Demonstration of emissions mitigation measures for diesel-powered off-road mobile sources in Mexico

Final Report

Prepared for:

Mexico Low Emissions Development (MLED) Program

USAID Contract # AID-523-C-11-00001

Prepared by:

Molina Center for Energy and the Environment (MCE2)

http://www.mce2.org

December 30, 2014

Acknowledgments

This project was coordinated and executed by the Molina Center for Strategic Studies in Energy and the Environment with the participation and collaboration of the Instituto Nacional de Ecología y Cambio Climático, Centro de Ciencias de la Atmósfera of the Universidad Nacional Autónoma de México, Instituto Tecnológico de Estudios Superiores de Monterrey campus Toluca, Secretaría del Medio Ambiente y Recursos Naturales, Secretaría del Medio Ambiente del Distrito Federal, Secretaría de Obras y Servicios del Distrito Federal, and California Air Resources Board.

The Molina Center would like to thank the California Air Resources Board for lending their AVL-MSS instrument for this project and their strong support and collaboration. Special thanks to Ing. Reyes Martínez Cordero of the Planta de Asfalto del Distrito Federal, Ing. Jaqueline de la Cruz of Geo-Construcción, and Mr. Antonio Nava of Sistema Maíz for providing their off-road vehicles used for testing.

The funding provided by the United States Agency for International Development (USAID) and the support from Tetra-Tech are gratefully acknowledged. The Project Team also would like to acknowledge INECC for providing funding for obtaining the emissions control devices.

Abstract

Diesel-powered off-road vehicles can be a major source of submicron carbonaceous particles that include black carbon, organic carbon and other co-pollutants. The design of effective strategies for mitigating black carbon and other particulate matter (PM) emissions should include the introduction of new emissions control technologies for diesel-powered off-road vehicles. However, there is relatively little information available for estimating the potential benefits in reducing emissions from off-road mobile sources in Mexico using existing exhaust treatment technologies. The overall objective of the present project is to characterize the particulate matter and gaseous emissions of selected diesel-powered off-road mobile sources in Mexico under real-world operating conditions using on-board portable emissions measurements systems (PEMS). The results can be used for evaluating the PM and gaseous emissions reductions by the implementation of readily available control emissions technologies in the diesel-powered off-road vehicles in Mexico.

This report describes the activities undertaken by the Molina Center and collaborators, including: 1) planning and logistical organization of the measurements, 2) selection of test vehicles, 3) emissions characterization of test vehicles without emissions control devices (or "baseline" measurements), 4) emissions characterization on the same off-road vehicles with the addition of emission control devices in their exhaust pipes; and 5) compilation of the databases obtained.

This pilot demonstration project has generated the first database of emissions factors and total emissions under real-world operations for selected off-road vehicles in Mexico, which is appropriate for assessing the impacts of implementing readily available control emissions technologies in Mexico and for building scenarios and mitigation measures.

Executive Summary

Black carbon contributes to the adverse impacts on human health, ecosystems, and visibility associated with fine particles (PM2.5). Black carbon also influences climate by directly absorbing sunlight in the atmosphere, reducing the reflectivity of snow and ice through deposition and interacting with clouds. Currently the best estimate, including direct effects, cloud effects, and snow and ice effects, suggests that black carbon could be the second largest contributor to global warming after carbon dioxide. Black carbon resides in the atmosphere only days to weeks, which implies that reducing the emissions of black carbon may result in a relatively rapid climate response in addition to significant improvements to public health and ecosystems.

Diesel-powered off-road vehicles (e.g., forklifts, specialty vehicles, portable generators, and a wide array of other mobile equipment used in agricultural, construction, and industrial activities) can be a major source of submicron carbonaceous particles that include black carbon, organic carbon and other co-pollutants. The design of effective strategies for mitigating black carbon and co-pollutant emissions in Mexico and other developing countries should include the introduction of new emissions control technologies for diesel-powered off-road vehicles. Recently, a variety of diesel vehicle exhaust treatment technologies designed to trap and eventually destroy a significant portion of diesel exhaust particles has become commercially available. However, in contrast to on-road mobile sources, there have been relatively less efforts in characterizing the emissions from off-road mobile sources, and there is relatively little information available for estimating the potential benefits for reducing emissions from off-road mobile sources in Mexico using exhaust treatment technologies.

In this pilot demonstration project, the particulate matter and gaseous emissions of selected diesel-powered off-road mobile sources in Mexico under real-world operating conditions have been characterized using on-board portable emissions measurements systems (PEMS). The results can be useful for evaluating the PM and gaseous emissions reductions by the implementation of readily available control emissions technologies in the diesel-powered off-road mobile sector in Mexico.

The project was conducted in various stages by the Molina Center personnel and collaborators. This report describes the activities undertaken by the project team which include: 1) planning and logistical organization of the measurements, 2) selection of test vehicles, 3) emissions characterization of test vehicles without emissions control devices (or "baseline" measurements), 4) emissions characterization on the same off-road vehicles with the addition of emission control devices in their exhaust pipes; and 5) compilation of the databases obtained.

The gaseous and PM emissions of eleven off-road vehicles have been measured for the baseline phase of this project and nine of the selected vehicles from the baseline were measured with emissions control devices. The selected vehicles included backhoes, tractor, crane, hammer, front loaders, dozers, compressor, and power generator, representing an important variety of heavy- and medium-duty diesel off-road vehicles. The measurements were carried out using three complementary PEMS (AVL Micro-soot Sensor, ECOSTAR, and AXION), representing abundant databases that have been obtained for the first time in Mexico of the emission characteristics of the sampled vehicles under real-world operating conditions.

It is anticipated that the results obtained from this pilot demonstration project will contribute to the assessment of the impacts of implementing readily available control emissions technologies in Mexico and for building scenarios and mitigation measures.

Given that currently there is limited information on the number, type and engine characteristics of the off-road vehicles in operation in Mexico, the large-scale implementation of technology-based mitigation strategies in the future should include efforts to support the compilation of fleet characteristics and reliable activity data for these vehicles. Several of the institutions and key contact persons that collaborated in this pilot demonstration project could help as a starting point to gather the much needed information.

List of Collaborating Institutions

Molina Center for Strategic Studies in Energy and the Environment

Centro de Ciencias de la Atmósfera, Universidad Nacional Autónoma de México

Centro de Investigación en Mecatrónica Automotriz, Tecnológico de Monterrey (campus Toluca)

California Air Resources Board

Instituto Nacional de Ecología y Cambio Climático

Planta de Asfalto del Distrito Federal

Geo-Construcción, Mexico, D.F.

Sistema Maíz, Mexico, D.F

Secretaría del Medio Ambiente del Distrito Federal

Secretaría de Obras y Servicios del Distrito Federal

Secretaría del Medio Ambiente y Recursos Naturales

Project Participants

Molina Center for Energy and the Environment
Luisa T. Molina
Miguel Zavala
Rodrigo Gonzalez Abraham
Jared Morante
Marco Vinicio Balam (consultant)

Instituto Nacional de Ecología y Cambio Climático
Victor Hugo Páramo
Sergio Zirath Hernández
Andrés Aguilar
Francisco Guardado
Abraham Ortinez

Tecnológico de Monterrey Campus Toluca
José Ignacio Huertas
Daniel Fernando Prato Sánchez

Universidad Nacional Autónoma de México
Aron Jazcilevich
José Manuel Hernández Solís
Raúl Alexander Gutiérrez
Agustín García
Gerardo Ruíz Suárez

Planta de Asfalto del Distrito Federal
Reyes Martínez Cordero
Rodrigo Díaz
José Mariano Plascencia Barrios
Carlos Hansen

Sistema Maíz
Efraín Bravo Camacho
Antonio Nava

Table of Acronyms and Abbreviations

AMECO	American Equipment Company, Inc.
AVL	Anstalt für Verbrennungskraftmaschinen (Institute for Internal Combustion Engines)
AXION	PEMS trademark of GlobalMRV Inc.
BC	Black Carbon
CARB	California Air Resources Board
CCA	Centro de Ciencias de la Atmósfera
CCAC	Climate and Clean Air Coalition
CIMA	Centro de Investigación en Mecatrónica Automotriz
DCL	Diesel Control Limited
DPF	Diesel Particle Filter
ECOSTAR	Trademark of Sensors Inc.
GEF	Global Environmental Facility
INECC	Instituto Nacional de Ecología y Cambio Climático
MCE2	Molina Center for Energy and the Environment
MLED	Mexico Low Emissions Development
MSS	Micro-Soot Sensor
OC	Organic Carbon
OCIMA	Organismo de Certificación de Implementos y Maquinaria
PEMS	Portable Emissions Measurements System
PIC	Pre-installation Compatibility
PM	Particulate Matter
RAVEM	Ride-Along Vehicle Emissions Measurement
SEDEMA	Secretaría del Medio Ambiente del Distrito Federal
SEMARNAT	Secretaría del Medio Ambiente y Recursos Naturales
SEMTECH	Trademark of Sensors Inc.
SLCPs	Short-Lived Climate Pollutants
TEC	Tecnológico de Monterrey
ULSD	Ultra-Low Sulfur Diesel
UNAM	Universidad Nacional Autónoma de México
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
VDEC	Verified Diesel Emissions Control
WMO	World Meteorological Organization

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1. Introduction

The combustion of fossil fuels from mobile sources generates substantial emissions of carbonaceous particulate matter (PM) that includes black carbon (BC), organic carbon (OC) and other co-pollutants. Fine PM contributes to the adverse impacts on human health, ecosystems, and visibility. Black carbon in the PM also contributes to global warming by absorbing sunlight in the atmosphere. Because black carbon resides in the atmosphere only days to weeks, reducing BC emissions may result in a relatively rapid climate response. Investigation of black carbon has recently gained momentum as it is one of the key short-lived climate pollutants (SLCPs) for mitigating near-term climate change as well as providing significant improvements to public health and ecosystems [Bachman, 2009; UNEP/WMO, 2011; UNEP, 2011; Shindell et al., 2012; US EPA, 2012].

In contrast to on-road mobile sources, there have been relatively less efforts in quantifying the potential benefits for reducing emissions from off-road mobile sources. Nevertheless, off-road diesel vehicles (e.g., forklifts, specialty vehicles, portable generators, and a wide array of other agricultural, construction, and industrial equipment) can be a major source of submicron carbonaceous particles in many parts of the world. Thus, the design of effective strategies for mitigating black carbon in Mexico and other developing countries should include the introduction of new emissions control technologies for diesel-powered off-road vehicles. Recently, a variety of diesel vehicle exhaust treatment technologies designed to trap and eventually destroy a significant portion of diesel exhaust black carbon particles have become commercially available. However, the carbonaceous emissions produced by a diesel engine typically depend on many parameters that vary in local settings and thus testing the effectiveness of exhaust treatment technologies requires sampling a full range of diesel vehicle operating parameters under real-world operating conditions.

The objective of the present project is to characterize the particulate matter and gaseous emissions of selected diesel-powered off-road mobile sources in Mexico under real-world operating conditions using on-board portable emissions measurements systems (PEMS). The results can be used for evaluating the PM and gaseous emissions reductions by the implementation of readily available control emissions technologies in the diesel-powered off-road mobile sector in Mexico. The project is expected to produce a database of emissions factors and total emissions under real-world operations for selected off-road vehicles suited for assessing the impacts of implementing readily available control emissions technologies in Mexico and for building scenarios and mitigation measures.

This project was coordinated and executed by the Molina Center for Strategic Studies in Energy and the Environment (MCE2) and included the participation and collaboration of the Instituto Nacional de Ecología y Cambio Climático (INECC), Centro de Ciencias de la Atmósfera of the Universidad Nacional Autónoma de México (CCA-UNAM), Tecnológico de Monterrey campus Toluca, the LTM Center for Energy and the Environment, Secretaría del Medio Ambiente y Recursos Naturales (SEMARNAT), Secretaría del Medio Ambiente del Distrito Federal (SEDEMA), Secretaría de Obras y Servicios del Distrito Federal, and the California Air Resources Board (CARB).

The project was performed in various stages including:

1) Sampling planning, selection and preparation of test vehicles, acquisition of diesel fuels and emissions control devices;
2) Sampling of test vehicles without emission control devices;
3) Sampling of test vehicles with emission control devices;
4) Data quality control and archive;
5) Preparation of document with description of results.

This final report integrates all the previous interim reports and activities performed during the entire development and implementation of this project.

2. Background

Mexico is one of the founding members of Climate and Clean Air Coalition (CCAC) and, through SEMARNAT and INECC, is committed to reducing emissions of SLCPs from key sources. The Mexican government has demonstrated this commitment through several efforts at the national and international levels, which include collaborating with UNEP on SLCP assessment reports [UNEP, 2011; UNEP/WMO, 2011], hosting several workshops on the science and policy of SLCPs to improve understanding of SLCPs and to share best practices with the support from INECC, MCE2 and WMO [INE, 2011], and collaborating with UNEP and MCE2 to implement a pilot project sponsored by Global Environment Facility (GEF) on integrated response to SLCPs that promotes clean energy and energy efficiency of SLCP emission sources, of which mobile sources are predominant. Thus, this USAID-sponsored pilot project on off-road emission characterization complements the study of on-road emissions that has been conducted as part of the GEF-sponsored project.

In contrast to on-road mobile sources, there have been relatively less efforts for quantifying the potential benefits for reducing emissions from off-road mobile sources. Nevertheless, off-road diesel vehicles can be a major source of submicron carbonaceous particles in many parts of the world. A recent global assessment indicates that off-road vehicles account about 36% of black carbon emissions from mobile sources [Bond et al., 2013]. Regionally, the emissions contributions of off-road vehicles may vary widely depending on the degree of local development and economic activities. The assessment of Bond et al. also indicates that uncertainties associated with the estimation of emissions from off-road sources can be even larger than for on-road sources because less local data has been compiled for these sources. The uncertainties also arise because the particle emissions produced by a diesel engine depend on many parameters under several operational conditions that vary locally, nationally, and regionally.

In Mexico, current estimates indicate that off-road diesel vehicles are responsible for about 20% of black carbon emissions, with a large contribution from equipment used for agricultural activities [SEMARNAT, 2013]. In comparison, on-road vehicles are estimated to contribute about half of the off-road black carbon emissions in Mexico. The large difference is mainly due to the almost prevalent lack of emissions control technology for the off-road Mexican vehicle fleet. Nevertheless, these estimates have been obtained with limited knowledge on the local emission factors and activity data for the off-road vehicles in Mexico.

Typical off-road vehicles include forklifts, specialty vehicles, airport service vehicles, large turf care equipment, portable generators, and a wide array of other agricultural, construction, and general industrial equipment. Most of these equipment use diesel fuel due to their large horsepower demand. Since typically these vehicles do not have any emission control technology, they can be large contributors of black carbon, organic matter, and other particle matter constituents. Over the past decade a variety of diesel vehicle exhaust treatment technologies designed to trap and eventually destroy a significant portion of diesel exhaust black carbon particles have become commercially available. These technologies are generally based on devices with surface chemical and physical properties that promote black carbon particle trapping and burn-off, the effectiveness of which can vary with control system age and operating conditions.

A recent study by California Air Resources Board measured 27 off-road vehicles from the construction sector using an on-board PEMS monitoring system [Durbin et al., 2013]. The study found that the emissions for the off-road vehicles were highly transient, with rapid and repeated changes in engine speed and load depending on the vehicle's operating conditions. The results from this USAID-sponsored study in Mexico also provide a framework for better understanding emissions from agricultural and construction equipment under real world operating conditions.

Estimating emissions of particle matter from the diesel-powered off-road vehicles in Mexico and the impact of emissions controls can be challenging in part because little is known about the effectiveness of diesel exhaust treatment technologies in the Mexican fleets. In contrast to laboratory or non-local sampling conditions, testing the effectiveness of exhaust treatment technologies requires sampling of a full range of diesel vehicle operating parameters under real-world operating conditions. This is because the level of exhaust of black carbon and other particle matter constituents produced by a diesel engine depends on many variables, including: fuel composition; engine load, engine type and condition, operation mode, and even ambient air temperature and pressure (altitude). The effectiveness of diesel exhaust treatment technologies also depends on many of the same variables; thus it should be measured from selected test vehicles with and without exhaust control systems under real-world operating conditions. Therefore, the design of effective strategies for mitigating black carbon and other PM emissions in Mexico should include the introduction of new emissions control technologies for diesel-powered off-road vehicles.

3. Development

3.1. Organization and planning of the field measurements

The initial efforts for this project focused on organizing and planning the field measurements for emissions characterization, which included the following activities:

1) Meeting with the collaborators in Mexico City to discuss and plan the project activities, potential calendar for measurements, logistical issues, identifying and organizing visits to potential measurement sites, and planning for the acquisition and installation of the diesel particle particles;

2) Numerous site visits to institutions and owners of off-road vehicles for negotiating and organizing their participation in the project;

3) Conference call meetings with CARB regarding the logistics for the transport of the AVL Micro-Soot Sensor (MSS) to Mexico City and the requirements for operating the instrument. As described below, the AVL-MSS instrument is the key instrument in this project for the measurement of black carbon;

– CARB recommended that a vibration damper should be installed for the off-road operation of their MSS. The Molina Center contacted the AVL office and ordered a vibration damper especially designed for the MSS instrument;

4) Meeting (in person or via telephone and Internet) with several manufacturers of diesel particle filters (DPFs) regarding the design, construction, cost and delivery of the specific DPF for the diesel vehicles to be tested;

5) Meeting with DPFs installer in California regarding the selection of vehicles appropriate for testing and the corresponding DPFs for demonstration of emission reduction, including the design and fabrication of the sampling connections between the vehicle and the instrument;

6) Contacting the custom brokers to prepare the importation of the micro-soot sensor as well as the insurance agents regarding comprehensive coverage of the equipment during transit and while deploying in Mexico;

7) Ordering the consumables and other supplies needed for the operation of the various PEMS instruments;

8) Designing the sampling line for the integration of all three PEMS (MSS, AXION, ECOSTAR) instruments;

9) Performing measurement tryouts testing of MSS, AXION, and ECOSTAR integrated systems on a diesel vehicle (INECC contributed with a diesel ISUZU van for integrated emissions testing tryouts);

10) Selection and acquisition of a portable electric generator suitable for powering the three integrated PEMS systems during measurements;

11) Acquisition of consumables and additional supplies (e.g. air regulators, calibration gases, etc.);

12) Design and construction of two metal frames for securing the stability of PEMS systems mounted on board the test vehicles;

13) Design and construction of sample ports and fittings for each test vehicle.

Following the completion of the baseline measurements, numerous actions were also undertaken for the planning of the measurements with the emission control devices installed on the test off-road vehicles, including:

1) Meeting with the collaborators in Mexico City to discuss logistical issues and planning for the acquisition and installation of the emissions control devices;

2) Site visits to institutions and owners of the off-road vehicles for scheduling the installation of the emission control devices and subsequent characterization of emissions;

3) Conference call meetings with CARB regarding the use of AVL Micro-Soot Sensor (MSS) to measure off-road vehicles with emission control devices;

4) Contacting the custom brokers regarding the importation of the DPF devices;

5) Ordering the consumables and other supplies needed for the operation of the various PEMS instruments;

6) Designing and construction of sampling line for the integration of all three PEMS (MSS, AXION, ECOSTAR) instruments with the emission control devices for each vehicle.

Details of the dates and team participants during these activities are described in Appendix 1.

3.1.1. Selection of off-road vehicles

During the process for selecting the off-road vehicles to be tested in the project, the team members organized several visits to governmental and private institutions that have several off-road vehicles as part of their routine operational activities. Table 1 lists the sites visited by the project team members for identifying test vehicles. These visits permitted to establish a direct communication between the project members and the personnel of the host institutions, to identify key participants and contact people, and to identify concerns and respond to inquiries regarding their participation in the project. Given that the owners of the vehicles were participating voluntarily, the establishment of an open and direct communication channel with our hosts was a vital element for the success of the project. Thus, during the visits, the team aimed to clearly present the objectives of the project and specify the nature of their participation and contributions.

The visits conducted by the team members also included the collection of the technical specifications of the off-road vehicles available. In coordination with the host institutions, opacity measurements on the vehicles were conducted at several sites by collaborating partners. The team members also visually inspected the general conditions of the vehicles and requested information on the type of mechanical maintenance practices followed. Appendix 2 presents a sample list of the vehicles visited and their technical specifications for both the vehicle type and their engines.

Table 1. Field visits for the identification of potential vehicles for the project.

Visit	Date	Institution & Activity	Address	Type of vehicles
1	02-12-2014	Asphalt plant	Av. Del Imán No. 263, Col. Ajusco, Del. Coyoacán, México D.F.	Wheel loader, Backhoe, Crawler Dozer
2	04-08-2014	Sugarcane mill	Av. Lázaro Cárdenas No. 51, Zacatepec, Morelos, México	Wheel loader, Grader, Harvester, crane
3	04-09-2014	Public works	Río Churubusco 1155. Colonia Carlos Zapata Vela. Delegación Iztacalco	Compactor, Backhoe loader
4	04-10-2014	Asphalt plant	Av. Del Imán No. 263, Col. Ajusco, Del. Coyoacán, México D.F.	Wheel loader, Backhoe, Crawler Dozer
5	04-11-2014	Public works – special projects	Av. Universidad 800, 4° piso. México, D.F.	Rubber wheeled roller, compactor, finisher
6	04-15-2014	Public works – special projects	Av. Universidad 800, 4° piso. México, D.F.	Rubber wheeled roller, compactor, finisher
7	04-30-2014	AMECO	3065A, Centro Industrial Tlalnepantla (Zona Ind.), 54030 Tlalnepantla, Estado de México, México	Motor grader, Bulldozer crawler, Excavator, Skid steer loader, among others
8	05-01-2014	Agriculture	Calle Cuahutémoc #50, San Miguel Topilejo, Tlalpan, Distrito Federal.	Tractors
9	05-02-2014	Asphalt plant	Unidad Productora de Triturados Basálticos Parres. Carretera Federal México Cuernavaca km 38.5, poblado de Parres, Delegación Tlalpan.	Rock truck, Bulldozer, Hydraulic Excavator, Front shovel
10	05-19-2014	Agriculture	Calle Cuahutémoc #50, San Miguel Topilejo, Tlalpan, Distrito Federal.	Tractors
11	05-20-2014	AMECO	3065A, Centro Industrial Tlalnepantla (Zona Ind.), 54030 Tlalnepantla, Estado de México, México	Motor grader, Bulldozer crawler, Excavator, Skid steer loader, among others

The following section presents a detailed description of the criteria considered for the selection of test vehicles. The review of the engine model horsepower rating and age of the vehicle are among the most important parameters to consider in the selection of the test vehicles. The final list of vehicles selected for baseline and filter-installed measurements is presented and described in detail later on in this document.

3.1.2. Criteria for selection of vehicles

The selection of vehicles for the testing of their baseline emission characteristics includes several technical and non-technical criteria. In addition, other technical criteria are also needed to take into account for the selection of vehicles that would have a diesel particle filter (DPF) installed for their emissions characterization.

A. Technical Criteria

a) *Mechanical condition*. Accumulated experience during emissions testing of off-road vehicles in California indicates that retrofitting of malfunctioning off-road vehicles is usually not successful (Chandan Misra, CARB, personal communication). Thus, the vehicle must be in good operational and mechanical conditions. In general, the conditions to look for are:

- No excessive vibration
- No excessive fuel consumption
- No excessive oil consumption
- Integrity of the exhaust system
- Low opacity (20 - 30 %, measured with an optical opacimeter)

b) *Engine technical specifications*. The engine horsepower, model, age, and volume displacement are critical technical specifications to consider for the selection of the test vehicles.

c) *Feasibility for installing the PEMS instruments*. The vehicle has to have enough available for simultaneously and safely hold the PEMS. Two important criteria are:

- Vehicle size. A sturdy flat area (e.g. the roof) is needed to safely attach the instruments. A larger vehicle is often related to larger horsepower.
- Design of the exhaust system should allow the installation of the sampling ports.

d) *Feasibility for installing a DPF*. For those vehicles that could be candidates for emissions control devices, the integrity and design of the exhaust system should allow the installation of the DPF. Additional technical criteria for the selection of the DPF's can be specified by the manufacturer and include exhaust temperature, back pressure, and operation cycles.

B. Non-technical Criteria

a) *Vehicle type and representativity*. Although this is a pilot demonstration project, if possible the selected test vehicle types should be those that are commonly used in Mexico for construction and agricultural activities. Similarly, the engine should also be of a representative horsepower. Thus, one of the primary activities was the appropriate selection of vehicles types to be used for the measurements. In Mexico there is no detailed information on the number, type and engine characteristics of the off road vehicles in operation. The first attempt for estimating emissions from off-road vehicles in Mexico was carried out for the National Emissions Inventory (NEI) of 1999, which was sponsored by SEMARNAT and led by the Eastern Research Group (ERG). The inventory consisted of adapting the NONROAD EPA model for the construction and agriculture equipment for Mexico [ERG, 2005]. These estimates were updated for the NEIs of 2005 and 2008 [SEMARNAT, 2009; SEMARNAT-INE, 2013].

The NEI documented that the activity data available for off-road sources is extremely limited for Mexico. Thus, for the estimations in the NEI, emissions factors were obtained directly from the NONROAD model databases whereas activity data for Mexico was estimated using several assumptions. In the case of construction equipment, the activity vehicle population data is assumed from the US off-road vehicle population distribution (using SCC codes) and Mexican data on fuel consumption distributed by states and municipalities. The activity hours for the construction equipment (hours/year) are also assumed from the NONROAD model. In the case of agricultural equipment, the NEI uses data cataloged from the 2007 Agricultural Census from INEGI.

Being a pilot project, generating a representative sample of emissions factors for off-road vehicles in Mexico is well beyond the scope for this study. Instead, we have performed real-world operation measurements for selected off-road vehicles used in mining and construction activities and a tractor used in the agriculture sector and obtained a database that can be used for estimating the emissions benefits of employing emissions control devices. During various sites visits the team project members discussed with the vehicles owners and personnel of the hosting institutions about their expert opinions on the type of off-road vehicles that are predominantly used in Mexico. Of particular importance were the discussions with personnel from the American Equipment Company (AMECO, a leader company in Mexico for renting and selling of off-road vehicles for the construction sector) and with lead members of the Sistema Maíz (a regional association of farmers for Mexico). These activities provided the needed guidance, albeit qualitatively, about the type of off-road vehicles that should be considered for the project. As shown later in this document, given their prevalence as high emitters of particulate matter and gases as well as their prevalence, the vehicles selected for measurement included large and medium normally used in construction and agricultural equipment. These include tractors, excavators, backhoes, cranes and wheel loaders, among others.

b) *Convenient location*. This includes assessing work security issues in the area and transporting personnel and equipment to the sampling location.

c) *Fuel accessibility*. Given that the current technology of emissions control devices works more efficiently with ultra-low sulfur diesel (ULSD) fuel, an important aspect considered in the selection of the test vehicles included the accessibility to ULSD. Fortunately, all the selected vehicles for testing were located within the Federal District in Mexico City where the ULSD is mandatory and readily available in all gas stations. All vehicles tested in this project used ULSD.

d) *Availability of equipment during the sampling period*. Since vehicle owners were participating on a voluntary basis, the availability of the vehicles during the proposed schedule of measurements was a very important aspect for the success of the project.

e) *Owner/operator participation for record keeping*. It is important to have a written record of the vehicle's operations and mechanical conditions before and after the DPF is installed and until the second sampling takes place. The vehicle should also be kept in good mechanical conditions after the installation of the DPF.

3.1.3. Portable emission measurements systems

The following portable emissions measurement systems (PEMS) were used in this project to obtain the relevant emissions data for the test vehicles:

1. **AVL Micro Soot-Sensor** (https://www.avl.com/micro-soot-sensor) portable system, which meets the EPA CERT 1065 certification requirements, to measure black carbon emissions from vehicles in use. The AVL system measures the black carbon with a temporal resolution of one second using a photo-acoustic micro-soot filter gravimetric sensor module [AVL, 2008]. In the photo-acoustic technique, intensity modulated light beam produces periodic heating of absorbing particles, which subsequently dissipate their heat and the resulting pressure fluctuations are detected by a microphone [Schindler et al., 2004]. The microphone signal is linearly related to the BC concentration in the measuring volume. Therefore, the MSS has no cross-sensitivity to other compounds, like hydrocarbons, sulfates or NO_2.

   The sensitivity of the MSS system is 5 $\mu g/m^3$ and the time resolution is 1 sec, which allow determining accurately the emissions from diesel engines equipped with emissions control technologies. The AVL-MSS system has a flow and data signals calibration protocol (no needed for soot as the operating principle is not based on the opacity of the sample) established by the manufacturer on the basis of artificial soot generator CAST

("Combustion Aerosol Standard"), which produces very stable concentrations of soot, together with a rotating disc diluter [Schindler et al., 2004]. The corresponding calibrations recommended by the manufacturer at the beginning of each period of measurements for each test vehicle were performed accordingly. The instrument was securely mounted on an AVL-designed metal frame with a special damping system for protection from damage resulting from shocks and vibrations under harsh operating conditions during field measurements.

2. **SEMTECH ECOSTAR** (http://www.sensors-inc.com/ecostar.html), which is a modular instrument that meets the certification requirements of the EPA CERT 1065. Each module is self-contained and can be operated in a stand-alone testing mode or integrated during real-world operation measurements. Carbon monoxide (CO) and carbon dioxide (CO_2) are measured by a non-dispersive infrared system (NDIR) both with accuracies of ±2%, whereas O_2 is measured with an electrochemical sensor with and accuracy of ±0.3%. Nitrogen monoxide (NO) and nitrogen dioxide (NO_2) are measured separately and simultaneously by a non-dispersive ultraviolet system (NDUV) with accuracies of ± 0.3% [Sensors, 2014]. This instrument uses a heated sampling flow tube measuring system for determining the mass of pollutants emitted. Thus, the concentrations and exhaust flow can be measured in real time, along with exhaust pressure and temperature. The calibration of this equipment required the use of high quality trace gases. Calibrations of the equipment were performed before and after each test. A shock mount plate was used at the bottom of the instrument to isolate the modules from excessive vibration during the tests.

3. **AXION** system (http://globalmrv.com/products/axionrs-2/), which is a portable emissions monitoring system from Global MRV for evaluating on-road and off-road vehicles or stationary equipment. The system consists of measuring hydrocarbons (HC), CO and CO_2 via NDIR systems and measuring NO_x as NO by an electromagnetic cell [Karim 2013]. The PM is measured using a laser light scattering technique. All pollutants were measured on a second by second basis. Data from several laboratories using various vehicles and fuels indicate that AXION accuracy is typically less than 10% for aggregate mass of NO_x and CO_2 [Yazdani and Frey, 2012]. The accuracy of HC and CO measurements depends on the fuel used and the emission levels. In addition to pollutant concentrations, this measurement system also provides vehicle speed, engine rpm, torque, pressure, exhaust flow, the air-fuel ratio, and fuel mass flow rates.

The AXION system has a calibration protocol directly designed by the manufacturer. The gas analyzer utilizes a two-point calibration system that includes “zero” calibration performed using ambient air at frequent intervals, and “span” calibration using a gas mixture of known composition. Due to the stability of output signals for this equipment, it is often not necessary to perform a calibration before each test. Nevertheless, calibrations were performed before the tests as needed following the manufacturer's recommendations.

3.2. Inspection of vehicles

In addition to the organization and planning activities described in the previous section, before the baseline measurements were performed the test vehicles were mechanically inspected by personnel of the company selected for installing the DPFs. To our knowledge, there are no local companies in Mexico that design or install emissions control devices for off-road vehicles. The selected company (Ironman Inc., from California, US) for this project has extensive knowledge and experience in diesel engines, CARB regulations, compliance planning, and installation of diesel emissions reduction technology.

The inspection of test vehicles was carried out during two technical visits in which a Pre-Installation Compatibility (PIC) test was performed for each vehicle. The PIC is a test directed towards the evaluation of the state or condition of the vehicle’s engine and the assessment of the vehicle’s exhaust system as well as the space availability for the installation of the emissions reduction technology. Figure 1 shows some examples of the steps taken during the PIC testing for several of the selected vehicles.

The inspection of the tested vehicles consisted of the following activities:

a) Opacity Test
b) Oil and fuel sample
c) Download engine ECU codes
d) Inspect the air intake system
e) Visual inspection of the engine

In addition to the PIC test, a data logger was installed on the exhaust tube of the test vehicle to obtain a temperature profile under real world operating conditions for several hours. To install the data logger, a technician drilled a small hole (of 3/8 inches in diameter) located about 6 inches after the exhaust manifold, and installed a small temperature probe into the exhaust stream that is connected to a small logger (about the size of a match box, see Figure 1).

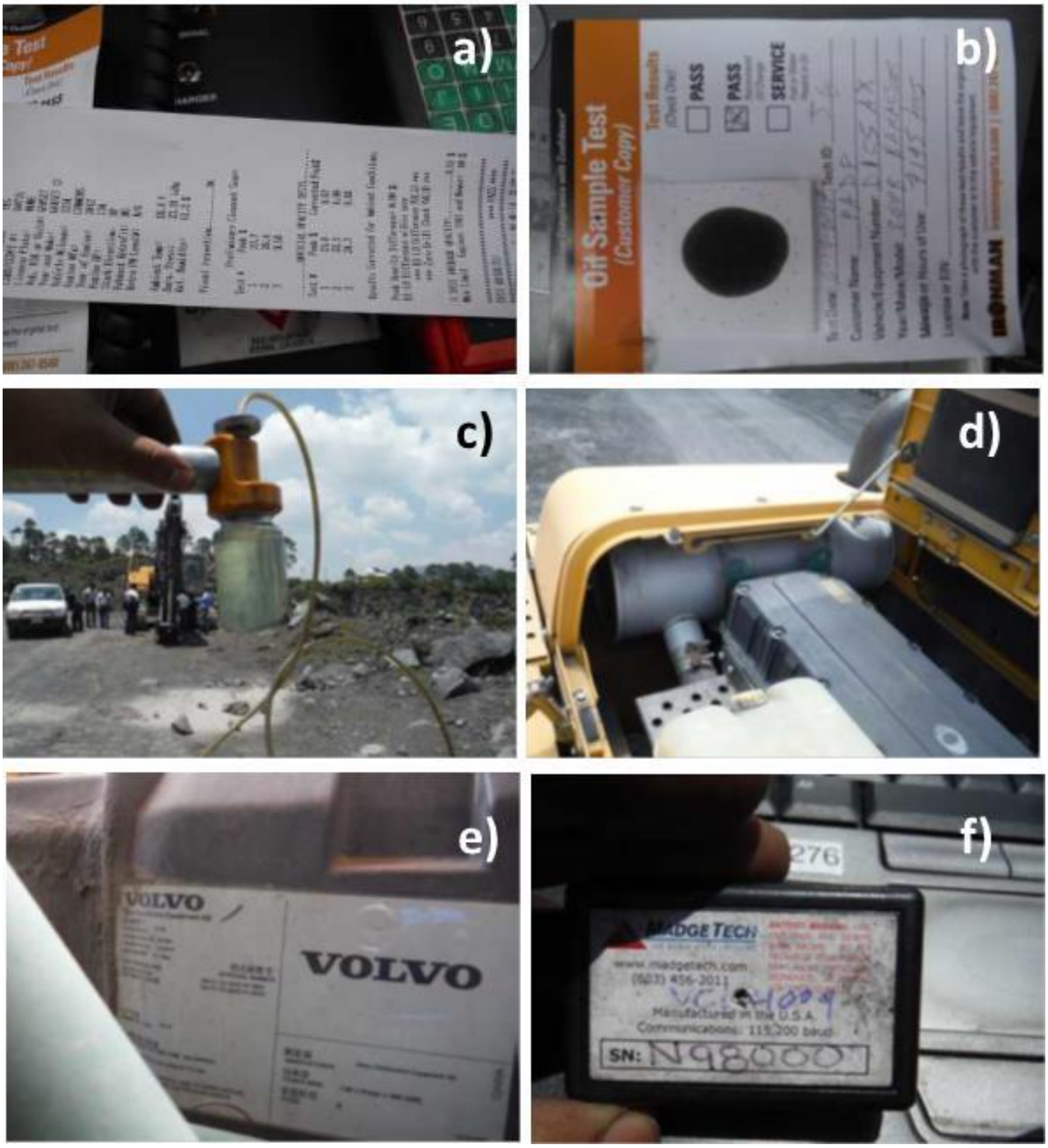

Figure 1. Examples of Pre-Installation Compatibility test procedure during the inspection of selected vehicles. a) results of opacity test, b) results of oil test, c) results of fuel test, d) inspection of engine and space availability for the installation of a DPF, e) vehicle technical data acquisition, f) installation of data logger.

A total of 24 vehicles were originally visited and mechanically inspected following the procedure and criteria developed for this project. Of these, 10 vehicles were further selected as potentially good candidates for the installation of an emissions reduction device. A summary of the results obtained from the inspection of the test vehicles is presented in Table 2. Each of the test vehicles passed the PIC and the additional selection tests (e.g., no excessive vibration, no excessive fuel and oil consumption, etc.) and a given emissions reduction technology was determined by the DPF installer according to the technical characteristics observed.

Data logging of temperature is required to understand better the real world operating conditions of the engine and to assess the best available emissions reduction technology for a given vehicle. The temperature data logging procedure is required for at least 24 hours of vehicle operation. After the process is completed, the data logger and the inserted probe can easily be removed and the hole sealed, without impact to the test vehicle or its engine's performance. This procedure was accomplished during the second technical visit of the DPF installer technician to the selected vehicles, which occurred about 4 weeks after the installation of the data loggers (see Appendix 1).

The Cummins power generator listed in Table 2 was not available for emissions characterization due to conflicts with the measurements schedule. Fortunately, after several potential searches, the Molina Center was able to find additional off-road equipment suitable for the baseline measurements. These equipment included a power generator (Cummins, engine model: 4B3,9-G1) and a heavy-duty air compressor (Cummins, engine model: LT10) used for powering large pneumatic drills. Both the power generator and the air compressor equipment belong to the Asphalt Plant at Parres and were added to the list of vehicles for baseline measurements (see Table 5 below). On the other hand, as described in the next section we were unable to install the DFP and perform the controlled emissions testing for the Link-Belt Crane at Geo-Construction due to last-minute schedule change by the crane owner.

Table 2. Results of the technical inspection of the test vehicles.

	Test Vehicle									
	1	2	3	4	5	6	7	8	9	10
Owner	Asphalt plant at Parres	Asphalt plant at Del Imán	Asphalt plant at Parres	Asphalt plant at Parres	Asphalt plant at Del Imán	Asphalt plant at Parres	Asphalt plant at Del Imán	Private owner	GEO Construcción	
Vehicle type	Back Hoe	Back Hoe	Excavator	Loader	Loader	Dozer D8T	Komatsu - Dozer	Tractor	Crane	Genset
Equip. ID	36-20	36-21	3112	WA600	WA600 - #2	Dozer	Dozer	TS6020	LS138 - 4339	Cummins
VIN	00115	TBD	TBD	KMTWA097A26060405	WA600 - #2	I-421000250-000007	KMT0D074C02080838	004TS60200021210080659	N9J7-9078	TBD
Equip. Make	Komatsu	Komatsu	Volvo	Komatsu	Komatsu	Caterpillar	Komatsu	New Holland	Linkbelt Hitachi	Cummins
Equip. Model	WB146	WB146	EC330B	WA600	WA600	D8T	D155AX-6	TS6020	138 HYLAB	TBD
Model Year	2007	2007	2010	2007	2007	2010	2008	2008	TBD	TBD
Engine Make	Komatsu	Komatsu	Volvo	Komatsu	Komatsu	Caterpillar	Komatsu	New Holland	Mitsubishi	Cummins
Engine Model	84D102	84D102	D12D	SAA6D170E-5	SAA6D170E-5	C15	SAA6D170E-5	TBD	TBD	6BT5.9-G2
Engine Year	2007	2007	2010	2007	2007	2010	2008	2008	TBD	2001
HP (ecu)	96	96	328	531	531	535	360	105	TBD	150
ESN	46940		857401	510913	510975	LHX25932	535123	TBD	6D16-A00050	87371816
EFN	7KLXL0275AAC	7KLXL0275AAC	TBD	7KLXL23.2FD6	7KLXL23.2FD6	ACPXL15.2ESW	8KLX15.2ED6	TBD	TBD	1CEXL0359ADA
Recommended[1]	p.DPF	p.DPF	DCL - Mine-X	DCL - Mine-X	DCL - Mine-X	DCL - Mine-X	DCL - Mine-X	DCL - DOC only	DCL - Mine-X	TBD
Equip. hours	TBD	TBD	2951	TBD	TBD	1348	TBD	TBD	5664	1234
Oil	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Fuel	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Opacity	14.10%	15.10%	3.48%	16.10%	15.60%	14.60%	10.80%	9%	11%	9.51%
240C @	58.76%	27.80%	75%	61.59%	61.86%	74.60%	0%	TBD	TBD	N/A
260C	54.22%	23.05%	71.39%	59.22%	56.71%	71.39%	0%	TBD	TBD	N/A
280C	49.55%	17.89%	67.94%	56.95%	50.90%	67.94%	0%	TBD	TBD	N/A
300C	45.30%	13.16%	64.44%	54.71%	43.34%	64.445	**0%**	TBD	TBD	N/A
DL pass[1]	Yes	Yes	Yes	Yes	Yes	Yes	TBD	N/A	TBD	N/A

[1]For Verified Diesel Emissions Control (VDEC).

4. Results

4.1 Measurement setup

Three complementary PEMS equipment were used for the emissions characterization of the tested vehicles, namely, the AXION that measures hydrocarbons CO, CO_2, NO_x, and PM10); the AVL Micro-Soot Sensor that measures BC in PM; and the SEMTECH ECOSTAR that measures the exhaust flow, CO, CO_2, NO and NO_2. All the parameters were measured at high-frequency resolution (1 second), allowing to capture the large temporal variability during real world operating conditions. The AVL-MSS and the SEMETCH ECOSTAR were used in all tested vehicles for co-measuring the gaseous and PM emission components, whereas the AXION PEMS system was interchangeably used in several selected test vehicles as described below.

The co-location sampling of the AXION and the SEMTECH ECOSTAR PEMS during the measurements in the same tested vehicles allowed the comparison of the emissions results for gaseous components. Similarly, the use of the co-location sampling with the AVL-MSS and the AXION PEMS allowed obtaining information on the fraction of emitted BC in the larger PM size for the tested vehicles.

The measurement of the emissions of the selected off-road vehicles involved a large number of preparatory activities before the tests were actually performed. Some of these activities are illustrated in Figure 2. A more detailed list of these activities is presented in Table 3. Similar procedures were followed in the measurements with the emissions control devices. Since each selected vehicle had a different geometry and accessibility, it was necessary to determine a priori the best possible solution for an appropriate location for safely mounting each PEMS, a portable power generator, zero air, and other needed accessories on the –often limited- space available for a given test vehicle. Similarly, each vehicle presented the challenge of designing and manufacturing a sampling line that would connect the vehicle exhaust with the DPF installed to the instruments inlet. Additionally, every step was taken to ensure no permanent modification of the test vehicles, as requested by the vehicle owners.

One of the top priorities during the measurements was securing the structural integrity of all the mounted instruments and equipment. This was particularly challenging to do for heavy-duty off-road vehicles that typically perform rough activities in a harsh environment, even when the operation procedures were described beforehand with the vehicle operators. Minimizing the large vibrations that were experienced on the selected vehicles required extensive use of dampening material and safety straps for safely holding the equipment and their accessories.

Due to the extreme vibrations and high temperatures, the dampening material often had to be replaced between tests.

Special attention was also taken not to interfere with the normal operations of the operators of the off-road vehicles during the tests, as well as to no pose any safety risks to their operations. All team participants wore safety gear during the measurements. Due to the coincidence of the measurements program with the end of the raining season in Mexico City, weather conditions were a constant concern during the planning and execution of the baseline measurements; some of the scheduled measurements had to be interrupted and re-scheduled due to heavy rain. Nevertheless, all these precautions paid off in that no safety or serious instruments damage occurred during the measurements.

Table 3. List of activities performed before measurements.

Activity
1. Review with hosts/collaborators the operation procedures and requirements for the measurements
2. Record technical specifications of the test vehicles
3. Review preventive maintenance program (oil change and filters) of test vehicles
4. Check structural integrity of off road equipment and identify security concerns
5. Determine space availability for installation of equipment
6. Measure exhaust pipe diameter of test vehicle
7. Inspect exhaust system integrity
8. Check on-site electrical availability
9. Design/construct the metal rack that will hold the instruments
10. Determine the instruments installation layout
11. Design sampling line from exhaust to location of PEMS
12. Determine/obtain requirements for installation of sampling probe and exhaust pipe

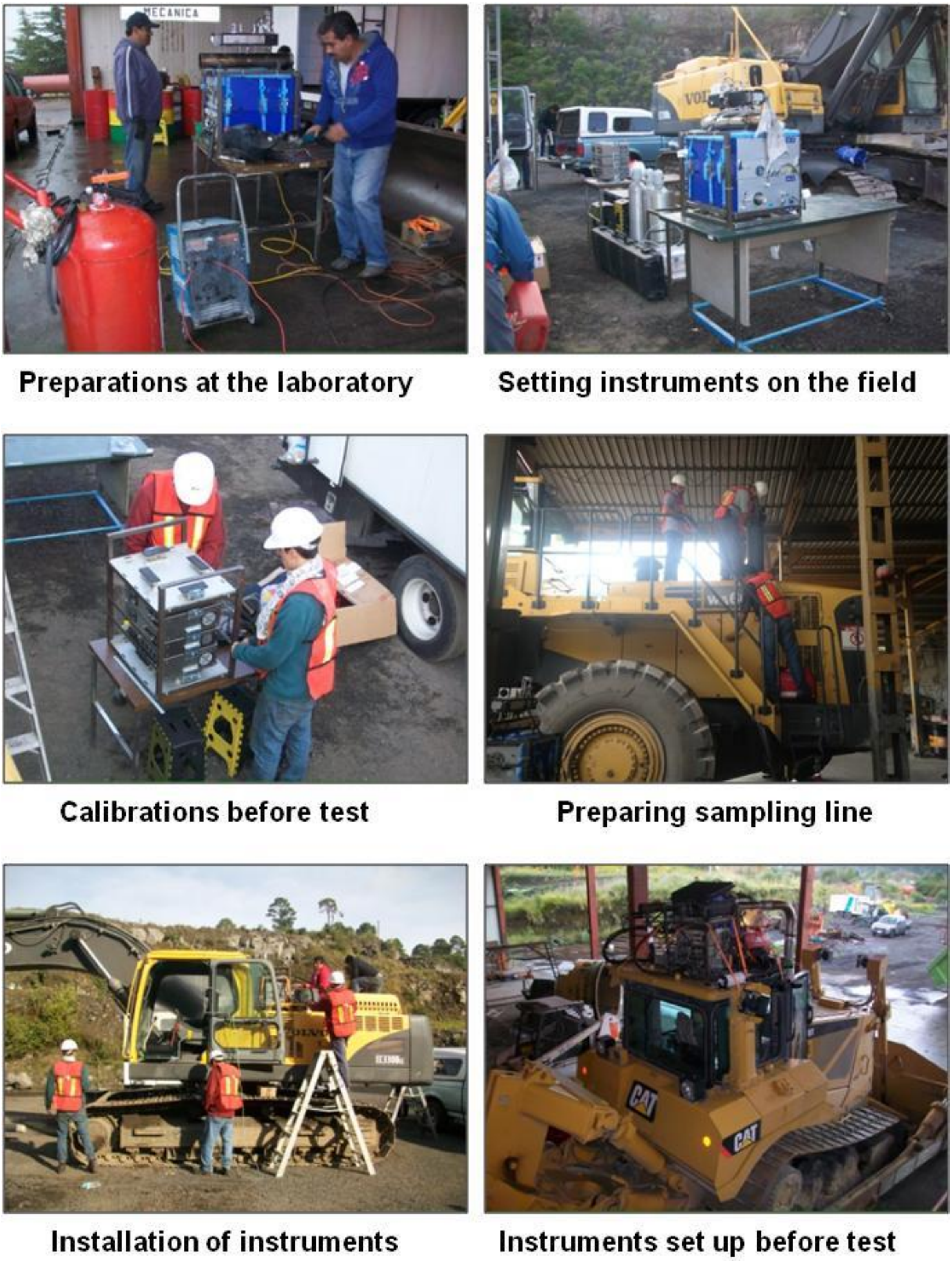

Figure 2. Illustration of procedure performed during preparation for testing and instruments set up for emissions characterization of several test vehicles.

4.2 Measurement protocol

The measurement protocol was developed by the team participants during the preparation activities of the tests. Nevertheless, the protocol itself was intended to be continuously updated as needed by the principal investigator in collaboration with the project team members before and during a given test was performed to adjust for whatever unexpected special requirements on the field. The measurement protocol included steps to be taken during the installation of the PEMS equipment and the needed accessories as well as the operation procedures that were to be followed during the actual measurements. As described before, safety for all participants involved in the project was the main driver for designing the measurement protocol. Table 4 shows the general activities for the protocol to be followed during experiments, both before and after installation of the emission control devices.

Table 4. Measurements protocol.

Installation of PEMS on test vehicle	
1.	Review with hosts/collaborators the procedures and requirements for the measurements
2.	Check the availability of items and accessories for the AVL-MSS, AXION, and ECOSTAR.
3.	Check electrical availability
4.	Review with participants the instruments installation layout
5.	Secure and install instruments rack to off road vehicle
6.	Secure and install each instrument on installed rack
7.	Check electrical connections to electric generator
8.	Installation of sampling line
9.	Verify the orientation of measurement port and probe
10.	Check/connect accessories (e.g. zero air) to the instruments and plug instrument to electric generator
11.	Perform tryout data acquisition. To do this follow instrument's sampling procedures. Let the first plume get out.
12.	Perform instruments calibrations
13.	Perform assessment of data collected. Solve problems and concerns as needed. This is our best chance to solve some of the instrument issues that might arise
14.	Visual record of installation and check for integrity of instruments.
15.	Visual assessment of tie downs, rack, roof, electric generator.

16.	Asses instrument integrity with onsite security personnel
Sampling of test vehicle	
17.	Review the operation test activities with operator of off-road vehicle
18.	Perform Time alignment for the computers
19.	Measure the fuel and operation hours at the beginning of the test
20.	Perform data acquisition following each PEMS sampling procedures
21.	Keep notes (measurements logbook) on the operation
22.	Stop vehicle if possible and retrieve data from instrument. Please be sure that data retrieval is done in a safe and secure conditions
23.	Perform quick assessment of acquired data. If needed, check error log and correct error
24.	Measure the fuel consumption
25.	Repeat data acquisition as needed
26.	Perform data back up
27.	Determine the need of additional measurements for that vehicle on the basis of the previous step
28.	Dismount equipment in a safe and secure environment

4.3 Baseline sampling of off-road vehicles

A description of the ten off-road vehicles selected for the baseline measurements is presented in Table 5. The selected equipment (backhoes, tractor, hammer, front loaders, dozers, crane, compressor, power generator) represents an important variety of heavy and medium duty diesel off-road vehicles. As described in the table, three of the test vehicles were sampled in two occasions due to either limited amount of data collected (e.g., if rain was approaching, for safety the test had to be interrupted and the test re-scheduled) or instruments malfunction. Additional sampling days were also programmed but needed to be cancelled early on due to weather conditions. Figure 3 illustrates several steps following the protocol during the measurements of selected off-road vehicles. Note that in some vehicles the space available for the installation of the instruments and accessories was rather limited and yet the equipment had to be securely installed.

Following the measurements protocol described in the previous section, an important part of the activities was to record with a logbook the operation events of the test vehicles. An example of the logbook events recorded for one of the selected off-road vehicles during both the baseline and filter-installed measurements is presented in Appendix 3. The operation activities were discussed before the test with each vehicle operator and requesting to follow them as much as possible. The operations themselves were suggested by the operators as the typical working activities of the off-road vehicle and often included: pulling, pushing, lifting, moving, dragging, and hammering, depending on the activities of the vehicle. These activities were carefully recorded as part of the logbook activities for each test. The information on the operations for each vehicle will be essential for the estimation of emissions factors from the obtained data.

Measurements were performed within the normal working areas for each test vehicle in Topilejo (2,700 m a.s.l.), Parres (2,990 m a.s.l.), and the Federal District (2,250 m a.s.l.) and thus represent high altitude sampling conditions. None of the tested vehicles had any major engine maintenance between the baseline and filter-installed measurements. The field logbooks recorded the vehicle operating conditions under which the measurements were obtained during the tests and included descriptions of the technical characteristics of the vehicles, the start and ending times for each test, the vehicle fuel tank level, hours of operation, as well as details on the operation conditions of the vehicles. Operational temperature (at the engine) was not measured. However, ambient and exhaust gas temperatures (at the sampling point) were obtained by the PEMS and are included in the delivered databases.

Sampling periods for each operation typically lasted 10 minutes and were repeated at least three times for each vehicle. In between each of these tests, the off-road vehicles were stopped (without turning off the test vehicle or the sampling instruments) and the data acquisition was confirmed and equipment safety conditions were reviewed. If any error conditions were detected, they were corrected before initiating the repetition of the next test. Due to the high-time resolution of the measurements and the multiple parameters obtained by each of the PEMS systems, abundant databases of the emission characteristics of the sampled vehicles have been obtained for each of the tested vehicles. Similarly, the obtained data is rich in operation conditions for a given test vehicle that will allow the analysis of their emissions characteristics by operation conditions.

Table 5. Vehicles tested during the baseline measurements.

Test	ID	Date	Make (Year)	Type	Vehicle ID	Photo	Location	PEMS
1	**1a**	9/18/2014	Komatsu 2010	Backhoe	WB-146 Iman		Asphalt plant at Del Imán	AVL-MSS ECOSTAR AXION
2	**2**	9/20/2014	Volvo 2008	Hammer	EC3308-LC		Asphalt plant at Parres	AVL-MSS ECOSTAR
3	**3a**	9/23/2014	Komatsu 2010	Front loader	WA-600 at Del Iman		Asphalt plant at Del Imán	AVL-MSS ECOSTAR AXION
4	**4**	9/25/2014	Komatsu 2008	Dozer	155-AX		Asphalt plant at Del Imán	AVL-MSS ECOSTAR AXION
5	**5**	9/26/2014	Komatsu 2010	Backhoe	WB-146 Parres		Asphalt plant at Parres	AVL-MSS ECOSTAR AXION
6	**6a**	9/30/2014	New Holland 2009	Tractor	TS- 6020		Private owner at Topilejo	AVL-MSS ECOSTAR
7	**7**	10/3/2014	Caterpillar 2008	Dozer	D8T		Asphalt plant at Parres	AVL-MSS ECOSTAR
8	**1b**	10/7/2014	Komatsu 2010	Backhoe	WB-146 Del Iman		Asphalt plant at Del Imán	AVL-MSS ECOSTAR
9	**3b**	10/10/2014	Komatsu 2010	Front loader	WA-600 at Del Iman		Asphalt plant at Del Imán	AVL-MSS ECOSTAR
10	**8**	10/14/2014	Link-Belt 2009	Crane	LS-138H5		Geo-Cons-trucción	AVL-MSS ECOSTAR
11	**6b**	10/16/2014	New Holland 2009	Tractor	TS- 6020		Private owner at Topilejo	AVL-MSS ECOSTAR
12	**9**	10/17/2014	Cummins 1999	Compressor	LT10		Asphalt plant at Parres	AVL-MSS ECOSTAR
13	**10**	10/17/2014	Cummins 2010	Power generator	4B3,9-G1		Asphalt plant at Parres	AVL-MSS ECOSTAR
14	**11**	10/31/2014	Komatsu 2010	Front loader	WA-600 at Parres		Asphalt plant at Parres	AVL-MSS ECOSTAR AXION

Performing test on dozer

Performing test on excavator

Performing test on front loader

Performing test on backhoe

Revisions between tests

Measuring team after test

Figure 3. Illustration of procedure performed during emissions characterization of several test vehicles.

Due to the high-frequency resolution of the measurements and the multiple parameters obtained by each of the PEMS systems, abundant databases of the emission characteristics of the sampled vehicles have been obtained, which is rich in operation conditions for a given vehicle. Figure 4 presents an example of the black carbon concentration data obtained during the baseline test of one of the backhoe vehicles. During real-world operating conditions for off-road vehicles, the concentration of emitted pollutants can vary by several orders of magnitude. Using Figure 4 as an example of the variability of emissions encountered during real-world operating conditions, the following list describes the events that the test vehicle was performing during a given sampling period (red letters in Figure 4).

a. Short peak related to start-up of vehicles' engine (but not cold emissions). Vehicle idles for a few minutes.
b. Vehicle moves out of the installation and instruments setup area to the testing area.
c. First test is performed using the front (bigger) bucket lifting and moving a large pile of dirt as testing material.
d. Second test with the front bucket starts, but is stopped for several minutes to check safety wrap strips of equipment.
e. Second test with front bucket continues, but another safety check is soon required.
f. Second test with front bucket is finished.
g. Third test with front bucket is accomplished.
h. Backhoe maneuvers for positioning itself ready for tests with smaller back-side bucket.
i. First test with smaller back bucket is accomplished.
j. Second test with smaller back bucket is accomplished.
k. Third test with smaller back bucket is accomplished.
l. Backhoe maneuvers and is moved back to the original area of installation and instruments setup.
m. Backhoe is idling.

The data obtained presents highly transient variations that reflect the operating conditions of the off-road vehicle during its working activities. Similarly, high temporal variability is also observed in the measured gas phase components for each vehicle type. Correspondingly abundant gaseous and PM emissions databases have been obtained for the selected vehicles described in this report. The time series of the gaseous and black carbon data obtained for each of the test vehicles is presented in Appendix 4. These represent the baseline measurement conditions for comparison with the results of the measurements of the same vehicles but with DPF installed.

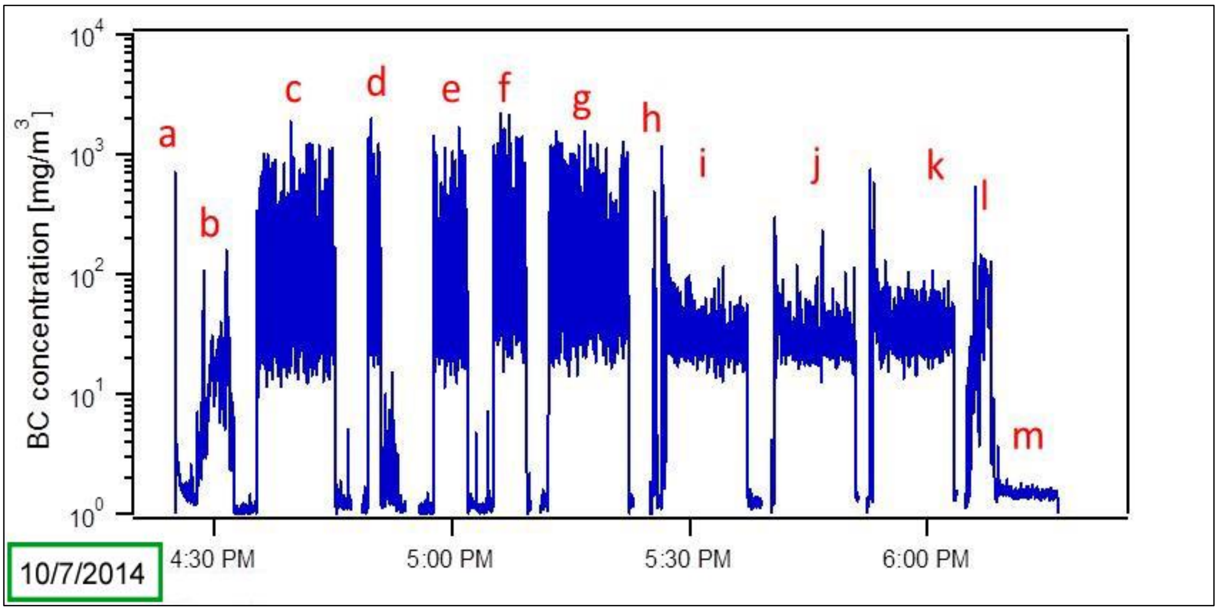

Figure 4. Black carbon concentrations obtained during the test of the Komatsu WB146 backhoe at the asphalt plant at Del Imán showing different operational conditions. See text for explanation of red letters.

4.4 Installation of DPFs for off-road vehicles

The installation of the DPF represents a difficult challenge due to the diversity in the exhaust pipe sizes, geometry and space availability for the installation of the filter, as well as specific requirements requested by the vehicle owners. Prior to the installation of each of the DPF devices, the installer carefully inspected the vehicles to overcome those challenges as described in Section 3.2. Figure 5 shows three examples of the installation of the emission control devices in different off-road vehicles that were tested in this project.

Figure 5. Installation of the emissions control devices on three test vehicles. Top: Permanent installation of the DPF on the exhaust of the Volvo excavator. Middle: Picture of the side view of the DPF installed on the exhaust of the tractor. Bottom: Installation and measurements of the Komatzu Dozer with the DPF installed in temporarily mode.

In the US, the EPA and CARB have verified the emissions performance of retrofit devices through specific testing protocols and statistical analysis. Just as in real-world operating conditions the actual emissions reductions for each emissions control device installed in an off-road vehicle will depend on several parameters, the associated costs will depend on the technology used and its application. Based on the accumulated experience with retrofitting diesel technologies, the EPA provides estimates for the costs in the US of several emissions control devices as shown in Table 6 [US EPA, 2013].

Table 6. Estimated typical costs (in US dollars) of diesel emissions control devices.

Technology	Typical costs (material)	Installation time
Diesel Oxidation Catalyst	$600-$4,000	1-3 hours
Diesel Particle Filter active or passive	$8,000-$50,000	6-8 hours
Partial Diesel Particulate Filter-Partial of Flow through	$4,000-$6,000	6-8 hours
Selective Catalytic Reduction	$10,000-$20,000 Urea $.80/gal	NA

Source: US-EPA, 2013.

The costs that EPA estimates in Table 6 do not include installation of the emissions control devices. Except for the Selective Catalytic Reduction, which requires the stock of urea, the devices do not require any supply material to perform. Nevertheless, as in any filtering technology, the accumulation of captured material may increase the pressure of the system reducing the performance and eventually the lifetime of the filter. In these cases the filters need to be treated thermally in a process known as “regeneration” in which the filter is cleaned — "regenerated" to its original state — by burning off the soot at a high temperature.

Passive regeneration occurs automatically when exhaust gases are hot enough during normal engine operation to burn off accumulated soot. This is a semi-continuous process that occurs when exhaust temperatures are sufficiently high, and is not noticeable to the operator. Active regeneration occurs when enough soot accumulates in the filter to raise exhaust backpressure to a predetermined limit. The process is initiated by injecting fuel into the exhaust automatically, requiring no operator interaction. The lifetime of the filter can also be monitored by the operator using an Electronic Control Unit (ECU) that continuously monitors the backpressure of the vehicle's exhaust system and display on the vehicle dashboard whether the filter may need regeneration. Material and installation costs may vary substantially between active and passive filter devices depending on the size of the engine.

As shown in Figure 5, some of the DPF installations had to be done externally to the test vehicle and the measurements had to be performed in static mode only. This was the case for the two front loaders and the two bulldozers belonging to the Asphalt Plant. Thus, the DPFs were installed only temporally while the measurements were carried out for these vehicles. The main reason was because of the size and complexity of the DPFs. In order to permanently install the emissions control devices in these vehicles, this would require making significant modifications to the test vehicles, which would imply putting these vehicles completely off their current workload for several days. This in turn would imply stopping the production line for the asphalt plant - a situation that was not affordable by the vehicles owner. Nevertheless, the other emissions control devices have been installed permanently and would allow monitoring their performance in the months ahead.

4.5 Sampling of off-road vehicles with emission control devices

The list of measured vehicles after the emission control devices were installed in their exhaust pipes is presented in Table 7. The type of emissions control device installed on each vehicle is also listed in the table. Only the backhoe at the asphalt plant in Av. Del Imán required the re-scheduling of a second test. As in the "baseline" measurements, each test was given an ID number. Each number refers to the measurement test carried out with a control device (the letter C refers to Controlled following the ID identifier in Table 5). The use of these identifiers will allow the direct comparison of results between vehicles tested with and without emission control devices.

Figure 6 shows a time series example of the achievable concentrations before and after a DPF was installed for the same backhoe described in Figure 4. As observed in Figure 6 (top panel), more than 2,000 mg/m^3 of black carbon could be emitted by a backhoe during a regular cycle in the baseline measurement conditions. After the emission control device was installed in the same backhoe, concentrations for a regular cycle did not exceed the 600 mg/m^3 (Figure 6, bottom panel).

Table 7. Vehicles tested after the installation of the emission control devices.

Test	ID	Date	Make (Year)	Type	Vehicle ID	Location	PEMS	Control type
15	**C_5**	11/22/2014	Komatsu 2010	Backhoe	WB-146 Parres	Asphalt plant at Parres	AVL-MSS ECOSTAR AXION	p-DPF
16	**C_1a**	11/24/2014	Komatsu 2010	Backhoe	WB-146 Parres	Asphalt plant at Del Imán	AVL-MSS ECOSTAR AXION	p-DPF
17	**C_4**	11/25/2014	Komatsu 2008	Dozer	155-AX	Asphalt plant at Del Imán	AVL-MSS ECOSTAR AXION	DPF
18	**C_6**	11/29/2014	New Holland 2009	Tractor	TS- 6020	Private owner at Topilejo	AVL-MSS ECOSTAR	p-DPF
19	**C_2**	12/1/2014	Volvo 2008	Hammer	EC3308-LC	Asphalt plant at Parres	AVL-MSS ECOSTAR	DPF
20	**C_11**	12/1/2014	Komatsu 2010	Front Loader	WA-600	Asphalt plant at Parres	AVL-MSS ECOSTAR AXION	DPF
21	**C_7**	12/2/2014	Caterpillar 2008	Dozer	D8T	Asphalt plant at Parres	AVL-MSS ECOSTAR AXION	DPF
22	**C_10**	12/5/2014	Cummins 2010	Generator	4B3,9-G1	Asphalt plant at Parres	AVL-MSS ECOSTAR AXION	DPF
23	**C_3**	12/5/2014	Komatsu 2010	Front Loader	WA-600	Asphalt plant at Del Imán	AVL-MSS ECOSTAR AXION	DPF
24	**C_1b**	12/6/2014	Komatsu 2010	Backhoe	WB-146 Parres	Asphalt plant at Del Imán	AVL-MSS ECOSTAR AXION	p-DPF

DPF: DCL Mine-X Sootfilter (Diesel Particulate Filter, passive regeneration)
p-DPF: DCL Mine-X Partial-Flow Diesel Particulate Filter

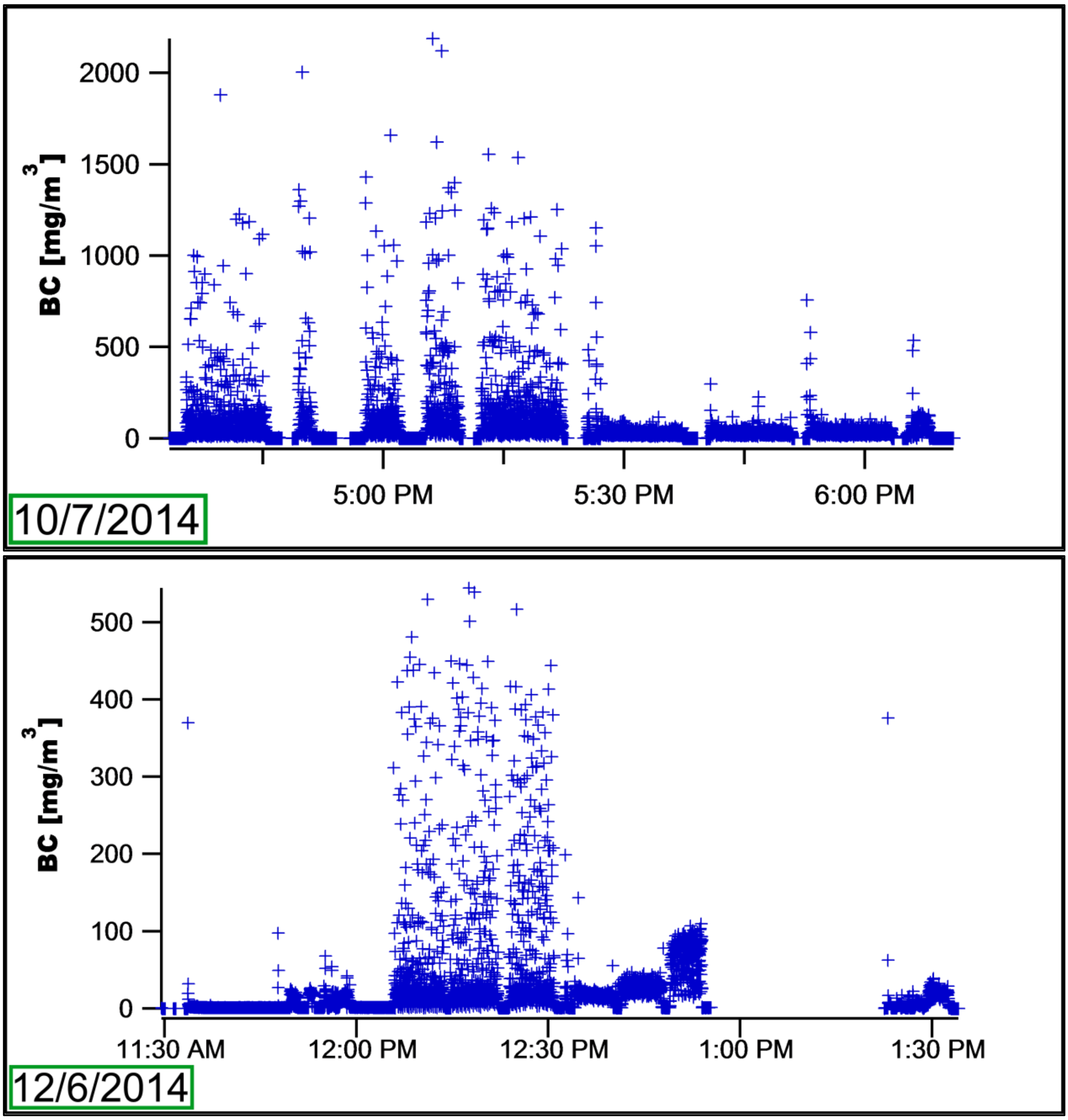

Figure 6. Black carbon concentrations obtained during the baseline measurements (top panel) and after the installation of an emission control device (bottom panel) of a Komatsu backhoe at the asphalt plant at Del Imán.

For the reasons explained in the previous section, for the two front loaders and the two bulldozers vehicles from the asphalt plant their DPFs were installed only temporally and the measurement test were done in stationary mode. For these vehicles, the comparison of their emissions characteristics can only be made with the time periods during the baseline measurements when the vehicles were actually in stationary mode. As explained in the measurements protocol, these periods occurred typically at the beginning of the measurements right after the calibrations of the instruments and before transporting to the testing area, as well as in-between operative-mode measurements pauses for inspection of equipment integrity and data collection for each tested vehicle. The time series of the data obtained for each of the selected vehicles with and without the installation of the emissions control devices is presented in Appendix 4.

5. Conclusions and Recommendations

This report describes the activities undertaken by the Molina Center project team and collaborators before and during the measurements of off-road vehicles with and without the installation of the emission control devices. Numerous activities have been performed by the collaborating teams to accomplish the objectives of this project, highlighting: planning of logistics for measurements; field visits to several off-road vehicles and organizational meetings with host institutions; setup of multiple instruments and accessories; acquisition of consumables; inspection of vehicles and application of selection criteria; selection of vehicles for measurements; development and implementation of measurements protocol; performing integrated AVL-MSS, ECOSTAR, and AXION calibrations and baseline sampling for each test vehicle; selection, acquisition and installation of emissions control devices for each test vehicle and performing integrated measurements with emissions control devices installed. The measurements during both baseline and with-filter phases were accomplished without any injury to personnel or serious instruments damage.

The gaseous and PM emissions of eleven off-road vehicles have been measured in the baseline phase of this project and nine of the selected vehicles from the baseline were measured with emissions control devices. The measurements represent abundant databases that have been obtained for the first time in Mexico of the emission characteristics of the sampled vehicles under real-world operating conditions. The databases for each selected vehicle have been organized and archived and have been included as electronic deliverables to the project’s sponsors.

The selected vehicles include: backhoes, tractor, crane, hammer, front loaders, dozers, compressor, and a power generator, representing an important variety of heavy- and medium-duty diesel off-road vehicles. Nevertheless, given that currently in Mexico there is no detailed information on the number, type and engine characteristics of the off-road vehicles in operation in the country, the implementation of technology-based mitigation strategies at large scale in the future should include efforts to support the compilation of fleet characteristics and reliable activity data for these vehicles. Fortunately, several of the institutions and key contact persons that collaborated in this project could help as a starting point to gather the much needed information.

Currently, to our knowledge, there are no local companies in Mexico that design or install DPFs for off-road vehicles; the emissions control devices for this project would have to be acquired elsewhere. Similarly, all vehicles tested in this project used ULSD before, during, and after the measurements took place. However, the availability of ultra-low sulfur diesel in all the Mexican territory is currently not yet a reality. The analysis of these and other additional aspects for the economic and political feasibility of implementing a technology-based mitigation strategy for off-road vehicles in Mexico is beyond the scope of this project. Nevertheless, it is anticipated that the results from this pilot demonstration project can be used for assessing the impacts of implementing readily available control emissions technologies in Mexico and for building scenarios and mitigation measures. This will support the accomplishment of USAID's interest components that include the development of clean energy pilot projects for emissions mitigation, providing a proof of concept of emission reduction projects as a basis for adoption of mitigation strategies for low-carbon development, and to serve as an effective demonstration to promote the implementation of mitigation projects at larger scale.

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Appendix 1

Measurements planning activities

Date	Activity	Participants
06-07 to 06-13, 2014	• Purchase of insurance and importation of AVL-MSS instrument to Mexico • Transport of AVL-MSS instrument to INECC's laboratory facilities	MCE2
06-15 to 06-18, 2014	• Visits of DPF installer to potential test vehicles and installation of data loggers (see document text for details)	MCE2, INECC, DPF installer
06-26-2014	• Requesting quotation of calibration gases for ECOSTAR system	MCE2, ITESM
06-27-2014	• Sent of AXION PEMS to US for calibration	MCE2, CCA-UNAM
06-30-2014	• Transport of ECOSTAR PEMS system to INECC's laboratory facilities for performing tryout tests • AXION PEMS is shipped back to Mexico from calibrations in the US	MCE2, ITESM, INECC
07-01-2014	• Preparation test tryout of ECOSTAR • Elaboration of working plan	MCE2, ITESM, INECC
07-02-2014	• Design and construction of zero air supply for the AVL-MSS instrument	MCE2, INECC
07-03-2014	• General meeting; elaboration of working plan • Elaboration of list of needed consumables • Contact asphalt plant director to request permission to inspect vehicles • Selection of electric generator	MCE2, ITESM, CCA-UNAM, INECC
07-04-2014	• Perform a tryout test with the MSS and ECOSTAR on the INECC's Isuzu van	MCE2, ITESM, INECC
07-05-2014	• Visit to asphalt plant for determining the need of installing an additional pressure sampling port for the AXION system	MCE2, CCA-UNAM
07-07-2014	• Transport of AXION system to INECC laboratory facilities for performing integrated tryout test	MCE2, CCA-UNAM, INECC
07-08-2014	• Design of metal frames for securing the instruments	MCE2, ITESM, CCA-UNAM, INECC
07-12-2014	• Purchase of insurance for additional sampling equipment	MCE2
07-16-2014	• Importation of electric generator and vibration damper for the AVL-MSS instrument	MCE2

07-16 to 07-18, 2014	• Visits of DPF installer to potential test vehicles, removal of previously installed data loggers (see document text for details)	MCE2, INECC, DPF installer
08-04, 2014	• Review of results from data obtained from data loggers	MCE2, DPF installer
07-11 to 09-15, 2014	• Visits to selected sites for defining the construction with a local welder of metal frames for securing the instruments and sampling lines for each vehicle	MCE2, ITESM, CCA-UNAM, INECC
09-16, 2014	• Acquisition of tools, laptop to use during tests, safety gear, and additional consumables • Purchase of calibration gases for ECOSTAR system	MCE2
09-18 to 10-17, 2014	• Performing baseline measurements (see text for details)	MCE2, ITESM, CCA-UNAM, INECC
10-20 to 11-20, 2014	• Meetings with vehicles owners for defining a measurements calendar	MCE2, ITESM, CCA-UNAM, INECC
10-20 to 11-20, 2014	• Purchase of filters and their importation to Mexico • Importation of filters installation tools and supplies	MCE2, IRONMAN
11-05 to 12-05, 2014	• Installation of filters (see text for details)	IRONMAN
11-05 to 12-06, 2014	• Performing measurements with filters installed (see text for details)	MCE2, ITESM, CCA-UNAM, INECC
12-05 to 12-10, 2014	• Organization equipment and cleaning of instruments • Re-importation of AVL-MSS instrument • Meeting with hosts and collaborators	MCE2, ITESM, CCA-UNAM, INECC

Appendix 2

List of vehicles visited for this project

Vehicle type	Model	Power (HP)	Year	Institution	Criteria
Wheel loader	Caterpillar 966C 	170	-	Sugarcane, Zacatepec	**Location**: Zacatepec **Security**: Yes **Space for equipment**: Yes **Space for test**: Yes **Opacity**: NA **Maintenance**: Preventive, according to operation logs. **Observations**: It is too far from DF to transport the equipment and personnel.
	Komatsu WA600 	530	2010	Asphalt Plant, Av. Del Imán	**Location**: Av. Iman. **Security**: Yes **Space for equipment**: Yes **Space for test**: Yes **Opacity**: K: 0.76 m-1 **Maintenance**: Preventive, according to operation logs. **Observations**: It is necessary to carry out another visit to confirm space availability, as well as exhaust distance to measurement equipment.
Compactor	HAMM HD90 	134	2009	Public works	**Location**: Secretaría de Servicios Urbanos D.F. **Security**: Yes **Space for equipment**: No **Space for test**: No **Opacity**: 1.96 (high) **Maintenance**: Preventive, according to operation logs. **Observations**: Given the "emergency" use of the vehicle, its availability for the test may be limited. Low vibration, hardy rooftop. However, exhaust is under the vehicle, so a special assembly is required.
	Hamm, HD90 	134	2010	Special projects, Public Works	**Location**: Undetermined **Security**: NO **Space for equipment**: Yes **Space for test**: No **Opacity**: 3.6 m-1 **Maintenance**: Preventive, according to operation logs. **Observations**: Asphalt temperature dependent. No facilities available for measurement equipment installation. No security available. Also, exhaust pipe location is hard to reach.
Backhoe-loader	JCB – 3CX 	85	2011	Public works	**Location**: Secretaría de Servicios Urbanos D.F. **Security**: Yes **Space for equipment**: Yes **Space for test**: No **Opacity**: 1.74 (High) **Maintenance**: Preventive, according to operation logs. **Observations**: Given the "emergency" use of the vehicle, its availability for the test may be

					limited. Sturdy rooftop, as well as space available for GenSet (area over the batteries).
	Caterpillar 	85	2011	Public works	**Location**: Secretaría de Servicios Urbanos D.F. **Security**: Sí **Space for equipment**: Yes **Space for test**: No **Opacity**: 0.73 (Low) **Maintenance**: Preventive according to operation logs. **Observations**: Given the "emergency" use of the vehicle, its availability for the test may be limited. Sturdy rooftop, as well as space available for GenSet (area over the batteries)..
	Komatsu WB146 	88	2010	Asphalt plant, Del Imán	**Location**: Asphalt plant at Del Imán **Security**: Yes **Space for equipment**: Yes **Space for test**: Yes **Opacity**: 2.44 (high) **Maintenance**: Preventive, according to operation logs. **Observations**: It is necessary to carry out another visit to confirm space availability.
	Caterpilar 		N/A	Special projects, Public Works	**Location**: Undetermined **Security**: NO **Space for equipment**: Yes **Space for test**: No **Opacity**: Pending **Maintenance**: Preventive, according to operation logs. **Observations**: Asphalt temperature dependent. No facilities available for measurement equipment installation. No security available.
Rubber wheeled roller	Hamm, GRW15 	114	2010	Special projects, Public Works	**Location**: Undetermined **Security**: NO **Space for equipment**: Yes **Space for test**: No **Opacity**: 3.6 m-1 **Maintenance**: Preventive, according to operation logs. **Observations**: Asphalt temperature dependent. No facilities available for measurement equipment installation. No security available.
Cold planner (fresadora)	Roadtech, RX500	500	2010	Special projects, Public Works	**Location**: Undetermined **Security**: NO **Space for equipment**: Yes **Space for test**: No **Opacity**: N/A **Maintenance**: Preventive, according to operation logs. **Observations**: Asphalt temperature dependent. No facilities available for measurement equipment installation. No

					security available.
Crawler Dozer	Komatsu 155AX 	354	2010	Asphalt Plant, Av. Iman	**Location**: Av. Del Imán. **Security**: Yes **Space for equipment**: Yes, on the roof-top **Space for test**: Yes **Opacity**: K: 0.76 m-1 **Maintenance**: Preventive, according to operation logs. **Observations**: It is necessary to carry out another visit to confirm space availability, as well as exhaust distance to measurement equipment.
Broce Broom		N/A	N/A	Special projects, Public Works	**Location**: Undetermined **Security**: NO **Space for equipment**: No **Space for test**: No **Opacity**: N/A **Maintenance**: Preventive, according to operation logs. **Observations**: Asphalt temperature dependent. No facilities available for measurement equipment installation. No security available. Leakages in the exhaust system.
Agricultural tractor	Ford 6600 	77	1981	Topilejo's Farmers Union	**Location**: Topilejo **Security**: No **Space for equipment**: No **Space for test**: No **Opacity**: N/A **Maintenance**: Very limited. **Observations**: Old vehicle with little or no maintenance. No facilities available for measurement equipment installation. No security available.
	Massey Ferguson 285 	N/A	1985	Topilejo's Farmers Union	**Location**: Topilejo **Security**: No **Space for equipment**: No **Space for test**: No **Opacity**: N/A **Maintenance**: Very limited. **Observations**: Old vehicle with little or no maintenance. No facilities available for measurement equipment installation. No security available.
		110 HP	N/A	Topilejo's Farmers Union	**Location**: Topilejo **Security**: No **Space for equipment**: No **Space for test**: No **Opacity**: N/A **Maintenance**: Very limited. **Observations**: Newer vehicle. Facilities available for measurement, and installation. Security available.
Rock truck	Caterpillar 770 	N/A	2008	Asphalt Plant, Parres	**Location**: Parres **Security**: Yes **Space for equipment**: Yes **Space for test**: Yes **Opacity**: N/A **Maintenance**: Preventive, according to operation logs. **Observations**: Excellent candidate.

					However, given the size of the vehicle, the cost of the DPF might be too high.
	Terex 33-05B 	N/A	>25 yr old	Asphalt Plant, Parres	**Location**: Parres **Security**: Yes **Space for equipment**: Yes **Space for test**: Yes **Opacity**: N/A **Maintenance**: Preventive, according to operation logs. **Observations**: Two vehicles available. However, they are old (mechanically controlled). Also, exhaust is in two parts. One is active when the load is in the upright (unloading) position, and the other one active when load is being transported.
Bulldozer	Caterpillar D8T 	N/A	N/A	Asphalt Plant, Parres	**Location**: Parres **Security**: Yes **Space for equipment**: Yes **Space for test**: Yes **Opacity**: N/A **Maintenance**: Preventive, according to operation logs. **Observations**: Candidate for baseline.
Front Shover	Caterpillar 5080 	N/A	N/A	Asphalt Plant, Parres	**Location**: Parres **Security**: Yes **Space for equipment**: Yes **Space for test**: Yes **Opacity**: N/A **Maintenance**: Preventive, according to operation logs. **Observations**: Excellent candidate. However, given the size of the vehicle, the cost of the DPF might be too high.
Hydraulic Excavator	Volvo 	N/A	N/A	Asphalt Plant, Parres	**Location**: Parres **Security**: Yes **Space for equipment**: Yes **Space for test**: Yes **Opacity**: N/A **Maintenance**: Preventive, according to operation logs. **Observations**: Excellent candidate. However, given its activity, vehicle is subject to substantial vibration.
Other vehicles		N/A	N/A	Asphalt Plant, Parres	**Location**: Parres **Security**: Yes **Space for equipment**: Yes **Space for test**: Yes **Opacity**: N/A **Maintenance**: Preventive, according to operation logs. **Observations**: Three additional vehicles available for study (one backhoe, Komatsu, and two front-loaders, Komatsu). However, they could not be checked during visit to Parres, due to instructions from Director of the place. Reason, unknown.

Appendix 3

Baseline Measurements Logbook - A

Item	Description
Vehicle ID	36-21
Owner	Asphalt plant at Del Imán
Equipment type[1]	Backhoe
Vehicle characteristics	
Vehicle Manufacturer	Komatsu
Model	WB146
Model Year	2010
Vehicle voltage (12V, 24 V)	2 (12)
Engine Characteristics	
Engine Manufacturer	Komatsu
Model	S4D102LE-2
Model year	2010
Engine's displacement (liters)	4.5
Configuration (e.g. V, in-line)	V
Compression ratio	NA
Rated power in bhp	92
Rated speed in RPM	2200
No. of cylinders	4
Turbocharger	Yes
Exhaust gas recirculation?	No
Tier	NA
Hours of operation	1115
Engine Family2	7KLXL0275AAC
Lug curve available (Y/N)	N
Max exhaust gas temperature (°C)	>300
Engine location on vehicle	Back side
Fuel	Ultra low sulfur diesel purchased at Federal District gas fuel stations
Observations	October 7, 2014. Vehicle was made available for testing at 12:00 PM. Annotations done by M. Zavala

[1] e.g. Wheel loader, excavator, tractor, scrapper, forklift, backhoe, etc.
[2] EPA Engine Family Name: Can be found on the engine's emission label and contains 12-13 characters.

Baseline Measurements Logbook – B. Test description

Item	Description
Vehicle ID	36-21
Owner	Asphalt plant at Del Imán
Equipment type	Backhoe
Vehicle characteristics	
Vehicle Manufacturer	Komatsu
Model	WB146
Model Year	2010
Date of test	10/7/2014
Initial time of test	4:27 PM
Driver/Operator name	Mtro. Alfonso
Name of participants in the test	Marco B., Francisco G., Daniel P., Miguel Z.
Description of test	Test A (for front larger bucket): 1) Bucket "attacks" pile of dirt approaching from zero speed, 2) lifting of pile of dirt, 3) back up (about 5 meters) and moves to the right, 4) stops and drops load, 5) backs up and moves to the starting point Test B (for back smaller bucket): 1) Bucket positions on top of dirt and "attacks", 2) lifting of pile of dirt, 3) arm rotates about 80 degrees to the right, 4) load is dropped, 5) arm returns to starting point.
Fuel	Ultra low sulfur diesel purchased at Federal District gas fuel stations
Fuel tank level	3/4
Engine working hours	1200

TEST NARRATIVE

Hour/Minute	Description
4:27	Vehicle leaves mechanical shop area towards testing area
4:32	Vehicle arrives to test area
	Test procedures are discussed with vehicle operator
	Visual inspection of installation and equipment security
4:35	First test starts (A)
	Visible plumes during acceleration periods (starting from zero speed)
4:45	First test ends
	Checking computers and data logging; checking zero air; perform standby
	Visual inspection of installation and equipment security
4:49	Second test starts (A)
4:51	Test stops temporally due to lose strap for the electric generator
4:54	Standby zeroing

4:57	Continue second test
	Operation conditions are harsh (driving style)
5:09	End second test
	Checking computers and data logging; checking zero air; perform standby
	Visual inspection of installation and equipment security
5:12	Start third test (A)
5:22	End third test
	Checking computers and data logging; checking zero air; perform standby
	Visual inspection of installation and equipment security
5:27	First test starts (B)
	Engine is run at constant RPM during tests
5:37	First test ends
5:40	Second test starts (B)
5:50	Second test ends
	Checking computers and data logging; checking zero air; perform standby
	Visual inspection of installation and equipment security
5:53	Third test starts (B)
6:03	Third test ends
	Checking computers and data logging; checking zero air; perform standby
	Visual inspection of installation and equipment security
	Return to mechanical shop area
	Perform calibrations during idling

Filter-installed Measurements Logbook – A

Item	Description
Vehicle ID	36-21
Owner	Asphalt plant at Iman
Equipment type[1]	Backhoe
Vehicle characteristics	
Vehicle Manufacturer	Komatsu
Model	WB146
Model Year	2010
Vehicle voltage (12V, 24 V)	2 (12)
Engine Characteristics	
Engine Manufacturer	Komatsu
Model	S4D102LE-2
Model year	2010
Engine's displacement (liters)	4.5
Configuration (e.g. V, in-line)	V
Compression ratio	NA
Rated power in bhp	92
Rated speed in RPM	2200
No. of cylinders	4
Turbocharger	Yes
Exhaust gas recirculation?	No
Tier	NA
Hours of operation	1397.2
Engine Family2	7KLXL0275AAC
Lug curve available (Y/N)	N
Max exhaust gas temper (°C)	>300
Engine location on vehicle	Back side
Fuel	Ultra low sulfur diesel purchased at Federal District gas fuel stations
Observations	December 6, 2014. Test performed in real world operating conditions with filter installed. Annotations done by Miguel Zavala

Measurements logbook – B. Test description

Item	Description
Vehicle ID	36-21
Owner	Asphalt plant at Del Imán
Equipment type	Backhoe
Vehicle Manufacturer	Komatsu
Model	WB146
Model Year	2010
Date of test	12/6/2014
Initial time of test	11:30 AM
Driver/Operator name	Mtro. Guillermo Zuñiga
Name of participants in the test	Francisco G., Daniel P., Marco B., Aron J., Andrés A., Miguel Z.
Description of test	Test A (for front larger bucket): 1) Bucket “attacks” pile of dirt approaching from zero speed, 2) lifting of pile of dirt, 3) back up (about 5 meters) and moves to the right, 4) stops and drops load, 5) backs up and moves to the starting point Test B (for back smaller bucket): 1) Bucket positions on top of dirt and “attacks”, 2) lifting of pile of dirt, 3) arm rotates about 80 degrees to the right, 4) load is dropped, 5) arm returns to starting point.
Fuel	Ultra low sulfur diesel purchased at Federal District gas fuel stations
Fuel tank level	Full tank
Engine working hours	1397.2

TEST NARRATIVE

Hour/Minute	Description
9:00	Team arrives to plant
11:31	MZ is setting zero check for the MSS.
	Vehicle is started on a few times for only a few seconds to check the validity of RPM readings by AXION.
11:34	Vehicle starting up. ECOSTAR calibrations start.
	Analysis note: Observe that even during idling conditions there are almost random small value short-term peaks in the data.
11:47	Aron is doing short-term (~3 seconds) accelerations puffs to test signal.
11:49	Moving back and forth for about 5 meters.
11:51	Bucket is moved up and down while idling.
11:54	Moving to test area
11:58	Arriving to test area. Note that this is not the same testing area as during the baseline measurements but the one where the material is being processed.

	Review of operation conditions with driver.
12:05,06	Test 1 starts
12:13	Test ends. Black puffs were observed during the test.
12:14	Test 2 starts.
12:21	Test ends.
	Note that Test 3 is being video recorded completely.
12:23	Test 3 starts.
12:30	Test ends.
12:32	Vehicle is moved to initiate test with smaller bucket
12:34	Test 1 (smaller bucket) starts
12:39	Test ends. Test was done at 2000 RPM
12:41	Test 2 (smaller bucket) starts (using 1800 RPM)
12:46	Test ends
12:48	Test 3 (smaller bucket) starts (sing 1500 RPM)
12:53	Test ends
12:55	2100 RPM for 40 seconds
	Return to mechanical shop.

Appendix 4

Time series of gaseous and PM emissions data.

Tests IDs shown below correspond to the vehicles described in Tables 5 and 6 in the text.

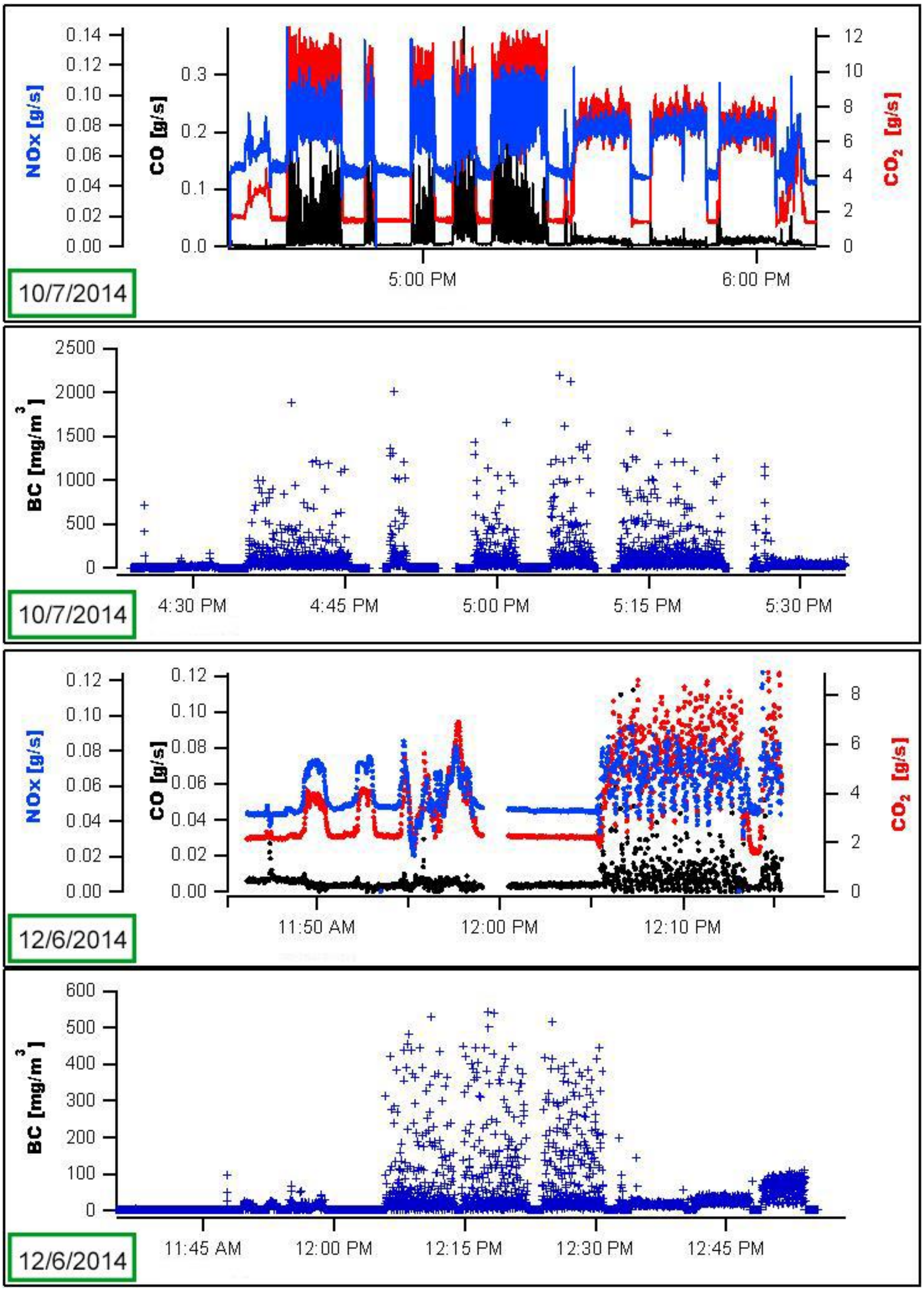

Figure 4.1. Gaseous and BC emissions for the backhoe at Del Imán for baseline (top panels) and after the installation of emissions control device (bottom panels).

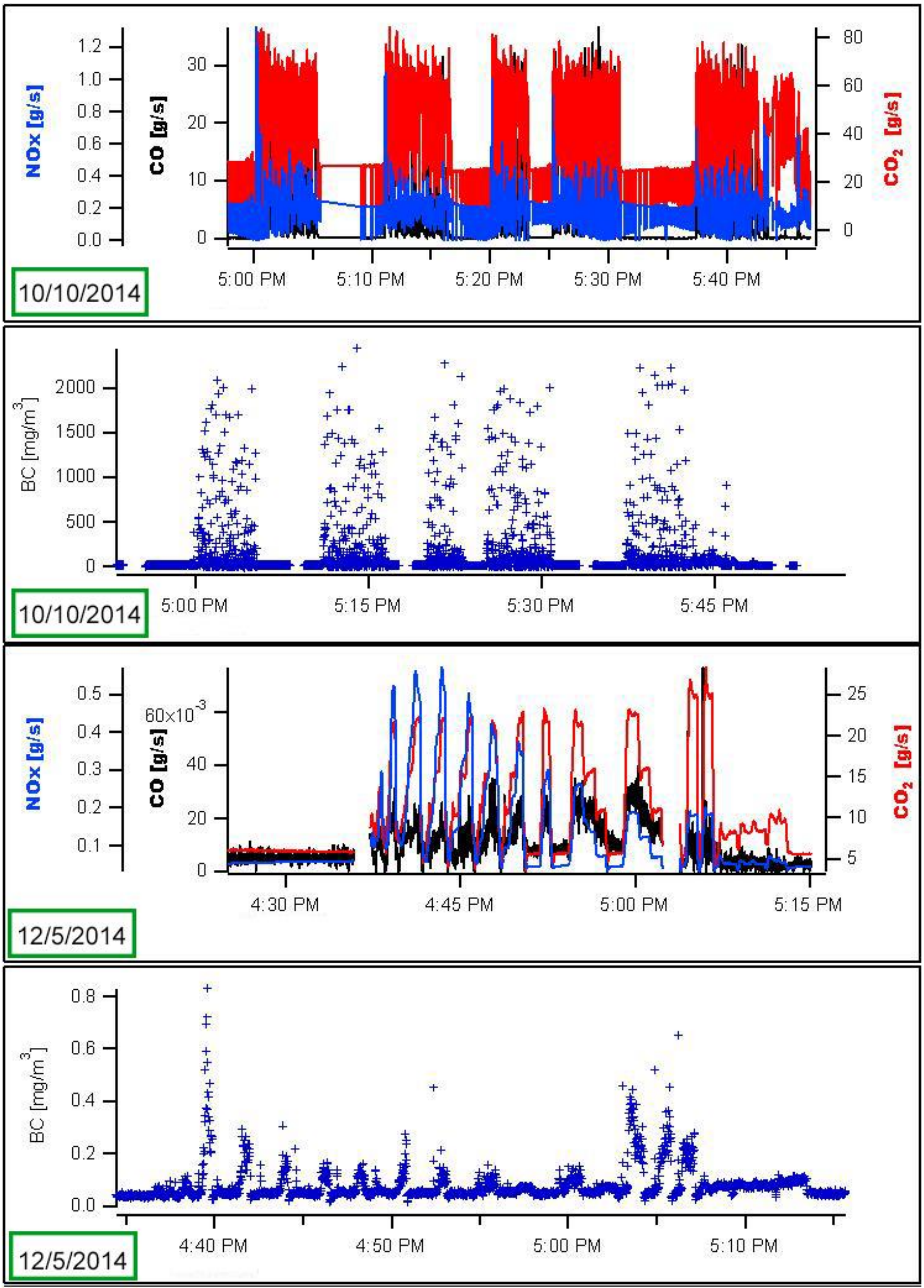

Figure 4.2. Gaseous and BC emissions for the front loader at Del Imán for baseline (top panels) and after the installation of emissions control device (bottom panels).

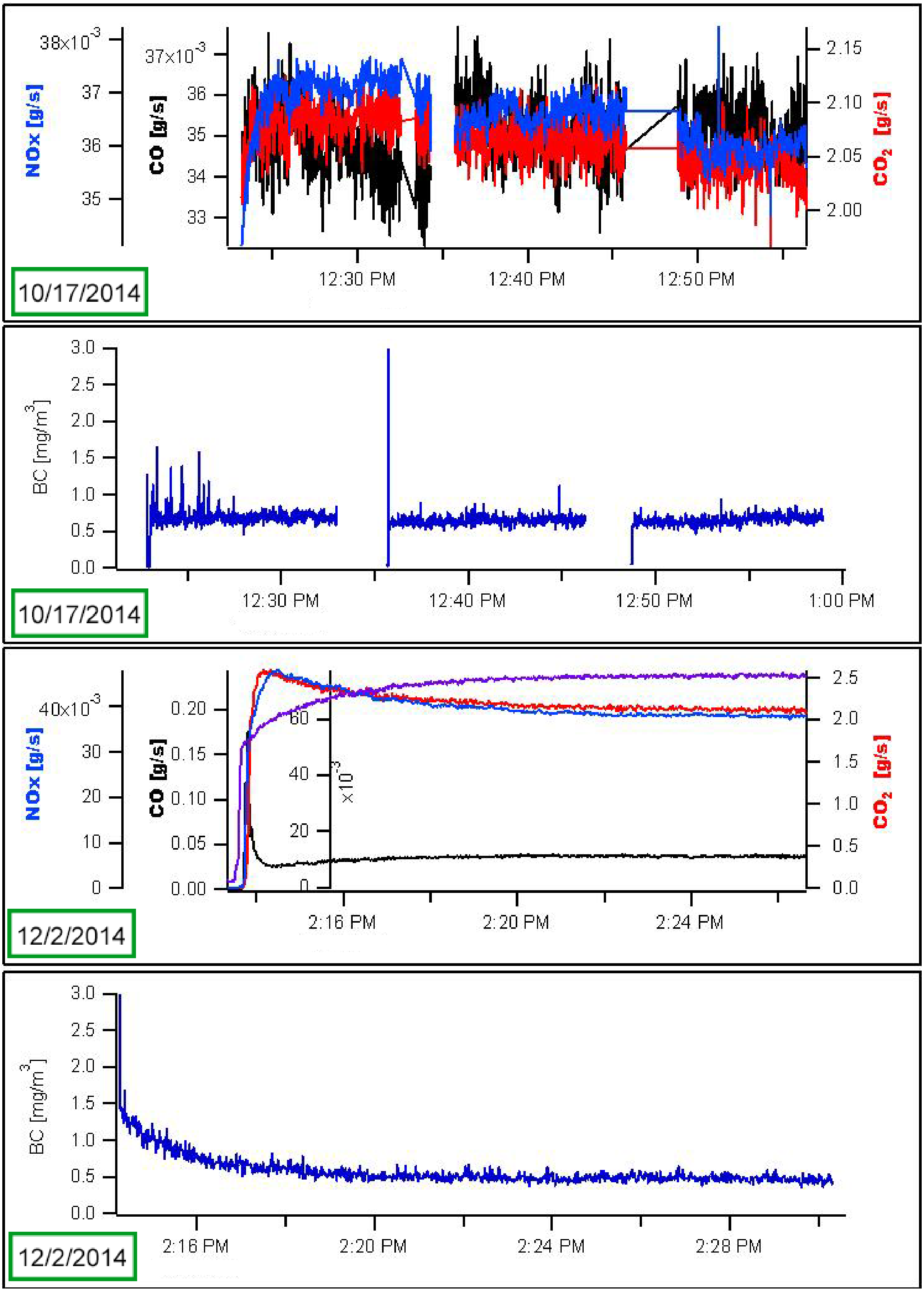

Figure 4.3. Gaseous and BC emissions for the power generator for baseline (top panels) and after the installation of emissions control device (bottom panels).

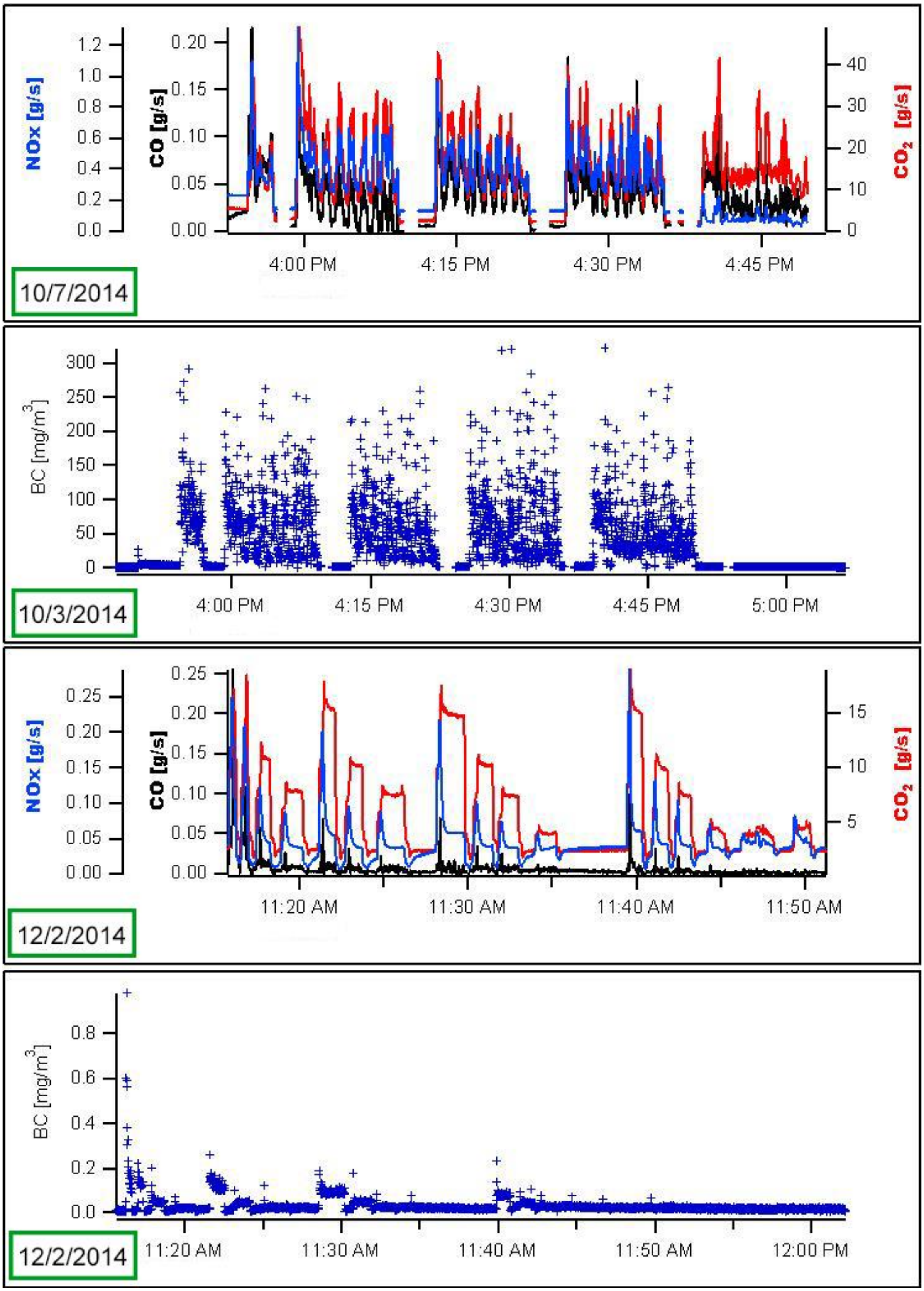

Figure 4.4. Gaseous and BC emissions for the bulldozer at Parres for baseline (top panels) and after the installation of emissions control device (bottom panels).

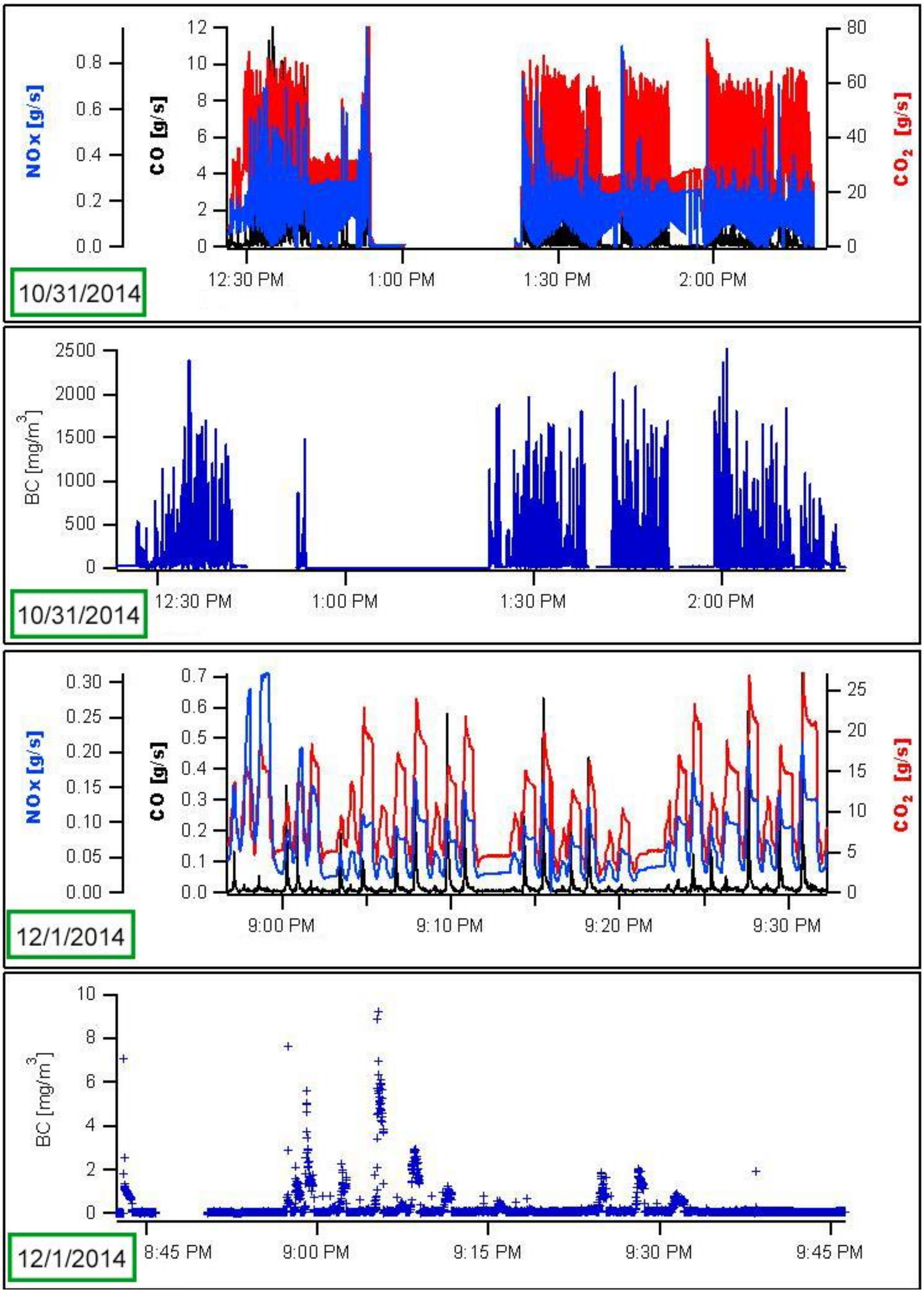

Figure 4.5. Gaseous and BC emissions for the front loader at Parres for baseline (top panels) and after the installation of emissions control device (bottom panels).

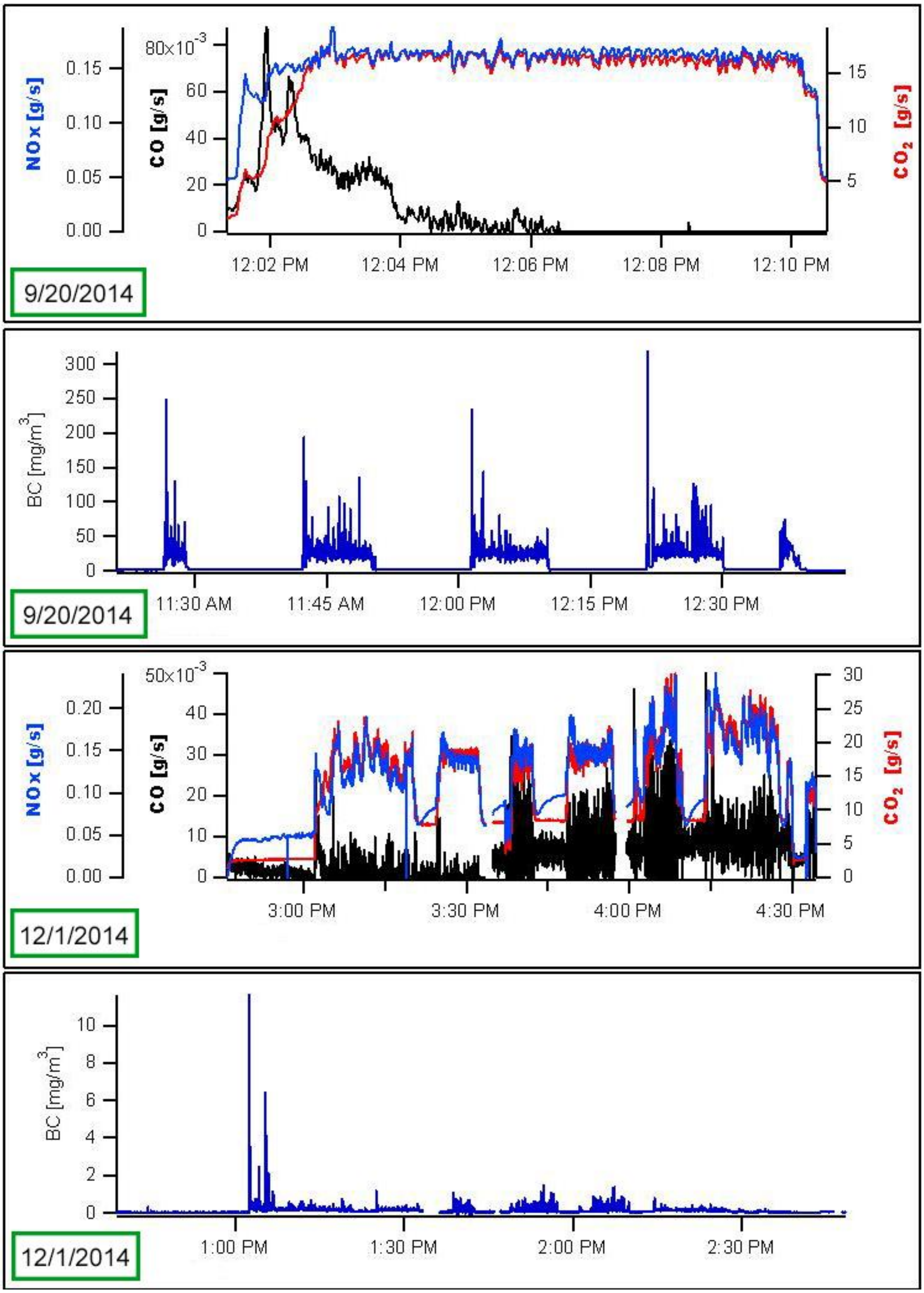

Figure 4.6. Gaseous and BC emissions for the hammer for baseline (top panels) and after the installation of emissions control device (bottom panels)

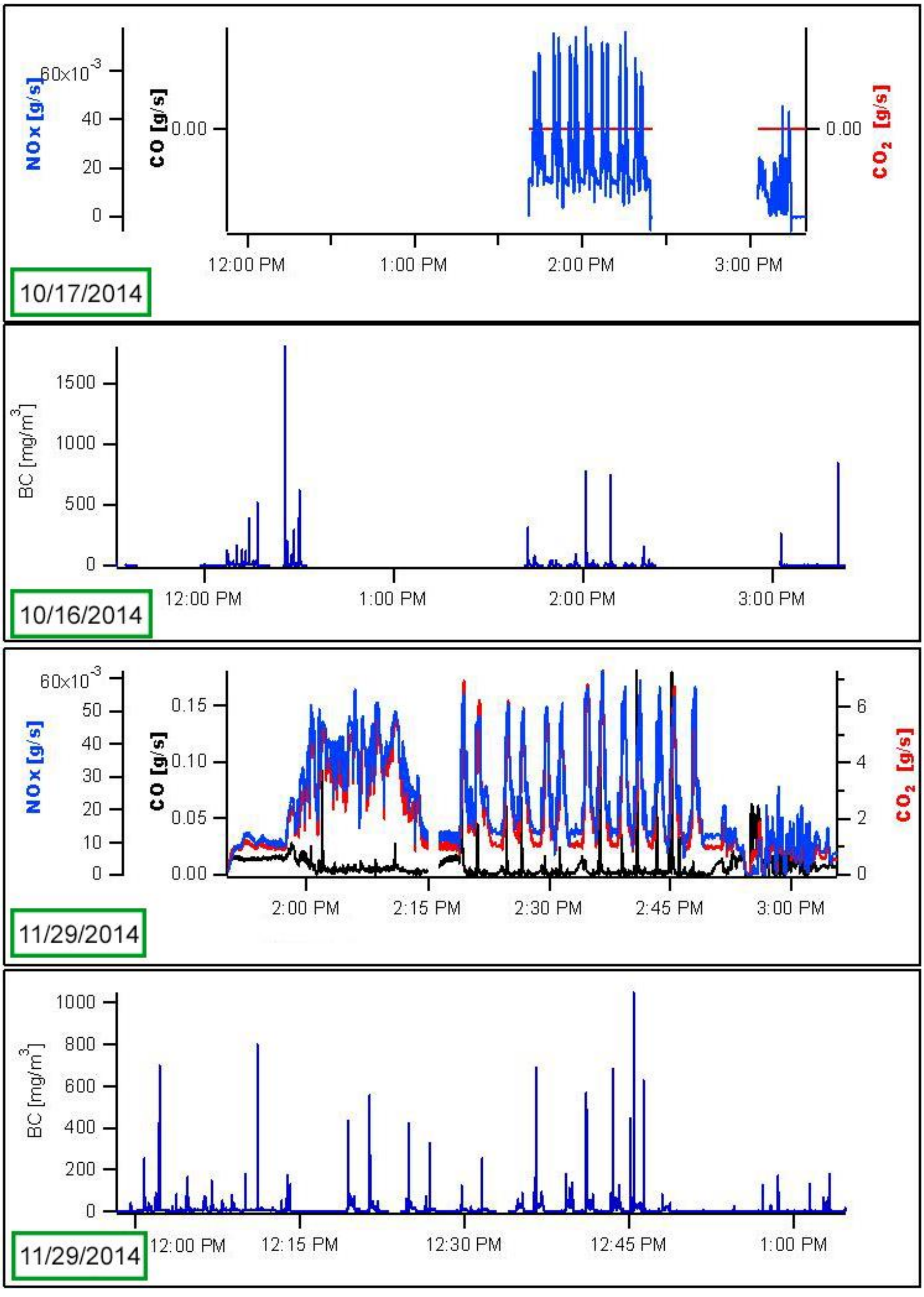

Figure 4.7. Gaseous and BC emissions for the tractor for baseline (top panels) and after the installation of emissions control device (bottom panels)

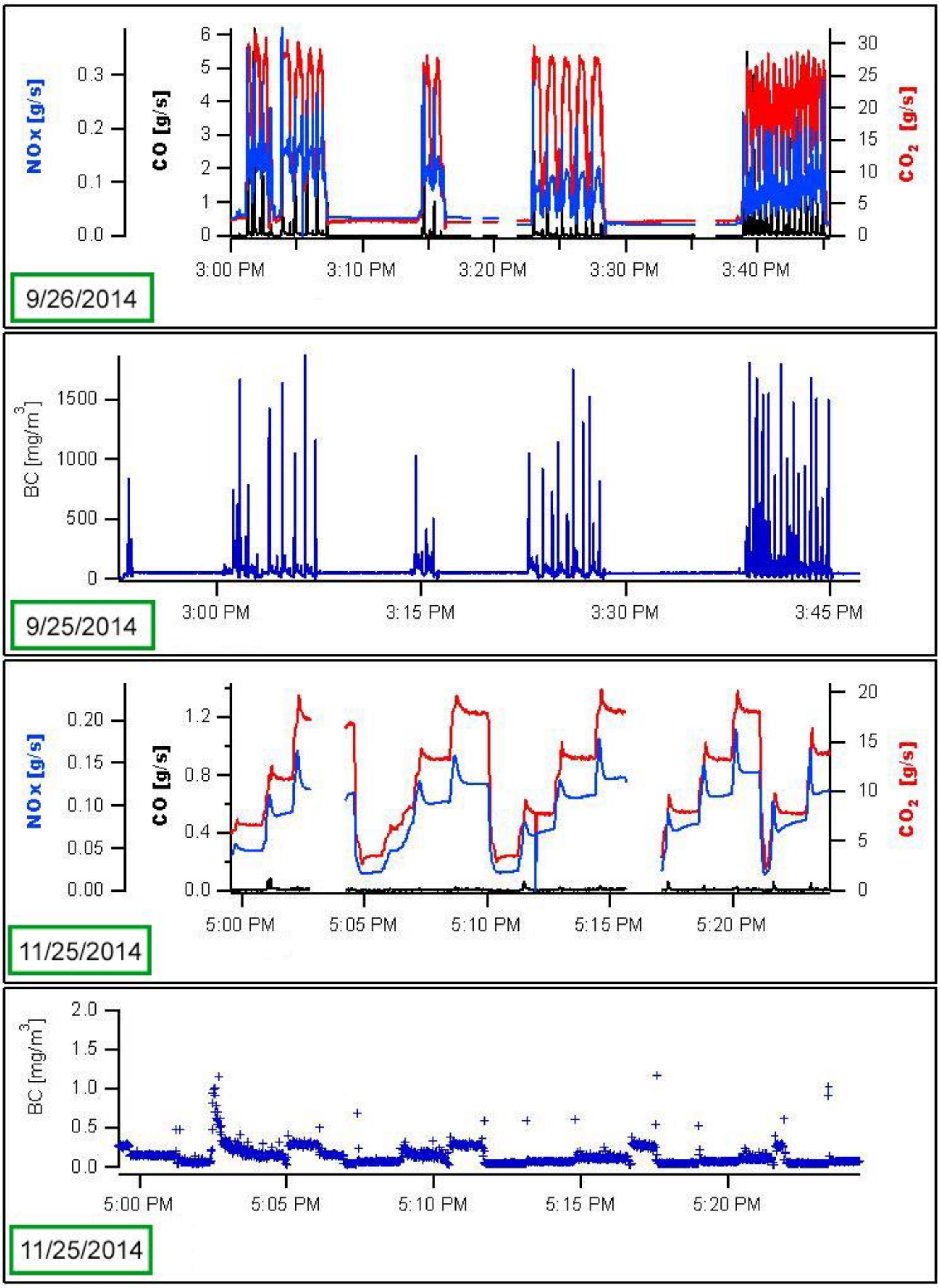

Figure 4.8. Gaseous and BC emissions for the bulldozer at Del Imán for baseline (top panels) and after the installation of emissions control device (bottom panels).

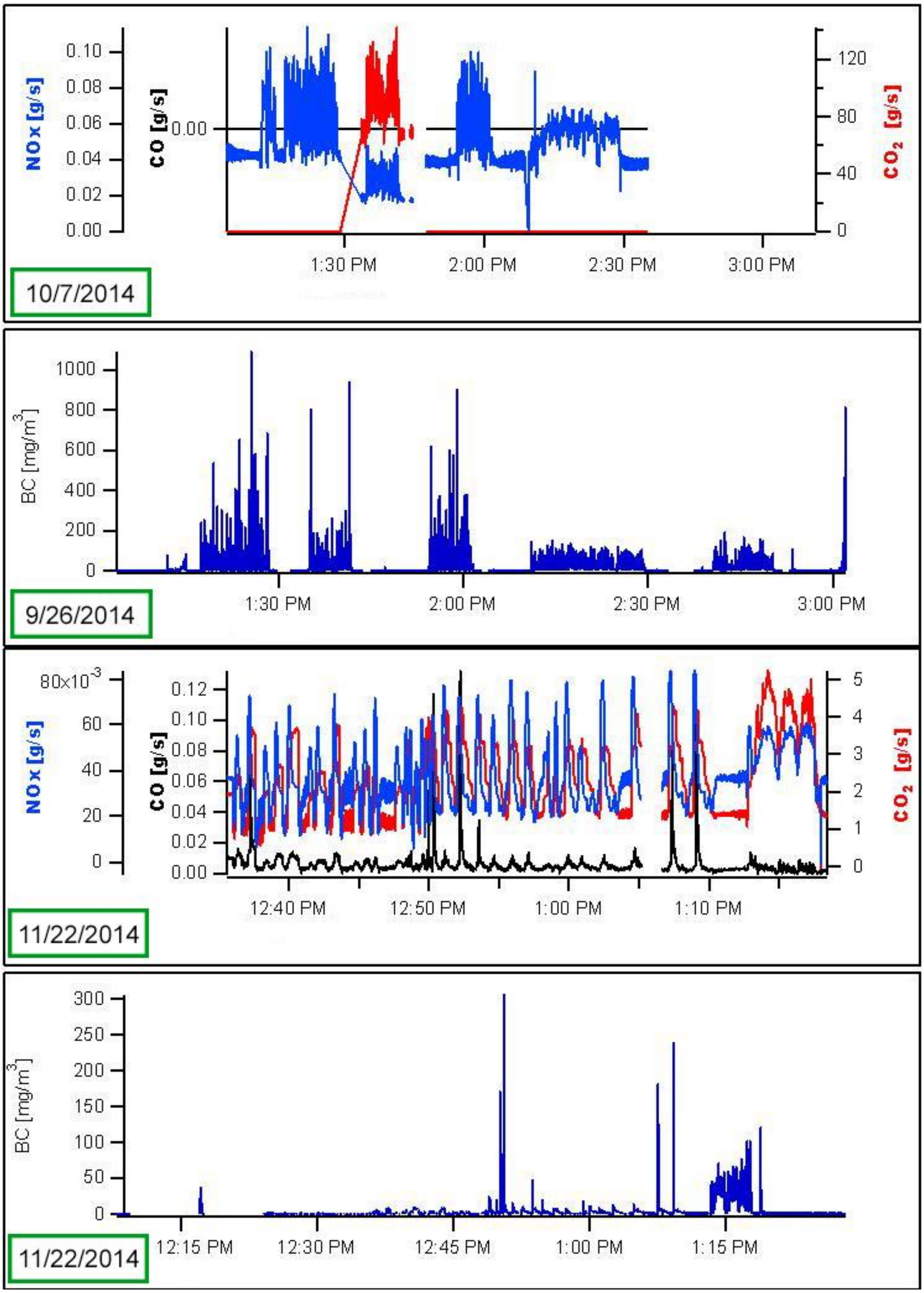

Figure 4.9. Gaseous and BC emissions for the backhoe at Parres for baseline (top panels) and after the installation of emissions control device (bottom panels).

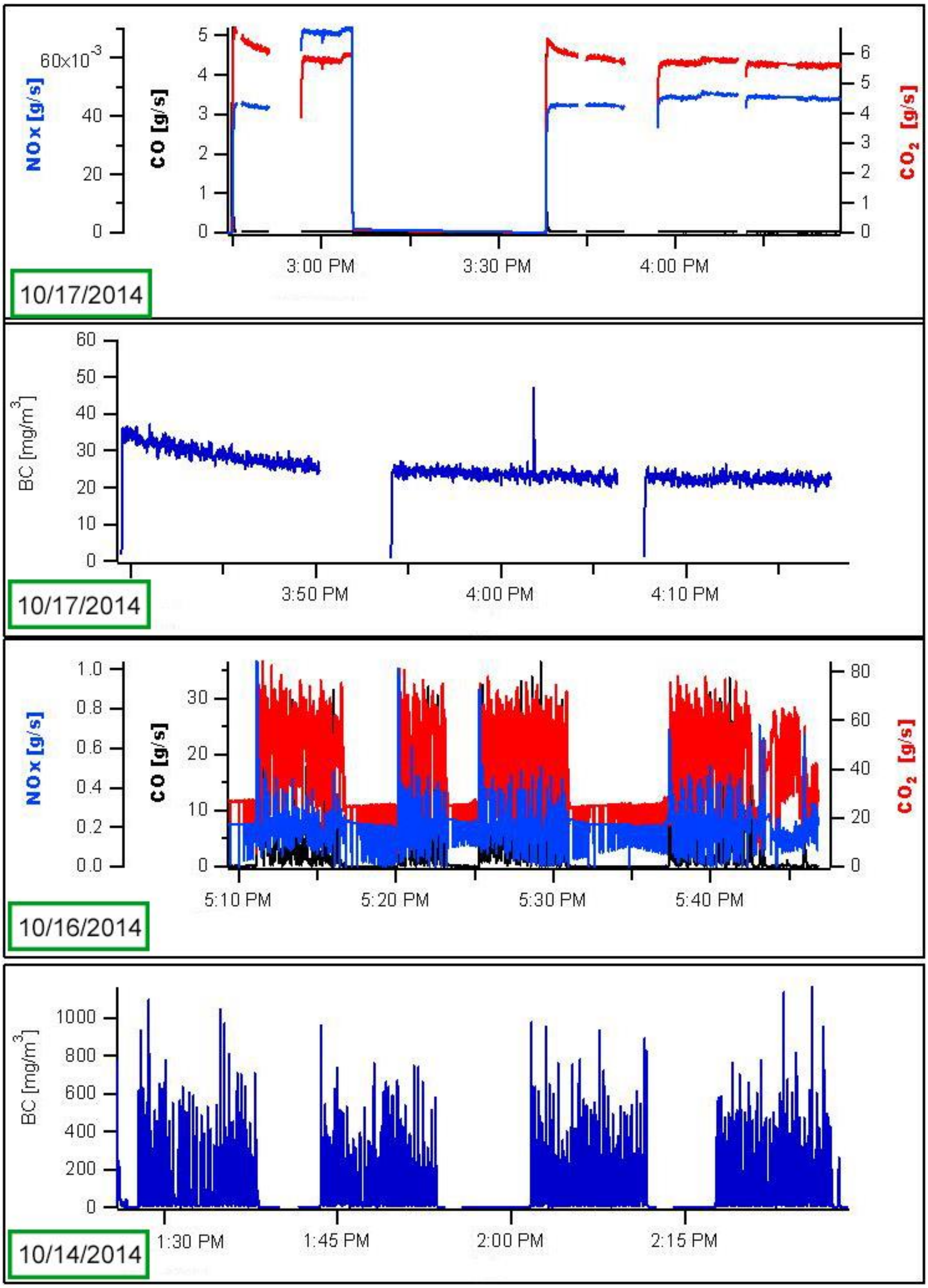

Figure 4.10. Gaseous and BC emissions for the baseline measurements of the compressor (top panels) and the crane (bottom panels).

Appendix 5

List of archived data files

AVLMSS

Category	Folder	Data File
AVLMSS	baseline measurements	P01_Iman_Backhoe_18sep14.csv
AVLMSS	baseline measurements	P02_Parres_Hammer_20sep14.csv
AVLMSS	baseline measurements	P03_Iman_FrontLoader_23sep14.csv
AVLMSS	baseline measurements	P04 Iman_Bulldozer_25sep14.csv
AVLMSS	baseline measurements	P05_Parres_Backhoe_26sept14.csv
AVLMSS	baseline measurements	P06_Topilejo_Tractor_30sep14.csv
AVLMSS	baseline measurements	P07_Parres_Bulldozer_3October14.csv
AVLMSS	baseline measurements	P08_Iman_Backhoe_07oct14.csv
AVLMSS	baseline measurements	P09_Iman_FrontLoader_10oct14.csv
AVLMSS	baseline measurements	P10_Pantitlan_Crane_14oct14.csv
AVLMSS	baseline measurements	P11_Topilejo_Tractor_16oct14.csv
AVLMSS	baseline measurements	P12_Parres_Compressor_17oct14.csv
AVLMSS	baseline measurements	P13_Parres_Generator_17oct14.csv
AVLMSS	baseline measurements	P14_Parres_FrontLoader_31oct14.csv
AVLMSS	filtered measurements	P15_Parres_Backhoe_22nov14.csv
AVLMSS	filtered measurements	P16_Iman_Backhoe_24nov14.csv
AVLMSS	filtered measurements	P17_Iman_Bulldozer_25nov14.csv
AVLMSS	filtered measurements	P18_Topilejo_Tractor_29nov14.csv
AVLMSS	filtered measurements	P19_Parres_Hammer_01dec14.csv
AVLMSS	filtered measurements	P20_Parres_FrontLoader_01dec14.csv
AVLMSS	filtered measurements	P21_Parres_Bulldozer_02dec14.csv
AVLMSS	filtered measurements	P22_Parres_Generator_02dec14.csv
AVLMSS	filtered measurements	P23_Iman_FrontLoader_05dec14.csv
AVLMSS	filtered measurements	P24_Iman_Backhoe_06dec14.csv

AXION

Category	Folder	Data File
AXION	baseline measurements/10-03-2014	14--11-03_01Axion.txt
AXION	baseline measurements/10-03-2015	14--11-03_01AxionBags.txt
AXION	baseline measurements/10-03-2016	14--11-03_01AxionConfig.txt
AXION	baseline measurements/10-03-2017	14--11-03_01AxionGA.txt
AXION	baseline measurements/10-03-2018	14--11-03_02Axion.txt
AXION	baseline measurements/10-03-2019	14--11-03_02AxionBags.txt
AXION	baseline measurements/10-03-2020	14--11-03_02AxionConfig.txt
AXION	baseline measurements/10-03-2021	14--11-03_02AxionGA.txt
AXION	baseline measurements/10-31-2014	14--11-01_01Axion.txt
AXION	baseline measurements/10-31-2014	14--11-01_01AxionBags.txt
AXION	baseline measurements/10-31-2014	14--11-01_01AxionConfig.txt
AXION	baseline measurements/10-31-2014	14--11-01_01AxionGA.txt
AXION	baseline measurements/9-18-2014	14--10-18_01Axion.txt

AXION	baseline measurements/9-18-2014	14--10-18_01AxionConfig.txt
AXION	baseline measurements/9-18-2014	14--10-18_01AxionGA.txt
AXION	baseline measurements/9-18-2014	14--10-18_02Axion.txt
AXION	baseline measurements/9-18-2014	14--10-18_02AxionConfig.txt
AXION	baseline measurements/9-18-2014	14--10-18_02AxionGA.txt
AXION	baseline measurements/9-23-2014	14--10-23_01Axion.txt
AXION	baseline measurements/9-23-2014	14--10-23_01AxionBags.txt
AXION	baseline measurements/9-23-2014	14--10-23_01AxionConfig.txt
AXION	baseline measurements/9-23-2014	14--10-23_01AxionGA.txt
AXION	baseline measurements/9-25-2014	14--10-25_01Axion.txt
AXION	baseline measurements/9-25-2014	14--10-25_01AxionConfig.txt
AXION	baseline measurements/9-25-2014	14--10-25_01AxionGA.txt
AXION	baseline measurements/9-25-2014	14--10-25_02Axion.txt
AXION	baseline measurements/9-25-2014	14--10-25_02AxionGA.txt
AXION	baseline measurements/9-25-2014	14--10-25_03Axion.txt
AXION	baseline measurements/9-25-2014	14--10-25_03AxionGA.txt
AXION	baseline measurements/9-26-2014	14--10-26_01Axion.txt
AXION	baseline measurements/9-26-2014	14--10-26_01AxionConfig.txt
AXION	baseline measurements/9-26-2014	14--10-26_01AxionGA.txt
AXION	filtered measurements/11-22-2014	14--11-23_01Axion.txt
AXION	filtered measurements/11-22-2014	14--11-23_01AxionCal.txt
AXION	filtered measurements/11-22-2014	14--11-23_01AxionConfig.txt
AXION	filtered measurements/11-22-2014	14--11-23_01AxionGA.txt
AXION	filtered measurements/11-22-2014	14--11-23_02Axion.txt
AXION	filtered measurements/11-22-2014	14--11-23_02AxionConfig.txt
AXION	filtered measurements/11-22-2014	14--11-23_02AxionGA.txt
AXION	filtered measurements/11-24-2014	14--11-25_01Axion.txt
AXION	filtered measurements/11-24-2014	14--11-25_01AxionGA.txt
AXION	filtered measurements/11-24-2014	14--11-25_02Axion.txt
AXION	filtered measurements/11-24-2014	14--11-25_02AxionConfig.txt
AXION	filtered measurements/11-24-2014	14--11-25_02AxionGA.txt
AXION	filtered measurements/11-24-2014	14--11-25_03Axion.txt
AXION	filtered measurements/11-24-2014	14--11-25_03AxionConfig.txt
AXION	filtered measurements/11-24-2014	14--11-25_03AxionGA.txt
AXION	filtered measurements/11-25-2014	14--11-25_02AxionConfig.txt
AXION	filtered measurements/11-25-2014	14--11-25_02AxionGA.txt
AXION	filtered measurements/11-25-2014	14--11-26_01Axion.txt
AXION	filtered measurements/11-25-2014	14--11-26_01AxionConfig.txt
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AXION	filtered measurements/11-25-2014	14--11-26_02Axion.txt
AXION	filtered measurements/11-25-2014	14--11-26_02AxionBags.txt
AXION	filtered measurements/12-01-2014	14--12-01_01Axion.txt
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AXION	filtered measurements/12-01-2014	14--12-01_01AxionGA.txt
AXION	filtered measurements/12-01-2014	14--12-01_02Axion.txt
AXION	filtered measurements/12-01-2014	14--12-01_02AxionConfig.txt
AXION	filtered measurements/12-01-2014	14--12-01_02AxionGA.txt
AXION	filtered measurements/12-02-2014	14--12-02_01Axion.txt
AXION	filtered measurements/12-02-2014	14--12-02_01AxionBags.txt
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AXION	filtered measurements/12-02-2014	14--12-02_01AxionGA.txt

AXION	filtered measurements/12-02-2014	14--12-02_02Axion.txt
AXION	filtered measurements/12-02-2014	14--12-02_02AxionConfig.txt
AXION	filtered measurements/12-02-2014	14--12-02_02AxionGA.txt
AXION	filtered measurements/12-02-2014	14--12-02_03Axion.txt
AXION	filtered measurements/12-02-2014	14--12-02_03AxionConfig.txt
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AXION	filtered measurements/12-05-2014	14--12-05_02AxionGA.txt
AXION	filtered measurements/12-06-2014	14--11-06_01Axion.txt
AXION	filtered measurements/12-06-2014	14--11-06_01AxionConfig.txt
AXION	filtered measurements/12-06-2014	14--11-06_01AxionGA.txt

ECOSTAR

Category	Folder	Data File
ECOSTAR	Baseline Measurements	P02_Volvo_Parres_9-20-2014.csv
ECOSTAR	Baseline Measurements	P02_Volvo_Parres_9-20-2014.xlsx
ECOSTAR	Baseline Measurements	P03_Frontloader_Iman_9-23-2014.csv
ECOSTAR	Baseline Measurements	P03_Frontloader_Iman_9-23-2014.xlsx
ECOSTAR	Baseline Measurements	P04_Bulldozer_D155AX_Iman_9-25-2014.csv
ECOSTAR	Baseline Measurements	P04_Bulldozer_D155AX_Iman_9-25-2014.xlsx
ECOSTAR	Baseline Measurements	P05_Backhoe_Parres_9-26-2014.csv
ECOSTAR	Baseline Measurements	P05_Backhoe_Parres_9-26-2014.xlsx
ECOSTAR	Baseline Measurements	P06_Tractor_agriculture_Topilejo_9-30-2014.csv
ECOSTAR	Baseline Measurements	P06_Tractor_agriculture_Topilejo_9-30-2014.xlsx
ECOSTAR	Baseline Measurements	P07_Bulldozer_Parres_10-03-2014.csv
ECOSTAR	Baseline Measurements	P07_Bulldozer_Parres_10-03-2014.xlsx
ECOSTAR	Baseline Measurements	P08_Backhoe_Iman_10-07-2014.csv
ECOSTAR	Baseline Measurements	P08_Backhoe_Iman_10-07-2014.xlsx
ECOSTAR	Baseline Measurements	P09_FrontLoader_Iman_10-10-2014.csv
ECOSTAR	Baseline Measurements	P09_FrontLoader_Iman_10-10-2014.xlsx
ECOSTAR	Baseline Measurements	P10_Crane_Pantitlan_14-10-2014.csv
ECOSTAR	Baseline Measurements	P10_Crane_Pantitlan_14-10-2014.xlsx
ECOSTAR	Baseline Measurements	P11_Tractor_agriculture_Topilejo_16-10-2014.csv
ECOSTAR	Baseline Measurements	P11_Tractor_agriculture_Topilejo_16-10-2014.xlsx
ECOSTAR	Baseline Measurements	P12_Compressor_Parres_17-10-2014.csv

ECOSTAR	Baseline Measurements	P12_Compressor_Parres_17-10-2014.xlsx
ECOSTAR	Baseline Measurements	P13_Generator_electrico_Parres_17-10-2014.csv
ECOSTAR	Baseline Measurements	P13_Generator_electrico_Parres_17-10-2014.xlsx
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ECOSTAR	Measurements with filters/01-12-2014_P19_Hammer_Volvo_Filter_Parres	FEM_1_201-AMBIENT.csv
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ECOSTAR	Measurements with filters/01-12-2014_P19_Hammer_Volvo_Filter_Parres	PDM_1_202.csv
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	2014_P19_Hammer_Volvo_Filter_Parres	
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ECOSTAR	Measurements with filters/01-12-2014_P20_FrontLoader_Filter_Parres	FEM_1_202-SAMPLE.csv
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ECOSTAR	Measurements with filters/01-12-2014_P20_FrontLoader_Filter_Parres	NOX_1_10-SAMPLE.csv
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ECOSTAR	Measurements with filters/01-12-2014_P20_FrontLoader_Filter_Parres	PDM_1_202.csv
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ECOSTAR	Measurements with filters/01-12-2014_P20_FrontLoader_Filter_Parres	TestFile_12-01-14_204147.tdms_index
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ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	FEM_1_1-PURGE.csv
ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	FEM_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	FEM_1_11-AMBIENT.csv
ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	FEM_1_11-PURGE.csv
ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	FEM_1_11-SAMPLE.csv
ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	FEM_1_200-AMBIENT.csv
ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	FEM_1_200-PURGE.csv
ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	FEM_1_201-AMBIENT.csv
ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	NOX_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	NOX_1_1-PURGE.csv
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ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	NOX_1_10-PURGE.csv
ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	NOX_1_10-SAMPLE.csv

ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	NOX_1_200-AMBIENT.csv
ECOSTAR	Measurements with filters/02-12-2014_P21_Bulldozer_Filter_Parres	NOX_1_202-PURGE.csv
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ECOSTAR	Measurements with filters/02-12-2014_P22_Generator_Filter_Parres	FEM_1_1-PURGE.csv
ECOSTAR	Measurements with filters/02-12-2014_P22_Generator_Filter_Parres	FEM_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/02-12-2014_P22_Generator_Filter_Parres	FEM_1_11-AMBIENT.csv
ECOSTAR	Measurements with filters/02-12-2014_P22_Generator_Filter_Parres	FEM_1_11-PURGE.csv
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ECOSTAR	Measurements with filters/02-12-2014_P22_Generator_Filter_Parres	FEM_1_201-AMBIENT.csv
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ECOSTAR	Measurements with filters/02-12-2014_P22_Generator_Filter_Parres	NOX_1_1-PURGE.csv
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ECOSTAR	Measurements with filters/02-12-2014_P22_Generator_Filter_Parres	NOX_1_10-PURGE.csv
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ECOSTAR	Measurements with filters/02-12-2014_P22_Generator_Filter_Parres	NOX_1_202-SAMPLE.csv
ECOSTAR	Measurements with filters/02-12-2014_P22_Generator_Filter_Parres	NOX_1_203-SAMPLE.csv
ECOSTAR	Measurements with filters/02-12-2014_P22_Generator_Filter_Parres	PDM_1_1.csv
ECOSTAR	Measurements with filters/02-12-2014_P22_Generator_Filter_Parres	PDM_1_202.csv
ECOSTAR	Measurements with filters/02-12-	TestFile.Log

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ECOSTAR	Measurements with filters/02-12-2014_P22_Generator_Filter_Parres	TestFile_12-02-14_141131.tdms_index
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	FEM_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	FEM_1_1-PURGE.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	FEM_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	FEM_1_200-AMBIENT.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	FEM_1_200-PURGE.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	FEM_1_201-AMBIENT.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	FEM_1_202-SAMPLE.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	NOX_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	NOX_1_1-PURGE.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	NOX_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	NOX_1_10-AMBIENT.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	NOX_1_10-PURGE.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	NOX_1_10-SAMPLE.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	NOX_1_200-AMBIENT.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	NOX_1_200-PURGE.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	NOX_1_202-SAMPLE.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	NOX_1_203-SAMPLE.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	PDM_1_1.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	PDM_1_202.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	TestFile.Log
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	TestFile_12-05-14_162452.csv
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	TestFile_12-05-14_162452.tdms
ECOSTAR	Measurements with filters/05-12-2014_P23_Frontloader_Filter_Iman	TestFile_12-05-14_162452.tdms_index
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	FEM_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/06-12-	FEM_1_1-PURGE.csv

	2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	FEM_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	FEM_1_11-AMBIENT.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	FEM_1_11-PURGE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	FEM_1_11-SAMPLE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	FEM_1_200-AMBIENT.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	FEM_1_200-PURGE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	FEM_1_201-AMBIENT.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	FEM_1_202-PURGE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	NOX_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	NOX_1_1-PURGE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	NOX_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	NOX_1_10-AMBIENT.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	NOX_1_10-PURGE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	NOX_1_10-SAMPLE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	NOX_1_200-PURGE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	NOX_1_202-PURGE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	NOX_1_203-PURGE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	PDM_1_1.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFil	TestFile.Log

	e_12-06-14_114547_Folder	
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	TestFile_12-06-14_114547.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	TestFile_12-06-14_114547.tdms
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_114547_Folder	TestFile_12-06-14_114547.tdms_index
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	FEM_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	FEM_1_11-SAMPLE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	FEM_1_202-SAMPLE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	NOX_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	NOX_1_10-SAMPLE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	NOX_1_202-SAMPLE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	NOX_1_203-SAMPLE.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	PDM_1_1.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	PDM_1_202.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	TestFile.Log
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	TestFile_12-06-14_131639.csv
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	TestFile_12-06-14_131639.tdms
ECOSTAR	Measurements with filters/06-12-2014_P24_Backhoe_Filter_Iman/TestFile_12-06-14_131639_Folder	TestFile_12-06-14_131639.tdms_index
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_120505_Folder	FEM_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_120505_Folder	FEM_1_11-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFi	FEM_1_202-SAMPLE.csv

	le_11-22-14_120505_Folder	
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_120505_Folder	NOX_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_120505_Folder	NOX_1_10-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_120505_Folder	NOX_1_202-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_120505_Folder	NOX_1_203-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_120505_Folder	PDM_1_1.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_120505_Folder	PDM_1_202.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_120505_Folder	TestFile.Log
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_120505_Folder	TestFile_11-22-14_120505.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_120505_Folder	TestFile_11-22-14_120505.tdms
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_120505_Folder	TestFile_11-22-14_120505.tdms_index
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_121645_Folder	FEM_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_121645_Folder	FEM_1_11-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_121645_Folder	FEM_1_202.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_121645_Folder	NOX_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_121645_Folder	NOX_1_10-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_121645_Folder	NOX_1_202-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_121645_Folder	NOX_1_203-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_121645_Folder	PDM_1_1.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFi	PDM_1_202.csv

	le_11-22-14_121645_Folder	
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_121645_Folder	TestFile.Log
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_121645_Folder	TestFile_11-22-14_121645.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_121645_Folder	TestFile_11-22-14_121645.tdms
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_121645_Folder	TestFile_11-22-14_121645.tdms_index
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	FEM_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	FEM_1_1-PURGE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	FEM_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	FEM_1_11-AMBIENT.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	FEM_1_11-PURGE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	FEM_1_11-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	FEM_1_200-PURGE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	FEM_1_201-AMBIENT.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	FEM_1_202-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	NOX_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	NOX_1_1-PURGE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	NOX_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	NOX_1_10-AMBIENT.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	NOX_1_10-PURGE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFi	NOX_1_10-SAMPLE.csv

	le_11-22-14_122348_Folder	
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	NOX_1_200-PURGE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	NOX_1_202-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	NOX_1_203-SAMPLE.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	PDM_1_1.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	PDM_1_202.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	TestFile.Log
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	TestFile_11-22-14_122348.csv
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	TestFile_11-22-14_122348.tdms
ECOSTAR	Measurements with filters/22-11-2014_P15_Backhoe_Filter_Parres/TestFile_11-22-14_122348_Folder	TestFile_11-22-14_122348.tdms_index
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	FEM_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	FEM_1_1-PURGE.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	FEM_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	FEM_1_11-AMBIENT.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	FEM_1_11-PURGE.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	FEM_1_11-SAMPLE.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	FEM_1_200-AMBIENT.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	FEM_1_200-PURGE.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	FEM_1_201-AMBIENT.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFil	FEM_1_202-AMBIENT.csv

	e_11-24-14_162901_Folder	
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	NOX_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	NOX_1_1-PURGE.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	NOX_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	NOX_1_10-AMBIENT.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	NOX_1_10-PURGE.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	NOX_1_10-SAMPLE.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	NOX_1_200-AMBIENT.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	NOX_1_200-PURGE.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	NOX_1_202-AMBIENT.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	NOX_1_203-AMBIENT.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	PDM_1_1.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	PDM_1_202.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	TestFile.Log
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	TestFile_11-24-14_162901.csv
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	TestFile_11-24-14_162901.tdms
ECOSTAR	Measurements with filters/24-11-2014_P16_Backhoe_Filter_Iman/TestFile_11-24-14_162901_Folder	TestFile_11-24-14_162901.tdms_index
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	FEM_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	FEM_1_1-PURGE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	FEM_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	FEM_1_11-AMBIENT.csv

ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	FEM_1_11-PURGE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	FEM_1_11-SAMPLE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	FEM_1_200-AMBIENT.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	FEM_1_200-PURGE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	FEM_1_201-AMBIENT.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	FEM_1_202-PURGE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	NOX_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	NOX_1_1-PURGE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	NOX_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	NOX_1_10-AMBIENT.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	NOX_1_10-PURGE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	NOX_1_10-SAMPLE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	NOX_1_200-AMBIENT.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	NOX_1_200-PURGE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	NOX_1_202-PURGE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	NOX_1_203-PURGE.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	PDM_1_1.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	TestFile.Log
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	TestFile_11-25-14_161417.csv
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	TestFile_11-25-14_161417.tdms
ECOSTAR	Measurements with filters/25-11-2014_P17_Bulldozer_Filter_Iman	TestFile_11-25-14_161417.tdms_index
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	FEM_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	FEM_1_1-PURGE.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	FEM_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	FEM_1_11-AMBIENT.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	FEM_1_11-PURGE.csv

ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	FEM_1_11-SAMPLE.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	FEM_1_200-AMBIENT.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	FEM_1_201-AMBIENT.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	FEM_1_202-PURGE.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	NOX_1_1-AMBIENT.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	NOX_1_1-PURGE.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	NOX_1_1-SAMPLE.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	NOX_1_10-AMBIENT.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	NOX_1_10-PURGE.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	NOX_1_10-SAMPLE.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	NOX_1_200-PURGE.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	NOX_1_202-PURGE.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	NOX_1_203-PURGE.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	PDM_1_1.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	PDM_1_202.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	TestFile.Log
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	TestFile_11-29-14_135009.csv
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	TestFile_11-29-14_135009.tdms
ECOSTAR	Measurements with filters/29-11-2014_P18_Tractor_Agriculture_Filter_Topilejo	TestFile_11-29-14_135009.tdms_index