CO EMISSIONS FROM A PORTABLE PROPANE CATALYTIC HEATER

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Prepared By David R. Tucholski

Directorate for Laboratory Sciences

United States Consumer Product Safety Commission

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EXECUTIVE SUMMARY

In 2001, staff at the U.S. Consumer Product Safety Commission (CPSC) began a project to document the carbon monoxide (CO) emissions from small portable propane heaters, which are often referred to as camp heaters. The objective of the project was to determine if the heaters complied with the combustion requirements in the voluntary standard for Portable Type Gas Camp Heaters (ANSI Z21.63-2000). The voluntary standard was revised in April 2000 to address the potential CO poisoning hazard that can result when propane heaters are operated in small-enclosed areas that are poorly ventilated, such as a tent.

Two types of heaters were tested as part of the project: infrared radiant heaters and catalytic heaters. Catalytic heaters differ from infrared radiant heaters in that heat is generated from a flameless catalytic reaction involving propane and oxygen. Although ANSI Z21.63 only applies to infrared radiant camp heaters, a catalytic heater was included as part of the project since the catalytic heater was being marketed for use inside tents and indoor areas. Between 1996 and June 2001, CPSC is aware of one CO poisoning death associated with use of a catalytic heater in a confined space (Mah, 2001). This report discusses the test results for the catalytic camp heater. Details of the test results for infrared radiant camp heaters are discussed in a separate report titled, "CO Emissions from Portable Propane Radiant Heaters" (Tucholski, 2002).

The voluntary standard applicable to catalytic camp heaters, ANSI Z21.62, *Portable Catalytic Camp Heaters for Use with Propane Gas*, has been inactive since 1992. A new standard is currently being written, and a draft of the standard was sent out for public review and comment on November 15, 2001. To date, the draft standard has not been adopted.

Although ANSI Z21.62 (draft) and ANSI Z21.63 (2000) both apply to gas-fired camp heaters, each standard has different combustion requirements. The combustion test specified in ANSI Z21.62 (draft) is conducted by operating the heater in a closed room (i.e., a room with no air exchanges). The CO concentration in the room cannot exceed 35 parts per million (ppm) when the oxygen (O_2) is depleted to 19.4 percent and the CO cannot exceed 250 ppm when the O_2 is depleted to 15.1 percent. In addition, the hydrocarbon concentration (measured as propane) cannot exceed 500 ppm when the O_2 is depleted to 19.4 percent. The combustion test specified in ANSI Z21.63 (2000) is conducted by operating the heater in a 100 ft^3 room at air exchange rates of 0.5, 1.0 and 1.5 air changes per hour (ACH). During any part of the test, the CO concentration in the room cannot exceed 100 ppm and the O_2 concentration cannot be depleted below 16 percent. The test is conducted until equilibrium is reached or until the flame self extinguishes.

At the time the project was conducted, CPSC staff was aware of only one manufacturer selling a small catalytic heater for recreational use. This heater was designed for use with a disposable 1-pound bottle of propane, which is typically used with camp heaters.

The combustion characteristics of the catalytic heater were evaluated by operating the heater in a 100 ft^3 test chamber at air exchange rates of 0.0, 0.5, 1.0, and 1.5 ACH. During the test, gas samples were continually withdrawn from the test chamber and analyzed for carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), and unburnt hydrocarbons in the form of propane. Long term testing of two identical catalytic heaters was also performed to determine if the catalyst degraded over time.

The following is a summary of CPSC staff's findings:

- On average, the catalytic heater operated for approximately 6.5 hours on a 1-pound disposable bottle of propane. This heater could not be attached to a larger fuel source (i.e., 20-pound tank).
- The peak CO concentration ranged from 68 ppm to 125 ppm and the steady state CO concentration ranged from 67 ppm to 109 ppm. Assuming a limited exposure time of up to 6.5

hours at these CO concentrations, the catalytic heater does not appear to pose a serious CO hazard to healthy adults when the CO concentration is considered by itself.

- When the catalytic heater was operated in a closed room (ACH ~ 0), the oxygen was depleted from an ambient concentration of 20.9 percent to 8.8 percent. Because the catalytic heater can deplete the O_2 concentration to such low levels, the heater poses a serious risk of hypoxia. The degree of hypoxia is further exacerbated by the moderate CO concentration and by an increase in the carbon dioxide concentration that accompanied the depletion of oxygen.
- As the oxygen decreased in the chamber, the catalytic heater became less effective at converting the propane and oxygen to carbon dioxide and water vapor. This was reflected by an increase in the hydrocarbon concentration in the chamber, which ranged from 1,050 ppm to 13,440 ppm (5 to 64 percent of the lower explosion limit of propane in air). The unreacted propane further increases the degree of hypoxia.
- The heater's catalyst did not appear to degrade over time. This observation is based on operating two identical heaters on 100 disposable 1-pound bottles of propane (equivalent to approximately 650 hours of total use). Emission tests were performed on each heater after every 20th bottle of propane (approximately every 130 hours).
- The catalytic heater did comply with the combustion requirements currently specified in the draft version of the standard for catalytic camp heaters (ANSI Z21.62-draft).
- The catalytic heater did not comply with the combustion requirements specified in the standard for infrared radiant camp heaters (ANSI Z21.63-2000). The heater depleted the O_2 concentration below 16 percent in the test chamber and also exceeded the 100 ppm limit for CO in the test chamber.

Based on these test results, CPSC staff plans to recommend the following to the *CSA/Z21 Joint Technical Advisory Group (TAG) on Refrigerators and Portable Camping Equipment*:

1. Replace the combustion requirements currently being proposed in the draft version of ANSI Z21.62 with the same combustion requirements specified in ANSI Z21.63 (i.e., CO ≤ 100 ppm and O_2 ≥ 16 percent when the heater is operated in a 100 ft^3 room at air exchange rates of 0.5, 1.0, and 1.5 ACH). Since the catalytic camp heaters can be used in the same environments as those in which the infrared radiant camp heaters are used, the catalytic camp heaters should meet the same requirements for CO emissions and O_2 depletion as those specified for infrared radiant camp heaters.
2. Limit the emissions of hydrocarbons (in the form of propane) to 500 ppm, when the catalytic heater is tested in a 100 ft^3 room at air exchange rates of 0.5, 1.0, 1.5 ACH. The current draft proposal of ANSI Z21.62 only checks the hydrocarbon emissions at an O_2 concentration of 19.4 percent during a closed room test.
3. Keep the requirement currently specified in the draft proposal of ANSI Z21.62 to retest the catalytic heater after operating the heater for 100 hours.

INTRODUCTION*

Background

In 2001, staff at the U.S. Consumer Product Safety Commission (CPSC) began a project to document the carbon monoxide (CO) emissions from camp heaters, which are small portable propane heaters. The objective of the project was to determine if the heaters complied with the combustion requirements in the voluntary standard for Portable Type Gas Camp Heaters (ANSI Z21.63-2000). The standard was revised in April 2000 to address the potential CO poisoning hazard that can result when propane heaters are operated in small-enclosed areas that are poorly ventilated, such as a tent.

Two types of heaters were tested as part of the project: infrared radiant heaters and catalytic heaters. Catalytic heaters differ from infrared radiant heaters in that heat is generated from a catalytic reaction involving propane and oxygen, without the presence of a flame. Although ANSI Z21.63 applies to infrared radiant camp heaters, a catalytic heater was included as part of the project since the heater was being marketed for use inside tents and other indoor areas. Between 1996 and June 2001, CPSC is aware of one CO poisoning death that occurred while a catalytic heater was being used in a confined space (Mah, 2001)

Catalytic Heaters

Catalytic heaters generate heat through a flameless catalytic reaction involving propane and oxygen. This is different from infrared radiant heaters, which generate a flame during the combustion process. The catalytic heater generates heat by bringing the propane and oxygen (air) into contact with a platinum catalyst. A chemical reaction then occurs in which the propane and oxygen are converted primarily into carbon dioxide and water vapor. During the chemical reaction, heat is also released. The chemical reaction occurs at a temperature well below the flame temperature of typical infrared radiant heaters. In order to start the reaction, the fuel and air mixture must be ignited by an external heat source, such as a spark or pilot light.

Figure 1 shows a catalytic heater currently available to consumers. The catalytic heater consists of a circular burner head and a control valve to turn the gas on and off. The catalytic material is dispersed throughout a catalyst-containing substrate, which has the appearance of a woven ceramic fiber pad. The substrate is located within the burner head and is covered with a perforated metal plate. The entire heater assembly attaches directly to a disposable bottle of propane.

At the time the project was conducted, CPSC staff was aware of only one manufacturer selling a small catalytic heater for recreational use (i.e., the heater was portable and operated off of a disposable 1-pound bottle of propane). Since the completion of the project, staff is aware of a least one other manufacturer who is marketing a catalytic heater for use in enclosed areas, such as tents, trailers and fishing huts. However, this catalytic heater operates off of a bulk tank of propane (e.g., 20-pound tank), not a disposable bottle.

* The views expressed in this report are those of the CPSC staff and do not necessarily reflect the views of the Commission.

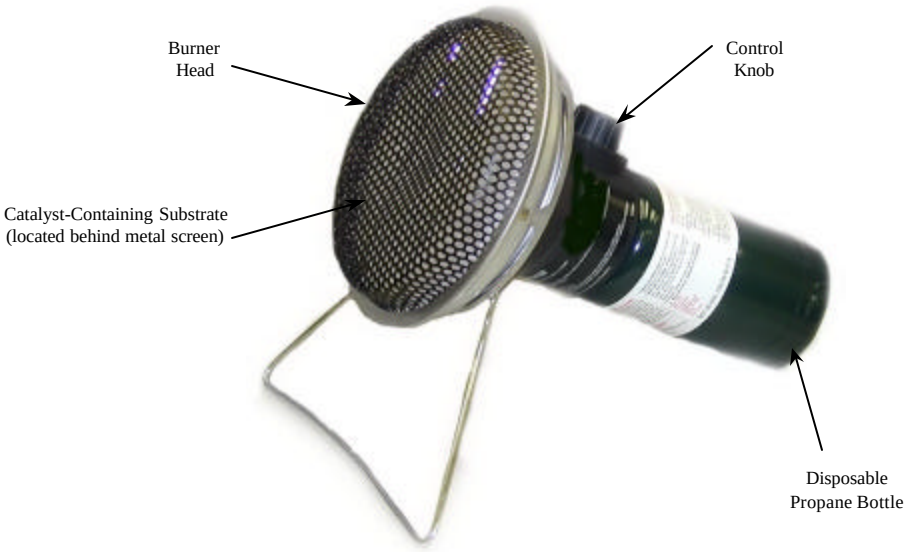

Figure 1. Catalytic heater

Voluntary Standards

The voluntary standard applicable to catalytic camp heaters is ANSI Z21.62, *American National Standard for Portable Catalytic Camp Heaters for Use with Propane Gas.* The standard was withdrawn in 1992 because the CSA/Z21 Joint Subcommittee on Gas Refrigerators and Portable Camping Equipment and a certification laboratory were unaware of any product that needed the standard for certification purposes. However, several catalytic heater manufacturers have recently requested that a new standard be written so that their products can be certified. At the June 2000 meeting of the CSA/Z21 Joint Subcommittee on Gas Refrigerators and Portable Camping Equipment, the subcommittee established a task group on catalytic heaters that is responsible for the development of a new harmonized standard for catalytic camp heaters. A draft of the standard was sent out for public review and comment on November 15, 2001. To date, the draft standard has not been adopted.

The combustion requirements currently being proposed in the draft version of the catalytic camp heater standard are the same combustion requirements as those of the previous standard written in 1977. In general, the heater is operated in a closed room with no air changes. When the oxygen concentration in the room is depleted to 19.4 percent, the concentration of CO cannot exceed 35 ppm and the concentration of hydrocarbons (unreacted fuels expressed as propane) cannot exceed 500 ppm. Furthermore, the concentration of CO cannot exceed 250 ppm when the oxygen concentration is depleted to 15.1 percent. The standard also specifies that the combustion test is to be repeated after operating the heater for 100 hours outside of the room.

The voluntary standard for portable infrared camp heaters is ANSI Z21.63 (2000), *American National Standard/CSA Standard for Portable Type Gas Camp Heaters.* The standard applies to unvented portable type gas-fired heaters, of the infrared type, that are intended for outdoor use and have a maximum input rate up to and including 12,000 Btu/hr. The standard was revised in April 2000 to address the CO poisoning hazard that can result when gas-fired camp heaters are used in enclosed areas that are poorly ventilated. ANSI Z21.63 (2000) specifies that when an infrared radiant heater is operated in a 100 ft^3 room at air exchange rates of 0.5, 1.0, and 1.5 air changes per hour, the CO concentration in the room cannot exceed 100 ppm. In addition, ANSI Z21.63 (2000) specifies that the O_2 concentration in the room cannot be depleted below 16 percent at any time.

TEST EQUIPMENT* AND SETUP

Heater Samples

At the time the project was conducted, CPSC staff was aware of only one manufacturer selling a small catalytic heater for recreational use. The Office of Compliance collected several of these heaters from a local retail store in October 1999. The heater has a nominal energy-input rate of 3,000 Btu/hr. Two identical catalytic heaters were tested as part of this project and are referred to as Heater 1 and Heater 2.

Propane Gas

The heaters were attached directly to a disposable 1-pound bottle of propane. Bottles from two different propane suppliers were used and the bottles were purchased locally at several different retail stores. A gas chromatograph analysis of gas samples taken from several bottles indicated that the propane gas consisted of approximately 90-95% propane (C_3H_8), 2-9% ethane (C_2H_6), 1-3% iso-butane (C_4H_{10}), and less than 1% butane (C_4H_{10}). A calorimeter was not available on site to measure the heating value of the propane gas, therefore a heating value of 2,500 Btu/ft^3 was assumed for the gas. A heating value of 2,500 Btu/ft^3 is often assumed for propane gas when the actual value is not known (AGA, 2001).

Test Chamber

Experiments were conducted inside a 100 ft^3 test chamber with an interior height of 6.6 ft, a width of 3.9 ft, and a depth of 3.9 ft. The chamber was constructed from sheets of fire retardant boards supported by a metal framework. A chilled water heat exchanger system was used to maintain the temperature inside the chamber at a set temperature. The cooling system could maintain the chamber temperature at 70°F ± 5°F for heaters rated less than approximately 5,000 Btu/hr. To enhance the heat transfer of the cooling system, fans were used to move air over the cooling coils of the heat exchanger. These fans also circulated the air within the chamber, which resulted in a well-mixed environment. The air exchange rate through the chamber could be varied from 0 to 6 air changes per hour (ACH) by controlling the speed of the supply fan and exhaust fan, and by changing the diameter of the opening for the supply air.

Combustion Gas Sampling System

Gas samples were continually withdrawn from the chamber through six equal length sample lines located within the chamber. The six sample lines were connected to a common manifold where the gas samples mixed. A pump conveyed the mixed gas sample to a series of gas analyzers. The gas sample was analyzed for CO, CO_2, O_2, and unburnt hydrocarbons measured as propane (C_3H_8). Table 1 provides a summary of the combustion gas analyzers. Water vapor formed during the combustion process was removed from the gas sample prior to analysis using a chilled water heat exchange system.

* The test equipment described herein including specific manufacturers' products used to monitor or control testing, and/or record or obtain data, are specifically identified to allow others to attempt to re-produce this work should they so desire. Mention of a specific product or manufacturer in this report does not constitute approval or endorsement by the Commission.

Table 1. Summary of combustion gas analyzers.

Gas Species	Gas Analyzer			Measurement Range
	Measuring Technique	Manufacturer	Model	
Carbon Monoxide (CO)	Non-Dispersive Infrared	Rosemount	880A	0 – 200 ppm 0 – 1,000 ppm 0 – 3,000 ppm
Carbon Dioxide (CO_2)	Non-Dispersive Infrared	Rosemount	880A	0 – 10 percent
Oxygen (O_2)	Paramagnetic	Rosemount	755R	0 – 20.9 percent
Hydrocarbon (C_3H_8)	Non-Dispersive Infrared	Rosemount	880A	0 - 100 percent of the Lower Explosive Limit*

* A lower explosion limit of 2.1 percent propane in air was assumed (Segeler, 1965).

Temperature

The air temperature in the chamber was measured at six locations in the chamber using K-type thermocouples (28-gauge, Omega). One thermocouple was located at the inlet of each sample tube.

Air Exchange Rate

The air exchange rate in the chamber was determined experimentally by measuring the exponential decay of a tracer gas once the heater shut off. Sulfur hexafluoride (SF_6) was used as the tracer gas for all tests. The concentration of SF_6 in the chamber was measured with an electron capture gas chromatograph analyzer (Largus Applied Technology, Model 101 Autotrac). The air exchange rates obtained from the decay of SF_6 were verified by the decay of CO, which occurred once the heater was off.

Energy-Input Rate of Heater

The energy-input rate of the heater was determined indirectly by measuring the amount of propane-fuel consumed by the heater over time. The mass of fuel consumed during a given time interval was measured using an electronic scale (Mettler, PM34 Delta Range).

Data Acquisition

A data acquisition system was used to collect and record the data. The system consisted of a personal computer, data acquisition interface hardware (Keithely), and data acquisition software (LABTECH® CONTROL). Gas concentrations and temperatures were recorded every 30 seconds by the data acquisition program. The program converted the voltage output from the gas analyzers into the appropriate concentration units (percent or parts per million). The only items not recorded by the data acquisition system were the concentration of SF_6 and the mass displayed on the electronic scale. The SF_6 analyzer contained an internal data acquisition program and recorded the concentration measurements directly to a 3.5-inch floppy disk located on the analyzer. The mass of fuel consumed was displayed on the electronic scale and recorded manually.

EXPERIMENTAL PROCEDURE

Emission Tests

The gas analyzers were calibrated each morning prior to any tests being conducted. Each gas analyzer was calibrated according to the instructions specified by the manufacturer. In general, the CO, CO_2, O_2, and hydrocarbon gas analyzers were zeroed with nitrogen gas. The CO, CO_2, and hydrocarbon

analyzers were then spanned using gases of known concentrations (EPA Protocol Standards). Since the CO analyzer had three different ranges available, the gas analyzer was spanned on each range using a gas appropriate for that range. The O_2 analyzer was spanned using room air, which was assumed to be 20.94 percent. The SF_6 analyzer was calibrated using a calibration gas supplied by the manufacturer of the SF_6 analyzer.

To begin a test, the air exchange rate of the test chamber was set by adjusting the speed of the inlet fan and the exhaust fan. The relationship between the fan speed (i.e., supply voltage) and the air exchange rate through the chamber was known prior to the tests. The chamber's cooling system was also started at this time.

After completing the initial setup of the chamber, the heater was attached to a disposable bottle of propane and the heater was placed on the electronic scale inside of the chamber. The propane to the heater was then ignited following the instructions specified by the heater manufacturer. The door to the chamber was closed and the data acquisition program was then started.

As the test proceeded, the mass displayed on the electronic scale was recorded on a data sheet at various time intervals. As a back up to the data recorded electronically by the data acquisition system, the concentrations of CO, CO_2, O_2, and hydrocarbons were periodically recorded manually on a data sheet.

The test proceeded until one of the following events occurred: (1) the concentrations of CO, CO_2, and O_2 reached equilibrium (steady state), (2) the hydrocarbon concentration exceeded approximately 50 percent of the lower explosive limit of propane, or (3) all of the fuel was consumed from the bottle. The heater could be turned off at any time by reaching into the chamber through a pair of glove ports and rotating the fuel control knob on the heater to the "Off" position. Once the heater was off, the SF_6 analyzer was started and a small volume of SF_6 tracer gas was injected into the chamber. The decay of the SF_6 gas was then monitored, with the concentration of the gas being recorded every two minutes.

Long Term Testing

Long term testing was performed on two identical catalytic heaters to determine if the catalyst degraded over time. The heaters were placed in the CPSC burn room in Building G, which has a volume of approximately 1500 ft^3 and was fairly well ventilated. The heaters were each attached to full 1-pound disposable bottle of propane and operated until the fuel was depleted (approximately 6.5 hours). The empty bottle was then removed and replaced with a full bottle. On average, two bottles per day were run through each heater. No gas measurements were taken in the burn room while the heaters operated. At every twentieth bottle (i.e., 20, 40, 60, 80, 100), the heater was placed in the test chamber and emissions tests were conducted at an air exchange rate of 0.5 ACH. An air exchange rate of 0.5 ACH was selected since this was the air exchange rate that was used for the first test with Heater 1. The emission test protocol was identical to the emission tests described in the previous section.

DATA ANALYSIS

Air Exchange Rate

The equation describing the air exchange rate in the chamber can be derived from a simple mass balance of SF_6 in the chamber. The decay of SF_6 with time can be described by Equation 1:

$$C_t = C_0 e^{-kt} \tag{1}$$

In Equation 1, C_t is the concentration of SF_6 at time t, C_o is the initial concentration of SF_6 at the start of the decay, k is the air exchange rate, and t is time. Equation 1 was derived based on the following assumptions: the air in the chamber is well mixed, the SF_6 does not get absorbed inside the chamber, and the background concentration of SF_6 is zero.

Equation 1 can be rearranged to solve for the quantity (kt) as follows:

$$Ln\left(\frac{C_t}{C_o}\right) = -kt \tag{2}$$

Equation 2 indicates that a plot of the quantity Ln (C_t/C_o) versus time (t) should be linear and that the air exchange rate (k) will be equal to the slope of this line. Since the line should be linear, linear regression can be used to fit a line to the data. An expression describing how well the line fits the data is the R^2 term, where R is the correlation coefficient. An R^2 value of 1.0 indicates that the line obtained by linear regression fits the data perfectly. For each test, a linear regression was performed on the SF_6 decay data and the air exchange rate was obtained from the slope of this line. The test was considered acceptable if the R^2 term was greater than 0.9.

CO Generation Rate

The rate at which the heater generated carbon monoxide, termed the CO source strength, can be derived from a simple mass balance of CO in the chamber. Between any two time intervals (t_i and t_{i+1}), the source strength can be calculated from the following equation,

$$S_{t_{i+1}} = \frac{Vk\left[C_{t_{i+1}} - C_{t_i} e^{-k\left(t_{i+1}-t_i\right)}\right]}{\left[1 - e^{-k\left(t_{i+1}-t_i\right)}\right]} \tag{3}$$

In Equation 3, $S_{t\,i+1}$ is the generation rate of CO at time t_{i+1}, V is the volume of the chamber, k is the air exchange rate, C_{ti+1} is the concentration of CO at time t_{i+1}, and $C_{t\,i}$ is the concentration of CO at time t_i. Equation 3 was derived based on assuming that the air in the chamber is well mixed and that the CO is not absorbed inside the chamber.

Energy Input Rate

The energy-input rate of the heater, Q, was calculated indirectly from the mass of propane consumed by the heater over time. The energy-input rate was calculated as follows:

$$Q = \left[\frac{C_1 HHV}{r}\right]\left[\frac{\Delta m}{\Delta t}\right] \tag{4}$$

In Equation 4, C_1 is a conversion constant, HHV is the heating value of propane, r is the density of the propane gas, and Dm is the mass of propane fuel consumed during the time interval Dt. A HHV of 2,500 Btu/ft^3 was assumed for propane. The density of the propane gas used in the calculation was 0.114 lb_m/ft^3 and is based on a temperature of 70°F and a pressure of 14.7 lb_f/in^2.

Hydrocarbon Concentration

The hydrocarbon concentration was measured in terms of the lower explosion limit (LEL) of propane in air. The hydrocarbon concentration was converted to a parts-per-million (ppm) basis by assuming a LEL of 2.1 percent (21,000 ppm) propane in air (Segeler, 1965). Therefore,

$$\text{Hydrocarbon (ppm)} = (21{,}000\ \text{ppm})\left[\frac{\%\ \text{LEL}}{100}\right] \tag{5}$$

RESULTS

A summary of the test data is provided in Appendix A. Table A1 provides an overall summary of the data for the emissions tests of Heater 1 at various air exchange rates. Table A2 compares the test data to the combustion requirements in ANSI Z21.63 (2000). Table A3 compares the test data to the combustion requirements in ANSI Z21.62 (draft). Table A4 provides a summary of the data from the long-term testing of Heater 1 and Heater 2.

Emissions Tests

Heater 1 was tested in the chamber at four target air exchange rates: 0.0, 0.5, 1.0, and 1.5 ACH. The actual air exchange rate for each test was within ± 0.1 ACH of the target air exchange rate.

The catalytic heater had a manufacturer's specified energy-input rate of 3,000 Btu/hr. The average energy-input rate for all tests was 3,210 Btu/hr ± 50 Btu/hr. At this rate, the heater operated for approximately 6.5 hours on a full 1-pound disposable bottle of propane.

Figure 2 illustrates how the maximum CO concentration in the test chamber varied with the air exchange rate. The bolded horizontal line at 100 ppm is the maximum allowable CO concentration specified in ANSI Z21.63 (2000), which is the voluntary standard for infrared radiant camp heaters. In the figure, two CO concentrations are shown for each test condition: a peak value and a steady state value. The peak CO concentration ranged from 68 ppm to 125 ppm and the steady state CO concentration ranged from 67 ppm to 109 ppm. When the air exchange rate was approximately 1.0 ACH, the steady state CO concentration remained above 100 ppm. At all other air exchange rates, the steady state CO concentration was less than 100 ppm.

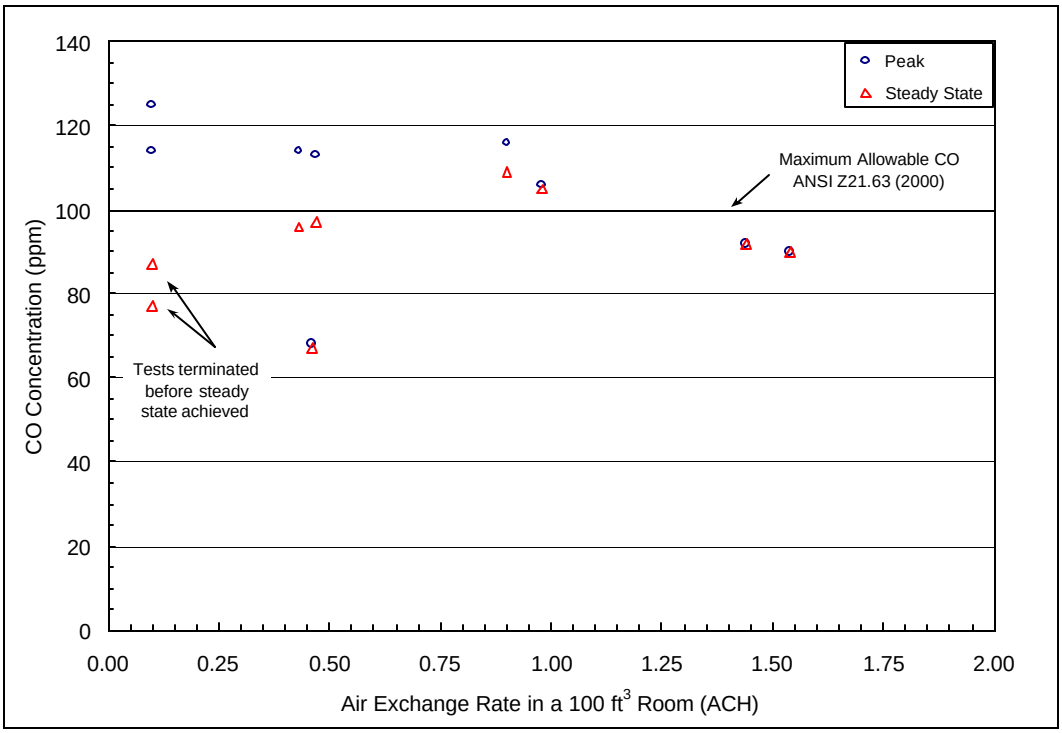

Figure 2. CO concentration in the test chamber as a function of the air exchange rate.

At an air exchange rate of 1.5 ACH, the peak and steady state CO concentrations were approximately the same (± 1 ppm). As the air exchange rate decreased below 1.5 ACH, the difference between the peak and steady state CO concentrations increased. An exception to this occurred during the very first test of the heater, which was conducted at an air exchange rate of 0.5 ACH. During this test, the

steady state CO concentration and the peak CO concentration were approximately equal (67 ppm and 68 ppm, respectively). Based on this result and the results of the subsequent tests, the variance between the peak and steady state CO concentrations appeared to occur only when consecutive tests were conducted in the test chamber at air exchange rates below 1.5 ACH. Operating the heater repeatedly at reduced air exchange rates may have caused the catalyst-containing substrate to become saturated with propane, thereby affecting the efficiency of the catalytic reaction.

The time required for the CO concentration to reach 100 ppm in the test chamber ranged from 1.0 hour to 3.9 hours. The time required for the CO concentration to reach steady state (t_{ss}) was a function of the air exchange rate: at 0.5 ACH, $t_{ss} \approx 6$ hrs, at 1.0 ACH, $t_{ss} \approx 3$ hrs, and at 1.5 ACH, $t_{ss} \approx 2$ hrs. During the closed room test (ACH ~ 0.0), the test was terminated after approximately 3.7 hours, due to the buildup of hydrocarbons in the test chamber. On average, the heater operated for approximately 6.5 hours on a full 1-pound disposable bottle of propane.

Figure 3 illustrates the relationship between the steady state O_2 concentrations in the test chamber and the air exchange rate. The bolded horizontal line at 16 percent O_2 is the minimum allowable O_2 concentration specified in ANSI Z21.63 (2000), which is the voluntary standard for infrared radiant camp heaters. Three data sets are shown in Figure 3. The open circles represent discrete experimental data points for steady state O_2 measurements made during tests conducted at different air exchange rates. The lower curve illustrates the theoretical steady state O_2 concentration that would be expected assuming 100 percent of the fuel had reacted to form the products of combustion. The upper curve illustrates the theoretical steady state O_2 concentration that would be expected from the CPSC test results, which found that that less than 100 percent of the fuel had reacted.

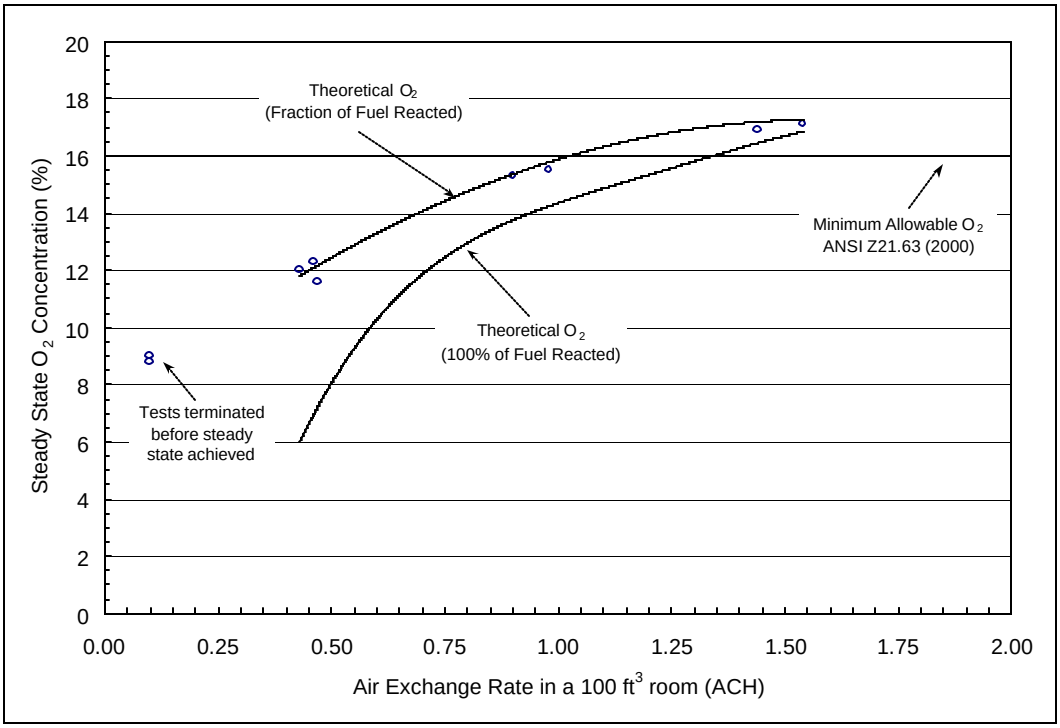

Figure 3. Steady state concentration of O_2 in the chamber as a function of the air exchange rate.

The experimental data points in Figure 3 show that the catalytic heater depleted the O_2 concentration below 16 percent when the air exchange rate was less than approximately 1.0 ACH. The time required to deplete the O_2 concentration from a normal room concentration of 20.9 percent to 16 percent ranged from 0.9 hours to 2.1 hours, depending on the air exchange rate. The minimum O_2

concentration measured in the chamber was 8.8 percent and occurred during a closed room test (ACH ~ 0.0). Due to the buildup of hydrocarbons in the test chamber during this test, the heater was shut off prior to the O_2 concentration reaching steady state. The O_2 concentration was depleted to 8.8 percent in approximately 3.7 hours.

The two theoretical curves shown in Figure 3 were determined from a simple mass balance of O_2 in a 100 ft^3 room, assuming an ambient and initial O_2 concentrations of 20.9 percent and assuming an O_2 depletion rate based on the mass flow rate of propane. The lower curve assumes 100 percent of the available fuel had reacted to form products of combustion. The upper curve is derived from the CPSC experimental data and accounts for the fact that some fraction of the available fuel did not react, as evidenced by the hydrocarbon concentrations measured in the chamber. It was assumed that the hydrocarbon concentration measured in the chamber was propane. The O_2 concentrations that were used to generate the upper curve were calculated as follows. First, the mass flow rate of the unreacted propane ($m_{unreacted}$) necessary to achieve a measured steady state hydrocarbon concentration in the chamber was determined from a simple mass balance of propane in a 100 ft^3 room at the specified air exchange rate. Next, the mass flow rate of the propane that actually reacted with the oxygen ($m_{reacted}$) was calculated by subtracting the mass flow rate of the unreacted propane ($m_{unreated}$) from the total mass flow rate of propane being supplied to the heater (m_{total}).

$$m_{reacted} = m_{total} - m_{unreacted} \quad (6)$$

Finally, the steady state O_2 concentration was calculated from a simple mass balance of O_2 in a 100 ft^3 room, assuming an O_2 depletion rate based on the mass flow of the reacted propane ($m_{reacted}$).

Figure 4 illustrates how the maximum concentration of hydrocarbons (measured as propane) in the chamber varied with the air exchange rate. The left side of the graph gives the hydrocarbon concentration in terms of the lower explosion limit (LEL) of propane gas in air and the right side of the graph gives the concentration on a parts-per-million (ppm) basis. As the air exchange rate decreased, the concentration of hydrocarbons increased. For all tests, the hydrocarbon concentration ranged from 1,050 ppm to 13,440 ppm (5 to 64 percent LEL). The maximum hydrocarbon concentration of 13,440 ppm (64 percent LEL) occurred during the closed room test and would have likely been higher had the test not been terminated early due to safety concerns.

An increase in the hydrocarbon concentrations indicates that the catalyst did not convert 100 percent of the propane to carbon dioxide and water. This observation is further substantiated by the fact that the oxygen was not being consumed at a rate necessary to burn 100 percent of the fuel being supplied to the burner (Figure 3). Figure 5 illustrates the relationship between the amount of fuel that reacted to the O_2 concentration in the chamber. The amount of fuel that reacted was calculated by dividing the mass flow rate of the propane that actually reacted with the oxygen ($m_{reacted}$) by the total mass flow rate of propane supplied to the burner (m_{total}). As the O_2 concentration decreased in chamber, the catalytic heater became less efficient in converting all of the propane into the products of combustion. Figure 5 is based on the steady state hydrocarbon concentrations measured in the chamber. Therefore, no calculations were made for the closed room tests (ACH ~ 0), since the tests were terminated before steady state was obtained. The hydrocarbon concentration was still increasing during the closed room tests when the test was terminated.

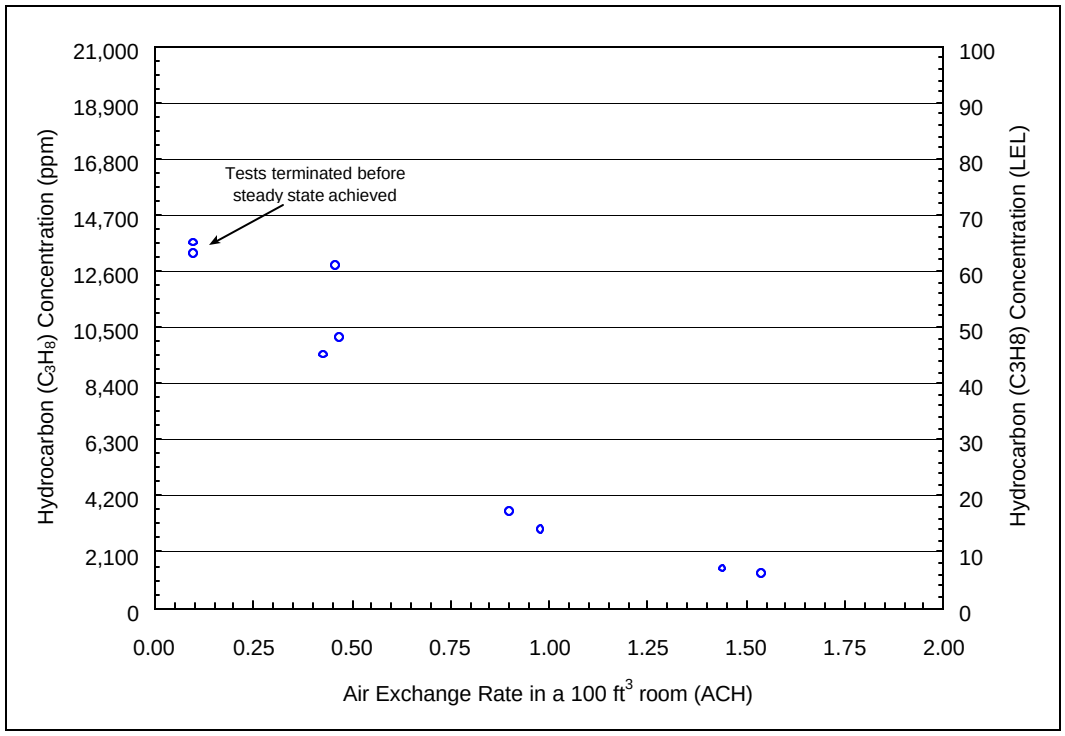

Figure 4. Steady state hydrocarbon concentration in the chamber as a function of the air exchange rate.

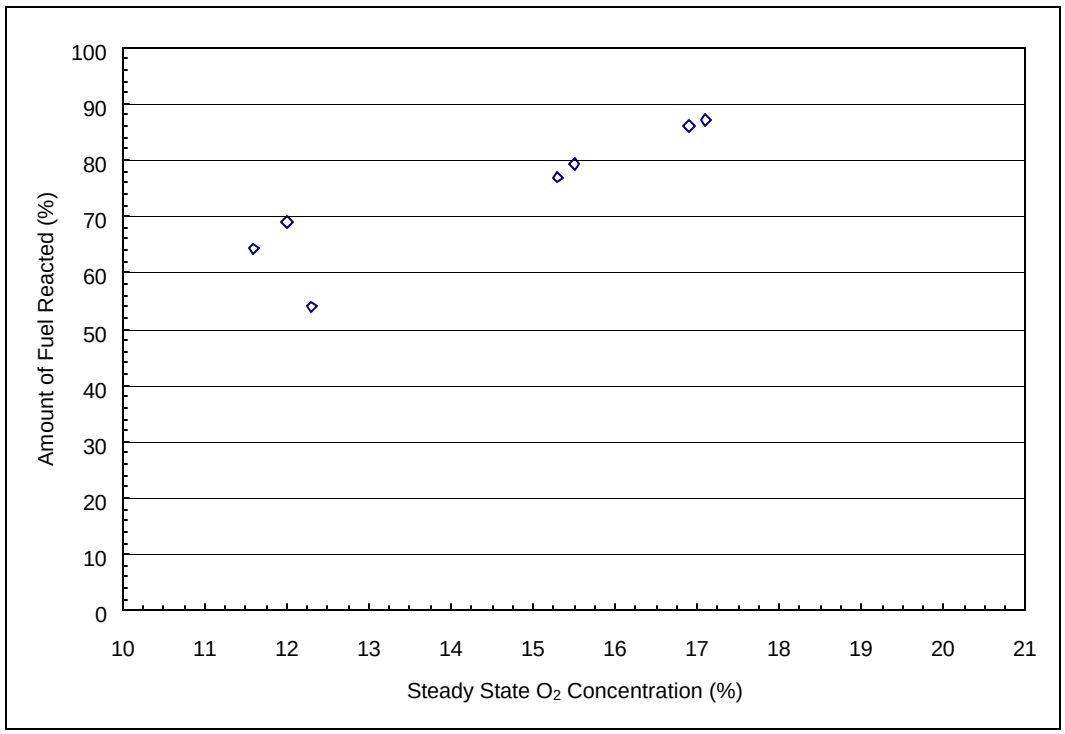

Figure 5. Amount of fuel that reacted as a function of the steady state O_2 concentration in the chamber.

Figure 6 illustrates how the CO generation rate of the catalytic heater varied as a function of the O_2 concentration in the chamber. The data shown is for all tests, which accounts for the scatter in the data. As the O_2 concentration decreased below approximately 17 percent O_2, the heater generated less CO. For all tests, the heater generated CO at rates up to 461 cc/hr. Below an O_2 concentration of approximately 12 percent, the heater generated a negligible amount of CO. The catalytic heater generated CO at a rate that was different than the infrared radiant camp heaters. In general, the infrared radiant camp heaters produced CO more rapidly as the O_2 concentration was depleted below approximately 16 percent (Tucholski, 2002).

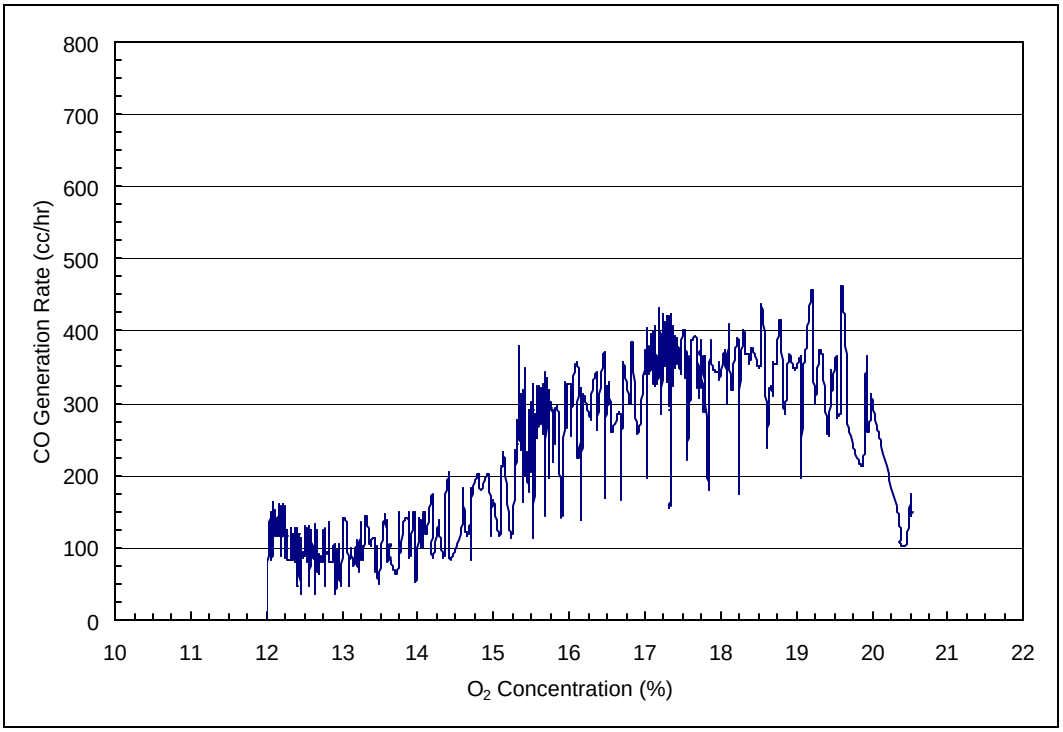

Figure 6. CO generation rate of the catalytic heater as a function of the O_2 concentration in the chamber.

Long Term Testing

Long term testing of two identical heaters (Heater 1 and Heater 2) was conducted to determine whether the catalyst degraded over time, thereby affecting the CO emissions from the heater. Each heater was operated on a total of 100 disposable 1-pound bottles of propane. On average, the heaters operated for approximately 6.5 hours per bottle. Therefore, each heater was operated for approximately 650 hours. At every 20th bottle (~130 hours), each heater was placed in the test chamber and an emissions test was preformed at an air exchange rate of 0.5 ACH. A summary of the data is provided in Table A4.

Figure 7 illustrates the steady state CO concentration obtained in the test chamber for every 20th test with Heater 1 and Heater 2. Although there was a slight variance in the CO concentration between tests (maximum ΔCO = 15 ppm), it does not appear that the catalyst degraded over time.

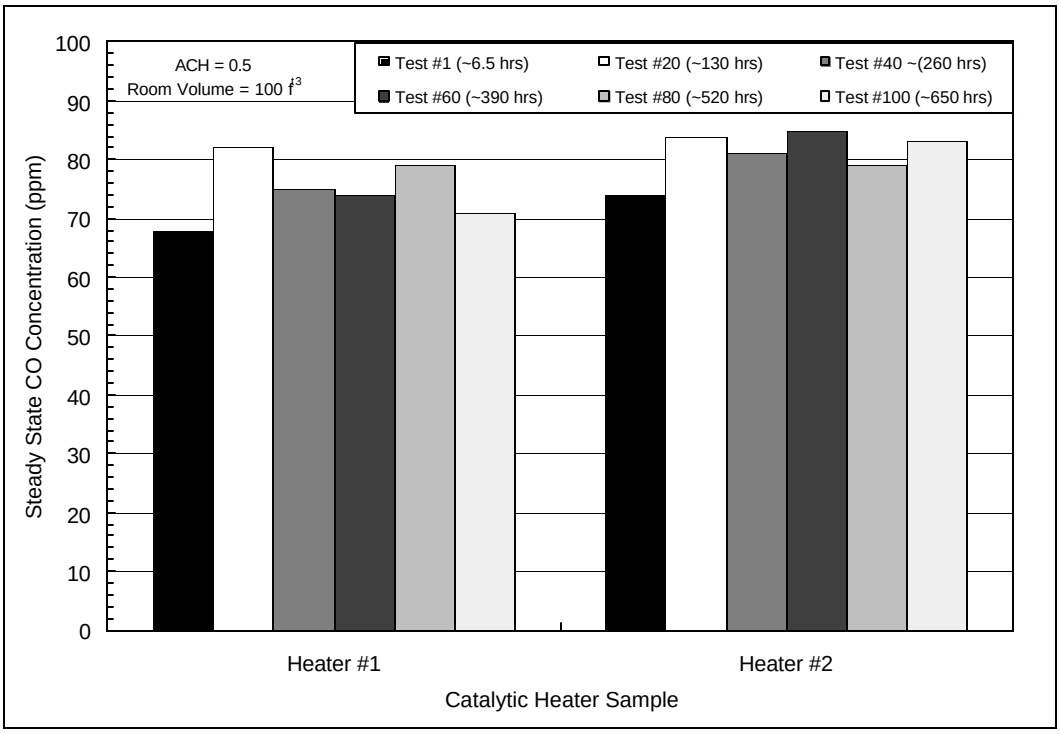

Figure 7. Steady state CO concentrations obtained in the test chamber for Heaters 1 and 2 during the long term testing of the heaters.

DISCUSSION

In 2001, CPSC staff began a project to document the CO emissions from currently available camp heaters to determine if the heaters complied with the combustion requirements in the voluntary standard for portable type gas camp heaters (ANSI Z21.63). The standard was revised in April 2000 to address the potential CO poisoning hazard that can result when gas-fired heaters are operated in small enclosed areas that are poorly ventilated, such as a tent. Although ANSI Z21.63 only applies to infrared radiant heaters, a catalytic heater was included as part of the project since the catalytic heater was being marketed for use inside tents. The applicable voluntary standard for catalytic camp heaters is ANSI Z21.62. The standard was withdrawn in 1992, but a new standard is currently being written. Table 2 provides a summary of the combustion test specified in each standard.

Table 2. Summary of the combustion tests specified in ANSI Z21.62 (draft) and ANSI Z21.63 (2000)

	ANSI Z21.62 (draft) Portable Catalytic Camp Heater	ANSI Z21.63 (2000) Portable Gas Fired Camp Heaters
Room Volume	Not Specified	100 ft^3
Air Exchange Rate	0 ACH	0.5, 1.0, 1.5 ACH
Length of Test	Until specific O_2 concentration reached	Until flame extinguishes or equilibrium reached
CO	≤ 35 ppm at 19.4 percent O_2 ≤ 250 ppm at 15.1 percent O_2	≤ 100 ppm throughout the test
O_2	No Requirement	≥ 16 percent throughout the test
Hydrocarbons	≤ 500 ppm at 19.4 percent O_2	No Requirement

CO Emissions

When the catalytic heater was operated at the test conditions specified in the standard for infrared radiant camp heaters (ANSI Z21.63), the steady state CO concentration ranged from 67 ppm to 109 ppm. Steady state was achieved in approximately 2 to 6 hours, depending on the air exchange rate. Since the CO concentration in the chamber exceeded 100 ppm during several of the tests, the catalytic heater would not comply with the CO requirement ANSI Z21.63 (2000). Assuming a limited exposure time of up to 6.5 hours at these CO concentrations, the catalytic heater does not appear to pose a serious CO hazard to healthy adults when the CO concentration is considered by itself. When the CO emissions from the catalytic camp heater are compared to those of a typical radiant camp heater, the catalytic heater generated much less CO (Tucholski, 2002).

Unlike the standard for infrared radiant camp heaters that limits the CO concentration to 100 ppm throughout the entire test, the current draft of the voluntary standard for portable catalytic camp heaters (ANSI Z21.62-draft) only limits the CO concentration at two specific O_2 concentrations. At an O_2 concentration of 19.4 percent, the CO concentration cannot exceed 35 ppm, and at an O_2 concentration of 15.1 percent, the CO cannot exceed 250 ppm. When the catalytic heater was tested in a closed room (ACH ~ 0), the CO concentration in the chamber ranged from 24 ppm to 27 ppm at an O_2 concentration of 19.4 percent. During the same tests, the CO concentrations ranged from 101 ppm to 110 ppm at an O_2 concentration of 15.1 percent.

Although the catalytic heater would meet the CO emission requirement being proposed in the new standard for catalytic camp heaters, CPSC staff does not agree with allowing the CO concentration to reach 250 ppm in a closed room. Sustained exposure to a CO concentration of 250 ppm for 6 to 7 hours could pose a serious CO hazard to healthy adults. Depending on an exposed individual's activity level, this could result in carboxyhemoglobin levels ranging from 24 to 29 percent, where severe headache, nausea, vomiting and mental confusion could be expected.[1] Instead, CPSC staff recommends that the CO concentration be limited to 100 ppm, the same limit as that specified in the standard for infrared radiant camp heaters. Camping heaters that meet the CO emissions requirement in ANSI Z21.63 (2000) should not pose a CO poisoning threat to healthy consumers when the heaters are brought into enclosed spaces.

O_2 Depletion

Catalytic heaters consume oxygen during the reaction to generate heat and therefore will deplete the oxygen in a small, poorly ventilated room. This point is better illustrated by Figure 8, which shows how the steady state oxygen concentration in a room is a function of the energy-input rate of the heater and the air exchange rate through the room. Figure 8 was constructed from a simple mass balance of O_2 in a 100 ft^3 room, assuming an ambient and initial O_2 concentration of 20.9 percent. It was also assumed that the propane heater consumed O_2 at a constant rate of 2 ft^3/hr for every 1000 Btu/hr of propane burned.[2] Figure 8 illustrates that for a constant energy-input rate, the steady state O_2 concentration in the room decreases as the air exchange rate decreases.

[1] Personal communication from Sandra E. Inkster, CPSC, Directorate for Health Sciences.

[2] This assumes that 5 ft^3 of oxygen is consumed for 1 ft^3 of propane gas and the heating value of propane is 2,500 Btu/ft^3. Therefore, (5 ft^3 O_2/1 ft^3 C_3H_8)(ft^3 C_3H_8/2,500 Btu)(1,000 Btu/hr) = 2 ft^3 O_2/hr for every 1000 Btu/hr of propane gas burned.

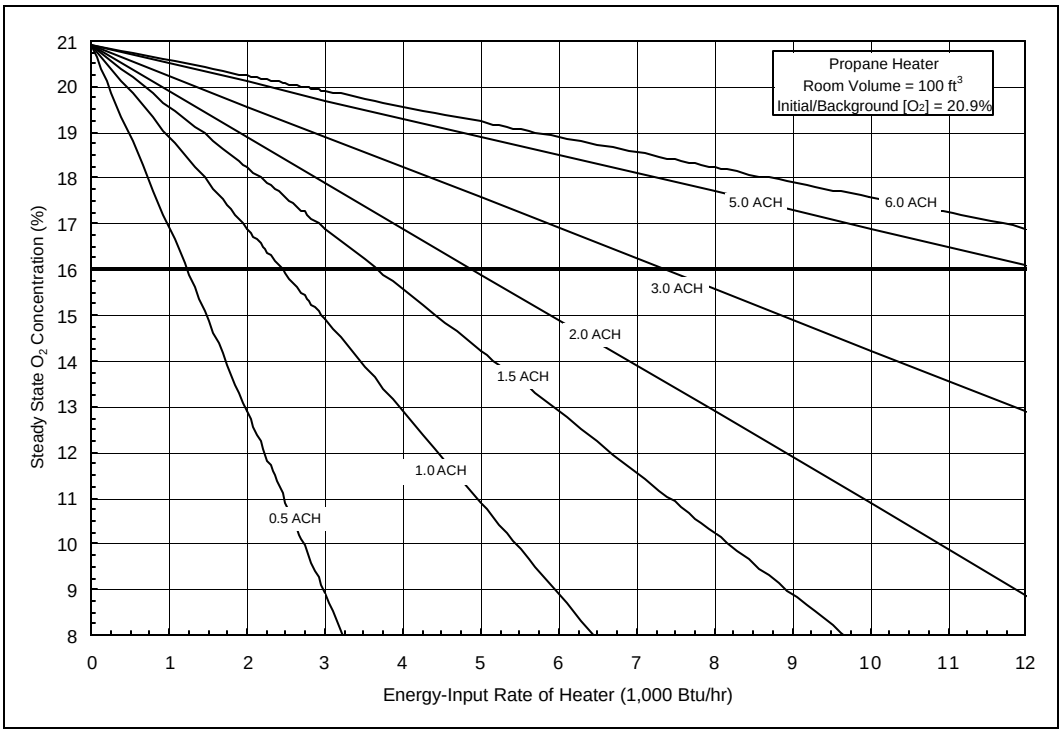

Figure 8. Predicted steady state O_2 concentrations in a 100 ft^3 room as a function of the energy-input rate of a propane heater and the air exchange rate of the room.

Unlike infrared radiant heaters that generate a flame during the combustion process and require a certain oxygen concentration to sustain the flame, the catalytic heaters have no flame and can operate at reduced oxygen levels. The flame on a typical infrared radiant heater self-extinguishes when the O_2 concentration is depleted below approximately 14 percent (Tucholski, 2002). Tests with the catalytic heater at low air exchange rates showed that the catalytic heater was capable of operating at much lower O_2 concentrations. During the closed room test, the O_2 concentration was depleted to 8.8 percent. The test was terminated early due to the build-up of hydrocarbons in the chamber. When the test was terminated, the oxygen concentration was still decreasing.

Catalytic heaters are being marketed as safe for indoor use. Because the catalytic heaters can deplete the O_2 concentration to low levels, CPSC staff is concerned with the possible health effects from reduced oxygen concentrations. Table 3 summaries the health effects associated with reduced oxygen concentrations. The degree of hypoxia is further exacerbated by the moderate CO concentration and by an increase in the carbon dioxide concentration that accompanied the depletion of oxygen (see Table A1).

Table 3. Reduced oxygen concentrations and health effects (adapted from Burton, 1996)

Oxygen Concentration (%)	Symptoms
20.9	Normal concentration in the air at sea level
12 - 16	Breathing and pulse rate increased, muscular coordination slightly disturbed
10 – 14	Emotional upsets, abnormal fatigue upon exertion, impaired respiration
6 – 10	Nausea and vomiting, inability to move freely, loss of consciousness may occur; may collapse and although aware of circumstances be unable to move or cry out
< 6	Convulsive movements, gasping respiration; respiration stops and a few minutes later heart action ceases

The current draft of the standard for portable catalytic camp heaters (ANSI Z21.62-draft) does not address the issue of oxygen depletion. CPSC staff recommends that the catalytic camp heaters meet the same requirement for O_2 depletion as the requirement for infrared radiant camp heaters (i.e., $O_2 \geq 16$ percent in a 100 ft^3 room at air exchange rates of 0.5, 1.0, and 1.5 ACH). Camping heaters that meet the O_2 depletion requirement in ANSI Z21.63 (2000) should not pose a health risk to healthy consumers when the heaters are brought into enclosed spaces.

For the three air exchange rates specified in ANSI Z21.63 (i.e., 0.5, 1.0 and 1.5 ACH), Table 4 lists the maximum energy-input rate that a propane heater can operate at without depleting the O_2 concentration below 16 percent. At the minimum air exchange rate of 0.5 ACH, a propane heater can operate at a maximum energy-input rate of 1,220 Btu/hr without depleting the O_2 concentration below 16 percent in a 100 ft^3 room.

Table 4. Calculated energy-input rate that a propane heater can operate at without depleting the O_2 concentration below 16 percent in a 100 ft^3 room.

Air Exchange Rate (air changes per hour)	Energy-Input Rate (Btu/hr)
0.5	1,220
1.0	2,450
1.5	3,700

If the catalytic heater is to operate at an energy-input rate greater than 1,220 Btu/hr, but not deplete the O_2 concentration below 16 percent, then the heater must incorporate some mechanism to shut the heater off when the O_2 concentration starts to be depleted. One such mechanism is an Oxygen Depletion Sensor (ODS). An ODS consists of a thermocouple, a pilot flame, and a solenoid gas valve. The pilot flame is used to heat the thermocouple, which then generates a current, sufficient enough to keep the solenoid gas valve open. When the oxygen level drops below 18 percent, the pilot flame self-extinguishes, causing the thermocouple to cool and the gas valve to close. Some manufacturers of infrared radiant heaters have incorporated an ODS on their heaters (Tucholski, 2002). CPSC staff is also aware of one catalytic heater manufacturer that incorporates an ODS on high-end catalytic heaters designed for use indoors, such as in mobile homes, cabins, and boats.

Hydrocarbon Emissions

As the O_2 concentration decreased in the chamber, the catalytic reaction became less effective, allowing more of the propane to pass through the heater unreacted. For all tests, the hydrocarbon concentration at the end of the test ranged from 1,050 ppm to 13,440 ppm (5 to 64 percent of the LEL of propane gas in air).

The current standard for portable infrared camp heaters (ANSI Z21.63) does not address the issue of hydrocarbon emissions. However, the standard currently being proposed for portable catalytic camp heaters (ANSI Z21.62-draft) does limit the hydrocarbon emission to 500 ppm when the O_2 concentration has been reduced to 19.4 percent in a room with no air changes. For both tests with no air changes, the hydrocarbon concentration was approximately 210 ppm (1 percent LEL) at an O_2 concentration of 19.4 percent.

Although Heater 1 would meet the hydrocarbon emission requirement currently being proposed in the new standard for catalytic heaters, the proposed standard does not address hydrocarbon emissions at lower O_2 concentrations. During the closed room tests, the hydrocarbon concentration reached 13,440 ppm (64 percent LEL) prior to the test being terminated. Therefore, the proposed standard for catalytic camp heaters does not adequately protect the consumer from high emissions of hydrocarbons. The

unreacted propane further acts to increase the degree of hypoxia experienced by an individual. To address this issue, CPSC staff recommends limiting the hydrocarbon emissions from catalytic camp heaters to 500 ppm throughout the entire test when the catalytic heater is tested in a 100 ft^3 room at air exchange rates of 0.5, 1.0 and 1.5 ACH.

Long Term Testing

Long term testing of two identical heaters was conducted to determine whether the heater's catalyst degraded over time, thereby affecting the CO emissions from the heater. Each heater was operated on a total of 100 disposable 1-pound bottles of propane, which was equivalent to approximately 650 hours of use. Based on the CO concentrations obtained during the chamber tests, which occurred every 20^{th} bottle (~130 hrs), the catalyst did not appear to degrade overtime. The current draft of the standard for catalytic camp heaters (ANS Z21.62) specifies that the combustion test is to be repeated after operating the heater for 100 hours. CPSC staff recommends that this portion of the combustion test be retained in the standard.

CONCLUSIONS

CPSC staff tested a catalytic heater as part of a project to document the CO emissions from currently available camp heaters in order to determine if the heaters complied with the combustion requirements in the voluntary standard *Portable Type Gas Camp Heaters* (ANSI Z21.63-2000). Although the catalytic heater is not within the scope of ANSI Z21.63, it was included as part of the project since the catalytic heater was being marketed for use inside tents and other indoor areas. The voluntary standard applicable for catalytic camp heaters is ANSI Z21.62, but the standard was withdrawn in 1992. A new standard is currently being written for catalytic camp heaters.

Although both ANSI Z21.62 (draft) and ANSI Z21.63 (2000) are for camp heaters (e.g., small portable heaters that typically use a disposable 1-pound bottle of propane), the two standards have different combustion requirements. ANSI Z21.62 (draft) limits the CO and hydrocarbon emissions at specific O_2 concentrations, but does not limit the depletion of O_2. ANSI Z21.63 (2000) limits the CO emissions and O_2 depletion throughout the entire test.

The following is a summary of CPSC staff's findings on the testing of the catalytic heater:

- The peak CO concentration ranged from 68 ppm to 125 ppm and the steady state CO concentration ranged from 67 ppm to 109 ppm. Assuming a limited exposure time of up to 6.5 hours at these CO concentrations, the catalytic heater does not appear to pose a serious CO hazard to healthy adults when the CO concentration is considered by itself.
- When the catalytic heater was operated in a closed room (ACH ~ 0), the oxygen was depleted from an ambient concentration of 20.9 percent to 8.8 percent. Because the catalytic heater can deplete the O_2 concentration to such low levels, the heater poses a serious risk of hypoxia. The degree of hypoxia is further exacerbated by the moderate CO concentration and by an increase in the carbon dioxide concentration that accompanied the depletion of oxygen.
- As the oxygen decreased in the chamber, the catalytic heater became less effective at converting the propane and oxygen to carbon dioxide and water vapor. This was reflected by an increase in the hydrocarbon concentration in the chamber, which ranged from 1,050 ppm to 13,440 ppm (5 to 64 percent of the lower explosion limit of propane in air). The unreacted propane further increases the degree of hypoxia.
- The heater's catalyst did not appear to degrade over time. This observation is based on operating two identical heaters on 100 disposable 1-pound bottles of propane (approximately 650 hours).

Emission tests were performed on each heater after every 20th bottle of propane (approximately every 130 hours).

- The catalytic heater did comply with the combustion requirements currently specified in the draft version of the standard for catalytic camp heaters (ANSI Z21.62).
- The catalytic heater did not comply with the combustion requirements specified in the standard for infrared radiant camp heaters (ANSI Z21.63-2000). The heater depleted the O_2 concentration below 16 percent in the test chamber and also exceeded the 100 ppm limit for CO in the test chamber.

Based on these test results, CPSC staff plans to recommend the following to the *CSA/Z21 Joint Technical Advisory Group (TAG) on Refrigerators and Portable Camping Equipment*:

1. Replace the combustion requirements currently being proposed in ANSI Z21.62 with the same combustion requirements specified in ANSI Z21.63 (i.e., CO ≤ 100 ppm and O_2 ≥ 16 percent when the heater is operated in a 100 ft^3 room at air exchange rates of 0.5, 1.0, and 1.5 ACH). Since the catalytic camp heaters can be used in the same environments as those in which the infrared radiant camp heaters are used, the catalytic camp heaters should meet the same requirements for CO emissions and O_2 depletion as those specified for infrared radiant camp heaters.
2. Limit the emissions of hydrocarbons (in the form of propane) to 500 ppm, when the catalytic heater is tested in a 100 ft^3 room at air exchange rates of 0.5, 1.0, 1.5 ACH. The current draft proposal of ANSI Z21.62 only checks the hydrocarbon emissions at an O_2 concentration of 19.4 percent during a closed room test.
3. Keep the requirement currently specified in the draft proposal of ANSI Z21.62 to retest the catalytic heater after operating the heater for 100 hours.

ACKNOWLEDGMENTS

The following individuals contributed to the overall project: Chris Brown, Ron Reichel, Richard Schenck, Scott Snyder, and John Worthington.

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APPENDIX A. SUMMARY OF TEST DATA

Table A1 – Summary of the emission tests of Heater 1.

Test #	Air Exchange Rate (1/hr)	Energy - Input Rate (Btu/hr)	Maximum CO (ppm)	Steady State CO_{ss} (ppm)	Minimum O_2 (%)	Maximum CO_2 (%)	Maximum HC		Time Heater Shut Off (hr)	Reason Heater Shut Off[1]	CO Generation Rate (cc/hr)		
							(% LEL)	(ppm)			Max	Min	Avg
4	0.10	3,140	114	77	8.8	7.9	62	13,020	3.68	LEL	347	65	205
8	0.10	3,250	125	87	9.0	7.9	64	13,440	3.60	LEL	351	35	208
9	0.43	3,230	114	96	12.0	5.8	44	9,240	6.62	EB	355	82	155
1	0.46	3,160	68	67	12.3	5.5	60	12,600	6.67	EB	255	46	103
5	0.47	3,250	113	97	11.6	5.8	47	9,870	6.90	EB	378	65	164
6	0.90	3,270	116	109	15.3	3.5	16	3,360	5.35	SS	461	144	308
2	0.98	3,240	106	105	15.5	3.4	13	2,730	6.65	EB	348	144	289
7	1.44	3,250	92	92	16.9	2.4	6	1,260	3.52	SS	410	144	364
3	1.54	3,140	90	90	17.1	2.3	5	1,050	6.65	EB	424	149	375

Note LEL = LEL of propane gas > 50 % in chamber, EB = Empty Bottle of propane, SS = Steady State of CO, CO_2, and O_2 Achieved

Table A2. Comparison of the test data to the combustion requirements in the standard for infrared radiant camp heaters (ANSI Z21.63-2000)

Test #	Air Exchange Rate (1/hr)		Energy -Input Rate (Btu/hr)	Maximum CO (ppm)	Minimum O_2 (%)	Pass/Fail ANSI Z21.63-2000	Time CO Reached 100 ppm (hrs)	Time O_2 Depleted to 16% (hrs)
	Target	Actual						
9	0.5	0.43	3,230	114	12.0	Fail	1.14	1.19
1	0.5	0.46	3,160	68	12.3	Fail	N/A	1.15
5	0.5	0.47	3,250	113	11.6	Fail	1.20	1.13
6	1.0	0.90	3,270	116	15.3	Fail	1.20	1.82
2	1.0	0.98	3,240	106	15.5	Fail	3.92	2.12
7	1.5	1.44	3,250	92	16.9	Pass	N/A	N/A
3	1.5	1.54	3,140	90	17.1	Pass	N/A	N/A

Table A3. Comparison of the test data to the combustion requirements in the proposed standard for catalytic camp heaters (ANSI Z21.62-draft)

Test #	Air Exchange Rate (1/hr)		Energy-Input Rate (Btu/hr)	CO at 19.4% O_2 (ppm)	CO at 19.4% O_2 (ppm)	HC at 19.4% O_2		Time O_2 Depleted to 19.4% (hrs)	Time O_2 Depleted to 15.1% (min)	Pass/Fail ANSI Z21.62-draft
	Target	Actual				(%LEL)	(ppm)			
4	0	0.10	3,140	24	101	1	210	0.27	1.17	Pass
8	0	0.10	3,250	27	110	1	210	0.27	1.17	Pass

Table A4 – Summary of the extended test of Heater 1 and Heater 2.

Test Sample	Test Number	Air Exchange Rate (1/hr)	Energy-Input Rate (Btu/hr)	Maximum CO (ppm)	Steady State CO (ppm)	Minimum O_2 (%)	Maximum CO_2 (%)	Maximum HC (% LEL)	Time Heater Shut Off (hr)	CO Generation Rate (cc/hr)		
										Max	Min	Avg
1	1	0.46	3,140	68	67	12.3	5.5	60	6.67	255	46	103
	20	0.53	3,370	82	82	12.9	5.3	38	6.25	297	80	151
	40	0.53	3,270	75	75	12.9	5.4	35	6.52	213	66	128
	60	0.54	3,350	74	74	12.8	5.4	40	6.35	231	69	133
	80	0.56	3,340	79	79	13.1	5.2	34	6.47	224	76	139
	100	0.54	3,250	71	71	12.8	5.4	35	6.50	159	59	113
2	1	0.42	3,330	74	73	11.3	5.9	47	6.43	176	46	103
	20	0.62	3,312	84	84	13.4	5.0	26	6.45	216	70	150
	40	0.53	3,312	81	81	12.6	5.6	37	6.42	192	71	132
	60	0.55	3,281	85	85	12.6	5.5	37	6.50	196	38	131
	80	0.50	3,234	79	79	12.3	5.6	37	6.63	188	66	119
	100	0.59	3,308	83	83	12.6	5.5	37	6.25	274	94	153