Environmental Technology Verification

Test Report of Mobile Source Emissions Control Devices

Clean Diesel Technologies Fuel-Borne Catalyst with Mitsui/PUREarth Catalyzed Wire Mesh Filter

Prepared by

Southwest Research Institute

RTI International

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**MOBILE DIESEL ENGINE AIR POLLUTION CONTROL**
APPLICATION:	**CONTROL OF EMISSIONS FROM MOBILE DIESEL ENGINES IN HIGHWAY USE BY DIESEL PARTICULATE FILTERS**
TECHNOLOGY NAME:	**CLEAN DIESEL TECHNOLOGIES, INC. FUEL-BORNE CATALYST WITH MITSUI/PUREarth CATALYZED WIRE MESH FILTER**
COMPANY:	**CLEAN DIESEL TECHNOLOGIES, INC.**
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups, which consist of buyers, vendor organizations, permitters, and other interested parties; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Air Pollution Control Technology Verification Center (APCTVC), one of six centers under the ETV Program, is operated by RTI International (RTI), in cooperation with EPA's National Risk Management Research Laboratory. The APCTVC has evaluated the performance of an emissions control system consisting of a fuel-borne catalyst for mobile diesel engines used with a catalyzed wire mesh filter.

ETV TEST DESCRIPTION

All tests were performed in accordance with the *Test/QA Plan for the Verification Testing of Diesel Exhaust Catalysts, PM Filters, and Engine Modification Technologies for Highway and Nonroad Use Diesel Engines* and the *Test-Specific Addendum to ETV Mobile Source Test/QA Plan for Clean Diesel Technologies, Inc. platinum/cerium fuel-borne catalyst & Mitsui/PurEarth catalyzed wire mesh filter.* These documents are written in accordance with the applicable generic verification protocol and include requirements for quality management, quality assurance, procedures for product selection, auditing of the test laboratories, and test reporting format.

The mobile diesel engine air pollution control technology was tested at Southwest Research Institute. The performance verified was the percentage emission reduction achieved by the technology for particulate matter (PM), nitrogen oxides (NO_x), hydrocarbons (HC), and carbon monoxide (CO) relative to the performance of the same baseline engine without the technology in place. Operating conditions were documented and ancillary performance measurements were also made. A summary description of the ETV test is provided in Table 1.

Table 1. Summary Description of the ETV Test

Test type	Highway Transient Federal Test Procedure (FTP), heavy-duty cycle
Engine family	LCE0505FAC5
Engine make–model year	Cummins Engine Company–1990 (certified to 1991 certification levels)
Service class	On-highway, heavy duty diesel engine
Engine rated power	206 kW (275 bhp) @ 2,000 rpm
Engine displacement	8.3 L
Technology	Clean Diesel Technologies' fuel-borne catalyst with Mitsui/PUREarth catalyzed wire mesh filter
Technology description	A platinum/cerium fuel-borne catalyst (0.5Pt/7.5Ce ppm) in ultralow-sulfur diesel (ULSD) fuel combined with a catalyzed wire mesh filter (Model ND3K2)
Test cycle or mode description	One cold-start and three hot-start tests according to FTP test
Test fuel description	EPA standard low-sulfur and ultralow-sulfur No. 2 diesel fuels per 40 CFR Part 86.1313
Critical measurements	PM, NOx, HC, and CO
Ancillary measurements	NO, NO_2, CO_2, exhaust back-pressure, exhaust temperature, and fuel consumption

VERIFIED TECHNOLOGY DESCRIPTION

This verification statement is applicable to Clean Diesel Technologies' platinum/cerium fuel-borne catalyst (FBC) at 0.5 ppm platinum and 7.5 ppm cerium (0.5Pt/7.5Ce ppm) ± 20% in commercial ULSD fuel (meeting the EPA specifications for 2007 at less than 15 ppm maximum sulfur content) with a lightly catalyzed wire mesh filter (CWMF) manufactured by Mitsui/PUREarth (model ND3K2). It is applicable to engines fueled by ultralow-sulfur (15 ppm or less) diesel fuel.

This verification statement describes the performance of the tested technology on the diesel engine and fuels identified in Table 1.

VERIFICATION OF PERFORMANCE

The Clean Diesel Technologies fuel-borne catalyst used with Mitsui/PUREarth's CWMF achieved the reduction in tailpipe emissions shown in Table 2 compared to baseline operation with low-sulfur diesel (LSD) fuel.

Table 2. Verified Emissions Reductions for System Consisting of Clean Diesel Technologies Fuel-borne Catalyst with Mitsui/PUREarth's CWMF

	Fuel		Mean Emissions Reduction (%)				95% Confidence Limits on the Emissions Reduction (%)			
Device type[a]	Baseline	Controlled	PM[b]	NO_x	HC	CO	PM[b]	NO_x	HC	CO
Degreened	LSD	FBC-treated ULSD	76	11	90	74	75-78	8.3-13	90-91	72-76
Aged	LSD	FBC-treated ULSD	76	8.4	88	58	74-77	5.4-11	88-89	54-63

[a] Degreened and Aged are defined in the generic verification protocol.

[b] The verified PM emissions reduction combines reductions related to the control technology and the change in fuel sulfur level.

Note: The engine backpressure averaged 13.3 KPa (4.5 in. Hg) and 12.5 KPa (3.7 in. Hg) for the the degreened and aged devices respectively, versus the engine manufacturer's specification of 8.1 KPa (2.4 in. Hg). The backpressure at engine rated conditions was 25.3 KPa (7.5 in. Hg) and 22.6 KPa (6.7 in. Hg) for the degreened and aged devices, respectively.

For the purposes of determining the status of the technology in regard to EPA's voluntary diesel retrofit program, the prospective user is encouraged to contact EPA's Office of Transportation and Air Quality (OTAQ) or visit the retrofit program web site at http://www.epa.gov/otaq/retrofit/.

The APCTVC QA Officer has reviewed the test results and quality control data and has concluded that the data quality objectives given in the generic verification protocol and test/QA plan have been attained. EPA and APCTVC quality assurance staff have conducted technical assessments at the test laboratory and of the data handling. These confirm that the ETV tests were conducted in accordance with the EPA-approved test/QA plan.

This verification statement verifies the emissions characteristics of the *Clean Diesel Technologies fuel-borne catalyst used with Mitsui/PUREarth's CWMF* for the stated application. Extrapolation outside that range should be done with caution and an understanding of the scientific principles that control the performance of the technologies. This verification focused on emissions. Potential technology users may obtain other types of performance information from the manufacturer.

In accordance with the generic verification protocol, this verification statement is valid, commencing on the date below, indefinitely for application of *Clean Diesel Technologies fuel-borne catalyst used with Mitsui/PUREarth's CWMF* within the range of applicability of the statement.

Original signed by L. W. Reiter *9/30/04*

Lawrence W. Reiter PhD Date
Acting Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original signed by A. R. Trenholm *9/30/04*

Andrew R. Trenholm Date
Director
Air Pollution Control Technology Verification Center

Environmental Technology Verification Report

Mobile Source Retrofit Air Pollution Control Devices

Clean Diesel Technologies' Fuel-borne Catalyst with Mitsui/PUREarth Catalyzed Wire Mesh Filter

Prepared by

RTI International
Southwest Research Institute

EPA Cooperative Agreement No. CR829434-01-1

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Notice

This document was prepared by RTI International (RTI) and its subcontractor Southwest Research Institute (SwRI), with partial funding from Cooperative Agreement No. CR829434-01-1 with the U.S. Environmental Protection Agency (EPA). The document has been submitted to RTI/EPA's peer and administrative reviews and has been approved for publication. Mention of corporation names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products.

Foreword

The Environmental Technology Verification (ETV) Program, established by the U.S. Environmental Protection Agency (EPA), is designed to accelerate the development and commercialization of new or improved technologies through third-party verification and reporting of performance. The goal of the ETV Program is to verify the performance of commercially ready environmental technologies through the evaluation of objective and quality-assured data so that potential purchasers and permitters are provided with an independent and credible assessment of the technology that they are buying or permitting.

The Air Pollution Control Technology Verification Center (APCTVC) is part of the EPA's ETV Program and is operated as a partnership between RTI International (RTI) and EPA. The Center verifies the performance of commercially ready air pollution control technologies. Verification tests use approved protocols and verified performance is reported in verification statements signed by EPA and RTI officials. RTI contracts with Southwest Research Institute (SwRI) to perform verification tests on engine emission control technologies.

Retrofit air pollution control devices used to control emissions from mobile diesel engines are among the technologies evaluated by the APCTVC. The APCTVC developed (and EPA approved) the *Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines* to provide guidance on the verification testing of specific products that are designed to control emissions from diesel engines.

The following report reviews the performance of the Clean Diesel Technologies' platinum/cerium fuel-borne catalyst used with Mitsui/PUREarth's catalyzed wire mesh filter (Model ND3K2). ETV testing of this technology was conducted during December 2003 at SwRI. All testing was performed in accordance with an approved test/QA plan that implements the requirements of the generic verification protocol at the test laboratory.

Availability of Report

Copies of this verification report are available from

- RTI International
  Engineering and Technology Unit
  P.O. Box 12194
  Research Triangle Park, NC 27709-2194

- U.S. Environmental Protection Agency
  Air Pollution Prevention and Control Division (E343-02)
  109 T. W. Alexander Drive
  Research Triangle Park, NC 27711

Web sites: http://www.epa.gov/etv/verifications/verification-index.html (electronic copy)
http://www.epa.gov/ncepihom/

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Acronyms/Abbreviations

ºF	degrees Fahrenheit
ºC	degrees Celsius
APCTVC	Air Pollution Control Technology Verification Center
bhp	brake horsepower
bhp-hr	brake horsepower-hour
BSFC	brake specific fuel consumption
CFR	Code of Federal Regulations
cm	centimeter(s)
CO	carbon monoxide
CO_2	carbon dioxide
CWMF	catalyzed wire mesh filter
EPA	US Environmental Protection Agency
ETV	Environmental Technology Verification
FBC	fuel-borne catalyst
FTP	Federal Test Procedure
ft	foot (feet)
g	gram(s)
HC	hydrocarbon(s)
HD	heavy duty
HFID	heated flame ionization detector
in.	inch(es)
in. Hg	inch(es) mercury
kW	kilowatt(s)
kWh	kilowatt hour(s)
kPa	kilopascal(s)
L	liter(s)
Lpm	liters per minute
lb	pound(s)
lb-ft	pound foot (feet)
LSD	low-sulfur diesel
m	meter(s)
mm	millimeter(s)
N	newton(s)
N-m	newton-meter
NO	nitrogen oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxide
NDIR	nondispersive infrared
OTAQ	Office of Transportation and Air Quality
Pa	pascal(s)
PM	particulate matter
ppm	parts per million by volume
QA	quality assurance
QC	quality control
rpm	revolutions per minute
RTI	RTI International
SOF	soluble organic fraction of the particulate matter consumption
SOP	standard operating procedure
SwRI	Southwest Research Institute
ULSD	ultralow-sulfur diesel

Acknowledgments

The authors acknowledge the support of all of those who helped plan and conduct the verification activities. In particular, we would like to thank Michael Kosusko, EPA's Project Manager, and Paul Groff, EPA's Quality Assurance Manager, both of EPA's National Risk Management Research Laboratory in Research Triangle Park, NC. We would also like to acknowledge the assistance and participation of all the Clean Diesel Technologies, Inc. personnel who supported the test effort.

For more information on the Clean Diesel Technologies fuel-borne catalyst used with the PUREarth catalyzed wire mesh filter, contact:

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Section 1.0
Introduction

This report reviews the performance of the Clean Diesel Technologies platinum/cerium fuel-borne catalyst (FBC) used with Mitsui/PUREarth's catalyzed wire mesh filter (CWMF), Model ND3K2. Environmental Technology Verification (ETV) testing of this technology was conducted during a series of tests in December 2003 by Southwest Research Institute (SwRI) under contract with the Air Pollution Control Technology Verification Center (APCTVC). The objective of the APCTVC and the ETV Program is to verify, with high data quality, the performance of air pollution control technologies. Control of air emissions from diesel engines is within the scope of the APCTVC. An APCTVC program area was designed by RTI International (RTI) and a technical panel of experts to evaluate the performance of diesel exhaust catalysts, particulate filters, and engine modification control technologies for mobile diesel engines. Based on the activities of this technical panel, the *Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines*[1] was developed. This protocol was chosen as the best guide to verify the immediate performance effects of Clean Diesel Technologies' technology versus a protocol developed for fuel modifications. The verified technology incorporates both a catalyst added to the fuel and a device (the catalyzed wire mesh filter). The specific test/quality assurance plan addendum for the ETV test of the technology submitted by Clean Diesel Technologies, Inc. was developed and approved on November 20, 2003.[2] The goal of the test was to measure the emissions control performance of the technology system and its emissions reduction relative to an uncontrolled engine.

A description of the Clean Diesel Technologies, Inc. technology is presented in Section 2. Section 3 documents the procedures and methods used for the test and the conditions over which the test was conducted. The results of the test are summarized and discussed in Section 4, and references are presented in Section 5.

This report contains only summary information and data as well as the verification statement. Complete documentation of the test results is provided in a separate test report[3] and audit of data quality report.[4] These reports include the raw test data from product testing and supplemental testing, equipment calibration results, and quality assurance (QA) and quality control (QC) activities and results. Complete documentation of QA/QC activities and results, raw test data, and equipment calibration results are retained in Southwest Research Institute's files for seven years.

Section 2.0
Description of Products

The APCTVC conducted verification testing for Clean Diesel Technologies system described below (descriptions were provided by Clean Diesel Technologies). The system consisted of Clean Diesel Technologies platinum/cerium fuel borne catalyst (FBC) at 0.5 ppm (+/- 20%) Platinum and 7.5 ppm (+/- 20%) cerium (0.5 Pt/7.5 Ce ppm) in commercial ultra low sulfur diesel fuel (ULSD) (meeting the EPA specifications for 2007 at less than 15 ppm maximum sulfur content) with a lightly catalyzed wire mesh filter manufactured by Mitsui/PUREarth (model ND3K2). The wire mesh filter is a multi-segmented module of wire mesh filters inside a stainless steel can. Gas flow enters through and inlet cone and is distributed around the outer circumference of the filter module and through the wire mesh filter. Cleaned gas exits through a hollow central core and out an end cone. The wire mesh filter is pre-catalyzed and designed for use with the platinum/cerium FBC. The technology was provided directly to the APCTVC's test organization, Southwest Research Institute (SwRI), as:

- sufficient CDT's platinum/cerium fuel borne catalyst (FBC) to prepare about 200 gallons of ULSD ETV test fuel,
- one new CWMF (labeled CWMF-6) from Mitsui/PUREarth, and
- one aged CWMF (labeled CWMF-0) from Mitsui/PUREarth with documented aging history.

The new CWMF-6 device (model no. ND3K2) was degreened at SwRI for a total of 50 hours on Platinum Plus FBC treated ULSD over repetitive Federal Test Procedure (FTP) cycles on the Cummins 8.3 liter test engine. This included 25 hours of operation prior to the first set of emissions tests and 25 hours of operation prior to the second set of emissions tests used for verification.

The aged CWMF-0 device (model no. ND3K2) was operated in commercial service for 1,000 hours on a 1991 Cummins 8.3 liter equipped refuse truck as part of a California Air Resources Board (CARB) sponsored demonstration program with Waste Management in Long Beach, California. The aged CWMF-0 was first installed in the field on May 21, 2003 and was removed and shipped to SwRI on October 2, 2003. Fuel in the CARB field program was ECD-1 ULSD treated at 0.5 Pt/7.5 Ce ppm using an automatic FBC injection system mounted at the fuel dispensing pump. Both degreened and aged CWMFs were identical lightly catalyzed, six section, wire mesh filters manufactured by PUREarth, Inc. a wholly owned subsidiary of Mitsui & Co., Ltd., of Japan. The fuel borne catalyst was CDT's EPA-registered Platinum Plus FBC.

All verification testing was conducted on a 1990 Cummins 8.3 L diesel engine (certified to 1991 certification emission levels) fueled by conventional No. 2 diesel fuel for the baseline test and ULSD containing the FBC for the control system tests. Each CWMF was mounted 1.5 to 1.8 m (5 to 6 ft) from the outlet of the turbocharger. Figure 1 shows the aged CWMF mounted in the exhaust system in Test Cell 11.

Figure 1. Aged CWMF in Test Cell 11.

Section 3.0
Test Documentation

The ETV testing took place during December 2003 at Southwest Research Institute under contract to the APCTVC. Testing was performed in accordance with:

- *Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines*,[1]
- *Test/QA Plan for the Verification Testing of Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines*,[5] and
- *Test-Specific Addendum to ETV Mobile Source Test/QA Plan for Clean Diesel Technologies, Inc. 0.5Pt/7.5Ce Catalyst &* Mitsui/PUREarth catalyzed wire mesh filter.[2]

The applicant had reviewed the generic verification protocol and had an opportunity to review the test/QA plan prior to testing.

3.1 Engine Description

The ETV testing was performed on an in-line, six-cylinder, 8.3 L, 1990 model year, Cummins Engine Company, heavy-duty (HD) on-highway diesel engine. The engine was rated for 205 kW (275 bhp) at 2,000 rpm. It was turbocharged and used a laboratory water-to-air heat exchanger for a charge air intercooler. The engine was owned by SwRI and has been used in a number of test programs at SwRI.

Table 1 provides the engine identification details. Figure 2 shows the engine mounted in SwRI's test cell.

Table 1. Engine Identification Information

Engine serial number	44535723, CPL-1262
Date of manufacture	October 1990
Make	Cummins Engine Company, Inc.
Model year	1990 (certified to 1991 certification levels)
Model	C 8.3-275
Engine displacement and configuration	8.3 L, in-line 6
Service class	On-highway, heavy-duty (HD) diesel engine
EPA engine family identification	LCE0505FAC5
Rated power	205 kW (275 bhp) at 2,000 rpm
Rated torque	1100 N-m (800 lb-ft) at 1,300 rpm
Certified emission control system	Mechanical control
Aspiration	Turbocharged, air-to-air intercooled
Fuel system	Direct injection, mechanically controlled unit injectors

FIGURE 2. 1990 CUMMINS 8.3 L HEAVY-DUTY DIESEL ENGINE MOUNTED IN ENGINE TEST CELL 11

3.2 Engine Fuel Description

Two different diesel fuels were used during this verification test: a conventional No. 2 low-sulfur diesel (LSD) fuel with a sulfur level of 386 ppm and a No. 2 ULSD fuel treated with a FBC and having a sulfur level of 8.8 ppm. The LSD fuel meets EPA's current diesel fuel specifications given in 40 CFR § 86.1313-98, Table N98-2.[6] Selected fuel properties from SwRI's independent analyses are summarized for both fuels in Table 2. The ULSD that was FBC-treated is commercially available in California and met emissions equivalency to CARB ULSD. The ULSD deviated from the CFR diesel fuel specifications for the cetane number and index, the 10% boiling point, the API gravity, and the minimum level of aromatics.

3.3 Summary of Emissions Measurement Procedures

The ETV tests consisted of baseline uncontrolled tests and tests with the control system installed. The baseline engine was tested on conventional LSD fuel. The installed degreened and aged CWMFs were tested with the FBC-treated ULSD. The engine and CWMFs were conditioned using the FBC-treated ULSD before the official tests with one cold- and three hot-start transient cycles conducted in accordance with the test/QA plan.[5] The standard HD Transient Federal Test Procedure[7] (FTP) for exhaust emissions testing was performed. Individual exhaust gas and particulate matter (PM) samples were taken for each cycle.

Table 2. Selected Fuel Properties and Specifications

Item	Code of Federal Regulations (CFR) Specification[a]		Test Fuel	
	ASTM	Type-2D	LSD EM-4895-F	FBC-treated ULSD EM-4920-F
Cetane number	D613	40–50	47.3	53.6
Cetane index	D976	40–50	46.7	51.1
Distillation range:				
Initial boiling point, ºC (ºF)	D86	171–204 (340–400)	177 (350)	181 (357)
10% Point, ºC (ºF)	D86	204–238 (400–460)	207 (404)	194 (382)
50% Point, ºC (ºF)	D86	243–282 (470–540)	258 (496)	245 (473)
90% Point, ºC (ºF)	D86	293–332 (560–630)	302 (575)	303 (578)
End point, ºC (ºF)	D86	321–366 (610–690)	328 (622)	341 (645)
Gravity (American Petroleum Institute)	D287	32–37	35.9	38.0
Specific gravity		–	0.8453	0.8347
Total sulfur, ppm	D2622	(300–500)[b] (7-15)[c]	386	8.6
Hydrocarbon composition:				
Aromatics (minimum), %	D1319	27	30.6	23.6
Paraffins, naphthenes, and Olefins, %	D1319	[d]	68.8	75.3
Flash point (minimum), ºC (ºF)	D93	54 (130)	67 (153)	[e]
Viscosity, centistokes @ 40 ºC	D445	2.0–3.2	2.3	[e]

[a] Diesel fuel specification as in 40 CFR 86.1313-98(b)(2)[6] for the year 1998 and beyond and 40 CFR 86.1313-2007(b)(2)[8] for the year 2007 and beyond for heavy-duty diesel engines.
[b] 1998 sulfur range specification.
[c] 2007 sulfur range specification.
[d] Remainder of the hydrocarbons.
[e] Item was not measured

Emissions Test Procedures

Exhaust emissions were measured using HD Transient FTP[7] and the experimental setup shown in Figure 3. Dilute exhaust emissions measured during tests over the transient FTP operating conditions included total hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), nitric oxide (NO), and exhaust PM. The CO and CO_2 levels were determined using nondispersive infrared (NDIR) instruments. Total HC were measured using continuous sampling techniques employing a heated flame ionization detector (HFID). The NO_x and NO were measured continuously using two separate chemiluminescent analyzers, with NO_2 reported as the difference between NO_x and NO.

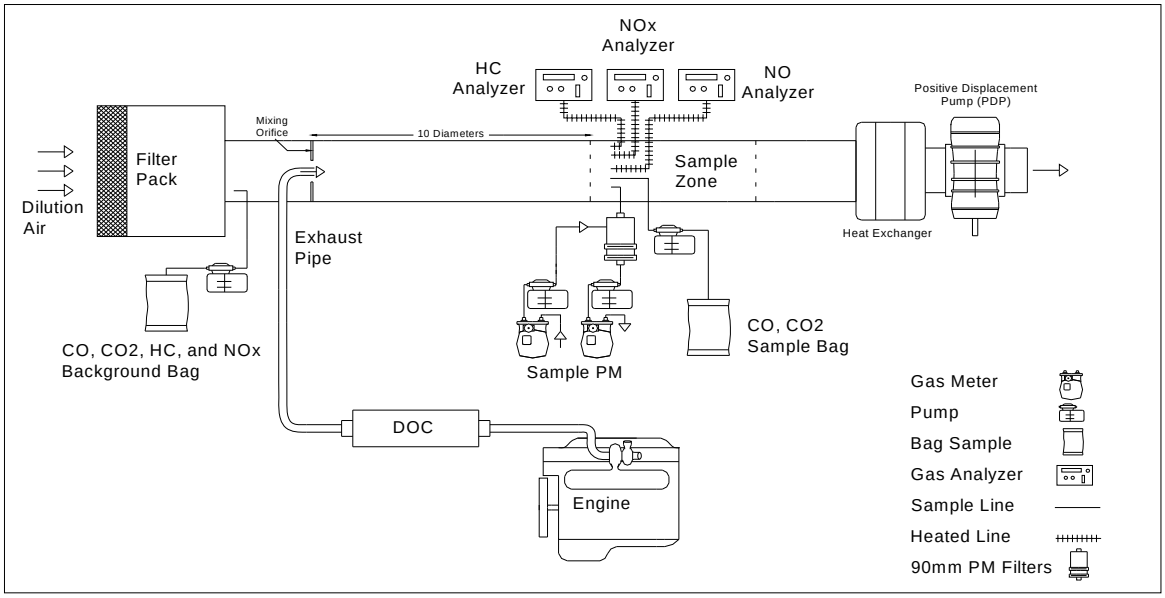


Figure 3. Constant volume sampler setup for emissions measurement.

The exhaust PM level for each test was determined using dilute sampling techniques that collected PM on a pair of 90-mm diameter Pallflex T60A20 filter media used in series. The particulate filter pair unit was weighed together both before and after each test to establish exhaust PM emissions for the test.

3.4 Deviations from the Test/QA Plan

The ETV testing was initially conducted from December 5 to 10, 2003. At the completion of those tests two problems were discovered. The reference map and the associated command cycle from the base fuel were not used throughout testing with the degreened and aged devices and the FTP statistical criteria for matching command cycle speed were not met during the cold-start transient tests with the ULSD and the degreened device. SwRI repeated the tests using the correct reference map and adjustments to achieve satisfactory statistical criteria over the test cycle. The repeat tests were conducted from December 19 to 29, 2003 and completed on December 29, 2003. The resulting data were used to calculate the verified performance presented in this report.

3.5 Documented Test Conditions

Engine Performance

Table 3 gives the observed engine power and peak torque at the manufacturer's listed speeds while validating the power output of the Cummins engine for the baseline and the controlled configurations. The engine performance was very similar for both configurations.

Table 3. Engine Performance Data

Fuel	Test Date	Test Number	Test Type	Rated Power[a] kW (bhp)[a]	Peak Torque[b] N-m (lb-ft)[b]
LSD	12/19/2003	BASE	Baseline	210 (282)	1150 (848)
FBC-treated ULSD	12/23/2003	CWMFNEW	Degreened device	210 (282)	1133 (836)
FBC-treated ULSD	12/29/2003	CWMFAGED	Aged device	210 (282)	1127 (831)

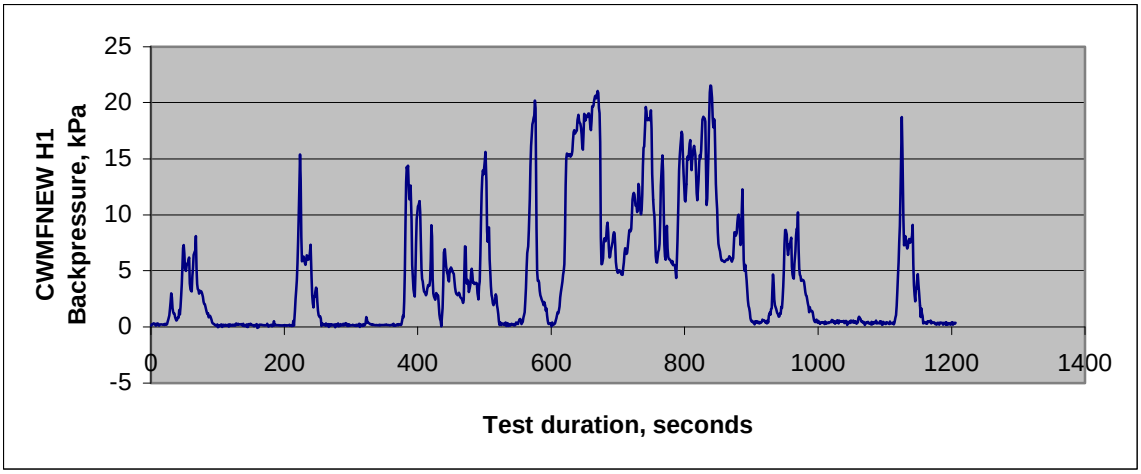
[a]Engine power at rated speed of 2,000 rpm.
[b]Engine peak torque at rated speed of 1,320 rpm.

Engine Exhaust Backpressure

The engine backpressure was set to 2.4 in. Hg (8.1 kPa) in accordance with the engine manufacturer specifications for the baseline configuration. For the controlled configurations, the engine manufacturer's specification could not be achieved, thus the exhaust restriction was minimized by fully opening the exhaust damper. The exhaust damper, part of the test system, is mounted within the engine exhaust pipe to simulate a backpressure on the engine. A backpressure of 7.5 in. Hg (25.3 kPa) was recorded at the engine rated conditions with the degreened CWMF and 6.7 in. Hg (22.6 kPa) was recorded with the aged CWMF. Table 4 shows the average backpressure for each controlled test and Figure 4 shows the backpressure measured during the first hot-start test for each device. The curves were nearly identical across tests within the device type.

Table 4. Test Average Backpressures

Test Number	Test Type	Test Date	Test Average Backpressure kPa (in. Hg)
Degreened CWMF with FBC-treated ULSD fuel			
CWMFNEW-C1	Cold-start	12/23/03	14.2 (4.2)
CWMFNEW-H1	Hot-start	12/23/03	15.2 (4.5)
CWMFNEW-H3	Hot-start	12/23/03	15.6 (4.6)
CWMFNEW-H4	Hot-start	12/23/03	15.9 (4.7)
Aged CWMF with FBC-treated ULSD fuel			
CWMFAGED-C1	Cold-start	12/29/03	11.5 (3.4)
CWMFAGED-H1	Hot-start	12/29/03	12.5 (3.7)
CWMFAGED-H2	Hot-start	12/29/03	12.5 (3.7)
CWMFAGED-H3	Hot-start	12/29/03	12.9 (3.8)



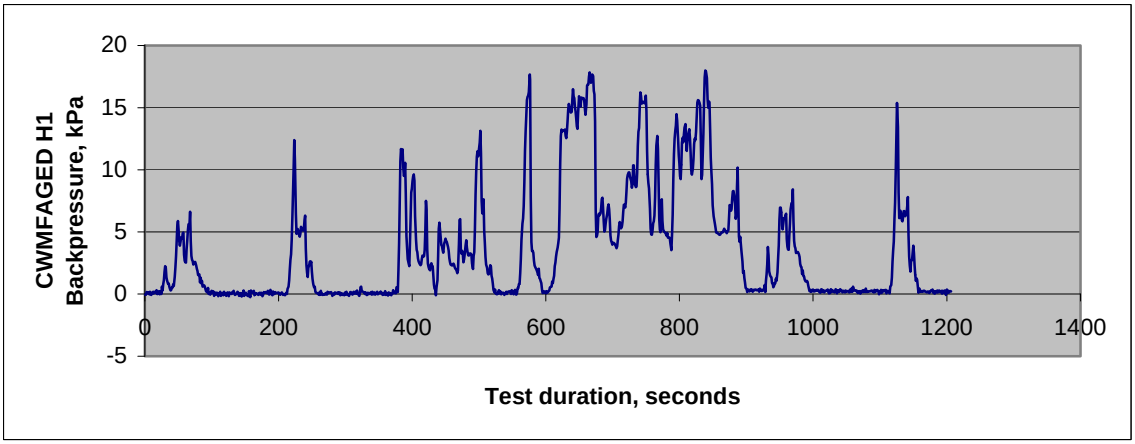


Figure 4. Engine backpressure during controlled tests.

Engine Exhaust Temperature

Temperature measurements were made in the exhaust system at the inlet and outlet of the CWMF for both the degreened and aged devices. The inlet temperature probe was located in the exhaust pipe about 15 cm (six in.) upstream of the inlet to the CWMF and the outlet temperature probe was located about 15 cm (six in.) downstream of the outlet. Inlet and outlet temperatures averaged over each test cycle are shown in Table 5.

Table 5. Average Engine Exhaust Temperature

Test Number	Test Type	Test Date	CWMF Inlet, ºC (ºF)	CWMF Outlet, ºC (ºF)
Degreened CWMF with FBC-treated ULSD fuel				
CWMFNEW-C1	Cold-start	12/23/03	113 (235)	101 (213)
CWMFNEW-H1	Hot-start	12/23/03	117 (243)	127 (260)
CWMFNEW-H3	Hot-start	12/23/03	116 (241)	126 (259)
CWMFNEW-H4	Hot-start	12/23/03	117 (242)	126 (259)
Aged CWMF with FBC-treated ULSD fuel				
CWMFAGED-C1	Cold-start	12/29/03	111 (231)	97 (207)
CWMFAGED-H1	Hot-start	12/29/03	115 (239)	121 (250)
CWMFAGED-H2	Hot-start	12/29/03	115 (239)	121 (250)
CWMFAGED-H3	Hot-start	12/29/03	115 (239)	121 (250)

Fuel Consumption

Table 6 presents the brake specific fuel consumption (BSFC) for all baseline and control configurations.

Table 6. Brake Specific Fuel Consumption

Test Number	Test Type	Test Date	BSFC, lb/bhp-hr	BSFC, kg/kWh	Weighted BSFC, lb/bhp-hr	Weighted BSFC, kg/kWh
Baseline with LSD fuel						
BASE-C1	Cold-start	12/19/03	0.398	0.241		
BASE-H1	Hot-start	12/19/03	0.386	0.234	0.388	0.235
BASE-H2	Hot-start	12/19/03	0.387	0.234	0.389	0.235
BASE-H3	Hot-start	12/19/03	0.385	0.233	0.387	0.234
Mean					0.388	0.235
Degreened CWMF with FBC-treated ULSD fuel						
CWMFNEW-C1	Cold-start	12/23/03	0.381	0.231		
CWMFNEW-H1	Hot-start	12/23/03	0.378	0.229	0.378	0.229
CWMFNEW-H3	Hot-start	12/23/03	0.384	0.232	0.384	0.232
CWMFNEW-H4	Hot-start	12/23/03	0.389	0.235	0.388	0.235
Mean					0.383	0.232
Aged CWMF with FBC-treated ULSD fuel						
CWMFAGED-C1	Cold-start	12/29/03	0.404	0.244		
CWMFAGED-H1	Hot-start	12/29/03	0.386	0.234	0.389	0.235
CWMFAGED-H2	Hot-start	12/29/03	0.384	0.232	0.387	0.234
CWMFAGED-H3	Hot-start	12/29/03	0.382	0.231	0.385	0.233
Mean					0.387	0.234

Section 4.0
Summary and Discussion of Emission Results

The baseline and controlled emissions data are summarized in Table 7. The emissions were measured at each test point for HC, CO, NO_x, and PM. Table 7 also provides data on soluble organic fraction (SOF) of the exhaust PM, speciation of the NO_x emissions, CO_2 emissions, and work. For each pollutant, hot-start test combination, the transient composite-weighted emissions per work (bhp-hr) were then calculated following the fractional calculation for highway engines as follows.

$$(E_{COMP})_m = \frac{1/7 \bullet E_{COLD} + 6/7 \bullet (E_{HOT})_m}{1/7 \bullet W_{COLD} + 6/7 \bullet (W_{HOT})_m} \quad (1)$$

where:

m = 1, 2, or 3 hot-start tests
E_{COMP} = composite emissions rate, g/kWh (g/bhp-hr)
E_{COLD} = cold-start mass emissions level, g
E_{HOT} = hot-start mass emissions level, g
W_{COLD} = cold-start brake horsepower-hour, kWh (bhp-hr)
W_{HOT} = hot-start brake horsepower-hour, kWh (bhp-hr)

These composite-weighted emissions rates are shown in Tables 8 and 9 and were used to calculate the mean and standard deviations for the baseline and controlled emissions rates. These data were in turn used to calculate mean emissions reductions and 95 percent confidence limits. These calculations are based on the generic verification protocol[1] and test/QA plan.[5]

Table 10 summarizes the composite weighted emission values and Table 11 the verified emissions reductions and their 95 percent confidence limits.

Table 7. Emissions Test Data

Test Number	Test Type	Test Date	Exhaust PM		NO_X	NO	NO_2[a]	NO_2/ NO_X, %	HC	CO	CO_2	Work, KWh (bhp-hr)
			g	% SOF[b]	g				g			
Baseline with LSD fuel												
BASE-C1	Cold-start	12/19/03	5.82	73	98.0	83.4	14.6	14.9	9.46	29.4	10.9	14.2 (19.1)
BASE-H1	Hot-start	12/19/03	3.52	57	97.6	83.7	13.9	14.2	7.13	23.5	10.7	14.4 (19.3)
BASE-H2	Hot-start	12/19/03	3.57	59	95.2	81.8	13.4	14.1	7.16	23.2	10.7	14.4 (19.3)
BASE-H3	Hot-start	12/19/03	3.58	59	97.0	81.9	15.1	15.6	7.16	23.6	10.6	14.4 (19.3)
Degreened CWMF with FBC-treated ULSD fuel												
CWMFNEW-C1	Cold-start	12/23/03	1.24	40	86.1	61.9	24.2	28.1	2.08	12.8	10.6	14.5 (19.4)
CWMFNEW-H1	Hot-start	12/23/03	0.877	24	88.6	59.0	29.6	33.4	0.623	5.03	10.6	14.5 (19.5)
CWMFNEW-H3	Hot-start	12/23/03	0.878	25	86.7	57.5	29.2	33.7	0.585	5.53	10.7	14.5 (19.5)
CWMFNEW-H4	Hot-start	12/23/03	0.859	25	87.7	58.6	29.1	33.1	0.364	5.48	10.9	14.5 (19.5)
Aged CWMF with FBC-treated ULSD fuel												
CWMFAGED-C1	Cold-start	12/29/03	1.37	28	90.7	62.6	28.1	30.9	2.08	16.4	11.1	14.2 (19.1)
CWMFAGED-H1	Hot-start	12/29/03	0.917	17	88.2	57.1	31.1	35.3	0.775	10.1	10.7	14.4 (19.3)
CWMFAGED-H2	Hot-start	12/29/03	0.851	18	88.7	56.1	32.6	36.8	0.699	9.22	10.6	14.3 (19.2)
CWMFAGED-H3	Hot-start	12/29/03	0.870	23	87.5	55.3	32.2	36.8	0.570	7.88	10.5	14.3(19.2)

[a] NO_2 calculated as NO_x - NO.

[b] SOF = soluble organic fraction.

Table 8. Composite Weighted Emissions Values (English units)

Test Number	Test Date	Exhaust PM	NO_X	NO	NO_2[a]	NO_2/NO_X, %		CO	CO_2
		g/bhp-hr					g/bhp-hr		
Baseline with LSD fuel									
BASE-H1	12/19/03	0.202	5.07	4.34	0.726	14.3	0.388	1.26	556
BASE-H2	12/19/03	0.202	4.97	4.26	0.706	14.3	0.389	1.25	558
BASE-H3	12/19/03	0.203	5.05	4.27	0.782	15.5	0.389	1.27	555
Degreened CWMF with FBC-treated ULSD fuelHC									
CWMFNEW-H1	12/23/03	0.0477	4.53	3.05	1.48	32.7	0.0426	0.315	543
CWMFNEW-H3	12/23/03	0.0477	4.45	2.99	1.46	32.9	0.0410	0.337	550
CWMFNEW-H4	12/23/03	0.0470	4.50	3.04	1.46	32.4	0.0313	0.336	556
Aged CWMF with FBC-treated ULSD fuel									
CWMFAGED-H1	12/29/03	0.0510	4.60	3.00	1.60	34.7	0.0500	0.570	557
CWMFAGED-H2	12/29/03	0.0482	4.64	2.97	1.67	35.9	0.0467	0.534	555
CWMFAGED-H3	12/29/03	0.0491	4.59	2.94	1.65	35.9	0.0410	0.475	553

[a] NO_2 calculated as NO_x - NO.

Table 9. Composite Weighted Emissions Values (metric units)

Test Number	Test Date	Exhaust PM	NO_X	NO	NO_2[a]	NO_2/NO_X, %	HC	CO	CO_2
		g/kWh					g/kWh		
Baseline with LSD fuel									
BASE-H1	12/19/03	0.271	6.80	5.82	0.973	14.3	0.520	1.69	745
BASE-H2	12/19/03	0.271	6.66	5.71	0.946	14.3	0.521	1.68	748
BASE-H3	12/19/03	0.272	6.77	5.72	1.05	15.5	0.521	1.70	744
Degreened CWMF with FBC-treated ULSD fuel									
CWMFNEW-H1	12/23/03	0.0639	6.07	4.09	1.98	32.7	0.0571	0.422	728
CWMFNEW-H3	12/23/03	0.0639	5.97	4.01	1.96	32.9	0.0550	0.452	737
CWMFNEW-H4	12/23/03	0.0630	6.03	4.08	1.96	32.4	0.0420	0.450	745
Aged CWMF with FBC-treated ULSD fuel									
CWMFAGED-H1	12/29/03	0.0684	6.17	4.02	2.14	34.7	0.0670	0.764	747
CWMFAGED-H2	12/29/03	0.0646	6.22	3.98	2.24	35.9	0.0626	0.716	744
CWMFAGED-H3	12/29/03	0.0658	6.15	3.94	2.21	35.9	0.0550	0.637	741

[a] NO_2 calculated as NO_x - NO.

Table 10. Summary of Verification Test Emission Values

Device type	Fuel	Mean Composite Weighted Emission Value, g/kWh (g/bhp-hr)				
		PM	NOx	HC	CO	CO2
Baseline	LSD	0.269 (0.201)	6.74 (5.03)	0.521 (0.389)	1.69 (1.26)	745 (556)
Degreened	FBC-treated ULSD	0.0637 (0.0475)	6.02 (4.49)	0.0513 (0.0383)	0.441 (0.329)	737 (550)
Aged	FBC-treated ULSD	0.0662 (0.0494)	6.18 (4.61)	0.615 (0.0459)	0.705 (0.526)	744 (555)

Table 11. Summary of Verification Test Emission Reductions

Device type	Fuel		Mean Emissions Reduction (%)				95% Confidence Limits on the Emissions Reduction (%)			
	Baseline	Controlled	PM[a]	NOx	HC	CO	PM[a]	NOx	HC	CO
Degreened	LSD	FBC-treated ULSD	76	11	90	74	75-78	8.3-13	90-91	72-76
Aged	LSD	FBC-treated ULSD	76	8.4	88	58	74-77	5.4-11	88-89	54-63

[a] The verified PM emissions reduction combines reductions related to the control technology and the change in fuel sulfur level.

4.1 Quality Assurance

The environmental technology verification of the CWMF with FBC-treated ULSD fuel for heavy-duty diesel engines was performed in accordance with the test/QA plan.[5] An audit of data quality included the review of equipment, personnel qualifications, procedures, record keeping, data validation, analysis, and reporting. Preliminary, in-process, and final inspections, and a review of 10 percent of the data showed that the requirements stipulated in the test/QA plan[5] were achieved. The EPA Quality Manager reviewed the test results and the quality control data and concluded that the data quality objectives given in the generic verification protocol were attained. EPA and RTI quality assurance staff conducted audits of SwRI's technical and quality systems in April 2002 and found no deficiencies that would adversely impact the quality of results. The equipment was appropriate for the verification testing, and it was operating satisfactorily. SwRI's technical staff were well qualified to perform the testing and conducted themselves in a professional manner.

Section 5.0
References

1. RTI International. Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines. Research Triangle Park, NC, January 2002, http://www.epa.gov/etv/pdfs/vp/05_vp_devrev.pdf.

2. RTI International. Test-Specific Addendum to ETV Mobile Source Test/QA Plan for Clean Diesel Technologies, Inc. platinum/cerium fuel-borne catalyst & Mitsui/PUREarth catalyzed wire mesh filter. Research Triangle Park, NC, November 2003.

3. Southwest Research Institute. Environmental Technology Verification of Clean Diesel Technology Inc. Fuel-borne Catalyst with Mitsui/PUREarth catalyzed wire mesh filter for Use with Heavy-Duty Diesel Engines. San Antonio, TX, March 2004.

4. Southwest Research Institute. Audit of Data Quality for Environmental Technology Verification of Clean Diesel Technology Inc. Fuel-borne Catalyst with Mitsui/PUREarth catalyzed wire mesh filter for Use with Heavy-Duty Diesel Engines. San Antonio, TX, March 2004.

5. RTI International. Test/QA Plan for the Verification Testing of Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines. Research Triangle Park, NC, April 2002, http://www.epa.gov/etv/pdfs/vp/05_tp_diesel.pdf.

6. Fuel specifications, 40 CFR § 86.1313-98, Table N98-2 (updated July 2001).

7. 40 CFR § 86, Subpart N, as of July 1, 1999, http://www.epa.gov/epahome/cfr40.htm.

8. Fuel specifications, 40 CFR § 86.1313-2007, Table N07-2 (updated January 2001).