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Emissions of regulated pollutants from in-use diesel back-up generators

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Abstract

Recent power outages have highlighted the need for reliable alternatives to the power grid such as diesel back-up generators (BUGs). As many BUGs are operated in close proximity to populations, there is a need for accurate emissions measurements from these units. This paper reports regulated emissions for diesel BUGs of varying model year, engine technology and manufacturer in the 60–2000 kW size and provides the largest emissions database for these engines. The average emission factors for oxides of nitrogen (NO_x) were determined to be approximately 41% and 47% lower than EPA's estimates in AP-42 for small and large BUGs, respectively. Average particulate matter (PM) emission factors were approximately 83% and 50% lower than AP-42 estimates for small and large BUGs, respectively. All BUGs tested had lower emissions than used in EPA's AP-42 emissions inventory for NO_x and PM. Results indicate that decreases in NO_x emission rates for BUGs paralleled the non-road and on-road emission standards. Minimal variation was noted for three engines of the same family and model year but with different hours of operation.

Keywords: Diesel emissions; NO_x; Diesel particulate matter; Off-road emissions; Regulated pollutants; Heavy-duty diesel

1. Introduction

Recent instabilities in the electricity market have highlighted the need for alternative sources of power. Back-up generators (BUGs) are the prevailing option for backup power in facilities where continuous power is essentially based on their combination of reliability, durability, affordability, and overall efficiency (Pistenmaa et al., 2003). Furthermore, most BUGs are operated in populated areas (Ryan et al., 2002). It is estimated that there were over 11,000 diesel-fueled emergency/standby engines in California in 2000 with sizes ranging from 50 to 6000 horsepower (California Air Resources Board (CARB), 2000; Waterland, 2001).

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Diesel PM emissions continue to be of interest because of increased risk to human health and have been identified by the CARB as a toxic air contaminant and a carcinogen (US EPA, 2002; CARB, 1988). NO_x emission inventories remain critical in non-attainment areas for ozone and particulate matter due to atmospheric reactions with hydrocarbons to form ozone and the atmospheric oxidation of NO_x to particulate nitrate. CO emissions are of interest due to the proximity of many of these BUGs to sensitive areas such as hospitals and schools.

Information on current BUGs emissions factors is very limited in terms of population size and test methodology. For example, EPA's AP-42, the primary compilation of emission factor information, is limited to a few studies in the 1970s and 1990s (US EPA, 1996). EPA's evaluation of the emission factors in AP-42 shows that these values are generally of low quality (US EPA, 1996). With the exception of the results reported in this publication, in-use emissions data are very limited. Certification values are available for units manufactured after 1996 when certification standards were implemented for these engines. However, in-use and certification values can differ.

In comparison, more data are available for heavy-duty diesel (HDD) engines used for on-road application. While many similarities do exist between the BUGs and HDD vehicle engines, the primary modes of operation are quite different. BUGs operate at near steady-state load conditions with slight variations in load causing short-lived transient events. HDDTs, on the other hand, operate in almost completely transient conditions. The differences in modes of operation cause the emissions of these engines to vary immensely (Shah et al., 2004; Kweon et al., 2002; Shi et al., 2000). Additionally, some on-road engines can exhibit non-linear NO_x and PM emissions due to engine timing controlled by the on-board electronic control module, which is not available in most BUGs (Cocker et al., 2004a).

This paper reports regulated emissions from a series of BUGs of different engine technologies, model years and engine size. In-use emission factors are compared with current EPA AP-42 emission factors. Comparisons made between engine manufacturer, model year, engine wear, and engine technology are reported in the paper.

2. Experimental

2.1. Emissions measurements

Engine emissions were measured using CE-CERT's Mobile Emissions Laboratory (MEL) (Cocker et al., 2004a). The MEL is comprised of a 53-foot refrigeration trailer equipped with a full-scale dilution tunnel. The laboratory is capable of total capture emissions measurements for engines up to 600 kW in size. 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 (Code of Federal Regulations, 2004a).

Exhaust from each BUG was captured by the MEL via an insulated, gastight, flexible, 316-L stainless steel tube. Partial exhaust was collected for BUGs exceeding 600 kW. Gaseous emissions were collected through heated lines from the primary dilution tunnel system. PM samples were withdrawn from a temperature controlled Secondary Dilution System (SDS) operating at 47 °C (Cocker et al., 2004b). PM samples were collected on Pall Gelman (Ann Arbor, MI) 47 mm PTFE Teflo® filters. Filter preparation and handling met the requirements of the CFR (Code of Federal Regulations, 2004a). Filter weights were measured with a Cahn (Madison, WI) C-35 microbalance.

2.2. Test protocol

Emissions testing was conducted over the five-mode test cycle specified in the CFR for non-road compression ignition engines (Code of Federal Regulations, 2004b). The cycle consists of operating the generator at rated engine speed at 10%, 25%, 50%, 75%, and 100% load. Duplicate tests were performed for each BUG. The BUGs were externally loaded with a programmable load bank which dissipates the electrical output of the generator as heat. The overall emission factor (EF) was calculated based on the methods and weighting factors specified within the 40CFR Part 89 (Code of Federal Regulations, 2004b).

$$\mathrm{EF} = \frac{\sum_{i=1}^{n} g_i \mathrm{WF}_i}{\sum_{i=1}^{n} P_i \mathrm{WF}_i}, \tag{1}$$

where EF is the total weighted emission factor (THC, CO, CO_2, PM, or NO_x) in g $(\mathrm{kW\,h})^{-1}$, g_i is