Carbon Monoxide and Portable Generators

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Serious concerns exist about the hazard of acute residential carbon monoxide (CO) exposures from portable gasoline-powered generators, which can result in death or serious adverse health effects. As of April 23, 2013 and as shown in Figure 1, the U.S. Consumer Product Safety Commission (CPSC) databases contain records of at least 800 deaths (involving 597 incidents) from CO poisoning caused by consumer use of a generator in the period of 1999 through 2012 (Hnatov 2013). Typically, these deaths occur when consumers use a generator in an enclosed or partially enclosed space or, less often, outdoors near a partially open door, window or vent. While avoiding the operation of such generators in or near a home is expected to reduce indoor CO exposures significantly, it may not be realistic to expect such usage to be eliminated completely.

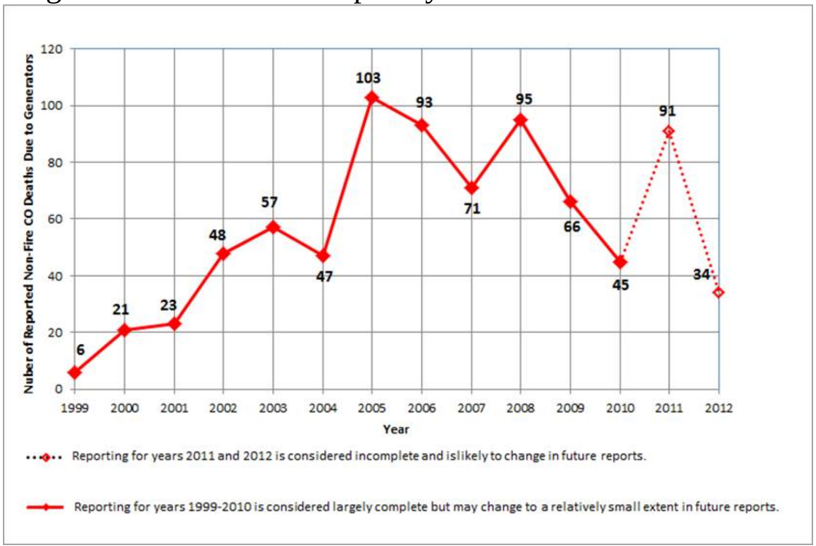

Figure 1. Increase in generator-related CO poisoning deaths since 1999 (Hnatov 2013)

Another means of reducing these exposures would be to decrease the amount of CO emitted from these devices. The magnitude of such reductions needed to reduce exposures to a specific level depends on the complex relationship between CO emissions from these generators and occupant exposure. In order to better understand the CO emissions from portable generators, the potential for reducing these emissions and the impacts on occupant exposure, a multi-year research effort was conducted involving both experimental and simulation studies (Emmerich et al. 2013 and Persily et al. 2013).

Measurements of CO emissions from portable generators

To better understand CO emission rates from both stock (currently available) and reduced-emission prototype portable generators operating in an enclosed space under real weather conditions, experiments were conducted in a single zone shed and in a three-bedroom test house with an attached garage. This paper summarizes the measurements conducted in the shed; the tests with the generator operating in the attached garage are described in Emmerich et al. (2013).

The shed experiments were conducted in a 43 m^3 single-walled, uninsulated timber structure for the purpose of measuring the CO emission rate and O_2 consumption rate of the generators. Figure 2 shows a generator installed in the shed along with the load bank used to place an electric load on the generator. The shed also had two operable windows at both sidewalls and an exhaust fan, which were used to vary the air change rate during the tests from about 0.5 h^{-1} to 10 h^{-1}. Tests were conducted with three different generators that were configured in multiple ways. Two unmodified ‘stock’ (i.e., in their as-purchased condition) generators were tested. The first generator has a full-load power rating of 5.5 kW with a 10 horsepower, carbureted, single cylinder gasoline engine and no CO emission control technology. The second generator is powered by a carbureted 11 horsepower single-cylinder gasoline and has an advertised full-load electric power rating of 5.0 kW. This generator was tested in both its stock, unmodified condition and modified as a low-CO emission prototype. The modifications included an engine management system (EMS) with sensors and actuators for electronic fuel injection (replacing the carburetor) and a muffler with a small catalytic converter. The third generator was similar to the second, but with an output rating of 7 kW and a different model EMS.

Figure 2. Generator in test shed

Figure 3 shows the measured CO and O_2 concentrations for two of the experiments with the first, unmodified generator (see Emmerich et al. 2013 for an explanation of the test conditions). The patterns of CO concentrations in both tests are almost an inverse to the O_2 levels for this unmodified generator. The CO level is low at the beginning of generator startup and increases steadily as the O_2 level drops. As the O_2 drops further, causing a very rich fuel mixture in the engine, CO generation reaches a maximum level. Test 13 shows an extreme case in which the generator eventually produces a zero electrical load when the O_2 drops to around 16.4 %, although it was set at a full load and the crankshaft was still rotating.

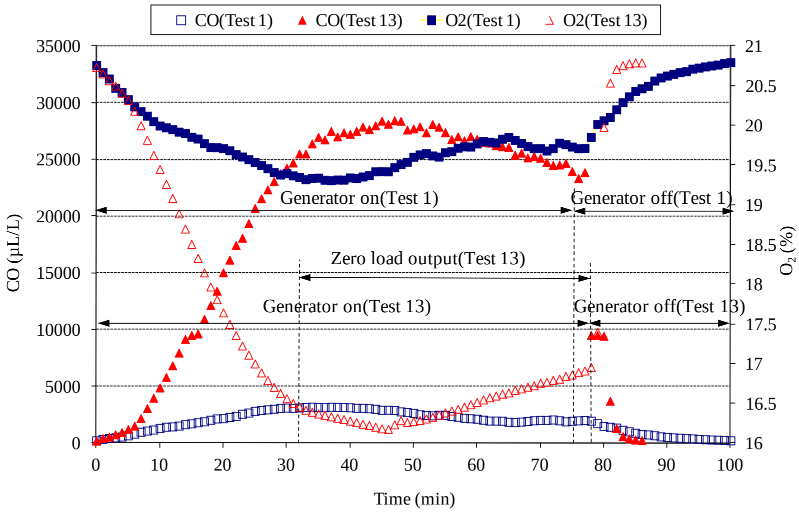

Figure 3. Measured CO and O_2 concentrations of Tests 1 and 13.

In order to generalize these test results to other conditions beyond these particular tests, it is necessary to convert the results into CO emission and O_2 consumption rates. Figure 4 shows 5-min average CO emission rates as a function of O_2 levels in the thirteen shed tests of the first, unmodified generator. For both full and half load settings, CO emission rates increase with decreasing O_2, reaching maximum values when O_2 drop to about 17 % to 18 %, and then decline at lower O_2 levels. Under the extreme case of Test 13 (5.0kw-CW-LA), the CO rate decreases dramatically as the O_2 level reaches around 16.4 % with an electrical output of zero. The solid points in Figure 4 are data points for a half-load setting (2.5 kW) and the hollow ones for a full load setting (5.0 kW).

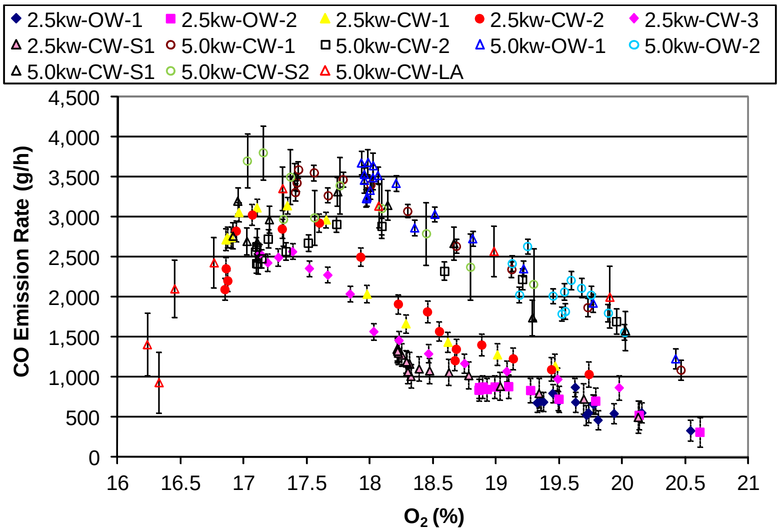

Figure 4. Five-minute averaged CO emission rates at different O_2 levels.

The second generator was tested in both unmodified and modified (low CO emission) configurations. Figure 5 presents the CO emission rates as a function of O_2 levels for the unmodified generator, while Figure 6 presents the CO emission rates as a function of O_2 levels for the modified generator. Although the modified generator was not tested as many times as the unmodified version, these figures show the dramatic reduction in CO emission rates due to the low CO emission modifications included on the prototype. Most of the modified generator's emission rates were well below 500 g/h.

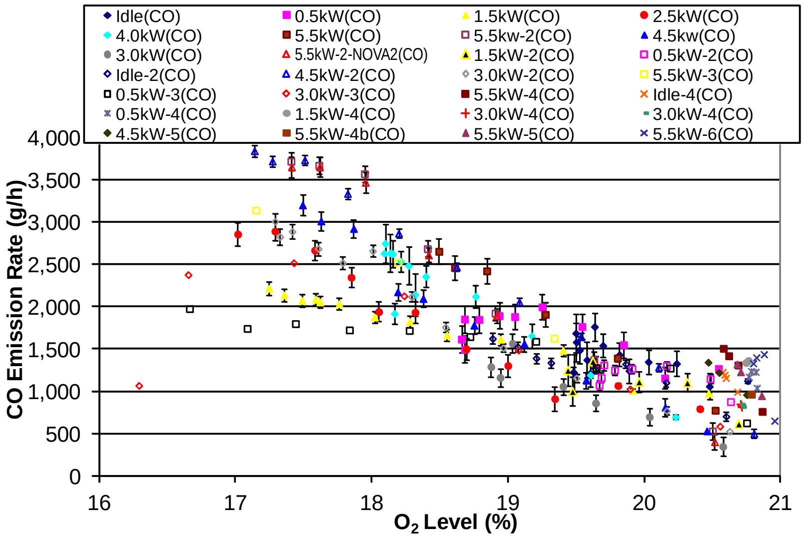

Figure 5. CO emission rates at different O_2 levels for unmodified Generator X.

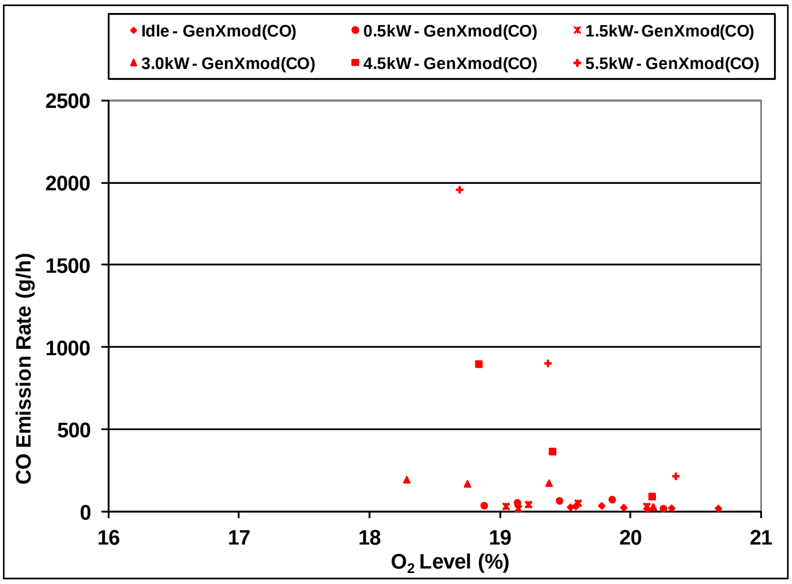

Figure 6. CO emission rates at different O_2 levels for modified generator

Simulations of CO Exposure from Portable Generators

To address the CO exposure associated with portable generators and to support potential control strategies such as reduced emissions, a better understanding of the relationship between CO emission rates and occupant exposure is needed. This relationship involves the interaction between generator location and operation, house characteristics, occupant location and activities, and weather conditions. In order to support life-safety based analyses of potential CO emission limits for generators, a computer simulation study was conducted to evaluate indoor CO exposures as a function of generator source location and CO emission rate. Simulations were performed using the multizone airflow and contaminant transport model CONTAM (Walton and Dols 2005), which was applied to 87 single-family, detached dwellings that are representative of the U.S. housing stock. Using these homes, indoor CO concentrations were calculated over a range of generator locations, CO emission rates, and weather conditions. These simulations yielded CO concentrations in the rooms of each house as a function of time during the 24-h analysis interval. In order to compare the results for different cases, the concentrations from each simulation were used to calculate COHb values in each occupied room. The maximum COHb value among the occupied rooms was used as a metric of CO exposure for each combination of house, source, and weather.

The results of the simulations constitute a large amount of data, which can be interpreted by considering the percentage of cases simulated that meet a specific criterion for the target value of maxCOHb. Determination of such criteria was beyond the scope of this project but for comparison purposes, the maximum source strength was estimated for which 80 % of the cases simulated are below 30 % maxCOHb for each of the source locations considered. The values of 80 % below 30 % maxCOHb are used only for illustrative purposes and are not presented as life-safety based limits to support any policy or regulatory decisions. Considering all the constant source results, the maximum source strength corresponding to 80 % of the cases having a value of maxCOHb below 30 % is 27 g/h. Note that the CO emission rates measured in unmodified generators mentioned earlier tended to be well above this value, but that the modified generators tested were in this range.

In 2006, CPSC issued an *Advance Notice of Proposed Rulemaking; Request for Comments and Information* describing its strategy to reduce generator engine CO emission rates. Additionally, Underwriters Laboratories, Inc. has formed a working group to develop a specific proposal for requirements for portable engine-generator sets that fall under the scope of UL 2201, *Portable Engine-Generator Assemblies* to reduce the risk of death and injury due to CO poisoning.

Acknowledgement
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