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Emission rates of regulated pollutants from on-road heavy-duty diesel vehicles

Sandip D. Shah[a,b], Kent C. Johnson[b], J. Wayne Miller[b], David R. Cocker III[a,b,*]

[a]Department of Chemical and Environmental Engineering, University of California, Riverside, CA 92521, USA
[b]Bourns College of Engineering, Center for Environmental Research and Technology (CE-CERT), 1084 Columbia Ave, Riverside, CA 92507, USA

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Abstract

Emissions from heavy-duty diesel (HDD) vehicles are affected by many factors. Changes in engine technology, operating mode, fuel properties, vehicle speed and ambient conditions can have significant effects on emission rates of regulated species. This paper presents the results of on-road emissions testing of 11 HDD vehicles (model years 1996–2000) over the ARB Four Phase driving schedule and the urban dynamometer driving schedule (UDDS). Emission rates were found to be highly dependent on vehicle operating mode. Per mile NO_x emission rates for vehicle operation at low speeds, in simulated congested traffic, were three times higher per mile emissions then while cruising on the freeway. Comparisons of NO_x emission factors to EMFAC baseline emission factors were within 5–40% for vehicles of various model years tested over the UDDS. A comparison of NO_x emission factors for a weighted average of the ARB four phase driving schedule yielded values within 17–57% of EMFAC values. Generally, particulate matter (PM) emission rates were lower than EMFAC values.

Keywords: Diesel emissions; NO_x; Oxides of nitrogen; On-road emissions; Regulated pollutants; Heavy-duty diesel

1. Introduction

Heavy-duty diesel (HDD) vehicles account for 30–60% of the on-road NO_x emissions inventory (US EPA, 1998; Kean et al., 2000). The variability in the estimated HDD contribution to inventories is due to the uncertainty the relationship between emission rates and factors such as test cycle, activity, engine programming and vehicle age (Clark et al., 2002; Dunlap et al., 1993; Dietzmann and Warner-Selph, 1985). Until recently, most emissions data were based on results testing engines in a laboratory following certification cycles. Dietzmann and Warner-Selph (1985) have demonstrated that emissions measured over certification cycles do not compare well with chassis dynamometer testing of vehicles over comparable test cycles. Currently, emission factors used in inventory estimates are based on compilations of data found in sources such as the California Air Resources Board's (CARB) EMFAC model (CARB, 2002). These emission factors are primarily based on certification data developed from stationary dynamometer testing or limited testing of vehicles on chassis dynamometers over standard cycles (CARB, 2002).

*Corresponding author. Department of Chemical and Environmental Engineering, University of California, Riverside, CA 92521, USA. Tel.: +1 951 781 5695; fax: +1 951 781 5790.
E-mail address: dcocker@engr.ucr.edu (D.R. Cocker III).

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Yanowitz et al. (1999) suggest that per mile NO_x emission rate variations due to differences in operating modes can be normalized on a fuel consumption basis. However, with the development of advanced engine controls, such as the electronic control module (ECM), newer HDD vehicles tend to stray from this generalization (Clark et al., 2002; Federal Register, 1998). The ECM controls fuel injection timing in such a manner that during certain cruising conditions, fuel consumption is reduced while NO_x emissions are increased. This effectively varies the emission rate of NO_x on a basis of fuel consumption (Federal Register, 1998). In order to accurately model and predict emissions, there is a critical need to measure the in-use emission factors of these newer vehicles as they operate on-road.

The effects of driving cycle on PM emissions and composition were the subject of a previous publication (Shah et al., 2004). In this paper, we examine the effects of various driving cycles on regulated gaseous emissions from HDD vehicles operated on the road. For the first time, on-road emission factors of gaseous pollutants, measured using a laboratory designed to meet the US Code of Federal Regulations (40 CFR 86) requirements for determining emissions from HDD engines, are presented for a fleet of vehicles. Comparisons of measured values to published EMFAC values are made.

2. Experimental section

2.1. Mobile emissions laboratory

Emissions testing was performed using CE-CERT's mobile emissions laboratory (MEL). The MEL is comprised of a 53-foot refrigeration trailer equipped with a full-scale dilution tunnel. The laboratory can be connected to test-vehicles and driven over the road with the total exhaust plumbed directly into the dilution tunnel via an insulated, gastight, flexible, 316-L stainless steel tube. The MEL is designed to measure emissions at the quality level specified in the US Congress Code of Federal Regulations for heavy duty diesel engines (40 CFR 86). Details of the laboratory are provided elsewhere (Cocker et al., 2004).

2.2. Gaseous analyzers

Analyzers for CO, CO_2, NO_x and THC extract samples from the dilution tunnel via heated filters and lines. The gaseous emissions analyzers utilized in the laboratory are listed in Table 1. Span and zero calibrations on each range of the analyzers are performed throughout the test day (a minimum of once in every 2 h). In addition, the laboratory undertakes weekly checks of the dilution tunnel and sampling systems via the injection of a known mass of propane and CO_2; audit bottle checks, NO_x converter checks, leak checks and calibrations of all auxiliary measurement devices such as mass flow controllers, thermocouples, barometric pressure and dew point sensors are performed on a routine basis. For every test, ambient measurements are compared against local reported values (airports) or independent measurements. The full details of QA/QC program can be found elsewhere (Cocker et al., 2004).

2.3. Test fleet, fuel and cycle

Table 2 summarizes the 11 HDD vehicles tested. Vehicles were procured from a truck dealer and tested on-road without modifications or repairs. Vehicle 10 was unable to maintain the most severe speeds and accelerations of portions of the test cycles. All vehicles were tested as is except for a change to CARB ultra-low-sulfur-diesel fuel (<15 ppm S); typical properties of the test fuel can be found in Table 3. Emissions testing were conducted following the ARB four phase schedule and the urban dynamometer driving schedule (UDDS) (40 CFR 86; Gautam et al., 2002). The ARB four phase driving schedule are derived based on activity data collected for 84 HDD vehicles operating in California and it consists of four phases: Cold-Start/Idle, Creep, Transient and

Table 1
Summary of gas-phase instrumentation in the MEL (11)

Gas component	Range[a]	Monitoring method
NO_x	10/30/100/300/1000 (ppm)	Chemiluminescence
CO	50/200/1000/3000 (ppm)	NDIR[b]
CO_2	0.5/2/8/16 (%)	NDIR
THC	10/30/100/300/1000 & 5000 (ppm C)	Heated FID[c]

[a]Multiple values of range indicate upper range of each instrument mode.
[b]Non-dispersive infrared detector.
[c]Flame ionization detector.