



## *Project Summary*

# Environmental Assessment of a Low-Emission Oil-Fired Residential Hot Water Condensing Heating System

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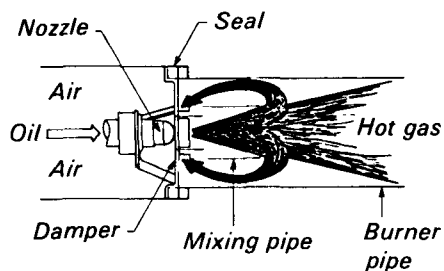
The report gives results of tests to evaluate multimedia emissions from a condensing hot water residential heating system equipped with a low-emission oil-fired burner manufactured by Maschinenfabrick Augsburg-Nurnberg (M.A.N.) of West Germany. Tests included continuous monitors for flue gas criteria pollutant emissions and laboratory analysis of samples utilizing gas chromatography (GC), infrared spectrometry (IR), liquid chromatography (LC), and gas chromatography/mass spectrometry (GC/MS) for organics; and spark source mass spectrometry (SSMS), atomic absorption spectrometry (AAS), and ion chromatography (IC) for trace metals and anions. Flue gas concentrations of  $\text{NO}_x$ ,  $\text{SO}_2$ , and CO averaged 76, 156, and 40 ppm, respectively, corrected to zero %  $\text{O}_2$ . Sulfate and copper were the primary pollutants in the tank water discharge, about 1,000 and 500 mg/l, respectively. Concentrations of copper and other trace metals in this water were attributed to leaching of heat transfer surfaces immersed in acidic ( $\text{pH} \approx 3.0$ ) water. Organic emissions measured 3.5 mg/dscm in the flue gas and <0.1 mg/l in the waste water. Biological tests indicated moderate mutagenic response of the flue gas and moderate toxicity of waste water to mammalian cells.

*This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).*

### Introduction

A number of low-emission, high-efficiency residential systems and burners have been developed recently. This report describes the results of extensive emissions testing of one of these units. The flue gas was analyzed for criteria pollutants as well as noncriteria organic and inorganic species. Since the unit was a condensing hot water heater, water tank composition was also determined.

The residential heater tested represents an innovative European design utilizing a condensing flue gas system and a high-efficiency low-emission burner. The burner, shown in Figure 1, is manufactured by Maschinenfabrick Augsburg-Nurnberg (M.A.N.) of West Germany. It utilizes a finely atomized distillate oil and recirculated hot combustion gases mixed with fresh air to complete combustion of the fuel in the burner pipe. The fuel oil can be pressurized to 2.1 MPa (about 300 psi) and is atomized by a 60° hollow-cone nozzle



**Figure 1.** M.A.N. residential oil-fired burner.

delivering about 0.53 ml/s (0.5 gal./hr). The combustion of the fuel in the mixing tube produces a stable blue flame. The recirculation of the combustion gases also causes NO<sub>x</sub> emissions to be 40-50% lower than those from a conventional high-pressure atomizing burner widely used for residential oil-fired furnaces. Because the M.A.N. burner recirculates the combustion gases internally within the burner pipe where combustion is completed, retrofit installation on existing residential heating systems is possible. Although other blue flame burner designs have been developed and implemented in the U.S., the retrofit capability of the M.A.N. design has made it attractive as a potential technique for reducing NO<sub>x</sub> emissions from existing residential units.

The firebox of the furnace is completely immersed in water. The water level reaches approximately 2 cm (less than 1 in.) below the top of three exhaust pipes. This water level is controlled by positioning the condensed water drain spout. Before the combustion products exit the furnace exhaust duct, they pass over the water surface and through a series of baffles and heat exchanger tubes. The cooling water, which absorbs heat from the furnace and carries it to the residence, enters through a heat exchanger tube near the top of the furnace and then flows through the immersed copper coils before it exits. Condensation of the water in the flue gas begins when cool water meets combustion products on their way out of the tank, condensing practically all the water produced by combustion of the fuel.

Condensing heating systems such as this can achieve thermal efficiencies exceeding 95% under normal cyclic operation. This high thermal recovery is a significant improvement over cyclic efficiencies of conventional residential heating systems, normally about 75-80%.

Tests were performed with the unit operating in a typical cyclic mode. Cycle frequency of the burner was controlled by adjusting the setting of the tank water thermostat and the cooling water flowrate. A thermostat setting of approximately 54°C (129°F) and a cooling water flowrate of 107 ml/s (1.7 gal/hr) resulted in burner cycle frequencies of 11-14 min on, 22-25 min off.

The sampling and analysis procedures used in this test program conformed to a modified EPA Level 1 protocol for the gas and liquid discharge streams. Flue gas measurements made at the exit of the furnace at about 1 m (3 ft) from the base of the uninsulated exhaust pipe included:

- Continuous monitors for NO, NO<sub>x</sub>, CO, CO<sub>2</sub>, O<sub>2</sub>, and total unburned hydrocarbons (TUHC).
- Source Assessment Sampling System (SASS) train sampling.
- EPA Method 5 for solid and condensable particulate mass emissions
- EPA Method 8 for SO<sub>2</sub> and SO<sub>3</sub>.
- Grab sample for onsite analysis of C<sub>1</sub> to C<sub>6</sub> hydrocarbons by gas chromatography.
- Bacharach smoke spot. The analysis protocol for SASS train samples included:
- Analyzing the filter catch, ashed XAD-2 resin, and the first impinger solution for 73 elements using spark source mass spectrometry (SSMS) and for Hg using cold-vapor atomic absorption spectrometry (AAS)
- Analyzing the second and third impinger solutions for As and Sb using furnace AAS techniques, and for Hg using cold-vapor AAS.
- Extracting the XAD-2 sorbent resin in a Soxhlet apparatus using methylene chloride, concentrating the extract to 10 ml, then determining the organic content of the extract in two boiling point ranges: 100-300°C by total chromatographable organics (TCO) analysis and >300°C by gravimetry.
- Further concentrating the extract to 1 ml and analyzing for the 58 semivolatile organic priority pollutants by gas chromatography/mass spectrometry

Water tank discharge samples collected were subjected to inorganic analysis by SSMS and AAS for Hg, As, and Sb; and to anion analysis for chloride, nitrate, and sulfate by ion chromatography.

They were also extracted with methylene chloride and subjected to the organic analysis protocol noted above.

The XAD-2 sorbent resin extract was also subjected to liquid chromatography separation into seven polarity fractions on silica gel to give compound category composition information. In addition, infrared spectra were obtained for the gravimetric residues of all extract samples (whole samples and liquid chromatography fractions).

The XAD-2 sorbent extract and the tank water discharge were subjected to mutagenicity and toxicity evaluation using the Level 1 Ames mutagenicity, CHO cytotoxicity, and the whole animal acute toxicity in rodent (RAT) bioassay tests.

## Summary and Conclusions

Table 1 lists flue gas emission levels of CO, CO<sub>2</sub>, NO, NO<sub>2</sub>, TUHC, particulate, SO<sub>x</sub>, and smoke in the flue gas measured during the period of firing. During the test there were peaks of CO and HC emissions at the start and end of burner-on times. The peak emissions at the start of each cycle are included in the reported emissions; however, the effects of burner shut-off were not included. Since the blower and the fuel pump were shut off at the same time, there was no forced air when the burner was shut off. Thus, the combustion air flowrate is unknown, and the CO and HC emissions at the end of the firing cycle cannot be evaluated.

Burner start-up peak emissions averaged 150 ppm for CO and 15 ppm for HCs. The NO started at zero and reached approximately 70 ppm on the average at 1.9% average excess O<sub>2</sub>. Smoke emissions measured with the Bacharach hand pump kit were zero during the entire burner-on period. NO emissions averaged 76 ppm at zero% O<sub>2</sub> over the duration of the test. This level is a 40% reduction from conventional residential heating systems burning distillate oil. Condensation of flue gas moisture apparently removed all NO<sub>2</sub> from the flue gas. Analysis to determine anions in the tank water and condensate drain collected during the test showed, in fact, that nitrates were absorbed in the water. Tank water nitrate levels reached 7 mg/l. The nitrogen content of the oil burned averaged 0.04%, making it a relatively high nitrogen distillate, leading to correspondingly high NO emissions.

Sulfur species (SO<sub>2</sub> and SO<sub>3</sub>) in the exhaust gas were analyzed by EPA Method 8. As expected, SO<sub>2</sub> was the

only sulfur species found in the exhaust gas. Both gaseous SO<sub>3</sub> and any condensed-phase sulfate were absorbed in the water, as indicated by the sulfate content of the tank water, which reached 990 mg/l. Chloride levels in the tank water reached 1.0 mg/l.

Bacharach smoke emissions were measured throughout the test program at various time intervals after fuel light-off. Smoke numbers were consistently zero throughout each firing period. The absence of smoke and relatively low CO emission peaks during burner light-off are attributable to the fuel oil delay valve of the M.A.N. burner which prevented ignition for approximately 15 sec after the blower started.

Table 2 shows results of the organic analysis of SASS samples by boiling point range: 100 to 300°C (TCO) and greater than 300°C (gravimetric). The flue gas results indicate that 74% of all the organic emissions were measured by TCO analysis of the XAD-2 extract. Still, total concentration of organic matter in the flue gas measured only 3.5 mg/dscm. The water analysis results indicate that some organic matter condensed in the water, however, the total concentration measured in the tank water discharge was less than 0.1 mg/l.

Infrared spectra of the gravimetric residue of the XAD-2 extract and the tank water discharge extract suggested the presence of aliphatic hydrocarbons and oxygenated species (carboxylic acids, esters, aldehydes, alcohols, etc.).

The XAD-2 extract was subjected to liquid chromatography separation. Results of this fractionation combined with infrared analysis of the gravimetric residue of sample fractions suggested that, of the 3.5 mg/dscm of organics emitted by the furnace, about 92% are aliphatic hydrocarbons and the remaining 8% are oxygenated species. This suggests that the bulk of the organics emitted consist of unburned fuel; the remainder is partially oxidized fuel.

Gas chromatography/mass spectrometry analysis of sample extracts was performed to determine the 58 semivolatiles organic priority pollutants. Of these, only naphthalene and phenanthrene or anthracene were detected, as also shown in Table 2.

Results of a SAM/IA evaluation of the data obtained in this test program are given in Table 3, which shows species with discharge severity (DS) greater than 0.1. In the flue gas stream, NO and

**Table 1. Flue Gas Emissions<sup>a</sup>**

Species	Range	Average
O <sub>2</sub> , percent dry	1.4 to 2.4	1.9
CO <sub>2</sub> , percent dry	12.6 to 14.0	12.9
H <sub>2</sub> O, percent	2.7 to 3.0	2.9
CO <sup>a</sup> , ppm at 0 percent O <sub>2</sub>	15 to 51	40
ng/J	4.5 to 15	12
NO, ppm at 0 percent O <sub>2</sub>	68 to 79	76
ng/J as NO <sub>2</sub>	33 to 39	37
NO <sub>2</sub>	0 <sup>b</sup>	0
TUHC, ppm at 0 percent O <sub>2</sub>	0.5 to 9.0	3.3
ng/J as C <sub>3</sub> H <sub>8</sub>	0.2 to 4.1	1.5
SO <sub>2</sub> , ppm at 0 percent O <sub>2</sub>	—	56
ng/J	—	106
SO <sub>3</sub>	0 <sup>b</sup>	0.0
Solid particulate, ng/J (Method 5)	—	1.3
Condensable particulate, ng/J (Method 5)	—	1.4
Smoke, Bacharach	0	0

<sup>a</sup>Includes peak emissions at the start of burner-on cycle.

<sup>b</sup>Nitrates and sulfates were absorbed in the tank water.

**Table 2. Organic Emissions Summary**

	Flue Gas mg/dscm	Tank Water Discharge mg/l
Total Chromatographable Organics (TCO)	2.6	<0.1
Gravimetric (GRAV)	0.9	<0.1
Total	3.5	<0.1
	µg/dscm	µg/l
Naphthalene	36	0.4
Phenanthrene/Anthracene	2	0.08

**Table 3. Discharge Severities Greater Than 0.1 for the Low-Emission Condensing Furnace System**

Pollutant Species	Flue Gas		Tank Water	
	Emitted Concentration µg/dscm	DS	Discharge Concentration µg/l	DS
Cu	5.9	0.03	5.0 × 10 <sup>5</sup>	100
SO <sub>4</sub>	—	—	9.9 × 10 <sup>5</sup>	67
NO <sub>x</sub>	9.9 × 10 <sup>4</sup>	11	—	—
SO <sub>2</sub>	1.3 × 10 <sup>5</sup>	10	—	—
Fe	15	0.015	1.0 × 10 <sup>4</sup>	6.7
Ni	8.6	0.57	1,000	4.4
Cr	3.4	3.4	700	2.8
Se	0.25	0.001	100	2.0
CO	3.1 × 10 <sup>4</sup>	0.77	—	—
Mn	1.4	<0.001	190	0.76
S	480	0.48	—	—
Zn	7.5	0.002	1.0 × 10 <sup>4</sup>	0.40
Aldehydes	100	0.40	—	—
Pb	2.8	0.019	70	0.28
Carboxylic acids	200	0.20	—	—
Na	220	0.11	—	—

SO<sub>2</sub> emissions were responsible for the highest DS values, both exceeding unity by a factor of nearly 10. CO and THCs (primarily aliphatics) were present in nonhazardous concentrations (DS <1.0). Four elements with DS greater than 0.1 were found in the flue gas: Cr, Ni, Na, and S, with only Cr having a DS exceeding unity. Both Cr and Ni emissions, however, are suspected contaminants inherent in sample preparation for trace element analysis.

Two organic categories had potential DS values greater than 0.1. However, these organic category DS values were calculated under the conservative assumption that all the organic content assignable to the respective category consisted of the compound with the lowest discharge multimedia environmental goal (DMEG) potentially present in the sample.

Trace elements in the tank water for which DS exceeded unity were Cu, Cr,

Fe, Ni, and Se. Cu concentrations, in fact, exceeded those of any other element detected in the tank water. This high concentration of Cu is attributed to leaching of heat exchanger copper coils immersed in the warm acidic tank water. In fact, concentrations of most of the other three trace elements of potential concern can be attributed to the leaching of metal surfaces in contact with the tank water. Sulfate (as sulfuric acid) in the tank water represents the next greatest potential concern.

Results of these bioassay analyses showed that the XAD-2 sorbent extract exhibited moderate mutagenicity in the Ames bioassay, and low to nondetectable toxicity in the CHO assay. The tank water discharge exhibited moderate cytotoxicity in the CHO assay, nondetectable toxicity in the rodent whole animal test, and nondetectable mutagenicity in the Ames bioassay.

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*Robert E. Hall is the EPA Project Officer (see below).*

*The complete report consists of two volumes, entitled "Environmental Assessment of a Low-Emission Oil-Fired Residential Hot Water Condensing Heating System:"*

*"Volume I. Technical Results," (Order No. PB 82-239 344; Cost: \$12.00, subject to change)*

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