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Publication Date

1989

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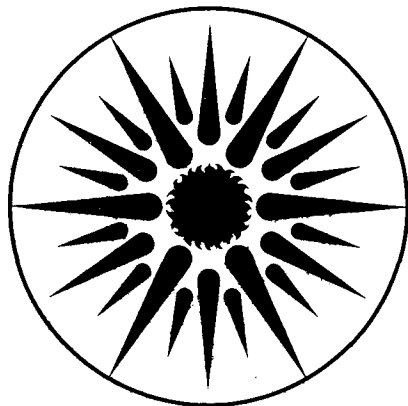
M.G. Apte and G.W. Traynor

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DISCLAIMER

POLLUTANT EMISSION RATES FROM A RADIANT FIBER-MATRIX UNVENTED GAS SPACE HEATER

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January 1989

ABSTRACT

A prototype unvented gas space heater (UVGSH) using a radiant fiber-matrix burner was operated in a 27 m³ (950 ft³) environmental chamber under two firing rates and at two different excess-air settings. Pollutant emission rates for carbon monoxide (CO), nitric oxide (NO), and nitrogen dioxide (NO_2) are reported. When compared to previously tested UVGSH's the radiant fiber-matrix burner was found to emit less CO and NO_2 per unit of fuel consumed.

INTRODUCTION

Results of previous studies (Apte and Traynor, 1986, Moschandreas et al.,1984, Leaderer, 1983) have shown that unvented space heaters can emit carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), nitrogen dioxide (NO_2), formaldehyde and respirable particles, while consuming oxygen. Recent advances in infrared radiant gas burner technology have led to the development of new burner designs for residential and commercial space heating appliances. In this report we present laboratory measurements of CO, NO, NO_2 and oxides of nitrogen (NO_x = NO + NO_2) reported as nitrogen [N(of NO_x)] emission rates from a prototype unvented gas space heater (UVGSH) using a radiant fiber-matrix burner.

EXPERIMENTAL

Heater. The prototype UVGSH consists of a radiant fiber-matrix gas burner built into a stainless steel heat exchanger with a forced-air blower. Different combustion conditions can be tested by changing the position of the air intake shutter, by adjusting the gas pressure at a fuel mixer valve, and by changing the orifice that helps control the total air/gas mixture supplied to the burner. The burner was operated with natural gas.

The heater emissions were measured under three different test conditions combining different burn rates, from approximately 20,000 and 32,000 kJ/h, and two different combustion air settings, nominally 10% and 40% excess air (see Table 1). Each test was run twice.

Facilities and Instrumentation. The testing facilities consisted of LBL's Mobile Atmo-
spheric Research Laboratory (MARL), an environmental chamber, and auxiliary
instrumentation (see Figure 1). The facilities were the same for all tests and were
described in more detail in a previous report (Girman *et al.* 1983). Important aspects are
summarized here.

The environmental chamber has a volume of 27 m³ (950 ft³) with a base air exchange
rate between 0.3 and 0.5 air changes per hour. The inside of the chamber is equipped with
six 10-cm (4-in) instrument fans to promote air mixing. Each fan has a maximum flow
rate of 60 m³/h (2100 ft³/h) and was positioned at least one meter from the heater to
avoid air drafts near the heaters. Use of the fans caused no visible disturbance of the
heater flame.

The real-time instruments for CO, CO_2, NO, NO_2, and O_2 were located inside the
MARL. Air was drawn into the MARL from the chamber via Teflon tubing and a
Teflon-lined pump. Temperature and humidity probes were located both inside the
chamber (out of the heater's plume) and outside the chamber.

Mass-Balance Model. A single-equation mass-balance model was used to calculate UVGSH
pollutant emission rates from laboratory data using a technique previously published
(Traynor *et al.*, 1982). This model has been used successfully to predict indoor air
pollution levels as well as to quantify indoor air quality parameters that can affect such
levels. The model is repeated here for completeness.

The mathematical expression for a change in the average indoor gaseous pollutant
concentration of a whole house follows.

$$dC = PaC_o dt + \frac{S}{V}dt - (a+k)Cdt \qquad (1)$$

where

C = indoor pollutant concentration (ppm)

P = Fraction of the outdoor pollutant level that penetrates the building shell (unitless)

a = air exchange rate (h^{-1})

C_o = outdoor pollutant concentration (ppm)

t = time

S = indoor pollutant source strength (cm^3/h)

V = volume (m^3)

k = net rate of removal processes other than air exchange (h^{-1})

The air exchange rate, a, is calculated from the decay in pollutant concentrations after the source is turned off (i.e., S = 0). Assuming C_o, P, a, S, and k are constant over the period of interest, Equation 1 can be solved for C(t), the chamber pollutant concentration at time t.

$$C(t) = \frac{PaC_o + S/V}{a+k}\left[1 - e^{-(a+k)t}\right] + C(0)e^{-(a+k)t} \qquad (2)$$

Equation 2 describes the spatial average concentration of a pollutant in an enclosed space of a given volume.

Solving Equation 2 for S, dividing it by the fuel consumption rate, R (kJ/h), and letting T equal the duration of appliance operation, we can obtain the emission rate, E cm^3/kJ.

$$E = \frac{S}{R} = \frac{V}{R}(a+k)\frac{C(T) - C(0)e^{-(a+k)T}}{1 - e^{-(a+k)T}} - \frac{VPaC_o}{R} \qquad (3)$$

The emission rate, E, in cm^3/kJ, has been converted to $\mu g/kJ$ by using the ideal gas law and the time-weighted average temperature and pressure in the chamber. Note that Equation. 3 relies on the final average indoor pollutant concentration, C(T). The use of

mixing fans increases the accuracy and precision of the C(T) measurement. To further increase the accuracy of the emission rates, they were normalized by the ratio of the theoretical CO_2 emission rate to the measured CO_2 emission rate. (The theoretical CO_2 emission rate for natural gas is approximately 51,000 μ g/kJ.

<u>Heater</u> <u>Testing</u> <u>Protocol</u>. Pollutant emission rates from the heaters were measured during a single burn period. It was assumed that since the fiber-matrix burner reaches a steady-state temperature within a few minutes that the emission rates measured during the single burn would represent steady-state emissions. The heater was lit outdoors and after about 10 minutes, the stack O_2 concentration was recorded. After the heater had warmed up for fifteen minutes, it was rolled indoors and into the environmental chamber and operated until approximately 5500 kJ (5220 Btu) of fuel was consumed. The heater was then remotely turned off, and the chamber pollutants were monitored for a one-hour period. Pollutant concentrations outside the chamber were monitored before ignition of the heaters and at the end of the decay period.

RESULTS AND DISCUSSION

Table 1 presents the measured emission rates of CO, NO, NO_2 and N(of NO_x), the measured fuel consumption rate, and the before-test stack O_2 concentration for all three test conditions.

The CO emission rates were low and varied considerably between replicate tests as well as between test conditions. The mean CO emission rate was 2.9 μ g/kJ for the 10% excess air tests and 7.4 μ g/kJ for the 40% excess air tests, however this difference is not significant at the 90% confidence level. These rates can be compared to those of several typical unvented gas and kerosene space heaters shown in Figure 2 (Apte and Traynor, 1986).

The NO emission rates were the lowest at the 40% excess air setting with an average value of 1.1 μ g/kJ. They were highest at the 24,000 kJ/h and 10% excess air setting, with

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a mean emission rate of 6.5 μ g/kJ. These rates tend to be higher than those measured from five other natural gas and propane fueled infrared heaters tested which had an average of 0.3   0.3 μ g/kJ (Apte and Traynor, 1986).

NO_2 emissions were quite low for all three test combinations, with the lowest average emission rate of 0.7 μ g/kJ occurring when the heater was operated at 31,500 kJ/h with 10% excess air. The emission rates averaged near 2.0 μ g/kJ in both of the other test combinations. These NO_2 emission rates can also be compared to those of several typical unvented gas and kerosene heaters shown in Figure 2 (Apte and Traynor, 1986).

Average N(of NO_x) emissions ranged from a low of 1.1 μ g/kJ from the 20,900 kJ/h and 40% excess air tests to a high of 3.2 μ g/kJ from the 31,500 kJ/h 10% excess air tests. The N(of NO_x) emissions from infrared gas heaters and radiant kerosene heaters reported by Apte and Traynor (1986) are similar to those seen in these tests.

Although the test data are insufficient to make strong conclusions, the emission rates of the 40% excess-air tests appear different than the rates of the 10% excess-air tests. CO emissions are slightly higher and NO and N(of NO_x) emissions are slightly lower in the 40% excess air-tests. A probable explanation for this is the cooling effect of the increased excess air.

An interesting observation was made during the 10% excess air tests. After the heater was rolled into the environmental test chamber, the chamber CO concentration would rise at a very slow rate, then, several minutes later, it started to rise rapidly. It is probable that, as the oxygen level is depleted in the chamber during the test, the amount of incomplete CO-producing combustion increased. The CO started its rapid rate of increase at an approximate oxygen concentration of 20.3%, or about 0.7% lower than atmospheric oxygen. In these tests, the CO emissions were so low that this phenomenon was not an important factor. However, in an environment where less O_2 were available or where the burner was tuned to a lower excess air setting, the CO emissions might become significant. It may be important to design the heaters to operate with sufficient excess air under all potential operating conditions.

CONCLUSIONS

The test results for the prototype UVGSH using a radiant fiber-matrix burner show reduced CO and NO_2 emissions when compared to the unvented heating appliances currently available. NO emissions were somewhat higher than those of other radiant/infrared heaters and N(of NO_x) emissions were similar to such heaters. Unvented appliances are popular because of their high end-use efficiency; however, the unvented design means a compromise in indoor air quality. If they must be used, reduced CO and NO_2 emissions are an attractive feature. However, it is important to keep the design improvements and CO and NO_2 emissions reduction in perspective since these heaters share the same fundamental limitations of high carbon dioxide emissions, moisture emissions, and oxygen depletion as other unvented space heaters.
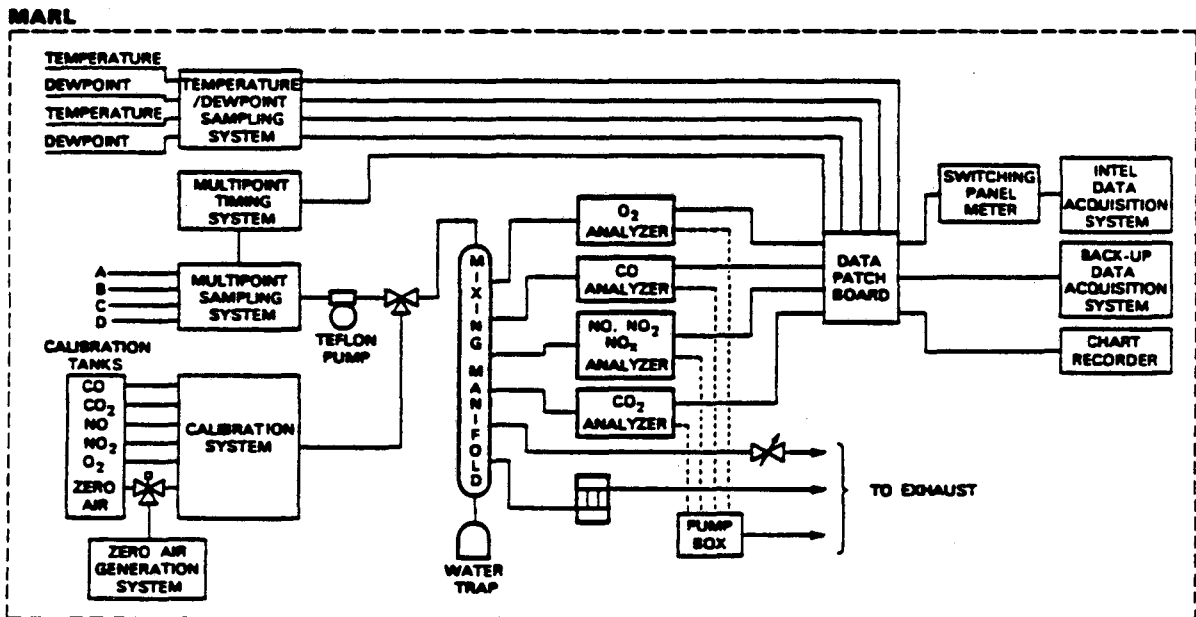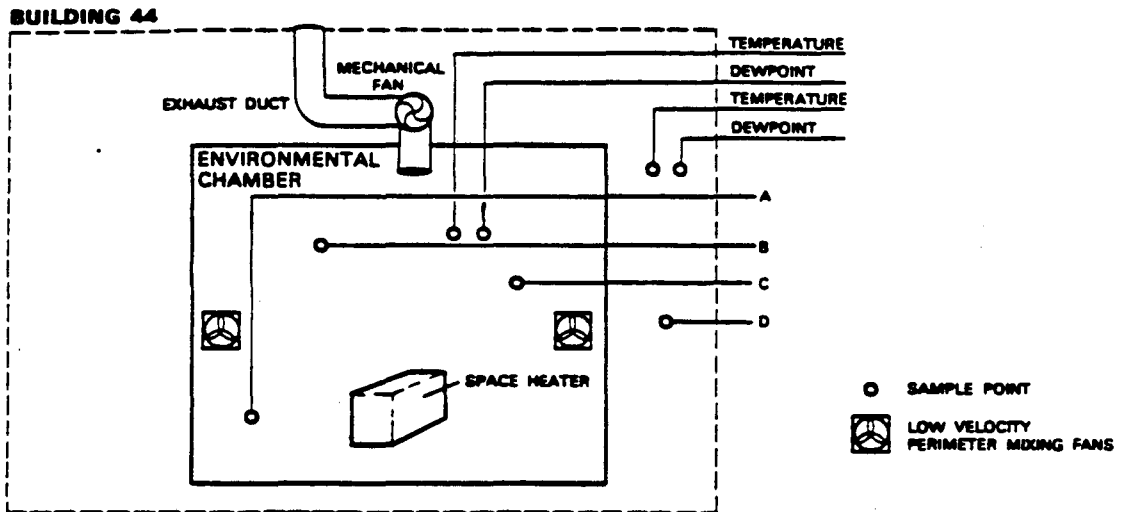
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TABLE 1.
Results from Testing of Prototype Radiant Fiber-Matrix UVGSH

Test Type	Fuel Consumption Rate (kJ/h)	Nominal Excess Air (%)	Measured O_2 (%)	Measured Excess Air (%)	Pollutant Emission Rates			
					CO ($\mu g/kJ$)	NO ($\mu g/kJ$)	NO_2 ($\mu g/kJ$)	N (of NO_x) ($\mu g/kJ$)
1a	31300	10	1.9	8	1.8	6.2	1.0	3.1
1b	31600	10	1.9	8	4.2	6.8	0.4	3.3
avg.=	31500	10	1.9	8	3.0	6.5	0.7	3.2
2a	20000	40	6.8	42	11.2	0.6	2.1	0.9
2b	21800	40	6.2	37	3.5	1.5	1.8	1.2
avg.=	20900	40	6.5	39	7.3	1.1	2.0	1.1
3a	24000	10	2.6	12	1.5	4.0	1.7	2.4
3b	24000	10	2.6	12	4.0	4.0	2.1	2.5
avg.=	24000	10	2.6	12	2.8	4.0	1.9	2.5

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Figure 1.   Schematic of environmental chamber and Mobile Atmospheric Research
Laboratory (MARL).
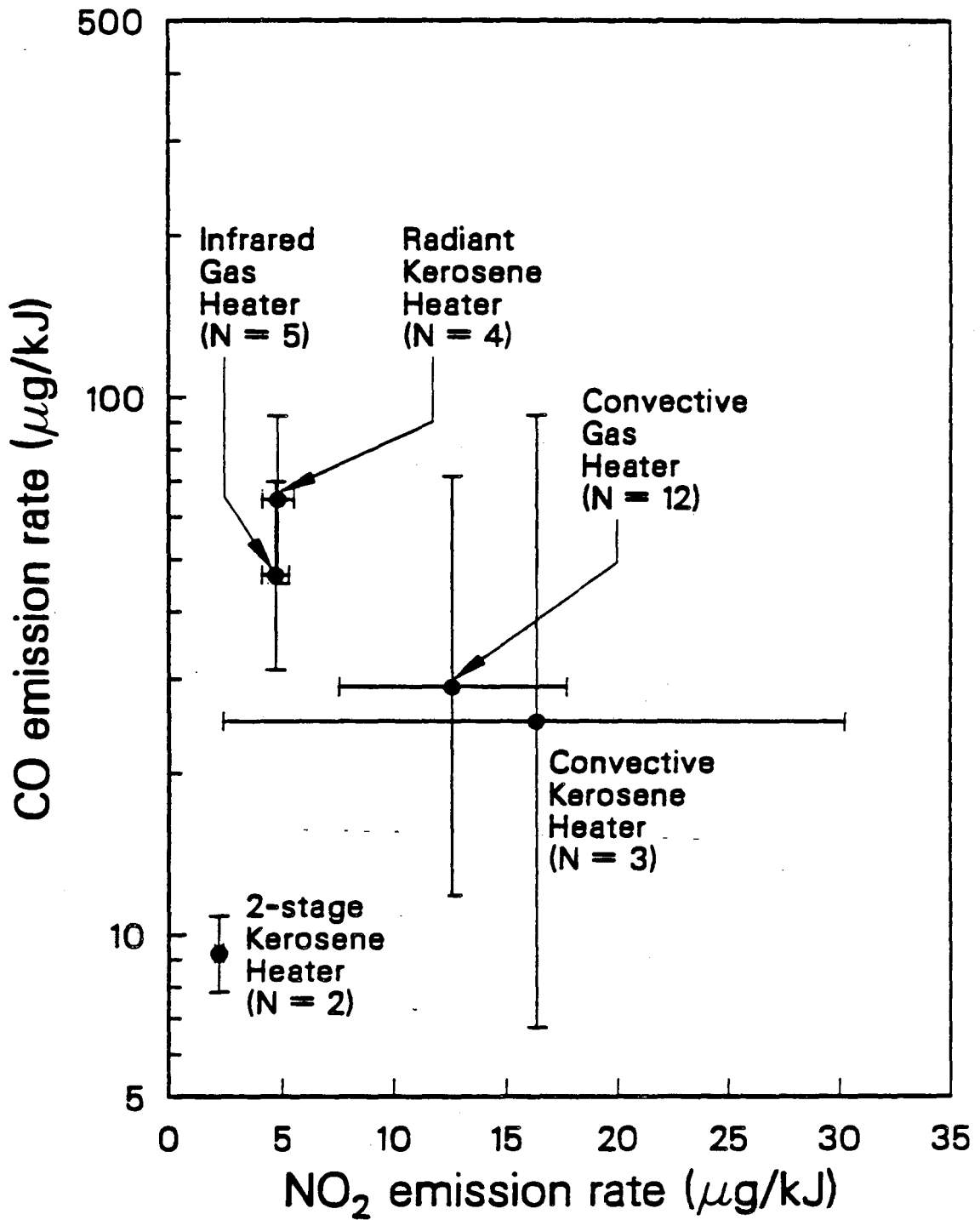
Figure 2. Emission rates (NO₂ vs. CO) from convective and infrared unvented gas space heaters and convective, radiant, and two-stage heaters.

XCG 864-7207

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