Appendix H

Diesel PM Control Technology Demonstration Program for Stationary Applications

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I. Background

There are a number of potentially effective emission control technologies for stationary applications available to reduce diesel particulate matter (PM). Diesel particulate filters (DPFs) and diesel oxidation catalysts (DOCs) have been effective for on-road applications and show potential for stationary engine applications, as well. To gather additional data on the technical feasibility of diesel PM control technologies and the applicability to stationary diesel-fueled engines, the Air Resources Board (ARB) funded a demonstration program. The purpose of the demonstration program was to:

- Demonstrate diesel PM control technologies on stationary engines.
- Identify applications and operating duty cycle conditions where specific particulate filter technologies may or may not be effective.

In this appendix, a brief background on the demonstration project is provided along with a description of the control technologies evaluated, the test results and the preliminary findings.

The stationary engine control device demonstration was performed in conjunction with a California Energy Commission Back-up Generator Program (CEC BUG). (CEC, 2001) The demonstration included testing of backup generators for baseline emission levels, retrofitting selected engines with commercially available PM control devices and testing controlled emission levels.

Emissions were tested for PM, total hydrocarbons (THC), methane, nonmethane hydrocarbons (NMHC), CO_2, CO, NOx, NO_2 per International Organization for Standardization Reciprocating Internal Combustion Engines-Exhaust Emission Measurement (ISO 8178) Parts 1, 2, and 4. (ISO/DP 8178, 1992) A five-mode D2 test cycle was used in all emission testing. The program was designed to support the testing and data requirements for control device verification under ARB's Verification Procedure, Warranty and In-Use Compliance Requirements of In-Use Strategies to Control Emissions from Diesel Engines (Verification Procedure). (ARB, 2002) To support verification, the test protocol included baseline testing and initial control efficiency, durability and post-durability control efficiency. Durability and post-durability testing was only performed for the devices that initially met the projected control efficiency for the targeted tier level (25 percent, 50 percent, or 85 percent). For the devices that did not meet the initial projected control efficiency, conditional durability and post-durability testing were not performed.

Emission testing was performed by University of California, Riverside, Bourns College of Engineering-Center for Environmental Research and Testing (UCR CE-CERT) under the direction of Wayne Miller, Ph.D.

II. Control Technologies

Diesel PM control technologies were selected based on a number of criteria: projected PM control efficiencies, commercial availability, demonstrated infield use, willingness of manufacturer to complete the verification process and product cost. Because the Verification Procedure is based on tiered emission levels, devices were selected that were projected to meet 25 percent, 50 percent, and 85 percent PM control. Technologies included emulsified diesel fuel, diesel oxidation catalysts, flow through filter technology and both active and passive particulate filters. When recommended by the control technology manufacturers, fuel-borne catalysts were used to enhance or promote regeneration. The control device technologies that were tested are described in Table H-1.

Table H-1: Control Strategies Included in Demonstration Program

Control Device Manufacturer	Product	Product Description
Lubrizol-Engine Control Systems	Sequentially Regenerated Combifilter	Triple bank silicon carbide particulate filter with online filter regeneration by electrical heating (Active DPF).
Johnson Matthey	Continuously Regenerating Trap (CRT)	Catalyzed diesel particulate filter (Passive DPF).
Sud Chemie	SC-DOC	Diesel Oxidation Catalyst (DOC 1).
CleanAir Systems Flow-Thru-Filter System and Clean Diesel Technologies (CDT) Fuel-Borne Catalyst	Flow-Thru-Filter System combined with CDT Fuel-Borne Catalyst	Combined system includes a DOC, flow through filter used with a CDT fuel-borne catalyst. The flow through filter component was removed prior to testing due to lower than required exhaust temperatures (DOC with Fuel-Borne Catalyst or DOC/FA).
Chevron	Proformix Fuel	Water emulsified fuel (20% water emulsification) utilizes Lubrizol's PuriNOx™ technology (Emulsified Fuel).
Catalytic Exhaust Products Particulate Filter and Clean Diesel Technologies Fuel-Borne Catalyst	SXS-B/FA combined with CDT Fuel-Borne Catalyst	Uncatalyzed diesel particulate filter used with a CDT fuel-borne catalyst (Particulate Filter with Fuel-Borne Catalyst or DPF/FBC).

All baseline engine tests were performed using currently available on-road diesel fuel that meets the specifications defined in Title 13, CCR sections 2281-2281 (CARB Diesel). (CCR Title 13, Sections 2281, 2282) Control device retrofit testing was performed using either CARB diesel or low sulfur diesel fuel (<15 ppm sulfur), as recommended by the control device manufacturer. Water emulsified diesel, developed to reduce both NOx and PM, was also included in the study as a control strategy for evaluation.

III. Emission Testing

Emissions testing was performed for particulate matter, CO_2, CO, NOx, NO_2, total hydrocarbons (THC) and non-methane hydrocarbons (NMHC) following the methods specified in ISO 8178. Exhaust analysis of the gaseous components was performed using the continuous measurement methods listed in Table H-2.

Table H-2: ISO 8178 Recommended Continuous Gaseous Sampling Analyzers

Gaseous Pollutant	Ambient Level Sampling Per ISO 8178
NOx and NO_2 (See Note 1)	Chemiluminescence
CO	Non-dispersive infrared (NDIR)
CO2	Non-dispersive infrared (NDIR)
Total Hydrocarbons	Flame ionization detector (FID)
CH4 and Non methane Hydrocarbons (NMHC)	GC combined with FID to measure CH4. NMHC from difference between THC and CH4

Note 1: Speciated NO_2 is not included in this test method. It was included in this study as required by CARB verification procedures.

Emission testing was performed using full-flow constant volume sampling (CVS) per ISO 8178. In the CVS method, the engine exhaust is diluted with air to maintain a constant total flow rate (air + exhaust) under all running conditions. Total exhaust (full-flow) is collected and mixed with air in the full-flow primary dilution tunnel. Particulate matter sampling is done from diluted exhaust gas. This is achieved by turbulent mixing of exhaust gases with air in a dilution tunnel. A sample for particulate measurement is drawn from that tunnel into a small secondary dilution tunnel, further mixed with air and collected on particulate filters maintained 52 ºC, maximum. Samples for continuous gas phase measurements are drawn from the primary dilution tunnel. The volumetric flow rate of the dilution air and diluted exhaust gas are measured along with temperatures and pressures, allowing computation of the total mass flow rate of exhaust and mass emission rates of the sampled components.

Eleven engines were tested for baseline emission levels. Seven diesel PM control systems were selected for testing on generators. Testing of the generators fitted with diesel PM control systems included five components:

- Baseline engine testing
- Control device retrofitting and retrofit degreening for 25 hours

- Control device emission testing to establish initial control efficiency
- Durability operation for conditional durability period (168 hours)
- Post-conditional durability emission testing.

During testing, degreening and durability operation, backpressure and exhaust temperature were monitored to establish exhaust temperature profiles, determine conformance to backpressure limits of the engine and ensure that the device was regenerating properly. Testing was performed in triplicate unless additional tests were required to quantify emission levels during distinct regeneration phases.

Durability cycling was performed for the control devices that successfully met the projected control efficiencies during the initial control device testing. The durability cycle included 24 cold starts followed by 24 hours of operation at 30 percent load, 24 hours at 50 percent load and 24 hours at 85 percent load. The cold starts were approximately ½ hour, under no load, with a 12-hour cooling period between starts. This durability cycle was repeated twice to reach the 167 hours required for conditional verification for stationary backup generators. The durability cycle was developed to model typical backup generator cold start maintenance cycling and emergency operation at three different projected operational loads. Since this program was designed to support the requirements of verification, testing was stopped if the device did not meet the projected level of control efficiency, the control device malfunctioned or clogged, or the engine backpressure limits were exceeded.

On successful completion of durability, the retrofitted engines will be emission tested to establish post-conditional durability control levels. The durability and post-durability test phases of the program are currently in progress and are expected to be complete in the late 2003 timeframe.

Test Cycles: Mass emission rates were measured at steady-state conditions for specified speeds and loads developed for off-road engine applications as listed in ISO 8178 Part 4. The specified test load was provided by using a generator load cell connected to the test engines. A test cycle includes a set of modes with a specified torque, speed and weighting value designed for specific engine uses. For a given test cycle, a weighted emission factor was calculated using weighted modal emission mass rates and divided by a weighted load value. Three of the common test modes are listed in Table H-3. EPA off-road engine certification is typically based on a C1 test cycle or a D2 test cycle, under special test procedures. Due to different modal loads, speeds and weighting values included in each test cycle, emission factors derived from different test cycles are not directly comparable. Since diesel generators only operate at rated speeds, field-testing could not be performed with a C1 cycle since it includes rated and intermediate speed modes. For generators, both D1 and D2 modes are acceptable. For this testing, the 5-mode D2 test cycle was selected since it is better representative of backup engines that have low load intermittent maintenance operation and higher load functional operation. In addition, a D1 emission factor can also be calculated using modes 1, 2, and 3 and D1 weighting factors.

Table H-3: Weighting Factors for C1, D1 and D2 Type ISO 8178 Test Cycles

Mode number	1	2	3	4	5	6	7	8	9	10	11
Torque, %	100	75	50	25	10	100	75	50	25	10	0
Speed	Rated speed					Intermediate speed					Low idle
Type C1	0.15	0.15	0.15	-	0.10	0.10	0.10	0.10	-	-	0.15
Constant speed											
Type D1	0.30	0.50	0.20	-	-	-	-	-	-	-	-
Type D2	0.05	0.25	0.30	0.30	0.10	-	-	-	-	-	-

Test Engines: Test engines were selected based on an analysis of the engine database compiled in CEC's BUG Program (CE-CERT, 2001). The database was developed by cataloging permitted backup generators in California that were greater than 300 kW. A test engine matrix was developed by determining predominant categories of engine manufactures, engine sizes and model years. Based on the analysis and as shown in Table H-4, engines from three manufactures were included in the study: Caterpillar, Cummins and Detroit Diesel. Two engine size categories were selected: 500 to 700 kW and 1500 to 2000 kW. Three model year groupings were selected: pre-1987, 1987-1996, and post-1996. A total of 11 engines were tested for baseline emissions, with one additional planned, in the 500 to 700 kW range. Two engine tests are still planned for the 1500 to 2000 kW range. Once the test engine categories were defined, the specific engine model and model year were selected based on engine availability and control device manufacturer's recommendations. Selection of the appropriate engine was typically based on engine design and operating parameters such as exhaust temperature and emission levels and targeted market for the retrofit device. When stationary engines were not available, equivalent portable generators were used for testing and retrofit.

Table H-4: Stationary Engine Control Demonstration Program Test Engine Matrix

Engine	Program ID	Model Year	Control
Detroit Diesel V92	Bug 2	1991	
CAT 3406B	Bug 3	1991	
Cummins KTA19G2	Bug 4	1990	
Cummins N14	Bug 5	1999	
Detroit Diesel Series 60	Bug 6	1999	
CAT 3412C	Bug 7	Post 96	
CAT 3408B	Bug 8	1990	Baseline (Planned)
CAT 3406C	Bug 12	2000	Passive DPF
CAT 3406C	Bug 10	2000	Active DPF
Detroit Diesel V92	Bug 14	1985	DOC/FBC
CAT 3406C	Bug 10	2000	DOC 1
Detroit Diesel V92	Bug 14	1985	DOC 1
CAT 3406C	Bug 9	Post 96	Emulsified Fuel
CAT 3406B	Bug 11	1986	Emulsified Fuel
CAT 3406C	Bug 10	2000	DPF/FBC (Planned)

Table H-5: Average D2 Weighted Emissions Factors for Baseline Engine Testing

				D2 Weighted Emission Factors (g/bhp-hr)						
Engine Make and Model	**Model Year**	**Fuel**	**Load (hp)**	**THC**	**CH4**	**NMHC**	**CO**	**NOx**	**CO_2**	**PM**
DDC V92 Bug 14	1985	CARB Diesel	389.62	0.66	0.05	0.61	1.72	10.79	713.74	0.20
DDC V92 Bug 2	1991	CARB Diesel	469.00	0.47	0.04	0.44	0.94	7.82	647.98	0.23
DDC Series 60 Bug 6	1999	CARB Diesel	400.66	0.07	0.01	0.06	0.55	7.45	551.29	0.06
CAT 3406B Bug 11	1986	CARB Diesel	399.32	0.15	0.03	0.12	0.68	11.32	572.27	0.09
CAT 3406B Bug 3	1991	CARB Diesel	402.00	0.12	0.03	0.10	0.95	10.22	613.57	0.11
CAT 3412C Bug 7	Post-96	CARB Diesel	730.30	0.10	0.03	0.07	1.12	7.67	606.93	0.16
CAT 3406C Bug 9	Post-96	CARB Diesel	469.00	0.16	0.03	0.27	1.23	6.51	546.22	0.15
CAT 3406C Bug 10	2000	CARB Diesel	464.98	0.08	0.02	0.07	1.47	6.78	564.02	0.16
CAT 3406C Bug 12	2000	CARB Diesel	465.86	0.09	0.02	0.07	1.04	6.61	557.20	0.14
CUM KTA 19G2 90 Bug 4	1990	CARB Diesel	477.04	0.39	0.04	0.35	0.69	7.03	546.4	0.22
CUM N14 99 Bug 5	1999	CARB Diesel	470.34	0.22	0.02	0.20	0.46	6.03	586.53	0.06

Figure H-1: Average D2 Weighted PM Emission Factors for Baseline Engine Testing

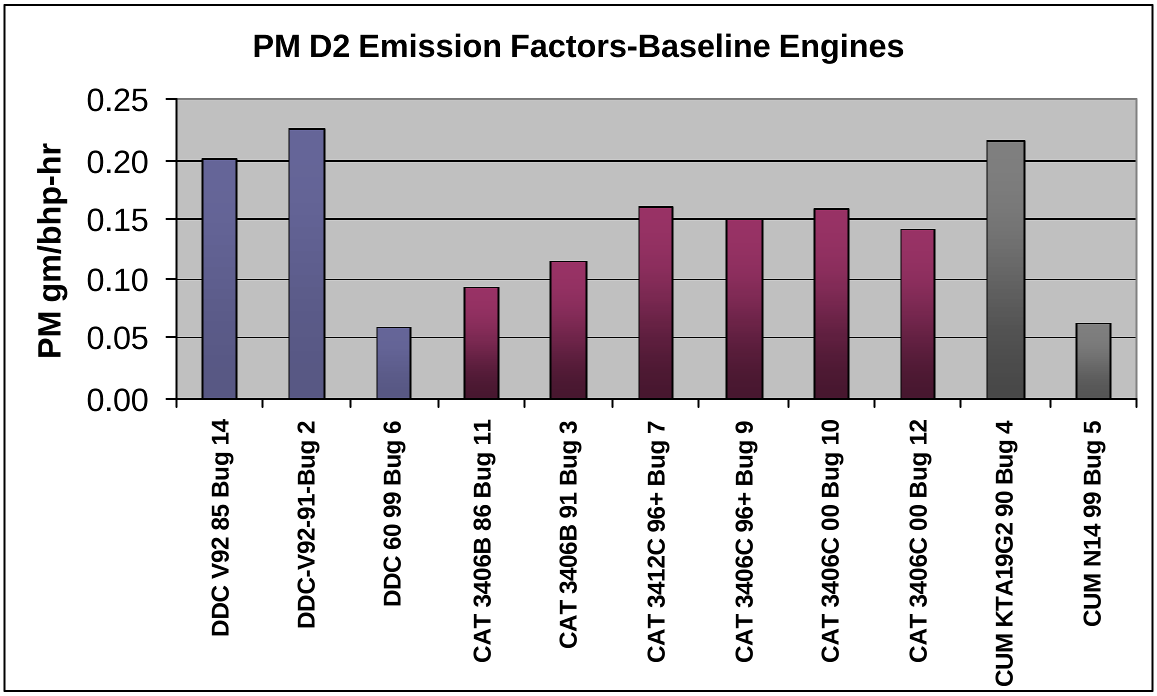
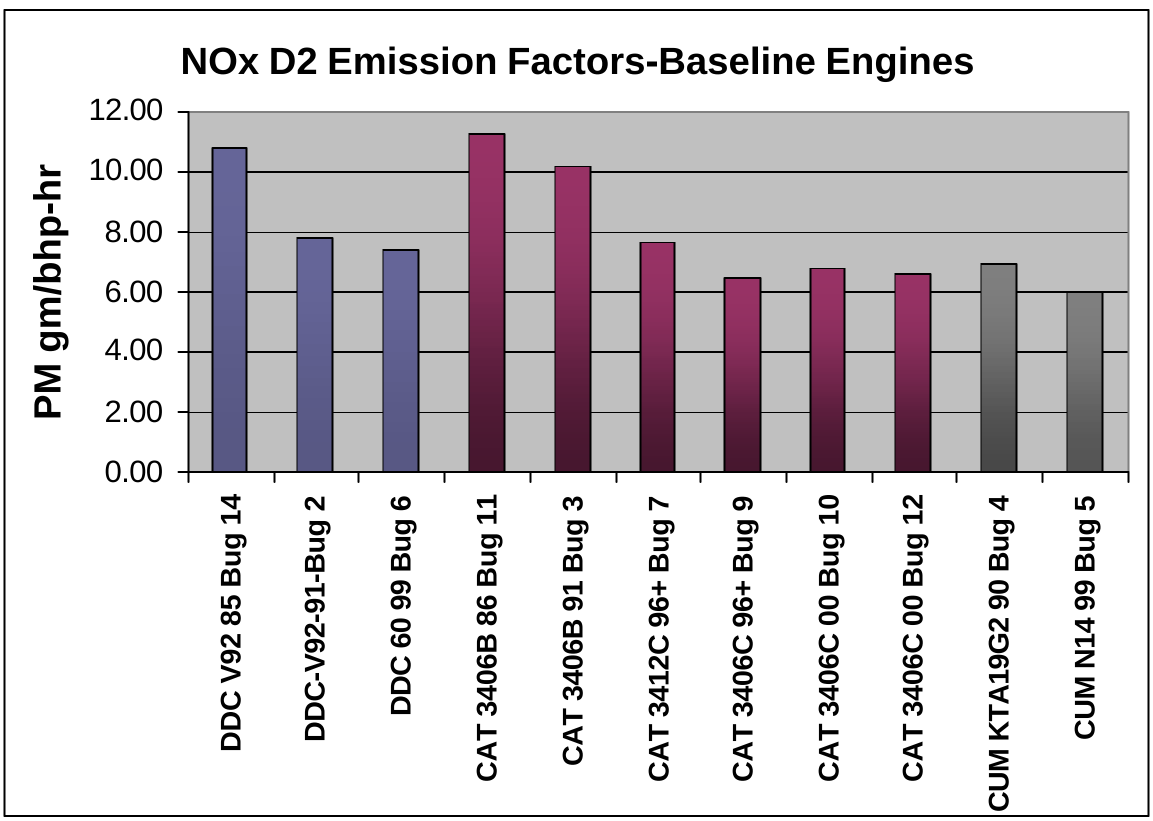


Figure H-2: Average D2 Weighted NOx Emission Factors for Baseline Engine Testing



Control Device Testing: To measure the initial control efficiency, retrofit engine emissions testing was performed after a 25 hour degreening process for PM and gaseous emissions per ISO 8178. For each of the control devices, average D2 weighted emission factors were measured and control efficiencies were calculated as listed in Table H-6. Following Table H-6, are detailed discussions on each device including a description of the technology and the results of the demonstration study.

Table H-6: D2 weighted Emission Factors and Control Efficiencies

		Average D2 Weighted Emission Factors (gm/bhp-hr)						
Configuration	**Fuel**	**100% Load (HP)**	**THC**	**CH_4**	**NMHC**	**CO**	**NOx**	**PM**
2000 CAT 3406C with Johnson Matthey CRT Passive DPF								
Baseline	CARB Diesel	465.9	0.087	0.015	0.074	1.041	6.608	0.142
Controlled	ULSD	467.1	0.007	0.003	0.004	0.228	6.212	0.012
Percent Reductions			92.3	82.6	94.1	78.1	6.0	91.4
2000 CAT 3406C with ECS Sequentially Regenerated Combifilter Active DPF								
Baseline	CARB Diesel	465.0	0.082	0.017	0.067	1.468	6.783	0.159
Controlled	ULSD	458.8	0.050	0.015	0.037	1.645	6.042	0.0003
Percent Reductions			39.5	16.1	44.7	-12.1	10.9	99.8
1985 2 stroke Detroit Diesel V92 with CleanAir Systems DOC and CDT Fuel-Borne Catalyst								
Baseline	CARB Diesel	389.6	0.659	0.053	0.613	1.715	10.785	0.201
Controlled	ULSD+FBC	389.6	0.200	0.014	0.188	0.100	11.545	0.121
Percent Reductions			69.6	73.0	69.3	94.1	-7.0	40.0
2000 CAT 3406C with Sud Chemie DOC								
Baseline	CARB Diesel	465.0	0.082	0.017	0.067	1.468	6.783	0.159
Controlled	CARB Diesel	467.7	0.011	0.002	0.009	0.058	7.168	0.129
Percent Reductions			86.7	90.3	85.9	96.0	-5.7	18.8
1985 2 stroke Detroit Diesel V92 with Sud Chemie DOC								
Baseline	CARB Diesel	389.6	0.659	0.053	0.613	1.715	10.785	0.201
Controlled	CARB Diesel	393.5	0.307	0.022	0.288	0.206	10.860	0.107
Percent Reductions			53.4	58.2	53.1	88.0	-0.7	46.9
1986 CAT 3406B with Emulsified Diesel								
Baseline	CARB Diesel	399.3	0.147	0.027	0.124	0.679	11.321	0.093
Controlled	Emulsified Fuel	363.1	0.161	0.026	0.139	0.496	10.914	0.076
Percent Reductions			-9.7	2.4	-12.0	27.0	3.6	17.8
Post- 96 CAT 3406C with Emulsified Diesel								
Baseline	CARB Diesel	469.0	0.163	0.031	0.270	1.234	6.512	0.150
Controlled	Emulsified Fuel	469.0	0.131	0.027	0.108	0.820	5.563	0.041
Percent Reductions			19.4	13.1	60.0	33.6	14.6	72.7

Active DPF

The Lubrizol-Engine Control Systems (ECS) electrically regenerated Combifilter was retrofitted on a model year (MY) 2000 Caterpillar 3406C generator. This control system includes three silicon carbide diesel particulate filters with an electrical regeneration system designed to provide continuous PM control. The triple filter system provides uninterrupted emission filtration during regeneration by switching the exhaust flow between filters. The regeneration system was electronically controlled and entirely automatic. The main components of the system are the ceramic wall-flow filter elements, electronic control unit (ECU), electrical heater system, compressed air blower system and valve system to switch the exhaust flow between filters. The system provides online regeneration by isolating one filter at a time from the exhaust stream to allow for electrical regeneration of that filter. The filter is regenerated by electrical heating combined with a low flow of compressed air. Upon completion of the regeneration cycle, the filter is brought back online for operation. The system operates in two modes: a soot cycle where all three filters are open to exhaust and a regeneration mode where one filter is isolated for regeneration. These two cycles continue throughout operation, sequentially regenerating one filter during each regeneration cycle. This design provides continuous filtration, with regeneration automated by the timed control system.

Because the system operates in two distinct modes, soot and regeneration, 5-mode emission testing was performed in triplicate for both modes. The average emission factors, listed in Table H-6, were calculated using modal data from all soot and regeneration modes. The emission test results show a greater than 99 percent reduction in PM. In addition, NMHC were reduced by approximately 45 percent and NOx by 10 percent. While the particulate matter reduction was very high, this system had two areas of concern. First, backpressure levels measured during durability were higher than anticipated. During the durability cycling, average backpressure was measured at approximately 50 inches H_2O at 65 and 85 percent loads, with a maximum of approximately 70 inches H_2O. This unit was originally designed for a smaller two-stroke Detroit Diesel engine. The manufacturer attributes the higher than anticipated backpressure to differences in engine exhaust flows and exhaust hardware between the Detroit Diesel and the Caterpillar 3406C engine. The manufacturer indicated that this was a sizing issue that would be addressed during the design phase of stationary source retrofitting.

The second issue concerned the regeneration control system. The regeneration control system initially had functional problems, which were corrected. Additionally, CE-CERT testing staff found that during the intermittent cold start portion of durability cycling, the soot mode (all three filters open) was longer than had been indicated by the manufacturer. The result may be that the filters are not regenerating as often as described during cold start operation. We believe this may be a due to interruption of the control cycle during intermittent use. This may be an additional source of system backpressure. Since the regeneration system is controlled strictly by timing and not by backpressure sensors, this control scheme may need optimization for applications with multiple cold starts. The manufacturer has indicated that both backpressure and regeneration cycling can be addressed and corrected within the control system design.

Passive DPF

The Johnson Matthey Continuously Regenerating Trap (CRT) was retrofitted on a MY2000 Caterpillar 3406C diesel generator. This is a passive, self-regenerating catalyzed diesel particulate filter. The CRT particulate filter is a patented emission control technology that contains a platinum-coated catalyst and a ceramic monolith particulate filter designed to control particulate matter (PM), carbon monoxide (CO) and hydrocarbon (HC) emissions through catalytic oxidation and filtration. The CRT is a trade name for a two-stage catalytic, passive filter configuration. The CRT system utilizes a ceramic wall-flow filter to trap particulates. The trapped particulate matter is continuously oxidized by nitrogen dioxide generated in an oxidation catalyst, which is placed upstream of the filter. The catalyst promotes the conversion of the NO in the exhaust to NO_2 in the first stage of the trap. The reverse process occurs in the subsequent particulate trap. The liberated oxygen atom burns the carbon in the particulate trap resulting in continuous regeneration at lower exhaust temperatures than are required for an uncatalyzed filter. The CRT requires low sulfur fuel.

The formation of NO_2 may problematic, since NO_2 levels for verified control devices are limited to 20 percent of the total engine baseline NOx emissions, as of January 1, 2003. Initial emission testing of the JM CRT resulted in control efficiencies just below 85 percent. A leak in the seal around the ceramic monolithic filter and housing was located and repaired and durability cycling began. Durability cycling was stopped after it was decided to retest the control efficiencies. After repairing the seal and retesting, the control efficiency was measure at 91 percent for PM and 94 percent for NMHC. The results of the retest are listed in Table H-6. In addition, hydrocarbons and carbon monoxides are also reduced significantly. NOx is reduced slightly, but the fraction of NO_2 increased. The controlled level of NO_2 is 25 percent of the total baseline NOx level, higher than the verification limit of 20 percent.

Diesel Oxidation Catalyst

The Sud-Chemie diesel oxidation catalyst (DOC 1) was retrofitted on a MY2000 Caterpillar 3406C and a MY1985 2 stroke Detroit Diesel V92. The SC-DOC contains a proprietary catalyst designed promote chemical oxidation of CO and HC as well as the SOF portion of diesel particulate while mitigating the oxidation of fuel sulfur to form sulfate particulate. Because of the selective catalyst formation, low sulfur diesel fuel is not required. Initial control device testing on the Caterpillar 3406C resulted in PM reductions of 18 percent, lower than originally anticipated. To investigate, Thermal/Optical Reflectance tests were performed on PM samples captured on parallel quartz filters to quantify the ratio of elemental carbon to organic carbon (EC/OC). The data indicated that the PM had a high ratio of EC/OC. Since diesel oxidation catalysts reduce the soluble organic fraction of the PM, the high ratio of elemental carbon may explain why the DOC efficiency was lower than originally expected. The DOC was also retrofitted on a MY1985 two stroke Detroit Diesel V92 and emission tested. The measured control efficiency was better than 46 percent for PM and 53 percent for NMHC. EC/OC ratios were lower, indicating a higher component of organic carbon species in the PM. Because of the additional testing, durability and post- durability emission testing was not performed for this control.

Diesel Oxidation Catalyst with Fuel-Borne Catalyst

The CleanAIR Flow Through Filter System was retrofitted on a MY1985 2-stroke Detroit Diesel V92. This system was projected to reduce PM by 50 percent without increasing NO_2 emissions. This system is a passive, flow-through-filter (FTF) combined with a Clean Diesel Technology (CDT) fuel borne catalyst to reduce diesel particulate emissions. A diesel oxidation catalyst (DOC), also part of the system, reduces CO and HC emissions. This system experienced regeneration problems during degreening operation (no load operation for 25 hours). The exhaust temperatures were not sufficient for regeneration and the flow-through-filter clogged. The flow-through-filter was removed and the DOC, combined with the fuel-borne catalyst was tested. The control efficiency of the DOC and FBC system was 40 percent for PM and 69 percent for NMHC, while NOx increased by approximately 7 percent. The conditional durability cycling of 168 hours for the DOC/FBC system is almost completed, indicating no durability problems, to date. Post- conditional-durability controlled emissions will be performed upon completion of durability.

Emulsified Fuel

Emulsified fuel testing was performed on two engines, a MY1986 Cat 3406B and a post- 96 CAT 3406C. Chevron Proformix fuel is a water emulsified diesel fuel that consists of a blend of water, conventional diesel fuel and an additive package, utilizing Lubrizol's PuriNOx technology. Small amounts of the additive package are added to the fuel to maintain the emulsion, enhance cetane and lubricity, inhibit corrosion, protect against freezing and prevent foaming. The water is suspended in droplets within the fuel lowering PM emissions by creating a leaner fuel environment in the engine. Also, the emulsified fuel creates cooling effect in the combustion chamber, thereby, decreasing NOx emissions. The formulation contains 77 percent diesel fuel, 20 percent water, and 3 percent additive package. Emissions testing of the CAT 3406B with emulsified fuel demonstrated PM reductions of 17 percent and NOx reductions of 3 percent. For the CAT 3406C, PM was reduced by 72 percent and NOx was reduced by approximately 14 percent. These varied results indicate that reductions may be dependent on engine design and combustion conditions and require further study.

Particulate Filter with Fuel-Borne Catalyst

The Catalytic Exhaust Products SXS-B/FA diesel particulate filter is an uncatalyzed ceramic wall flow filter combined with Clean Diesel Technology fuel-borne catalyst. It is planned for installation on a MY2000 Caterpillar 3406C diesel generator. This system combines a ceramic monolith trap with a Clean Diesel Technology fuel-borne catalyst to facilitate regeneration of diesel particulate filter. The bare wall flow diesel particulate filter requires a minimum exhaust gas temperature of approximately 550 to 600 ºC for 20 percent of operation in order for the particulate filter to regenerate properly. Addition of fuel borne catalysts assist in regeneration and allow the diesel particulate filter to regenerate at exhaust temperatures in the range of 320 to 350+ ºC. Installation and emission testing for this system has not been completed, but is planned for late 2003.

IV. Discussion

Diesel Particulate Filters: Both active and passive diesel particulate filters were tested for backup generator applications. Control efficiency for both technologies were better than 90 percent. The technologies were capable of regenerating under the intermittent cold start maintenance cycling and loaded operation, typical for backup generators. While the passive CRT DPF did have increased levels of NO_2, overall NOx levels decreased by approximately 6 percent. The actively regenerating system showed better than 99 percent reduction for PM, with regeneration independent of exhaust temperature by design. Issues involving high backpressure levels and active regeneration control design need to be addressed during system design for stationary sources. The results from the demonstration testing indicate that both active and passive technologies are effective in reducing PM better than 85 percent. Durability testing for intermittent cold start and extended high load operation indicates that these technologies may be effective for other steady-state stationary engine applications, as well. The technologies are currently commercially available for retrofit applications.

Diesel Oxidation Catalysts: The effectiveness of diesel oxidation catalysts reportedly depends on the level of soluble organic fraction in the PM. Comparison testing on two engines showed that for low ratios of organic PM components, PM control effectiveness was lower than anticipated. (CE-CERT, 2003) Where the ratio of organic components was higher, the control efficiency increased significantly. Testing of two commercially available DOC technologies on a two stroke Detroit Diesel V92 showed control efficiencies in the range of 40 to 46 percent for PM and 53 to 69 for NMHC. NOx levels increased 1 to 7 percent. The NOx increases may be due to differences in ambient conditions during testing and are well below the limits included in the Verification Procedure. Demonstration testing indicates that DOC technologies are effective in providing better than 30 percent control efficiency for appropriate engine types.

Emulsified Fuel: Testing of emulsified fuels for two different Caterpillar engines resulted in a wide range of control efficiency for PM from 17 to 72 percent. Control efficiencies for NMHC were even more varied, ranging from a decrease of 60 percent to an increase in 12 percent. For both tests, NOx reductions ranged from 3 to 14 percent. These wide variations in test results indicate that further testing is required. Results also show that for certain engine types, emulsified fuel could be a very effective technology to reduce PM significantly, while also providing reductions in NOx.

Figure H-3. Average D2 Weighted PM Emission Factors for Baseline and Controlled Engine Testing

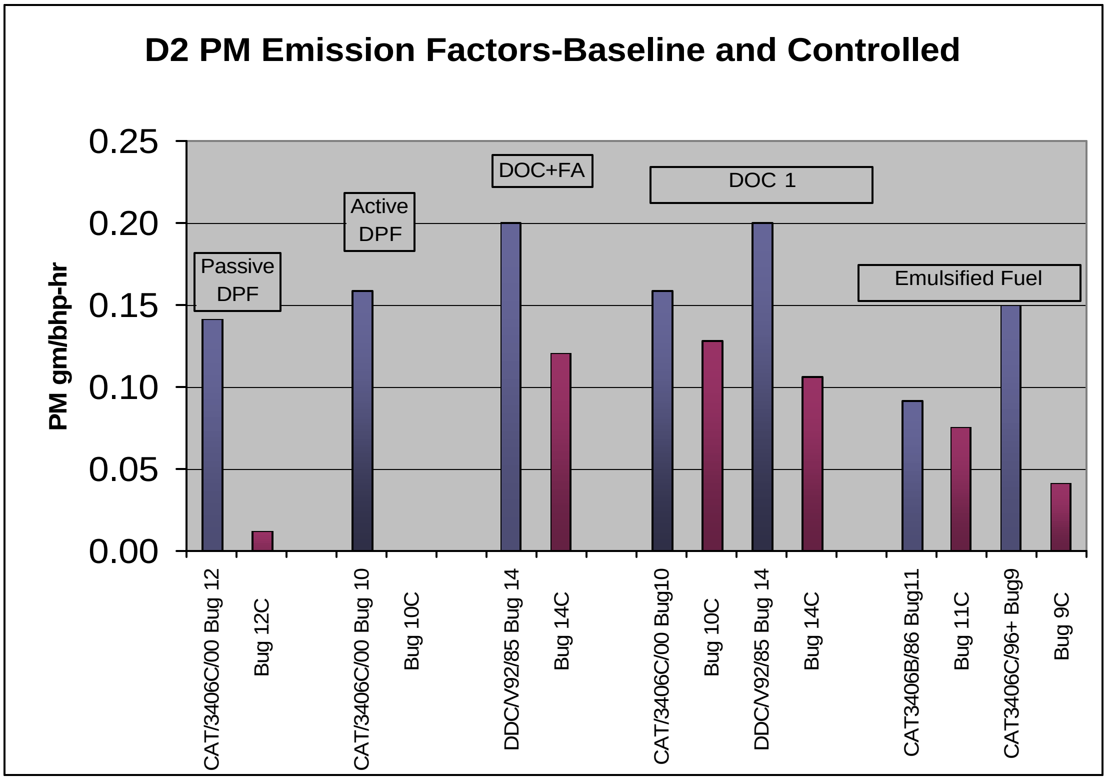


Figure H-4: Average D2 Weighted NOx Emission Factors for Baseline and Controlled Engine Testing

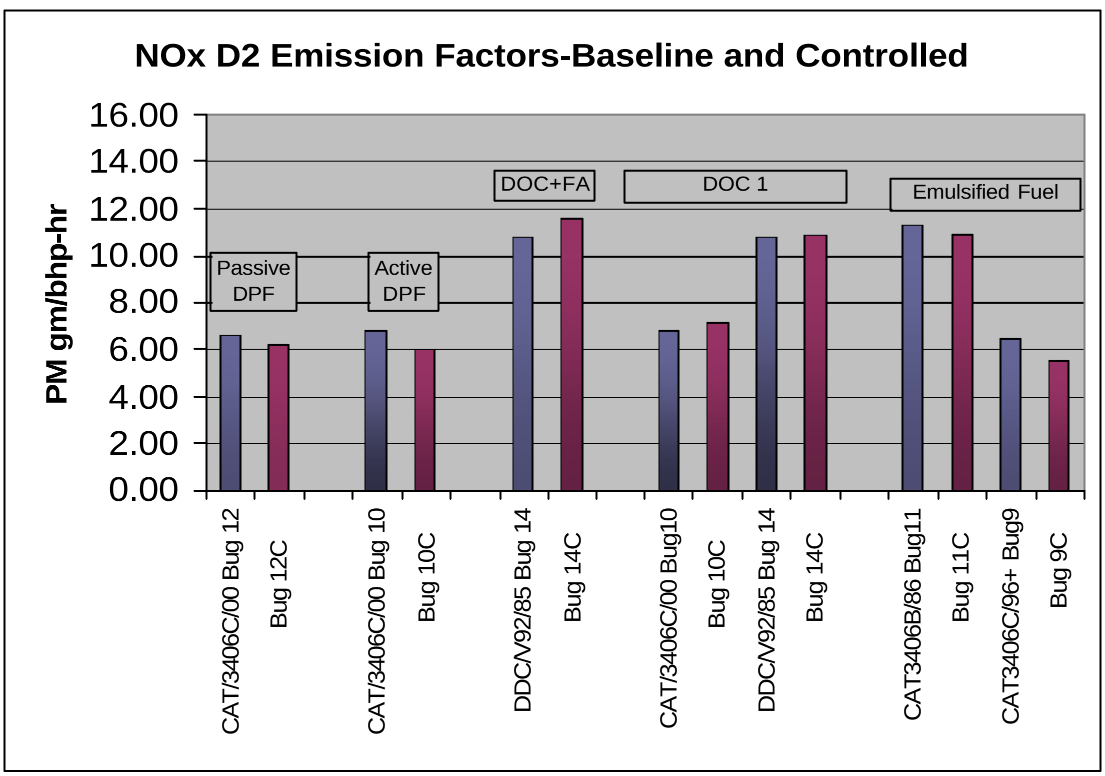
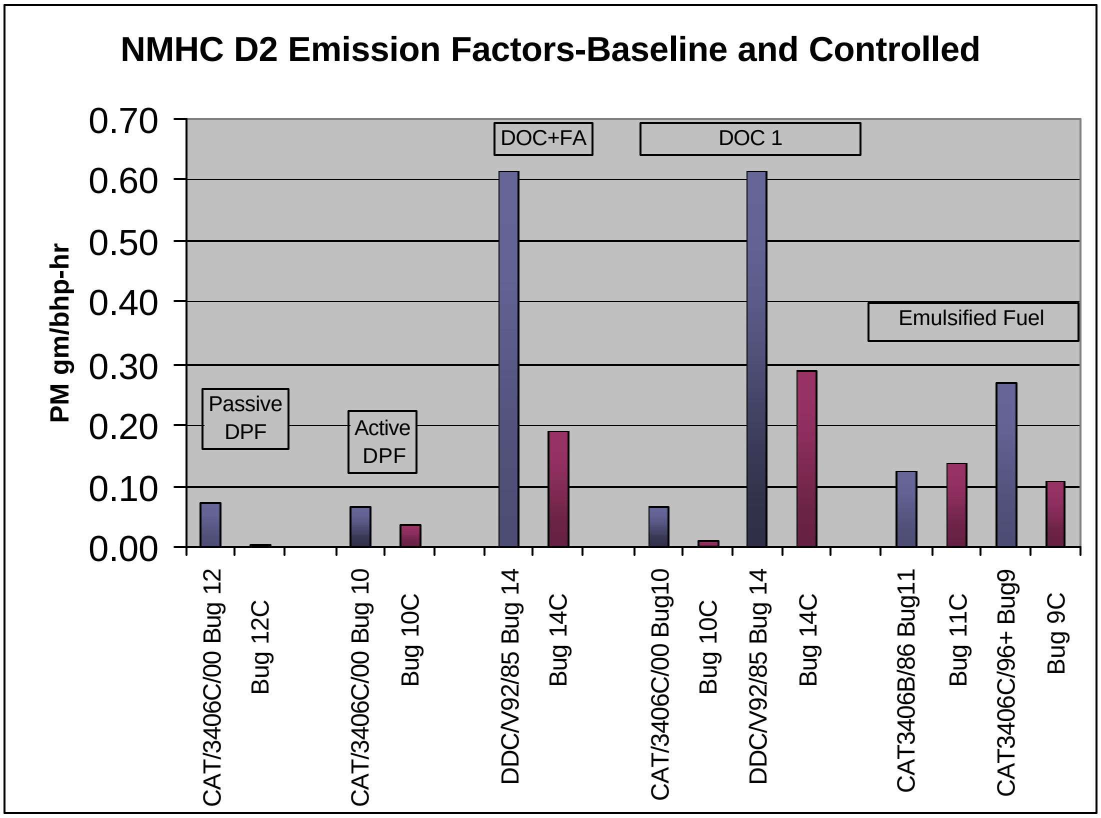


Figure H-5: Average D2 Weighted NMHC Emission Factors for Baseline and Controlled Engine Testing



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