Methodology for Activity, Fuel Use, and Emissions Data Collection and Analysis for Nonroad Construction Equipment

Extended Abstract # 447

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1.0 INTRODUCTION

Nonroad diesel powered equipment is now coming under increased scrutiny because it is a significant source of nonroad mobile source air pollutant emissions. Emissions from nonroad construction equipment are typically quantified based on steady-state engine dynamometer tests. However, such tests do not represent the real world effects of actual duty cycles. Therefore, there is a need to quantify energy use and emissions from construction equipment based on in-use measurement methods. Compared with other types of vehicles, there has been relatively little real world measurement of in-use emissions of nonroad diesel powered vehicles. The purpose of this paper is to suggest a set of standard procedures for field data collection and analysis for this equipment. A methodology for collecting and analyzing real-world in-use data from nonroad construction equipment is presented herein. This methodology is being used in ongoing projects to measure the in-use activity and emissions of frond-end loaders, bulldozers, excavators, backhoes, off-highway trucks, skid steer loaders, and generators. The results from the application of the methodology summarized here will improve the characterization of in-use activity and emissions of these vehicles, which can further support the development of highly accurate emission inventories and improved approaches to air quality management.

2.0 METHODOLOGY

The methodology is based on second-by-second measurement of in-use activity and emissions using a portable emissions measurement system (PEMS). The procedure for field data collection includes the development of a study design, installation of the PEMS, field measurement, data quality assurance, analysis of the data, and reporting of the results.

2.1 Development of the Study Design

The first project activity was to define all of the attributes of a complete study design for construction equipment field data collection. The key elements of the study design are briefly summarized here:

1. **Study Location –** The primary study area has been construction sites on or near the North Carolina State University (NCSU) campus. NCSU is undergoing significant construction activities. Most of the contractors working for NCSU are willing to cooperate with our project.
2. **Vehicle Selection –** The types of construction vehicles selected for data collection were prioritized based on analyses using the U.S. Environmental Protection Agency's NONROAD

model. The selected equipment contributed to 70% of nonroad construction emissions in the United States. This study included excavators, dozers, off-highway trucks, backhoes, front-end loaders, skid steer loaders, and generators.

3. **Vehicle Activities** – Vehicle activities have been characterized for each type of construction equipment. These activities are translated into activity-based "modes" for each type of equipment such as idle, moving, loading, and scraping, and into engine-based modes, based on manifold absolute pressure.
4. **Data Collection Scheduling** – Prior to data collection activity, cooperation must be obtained from the owner, the supervisor and the equipment operator to access the equipment for installation of the PEMS. Permission must also be obtained to interact with the operator during data collection.
5. **Driver/Operator** – The driver or operator was assigned based on the contractor's driver schedule. On occasion, the operator might alter their work schedule, or there may be unanticipated problems with the equipment itself resulting in data collection delays.

2.2 Installation of the PEMS

Installation of the PEMS must take into account the configuration of the vehicle and the amount of time required to install the PEMS. PEMS have been used for a number of years for light duty vehicles. However, for construction vehicles, the installation procedure is more complicated than for light-duty vehicles. The general procedures include pre-installation, installation, and decommissioning. In order to have sufficient time to set up the PEMS without interfering with construction work, the data collection crew pre-installs major components of the PEMS one day prior to each test. This includes installing all wiring, hoses, engine sensors, and installation of the safety cage. On the day of the test the main unit is secured inside the safety cage and is connected to the hoses and cables that were installed during pre-installation. In addition, the installation procedure includes set up of the GPS receiver as well as other equipment used to monitor site conditions and vehicle activity. The latter includes a laptop that is used to record modes of activity for the vehicle. The data collection crew synchronizes the time of the laptop computer to that of the main unit of the PEMS. If two personnel are involved in installation, typical time spent was 2 hours and 30 minutes for pre-installation and 1 hour and 30 minutes for installation. After data collection is complete, all equipment is removed from the vehicle and the site. This takes approximately 35 minutes. The PEMS is then cleaned and stored in the laboratory.

2.3 Field Measurement

During field measurement, the data collection crew assesses and records field conditions, collects emission data, monitors vehicle activity, and archives the field data. The PEMS must be warmed up for at least 45 minutes and record data for 3 to 5 hours. One of the most significant challenges to data collection is vibration from the vehicle that is transmitted to the instrument. This may cause internal damage to the PEMS which has not been "ruggedized" for such use. A safety cage with rubber and foam pads were designed and manufactured to reduce the vibration from the chassis of the test equipment.

2.4 Data Quality Assurance

Data screening and quality assurance are procedures for reviewing the field data in order to produce a valid database of emission quantities. These procedures determine whether any errors or problems exist in the data, correct such errors or problems where possible, and remove invalid data if errors or problems cannot be corrected. Such procedures were defined, tested, and utilized. A number of possible errors and problems have been identified from previous work (*1*, *2*), such as analyzer freezing, inter-analyzer discrepancy, missing MAP, unusual engine speed, unusual manifold absolute pressure, unusual intake air temperature, and air leakage. The use of a sensor array requires the modification of the data screening and quality assurance procedures to account for problems and errors that can occur in conjunction with the sensor array. For instance, occasional problems have been observed involving unusual engine RPM or missing values of MAP. During field data collection, the data streams are periodically reviewed to determine if such problems exist and, if so, attempts are made to correct these problems by reinstalling the sensor array.

2.5 Analysis of the Data

The field data results were analyzed in terms of the effect of engine activity on fuel use and emissions. They were also analyzed in terms of the fuel use and average emission rate for task-oriented modes. For each of these two different types of analysis, which are referred to here as engine-based versus task-oriented, emission factors were estimated on a per time basis and on a per gallon of fuel consumed basis.

3.0 FIELD ISSUES

After applying these procedures to real-world measurement numerous lessons were learned about conducting the study in a real-world construction environment. Some of these lessons are summarized here in terms of preliminaries, installation of the PEMS, field measurement, data quality assurance, and analysis of the data.

3.1 Preliminaries

The first step in this work is to identify the equipment to be tested. This includes considering type of equipment, engine size, and age. Locating equipment is the next step and it is one that is not always easy. Getting collaboration from the equipment operator or supervisor is important. In order to test the equipment, approval for access to the construction site as well as to the equipment is needed.

3.2 Installation of the PEMS

The PEMS is vulnerable to damage from impact with trees and other obstacles since it is often located on top of a vehicle that is working on an often cramped work site. The PEMS must be protected from damage by tree branches or other potential obstacles that might be encountered at a construction site. Vibration from the equipment and dust from the construction site are two other key considerations. Each of these factors can potentially damage to the system in serious ways. A safety cage was designed to secure the PEMS to avoid any collisions. Rubber and foam pads are used in order to reduce vibrations coming from the chassis of the test equipment to the cage and to the main unit. A filtering material is used to protect the PEMS from dust.

3.3 Field Measurement

Ambient conditions, such as temperature, can significantly affect the feasibility of data collection. In hot weather, the PEMS was found to overheat when the ambient temperature was above 90 °F.

The data collection crew should stop data collection when the ambient temperature reaches 90 °F. In cold weather, the residual water in the sampling hoses may be frozen when temperatures are very low. If sampling hoses are connected to the PEMS before evaporating the moisture damage may result to the PEMS. A recommended practice is to keep sampling hoses in a warm place to avoid this problem.

3.4 Data Quality Assurance

The results show that approximately 4.6 percent of data are deleted as a result of the quality assurance check. The most significant sources of the QA errors are analyzer freezing and inter-analyzer discrepancies. While the engine data keep changing, emissions data from the analyzers stay the same for a period of several seconds. This error is called "Gas Analyzer Freezing." The Montana system is composed of two identical gas analyzers to measure NO, HC, CO, and CO_2 pollutants from exhaust flow. Each gas analyzer receives a continuous sample of exhaust gas simultaneously. However, these analyzers may not produce identical measurements due to the influence of environmental factors, drift in data, or the effect of zeroing calibration process. This error is called "Inter-Analyzer Discrepancies."

3.5 Analysis of the Data

A bulldozer was chosen as an example in this study because bulldozers are the second largest NO_x emission source among nonroad vehicles in EPA's NONROAD model. The results are shown in Figure 1. NO emission rate is highly proportional to the manifold absolute pressure for engine-based modes. For task-oriented modes, there is a significant difference between idle and non-idle modes for mass per time emission rates. NO emission rates during an idling mode are typically less than those in non-idling modes.

4.0 RECOMMENDATIONS

The procedures provided in this paper are applicable to any construction sites and any type of nonroad construction equipment. Recommendations are made based on the experience gained in attempting to obtain valid energy use and emissions data for nonroad construction equipment. Foam should be placed under the main unit of the PEMS and under the safety cage to reduce vibration and equipment damage. An appropriate cover must be installed to prevent damage from dust. In order to prevent data quality problems, the data collection crew should check the PEMS every 30 minutes periodically during data collection to ensure that no problems have occurred. More sophisticated definitions of modes of activity are needed to link emissions to typical vehicle activities. Methods need to be developed to inventory equipment so that total emission inventories can be developed. Energy use and emissions also need to be linked to typical construction operations and quantities so that emission inventories can be linked to typical construction project measures as well as to vehicles and equipment thus resulting in an opportunity to have an entirely new approach to emission prediction.

5.0 SUMMARY

This paper demonstrates field data collection procedures for study design, installing the PEMS, collecting data from the PEMS, quality assurance, and analysis of data for nonroad construction equipment. In order to construct a valid database, procedures for determining whether any errors or problems exist in the data were developed, including approaches for checking data while in the collected. The methodology for data collection and analysis described here is recommended and intended for future use in conjunction with measurement and evaluation of activity, fuel use, and emissions of construction vehicles.

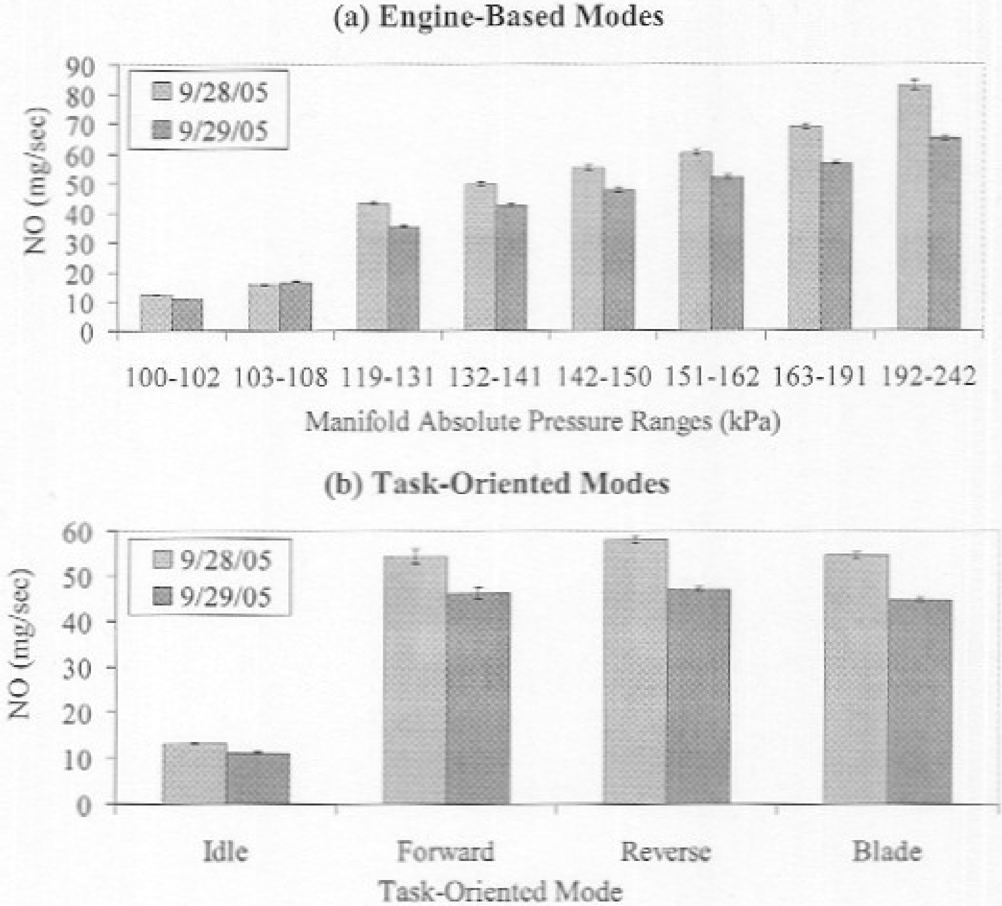

Figure 1. Average NO Emission Rates of (a) Engine-Based and (b) Task-Oriented Modes

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7.0 REFERENCES

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