
ULSD	960	2.06	0.137	1.15	0.0799	185.1
ULSD	962	2.02	0.143	1.15	0.0845	187.2
ULSD	963	2.05	0.140	1.21	0.0871	184.8
Mean		*2.05*	*0.172*	*1.19*	*0.0859*	*184.5*
Standard Deviation		*0.01*	*0.03*	*0.03*	*0.004*	*1.75*
COV%		*0.71*	*19.77*	*2.51*	*4.91*	*0.95*
B20	952	2.16	0.168	1.05	0.0667	188.9
B20	953	2.18	0.161	1.02	0.0625	189.0
B20	954	2.19	0.147	0.99	0.0612	189.4
B20	955	2.23	0.151	1.00	0.0606	189.5
B20	972	2.13	0.155	1.14	0.0736	191.8
B20	973	2.17	0.128	1.07	0.0638	190.4
Mean		*2.18*	*0.152*	*1.04*	*0.0647*	*189.8*
Standard Deviation		*0.04*	*0.01*	*0.06*	*0.005*	*1.11*
COV%		*1.63*	*8.96*	*5.41*	*7.51*	*0.58*
With DPF:						
ULSD	981	2.06	-0.001	0.02	0.0055	187.2
ULSD	982	2.08	-0.001	0.01	0.0049	188.3
ULSD	983	2.07	0.002	0.03	0.0042	187.5
ULSD	1001	2.06	0.001	0.03	-	188.1
Mean		*2.07*	*0.0002*	*0.02*	*0.0049*	*187.8*
Standard Deviation		*0.01*	*0.002*	*0.01*	*0.001*	*0.53*
COV%		*0.53*	*620.15*	*48.67*	*13.36*	*0.28*
B20	987	2.18	0.001	0.01	0.0018	192.9
B20	988	2.18	0.001	0.01	0.0017	192.9
B20	994	2.15	-0.001	-0.01	0.0013	193.0
Mean		*2.17*	*0.0004*	*0.005*	*0.0016*	*192.9*
Standard Deviation		*0.02*	*0.001*	*0.01*	*0.0002*	*0.08*
COV%		*0.84*	*250.54*	*229.56*	*15.09*	*0.04*

[a] Negative values indicate emissions below background levels.
[b] 1 g/bhp-h = 1.341 g/kW-h.

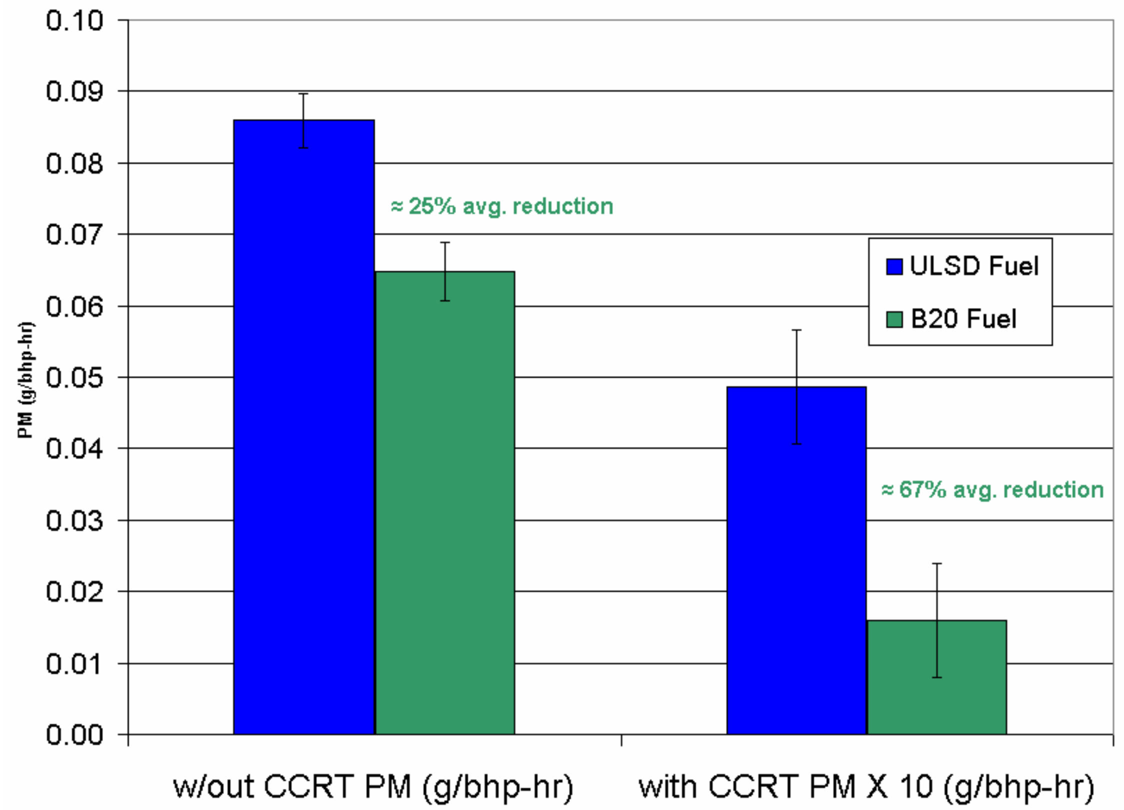

Figure 6. Particulate matter emissions transient test results (error bars represent 95% confidence interval based on repeated tests)

Conclusions, Recommendations, and Future Work

Results show that on average, the BPT is 45°C lower than 2007 certification diesel for B20 blends and more than 112°C lower for neat biodiesel. Filter regeneration rate measurements indicate that biodiesel causes a significant increase in regeneration rate, even at the 5% blending level. Transient emissions tests show a 25% PM reduction for B20 without the DPF installed. Installation of the DPF caused PM emissions to drop by more than a factor of 10 for petrodiesel. Use of B20 with the DPF produced an additional PM reduction of 67% below the petrodiesel+DPF level. However, it is important to note that this additional PM reduction is only 0.0033 g/bhp-hr, a very small reduction from an already very clean engine. The use of B20 caused a 2.9% increase in fuel consumption, consistent with the lower energy content of this fuel. Installation of the DPF caused a nearly 2% fuel economy penalty for both ULSD and B20. Thus, for the B20 plus DPF configuration the total fuel economy penalty was nearly 5%. These results do not allow an assessment to be made of the relative importance of the increased availability of NO_2 (caused by the higher NO_x emissions from biodiesel) versus increased reactivity of soot. Overall the results suggest significant benefits to the use of biodiesel blends in engines equipped with DPFs. The significant lowering of BPT and increase in regeneration rate might allow passive DPFs to be used in lower temperature engine duty cycles, avoiding the need for actively regenerated filters and their associated fuel economy penalty. Actively regenerated systems might require less frequent regeneration, also resulting in a lower fuel economy penalty. These hypothetical fuel economy benefits have yet to be demonstrated and will be the subject of future research.

In practice, one of the design considerations for DPFs is the expected exhaust temperature range to be encountered in the real-world duty cycle for a given application. This is especially critical for applying catalyzed DPF technology which is designed to passively regenerate during normal vehicle operation. Low-exhaust temperature duty cycles may not be able to employ passive systems. The work reported here shows measurable improvements in DPF regeneration performance at steady-state conditions with biodiesel blends and suggests the potential for biodiesel blends to extend the useful range of a given DPF design to lower operating temperatures. This may also allow passive DPFs with a modest fuel economy penalty to replace actively regenerated DPFs that have higher fuel economy penalty in some applications.

The next phase of this research will investigate transient operation with baseline diesel and biodiesel blends over a range of controlled differences in mean exhaust temperature. Mean exhaust temperature would be controlled by installation of a heat exchanger on the exhaust line upstream of the DPF. The data acquired will show if the improvements in DPF regeneration performance with biodiesel blends are significant enough to allow biodiesel blends to be an enabler for successful application of catalyzed DPFs in lower exhaust temperature applications that would not be suitable for passive DPF technology. The data will also allow an assessment of the potential for DPFs to be smaller and/or contain less precious metal for design applications, which use biodiesel blends. In addition, this work could determine if active regeneration of DPF systems leads to fuel savings by operation with biodiesel blends by minimizing the time and amount of fuel required during active regeneration periods.

References

1. Tyson, K.S.; Bozell, J.; Wallace, R.; Petersen, E.; Moens, L. “Biomass Oil Analysis: Research Needs and Recommendations,” Technical Report, National Renewable Energy Laboratory/TP-510-34796, June 2004.
2. Sheehan, J.; Camobreco, V.; Duffield, J.; Graboski, M.; Shapouri, H. “An Overview of Biodiesel and Petroleum Diesel Life Cycles,” National Renewable Energy Laboratory/TP-580-24772, May 1998.
3. U.S. Environmental Protection Agency. 2002. “A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions,” Draft Technical Report, EPA420-P-02-001.
4. McCormick, R.L.; Tennant, C.; Hayes, R.R.; Black, S.; Williams, A.; Ireland, J.; McDaniel, T.; Frailey, M.; Sharp, C.A. “Regulated Emissions from Biodiesel Tested in Heavy-Duty Engines Meeting 2004 Emission Standards,” *Society of Automotive Engineers* 2005-01-2200 (2005).
5. Frank, B.P.; Tang, S.; Lanni, T.; Rideout, G.; Beregszaszy, C.; Meyer, N.; Chatterjee, S.; Conway, R.; Lowell, D.; Bush, C.; Evans, J. “A Study of the Effects of Fuel Type and Emission Control Systems on Regulated Gaseous Emissions from Heavy-Duty Diesel Engines,” *Society of Automotive Engineers* 2004-01-1085 (2004).
6. Boehman, A.L.; Song, J.; Alam, M. “Impact of Biodiesel Blending on Diesel Soot and the Regeneration of Particulate Filters,” *Energy and Fuels*, **19**, 1857-1864 (2005).
7. Boehman, A.L. “Effect of Alternative Fuels on Soot Properties and Regeneration of Diesel Particulate Filters,” presented at 2005 Biodiesel Technical Workshop, Denver Colorado, November 2005.
8. Graboski, M.S.; McCormick, R.L. “Combustion of Fat and Vegetable Oil Derived Fuels in Diesel Engines,” *Progress in Energy and Combustion Science*, **24** 125-163 (1998).

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