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NIOSH HEALTH HAZARD EVALUATION REPORT

HETA # 2003-0318-2936
Evaluation of Two Exhaust Stack Configurations on Two Houseboats at Table Rock Lake, Missouri

June 2004

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

NIOSH

PREFACE

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HETAB also provides, upon request, technical and consultative assistance to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Ronald M. Hall of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS), and Duane Hammond and Scott Earnest of the Division of Applied Research and Technology (DART). Desktop publishing was performed by Robin Smith. Review and preparation for printing were performed by Penny Arthur.

Copies of this report have been sent to the houseboat companies who participated in the evaluation, the Houseboat Industry Association (HIA), and the OSHA Regional Office. This report is not copyrighted and may be freely reproduced. The report may be viewed and printed from the following internet address: www.cdc.gov/niosh/hhe/hhesearch.html. Single copies of this report will be available for a period of three years from the date of this report. To expedite your request, include a self-addressed mailing label along with your written request to:

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Evaluation of Two Exhaust Stack Configurations on Two Houseboats at Table Rock Lake, Missouri

NIOSH evaluated exhaust stack performance for control of carbon monoxide (CO) on two houseboats from August 25 - 28, 2003, at Table Rock Lake, Missouri.

What NIOSH Did

- We evaluated two generator exhaust stack designs on two houseboats, and compared them to side exhaust configurations.
- We measured area CO concentrations at various locations on the upper and lower decks of the houseboats.
- We evaluated the boats in a cove, after dark, and under different generator loads, houseboat trim angles, and environmental conditions (i.e., temperature and humidity).

What NIOSH Found

- The results of this evaluation were similar to results from previous NIOSH exhaust stack evaluations.
- Both exhaust stack configurations performed much better than the side exhaust configuration (even on the upper deck).
- The exhaust stack designs reduced mean and peak CO concentrations 87% to 99.9% (when compared to side exhaust) at the majority of outdoor locations on the lower stern deck.
- The exhaust stack designs reduced mean and peak CO concentrations 47% to 99% (when compared to side exhaust) at the majority of upper deck locations.
- The exhaust stack must be designed properly to prevent exhaust gases from being forced out of the water discharge (near water level).

What the Houseboat Industry Association (HIA) Can Do

- Recommend that houseboats with gasoline powered generators be evaluated for CO exposures.
- Recommend retrofitting houseboat generator exhaust systems with properly designed and operating exhaust stacks that discharge CO to non-occupied areas well above the upper deck.
- Recommend the use of redundant systems, such as exhaust stacks with cleaner burning engines equipped with after treatment devices, when they become available.
- Recommend that the stack exhaust be clearly labeled to notify anyone on the houseboat to avoid the exhaust gases.
- Recommend the use of warning labels to address hanging clothing or other items that might block or restrict the stack outlet, unauthorized stack alterations, or climbing or tampering with the stack.
- Recommend labeling the water discharge area as a potential CO hazard area.

CDC Workplace Safety and Health

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NIOSH

Health Hazard Evaluation Report 2003-0318-2936
Evaluation of Two Exhaust Stack Configurations on Two Houseboats at Table Rock Lake, Missouri

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SUMMARY

In response to a request from the Houseboat Industry Association (HIA) and working under an interagency agreement with the United States Coast Guard, the National Institute for Occupational Safety and Health (NIOSH) evaluated carbon monoxide (CO) exposures and engineering controls associated with gasoline-powered generator exhaust on houseboats. The current health hazard evaluation (HHE) is part of a series of studies conducted by NIOSH investigators to identify and recommend effective engineering controls to prevent CO poisonings on houseboats and other recreational marine vessels.

In the Spring of 2003, the HIA sent a letter to NIOSH and the Coast Guard Office of Boating Safety requesting further testing of houseboats having generator exhaust stacks. HIA indicated that their members would provide houseboats and testing sites. HIA members were concerned that previous NIOSH evaluations of houseboat generator exhaust stacks failed to include all appropriate environmental and operational conditions. Therefore the HIA requested that additional testing be performed under the following conditions: 1) in a cove, 2) after dark, 3) under various generator loads, 4) at different houseboat trim angles, and 5) during temperature inversions. Side exhaust versus stack exhaust was also evaluated.

NIOSH researchers conducted two field evaluations in August 2003. The evaluation at Lake Cumberland, Kentucky, was described in a separate report (NIOSH Publication No. EPHB 171-34a). The evaluation at Table Rock Lake, Missouri is described in this report. The houseboats evaluated at Table Rock Lake were provided by Fun Country Marine Industries and Sumerset Houseboats.

The evaluation at Lake Cumberland found problems with the stack design where CO gases were discharged with the water on the side of the boat. Based on those results, design changes were made to help alleviate the problem on houseboat #2 at Table Rock Lake. The design changes included the removal of a 3 foot (2 inch inner diameter) section of flexible exhaust hose, and the removal of a 180º angle.

This survey indicated that high temperature/high humidity environments, generator loading, and houseboat trim angles had relatively small effects on exhaust stack performance.

Results of this study were consistent with those of previous NIOSH exhaust stack evaluations. Both exhaust stacks on the two houseboats performed dramatically better than side exhaust (even on the upper deck of the houseboat). With the exhaust stack, results indicated a reduction of mean and peak CO concentrations of approximately 87% to 99.9%, when compared to results obtained with the side exhaust, at the majority of outside lower deck locations on both houseboats. On the upper deck of the houseboats, mean and peak results obtained with the exhaust stack indicated a range of reductions of approximately 47% to 99% in the majority of upper deck locations, when compared to the side exhaust configuration.

Based upon the results of NIOSH exhaust stack studies, investigators recommend that houseboats using gasoline-powered generators be evaluated for potential CO exposures and poisonings, especially near the lower stern deck. Houseboat manufacturers, rental companies, and owners should consider retrofitting their gasoline-powered generators with engineering controls to reduce the potential hazard of CO poisoning and death. Other engineering control options such as cleaner burning engines and after-treatment devices are being developed, and these options could also play an important role in preventing future poisonings

Properly installed exhaust stacks have performed well during all NIOSH evaluations, and they are successfully being used to help prevent CO poisonings on hundreds of houseboats across the U.S. During this evaluation, the exhaust stacks performed well under a variety of environmental and operational conditions.

Keywords: SIC Code: 4493 (Establishments primarily engaged in operating marinas and which perform incidental boat repair) carbon monoxide, houseboats, boats, exhaust stack, side exhaust

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INTRODUCTION

On July 8, 2003, the National Institute for Occupational Safety and Health (NIOSH) received a request from the Houseboat Industry Association (HIA) to evaluate parameters related to exhaust stack performance and control of carbon monoxide (CO) exposures on houseboats at Table Rock Lake, Missouri. These parameters included high temperature/high humidity environments, temperature inversions, generator loading, and houseboat trim angles. The exhaust stack evaluations were conducted on two houseboats (each equipped with exhaust stack systems connected to gasoline-powered generators) from August 25 - 28, 2003.

Investigations of CO-related poisonings and deaths on houseboats were initially conducted at Lake Powell, Arizona, in September and October 2000, involving representatives from NIOSH, U.S. Coast Guard, U.S. National Park Service (USNPS), Department of Interior, and Utah Parks and Recreation. These investigations measured hazardous CO concentrations on houseboats.[1] Some of the severely 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.

Epidemiological investigations have discovered that from 1990 through 2003, 165 boat-related CO poisonings occurred on Lake Powell near the border of Arizona and Utah. One-hundred-thirteen of the poisonings occurred on houseboats, and 104 of these poisonings were attributable to generator exhaust alone. Ten of the 113 houseboat-related CO poisonings resulted in death.[2] Five-hundred and three CO poisonings related to recreational boats have been identified across the United States and that number continues to increase (493 of these poisonings occurred between 1990–2003; 6 occurred in the 1980's; and 4 have no specific date).[2]

BACKGROUND

Engineering control studies of these exhaust stacks began in February 2001 at Lake Powell in Arizona, and Lake Cumberland in Somerset, Kentucky.[3,4] These studies demonstrated that an exhaust stack extending nine feet above the houseboat's upper deck dramatically reduced the CO concentrations on and near the houseboat.

A meeting was convened to address the CO hazard by the U.S. Coast Guard, Office of Boating Safety, Recreational Boating Product Assurance Division on May 3, 2001, in Lexington, Kentucky. This meeting was attended by houseboat manufacturers, marine product manufacturers, government representatives, and others. Following the meeting, NIOSH researchers were asked to evaluate the performance of a new prototype emission control device (ECD) and an interlocking device and to conduct further evaluations of the stack exhaust system. These evaluations were conducted in June 2001 at Callville Bay Marina, Nevada. These studies indicated that although the ECD, interlock, and stack exhaust system each performed well, longer term testing of the ECD should be conducted.[5,6] Concerns were also expressed regarding potential use of the safety interlock as a primary control option.

Following the June 2001 evaluations at Callville Bay Marina, Nevada, an interagency agreement was signed between the U.S. Coast Guard, Office of Boating Safety and the NIOSH, Division of Applied Research and Technology (DART), to conduct further field evaluations and computational fluid dynamics (CFD) modeling of engineering controls for CO on houseboats and other marine vessels.

In October 2002, an additional study was conducted at Callville Bay Marina, Nevada, to evaluate the performance of the exhaust stack and two production ECDs that had been installed and used on gasoline-powered generators for several thousand hours. Results from the study indicated some complications with the long-term performance of the production ECD.[7]

Following the October 2002 evaluations at Lake Mead, Nevada, NIOSH and the U.S. Coast Guard held a workshop at Annapolis, Maryland. Following this workshop, the HIA requested additional testing of the exhaust stack. This report provides background information and describes the evaluation methods, results, conclusions, and recommendations from that testing.

METHODS

Measurements of CO and other exhaust gases, ventilation, and wind-velocity were collected on two houseboats. Data were collected to evaluate the effectiveness of the exhaust stacks in reducing CO concentrations. The evaluations took place in a cove, during the day, overnight, in high temperatures and humidities, and under various generator loads and houseboat trim angles.

Description of the Houseboats

Houseboat #1: 2000 Fun Country Marine Houseboat with Vertical Exhaust Stack (see Figure 1)
Engines: Two 150 hp Evinrude Ficht outboard engines
Generator: 15 Kw Kohler gas generator
Approximate dimensions of houseboat: 67 ft. X 14 ft.
Exhaust Configuration: Centek Combo-Sep® muffler/gas/water separator to straight vertical exhaust stack approximately 9 feet above upper deck and starboard side water drain (at water level).

Houseboat #2: 2002 Sumerset Houseboat with Flag Pole Exhaust Stack (see Figure 2)
Engines: Two 5.0L MPI Mercruiser engines with Bravo II out drive
Generator: 20 kw Westerbeke gas generator
Approximate dimensions of houseboat: 87 ft. X 18 ft.
Exhaust Configuration: Centek Combo-Sep® muffler/gas/water separator to flag pole exhaust stack approximately 6 feet above upper deck and port side water drain (at water level).

The generators on the houseboats provided electrical power for air conditioning, kitchen appliances, entertainment systems, navigation, communications equipment, etc. The gasoline generators were housed in the engine compartment beneath the stern deck.

When generators are 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. Because the generator sits below the waterline, the water-jacketed exhaust passes through a lift muffler that further reduces noise and forces the exhaust gases and water up and out through a hole at the side of the boat. On boats with exhaust stacks, the water-jacketed exhaust passes through a muffler/gas/water separator (Figure 3) which is designed to route the exhaust gases up through the stack while the water flows out near the water line at the side of the boat. Inside the water separator, exhaust gases are physically mixed with cooling water. For an exhaust stack to function properly, the cooling water and the exhaust gases must be separated. The efficiency of the separation process is important to prevent water from entering the stack. Also, the balance of the resistance to flow must be minimized at the stack and the water drain outlet paths.

Description of the Evaluation Equipment

Emissions from the generator were characterized using a Ferret Instruments (Cheboygan, Michigan) Gaslink LT Five Gas Emissions Analyzer. This analyzer measures CO, carbon dioxide (CO_2), hydrocarbons, oxygen (O_2), and nitrogen oxides (NO_x). CO, CO_2, and O_2, are expressed as percentages while hydrocarbons and NO_x are expressed in ppm. [One percent of contaminant is equivalent to 10,000 ppm.]

CO concentrations were measured at various locations on the houseboat using ToxiUltra Atmospheric Monitors (Biosystems, Inc. [Middletown, Connecticut]) with CO sensors. ToxiUltra 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 30 second sampling intervals. The instruments have a nominal range from 0 ppm to 999 ppm.

CO concentrations were also measured directly in the generator exhaust with detector tubes [Draeger A.G. (Lubeck, Germany) CO, CH 29901– range 0.3% (3,000 ppm) to 7% (70,000 ppm)]. 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 measurements were gathered each minute during the air sampling using an omnidirectional ultrasonic anemometer (Gill Instruments Ltd., Hampshire, United Kingdom). This instrument uses a basic time-of-flight operating principle that depends upon the dimensions and geometry of an array of transducers. Transducer pairs alternately transmit and receive pulses of high frequency ultrasound. The time-of-flight of the ultrasonic waves is measured and recorded, and this time is used to calculate wind velocities in the X-, Y-, and Z-axes. This instrument is capable of measuring wind velocities up to 45 meters per second (m/sec) and taking 100 measurements per second.

Air velocity exiting the exhaust stacks was evaluated using a VelociCalc Plus Model 8360 air velocity meter (TSI Inc., St. Paul, Minnesota). The velocity readings were collected at the face of the exhaust stack. Velocity influences the dispersion of exhaust gases into the environment which can affect exposure potential.

Description of Procedures

The evaluation was performed over a four-day period using five generator test conditions as requested by the HIA. On the last day of the evaluation, an additional test condition was evaluated on houseboat #2 (Condition #6). Each test condition was performed on Table Rock Lake. Details concerning the test conditions are given below:

1) Generator exhausting through the side exhaust terminus without a load on the generator and with no extra weight on the back of the boat.

2) Generator exhausting through the exhaust stack with a load on the generator and no extra weight on the back of the boat.

3) Generator exhausting through the exhaust stack without a load on the generator and with no extra weight on the back of the boat.

4) Generator exhausting through the exhaust stack with a load on the generator and with the extra weight (on houseboat #1 extra weight was provided by filling the 300-gallon hot tub [approximately 2490 pounds], located on the rear center of the top deck, and on houseboat #2 extra weight was provided by placing sand bags, weighing a total of approximately 500 pounds, on the back swim platform).

5) Generator exhausting through the exhaust stack without a load on the generator and with the extra weight on the back of the boat.

6) Generator exhausting through the side exhaust terminus with a load on the generator and with extra weight on the back of the boat

(conducted the last day of the evaluation on Houseboat #2).

Typical sampling locations for the ToxiUltra real-time CO monitors on the lower and upper decks of the houseboats, designated with pentagons, are shown in Figure 4. Several monitors were placed on the boats' stern swim platforms because people commonly enter and exit the water via this structure.

EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to 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 a 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 criterion. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increases the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),[8] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®),[9] and (3) the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[10] Employers are encouraged to follow the OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criteria.

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 should understand that not all hazardous chemicals have specific OSHA exposure limits such as PELs and short-term exposure limits (STELs). An employer is still required by OSHA to protect their employees from hazards, even in the absence of a specific OSHA PEL.

A time-weighted average (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.

Carbon Monoxide (CO)

Occupational criteria for CO exposures are applicable to USNPS and concessionaire employees. The occupational exposure limits noted below are designed for working populations and should not be used for interpreting general population exposures (such as visitors engaged in boating activities). The general public includes the very young, very old, and individuals that may have preexisting health conditions. The effects of CO are more pronounced in a shorter time 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 (when oxygen is displaced on the oxygen-carrying molecule known as hemoglobin with carbon monoxide [COHb]). Standards relevant to the general population take these factors into consideration, and are listed following the occupational criteria.

The NIOSH REL for occupational exposures to CO in air is 35 ppm for full shift TWA exposure, and a ceiling limit of 200 ppm, which should never be exceeded.[8] The NIOSH REL of 35 ppm is designed to protect workers from health effects associated with COHb levels in excess of 5%.[11] NIOSH has established the IDLH value for CO of 1,200 ppm.[12] The ACGIH recommends an 8-hour TWA TLV for occupational exposure to CO of 25 ppm.[9] The OSHA PEL for CO is 50 ppm for an 8-hour TWA exposure.[10]

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.[13] 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 TWA exposures related to CO exposure in the general population.[14] WHO guidelines are intended to ensure that COHb levels do not exceed 2.5% when a normal subject engages in light or moderate exercise. Those guidelines are:

- 87 ppm for 15 minutes
- 52 ppm for 30 minutes
- 26 ppm for 1 hour
- 9 ppm for 8 hours

RESULTS

Results of Air Sampling with ToxiUltra CO Monitors

Real-time CO monitoring results on the lower deck of the houseboats are shown in Figures 5 and 6. Real-time CO monitoring results on the upper deck (monitor location is near the exhaust stacks) of the houseboats are shown in Figures 7 and 8. CO concentrations on the stern deck and swim platform were very low for the vertical stack (houseboat #1) and flagpole stack (houseboat #2), while side exhaust produced high concentrations (Figures 5 and 6). The peak CO value (on the lower level back deck of houseboat #1) for the side exhaust configuration was beyond the instrument range for the ToxiUltra CO monitor and indicated a peak concentration greater than 1000 ppm (the IDLH value is 1,200 ppm for CO). The peak CO value for the side exhaust configuration on houseboat #2 (on the lower level port side of the swim platform) indicated a peak concentration of 742 ppm. The CO concentrations on the top deck near the exhaust stacks of both houseboats (Figure 7 and Figure 8) indicated higher CO concentrations with the side exhaust configuration (under conditions of no generator load and no extra weight) than the stack exhaust configuration. The summary statistics for all of the ToxiUltra monitors are provided in Tables I through VIII.

Stack vs. Side exhaust Lower Deck CO Results

The stack and side exhaust CO data collected on August 25, 2003, for houseboat #1 indicated CO mean reductions of approximately 87% to 99% with the vertical stack exhaust as compared to side exhaust on all outside locations at the lower back deck (see Table I). Peak CO reductions ranged from 91% to 99.4% with the stack exhaust (when compared to the side exhaust configuration). CO data collected on August 25th inside the boat (kitchen area) did not indicate a large difference in mean and peak concentrations of CO with the two different exhaust configurations. CO levels near the water and side exhaust discharge exceeded the CO monitor's scale (>1000 ppm) with the side exhaust configuration. The CO levels measured at the water discharge area indicated a mean of 0.2 ppm, and a peak level of 6 ppm with the stack exhaust configuration.

The stack and side exhaust CO data collected on August 26, 2003, for houseboat #1 indicated CO mean reductions of approximately 89% to 97%, and CO peak reductions of approximately 93.5% to 98% with the vertical stack exhaust as compared to side exhaust on all outside locations on the lower back deck, with the exception of the port swim platform location (see Table I). The port swim platform location indicated a mean CO concentration of 2.6 ppm for the side exhaust and 3 ppm for the stack exhaust. Peak CO levels on the port swim platform were 3 ppm with side exhaust and 2 ppm with the stack exhaust.

The flag pole stack and side exhaust CO data collected on August 27, 2003, for houseboat #2 indicated CO mean reductions of approximately 97.8% to 99.9% with the flag pole stack exhaust as compared to side exhaust on all outside locations on the lower back deck (see Table II). CO data collected on August 27th inside the boat (back bedroom area), indicated reductions of 33% to 63% of the mean CO values, and 78% to 89% reductions in the peak CO values with the flag pole stack versus the side exhaust configuration (see Table II).

The flag pole stack and side exhaust CO data collected on August 28, 2003, for houseboat #2 indicated CO mean reductions of approximately 90% to 99% with the flag pole stack exhaust as compared to side exhaust on all outside locations on the lower back deck (see Table II). Stack exhaust peak CO levels collected on August 28th indicated reductions ranging from 92% to 99% (when compared to the side exhaust configuration) at lower deck outside locations. CO data collected inside the boat (back bedroom area) indicated similar mean and peak CO values for the two exhaust configurations (see Table II).

Stack vs. Side Exhaust Upper Deck CO Results

On August 25, 2003, upper deck CO mean concentrations on houseboat #1 indicated reductions of approximately 95% to 99% when using the exhaust stack as compared to the side exhaust configuration (see Table III). Peak CO measurements on August 25th indicated that the stack reduced CO peak levels by 97% to 99% on the upper deck locations when compared to the side exhaust configuration. On August 26, 2003, CO measurements on houseboat #1 indicated that the stack reduced mean CO levels on the upper deck by approximately 76% to 99% in all locations except the top deck bar location. The mean CO concentrations at the top deck bar were low and similar for both exhaust configurations. Peak CO levels on the upper deck of houseboat #1 collected on August 26th, indicated reductions of 81% to 99% (with the use of the exhaust stack as compared to the side exhaust configuration) in all locations except the top deck bar location. Peak CO levels at the top deck bar location were low and similar for both exhaust configurations.

On August 27, 2003 upper deck CO mean concentrations on houseboat #2 indicated reductions of approximately 70% to 97% in all locations except the top deck bar location (when using the exhaust stack as compared to the side exhaust configuration [see Table IV]). CO mean measurements obtained at the top deck bar location indicated means of 1.2 and 7.1 ppm with the stack exhaust and 1.1 with the side exhaust configuration. Peak CO measurements on August 27th indicated that the stack reduced CO peak levels by 76% to 96% (when compared to the side exhaust) in all locations on the upper deck except the top deck bar location. The peak CO levels obtained at the top bar location indicated higher levels with the stack exhaust (4 ppm and 91 ppm) when compared to the side exhaust configuration (2 ppm [see Table IV]).

Upper deck CO measurements obtained on houseboat #2 on August 28, 2003, indicated that the stack reduced mean CO levels on the upper deck by approximately 47% to 97%, and it reduced peak CO levels approximately 83% to

97% (as compared to the side exhaust configuration) in all locations. On the starboard side top deck location, an accurate percent reduction could not be calculated because CO was not detected in this location with the stack exhaust configuration (see Table IV).

Stack Exhaust CO Results (Conditions 2, 4, and 5)

Tables V-VIII list upper and lower deck CO results for houseboat #1 and #2 when using the exhaust stack. The data listed in these tables was collected under the test configurations of 2, 4, and 5. The highest mean CO concentration on the upper deck of houseboat #1 was collected at the port rear side location near the exhaust stack which indicated a mean of 6.4 ppm (under condition 2). The highest CO peak of 263 ppm was also measured at the port rear side location (under condition #4). The CO means on the upper deck of houseboat #1 ranged from 0.02 – 6.4 ppm, and the peak CO measurements ranged from 1 ppm – 263 ppm (see Table V).

The highest mean CO concentration on the lower deck of houseboat #1 was 20 ppm. This mean CO concentration was collected at the water discharge location on the starboard side of the back deck. All other locations on the lower deck indicated CO mean concentrations ranging from 0.06 ppm to 5.5 ppm. The highest CO peak concentration of 480 ppm was measured on the starboard swim platform. This peak level may be a result of the propulsion engine on a recreational boat pulling up to the houseboat. All other peak CO levels on the lower deck of houseboat #1 ranged from 1 ppm to 95 ppm (see Table VI).

The upper deck CO statistics for Houseboat #2 with the flagpole design are listed in Table VII. The highest CO mean of 7 ppm was measured at the top deck port side location near the stack. The mean CO concentrations on the upper deck of houseboat #2 ranged from 0.05 ppm to 7 ppm (under testing conditions 2, 4, and 5). The peak CO measurements obtained on the upper deck indicated the highest peak was 72 ppm and was measured on the port side top deck location (near stack). The peaks on the upper deck of houseboat #2 ranged from 1 ppm to 72 ppm.

Lower deck CO statistics for houseboat #2 under the testing conditions of 2, 4, and 5 are listed in Table VIII. The highest CO mean of 20 ppm was obtained at the sliding door location. The means on the lower deck ranged from 0.3 ppm to 20 ppm. The highest two CO peak measurements of 518 ppm and 212 ppm were measured at the water discharge area (the monitor was hanging over the side of the boat near the water discharge). These measurements were collected during the first run of the day at the beginning of the measurement periods. The water combo separator may not have been operating properly due to being empty (the separator may not have been filled with water). If the water separator is not operating as designed CO gases may exit out of the water discharge outlet (where the side exhaust configuration discharges combustion gases). After the system operated for approximately 5 to 10 minutes the CO levels lowered and resulted in mean CO concentrations of 13.7 ppm and 13.8 ppm (see Table VIII). The peak CO levels for the other lower deck locations on houseboat #2 ranged from 5 ppm to 131 ppm.

Gas Emissions Analyzer and Detector Tube Results

Gas emissions analyzers and detector tubes were used to characterize CO concentrations in and near the exhaust stack and near the water and side exhaust discharge area. This 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. The emissions analyzer indicated that CO concentrations measured directly in the exhaust stack of houseboat #1 ranged from approximately 6% (60,000 ppm) to 8.6% (86,000 ppm), and detector tube results ranged from approximately 6.5% (65,000 ppm) to >7% (70,000 ppm [upper limit of detector tube]). The emission analyzer also indicated CO concentrations on houseboat #1 ranged from approximately 0.01% (100 ppm) to 0.3% (3,000 ppm) 6 inches away from the water and CO discharge area with the side exhaust configuration. CO detector tube results obtained at this location (6 inches away from water and CO discharge) with the side exhaust configuration ranged from approximately 150 ppm to 3,000 ppm.

The emissions analyzer indicated that CO concentrations measured directly in the exhaust stack of houseboat #2 ranged from approximately 5% (50,000 ppm) to 7.68% (76,800 ppm), and detector tube results ranged from approximately 2.8% (2,800 ppm taken at edge of stack and not directly in the stack) to >7% (70,000 ppm [upper limit of detector tube]). A CO detector tube result obtained on houseboat #2 at approximately 6 inches away from the water and CO discharge area (with the side exhaust configuration) indicated a concentration of 2% (20,000 ppm).

Wind and Stack Velocity Measurements

Wind velocity measurements were gathered during the survey with an ultrasonic anemometer. All data were gathered while the houseboats were stationary. All of the testing occurred in a cove where the boats were oriented in different directions. An attempt was made to position the boats in a manner such that wind was moving from the stern of the houseboat (near the CO emission sources) toward the bow of the houseboat to establish near worst case testing scenarios.

A summary of wind velocity data is shown in Table IX. This table lists the houseboat bearing, average wind speed and direction, and standard deviations. As shown in the table, the first houseboat was oriented at 210° SW, and the second houseboat was located at 65° NE. Average wind direction ranged from 126° SE to 244° SW. Average wind speeds ranged from 0.4 m/sec to 1.9 m/sec.

Velocity measurements of exhaust from the stack on houseboat #1 indicated an average face velocity of 730 fpm. The flagpole stack on houseboat #2 indicated an average face velocity of 3340 fpm. The temperature and humidity measurements collected in the flagpole exhaust stack on houseboat #2 indicated temperatures between 99 °F and 100 °F, and humidity levels between 54% and 55%.

Ambient Temperature and Relative Humidity

A summary of the ambient temperature and relative humidity data is shown in Table X. Ambient temperatures over the sampling period ranged from 68.5 °F to 99.1°F and relative humidity (RH) ranged from 36.5% to 100%. Humidity was lowest on Tuesday (8/26/03) during the afternoon testing. The high temperature over the sampling periods ranged from 77.5°F to 99.1°F and the low temperature ranged from 68.5°F to 80.6°F. The average temperature during each sampling period is also shown in the table. The lowest average temperature was 72.4°F on Tuesday (8/26/03) night and the highest average was 91.1°F on Monday (8/25/03).

DISCUSSION AND CONCLUSIONS

The CO hazard to swimmers and occupants on houseboats that have gasoline-powered generators can be greatly reduced by retrofitting engineering control systems to the generators. Previous NIOSH studies have shown that an exhaust stack (that releases the CO and other emissions high above the upper deck of the houseboat in non-occupied areas) allows the contaminants to diffuse and dissipate into the atmosphere away from boat occupants.[3, 6] The present study, requested by the HIA, evaluated the exhaust stacks on two houseboats on the lake in the afternoon (in a cove), at night, overnight, under a variety of generator load conditions, trim angles, and in high temperatures and humidities. Results from the stack testing do not appear to indicate a noticeable difference between CO concentrations and different environmental conditions.

Stack Exhaust

Data gathered when the houseboats were stationary in the cove indicated that the exhaust stack performed well and kept CO concentrations on both decks of the houseboat below life threatening levels. These tests also indicate that uncontrolled exhaust from a gasoline-powered generator using side exhaust close to the water can result in potentially life threatening CO levels.

While results obtained with the stack are a dramatic improvement when compared to side exhaust, further reductions in CO concentrations could be achieved by extending the stack height and ensuring that static pressure in the stack does not force any exhaust gases out through the water outlet. To achieve lower CO concentrations on a houseboat, it is important that the exhaust stack, water separator, and associated piping and hoses be designed and installed properly. This can be accomplished by increasing stack diameter, reducing the length of the total stack run from the water separator, and eliminating unnecessary elbows. Another modification that could improve performance is to eliminate horizontal runs which can allow water to collect and obstruct flow, rather than draining back to the water separator.

Stack Design and Performance

A stack exhaust evaluation conducted at Lake Cumberland, Kentucky, found problems with the design where CO gases were discharged out with the water on the side of the boat. Design changes and recommendations on the stack were made to reduce this problem.[15] The exhaust stack evaluated on Houseboat #2 was modified prior to our evaluation to help alleviate potential problems with the stack design noticed during the previous Lake Cumberland survey. The design changes made to the stack on houseboat #2 included the removal of a 3 foot (2 inch inner diameter) section of flexible exhaust hose, and the removal of a 180º angle. The angle was removed by placing the gas discharge on the opposite side of the combo separator.

If the stack exhaust is not designed properly, the performance could be hindered. Rather than hazardous exhaust gases passing through the stack to a height well above the upper deck, high static pressure in the stack could force exhaust gases to pass out the side terminus near the water line. Increasing the number of elbows and the distance that the exhaust gases must travel increases the frictional and fitting losses in the pipe system and requires a higher initial velocity pressure to accelerate the same volume of exhaust through the same diameter of pipe. Horizontal runs should be avoided while still maintaining an appropriate vertical height above the upper deck. Other factors affecting static pressure in the stack include the inside diameter of the pipe and the roughness of the inside wall of the pipe. All of these combined factors account for increased pressure in the pipe system, and if high enough can be equated to plugging or sealing the end of the stack. Since exhaust gases and fluid flow will travel the path of least resistance, careful attention should be made to determine what necessary pressure differences are required to balance out the exhaust system. In addition to proper stack design, proper design of the water outlet and water separator is necessary to prevent water from traveling up the stack.

The velocity pressure method illustrated in the Industrial Ventilation Manual[16] provides a technique for performing calculations to help design the exhaust stack system. The method is based on the fact that all frictional and dynamic (fitting) losses in ducts are functions of velocity pressure and can be calculated by a loss coefficient multiplied by the velocity pressure. Figure 5-11 of the ventilation manual provides a calculation spreadsheet for performing velocity pressure calculations and sample calculations for non-standard conditions.[16] It is important to point out that the system design considers the conditions at initial start-up and installation.

The cumulative static pressure in the exhaust stack can be found by totaling the duct losses and losses from velocity increase or any other losses. If the resulting cumulative static pressure is too high, the system parameters can be decreased by changing the parameters that create losses to balance the system with the water outlet pressure. While multiple methods can be used to increase the pressure on the water side, efforts should focus on reducing static pressure in the stack to prevent excessive backpressure on the generator.

Some manufacturers have been using a trial and error approach to determine the pressure differences between the stack and water outlet by altering the input variables such as pipe diameter, number of elbows, and overall length to arrive at a balance of the exhaust system. Manufacturers should be careful to do extensive testing and verify the system is in balance at multiple generator load conditions and that exhaust gas bubbles (indicating the presence of exhaust gases in the water discharge) are not present at the water outlet during operation of the generator. Manufacturers should perform CO testing on houseboats equipped with stacks to insure that the exhaust gases are going through the stack and are discharged in non-occupied areas well above the top deck. Manufacturers are also encouraged to test CO levels at the water discharge area to make sure CO gases are not being discharged with the water.

RECOMMENDATIONS

The following recommendations are provided to reduce CO concentrations near houseboats and provide a safer and healthier environment.

1) All manufacturers/owners/users of houseboats that use gasoline-powered generators should be aware of the location of the exhaust terminus. Based on data from numerous NIOSH field surveys, NIOSH investigators recommend that houseboats with gasoline-powered generators be evaluated for potential CO exposures and poisonings and retrofitted with control systems to reduce the potential CO hazard.

2) The CO results obtained during this evaluation indicated that the vertical exhaust stack and flagpole stack performed well. Based upon the results of this and previous NIOSH evaluations, NIOSH researchers believe that when properly designed and installed, the exhaust stack is a viable, low-cost, engineering control that can dramatically improve the safety of houseboat users. Manufacturers/owners/users of houseboats that have gasoline-powered generators equipped with exhaust stacks should routinely check their systems to ensure that they are properly installed and operating. If static pressure in the stack is too high, exhaust gases can be forced out of the water outlet on the side of the boat. If the water outlet is below the water line, bubbles will be visible near the water outlet indicating that CO and other exhaust gases are being released. Modifications should be made to any existing exhaust stacks that are not properly designed and/or installed. Modifications should be made to ensure that all of the exhaust gases flow through the stack. These changes to exhaust stacks should be made in consultation with the manufacturer of the water separator.

3) In multiple evaluations, properly designed exhaust stacks have been shown to be effective in reducing concentrations of CO on houseboats by exhausting the hazardous CO high above the top deck. While concentrations on the boat remain relatively low (with the stack exhaust as compared to the side exhaust), CO measurements taken directly at the stack outlet in this evaluation indicated a range of 5% to 8.6% CO (50,000 ppm to 86,000 ppm). Because this concentration is 42 to 72 times greater than the immediately dangerous to life and health value for breathing zone concentrations of CO, it would be prudent for houseboat manufacturers to clearly label and identify the exhaust outlet to notify users or anyone on the houseboat to stay clear of the exhaust gases. The label should include warnings against actions such as hanging clothing or other items that might block or restrict the outlet, making any unauthorized stack alterations, or climbing on or otherwise tampering with the exhaust stack. If the stack is damaged or exhaust flow is hindered, the exhaust gases may be forced out the side of the boat with the discharge water. Therefore, it may also be necessary to warn users to stay clear of the water discharge area by labeling the water discharge area as a potential CO hazard.

4) As new engineering control devices for reducing CO emissions and exposures are developed, independent testing is needed to ensure that these systems perform adequately. These future devices could utilize a variety of methods to reduce the hazard. Additional protection from CO poisoning could be gained

by implementing multiple controls in series. For example, a fuel injected generator fitted with a properly functioning emission control device connected to a well designed exhaust stack will provide a dramatically higher level of protection against possible CO poisoning than a single control. However, all of these controls need independent testing and evaluation to ensure that they will meet the needs of the boating public and do not create additional hazards (i.e., fire or other safety hazards).

5) A critical component of the stack system is the exhaust gas/water separator. This separator can be incorporated within the same unit with a muffler, or it can be a discrete separate unit. To obtain optimum performance and best possible separation of the exhaust gases and the cooling water, the flow of exhaust gases and water must be balanced. The separator uses gravity and centrifugal forces to obtain separation. The resistance to flow in the water drain from the separator must be adjusted to ensure that gases cannot enter that part of the system and the resistance to flow in the exhaust gas piping (stack) must be designed to prevent the water level within the separator from rising to a point where it can be drawn into the exhaust gases. The optimum and proper performance of the separator is highly dependent on the piping sizing and arrangement, to and from the unit. The manufacturer of the separator can be very helpful with the system design and should be consulted during design of the stack and before final fitting of the unit(s).[17]

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Figure 1. **Houseboat #1.** 2000 Fun Country Marine Houseboat with Vertical Exhaust Stack.

Figure 2. **Houseboat #2.** 2002 Sumerset Houseboat with Flag Pole Exhaust Stack.

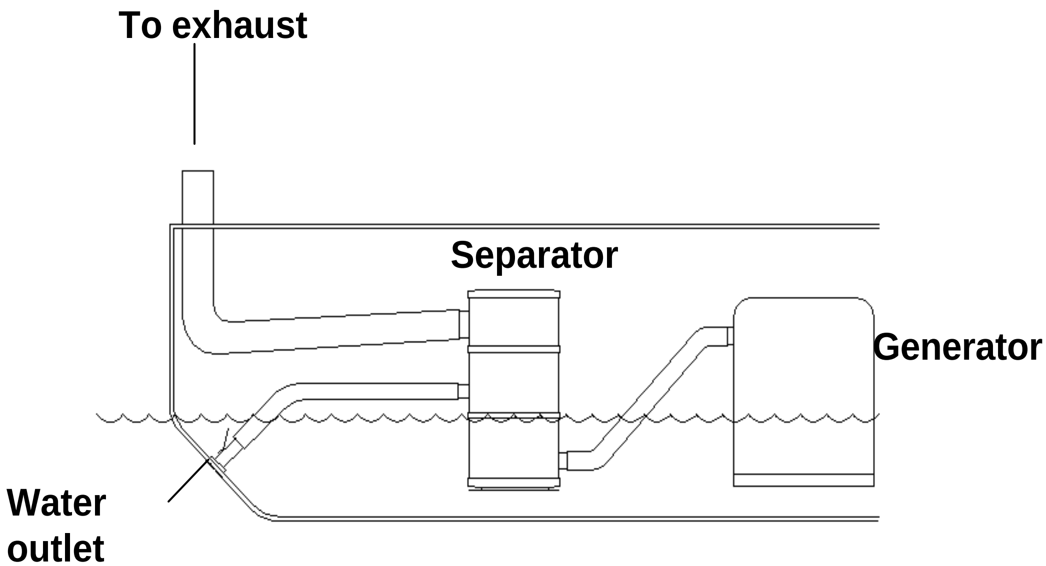

Figure 3: Simplified gas water separator configuration.

Sampling locations for ToxiUltra CO monitors on the lower and upper deck of the houseboats

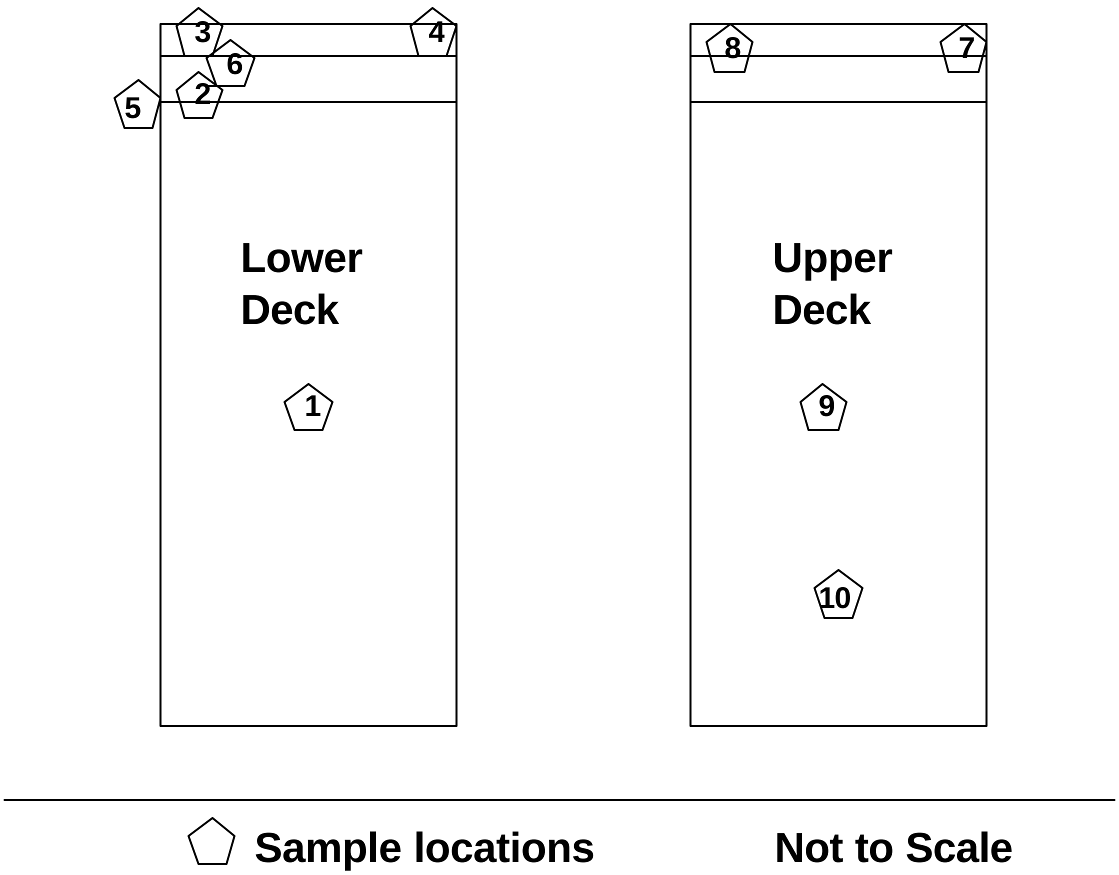

Figure 4: Sampling locations on the houseboats.

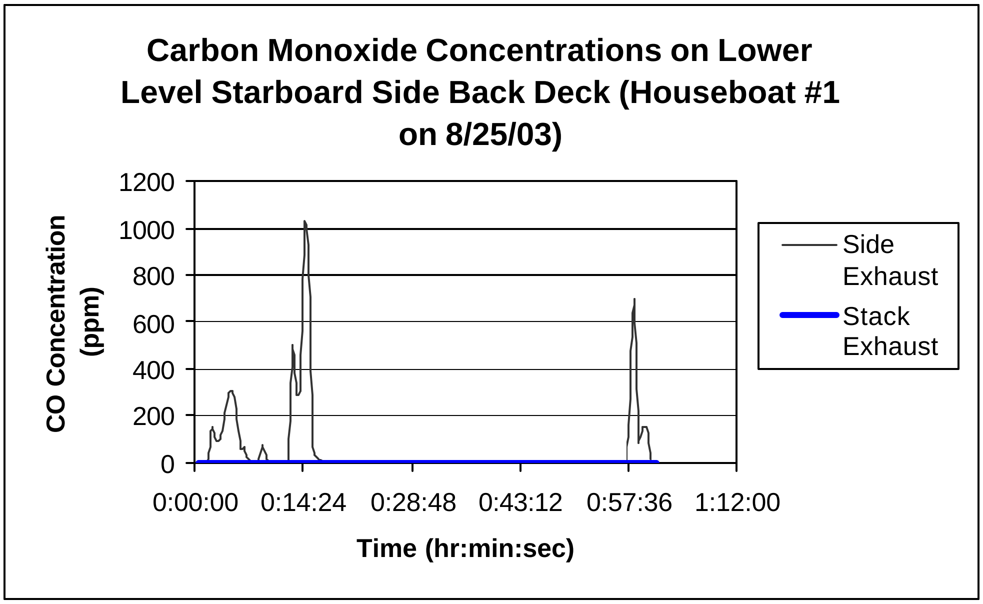

Figure 5. Comparison of CO concentrations on the lower level starboard side back deck of houseboat #1 (side exhaust was located on starboard rear side of boat at water level). Under conditions of no generator load and no extra weight.

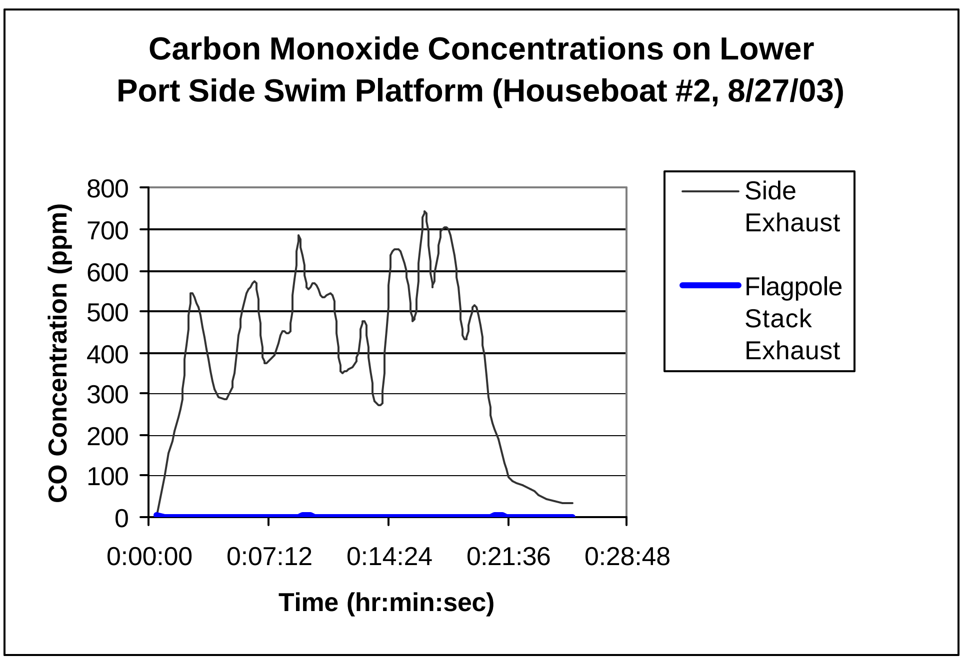

Figure 6. Comparison of CO concentrations on the lower level port side swim platform of houseboat #2 (side exhaust was located on port rear side of boat at water level). Under conditions of no generator load and no extra weight.

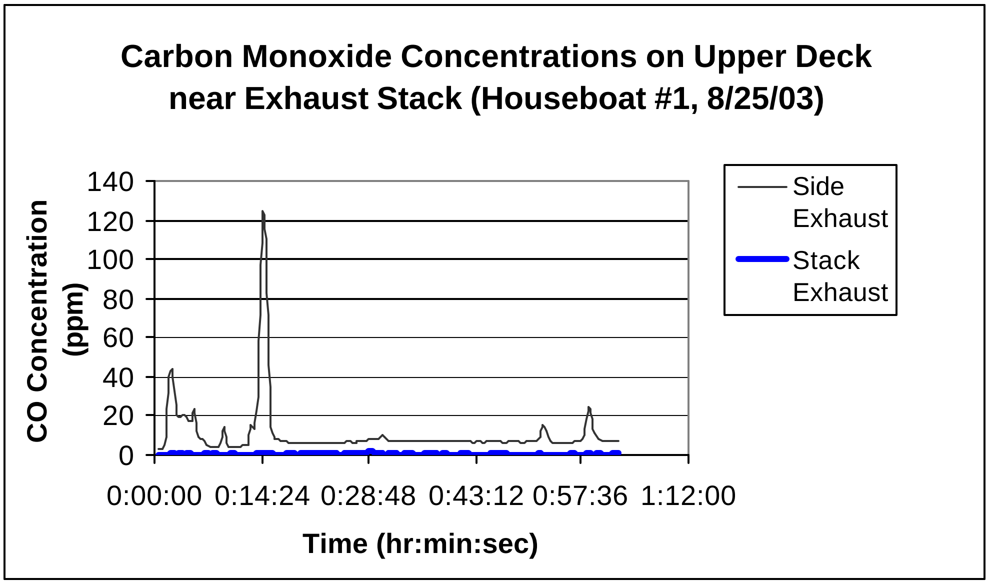

Figure 7. Comparison of CO concentrations on the upper level of houseboat #1 near the exhaust stack. (under conditions of no generator load and no extra weight).

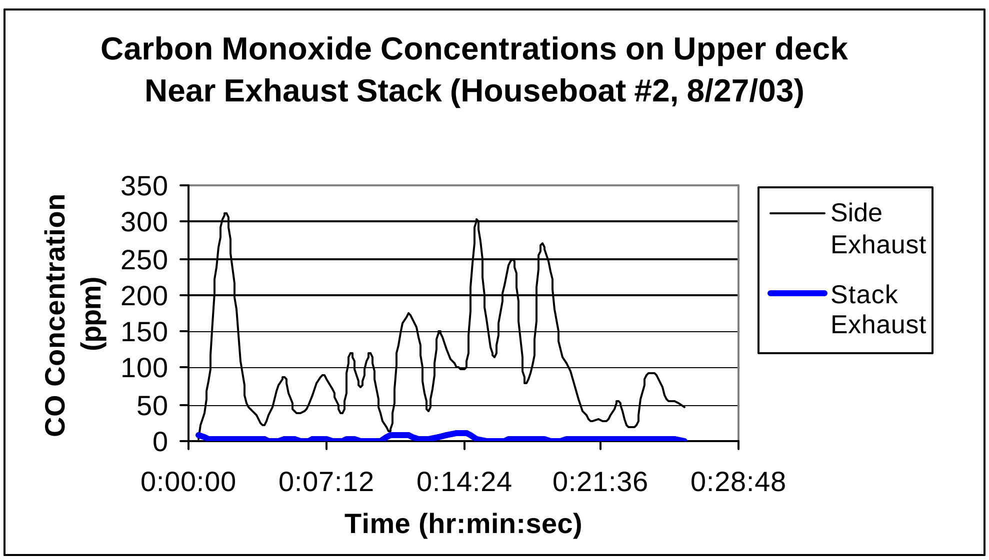

Figure 8. Comparison of CO concentrations on the upper level of houseboat #2 near the exhaust stack. (under conditions of no generator load and no extra weight).

Table I--CO Concentrations (ppm)

Lower deck comparison on Houseboat #1 of vertical stack and side exhaust with no generator load and no extra weight (Conditions #1 and #3)

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Sample Location (See Figure 4)	Vertical Stack 8/25/03 Condition #3	Side Exhaust 8/25/03 Condition #1	Vertical Stack 8/26/03 Condition #3	Side Exhaust 8/26/03 Condition #1
Slide @ breathing zone height #6	Mean = 1.06 Std. Dev. = 0.34 Peak = 2 N = 125	Mean = 15 Std. Dev. = 45 Peak = 336 N = 156	Mean = 0.6 Std. Dev.=2.1 Peak = 10 N = 32	Mean = 17 Std. Dev.=30 Peak = 153 N = 73
Sliding door #2	Mean = 2.4 Std. Dev. = 7.6 Peak = 51 N = 125	Mean = 18.4 Std. Dev. = 62 Peak = 555 N = 156	Mean = 3 Std. Dev.=2.6 Peak = 13 N = 34	Mean = 27 Std. Dev.=75 Peak = 563 N = 77
Starboard swim platform #3	Mean = 0.61 Std. Dev. = 0.52 Peak = 2 N = 123	Mean = 49 Std. Dev. =146 *Peak = 1022 N = 156	Mean = 1.4 Std. Dev.=3 Peak = 13 N = 32	Mean = 54 Std. Dev.=69 Peak = 220 N = 71
Port swim platform #4	Mean = 0.1 Std. Dev. = 0.3 Peak = 1 N = 126	Mean = 9 Std. Dev.=43 Peak = 404 N = 154	Mean = 3 Std. Dev.=10 Peak = 40 N = 30	Mean = 2.6 Std. Dev.=2.9 Peak = 14 N = 73
Kitchen #1	Mean = 3.6 Std. Dev. = 1.2 Peak = 10 N = 125	Mean = 6.4 Std. Dev. = 1 Peak = 8 N = 156	Mean = 1.8 Std. Dev.=0.39 Peak = 2 N = 34	Mean = 2.3 Std. Dev.=0.57 Peak = 3 N = 71
Hanging on starboard side of boat near water discharge #5	Mean = 0.2 Std. Dev. = 0.86 Peak = 6 N = 124	No data CO levels too high to measure with monitor	Mean = 4.3 Std. Dev.=6.2 Peak = 25 N = 33	**Mean = 59 Std. Dev.=169 *Peak = 1052 N = 74

N= number of data points

** - Monitor was moved onto floor of back deck to avoid burning out the CO sensor- Peak levels were greater than the instrument range.

* Peak Levels exceeded upper limit of CO instrument.

Std.Dev. = Standard Deviation

CO = Carbon Monoxide

ppm = parts per million

Table II--CO Concentrations (ppm)

Lower deck comparison on Houseboat #2 of Flag Pole stack and side exhaust with no generator load and no extra weight (Conditions #1 and #3) for 8/27/03, and with generator load and extra weight (Conditions #4 and #6) for 8/28/03.

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Sample Location (See Figure 4)	Flag Pole Stack 8/27/03 Condition #3 (1847-1950)	Flag Pole Stack 8/27/03 Condition #3 (2046-2125)	Side Exhaust 8/27/03 Condition #1	Flag Pole Stack 8/28/03 Condition #4 (1406-1424)	Side Exhaust 8/28/03 Condition #6
Stairs @ breathing zone height #6	Mean = 7.5 Std. Dev. = 5.3 Peak = 27 N = 126	Mean = 5.6 Std. Dev. = 6.2 Peak = 30 N = 77	Mean = 345 Std. Dev.= 234 *Peak = 1061 N = 52	Mean = 1.4 Std. Dev.=1.4 Peak = 5 N = 36	Mean = 61 Std. Dev.=37 Peak = 157 N = 25
Starboard side Closet door #2	Mean = 5.2 Std. Dev. = 2.7 Peak = 25 N = 126	Mean = 7.2 Std. Dev. = 2.5 Peak = 17 N = 78	Mean = 628 Std. Dev. =360 *Peak = 1246 N = 50	Mean = 9.5 Std. Dev.=4.5 Peak = 22 N = 36	Mean = 98 Std. Dev.=75 Peak = 278 N = 26
Starboard swim platform #3	Mean = 0.73 Std. Dev. = 0.86 Peak = 4 N = 126	Mean = 2.8 Std. Dev. =12 Peak =71 N = 78	Mean = 166 Std. Dev. =108 Peak = 467 N = 50	Mean = 0.3 Std. Dev.=0.59 Peak = 2 N = 36	Mean = 94 Std. Dev.=81 Peak = 272 N = 27
Port swim platform #4	Mean = 1.2 Std. Dev. = 0.99 Peak = 4 N = 126	Mean = 7.4 Std. Dev. = 12 Peak = 81 N = 78	Mean = 386 Std. Dev.=208 Peak = 742 N = 50	Mean = 2.3 Std. Dev.=2.2 Peak = 9 N = 36	Mean = 301 Std. Dev.=231 Peak = 922 N = 27
Back Bedroom (Inside Boat) #1	Mean = 4.4 Std. Dev. = 0.49 Peak = 5 N = 126	Mean = 8 Std. Dev. = 1.2 Peak = 10 N = 78	Mean = 12 Std. Dev.=12.6 Peak = 45 N = 51	Mean = 5.8 Std. Dev.=0.51 Peak = 7 N = 36	Mean = 6.3 Std. Dev.=0.45 Peak = 7 N = 26
Hanging on starboard side of boat near water discharge #5	Mean = 1.2 Std. Dev. = 5.5 Peak = 35 N = 126	No Data Collected During this Time Frame	**Mean = 1094 Std. Dev. = 2.5 **Peak = 1099 N = 6	Mean = 6.9 Std. Dev.=5.6 Peak = 25 N = 38	Mean = 434 Std. Dev.=444 *Peak = 1110 N = 26

N= number of data points

** Monitor was shut off to avoid burning out the CO sensor- Peak levels were greater than the range of the instrument.

* Peak Levels exceeded upper limit of CO instrument.

Std.Dev. = Standard Deviation

CO = Carbon Monoxide

ppm = parts per million

Table III--CO Concentrations (ppm)

Upperdeck comparison on Houseboat #1 of vertical stack and side exhaust with no generator load and no extra weight (Conditions #1 and #3)

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Sample Location (See Figure 4)	Vertical Stack 8/25/03 Condition #3	Side Exhaust 8/25/03 Condition #1	Vertical Stack 8/26/03 Condition #3	Side Exhaust 8/26/03 Condition #1
Top Deck Port Rear Side (near stack exhaust) #7	Mean = 0.46 Std. Dev. = 0.52 Peak = 2 N = 125	Mean = 9.8 Std. Dev. = 13 Peak = 124 N = 156	Mean = 0.47 Std. Dev.=1.2 Peak = 5 N = 32	Mean = 10 Std. Dev.=26 Peak = 156 N = 76
Top Deck Center #9	Mean = 0.36 Std. Dev. = 0.48 Peak = 1 N = 125	Mean = 7 Std. Dev. = 7.7 Peak = 63 N = 156	Mean = 1.3 Std. Dev.=1.9 Peak = 9 N = 32	Mean = 5.4 Std. Dev.=9.3 Peak = 48 N = 77
Top Deck Bar #10	Mean = 0.2 Std. Dev. = 0.41 Peak = 1 N = 123	Mean = 3.6 Std. Dev. =5.9 Peak = 44 N = 156	Mean = 1 Std. Dev.=1.7 Peak = 9 N = 32	Mean = 1.1 Std. Dev.=1.2 Peak = 6 N = 78
Top Deck Starboard side #8	Mean = 0.27 Std. Dev. = 0.44 Peak = 1 N = 125	Mean = 44 Std. Dev.=46 Peak = 304 N = 156	Mean = 0.44 Std. Dev.=0.98 Peak = 4 N = 32	Mean = 38 Std. Dev.=73.5 Peak = 370 N = 76

N= number of data points

Std.Dev. = Standard Deviation

CO = Carbon Monoxide

ppm = parts per million

Table IV--CO Concentrations (ppm)

Upper deck comparison on Houseboat #2 of Flag Pole Stack and side exhaust with no generator load and no extra weight (Conditions #1 and #3) for 8/27/03, and with generator load and extra weight (Conditions #4 and #6) for 8/28/03.

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Sample Location (See Figure 4)	Flag Pole Stack 8/27/03 Condition #3 (1847-1950)	Flag Pole Stack 8/27/03 Condition #3 (2046-2125)	Side Exhaust 8/27/03 Condition #1	Flag Pole Stack 8/28/03 Condition #4 (1406-1424)	Side Exhaust 8/28/03 Condition #6
Top Deck Port Rear Side (near Flag Pole Stack) #7	Mean = 3.1 Std. Dev. =2.4 Peak = 11 N = 126	Mean = 2.6 Std. Dev. =2.5 Peak = 11 N = 75	Mean = 103 Std. Dev. = 76 Peak = 311 N = 51	Mean = 1 Std. Dev. =1.4 Peak = 5 N = 38	Mean = 34 Std. Dev. =34 Peak = 117 N = 26
Top Deck Center#9	Mean = 0.53 Std. Dev. = 0.6 Peak = 4 N = 126	Mean = 0.76 Std. Dev. = 0.66 Peak = 4 N = 74	Mean =2.5 Std. Dev. =7.8 Peak = 45 N = 50	Mean = 0.42 Std. Dev. = 0.72 Peak = 3 N = 38	Mean = 15 Std. Dev. =20 Peak = 84 N = 26
Top Deck Bar #10	Mean = 1.2 Std. Dev. =0.46 Peak = 4 N = 126	Mean = 7.1 Std. Dev. = 13.9 Peak =91 N = 75	Mean = 1.1 Std. Dev.=0.35 Peak = 2 N = 50	Mean = 0.58 Std. Dev. = 0.5 Peak = 1 N = 36	Mean = 1.1 Std. Dev. =1.2 Peak = 6 N = 26
Top Deck Starboard Side #8	Mean = 0.42 Std. Dev. = 1.4 Peak = 8 N = 128	Mean = 0.4 Std. Dev. =1.9 Peak = 13 N = 74	Mean = 6.9 Std. Dev. =11 Peak = 54 N = 51	Mean = ND Std. Dev. =ND Peak = ND N = 38	Mean =15 Std. Dev. =17 Peak = 64 N = 26

N= number of data points

ND = CO not detected

Std.Dev. = Standard Deviation

CO = Carbon Monoxide

ppm = parts per million

Table V--CO Concentrations (ppm)

Upperdeck comparison of Conditions #2, #4, and #5 for Houseboat #1 (Verticle Stack)

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Sample Location (See Figure 4)	**Condition #2 8/25/03 (1645-2051)**	**Condition #2 8/25/03 Overnight (2153-0724)**	**Condition #4 8/26/03**	**Condition #5 8/26/03**	**Condition #2 8/26/03**
Top Deck Port Rear Side (near Stack) #7 8/25/03	Mean =6.4 Std. Dev. = 17 Peak = 177 N = 489	Mean =1 Std. Dev. = 7 Peak = 101 N = 1143	Mean = 0.8 Std. Dev. = 8.6 Peak = 263 N = 1355	Mean=0.87 Std. Dev. =3.4 Peak = 37 N = 132	Mean= 2 Std. Dev. =1.9 Peak = 5 N = 80
Top Deck Center #9 8/25/03	Mean = 1.2 Std. Dev. = 2.9 Peak =36 N = 490	Mean =0.06 Std. Dev. = 0.29 Peak = 4 N = 1142	Mean =0.96 Std. Dev. = 1.7 Peak =41 N = 1352	Mean=0.83 Std. Dev.=0.77 Peak =6 N = 134	Mean=2.4 Std. Dev. =1.1 Peak = 5 N = 80
Top Deck Bar #10 8/25/03	Mean =0.77 Std. Dev.= 0.95 Peak =10 N = 490	Mean =0.02 Std. Dev. = 0.14 Peak = 2 N = 1143	Mean = 0.37 Std. Dev.= 0.85 Peak = 17 N = 1353	Mean=0.76 Std. Dev. = 2.7 Peak =20 N = 134	Mean= 0.64 Std. Dev. =0.48 Peak = 1 N = 80
Top Deck Starboard side #8 8/25/03	Mean =5 Std. Dev. = 9.9 Peak = 97 N = 490	Mean =0.04 Std. Dev. = 0.46 Peak = 9 N = 1142	Mean = 0.5 Std. Dev. = 1.6 Peak = 35 N = 1353	Mean =0.3 Std. Dev. = 0.86 Peak =8 N = 134	Mean=0.56 Std. Dev. =2.7 Peak = 18 N = 80

N= number of data points

Std.Dev. = Standard Deviation

CO = Carbon Monoxide

ppm = parts per million

Table VI--CO Concentrations (ppm)

Lower deck comparison of Conditions #2, #4, and #5 for Houseboat #1 (Verticle Stack)

HETA 2003-0318-2936

Sample Location (See Figure 4)	Condition #2 8/25/03 (1645-2051)	Condition #2 8/25/03 Overnight (2153-0724)	Condition #4 8/26/03 Overnight	Condition #5 8/26/03	Condition #2 8/26/03
Slide @ breathing zone height #6	Mean =2.8 Std. Dev. = 5.6 Peak = 82 N = 490	Mean =0.5 Std. Dev. = 0.64 Peak = 11 N = 1144	Mean =0.57 Std. Dev. = 4.3 Peak = 95 N = 1350	Mean =0.4 Std. Dev. = 0.69 Peak = 4 N = 136	Mean = 0.06 Std. Dev. =0.24 Peak = 1 N = 80
Sliding door #2	Mean =2.8 Std. Dev. = 4.5 Peak = 49 N = 490	Mean =0.16 Std. Dev. = 0.94 Peak = 17 N = 1144	Mean =0.71 Std. Dev. = 1.9 Peak = 33 N = 1350	Mean =0.92 Std. Dev. = 0.74 Peak = 4 N = 134	Mean = 2.7 Std. Dev. =0.49 Peak = 4 N = 80
Starboard swim platform #3	Mean =5.6 Std. Dev. = 32.9 Peak = *480 N = 492	Mean =0.5 Std. Dev. = 0.64 Peak = 11 N = 1144	Mean =0.67 Std. Dev. = 1.8 Peak = 36 N = 1350	Mean = 0.6 Std. Dev. =0.7 Peak = 4 N = 134	Mean = 0.3 Std. Dev. =0.5 Peak = 1 N = 80
Port swim platform #4	Mean =1.3 Std. Dev. = 3.4 Peak = 32 N = 491	Mean =0.38 Std. Dev. = 3.3 Peak = 70 N = 1142	Mean = 0.5 Std. Dev. =1.7 Peak = 45 N = 1351	Mean = 0.87 Std. Dev. =2 Peak = 15 N = 134	Mean = 0.3 Std. Dev. =0.53 Peak = 2 N = 80
Kitchen #1	Mean =3.1 Std. Dev. = 0.46 Peak = 5 N = 490	Mean = 2.9 Std. Dev. = 0.34 Peak = 4 N = 1144	Mean = 2 Std. Dev. =0.44 Peak = 4 N = 1351	Mean = 1.4 Std. Dev. =0.49 Peak = 2 N = 136	Mean = 2 Std. Dev. =0.47 Peak = 3 N = 82
Hanging on starboard side of boat near water discharge #5	Mean =3.2 Std. Dev. = 9.4 Peak = 78 N = 492	Mean = 0.53 Std. Dev. = 1.3 Peak = 10 N = 1142	Mean = 2.8 Std. Dev. =5.7 Peak = 47 N = 1354	Mean = 4.7 Std. Dev. =9.6 Peak = 56 N = 129	Mean = 20 Std. Dev. =9 Peak = 43 N = 58

N= number of data points.

* High Peak may be a result of boat pulling up to houseboat. Peak may be from boat engine exhaust and may not be a result of stack emissions from generator on houseboat.

Std.Dev. = Standard Deviation

CO = Carbon Monoxide

ppm = parts per million

Table VII--CO Concentrations (ppm)

Upperdeck comparison of Conditions #2, #4, and #5 for Houseboat #2 (Flag Pole Stack)

HETA 2003-0318-2936

Sample Location (See Figure 4)	Condition #2 8/27/03 (1744-1847)	Condition #2 8/27/03 (2020-2046)	Condition #4 8/28/03 (1252-1333)	Condition #5 8/28/03 (1333-1406)	Condition #5 8/28/03 (1444-1506)
Top Deck Port Rear Side (near Stack) #7 8/25/03	Mean = 3.9 Std. Dev. =7.5 Peak = 54 N = 133	Mean = 7 Std. Dev. = 5 Peak = 30 N = 55	Mean = 5.8 Std. Dev. = 11.6 Peak = 72 N = 82	Mean = 0.43 Std. Dev. = 1.1 Peak = 4 N = 14	Mean = 1 Std. Dev. = 1.6 Peak = 7 N = 43
Top Deck Center#9 8/25/03	Mean = 2.1 Std. Dev. =8.2 Peak = 64 N = 132	Mean =0.6 Std. Dev. = 0.52 Peak = 2 N = 56	Mean = 6.9 Std. Dev. = 9.6 Peak = 68 N = 82	Mean = 2.9 Std. Dev. = 7.3 Peak = 26 N = 16	Mean = 0.63 Std. Dev. = 0.79 Peak = 3 N = 43
Top Deck Bar #10 8/25/03	Mean = 1.5 Std. Dev. =1.5 Peak = 11 N = 133	No Data Collected at this location During this Time Frame	Mean = 3.2 Std. Dev. = 7.5 Peak = 55 N = 82	Mean = 0.87 Std. Dev. = 0.35 Peak = 1 N = 15	Mean = 0.73 Std. Dev. = 0.45 Peak = 1 N = 44
Top Deck Starboard side #8 8/25/03	Mean = 1.1 Std. Dev. = 4 Peak = 24 N = 131	Mean = 0.18 Std. Dev. = 0.7 Peak = 4 N = 55	Mean = 2.4 Std. Dev. = 11 Peak = 70 N = 82	Mean = 0.08 Std. Dev. = 0.28 Peak = 1 N = 13	Mean = 0.05 Std. Dev. = 0.21 Peak = 1 N = 44

N= number of data points

Std.Dev. = Standard Deviation

CO = Carbon Monoxide

ppm = parts per million

Table VIII--CO Concentrations (ppm)

Lower deck comparison of Conditions #2, #4, and #5 for Houseboat #2 (Flag Pole Stack)

HETA 2003-0318-2936

Sample Location (See Figure 4)	Condition #2 8/27/03 (1744-1847)	Condition #2 8/27/03 (2020-2046)	Condition #4 8/28/03 (1252-1333)	Condition #5 8/28/03 (1333-1406)	Condition #5 8/28/03 (1444-1506)
Stairs @ breathing zone height #6	Mean = 2.9 Std. Dev. = 4.7 Peak = 29 N = 135	Mean = 6.8 Std. Dev. = 5 Peak = 26 N = 56	Mean = 2.6 Std. Dev. = 9.4 Peak = 56 N = 82	Mean = 1.6 Std. Dev. = 2 Peak = 6 N = 12	Mean = 0.3 Std. Dev. = 1 Peak = 5 N = 46
Sliding door #2	Mean = 12.3 Std. Dev. = 14.5 Peak = 131 N = 132	Mean = 20 Std. Dev. = 11.2 Peak = 86 N = 56	Mean = 6.7 Std. Dev. = 8.2 Peak = 56 N = 80	Mean = 8.5 Std. Dev. = 4.2 Peak = 17 N = 13	Mean = 11.3 Std. Dev. = 9.9 Peak = 54 N = 48
Starboard swim platform #3	Mean = 1.7 Std. Dev. = 5.8 Peak = 34 N = 132	Mean = 1 Std. Dev. = 1.8 Peak = 8 N = 56	Mean = 5 Std. Dev. = 8.4 Peak = 56 N = 82	Mean = 1.1 Std. Dev. = 1.9 Peak = 5 N = 10	Mean = 1.4 Std. Dev. = 1.2 Peak = 5 N = 47
Port swim Platform #4	Mean = 1.5 Std. Dev. = 5.4 Peak = 38 N = 132	Mean = 15 Std. Dev. = 6 Peak = 32 N = 56	Mean = 6.7 Std. Dev. = 6 Peak = 25 N = 82	Mean = 2.3 Std. Dev. = 2.4 Peak = 7 N = 12	Mean = 6.5 Std. Dev. = 4.4 Peak = 18 N = 48
Back Bedroom (Inside Boat) #1	Mean = 5.4 Std. Dev. = 1.2 Peak = 7 N = 137	Mean = 12.2 Std. Dev. = 2.4 Peak = 19 N = 53	Mean = 2.8 Std. Dev. = 1.1 Peak = 6 N = 80	Mean = 5.2 Std. Dev. = 0.56 Peak = 6 N = 13	Mean = 5.8 Std. Dev. = 0.5 Peak = 7 N = 48
Hanging on starboard side of boat near water discharge #5	Mean = 13.7 Std. Dev. = 51 *Peak = 518 N = 132	No data collected at this location for this time period	Mean = 13.8 Std. Dev. = 31 *Peak = 212 N = 82	Mean = 5.4 Std. Dev. = 4.8 Peak = 18 N = 16	Mean = 13.9 Std. Dev. = 15.6 Peak = 61 N = 47

N= number of data points.

* High Peak may be a result of water combo separator filling up with water (first run of the day). During this process when generator is first started it may result with some CO exiting through the water outlet until combo separator is filled with water. If system has too much static pressure on the gas discharge side, CO can be emitted out of water discharge near water level.

CO = Carbon Monoxide

ppm = parts per million

Std.Dev. = Standard Deviation

Table IX-- Boat Heading and Wind Velocity Data
HETA 2003-0318-2936

Day/Boat	Houseboat Bearing	Average Wind Direction	Average Wind Speed (meters/sec)	Standard Deviation Wind Speed (meters/sec)
Monday afternoon Houseboat #1	210º	126º	1.5 m/sec	0.8 m/sec
Monday night Houseboat #1	210º	239º	0.4 m/sec	0.2 m/sec
Tuesday afternoon Houseboat #1	210º	133º	1.9 m/sec	1.1 m/sec
Tuesday night Houseboat #1	210º	244º	0.5 m/sec	0.3 m/sec
Wednesday evening Houseboat #2	65º	135º	0.5 m/sec	0.3 m/sec
Thursday afternoon Houseboat #2	65º	131º	1.5 m/sec	0.9 m/sec

Table X-- Ambient Temperature and Relative Humidity Data
HETA 2003-0318-2936

Day/Boat	Temp Range	Temp Avg.	Temp Std. Dev.	Humidity Range	Humidity Average	Humidity Std. Dev.	Number of Data Points
Monday afternoon Houseboat #1	74.8 – 97.2°F	91.1°F	8.6	40 – 63 %RH	47% RH	5.9	125
Monday night Houseboat #1	77 – 96.4°F	83.2°F	5.9	42.5 – 80 %RH	68% RH	11.6	861
Tuesday afternoon Houseboat #1	71.2 – 99.1°F	82.9°F	10.7	36.5 – 87 %RH	45% RH	7.5	385
Tuesday night Houseboat #1	68.5 – 77.5°F	72.4°F	2.4	75 – 100 %RH	94% RH	6.1	908
Wednesday evening Houseboat #2	73 – 89.8°F	76.8°F	6.0	52 – 86 %RH	68% RH	6.8	1037
Thursday afternoon Houseboat #2	80.6 – 90.3°F	86°F	2.9	50.5 – 75.5 %RH	63% RH	6.8	194

Temp= Temperature
Std.Dev. = Standard Deviation

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