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August 2005

Environmental Technology Verification Report

New Condensator, Inc. - The Condensator Diesel Engine Retrofit Crankcase Ventilation System

Prepared by:

Greenhouse Gas Technology Center
Southern Research Institute

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

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

SOUTHERN RESEARCH INSTITUTE

ETV Joint Verification Statement

TECHNOLOGY TYPE:	Diesel Engine Retrofit Crankcase Ventilation System
APPLICATION:	Heavy Duty Diesel Engine
TECHNOLOGY NAME:	The Condensator
COMPANY:	New Condensator, 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 purchase, design, distribution, financing, permitting, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups that consist of buyers, vendor organizations, and permitters, and with the full participation of individual technology developers. The program evaluates the performance of technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests, 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 Greenhouse Gas Technology Center (GHG Center), one of six verification organizations under the ETV program, is operated by Southern Research Institute in cooperation with EPA's National Risk Management Research Laboratory. One sector of significant interest to GHG Center stakeholders is transportation - particularly technologies that result in fuel economy improvements and emission reductions. The GHG Center recently evaluated the performance of a technology that is planned for use as a retrofit device for existing light and heavy duty diesel engines. Many on and off-road heavy duty diesel engines have an open crankcase and blow-by tube, especially on older vehicles. On these engines, crankcase blow-by is emitted directly to the atmosphere through the blow-by tube, resulting in emissions of particulate matter (PM), carbon monoxide (CO), hydrocarbons (THC), and other pollutants. The Condensator technology, offered by New Condensator, Inc. of Grass Valley, California (NCI), is applicable to diesel engines that have open crankcase ventilation systems. NCI's Condensator is designed to capture and filter these emissions. This verification statement provides the results of the Condensator performance verification.

TECHNOLOGY DESCRIPTION

The following technology description is based on information provided by NCI and does not represent verified information. This technology is applicable to light- to heavy-duty vehicles, both on- and off-road, and is also available for marine and generator applications. The Condensator is designed to collect and filter the blow-by exhaust from the crankcase and re-route exhaust vapors back to the engine air intake. This removes particulate from the blow-by exhaust and creates a closed crankcase system. NCI claims that enhanced fuel economy, reduced opacity, reduced emissions, and containment of the blow-by gases are the benefits of using this technology. A Model 2DX Condensator was used for this verification.

The Model 2DX Condensator consists of a blow-by manifold, two Condensator containers, and associated tubing to route filtered exhaust gases back to the engine intake. The two Condensator containers are arranged in parallel and hold the collected waste/sludge. Each contains a silica bead separator system that filters the crankcase exhaust. Rubber hoses are used to connect the Condensator containers to the air intake and blow-by tube. Hose clamps keep the hoses in place. NCI requires the Condensator unit to be installed away from extreme heat such as exhaust manifolds.

According to NCI, crankcase exhaust comes in contact with silica bead separators in the Condensator, resulting in a molecular separation process where large, heavier oil molecules condense and collect in the Condensator containers. Water and acid present with the oil will also drop into the containers. Gaseous emissions, including hydrocarbons, continue through the system and are vented back into the engine air intake. Waste oil and condensate collected in the Condensator containers should be emptied during vehicle oil changes. The separators are cleaned periodically in a solvent to dislodge and remove any carbon or sludge that may have attached to the silica beads.

VERIFICATION DESCRIPTION

The verification testing was conducted in January 2005 to evaluate the performance on the Condensator technology on a 1997 Cummins N-14 370 HP turbocharged diesel engine. Verification tests were conducted at Southwest Research Institute's (SwRI) Department of Engine and Emissions Research (DEER) in San Antonio, TX. The testing was planned and executed by the GHG Center to independently verify the change in fuel economy and engine emissions resulting from the use of the Condensator.

The primary verification parameters were changes in fuel economy expressed as brake specific fuel consumption (BSFC) and engine PM emissions. Determination of emissions of NO_X, CO, CO_2, THC, and methane (CH_4), were also conducted as secondary verification parameters. Improvement in engine performance for the primary parameters is expressed as the mean change, or delta (Δ), between results from tests conducted on the engine without the Condensator (baseline tests) and with the Condensator installed (modified engine tests). Modified engine tests include initial testing immediately after installation of the Condensator and cumulative testing after operating the engine with the Condensator installed over a 45-hour durability cycle break-in period. The verification's data quality objective (DQO) for these parameters was to demonstrate a statistically significant delta of 10 percent or greater. A detailed discussion of the data analysis and statistical procedures can be found in the test plan.

The testing was conducted following the approach and procedures specified in the test plan and the ETV *Generic Verification Protocol (GVP) for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines*. The GVP makes use of the Federal Test Procedure (FTP) as listed in 40 CFR Part 86 for highway engines as a standard test protocol. Specific details regarding the FTP, measurement equipment, and statistical analysis of results can be found in the test plan titled *Test and Quality Assurance Plan for the New Condensator, Inc. – The Condensator Diesel Engine Retrofit Crankcase Ventilation System* (SRI/USEPA-GHG-QAP-36) and the GVP.

Quality Assurance (QA) oversight of the verification testing was provided following specifications in the ETV Quality Management Plan (QMP). The GHG Center's QA manager conducted an audit of data quality on at least 10 percent of the data generated during this verification and a review of the report. Data review and validation was conducted at three levels including the field team leader (for data generated by subcontractors), the project manager, and the QA manager. Through these activities, the QA manager has concluded that the data meet the data quality objectives that are specified in the Test and Quality Assurance Plan. Both documents can be downloaded from the ETV Program web-site (www.epa.gov/etv).

The verification evaluated baseline engine performance without the Condensator, immediate effect on performance after installation of the Condensator, and cumulative engine performance after operating the engine with the Condensator for a period of 45 hours. The general sequence of test events was as follows:

1. Install and inspect the test engine;
2. Change the engine oil and filter and conduct 25-hour break-in run;
3. Map the baseline engine (develop torque curve);
4. Precondition and soak the baseline engine;
5. Perform baseline engine testing for exhaust emissions, blow-by emission, and fuel consumption;
6. Install the Condensator system;
7. Map the modified engine;
8. Precondition and soak the modified engine;
9. Perform modified engine testing for exhaust emissions and fuel consumption;
10. Perform 45 hour modified engine durability break-in period;
11. Repeat the modified engine testing for exhaust emissions and fuel consumption;
12. Evaluate the test data for data quality; and
13. Complete additional testing as necessary to achieve data quality objectives.

The test runs consisted of operating the test engine over the specified FTP test cycle for one cold-start test, and a minimum of three hot-start tests for both the baseline and modified engine. During each test run, BSFC was evaluated over the FTP transient cycles along with engine emissions of NO_x, PM, THC, CO, CO_2, and CH_4. BSFC is the ratio of the engine fuel consumption to the engine power output expressed in units of pounds mass of fuel per brake horsepower-hour (lb/Bhp-hr). PM samples collected from the blow-by tube during the baseline engine testing were also analyzed for soluble organic fraction (SOF) after the gravimetric particulate determination.

VERIFICATION OF PERFORMANCE

The Condensator system was installed by a Cummins technician without problems, and installation was approved by NCI representatives. The presence of the Condensator did introduce an impact on the engine's crankcase pressure. By routing the crankcase blow-by vent to the engine air intake, the Condensator changed the crankcase pressure from ambient to a vacuum in the range of 8 to 20 inches of water (depending on engine speed and torque). After consulting with the Cummins technician, testing was continued because the engine was operating normally and power output was approximately the same as before installation of the Condensator. No other impacts on engine performance were observed, the open crankcase was closed, and the blow by emissions (essentially all unburned organic material) were successfully routed back into the engine.

Results of the BSFC and PM emissions testing are summarized in Tables S-1 and S-2. Table S-3 summarizes results for the secondary emissions parameters.

Table S-1. BSFC Results

Parameter	Baseline Tests	Initial Condensator Tests	Cumulative Condensator Tests
Mean BSFC (lb/Bhp-hr)	**0.390**	**0.392**	**0.3857**
Standard deviation (lb/Bhp-hr)	0.003	0.004	0.0014
BSFC delta (lb/Bhp-hr)	--	0.002	-0.003
BSFC delta (%)	--	0.4	-0.8
Statistically significant change?	--	No	No

- Installation of the Condensator did not result in statistically significant changes in the test engine's BSFC.

Table S-2. PM Emissions and Statistical Analysis

Parameter	Baseline Tests	Initial Condensator Tests	Cumulative Condensator Tests
Mean PM emissions (g/Bhp-hr)	**0.1133**	**0.1021**	**0.109**
Standard deviation (g/Bhp-hr)	0.0010	0.0009	0.003
PM delta (g/Bhp-hr)	--	-0.011	-0.005
PM delta (%)	--	-9.8	-4.0
Statistically significant change?	--	Yes	No

- By eliminating the crankcase blow-by emissions point, total engine PM emissions were immediately reduced by 9.84 percent, ± 1.8 percent statistical uncertainty, after installation of the Condensator. PM emissions dropped from 0.113 to 0.102 g/Bhp-hr. After the 45 hour break-in period, total engine PM emissions increased slightly to 0.109 g/Bhp-hr, resulting in a reduction from the baseline emission level of 4.04 percent. This change was not statistically significant according to the analysis used here.

- The SOF analyses conducted on the PM samples collection from the blow-by tube indicated that essentially all of the PM collected was soluble organic material (SOF was 100 percent).

Table S-3. Mean Composite Engine Emission Rates

Parameter	Mean Composite Baseline Emissions (g/Bhp-hr)	Mean Composite Initial Condensator Emissions (g/Bhp-hr)	% Decrease (Increase)	Mean Composite Cumulative Condensator Emissions (g/Bhp-hr)	% Decrease (Increase)
NO_X	4.59	4.62	(0.6)	4.51	1.8
CO	0.746	0.721	0	0.708	5
CO_2	561	563	(0.4)	556	0.9
THC	0.203	0.206	(1)	0.226	(11)

- Statistical analyses were not specified for the secondary verification parameters. The data indicate that NO_X and CO_2 emissions were essentially unchanged after installation of the Condensator and CO emissions were reduced by approximately 5 percent after break-in. Emissions of THC were extremely low during all test periods (generally less than 9 parts per million). Emissions of CH_4 were not detected and are considered negligible.

Detailed results of the verification are presented in the final report titled *Environmental Technology Verification Report for New Condensator, Inc. – The Condensator Diesel Engine Retrofit Crankcase Ventilation System* (SRI 2005). Copies of the report or this verification statement can be downloaded from the GHG Center's web-site (www.sri-rtp.com) or the ETV Program web-site (www.epa.gov/etv).

Signed by Sally Gutierrez (8/26/2005)

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Greenhouse Gas Technology Center

A U.S. EPA Sponsored Environmental Technology Verification (ETV) Organization

Environmental Technology Verification Report

New Condensator, Inc. - The Condensator Diesel Engine Retrofit Crankcase Ventilation System

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LIST OF ACRONYMS AND ABBREVIATIONS

ADQ	audit of data quality
ASTM	American Society for Testing and Materials
BSFC	brake specific fuel consumption
CFR	Code of Federal Regulations
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
COV	coefficient of variation
CVS	constant volume sampling
DEER	Department of Engine and Emissions Research
DQI	data quality indicator
DQO	data quality objective
EPA-ORD	Environmental Protection Agency Office of Research and Development
ETV	Environmental Technology Verification
FS	full scale
FTP	Federal Test Procedure
g/Bhp-hr	grams per brake horsepower-hour
GHG	greenhouse gas
GVP	Generic Verification Protocol
hp	horsepower
lb/Bhp-hr	pounds per brake horsepower-hour
NCI	New Condensator, Inc.
NIST	National Institute of Standards and Technology
NO_X	blend of NO, NO_2, and other oxides of nitrogen
PM	particulate matter
ppm	parts per million
QA	quality assurance
QA/QC	quality assurance / quality control
QMP	Quality Management Plan
SAO	smooth approach orifice
SOF	soluble organic fraction
SOP	standard operating procedure
SwRI	Southwest Research Institute
THC	total hydrocarbons (as carbon)

1.0 INTRODUCTION

1.1. BACKGROUND

The U.S. Environmental Protection Agency's Office of Research and Development (EPA-ORD) operates the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative technologies. The program's goal is to further environmental protection by accelerating the acceptance and use of these technologies. Primary ETV activities are independent performance verification and information dissemination. Congress funds ETV in response to the belief that many viable environmental technologies exist that are not being used for the lack of credible third-party performance data. With performance data developed under this program, technology buyers, financiers, and permitters will be better equipped to make informed decisions regarding new technology purchases and use.

The Greenhouse Gas Technology Center (GHG Center) is one of several ETV organizations. EPA's ETV partner, Southern Research Institute (Southern), manages the GHG Center. The GHG Center conducts independent verification of promising GHG mitigation and monitoring technologies. It develops verification Test and Quality Assurance Plans (test plans), conducts field tests, collects and interprets field and other data, obtains independent peer-review input, reports findings, and publicizes verifications through numerous outreach efforts. The GHG Center conducts verifications according to the externally reviewed test plans and recognized quality assurance / quality control (QA/QC) protocols.

Volunteer stakeholder groups guide the GHG Center's ETV activities. These stakeholders advise on appropriate technologies for testing, help disseminate results, and review test plans and reports. National and international environmental policy, technology, and regulatory experts participate in the GHG Center's Executive Stakeholder Group. The group includes industry trade organizations, environmental technology finance groups, governmental organizations, and other interested parties. Industry-specific stakeholders provide testing strategy guidance within their expertise and peer-review key documents prepared by the GHG Center.

One sector of significant interest to GHG Center stakeholders is transportation – particularly technologies that result in fuel economy improvements. The Department of Energy reports that in 2001, "other trucks" (all trucks other than light-duty trucks) consuming diesel fuel emitted approximately 72.5 million metric tons of carbon dioxide (CO_2). These emissions increase to 107.5 million metric tons when considering all diesel vehicles in the transportation sector. Small fuel efficiency or emission rate improvements are expected to have a significantly beneficial impact on nationwide greenhouse gas emissions.

New Condensator, Inc. (NCI) of Grass Valley, California owns the rights to a technology that is planned for use as a retrofit device for existing light and heavy duty diesel engines. The Condensator technology is applicable to diesel engines that have open crankcase ventilation systems. The Condensator is designed to collect and filter the blow-by exhaust from the crankcase and re-route exhaust vapors back to the engine air intake, essentially converting the engine to a closed crankcase system. NCI claims that enhanced fuel economy, reduced opacity, and 100% containment of the blow-by gases are the benefits of using this technology.

The verification testing was conducted in January 2005 to evaluate the performance on the Condensator technology on a 1997 Cummins N-14 370 HP turbocharged diesel engine. Verification tests were conducted at Southwest Research Institute's (SwRI) Department of Engine and Emissions Research (DEER) in San Antonio, TX. The testing was planned and executed by the GHG Center to independently verify the change in fuel economy and engine emissions resulting from the use of the Condensator. This report presents the results of these verification tests.

Details on the verification test design, measurement test procedures, and QA/QC procedures can be found in the test plan titled *Test and Quality Assurance Plan for the New Condensator, Inc. – The Condensator Diesel Engine Retrofit Crankcase Ventilation System* (SRI/USEPA-GHG-QAP-36) [1]. The test plan can be downloaded from the GHG Center's Web site (www.sri-rtp.com) or the ETV Program web site (www.epa.gov/etv). The test plan was based largely on the approach and procedures specified in the ETV *Generic Verification Protocol (GVP) for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines* [2], which can also be downloaded from the ETV Program web site cited above.

The test plan describes the rationale for the experimental design, the testing and instrument calibration procedures planned for use, and specific QA/QC goals and procedures. The test plan was reviewed and revised based on comments received from NCI, SwRI, and the EPA Quality Assurance Team. The test plan meets the requirements of the GHG Center's Quality Management Plan (QMP) and satisfies the ETV QMP requirements. Deviations from the test plan were sometimes required. The rationale for these deviations and their descriptions are discussed in this report.

The remainder of Section 1.0 describes the Condensator technology, the SwRI test facility, and the performance verification procedures that were followed. Section 2.0 presents test results and Section 3.0 assesses the quality of the data obtained.

1.2. THE CONDENSATOR CRANKCASE VENTILATION SYSTEM

The following technology description is based on information provided by NCI and does not represent verified information. Many on and off-road heavy duty diesel engines have an open crankcase and blow-by tube, especially on older vehicles. On these engines, crankcase blow-by is emitted directly to the atmosphere through the blow-by tube, resulting in emissions of particulate matter (PM), carbon monoxide (CO), hydrocarbons (THC), and other pollutants. NCI's Condensator is designed to capture and filter these emissions. This technology is applicable to light- to heavy-duty vehicles, both on- and off-road, and is also available for marine and generator applications. The Condensator is designed to collect and filter the blow-by exhaust from the crankcase and re-route exhaust vapors back to the engine air intake. This removes particulate from the blow-by exhaust and creates a closed crankcase system. NCI claims that enhanced fuel economy, reduced opacity, reduced emissions, and containment of the blow-by gases are the benefits of using this technology. A Model 2DX Condensator was used for this verification.

The Model 2DX Condensator consists of a blow-by manifold, two Condensator containers, and associated tubing to route filtered exhaust gases back to the engine intake. The two Condensator containers are arranged in parallel and hold the collected waste/sludge. Each contains a silica bead separator system that filters the crankcase exhaust. Rubber hoses are used to connect the Condensator containers to the air intake and blow-by tube. Hose clamps keep the hoses in place. NCI requires the Condensator unit to be installed away from extreme heat such as exhaust manifolds. Figure 1-1 shows the Condensator installed on the test engine used during this verification.

Figure 1-1. NCI Condensator on the Cummins N-14 Test Engine

According to NCI, crankcase exhaust comes in contact with silica bead separators in the Condensator, resulting in a molecular separation process where large, heavier oil molecules condense and collect in the Condensator containers. Water and acid present with the oil will also drop into the containers. Gaseous emissions, including hydrocarbons, continue through the system and are vented back into the engine air intake. Waste oil and condensate collected in the Condensator containers should be emptied during vehicle oil changes. This is done by unscrewing the container from the head and properly disposing of the waste. The separators are cleaned periodically in a solvent to dislodge and remove any carbon or sludge that may have attached to the silica beads. NCI states that this technology can provide the following benefits:

- Increase fuel efficiency in open crankcase diesel engines;
- Lower emissions in diesel engines, especially PM, CO, and hydrocarbons;
- Save operating costs with lower fuel costs and increased vehicle mileage; and
- Be applicable to any diesel engines with open crankcase including light and heavy duty, on and off road, and marine engines.

1.3. PERFORMANCE VERIFICATION OVERVIEW

1.3.1. Introduction and Verification Parameters

The primary verification parameters were changes in fuel economy expressed as brake specific fuel consumption (BSFC) and engine PM emissions. Determination of emissions of NO_X, CO, CO_2, THC, and methane (CH_4), were also conducted as secondary verification parameters. Improvement in engine performance for the primary parameters is expressed as the mean change, or delta (Δ), between results from tests conducted on the engine without the Condensator (baseline tests) and with the Condensator installed (modified engine tests). Modified engine tests include initial testing immediately after installation of the Condensator and cumulative testing after operating the engine with the Condensator installed over a 45-hour durability cycle break-in period. The verification's data quality objective (DQO) for these parameters was to demonstrate a statistically significant delta of 10 percent or greater. This section provides a brief description of the verification testing approach and procedures. A detailed discussion of the data analysis and statistical procedures can be found in the test plan.

The GVP makes use of the Federal Test Procedure (FTP) as listed in the Code of Federal Regulations, Title 40, Part 86 (40 CFR 86) [3] for highway engines as a standard test protocol. This section provides a brief description of the verification test program. Specific details regarding the FTP, measurement equipment, and statistical analysis of results can be found in the test plan and GVP. The test plan also contains the DQOs and QA/QC procedures.

1.3.2. Verification Test Facilities

The testing was conducted in SwRI's heavy-duty diesel engine dynamometer cell 8. The dynamometer is equipped with a constant volume sampling system, an array of emissions analyzers, a fuel supply cart, and ambient monitoring and control equipment. The testing and measurement equipment is described in section 1.4.3.

The diesel engine used in the test program was a Cummins N-14 370-HP turbocharged engine manufactured in 1996 (Figure 1-2). This engine was selected for testing because it represents a large segment of heavy-duty diesel engines currently on the road for which the Condensator technology is intended. Prior to the start of testing (January 21, 2005), a Cummins technician inspected the engine in the test cell and verified that the engine was without mechanical problems and operating within its acceptable range of specifications.

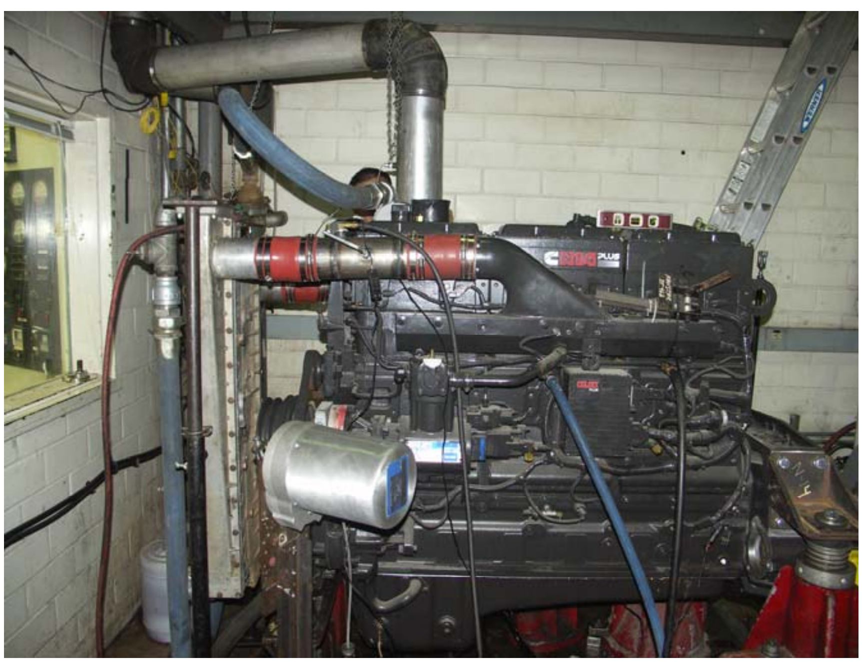

Figure 1-2. The Cummins N-14 Test Engine in the Dynamometer Test Cell

All testing was conducted using standard diesel test fuel (as specified in 40 CFR 86.1313-98) with a certified sulfur content of 347 ppm. The GHG Center reviewed the fuel analyses (dated December 20, 2004) and verified that the fuel was within specifications.

The engine dynamometer simulates operating conditions of the engine by applying loads to the engine and measuring the amount of power that the engine can produce against the load. The engine is operated on the dynamometer over a simulated duty cycle that mimics a typical on-road heavy-duty vehicle. This is the "transient" cycle heavy-duty FTP specified in 40 CFR 86.1333. Exhaust emissions from the engine are collected through a constant volume sampling (CVS) system and then analyzed to determine emission concentrations. A constant speed blower in the CVS dilutes the exhaust with ambient air while the engine operates on the dynamometer. This dilution prevents the exhaust moisture from condensing and provides controllable sampling conditions. A sample pump and a control system transfers diluted exhaust to emission analyzers, sample bags, and the particulate filters. Samples are collected at constant sampling rates.

Crankcase blow-by PM emissions were also quantified during the baseline testing. The blow-by emissions tests were conducted following procedures developed by SwRI specifically designed to measure PM emissions from an open crankcase blow-by tube (SOP 07-043). Total baseline engine PM emissions were quantified as the sum of the PM emissions measured from the engine exhaust and the blow-by tube.

1.3.3. Testing and Measurement Equipment

The equipment used in determining the fuel economy and emissions of the test engine was specified in the test plan and conducted in accordance with 40 CFR 86. The following subsections provide details regarding specific equipment used during testing.

1.3.3.1. Constant Volume Sampling System

A Horiba Variable-Flow constant volume sampling (CVS) system was used to sample exhaust emissions. The engine exhaust pipe is connected to the CVS inlet. A constant speed blower pulls ambient air into the CVS while the engine operates on the dynamometer. The air is used to dilute the exhaust stream to prevent the exhaust moisture from condensing and to provide controllable sampling conditions to the analyzers (specifically, sample flow rate). A sample pump and control system transfer diluted exhaust to several different Tedlar bags during specific phases of each FTP and Highway Fuel Economy Test run. A regulating needle valve maintains a constant sample flow rate into the bags.

The balance of the dilute exhaust passes through a Horiba smooth-approach orifice (SAO) which measures the flow rate. The bag sampling rate must remain proportional to the total dilute exhaust volume flow rate throughout each test run to ensure that the sample represents the entire volume. SAO throat pressure and temperature measurements using calibrated pressure and temperature transducers, correlated with the SAO's National Institute of Standards and Technology (NIST) traceable calibration, allow accurate dilute exhaust volume determinations. This determination generates a feedback signal that adjusts the turbine blower speed. The continuous adjustment allows the blower to maintain constant volumetric flow through the CVS system. The CVS both measures the dilute exhaust volumetric flow and controls the sample dilution ratio to within ± 0.5 percent.

1.3.3.2. Exhaust Gas Analyzers

Technicians used a Horiba analytical bench equipped with instrumental analyzers to determine carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbons (THC), methane (CH_4) and nitrogen oxides (NO_X) concentrations in the dilute exhaust. Each analyzer is accurate to ± 2 percent. Sample pumps transfer the dilute exhaust from the sample bags to each analyzer as commanded by the control system.

The Horiba triple analytical bench consists of feedgas, tailpipe and bag analytical benches, a sample-conditioning unit, and various automated flow controls. The Horiba instrumental emission analyzers used to analyze exhaust emissions using the CVS bag cart are:

- AIA-210 Infrared Low-Low CO Analyzer (LLCO)
- AIA-220 Infrared CO_2 and Low CO Analyzer (CO_2/LCO)
- FIA-220 Flame Ionization Total Hydrocarbons (THC) Analyzer
- CLA-220 Chemiluminescent NO/NO_x Analyzer
- GC-FIA Gas Chromatographic/Flame Ionization Methane Analyzer

Sampling, analysis, dynamometer monitoring, and other equipment or processes, including bag leak checks, calibrations, and analyzer zero/span checks are all controlled by a Horiba VETS-9200 computerized emissions testing control system. The VETS-9200 collects data from the test equipment, calculates and reports test results, and facilitates system calibrations and quality control checks. The VETS also records raw sensor outputs, applies the appropriate engineering conversion and averaging algorithms, and flags data which are outside the permitted values.

1.3.4. Test Procedure and Sequence

The test procedures and details regarding each phase of the test are described in the test plan. The general sequence of test events was as follows:

1. Install and inspect the test engine;
2. Change the engine oil and filter and conduct 25-hour break-in run;
3. Map the baseline engine (develop torque curve);
4. Precondition and soak the baseline engine;
5. Perform baseline engine testing for exhaust emissions, blow-by emission, and fuel consumption;
6. Install the Condensator system;
7. Map the modified engine;
8. Precondition and soak the modified engine;
9. Perform modified engine testing for exhaust emissions and fuel consumption;
10. Perform 45 hour modified engine durability break-in period;
11. Repeat the modified engine testing for exhaust emissions and fuel consumption;
12. Evaluate the test data for data quality; and
13. Complete additional testing as necessary to achieve data quality objectives.

The test runs consisted of operating the test engine over the specified FTP test cycle for one cold-start test, and a minimum of three hot-start tests for both the baseline and modified engine. During each test run, BSFC was evaluated over the FTP transient cycles along with engine emissions of NO_x, PM, THC, CO, CO_2, and CH_4. BSFC is the ratio of the engine fuel consumption to the engine power output expressed in units of pounds mass of fuel per brake horsepower-hour (lb/Bhp-hr). The calculation of BSFC is shown at 40 CFR 86.1342-90. The equation and supporting parameters are:

$$BSFC = \frac{\frac{1}{7}(M_c) + \frac{6}{7}(M_h)}{\frac{1}{7}(Bhp - hr_c) + \frac{6}{7}(Bhp - hr_h)} \quad \text{Equation 1}$$

where: BSFC = brake-specific fuel consumption in pounds of fuel per brake horsepower-hour, lb/Bhp-hr

M_c = mass of fuel used by the engine during the cold start test, lbs

M_h = mass of fuel used by the engine during the hot start test, lbs

$Bhp\text{-}hr_c$ = total brake horsepower-hours for the cold start test

$Bhp\text{-}hr_h$ = total brake horsepower-hours for the hot start test

The Bhp-hr values for each test are calculated using the engine torque and speed data measured on the dynamometer. The mass of fuel, M, used during each test is calculated via a carbon balance method using the emission rates and fuel properties determined during testing. These rather complex calculations are specified in 40 CFR 86.1342-90 and not repeated here. Generally, the calculations rely on the measured engine exhaust mass emissions of THC, CO, and CO_2 and the measured test fuel carbon weight fraction, specific gravity, and net heating value. These fuel properties are cited on the fuel certificate of analyses (Appendix A-1) and are determined using the following methods:

- Specific gravity – ASTM D1298 [4]
- Carbon weight fraction – ASTM D3343 [5]
- Net heating value – ASTM D3348 [6]

Pollutant emission rates are calculated using the same approach. Substituting measured emission rates for each pollutant into Equation 1 above for the mass of fuel used during the cold and hot start tests (M_c and M_h) results in calculation of the composite emission rate for each test run in units of grams per brake horsepower-hour (g/Bhp-hr).

Engine and dynamometer operating conditions were recorded during all test periods. Sampling system, emission analyzer, and test cell operations were also monitored. At the conclusion of testing, the PM samples collected from the blow-by tube were analyzed for soluble organic fraction (SOF). SOF was determined using an internal SOP developed by SwRI. The procedure basically uses solvent extraction and gravimetric procedures to determine the SOF. Each test run was followed by evaluation of data quality in accordance with the requirements of Section 3 of the test plan. Achievement of all data quality indicator goals and FTP requirements allowed the field team leader to declare a run valid.

2.0 VERIFICATION RESULTS

2.1. VERIFICATION OVERVIEW

Test preparations and verification testing was conducted between January 17 and February 1, 2005. Table 2-1 summarizes the daily events during the verification test period.

Table 2-1. Summary of Condensator Verification Activities

Date(s)	Activities Performed
01/17-18/05	Engine transported to test cell 8 and installed onto dynamometer.
01/19/05	Engine oil changed and engine inspected by Cummins technician.
01/20/05	25-hour engine break-in conducted.
01/21/05	Dynamometer and sampling system QA checks conducted, engine mapping completed.
01/24-25/05	Engine preconditioning completed and blow-by particulate sampling system installed.
01/26/05	Baseline tests conducted (one cold and three hot start tests), cold start test invalidated due to excessive drift in engine speed from the engine map.
01/27/05	Baseline cold start test repeated, Condensator installed by Cummins technician. Engine mapping and preconditioning completed.
01/28/05	Initial modified engine tests completed (one cold and three hot-start tests).
01/29-30/05	Engine run on Cummins durability cycle for 45-hour break-in period.
01/31/05	Second set of modified engine tests completed (one cold and three hot-start tests). Tests invalidated due to engine mechanical problem. Engine repaired.
02/01/05	Third set of modified engine tests repeated (one cold and six hot-start tests). Verification testing complete.

The verification testing generally proceeded smoothly with no major upsets or engine problems. The first cold start test conducted on the baseline engine was invalidated by SwRI because the measured engine speed exceeded variability limits with respect to the baseline engine map.

The Condensator system was installed by a Cummins technician without problems, and installation was approved by NCI representatives. The presence of the Condensator did impact on the engine's crankcase pressure. By routing the crankcase blow-by vent to the engine air intake and completely eliminating blow by exhaust, the Condensator changed the crankcase pressure from ambient to a vacuum in the range of 8 to 20 inches of water (depending on engine speed and torque). After consulting with the Cummins technician, testing was continued because the engine appeared to be operating normally and power output was approximately the same as before installation of the Condensator. No other impacts on engine performance were observed, the open crankcase was closed, and the blow by emissions (essentially all unburned organic material) was successfully routed back into the engine.

The set of test runs conducted after the 45-hour Condensator durability cycle break-in period was invalidated after an engine problem occurred during those tests. Specifically, the Woods coupling broke and two of the bolts holding the adapter plate on the engine sheared. Repairs were made and the testing was repeated. A total of six hot start tests were conducted after the 45 hour durability break-in cycle due to variability in the data (see section 3.1).

2.2. BSFC RESULTS

Table 2-2 summarizes the engine BSFC for each set of tests conducted. The table includes the BSFC for each individual cold and hot start test run, and the mean composite BSFC for each set of tests calculated using the cold start data and individual hot start data weighted in accordance with Equation 1.

Table 2-2. Summary of BSFC Verification Results

Test Run ID	Date (Time)	BSFC (lb/Bhp-hr)	
		Individual Test Run	Composite
Baseline Tests			
Cold start 1	01/26/05 (1129)	VOID – engine speed trace out of spec.	
Hot start 1	01/26/05 (1256)	0.390	0.392
Hot start 2	01/26/05 (1356)	0.385	0.387
Hot start 3	01/26/05 (1416)	0.390	0.391
Cold start 2	01/27/05 (0924)	0.400	NA
Mean			**0.390**
Standard Deviation			**0.003**
Initial Condensator Tests			
Cold start 1	01/28/05 (0842)	0.401	NA
Hot start 1	01/28/05 (0922)	0.393	0.394
Hot start 2	01/28/05 (1002)	0.385	0.387
Hot start 3	01/28/05 (1042)	0.391	0.393
Mean			**0.392**
Standard Deviation			**0.004**
Cumulative Effect Condensator Tests			
Cold start 2	01/31/05 (0924)	0.398	VOID – Tests invalidated due to broken Woods coupling and adapter plate
Hot start 4	01/31/05 (1004)	0.380	
Hot start 5	01/31/05 (1044)	0.379	
Cold start 3	02/01/05 (0850)	0.410	NA
Hot start 6	02/01/05 (0930)	0.384	0.387
Hot start 7	02/01/05 (1010)	0.382	0.386
Hot start 8	02/01/05 (1050)	0.373	VOID – Sample bag leak
Hot start 9	02/01/05 (1531)	0.380	0.384
Hot start 10	02/01/05 (1611)	0.383	0.387
Hot start 11	02/01/05 (1651)	0.384	0.388
Mean			**0.3857**
Standard Deviation			**0.0014**

In addition to test runs invalidated for reasons outlined in Section 2.1, hot start test 8 was also invalidated during data analysis. SwRI analysts indicated that the CO_2 concentration in the bag sample was suspiciously lower than the other samples collected, indicating a possible leak in the bag. Analysts conducted subsequent CO_2 analyses on the sample after an approximately 1-hour holding time, and confirmed that CO_2 levels continued to drop (indicating a leak in the bag). In order to determine if this test run could be eliminated from the data set, an analysis was performed testing the statistical significance of the suspect test run using the ASTM *Standard Practice for Dealing with Outlying Observations* (E 178-02), Section 6.1, *Recommended Criteria for Single Samples* [7]. The analysis confirmed that the test run was an outlying observation and it could be removed from the data set without compromising the integrity of the overall test results.

Based on the valid test runs only, the mean engine BSFC during baseline, initial Condensator, and cumulative Condensator test conditions were 0.390, 0.392, and 0.387 lb/Bhp-hr, respectively. Following the test plan, a t-test was used to evaluate the statistical significance of these small changes in BSFC. Changes in BSFC for both the initial and cumulative Condensator tests were not statistically significant, so confidence intervals were not calculated. Table 2-3 summarizes the statistical analysis of the tests including the coefficient of variation (COV) and t-test results for each data set. This analysis requires the assumption that the baseline and Condensator test sets have similar variance. Analysts used an F-test to determine the degree of similarity between the sample variances. The F-test evaluation indicates that the variance of the baseline data compared to the initial and cumulative Condensator tests are similar. Detailed COV, t-test, and f-test analyses are maintained in the GHG Center files.

Table 2-3. Statistical Analysis of BSFC Results

Parameter	Baseline Tests	Initial Condensator Tests	Cumulative Condensator Tests
Mean BSFC (lb/Bhp-hr)	0.390	0.392	0.3867
Standard deviation (lb/Bhp-hr)	0.003	0.004	0.0014
BSFC delta (lb/Bhp-hr)	--	0.002	-0.003
BSFC delta (%)	--	0.4	-0.8
Coefficient of Variation	0.8	1.0	0.37
Statistically significant change ($t_{test} > t_{0.025,\ DF}$)?	--	NO	NO

2.3. EMISSION TESTING RESULTS

2.3.1. PM Emissions

The primary engine emissions verification parameter for the Condensator was to determine the reduction in PM emissions. Table 2-4 summarizes the engine PM emissions for each set of tests conducted. The table includes the PM emissions for each individual cold and hot start test run, and the mean composite PM emission rate for each set of tests. Test runs that were invalidated for the BSFC tests were also considered invalid for the emissions analyses, with the exception of hot start test 8. A leak in the bag used to measure CO_2 would not affect the PM emissions determination, so this run was included in the analysis.

Table 2-4. Summary of Engine PM Emissions Verification Results

Test Run ID	Date (Time)	PM Emissions (g/Bhp-hr)		
		Individual Test Run		Composite Emission Rate
		Blow-by Emissions	Engine Emissions	
Baseline Tests				
Cold start 1	01/26/05 (1129)	VOID – engine speed trace out of spec.		
Hot start 1	01/26/05 (1256)	0.006	0.106	0.114
Hot start 2	01/26/05 (1356)	0.006	0.104	0.112
Hot start 3	01/26/05 (1416)	0.007	0.105	0.114
Cold start 2	01/27/05 (0924)	0.003	0.122	NA
Mean		**0.0055**	**0.109**	**0.1133**
Standard Deviation				**0.0010**
Initial Condensator Tests				
Cold start 1	01/28/05 (0842)	Blow-by emissions eliminated by installation of the Condensator	0.109	NA
Hot start 1	01/28/05 (0922)		0.102	0.103
Hot start 2	01/28/05 (1002)		0.100	0.101
Hot start 3	01/28/05 (1042)		0.101	0.102
Mean				**0.1021**
Standard Deviation				**0.0009**
Cumulative Effect Condensator Tests				
Cold start 2	01/31/05 (0924)		VOID – Tests invalidated due to broken Woods coupling and adapter plate	
Hot start 4	01/31/05 (1004)			
Hot start 5	01/31/05 (1044)			
Cold start 3	02/01/05 (0850)		0.125	NA
Hot start 6	02/01/05 (0930)		0.109	0.111
Hot start 7	02/01/05 (1010)		0.103	0.106
Hot start 8	02/01/05 (1050)		0.102	0.105
Hot start 9	02/01/05 (1531)		0.112	0.114
Hot start 10	02/01/05 (1611)		0.106	0.109
Hot start 11	02/01/05 (1651)		0.104	0.107
Mean				**0.109**
Standard Deviation				**0.003**

Based on the valid test runs only, the mean engine PM emissions during baseline, initial Condensator, and cumulative Condensator test conditions were 0.113, 0.102, and 0.109 g/Bhp-hr, respectively. Following the test plan, a t-test was used to evaluate the statistical significance of these changes in PM emissions. Changes in PM emissions for the initial Condensator test were statistically significant, so a confidence interval was calculated. After installation of the Condensator, particulate emissions were reduced by 9.8 ± 1.8 percent. Elimination of the blow by exhaust point accounted for about 4.9 percent of that decrease. Test results indicate that PM emissions were also lower for the cumulative Condensator tests, but the reduction was not statistically significant, so a confidence interval was not calculated. The F-test evaluation summarized in Table 2-7 indicates that the variance of the baseline data compared to the initial and cumulative Condensator tests are similar. Table 2-5 summarizes the statistics. Detailed COV, t-test, and F-test analyses are maintained in the GHG Center files.

Table 2-5. Statistical Analysis of PM Results

Parameter	Baseline Tests	Initial Condensator Tests	Cumulative Condensator Tests
Mean PM emissions (g/Bhp-hr)	0.1133	0.1021	0.109
Standard deviation (g/Bhp-hr)	0.0010	0.0009	0.003
PM delta (g/Bhp-hr)	--	-0.011	-0.005
PM delta (%)	--	-9.8	-4.0
Coefficient of Variation	0.88	0.8	3.0
Statistically significant change ($t_{test} > t_{0.025, DF}$)?	--	Yes	No
95% Confidence Interval	--	0.002	--

The particulate analysis also included an evaluation of the soluble organic fraction (SOF) of the particulate matter collected from the blow-by tube during the baseline tests. The results are summarized in Table 2-6.

Table 2-6. Soluble Organic Fraction of Blow-By PM for Baseline Tests

Parameter	Cold Start 2	Hot Start 1	Hot Start 2	Hot Start 3
Clean Filter weight, g	9.40	9.03	9.25	9.30
Filter Weight with Blow-by, g	9.48	9.20	9.42	9.50
Weight Blow-by, g	0.08	0.17	0.17	0.30
Reweighed Before Extraction, g	9.47	9.20	9.42	9.49
Weight After Extraction, g	9.39	9.04	9.25	9.31
Extracted Material, g	0.08	0.16	0.17	0.18

Filter weights after the SOF extraction process are essentially the same as the clean filter weights - all were within 0.2 percent of the clean filter weight. This indicates that the particulate matter emitted from the blow by tube was all soluble organic material, so the SOF is 100 percent.

2.3.2. NO_X, CO, CO_2, THC, and CH_4 Emissions

Determination of NO_X, CO, CO_2, THC, and CH_4 engine emissions was conducted as secondary verification parameters. Emissions of these pollutants are summarized in Table 2-7.

Table 2-7. Mean Composite Engine Emission Rates

Parameter	Mean Composite Baseline Emissions (g/Bhp-hr)	Mean Composite Initial Condensator Emissions (g/Bhp-hr)	% Decrease (Increase)	Mean Composite Cumulative Condensator Emissions (g/Bhp-hr)	% Decrease (Increase)
NO_X	4.59 ± 0.03	4.62 ± 0.03	(0.6)	4.51 ± 0.02	1.8
CO	0.746 ± 0.009	0.72 ± 0.16	0	0.708 ± 0.008	5
CO_2	561 ± 4	563 ± 5	(0.4)	556 ± 2	0.9
THC	0.203 ± 0.008	0.206 ± 0.004	(1)	0.226 ± 0.010	(11)

No statistical analyses were specified in the test plan for the secondary verification parameters. The data indicate that NO_X and CO_2 emissions were essentially unchanged after installation of the Condensator and CO emissions were reduced by approximately 5 percent after break-in. Emissions of THC were extremely low during all test periods (generally less than 9 parts per million). Emissions of CH_4 were not detected and are considered negligible.

3.0 DATA QUALITY

3.1. DATA QUALITY OBJECTIVES

The GHG Center selects methodologies and instruments for all ETV verifications to ensure a stated level of data quality in the final results. The test plan described these data quality objectives (DQOs). The test plan also listed contributing measurements, their accuracy requirements, QA/QC checks, and other data quality indicators (DQIs) that, if met, would ensure achievement of the DQOs.

The primary verification parameters for this test were reductions in BSFC and PM emissions. The DQO for these parameters was to demonstrate a statistically significant reduction in BSFC or PM emissions of 10 percent or greater. The test plan used historical COV data from a similar verification to relate the determinations' overall accuracy to the ability to report statistically significant changes in these parameters. Specifically, the historical COVs for BSFC and PM emissions were 0.7 and 2.2 percent, respectively. It was predicted that meeting these COVs would allow the Center to report statistically significant changes for BSFC and PM emissions 1.6 and 5.0 percent respectively, well within the 10 percent DQO. Table 3-1 summarizes the COVs for each data set generated.

Table 3-1. DQOs for BSFC and PM Emissions Results

Parameter	Test Condition	Mean Value	Number of Valid Tests	Standard Deviation	COV, percent
BSFC (lb/Bhp-hr)	Baseline	0.390	3	0.003	0.691
	Initial Condensator	0.392	3	0.004	0.934
	Cumulative Condensator	0.3867	5	0.0014	0.367
PM emissions (g/Bhp-hr)	Baseline	0.1133	3	0.0010	0.874
	Initial Condensator	0.1021	3	0.0009	0.839
	Cumulative Condensator	0.109	6	0.003	3.03

For the BSFC determination, the highest COV achieved was approximately 0.9 percent for the initial Condensator data set. However, it was determined that conducting additional tests would only have reduced the COV if all the additional test runs had the same result as the first three tests. While this situation may have reduced the COV, it would not have changed the conclusion that changes in BSFC were insignificant. Therefore no additional test runs were conducted and the DQO was attained.

For PM emissions, the Center was able to demonstrate a statistically significant reduction of approximately 9.8 percent for the initial Condensator tests with a COV of approximately 0.9 percent. The COV for the Cumulative Condensator tests was approximately 3.0, but was small enough to demonstrate that cumulative effects were not significant. The DQO for reductions in PM emissions was therefore attained.

The results in Table 2-3 show that both the initial and cumulative Condensator results for BSFC failed the t-test and are not statistically significant. Table 2-6 shows that the initial Condensator results for PM emissions passed the t-test and are statistically significant. The initial Condensator results show a decrease in PM emissions of 0.0111 ± 0.002 g/Bhp-hr. This is a decrease of 9.84 ± 1.8% from the baseline test. The cumulative Condensator test results did not pass the t-test, showing no statistically significant change in PM emissions.

No explicit DQOs were adopted for NO_X, CO, CO_2, THC, and CH_4 because these were secondary verification parameters. An implicit DQO for these parameters was for all emissions tests to conform to the specified reference methods. This DQO was achieved, as all emissions testing met the requirements set forth in the test plan.

3.2. MEASUREMENT SYSTEM QA/QC CHECKS

Tables 3-2 through 3-5 summarize the QA/QC checks and calibrations for the emissions measurement system, the instrumental analyzers, the particulate emissions determination, and supplementary test equipment. The checks confirm that the measurement systems and instruments met the proper specifications and therefore yielded satisfactory results.

Table 3-2. CVS System Data Quality Indicators and QA/QC Checks								
Parameter	**Data Quality Indicator Goals**			**QA/QC Checks**				
	Accuracy	**How Verified**	**Frequency**	**Description**	**Frequency**	**Allowable Result**	**Actual Result**	**Date(s) Completed**
Pressure	± 2.0 % of reading	Calibration of sensors with NIST-traceable standard	At initial installation, annually, or after major repairs	Inspect calibration certificates	Prior to test	Current calibration meeting DQI goal	Calibration meets DQI goal	1/21/05
Temperature	± 2.0 % of reading	Calibration of sensors with NIST-traceable standard		Inspect calibration certificates	Prior to test	Current calibration meeting DQI goal	Calibration meets DQI goal	1/21/05
Volumetric flow rate	± 0.5 % of reading	CVS and propane critical orifice calibration		Inspect calibration data	Prior to test	Current calibration meeting DQI goal	Calibration meets DQI goal	1/21/05
				Propane composition verification via analysis with FID	Prior to placing new propane tank in service	< 0.35 % difference from previously used and verified tank	Within allowable range	1/21/05
				Propane injection check	Weekly	Difference between injected and recovered propane ≤ ± 2.0 %	Within allowable range	1/21/05
				Sample bag leak check	Before each test run	Maintain 10” Hg for 10 seconds	Within allowable range	1/21/05
				Flow rate verification	Before each test run	≤ ± 5 cfm of nominal test point	Within allowable range	1/26/05, 1/27/05, 1/28/05, 1/31/05, 2/1/05
				Dilution air temperature	During each test run	Between 20 and 30 ^{o}C	All test runs within allowable range	1/26/05, 1/27/05, 1/28/05, 1/31/05, 2/1/05

Table 3-3. Instrumental Analyzers Data Quality Indicators and QA/QC Checks								
Parameter	**Data Quality Indicator Goals**			**QA/QC Checks**				
	Accuracy	**How Verified**	**Frequency**	**Description**	**Frequency**	**Allowable Result**	**Actual Result**	**Date Completed**
CO CO_2 NO_x THC	± 1.0 % FS or ± 2.0 % for each calibration gas	11-point calibration (including zero) with gas divider; protocol calibration gases	Monthly	Review and verify analyzer calibration	Once during test & upon completion of new calibration	Current calibration meeting DQI goal	Calibration meets DQI goal	1/13/05
				Gas divider linearity verification	Monthly	All points within ± 2.0 % of linear fit; FS within ± 0.5 % of known value	Within allowable range	9/4/04
				Calibration gas certification or naming (Perfomance Evaluation Audit)	Prior to service	Average concentration of three readings must be within ± 1 % for calibration gas and NIST-traceable reference material	Within allowable range	CO: 9/21/04 CO_2: 9/21/04 NO_x: 12/22/04 THC: 7/8/04
				Zero gas verification	Prior to service	HC < 1 ppmv CO < 1 ppmv CO_2 < 400 ppmv NO_X < 0.1 ppmv O_2 between 18 and 21 %	Within allowable range	12/6/04
				Analyzer zero and span	Before and after each test run	All values within ± 2.0 % of point of ± 1.0 % of FS; zero point within ± 0.2 % of FS	All within allowable range	Before and after each test run
CO_2 only				Wet CO_2 interference check	Monthly	CO (0 to 300 ppmv) interference ≤ 3 ppmv; CO (> 300 ppmv) interference ≤ 1 % FS	Within allowable range	1/21/05
NO_X only				NO_x Quench Check	Annually	NO_x quench ≤ 3.0 %	Within range	10/5/04
				Converter Efficiency Check	Monthly	Converter Efficiency >90%	Within range	1/13/05

Table 3-4. Particulate Matter Analysis Data Quality Indicators and QA/QC Checks							
Data Quality Indicator Goals			QA/QC Checks				
Accuracy	**How Verified**	**Frequency**	**Description**	**Frequency**	**Allowable Result**	**Actual Result**	**Date Completed**
± 1.0 μg	NIST-traceable scale calibration, weighing room controls, filter weight control	Daily	NIST-traceable calibration weight cross-check	Daily	Weight change <1.0 μg	Within allowable range	1/24/05, 1/31/05
			Weight room temperature	Daily	Between 19 and 25 ^{o}C	Within allowable range	1/26/05, 1/27/05, 1/28/05, 1/31/05, 2/1/05
			Weight room relative humidity	Daily	Between 35 and 53% RH	Within allowable range	1/26/05, 1/27/05, 1/28/05, 1/31/05, 2/1/05
			Reference filter weight change	Daily	Weight change <20 μg	Within allowable range	1/26/05, 1/27/05, 1/28/05, 1/31/05, 2/1/05

Table 3-5. Supplementary Instruments and Additional QA/QC Checks				
Description	**Frequency**	**Allowable Result**	**Actual Result**	**Date Completed**
Test cell Wet/dry bulb thermometer calibration	Monthly	Within ± 1.0 ^{o}F NIST-traceable standard	Meets specifications	1/11/05
Test cell Barometer calibration	Weekly	Within ± 0.1" Hg of NIST-traceable standard	Meets specifications	1/25/05
Test cell temperature	Each test run	Between 68 and 86 ^{o}F	Within allowable range	1/26/05, 1/27/05, 1/28/05, 1/31/05, 2/1/05
Test fuel analysis	Prior to testing	Conforms to 40 CFR §86.1313 specifications (See Appendix A-1)	Meets specifications	1/25/05

Table 3-6. Dynamometer Data Quality Indicators and QA/QC Checks								
Parameter	**Data Quality Indicator Goals**			**QA/QC Checks**				
	Accuracy	**How Verified**	**Frequency**	**Description**	**Frequency**	**Allowable Result**	**Actual Result**	**Date Completed**
Speed	± 2.0 %	60-tooth wheel combined with frequency counter	At initial installation, annually, or after major repairs	Inspect calibration certificate	Prior to test	Current calibration meeting DQI goal	Calibration meets DQI goal	1/22/05
Load (Torque Sensor)	±0.5%	NIST-traceable weights and torque arm	Weekly	Inspect calibration certificate	Prior to test and after new calibration	Current calibration meeting DQI goal	Calibration meets DQI goal	1/22/05
				Torque trace acceptance test	Each test run	± 2.5 lb.ft for values ≤ 550 lb.ft, ± 5.0 lb.ft for values ≤ 1050 lb.ft, ± 10 lb.ft for values ≤ 1550 lb.ft	All within allowable range	After each test run

3.3. AUDITS

The GHG Center's QA manager performed the audit of data quality (ADQ) by randomly selecting at least 10% of the data, implementing an independent analysis, and comparing the results to those cited in this report. The QA manager then drafted a report which describes the audit and submitted it directly to the GHG Center Director. In general, the audit results were satisfactory.

The GHG Center specifies internal Performance Evaluation Audits (PEAs), as applicable, on critical measurements of every verification test. For this verification, the Center used the SwRI quality infrastructure for an internal PEA for this test. SwRI maintains a set of NIST-certified gas standard mixtures in the concentration ranges applicable to these measurements. The monthly calibration procedure requires that the DEER challenge the analytical instruments with these standards as a performance check independent of the calibration gas standards (internally referred to as calibration gas naming). The GHG Center used this internal check in lieu of a blind PEA. Results for each analyzer type are shown to be acceptable (within ± 1% for calibration gas and NIST-traceable reference material) in Table 3-3.

4.0 REFERENCES

1. *Test and Quality Assurance Plan for the New Condensator, Inc. — The Condensator Diesel Engine Retrofit Crankcase Ventilation System* (SRI/USEPA-GHG-QAP-36), December, 2004, www.epa.gov/etv.

2. *Generic Verification Protocol for Diesel Exhaust Catalysts, Particulate Filters, and Engine Modification Control Technologies for Highway and Nonroad Use Diesel Engines*, Research Triangle Institute, EPA Cooperative Agreement No. CR826152-01-3, January 2002, www.epa.gov/etv.

3. *Control of Emissions from New and In-use Highway Vehicles and Engines*, Code of Federal Regulations, Title 40, Part 86, U.S. Office of the Federal Register, Washington, DC, 2003.

4. *Standard Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products*, American Society for Testing and Materials, ASTM D1298-99, West Conshohocken, PA. 2001.

5. *Standard Test Method for Estimation of Hydrogen Content of Aviation Fuels,* American Society for Testing and Materials, ASTM D3343-95, West Conshohocken, PA. 2001.

6. *Standard Test Method for Rapid Field Test for Trace Lead in Unleaded Gasoline*, American Society for Testing and Materials, ASTM D3348-98, West Conshohocken, PA. 2001

7. *Standard Practice for Dealing with Outlying Observations* (E 178-02), American Society for Testing and Materials, ASTM International, West Conshohocken, PA. 2002.

8. *Environmental Technology Verification of New Condensator Diesel Engine Retrofit Crankcase Ventilation System for Use With Heavy-Duty Diesel Engines,* Southwest Research Institute (SwRI 03.11259), April 2005.

APPENDICES

APPENDIX A-1. TEST FUEL ANALYSIS

Chevron Phillips Chemical Company LP

DATE OF SHIPMENT
12-20-04

CUSTOMER PO NO.
542906G

SALES ORDER NO.
6001641

TRAILER NO. 388

MFG. DATE: 11-2004
SHELF LIFE: UNDETERMINED

Em-5402-F m Smith + Vald

CERTIFICATE OF ANALYSIS

DIESEL .05 LS CERT FUEL (#2)
LOT 4KP05201

TESTS	RESULTS	SPECIFICATIONS	METHOD
Specific Gravity, 60/60	0.8436	0.8398 – 0.8654	ASTM D-4052
API Gravity	36.23	32 – 36	ASTM D-1250
Corrosion, 50°C, 3 hrs	1A	3 Max	ASTM D-130
Sulfur, ppm	346.9	300 – 500	ASTM D-5453
Flash Point, °F	148.5	130 Min	ASTM D-93
Pour Point, °F	-15	0 Max	ASTM D-97
Cloud Point, °F	-2	10 Max	ASTM D-2500
Viscosity, cs 40°C	2.53	2.2 – 3.2	ASTM D-445
Carbon wt%	86.76	Report	ASTM D-3343
Hydrogen wt%	13.20	Report	ASTM D-3343
Carbon Density (gm/gal)	2770	2750 – 2806	Calculated
Net Heat of Combustion BTU/LB	18455	Report	ASTM D-3338
Particulate Matter, mg/l	0.6	15 Max	ASTM D-2276
Cetane Index	47.6	46 – 48	ASTM D-976
Cetane Number	46.4	46 – 48	ASTM D-613
DISTILLATION, °F			**ASTM D-86**
IBP	358.0	340 – 400	
5%	389.8		
10%	409.8	400 – 460	
20%	437.5		
30%	459.3		
40%	479.8		
50%	498.7	470 – 540	
60%	517.3		
70%	536.5		
80%	559.8		
90%	590.0	560 – 630	
95%	620.1		
EP	645.8	610 – 690	
Loss	0.3		
Residue	1.0		
HYDROCARBON TYPE, VOL%			**ASTM D-1319**
Aromatics	29.4	28 – 31	
Olefins	1.2	Report	
Saturates	69.4	Report	
SFC Aromatics, wt%	31.59	Report	
Polynuclear Aromatics, wt%	7.40	Report	

D.G. Doerr teh

D.G. Doerr
Fuels Unit Team Leader

EJN: teh
12/20/04