Characterization of CO_2 Emissions from Nonroad Diesel Construction Equipment

Extended Abstract #40

M. Phil Lewis, Ph.D., P.E.
Oklahoma State University, School of Civil and Environmental Engineering, 207 Engineering South, Stillwater, OK 74078

INTRODUCTION

With an increased focus on the impact of greenhouse gas (GHG) emissions on global warming and climate change, all GHG emissions sources need to be closely evaluated, including the construction sector. The United States Environmental Protection Agency's (EPA) NONROAD model estimates that there are over two million items of construction and mining equipment currently in use across the nation and this equipment will use nearly seven billion gallons of diesel fuel in 2011.[1] As a result, over 75 million tons of carbon dioxide (CO_2) will be emitted into the atmosphere this year from diesel-powered construction and mining equipment.

Carbon dioxide emissions from construction equipment can be difficult to characterize because of variability in equipment types, engine sizes, engine model years, engine loads, and equipment duty cycles. Most construction equipment emissions inventories, such as NONROAD, rely on engine dynamometer data obtained from laboratory experiments that may not accurately reflect the episodic behavior of construction equipment activity. Real-world data is needed to assess the true nature of CO_2 emissions from nonroad diesel construction equipment.

The objective of this paper is to present CO_2 emissions results based on a field study of seven types (34 total items) of nonroad diesel construction equipment as they performed real-world duty cycles. These results include both idle and non-idle CO_2 emission rates (which are not available from NONROAD) as well as the average combined emission rate for the equipment. These results are used to compare the real-world CO_2 emission rates to those used by NONROAD and also to compare the variability in CO_2 emission rates among equipment types.

METHODOLOGY

A field study was conducted by researchers at North Carolina State University (NCSU) to assess the air pollutant emissions from construction equipment as they performed real-world duty cycles.[2] For each item of equipment, second-by-second emissions data including nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM), and CO_2, were collected for the observed duty cycles of the equipment; hence, a time-based link was established between these pollutant emissions and the equipment activity that emitted them. Furthermore, a carbon balance was used to estimate the fuel use rate of the equipment on a second-by-second basis. A detailed description of the field data methodology is presented by Rasdorf.[3]

The instrumentation used to collect the field emissions data was an on-board portable emissions measurement system (PEMS) that gathered engine and emissions data directly from the equipment while it was in use. The PEMS used for this study was the Montana System which was manufactured by Clean Air Technologies International, Inc.[4] The PEMS was placed in a protective safety cage and attached to the body of the equipment, usually on the roof of the roll-over protective system. A sensor array was connected to the engine to collect engine performance data such as engine speed, intake air temperature, and manifold absolute pressure and sample probes were placed into the engine exhaust pipe to collect exhaust emissions data. In addition to the emissions data, engine attributes were collected for each item of equipment, including rated horsepower of the engine, engine model year, and EPA engine tier classification.

RESULTS

The field data results presented here are related to 34 items of equipment including eight backhoes, six bulldozers, three excavators, six motor graders, three off-road trucks, three track loaders, and five wheel loaders. The rated engine horsepower ranged from 70 HP to 306 HP and the model years ranged from 1988 to 2007. There were six Tier 0 engines that were tested, 17 Tier 1, 10 Tier 2, and one Tier 3.

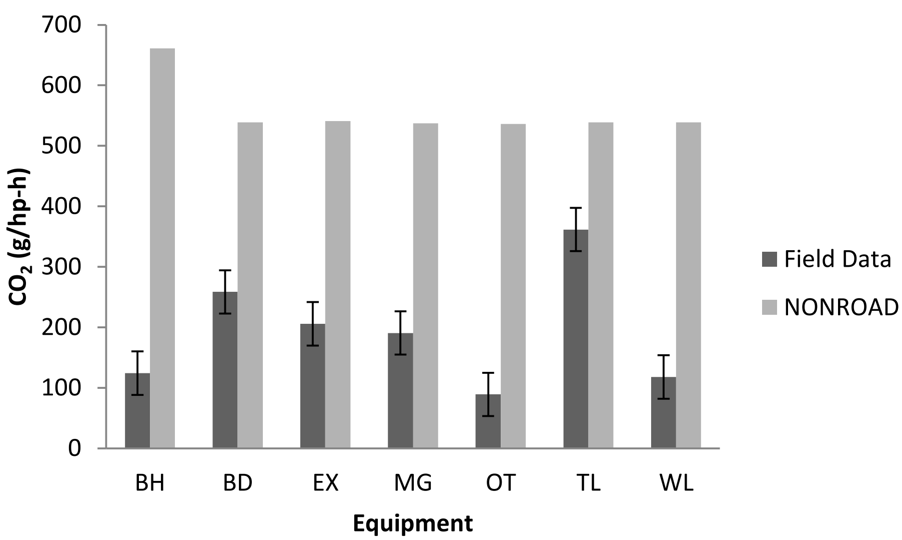
Table 1. Summary Statistics for CO_2 Emission Rates (g/hp-h)

		Average	Max	Min	SD	95% CI
Backhoes (n = 8)	Idle	40	55	29	10	7
	Non-Idle	139	244	69	62	43
	Combined	124	233	65	56	39
Bulldozers (n = 6)	Idle	75	124	38	30	24
	Non-Idle	303	516	121	139	111
	Combined	258	481	111	132	106
Excavators (n = 3)	Idle	56	87	38	27	31
	Non-Idle	280	304	244	32	36
	Combined	206	225	177	25	28
Motor Graders (n = 6)	Idle	45	72	18	22	18
	Non-Idle	220	313	141	70	56
	Combined	191	292	128	72	58
Off Road Trucks (n = 3)	Idle	37	39	34	3	3
	Non-Idle	162	196	298	31	35
	Combined	89	112	67	23	26
Track Loaders (n = 3)	Idle	114	243	46	111	126
	Non-Idle	406	471	298	95	107
	Combined	362	443	256	96	108
Wheel Loaders (n = 5)	Idle	39	55	23	14	12
	Non-Idle	154	200	127	28	25
	Combined	118	177	85	38	33

Summary statistics for the idle, non-idle, and combined (idle + non-idle) CO_2 emission rates are presented for each type of equipment in Table 1. The non-idle emission rates are approximately 3.5 to 5.0 times higher than the idle emission rates for all types of equipment. The average idle emission rates range from 37 g/hp-h (Off Road Trucks) to 114 g/hp-h (Track Loaders) and the average non-idle emission rates range from 139 g/hp-h (Backhoes) to 406 g/hp-h (Track Loaders); thus, Track Loaders have the highest overall average CO_2 emission rates for both idle and non-idle activity.

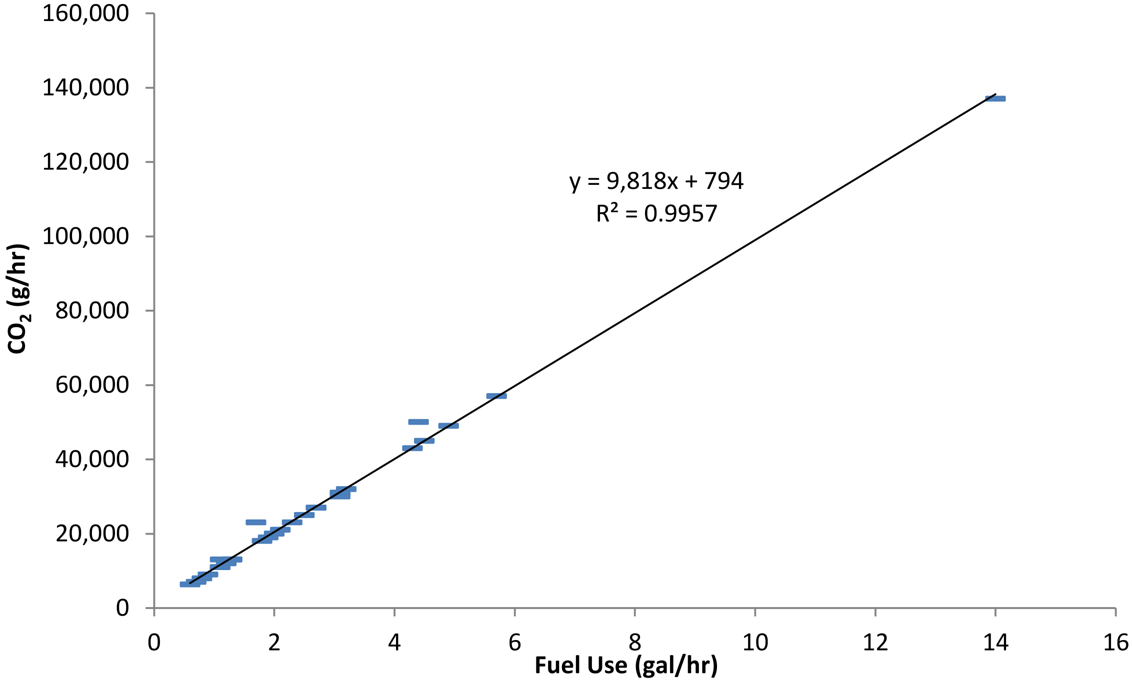
In order to provide a benchmark comparison for the field data, the average combined CO_2 emission rates observed in the field were graphed with the CO_2 emission rates used by the NONROAD model, as seen in Figure 2. The NONROAD model essentially uses the same CO_2 emission rates for bulldozers, excavators, motor graders, off road trucks, track loaders, and wheel loaders (536-541 g/hp-h) but a higher rate for backhoes (661 g/hp-h); however, the field data exhibit more variability in emission rates among equipment types compared to the NONROAD results. Furthermore, the field data results are much lower than the NONROAD emission rates. On average, the NONROAD emission rates are approximately three times higher than the average combined emission rates for each type of equipment observed in the field.

Figure 1. Comparison of Field Data vs. NONROAD Model CO_2 Emission Rates



CO_2 emissions are highly correlated to fuel use. Approximately 99% of the carbon in diesel fuel is emitted in the form of CO_2 (EPA 2005).[5] Figure 2 shows the relationship between CO_2 emissions and diesel fuel consumption for the field data based on the average combined CO_2 emissions and fuel use rates for each item of equipment that was tested. According to Figure 2, approximately 10,612 grams of CO_2 are emitted per gallon of fuel consumed. This value is quantitatively similar to the CO_2 emission factor of 10,084 g/gal published by EPA.[5] Thus, on a mass per fuel consumed basis, CO_2 emission rates have very little variability and are practically constant at 10 kg/gal. However, on a mass per time basis (such as those shown in Table 1 and Figure 1), CO_2 emission rates are sensitive to engine loads and equipment activity and vary over time.

Figure 2. Relationship between CO_2 Emissions and Fuel Consumption



CONCLUSIONS

Field data is essential for characterizing CO_2 emissions from construction equipment. Currently, much of what is presumed about this topic has been based on assumptions related to fuel use and emission rates. This paper presents a foundational database of idle and non-idle CO_2 emission rates based on field data from 34 items of heavy duty diesel equipment that were performing common construction activities.

CO_2 emission rates are highly correlated to fuel use rates. Although this is not new knowledge, the mass per time CO_2 emissions field data presented here correspond closely with published data related to mass per fuel consumed CO_2 emission rates for diesel equipment. On average, non-idle CO_2 emission rates are approximately three to five times higher than idle emission rates on a mass per time basis for the equipment presented in this study.

For the seven types of equipment observed, track loaders had the highest overall average combined CO_2 emission rates and off road trucks had the lowest. These two types of equipment represent a CO_2 emissions range of 273 g/hp-h. The NONROAD model uses CO_2 emission rates of 536 and 539 g/hp-h, respectively for off road trucks and track loaders, a range of 3 g/hp-h. Thus, not only are the NONROAD emission rates much higher but they also do not represent the variability among equipment types that is exhibited by the field data.

RECOMMENDATIONS

Additional research is needed to expand the database of CO_2 emissions rates presented here. Expansion should include other types of commonly used nonroad equipment such as compactors, cranes, rollers, and scrapers. To completely quantify the carbon footprint of construction projects, highway vehicles such as light duty pickup trucks and heavy duty dump trucks should also be included. Furthermore, the methodology presented here should be used to analyze other air pollutants including NO_x, HC, CO, and PM.

Further investigation of the field data is needed to determine the factors that influence the variability in mass per time CO_2 emissions rates, including engine data such as horsepower rating, model year, EPA engine tier, and hours of use. This type of investigation may also clarify the influence of engine age and maintenance condition on fuel use and emissions rates. Other potential factors affecting emission rates include parameters related to equipment activity, such as the type of activity being performed, adverse site conditions, operator skill level, and weather conditions. These parameters generally have the ability to influence the productivity of the equipment and the resulting engine loads and therefore affect the fuel use and emissions rates.

Additional research is needed to target idle and non-idle time activity durations for construction equipment and to evaluate the factors that affect idle time. This new field data can be collected with a subset of instruments that focus on engine behavior, such as revolutions per minute (RPM) and manifold absolute pressure (MAP). Some newer construction equipment are equipped with on-board engine diagnostics technology, which may be useful in obtaining field data related to idle and non-idle time.

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