In-Depth Survey Report

FOLLOW UP EVALUATION OF KOHLER LOW EMISSION TECHNOLOGY TO PREVENT CARBON MONOXIDE POISONINGS FROM HOUSEBOAT GENERATOR EXHAUST

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EPHB Report No. EPHB 289-14a
Forever Resorts
Boulder City, Nevada

June 2011

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Site Surveyed: Forever Resorts, Boulder City, Nevada

NAICS Code: N/A

Survey Dates: July 27 – 28, 2009

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Abstract

In recent years, researchers from the National Institute for Occupational Safety and Health (NIOSH), working under an interagency agreement with the United States Coast Guard, evaluated carbon monoxide (CO) emissions and exposures from gasoline-powered generators equipped with emission control devices. This evaluation was part of a series of studies conducted by NIOSH investigators to identify and recommend effective engineering controls to reduce the CO hazard and prevent CO poisonings on houseboats and other recreational marine vessels.

In previous studies, NIOSH researchers have evaluated CO emissions from Westerbeke generators that have included the necessary technology to reduce and control CO emissions. Kohler Power Systems recently released to the public a new line of low CO emission generators with catalytic technology. During this study, NIOSH engineers conducted a follow up evaluation of a 15 kW low CO emission Kohler generator installed in a 16' x 59' houseboat equipped with a stack exhaust configuration. At the time of this evaluation, the 15 kW generator was the largest low CO generator manufactured by Kohler for the houseboat market. The new Kohler generator had been used for a full rental season and it recorded 1082 hours prior to the evaluation. Representatives from Kohler, the U.S. Coast Guard, and Forever Resorts attended the evaluation.

Results from this follow up evaluation on the Kohler 15 kW low CO emission generator showed higher levels of CO when compared to results obtained from the initial evaluation. Average onboard environmental CO concentrations measured at various locations on the houseboat were generally single digit concentrations. Inspection of the catalytic converter element showed complete degradation of the ceramic element that composes the catalytic converter. The catalytic converter was replaced and CO concentrations were again consistent with the results obtained from the initial evaluation. Following the cold start of the engine, initial CO concentrations reached approximately 80,000 ppm and then decreased to 3500 – 5000 ppm within 3 – 5 minutes after cold start. Once the catalytic converter was replaced, these CO concentrations decreased to 200 – 300 ppm within 4 to 5 minutes after initial start up with. The combination of well maintained low-emission technology along with a well designed stack led to low environmental CO concentrations at all measured locations on the houseboat (usually single digit concentrations).

It is important that the boater/owner/operator follow all maintenance recommendations provided by the manufacturer. For the Kohler low emission generator, some of those recommendations include checking/replacing the catalyst every 500 hours or yearly. Use of the vertical exhaust stack with low emission generators is recommended, as this will ensure redundancy in the system in the event of catalyst degradation or oxygen sensor malfunction. Development and commercialization of these systems is a major step forward in control systems to provide a safer environment around houseboats and other marine vessels.

Introduction

Background for Control Technology Studies

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational Safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, EPHB has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. Examples of these completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concept techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

Background for this Study

On July 27 – 28, 2009, researchers from the National Institute for Occupational Safety and Health (NIOSH) evaluated the control of carbon monoxide (CO) emissions and exposures at Callville Bay Marina on Lake Mead, Nevada. The evaluation primarily involved the testing of a Kohler generator installed on a houseboat over a year before the evaluation. The 15 kW low emission generator, equipped with an exhaust system routed to a vertical stack exhaust, was installed on a Fun Country Marine VIP XT (16 X 59') houseboat about one year prior to this follow up evaluation. The results of the initial evaluation are included on a separate NIOSH report. All of the evaluations were conducted while the houseboat was docked at the marina.

Representatives from NIOSH, U.S. Coast Guard (USCG), U.S. National Park Service (USNPS), Department of Interior (DOI), and Utah Parks and Recreation (UPR) conducted initial investigations of CO-related poisonings and deaths on houseboats at Lake Powell in September and October 2000. These investigations measured hazardous CO concentrations on houseboats at Lake Powell [McCammon and Radtke 2000]. Some of the very hazardous situations identified during the early studies included:

- The open space under the swim platform could be lethal under certain circumstances (i.e., generator/motor exhaust discharging into this area) on some houseboats.
- Some CO concentrations above and around the swim platform were at or above the immediately dangerous to life and health (IDLH) level [greater than 1,200 parts of CO per million parts of air (ppm)].
- Measurements of personal CO exposure during boat maintenance activities indicated that employees may be exposed to hazardous concentrations of CO.

Engineering control studies began in February 2001 at Lake Powell and Somerset, Kentucky [Dunn, Hall et al. 2001; Earnest, Dunn et al. 2001]. Results of these studies demonstrated that an exhaust stack extending 9 feet above the houseboat's upper deck dramatically reduced the CO concentrations on and near the houseboat and provided a much safer environment. The USCG, Office of Boating Safety, Recreational Boating Product Assurance Division convened a meeting on May 3, 2001, in Lexington, Kentucky. Houseboat manufacturers, marine product manufacturers, government representatives, and others interested in addressing the CO hazard attended this meeting. Following the meeting, NIOSH researchers were asked to evaluate the performance of a new prototype emissions control device (ECD) and an interlocking device and to conduct further evaluations of the dry stack. These evaluations were conducted in June 2001 at Callville Bay Marina, NV. The findings of these studies indicated that although the ECD, interlock, and dry stack each performed well, longer term testing of the ECD should be conducted [Dunn, Earnest et al. 2001; Earnest, Dunn et al. 2001]. A second evaluation of the prototype ECD in October 2001 showed that performance of the prototype ECD had substantially degraded after thousands of hours of use; however, a new production ECD was developed that performed well. The prototype ECD consisted of a combination of stainless steel and cast iron while the production ECD consisted entirely of stainless steel to reduce corrosion with several engineering improvements. NIOSH researchers conducted a follow-up survey to evaluate the performance of the improved ECD after 2,000+ hours of use. The results showed that the improved ECDs were somewhat effective at reducing CO concentrations; however, their performance had substantially degraded from when they were new [Earnest, Hall et al. 2003].

The current report provides the findings and conclusions for the performance of a follow up-evaluation of a new Kohler low emission generator equipped with multi-port fuel injection and a catalytic converter to control CO emissions. The engine marked 1082 hours at the time of this evaluation.

Plant and Process Description

Occupational Exposure Limits and Health Effects

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH investigators use mandatory and recommended OELs when evaluating chemical, physical, and biological agents in the workplace. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Combined effects are often not considered in the OEL. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus can increase the overall exposure. Finally, OELs may change over the years as new information on the toxic effects of an agent become available.

Most OELs are expressed as a TWA exposure. A TWA exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended STEL or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

In the U.S., OELs have been established by Federal agencies, professional organizations, state and local governments, and other entities. The U.S. Department of Labor OSHA PELs [CFR 2003] are occupational exposure limits that are legally enforceable in covered workplaces under the Occupational Safety and

Health Act. NIOSH recommendations are based on a critical review of the scientific and technical information available on the prevalence of health effects, the existence of safety and health risks, and the adequacy of methods to identify and control hazards [NIOSH 1992]. They have been developed using a weight of evidence approach and formal peer review process. Other OELs that are commonly used and cited in the U.S. include the TLVs® recommended by ACGIH®, a professional organization [ACGIH 2010]. ACGIH TLVs are considered voluntary guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards." WEELs are recommended OELs developed by AIHA, another professional organization. WEELs have been established for some chemicals "when no other legal or authoritative limits exist." [AIHA 2007].

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91–596, sec. 5(a)(1)]. Thus, employers are required to comply with OSHA PELs. Some hazardous agents do not have PELs, however, and for others, the PELs do not reflect the most current health-based information. Thus, NIOSH investigators encourage employers to consider the other OELs in making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminating or minimizing identified workplace hazards. This includes, in preferential order, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation) (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection).

Symptoms and Exposure Limits

CO is a lethal poison produced when fuels such as gasoline or propane are burned. It is one of many chemicals found in engine exhaust resulting from incomplete combustion. Because CO is a colorless, odorless, and tasteless gas, it can overcome the exposed person without warning. The initial symptoms of CO poisoning may include headache, dizziness, drowsiness, or nausea. Symptoms may advance to vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered. If the exposure level is high, loss of consciousness may occur without other symptoms. Coma or death may occur if high exposures continue [NIOSH 1972; NIOSH 1977; NIOSH 1979]. The display of symptoms varies widely from individual to individual, and may occur sooner in susceptible individuals such as young or aged people, people with preexisting lung or heart disease, or those living at high altitudes [Proctor, Hughes et al. 1988; ACGIH 1996; NIOSH 2000].

Exposure to CO limits the ability of the blood to carry oxygen to the tissues by binding with the hemoglobin to form carboxyhemoglobin (COHb). Blood has an estimated 210-250 times greater affinity for CO than oxygen, thus the presence of CO in the blood can interfere with oxygen uptake and delivery to the body [Forbes, Sargent et al. 1945].

Although NIOSH typically focuses on occupational safety and health issues, the Institute is a public health agency, and cannot ignore the overlapping exposure concerns in this type of setting. NIOSH researchers have performed a considerable amount of work related to controlling CO exposures in the past [Ehlers, McCammon et al. 1996; Earnest, Mickelsen et al. 1997; Kovein, Earnest et al. 1998]. The general boating public may range from infant to aged, be in various states of health and susceptibility, and be functioning at a higher rate of metabolism because of increased physical activity.

Exposure Criteria

Occupational criteria for CO exposures are applicable to USNPS and concessionaire employees shown to be at risk of boat-related CO poisoning. The occupational exposure limits noted below should not be used for interpreting general population exposures (such as visitors engaged in boating activities) because occupational standards do not provide the same degree of protection as they do for the healthy worker population. The effects of CO are more pronounced and the time of onset of effects is shorter if the person is physically active, very young, very old, or has preexisting health conditions such as lung or heart disease. Persons at extremes of age and persons with underlying health conditions may have marked symptoms and may suffer serious complications at lower levels of carboxyhemoglobin. Standards relevant to the general population consider these factors and are listed following the occupational criteria.

The NIOSH Recommended Exposure Limit (REL) for occupational exposures to CO gas in air is 35 ppm for full shift time-weighted average (TWA) exposure, and a ceiling limit of 200 ppm, which should never be exceeded [CDC 1988; CFR 1997]. The NIOSH REL of 35 ppm is established to protect workers from health effects associated with COHb levels in excess of 5% [Kales 1993]. NIOSH has established the IDLH value for CO of 1,200 ppm [NIOSH 2000]. The American Conference of Governmental Industrial Hygienists (ACGIH) recommends an 8-hour TWA threshold limit value (TLV) for occupational exposure of 25 ppm [ACGIH 1996] and discourages exposures above 125 ppm for more than 30 minutes during a workday.

The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for CO is 50 ppm for an 8-hour TWA exposure [CFR 1997].

Health Criteria Relevant to the General Public

The U.S. Environmental Protection Agency (EPA) has promulgated a National Ambient Air Quality Standard (NAAQS) for CO. This standard requires that ambient air contain no more than 9 ppm CO for an 8-hour TWA, and 35 ppm for a 1-hour average [EPA 1991]. The NAAQS for CO was established to protect the most sensitive members of the general population.

The World Health Organization (WHO) has recommended guideline values and periods of time-weighted average exposures related to CO exposure in the general population (WHO 1999). WHO guidelines are intended to ensure that COHb levels not exceed 2.5% when a normal subject engages in light or moderate exercise. Those guidelines are:

100 mg/m^3 (87 ppm) for 15 minutes

60 mg/m^3 (52 ppm) for 30 minutes

30 mg/m^3 (26 ppm) for 1 hour

10 mg/m^3 (9 ppm) for 8 hours

Methodology

Carbon monoxide (CO) and other environmental measurements were collected on a houseboat built by Fun Country Marine Industries, Inc. (Muncie, IN). Testing involved the evaluation of a Kohler low emission generator equipped with multi-port direct fuel injection and catalytic converter. A 15 kW Kohler generator, equipped with an exhaust system routed to a vertical stack exhaust, was tested on a Fun Country Marine VIP XT (16' X 59') houseboat. All of the evaluations were conducted while the houseboats were docked at the marina. The generator marked 1082 hours at the time of this evaluation.

The generator on the houseboat provided electrical power for air conditioning, kitchen appliances, entertainment systems, navigation, and communications equipment. The engine compartment beneath the stern deck near the drive engines housed the generator. These generators are similar in size to engines used on small automobiles. When used on houseboats, the hot exhaust gases from the generators are injected with water near the end of the exhaust manifold in a process commonly called water-jacketing. Water-jacketing is used for exhaust cooling and noise reduction.

Control Technology

Description of the Evaluated Engineering Controls

The evaluated houseboat had a continuous vertical exhaust stack fitted to the generator set. The exhaust stack on the Fun Country houseboat was designed to comply with the revised American Boat and Yacht Council (ABYC) Standard P-1 for recreational boat exhaust. A 2-inch nominal, schedule 40 aluminum pipe, having an approximately 2.5-inch outside diameter and 2.0-inch inside diameter was used as the stack [ABYC 2002].

The focus of this study was to evaluate the performance of a Kohler generator specifically designed to produce low CO emissions after one full season of use. The 15 kW Kohler generator was tested on a Fun Country Marine VIP XT (16' X 59') houseboat. The generator marked 1082 hours and was installed specifically for this evaluation almost one year prior to this field study. The results of the initial evaluation are included on a separate NIOSH report. Given the proprietary nature of this technology, little information could be obtained regarding the specific control technologies used to reduce the CO emissions. However, a multi-port direct fuel injection system was implemented to efficiently combust the gasoline to help reduce exhaust emissions, including CO.

A catalytic control device was designed to optimize the chemical oxidation of CO in the generator exhaust emissions. To prevent excessive heat buildup in the catalyst, the device was water-jacketed. Stainless steel was selected as the catalyst housing to inhibit corrosion from the harsh marine environment. The catalytic ingredients used in the catalyst were not revealed by the manufacturer, but normally catalysts are composed of metal or metal oxides (e.g., Pt, Pd, Rh, V_2O_5). These metals are normally dispersed onto a high surface area porous structure (e.g., Al_2O_3, SiO_2) located within the catalyst. Exhaust gases adsorbed onto the surface undergo catalytic reactions. A catalyst increases the rate of a chemical reaction without undergoing a permanent change itself [Heck, R.M., Farrauto, R.J., 1995].

The Kohler low emission generator incorporates a detection system, mounted on the back of the generator, which displays a warning as well as an audible alarm in the event that CO readings exceed 400 ppm during 4 minutes or longer and will shut down the generator after 15 minutes if CO concentrations continue to be above 400 ppm. The generator controller will provide a shut down fault code if the catalyst is degraded or not working properly. This line of generators also incorporates the capability of hard wiring into external CO sensors that should be capable of shutting down the engine if high CO concentrations are measured by the CO sensor.

Description of the Evaluation Equipment

A Testo Instruments (Lenzkirch, Germany) five-gas emissions analyzer was used to characterize emissions from the generator. This analyzer measured CO, carbon dioxide (CO_2), hydrocarbons, oxygen, and nitrogen oxides (NO_x). All measurements are expressed as percentages except hydrocarbons and NO_x, which are expressed in ppm. One percent of contaminant is equivalent to 10,000 ppm. The Testo unit was calibrated before starting the evaluation on this engine, and the instrument completed post-calibration procedures successfully.

ToxiUltra Atmospheric Monitors (Biometrics, Inc.) with CO sensors measured CO concentrations at various locations on the houseboat. ToxiUltra CO monitors were calibrated before and after use according to the manufacturer's recommendations. These monitors are direct-reading instruments with data logging capabilities. The instruments were operated in the passive diffusion mode with a 30 second sampling interval. The instruments have a nominal range from 0 ppm to 999 ppm. Accuracy is +/- 1 ppm or 5 percent of the reading, whichever is greatest.

CO concentrations were also measured with detector tubes [Dräger A.G. (Lubeck, Germany) CO, CH 29901 ranges 2-60 ppm, 10-3,000 ppm, and 3,000-70,000 ppm] directly in the generator exhaust when testing a houseboat in a top stack exhaust configuration. The detector tubes are used by drawing air through the tube with a bellows type pump. The resulting length of the stain in the tube (produced by a chemical reaction with the sorbent) is proportional to the concentration of the air contaminant.

Wind velocity and direction, temperature, and relative humidity measurements were collected during the air sampling using a HOBO Weather Station (Onset Computer Corporation, Bourne, MA). This instrument recorded information every second for the duration of the field investigation.

Description of Procedures

The evaluation was performed using a variety of operating conditions and generator exhaust configurations. The houseboat was tested while moored at the marina. Details concerning the generator testing are summarized below:

- **Fun Country Marine VIP XT (16' X 59') with a 15 kW low emission Kohler generator.** In this houseboat, the generator emissions were routed to exhaust through a vertical exhaust stack. Additionally, testing was accomplished under no-load, half-load and full load conditions. Half-load conditions were created by running the air conditioning unit. Full load conditions were created by running the air conditioning, the stove, the water heater and all the appliances available in the houseboat. In each case, the generator operated under half-load and full-load conditions when sufficiently warm (60 minutes of operation under no-load generator operation).

Figure 1 presents the typical sampling locations, designated with numbers, for the ToxiUltra real-time CO monitors on the lower and upper decks of the houseboats. The monitors were placed at ten sample locations on the upper and lower decks of the houseboat to provide representative samples of occupied areas. Grab samples using the Testo Five Gas Analyzer and Dräger detector tubes were also taken within the generator exhausts (top exhaust configuration). Additionally, wind direction and velocity, temperature, and relative humidity measurements were collected during the evaluation.

Results

Results of Air Sampling with ToxiUltra CO Monitors

Real-time CO monitoring was conducted at numerous locations on the evaluated houseboats (Figure 1). Table I presents the summary statistics for the data. Details concerning the sample results for each houseboat are summarized below:

- **Fun Country Marine VIP XT (16’ X 59’) with a 15 kW Kohler low emissions generator.** Table I presents the results for sampling conducted on this generator. CO concentrations around the houseboats were low for all tested conditions and were mostly single digit concentrations (average CO concentrations were typically below 5 ppm). The initial run at no-load conditions is included on the tables but not considered for analysis of CO emissions from this engine. A major difference can be observed between initial no-load conditions and the final no-load conditions completed at the end of the evaluation. Side exhaust testing was not completed during this evaluation since hardware was not available to install the proper routing of the exhaust gases through the side of the houseboat. This evaluation is a follow up conducted on this Kohler engine after the engine had logged a full rental season of use with 1082 hours recorded on the equipment. The combination of low-emission technology along with a well designed stack led to low environmental CO concentrations at all measured locations on the houseboat (usually single digit concentrations).

Gas Emissions Analyzer and Detector Tubes Results

Gas emissions analyzers and detector tubes were used to characterize CO concentrations in and near the exhaust stack. This additional equipment was used because it is capable of reading higher CO concentrations than the ToxiUltra CO monitors which have an upper limit of approximately 1,000 ppm. Figures 2 through 9 present graphs of the data collected using the emissions analyzer while Tables II and III (detector tubes) summarize the grab sample data. These results are discussed for the evaluated houseboat.

- **Fun Country Marine VIP XT (16' X 59') with a 15 kW Kohler low emission generator.** CO concentrations for all tested conditions were considerably higher when compared to results from the initial assessment. Measurements collected using the gas emissions analyzer are expressed in ppm. CO concentrations collected within the vertical exhaust plume reached instantaneous levels 80,000 ppm during the cold start of the engine. These concentrations decreased to approximately 5000 ppm within 3 minutes and remained stable for the duration of the test. CO concentrations were greatly affected when increasing load on the generator. After the engine reached operating temperature, CO concentrations oscillated between 500 to 8000 ppm and remained constant for the duration of all testing conditions. Measurements collected using detector tubes were consistent with the data collected with the emissions analyzer. As mentioned above, the results obtained were consistently higher and these partial results were communicated to the property manager and the Kohler representative that attended the evaluation. After troubleshooting and inspection of the equipment, the technician pulled the catalytic converter of the generator and noted that the internal mesh of the catalytic converter was completely destroyed. Kohler personnel installed a new catalytic converter and the CO emissions from the generator assembly were low matching the results obtained from the initial evaluation.

Weather Measurements

During the survey, a HOBO weather station gathered wind velocity and temperature measurements. All of the testing occurred at the marina where the houseboats were oriented at a constant bearing of approximately 260° (roughly northwest). Average ambient temperature during the day ranged from 82ºF to 105ºF. Wind speeds were variable during the evaluation with an average wind velocity of 3.8 miles per hour (mph) with a maximum-recorded speed of 11.4 mph. The predominant wind direction was roughly southwest (bearing of 176°).

Conclusions

Recent NIOSH studies have indicated that retrofitting emission control devices such as a catalytic converter to gasoline-powered engines can greatly reduce the risk of CO poisoning to swimmers and occupants of houseboats and other marine vessels. Houseboats equipped with an exhaust stack, that releases the CO and other emission components high above the upper deck of the houseboats, allows the contaminants to diffuse and dissipate into the atmosphere away from boat occupants (Dunn, Hall et al. 2001; Earnest, Dunn et al. 2001). This study specifically evaluated the performance of a Kohler 15 kW generator equipped with a catalytic converter designed to reduce CO emissions and protect boat occupants once the engine had been in use for one full boat rental season. At the time of this evaluation, the generator assembly had recorded 1082 hours of use. This study was also designed to complete a follow up evaluation on the first generation of Kohler generators equipped with catalytic technology under a variety of electrical load conditions.

Kohler Generator Performance

Initial testing results for this generator showed low CO concentrations through the range of electrical load. CO concentrations collected within the generator exhaust plume reached 80,000 ppm on the initial start up of the engine. These high values decreased within 3 minutes to approximately 5000 ppm and remained consistent for the duration of the evaluation. An increase in electrical load affected the performance of this generator, as CO concentrations were consistently higher when compared to the results of the initial evaluation. After inspection of the system, Kohler personnel replaced the catalytic converter assembly and CO emissions from the generator were again in the 200 – 300 ppm range. It is important to note that despite complete degradation of the catalytic converter element, onboard environmental CO concentrations remained consistently low due to a well designed and installed stack exhaust. It is important to have redundant safety mechanisms to prevent elevated CO exposures in case one of the systems fails to perform as designed.

Recommendations

The following section indicates general guidelines and known good practices that help to reduce CO concentrations near houseboats and provide a safer and healthier environment.

All manufacturers/owners/users of U.S. houseboats with gasoline-powered generators should be aware of and concerned about the location of the exhaust terminus. Based on data from numerous NIOSH field surveys, we recommend evaluation of houseboats with gasoline-powered generators for potential CO exposures. It is recommended that these houseboats be retrofitted with effective control systems to reduce the potential hazard of CO poisoning.

The Kohler low emissions generator equipped with multi-port fuel injection and catalytic converter dramatically reduced CO emissions during the current evaluation. CO measurement taken directly in the exhaust stack ranged from 200 – 300 ppm after the generator reached operating temperature with a new catalytic converter. In order to ensure that the systems continue to operate effectively, houseboat owners and operators should follow all manufacturers' recommendations with regard to routine maintenance and replacement schedules. For the Kohler low emission generator, some of those recommendations include checking/replacing the catalyst every 500 hours or yearly.

The vertical exhaust stack on the Fun Country Marine houseboat performed consistently well during the current study. Based upon the results of this and previous NIOSH evaluations of the vertical exhaust stack, NIOSH research indicates that the vertical stack, when properly designed and installed, is a viable, low-cost, engineering control that will dramatically improve the safety of houseboat users. All houseboat manufacturers and owners should be encouraged to retrofit a vertical exhaust stack to older existing generators, and to houseboats equipped with low emissions generators for system redundancy.

Houseboats manufacturers should continue to identify and correct any design or operational issues that may present problems related to the performance of the low-emissions generators and dry stack. Public education efforts about the CO hazard should continue to inform and warn all individuals (including boat owners, renters, and workers) potentially exposed to CO hazards. Training about the specific boat-related CO hazards should be provided to houseboat renters, who may be completely unaware of this deadly hazard. Education efforts should be continued and enhanced to include specific information about the circumstances that most likely lead to excessive build up of CO concentrations.

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Appendix

Table I--CO Concentrations (ppm) on Fun Country Marine VIP XT (16' X59') Houseboat, 15-kW Kohler low emissions Generator, Stack-Exhaust Configuration, Old Catalytic Converter (07/28/2009)

Sample Location (Sample #)	Generator No load (Initial)	Generator 1/2 load	Generator 3/4 load	Generator No load (Final)
Lower Stern Deck Starboard Side (Sample #1)	Mean = 3.3 Std. Dev. = 1.2 Peak = 6.0 N = 240	Mean = 4.8 Std. Dev. = 0.9 Peak = 10.0 N = 156	Mean = 5.8 Std. Dev. = 0.9 Peak = 8.0 N = 172	Mean = 8.1 Std. Dev. = 0.9 Peak = 10.0 N = 125
Lower Stern Deck Port Side (Sample #2)	Mean = 9.2 Std. Dev. = 1.0 Peak = 11.0 N = 240	Mean = 11.3 Std. Dev. = 0.7 Peak = 15.0 N = 156	Mean = 14.0 Std. Dev. = 1.9 Peak = 18.0 N = 172	Mean = 14.4 Std. Dev. = 1.5 Peak = 17.0 N = 125
Lower Deck Starboard Side (near door) (Sample #3)	Mean = 4.7 Std. Dev. = 1.0 Peak = 7.0 N = 240	Mean = 6.0 Std. Dev. = 0.8 Peak = 8.0 N = 156	Mean = 5.7 Std. Dev. = 0.7 Peak = 8.0 N = 172	Mean = 5.9 Std. Dev. = 0.5 Peak = 7.0 N = 125
Lower Deck Port Side (near stairs) (Sample #4)	Mean = 2.1 Std. Dev. = 0.5 Peak = 4.0 N = 240	Mean = 2.1 Std. Dev. = 0.7 Peak = 6.0 N = 156	Mean = 2.0 Std. Dev. = 0.5 Peak = 4.0 N = 172	Mean = 2.0 Std. Dev. = 0.4 Peak = 3.0 N = 125
Lower Deck Kitchen (Sample #5)	Mean = 1.0 Std. Dev. = 0.5 Peak = 2.0 N = 240	Mean = 0.2 Std. Dev. = 0.4 Peak = 1.0 N = 156	Mean = 0.5 Std. Dev. = 0.5 Peak = 2.0 N = 172	Mean = 0.7 Std. Dev. = 0.5 Peak = 2.0 N = 125
Upper Stern Deck Port Side (near stack) (Sample #6)	Mean = 0.5 Std. Dev. = 0.5 Peak = 2.0 N = 240	Mean = 1.0 Std. Dev. = 0.6 Peak = 2.0 N = 156	Mean = 1.0 Std. Dev. = 0.8 Peak = 2.0 N = 172	Mean = 1.3 Std. Dev. = 0.5 Peak = 2.0 N = 125
Upper Stern Deck Starboard Side (near slide) (Sample #7)	Mean = 2.8 Std. Dev. = 1.6 Peak = 7.0 N = 240	Mean = 8.4 Std. Dev. = 0.9 Peak = 12.0 N = 156	Mean = 10.8 Std. Dev. = 2.3 Peak = 16.0 N = 172	Mean = 14.0 Std. Dev. = 1.1 Peak = 16.0 N = 125
Upper Deck Starboard Side (near rail) (Sample #8)	Mean = 0.6 Std. Dev. = 0.5 Peak = 4.0 N = 240	Mean = 0.3 Std. Dev. = 0.7 Peak = 4.0 N = 156	Mean = 4.5 Std. Dev. = 3.7 Peak = 12.0 N = 172	Mean = 10.7 Std. Dev. = 1.2 Peak = 14.0 N = 125
Upper Stern Deck Wet Bar (Sample #9)	Mean = 5.7 Std. Dev. = 0.5 Peak = 7.0 N = 240	Mean = 5.8 Std. Dev. = 0.6 Peak = 9.0 N = 156	Mean = 5.9 Std. Dev. = 1.0 Peak = 12.0 N = 172	Mean = 5.9 Std. Dev. = 0.4 Peak = 7.0 N = 125

Table II -- CO Detector Tube Results (ppm) taken within the Exhaust Plumes (Top Exhaust Configuration), Old Catalytic Converter

Boat, Condition (Test Date)	Sample	Condition	Sample Result (ppm)
CO Concentrations (ppm) on Fun Country Marine VIP XT (16' X 59') Houseboat, 15 kW Kohler low emission Generator	1	1	>6500 (1 min after CS)
	2	1	4000 (1.5 min after CS)
	3	1	>1000 (5 min after CS)
	4	1	<5000 (10 min after CS)
	5	1	>1000 (1 hour after CS)
	6	2	>3000 (1 min after 50% load)
	7	2	>5000 (1.5 min after 50% load)
	8	2	>5000 (15 min after 50% load)
	9	2	<5000 (20 min after 50% load)
	10	3	<7000 (1 min after 100% load)
	11	3	5000 (15 min after 100% load)

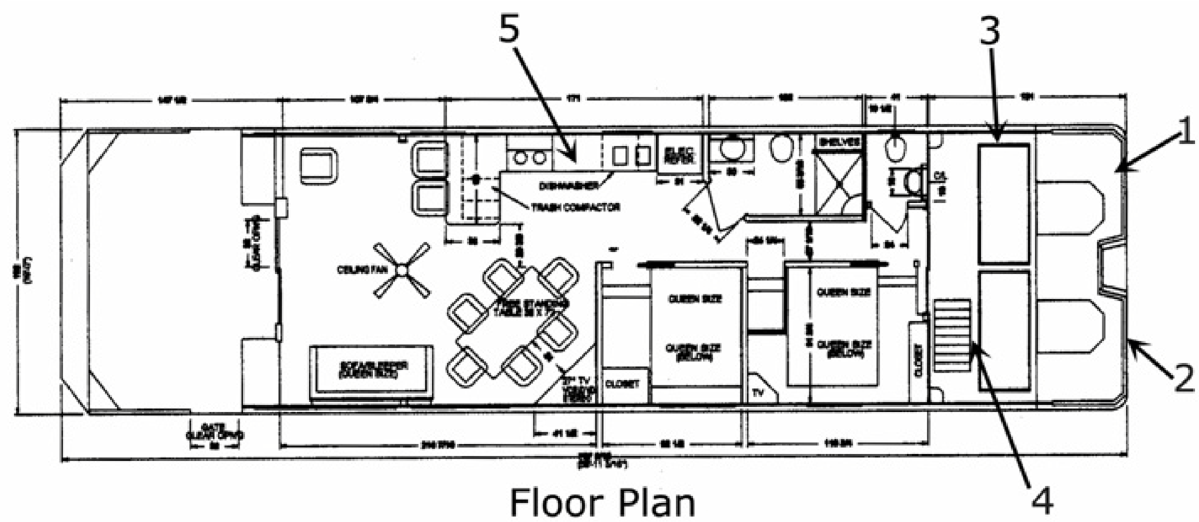
ND = none detected
CS = cold start
Condition 1: stack, no generator load
Condition 2: stack, ½ generator load
Condition 3: stack, full generator load
Condition 4: stack, no generator load

Table III -- CO Detector Tube Results (ppm) taken within the Exhaust Plumes (Top Exhaust Configuration), New Catalytic Converter

Boat, Condition (Test Date)	Sample	Condition	Sample Result (ppm)
CO Concentrations (ppm) on Fun Country Marine VIP XT (16' X 59') Houseboat, 15 kW Kohler low emission Generator	1	1	1.7% (1 min after CS)
	2	1	<0.3% (1.5 min after CS)
	3	1	<1000 (5 min after CS)
	4	1	200 (1 min after 50% load)
	5	1	100 (3 min after 50% load)
	6	2	<100 (1 min after full load)
	7	2	<100 (1.5 min after full load)

ND = none detected
CS = cold start
Condition 1: stack, no generator load
Condition 2: stack, ½ generator load
Condition 3: stack, full generator load
Condition 4: stack, no generator load

Figure 1 - Diagram of evaluated houseboats and air sampling locations



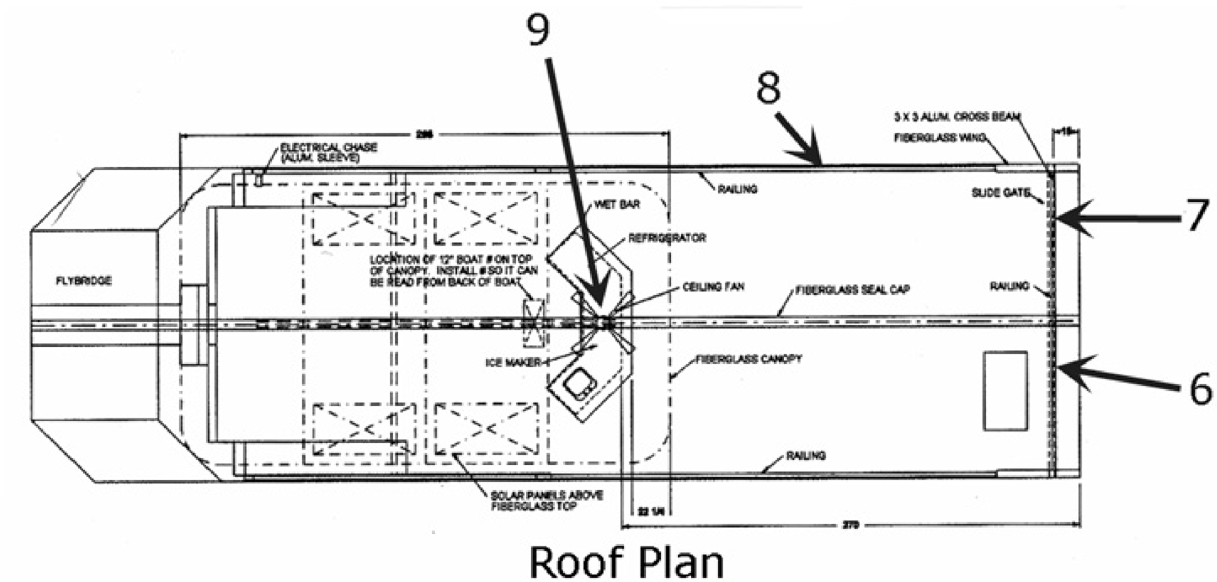


Figure 2 - CO readings from Testo Emissions Analyzer Results (ppm) taken within the Exhaust Plumes (Top Exhaust Configuration) – Condition 1 (Old Catalytic Converter)

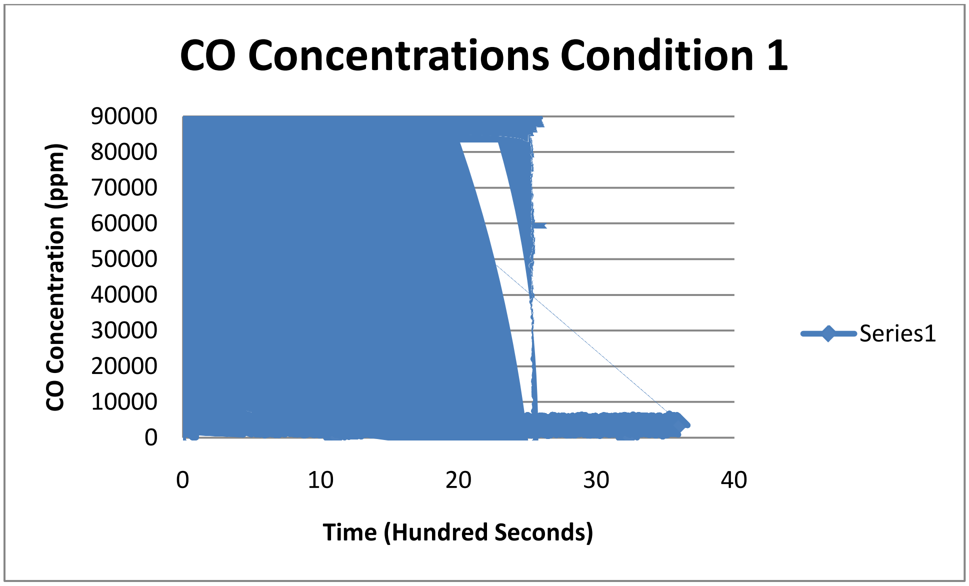


Figure 3 - CO readings from Testo Emissions Analyzer Results (ppm) taken within the Exhaust Plumes (Top Exhaust Configuration) – Condition 2 (Old Catalytic Converter)

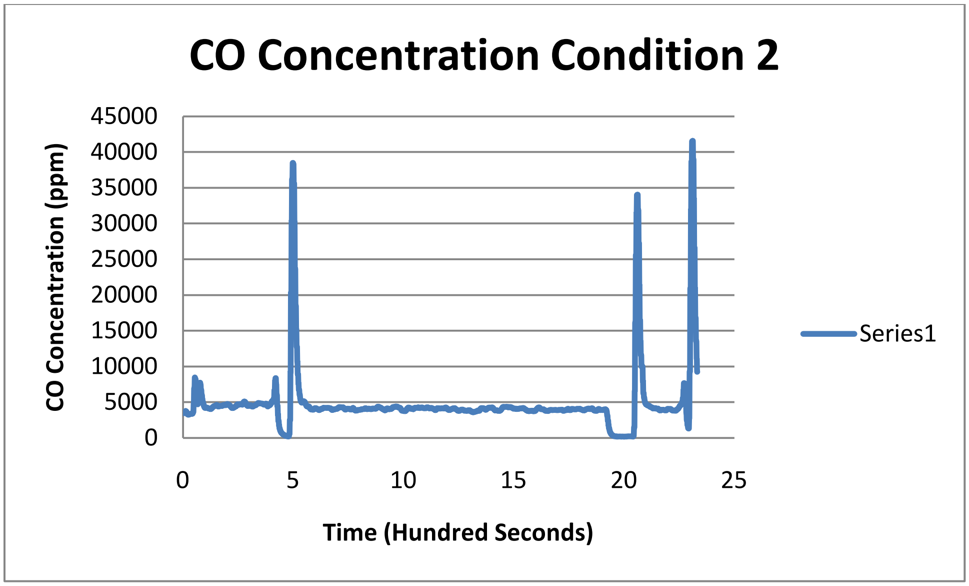


Figure 4 - CO readings from Testo Emissions Analyzer Results (ppm) taken within the Exhaust Plumes (Top Exhaust Configuration) – Condition 3 (Old Catalytic Converter)

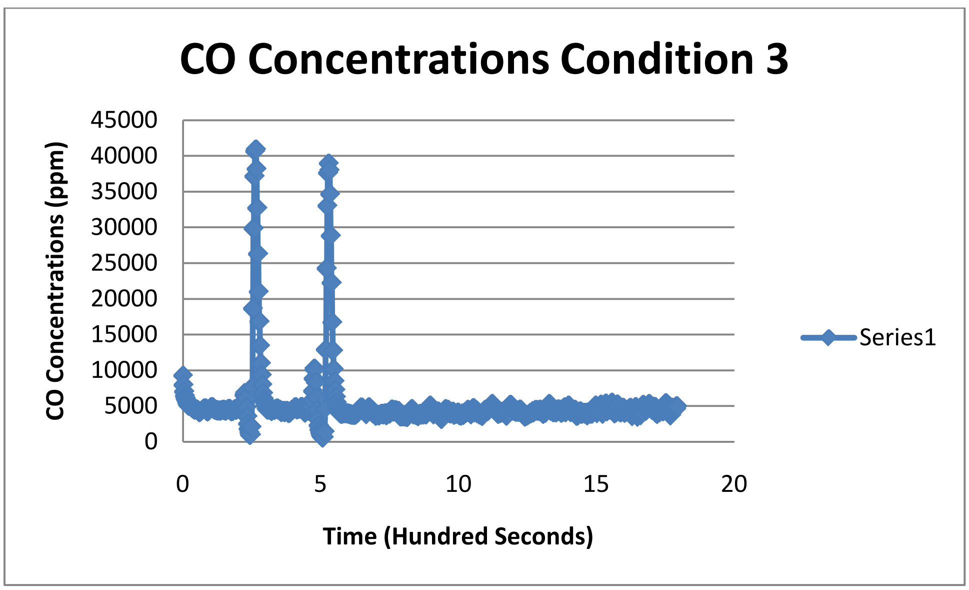


Figure 5 - CO readings from Testo Emissions Analyzer Results (ppm) taken within the Exhaust Plumes (Top Exhaust Configuration) – Condition 4 (Old Catalytic Converter)

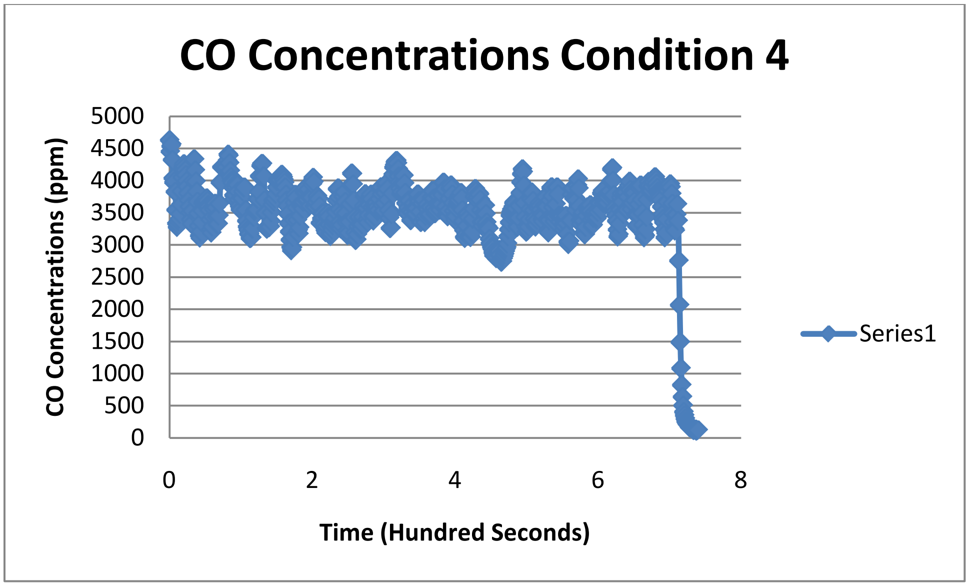

CO Concentrations Condition 4
CO Concentrations (ppm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
Time (Hundred Seconds)
Series1

Figure 6 - CO readings from Testo Emissions Analyzer Results (ppm) taken within the Exhaust Plumes (Top Exhaust Configuration) – Condition 1 (New Catalytic Converter)

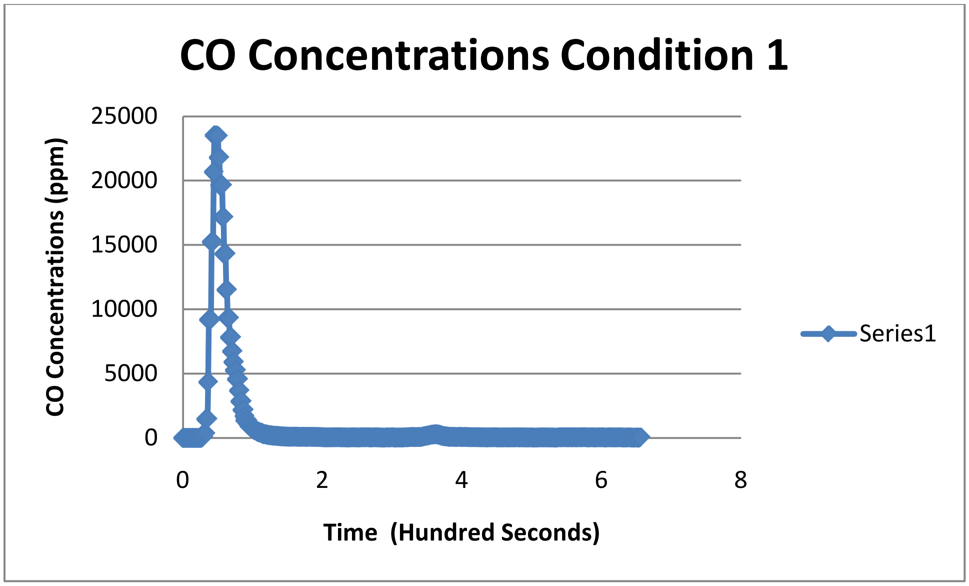


Figure 7 - CO readings from Testo Emissions Analyzer Results (ppm) taken within the Exhaust Plumes (Top Exhaust Configuration) – Condition 2 (New Catalytic Converter)

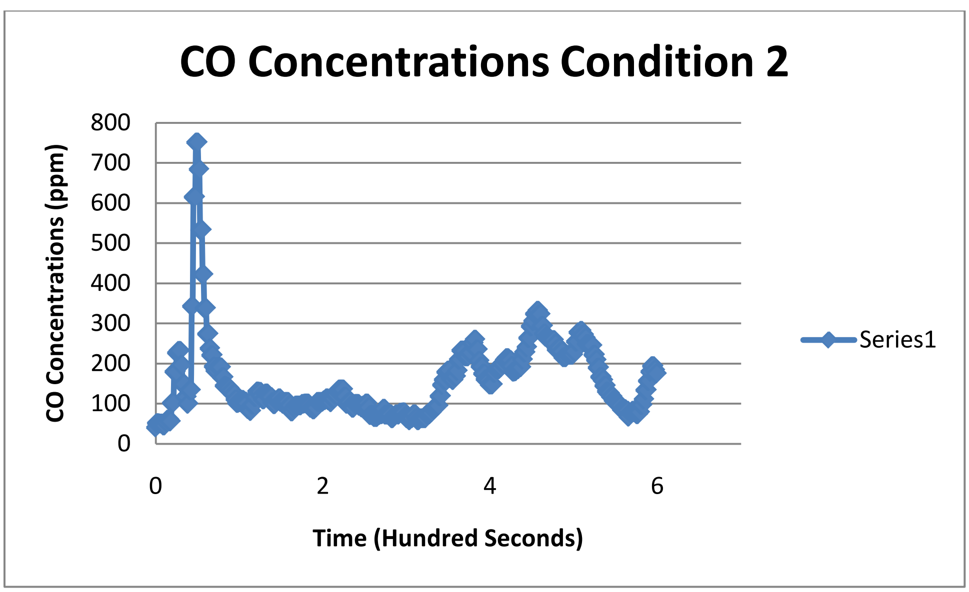


Figure 8 - CO readings from Testo Emissions Analyzer Results (ppm) taken within the Exhaust Plumes (Top Exhaust Configuration) – Condition 3 (New Catalytic Converter)

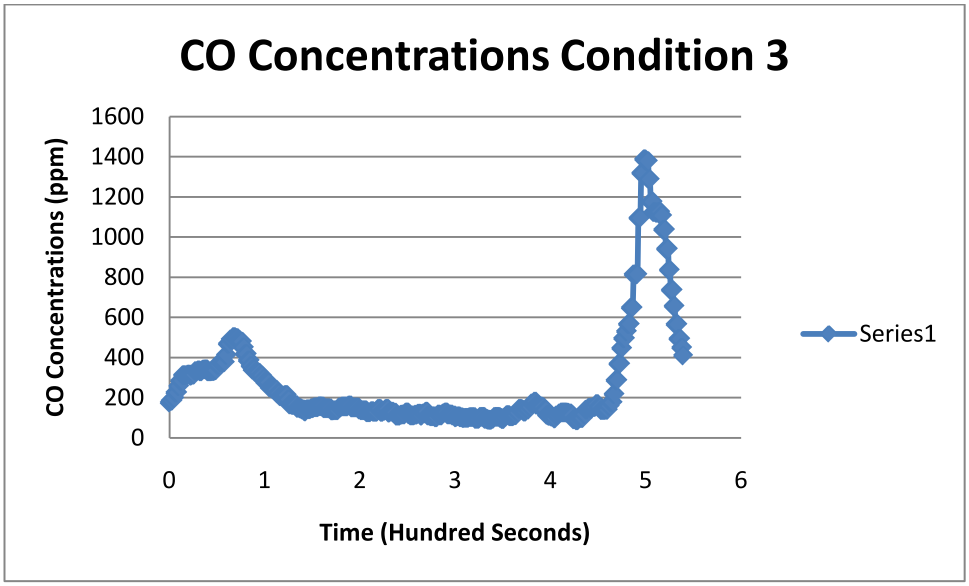


Figure 9 - CO readings from Testo Emissions Analyzer Results (ppm) taken within the Exhaust Plumes (Top Exhaust Configuration) – Condition 4 (New Catalytic Converter)

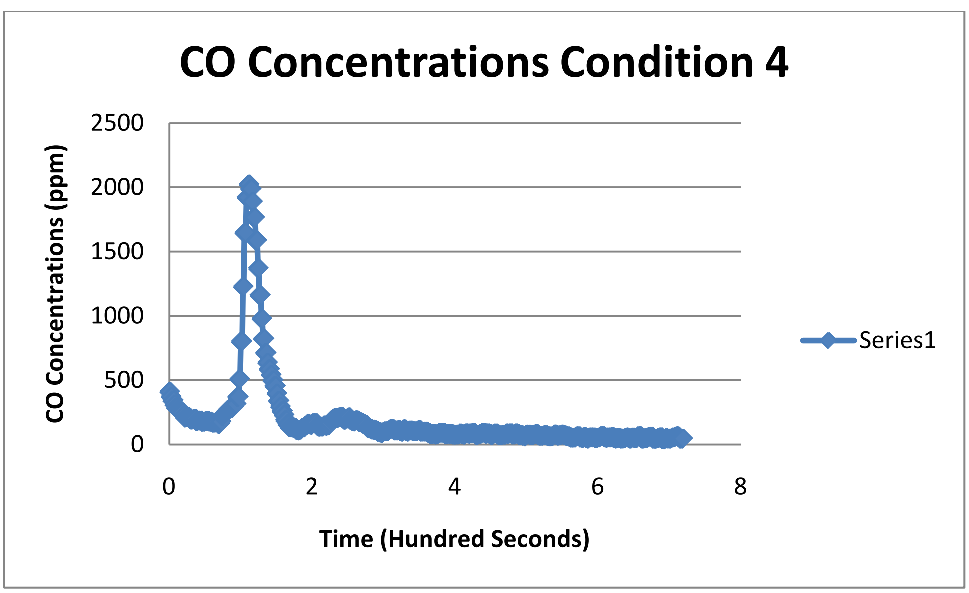


Figure 10 - Photo of the 15 kW Kohler low emission generator

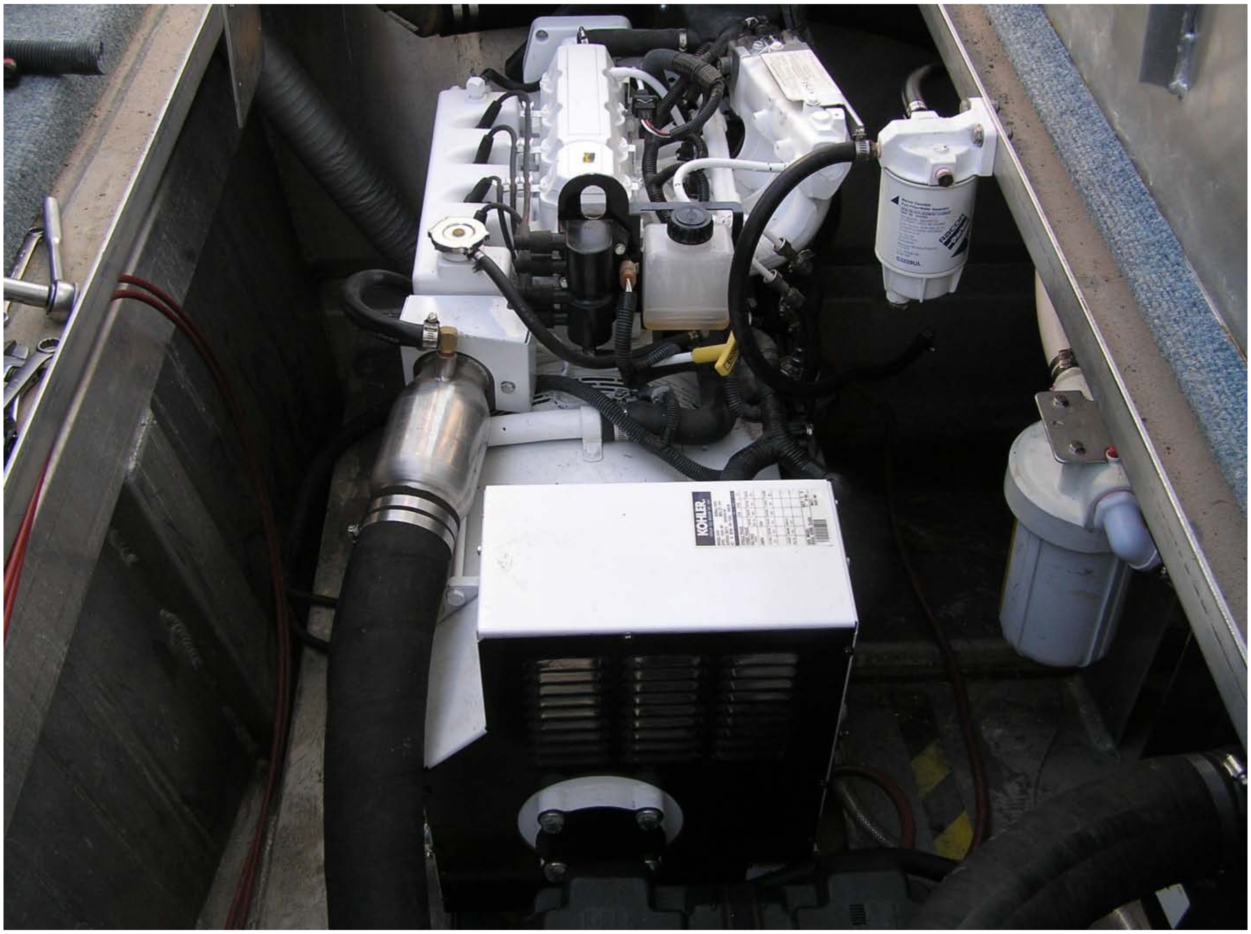
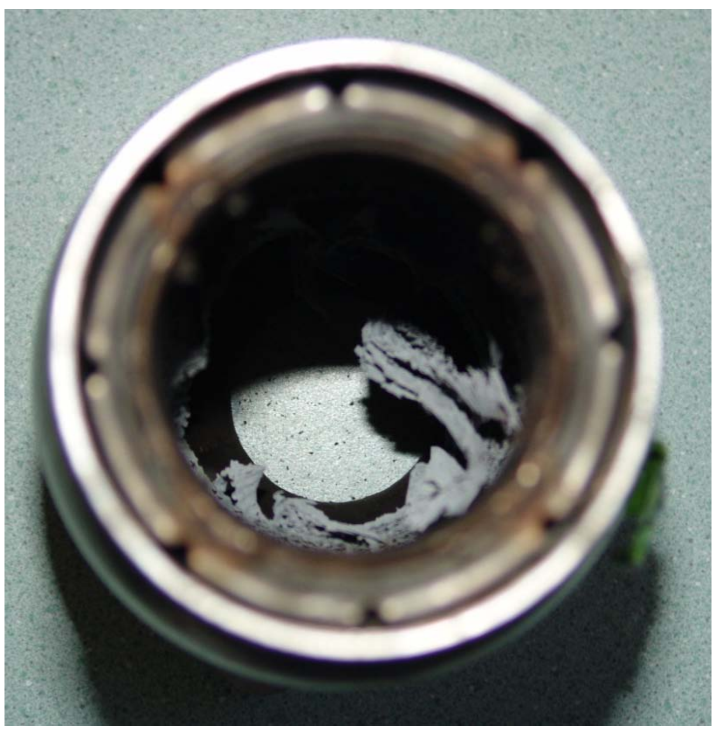


Figure 11 - Photo of the 15 kW Kohler New Catalytic Converter

Figure 12 - Photo of the 15 kW Kohler Old Catalytic Converter



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