PM REMOVAL EFFICIENCY FROM DIESEL GENSETS EQUIPPED WITH AFTERMARKET CONTROL DEVICES

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ABSTRACT

Diesel particulate matter (PM) has been associated with adverse health effects in humans and is classified as a human carcinogen. Additionally, diesel PM, particularly the strongly light absorbing fraction, black carbon (BC), is an important climate forcer. These adverse impacts of diesel PM and BC have spurred interest in reducing emissions from diesel combustion sources. In order to inform future regulatory efforts to address PM and BC emissions, a study was performed to determine effectiveness of aftermarket control devices on diesel gensets. Three diesel gensets of varying engine displacement and physical size were tested uncontrolled or with an aftermarket diesel particulate filter (DPF) or diesel oxidation catalyst (DOC). While the main function of a DOC is to oxidize hydrocarbons and CO in the engine exhaust, it has been suggested by manufacturers that a co-benefit for PM removal exists as well.

METHODS

Three large-scale Caterpillar gensets were tested (Table 1) both uncontrolled and controlled at 50% and 90% load. Gaseous and particulate emissions were characterized by a suite of instrumentation and filter methods (Table 2).

Three aftermarket control technologies were used:

- Passive Diesel Particulate Filter (P-DPF) – heat from engine exhaust is used to burn off any deposited PM on the filter
- Active Diesel Particulate Filter (A-DPF) – heat from an electrical charge is used to burn off any deposited PM on the filter
- Diesel Oxidation Catalyst (DOC) – a catalyst on a cordierite filter substrate reacts with exhaust to control hydrocarbons and/or CO

Table 2: Description of particle instrumentation and methods for measurement and calculations

	Instrument Description	Instrument	Sampling Interval
Black carbon (BC)	7-wavelength aethalometer, filter-based absorption	AE-633 Teledyne API	1 minute
Light absorption/scattering	3-wavelength photoacoustic absorption and inverse nephalometer	PASS-3 Droplet Measurement Technology	2 second
Elemental carbon (EC)	thermal optical carbon analyzer	OC/EC Analyzer Sunset Laboratory	variable
PM mass	gravimetric		variable
Number concentration	differential mobility analyzer and particle counter	SMPS TSI, Inc.	~2 minute scan

Light absorption and scattering coefficients were used to calculate the single scatter albedo (SSA) and the absorption angstrom exponent (α). The SSA is the ratio of the scattering coefficient to the extinction coefficient, and determines whether BC will warm or cool the surrounding atmosphere. The variation of absorption with wavelength is described by α, and when greater than 1 can indicate the presence of coatings or absorbing organic compounds on diesel exhaust particles.

Exhaust from each genset was routed either to a control device then exhaust duct or directly to an exhaust duct. A sampling probe was place in the center to avoid wall effects while sampling. An undiluted and filtered sample was taken for gas phase measurements. A diluted sample for PM measurements was obtained with an eductor supplied with filtered dry dilution air scrubbed of CO_2. Varying dilution ratios were obtained by changing the orifice in the eductor. Dilution ratios were optimized for each condition to obtain PM concentrations within the instrument measurement ranges.

Acknowledgments/ Disclaimers

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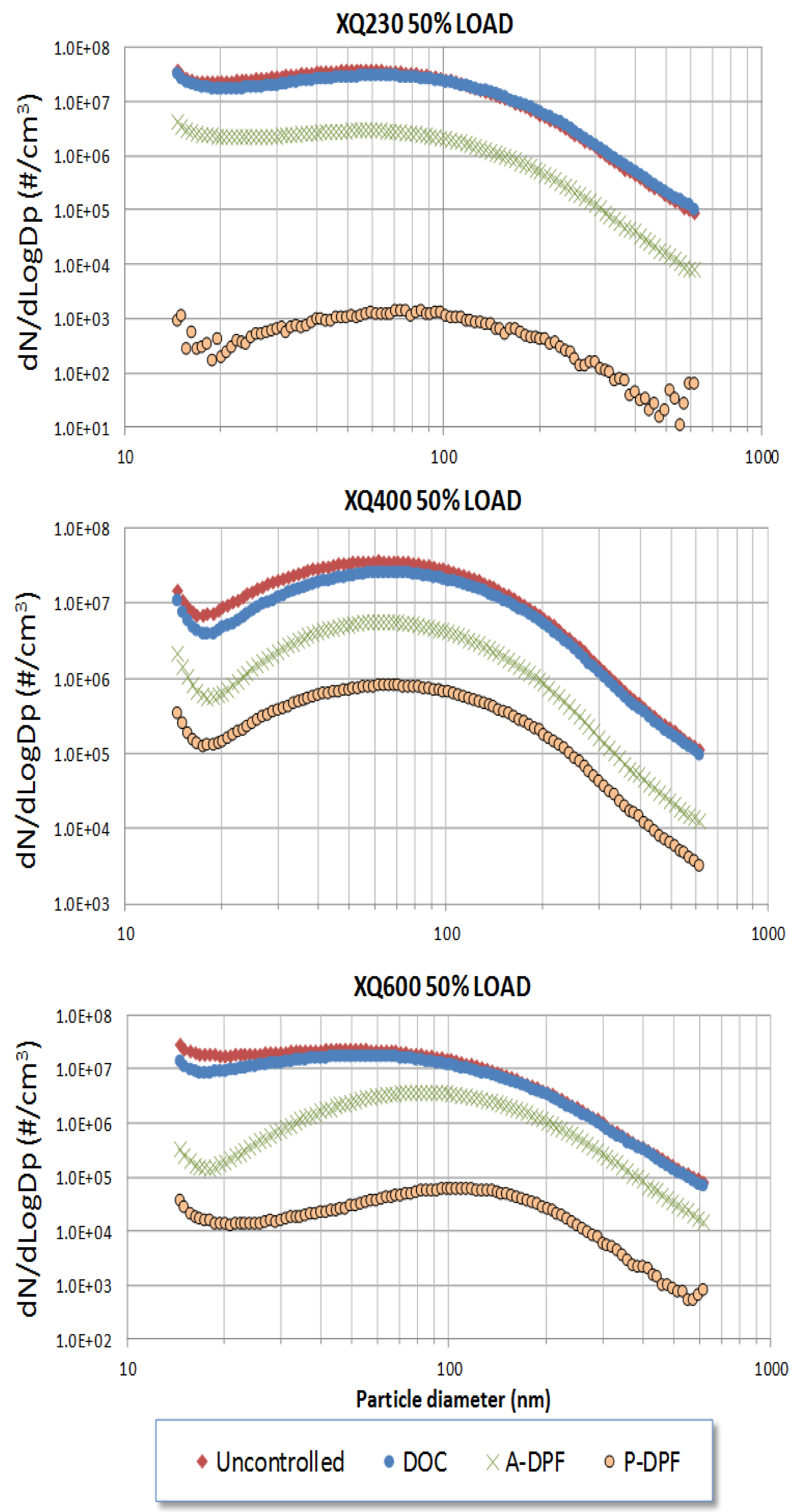

Figure 1: Particle size distribution at 50% load for (a) XQ230, (b) XQ400, and (c) XQ600 with and without aftermarket controls (similar trends occur for each genset at 90% load)

Table 1: Genset Description

Genset Model	Genset Certification Year	EPA Tier Rating	Maximum Power Output	Engine Model	Engine Displacement (in Liters)
XQ230	2009	3	230	CAT C9 ATAAC I-6, 4-stroke, water-cooled	8.8
XQ400	2005	3	400	CAT C15 ATAAC I-6, 4-stroke, water-cooled	15.8
XQ600	2006	2	600	CAT 3412 ATAAC V-12, 4-stroke, water-cooled	27

Table 3: Particulate emissions and optical properties from largest genset tested both uncontrolled and controlled at 50% and 90% load (data also collected for XQ230 and XQ400 but not displayed here)

			Particulate Emissions			Particle Number Count			Optical Characteristics			
			PM mass	EC	BC	Nuclei	Accum.	Total	EC/PM	Absorption	α	SSA
	Units		lb/MMBtu	lb/MMBtu	lb/MMBtu	no/MMBtu	no/MMBtu	no/MMBtu		1/Mm		
XQ600	50% Load	Uncontr'd	6.59E-03	4.29E-03	8.92E-03	1.55E+15	9.31E+15	1.09E+16	0.65	2.68E+04	1.128	0.231
		P-DPF	7.62E-05	2.40E-05	5.38E-05	1.49E+12	2.09E+13	2.24E+13	0.32	9.41E+02	4.153 *	0.066
		A-DPF	2.34E-03	7.48E-04	2.27E-03	1.38E+13	1.15E+15	1.16E+15	0.32	8.00E+03	1.278 *	0.207 *
		DOC	6.30E-03 *	4.17E-03 *	8.01E-03 *	7.43E+14	7.01E+15	7.75E+15	0.66	2.65E+04 *	1.178 *	0.222
	90% Load	Uncontr'd	1.08E-02	6.77E-03	1.41E-02	8.94E+14	6.65E+15	7.55E+15	0.63	4.37E+04	0.993	0.264
		P-DPF	1.40E-04	8.98E-05	2.32E-04	1.98E+12	5.72E+13 *	5.92E+13	0.64	1.68E+03	2.153 *	0.141
		A-DPF	4.02E-03 *	1.38E-03 *	4.20E-03 *	1.11E+13	1.22E+15 *	1.23E+15 *	0.34	1.64E+04	1.089 *	0.229 *
		DOC	5.67E-03 *	4.47E-03 *	9.52E-03 *	4.55E+14	4.51E+15 *	4.97E+15 *	0.79	4.09E+04 *	1.096 *	0.254 *

*Represents instances where removal, as compared to uncontrolled, was statistically insignificant

RESULTS

Table 4: Control device average PM, BC, and EC removal

		Average PM % Removal	Average EC % Removal	Average BC % Removal
50% Load	P-DPF	98 ± 1.6	99 ± 1.6	99 ± 1.8
	A-DPF	80 ± 14	87 ± 4.1	85 ± 10
	DOC	3.0 ± 19	-1.0 ± 18	9.7 ± 0.6
90% Load	P-DPF	96 ± 4.3	99 ± 1.2	99 ± 1.2
	A-DPF	80 ± 16	85 ± 9.3	80 ± 11
	DOC	17 ± 28	20 ± 17	11 ± 31

- Both the P-DPF and the A-DPF tested were found to be viable means to mitigate PM, BC, and EC emissions from each large-scale diesel gensets tested (removals from 80-99%), while the DOC produced statistically insignificant removal (0-25%).
- Changing engine loads provided a small but statistically significant increase in the single scatter albedo (SSA). The addition of aftermarket controls caused a slight decrease in SSA with an increase in angstrom exponent (α) that was not statistically significant.

Changes in EC/PM ratios suggest a shift in composition when any of the three aftermarket controls are utilized. Further, in all cases BC measured was roughly twice that of the EC measured.

- All particle size distributions were bi-modal, as expected, with approximately 86-95% of particles in the accumulation mode (>20nm) and 5-19% in the nuclei mode (<20nm). The highest average (for all three gensets) particle removal efficiency was measured with the P-DPF at greater than 97%, followed by the A-DPF at greater than 82%.

* Note that the nuclei mode is biased low as the SMPS did not measure below 14.6nm.