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Project Summary

Evaluation of Combustion Modification Effects on Emissions and Efficiency of Wood-Fired Industrial Boilers

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Results of full-scale tests to evaluate combustion modifications for emission control and efficiency enhancement on two wood-fired industrial boilers are reported. These modifications consisted of lower excess air and variations in the overfire air system operation.

The boiler at Location 3 was fueled with a combination of wood bark and coal. The implementation of lower excess air reduced NO_x emissions by 37.2 percent and improved thermal efficiency by 1.2 percent. Variations in the overfire air system reduced NO_x by 20.7 percent and improved efficiency by 1.63 percent.

The boiler at Location 5 was fired with hogged wood as the primary fuel and oil as the supplemental fuel. The effectiveness of lower excess air in reducing NO_x was 12.5 percent with a slight improvement in efficiency (0.6 percent). Adjustment of the auxiliary air dampers producd a 17.2 percent NO_x reduction and a 1.7 percent improvement in efficiency. Polycyclic organic matter (POM) was sampled at both baseline and optimum low-NO_x conditions. On a $\mu g/m^3$ basis, the POM for low-NO_x conditions exceeded the baseline results by a factor of two to three. The results obtained are compared to previous POM sampling on industrial steam boilers.

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

The activities reported here include tests performed on a wood bark/coal-fired boiler (Location 3) and a hogged wood fuel boiler (Location 5). Oil was the supplemental fuel at Location 5. Variations in load, excess air and overfire air system adjustments were the combustion modifications common to both boilers. In addition, lower combustion air preheat and supplemental fuel oil air damper positioning were implemented at Location 5. Polycyclic organic matter (POM) was also sampled at Location 5 at both baseline and optimum low-NO_x conditions.

Table 1 summarizes the reductions in NO and changes in efficiency measured at Location 3 for each combustion control. The overfire air system modification consisted of increasing the overfire air ports from 1 to 1.5 in. (2.54 to 3.81 cm) diameter. As noted, the lowest NO level obtained resulted from implementing lower excess air before the modification of overfire air ports. This arrangement also produced an increase in boiler efficiency of 1.2 percent.

Table 2 summarizes the NO reductions achieved at Location 5 and the change in efficiency for all modifications except reduced combustion air preheat. This modification could not be fully implemented since the combustion air temperature could be reduced by only 16-22 K. Also noted in this table is the NO mass emission factor measured after each modification had been implemented. Increased load (18 percent) actually reduced the NO concentration and mass emission factor. This NO characteristic is somewhat unusual; i.e., peak NO occurs in the mid-load range. This occurrence may be due to the boiler's O_2 vs. load characteristic which could produce a maximum NO concentration at less than full load.

Polycyclic organic matter (POM) samples were collected and analyzed for boiler operation at both baseline and low-NO_x (auxiliary air damper adjustment) conditions. The significant finding was that the total POM at the low-NO_x condition was two to three times higher than that measured under baseline conditions. This large difference could be due more to fuel property variations than to combustion modification, although the trend of higher POM with lower NO_x has been observed previously.

Emissions Test Instrumentation

All emission measurement instrumentation for the full-scale testing was carried out in an 8 x 42 ft (2.4 x 12.8 m) mobile laboratory trailer. The gaseous species measurements were made with analyzers located in the trailer. The emission measurement instrumentation used is listed in Table 3.

Table 1. *Summary of Combustion Modifications At Location 3*

Control	NO Reduction, %	Efficiency Change, %	NO After Control ng/J[a]
Lower Excess Air[b] (146)[c]	37.2	+1.2	92
Lower Excess Air[d] (184)	18.5	+0.9	150
Overfire Air Dampers[d] (174)	20.7	+1.6	138
Load Reduction (51%)[d,e] (140)	7.9	-4.0	129

[a] *NO as NO_2.*
[b] *Before overfire air system modification.*
[c] *Value in parentheses is baseline NO (ng/J) before combustion modification.*
[d] *After overfire air system modification.*
[e] *Load reduction referenced to nominal operation at 80% of rating.*

Table 2. *Summary of Combustion Modifications At Location 5*

Modification	NO Reduction, %	Efficiency Change, %	NO After Modification ng/J[a]
Lower Excess Air (40)[b]	12.5	+0.6	35
Increase Overfire Air (46)	21.7	-1.3	36
Auxiliary Air Damper (36)	17.2	+1.7	30
Load Change[c]			
+18% (40)	27.5	+0.9	29
-30% (40)	30.0	+1.8	28

[a] *NO as NO_2.*
[b] *Value in parentheses is baseline NO (ng/J) before combustion modification.*
[c] *Load change referenced to nominal operation at 76.5% of rating.*

Table 3. *Emissions Measurement Instrumentation*

Species	Manufacturer	Measurement Method	Model No.
Hydrocarbon	*Beckman Instruments*	*Flame Ionization*	*402*
Carbon Monoxide	*Beckman Instruments*	*IR Spectrometer*	*865*
Oxygen	*Teledyne*	*Polargraphic*	*326A*
Carbon Dioxide	*Beckman Instruments*	*IR Spectrometer*	*864*
Nitrogen Oxides	*Thermo Electron Co.*	*Chemiluminescent*	*10A*
Particulates	*Joy Manufacturing Co.*	*EPA Method 5 Train*	*EPA*
Sulfur Dioxide	*DuPont Instruments*	*UV Spectrometer*	*400*

Results

Location 3, Wood Bark/Coal Boiler

Combustion modifications implemented consisted of lower excess air, variation in overfire air damper positioning, and load changes. In addition, the overfire air system nozzle size was increased, and the effect of lower excess air was re-evaluated.

Figure 1 depicts the effect of oxygen on NO emissions before the increase in overfire air nozzle size. Reducing the oxygen from 9.3 percent (as found, Test 1) to 7.8 percent (Test 4) lowered the NO emissions by 37.2 percent while increasing the efficiency by 1.2 percent. As noted in Figure 2, the effectiveness of lower excess air after the overfire air modification was less pronounced.

With respect to boiler operation at 80 percent of rated load (Test 31) only a 7.9 percent reduction in NO was measured when the load was reduced by 51 percent (Test 29) as shown in Figure 3. This control caused the boiler efficiency to decrease by 4 percent.

Variations in the overfire air damper positioning, at constant overall oxygen (9.8-9.9 percent), were shown to reduce NO emissions by 20.7 percent and increase efficiency by 1.6 percent. This result was obtained by partly closing the lower row of overfire air ports and fly-ash reinjection ports.

Total and solid particulate emissions were measured downstream of the multiclone at the low-NO_x condition. Total particulate was 138 ng/J (0.320 lb/10^6 Btu) and the solid particulate was 118 ng/J (0.274 lb/10^6 Btu) with the unit operating at 8.2 percent O_2.

The low-NO_x cascade impactor test is shown in Figure 4. Particulate diameter as a function of cumulative proportion of impactor catch is plotted. About 27 percent of the particles are below 3 µm aerodynamic diameter. The geometric mean and geometric dispersion are 6 and 1.099 µm, respectively. A comparison of the baseline and low-NO_x results indicates that the geometric mean particle size for baseline operation is approximately 50 percent of that measured during low-NO_x operation (3.2 µm vs. 6 µm). Closing the dampers for the overfire air and fly-ash reinjection (low-NO_x configuration) resulted in the production of larger particulates, but at a reduced mass rate (118 vs. 155 ng/J).

Location 5, Hogged Wood Boiler

NO emissions from this boiler were very low: only one measurement exceeded 100 ppm. Combustion modifications implemented were lower excess air, load variations, increased overfire air flow, and auxiliary air damper positioning. The effectiveness of reduced combustion air preheat could not be established since only a modest (16-22 K) reduction was possible when the steam coil portion of the air heater was bypassed.

The effect on NO of excess air variations is shown in Figure 5 for three different loads. With respect to nominal operation at 19.3 kg/s (153,000 lb/hr) steam flow and 7.2 percent O_2 (Test 5/2-1A), a load reduction of 30 percent produced a NO reduction of 30 percent and an efficiency increase of 1.8 percent.

The effectiveness of lower excess air at constant load is also shown in Figure 5. At a load of 19.3 kg/s (153,000 lb/hr) nd 7.2 percent O_2, a 12.5 percent reduction in NO was computed when the O_2 was lowered to 5.7 percent (Test 5/2-4).

The overfire air flow, as a percentage of total combustion air, was increased from a baseline value of 5.7 percent to 9.7 percent. This had the effect of reducing the primary combustion air admitted under the grate. This modification reduced the NO emissions by 21.7 percent; however, the boiler efficiency was also lowered by 1.3 percent.

Each auxiliary oil burner has an independent air supply. Opening this air supply (with the burner off) implements another form of staged combustion. Tests conducted in this configuration, when compared to all baseline tests, produced a NO reduction of 17.2 percent and a 1.7 percent increase in efficiency.

Figure 6 presents all particulate measurements made at the boiler outlet as a function of the corresponding NO levels. A trend of lower particulate emissions with lower NO emissions is noted. The reason for this behavior is not known at present.

Polycyclic organic matter (POM) samples were obtained at the boiler outlet under both baseline and low-NO_x (auxiliary oil burner air dampers open) conditions. Table 4 presents the speciated analyses from which it is noted that the total POM under low-NO_x conditions is two to three times greater (on a $\mu g/m^3$ basis) than for baseline operation. This trend (i.e., higher POM with lower NO_x) was observed previously,* and is attributed to more fuel-rich conditions in the burning zone.

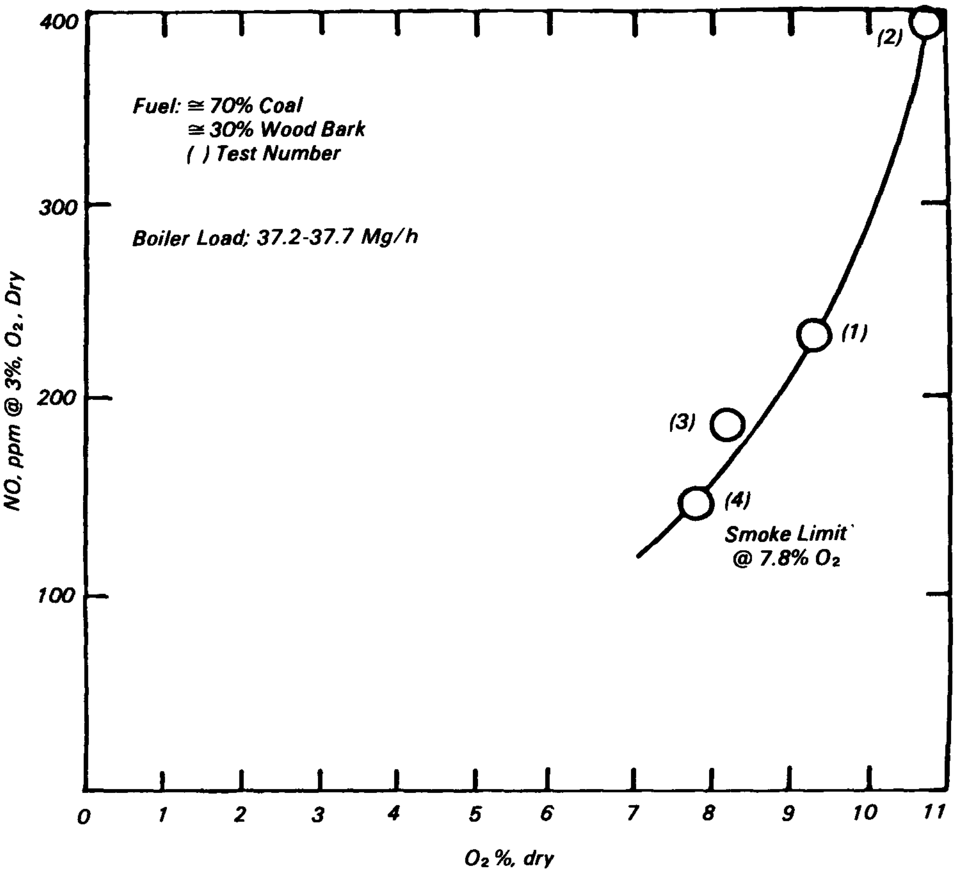

Figure 1. *Location 3—NO emissions as a function of O_2 before overfire air nozzle modification.*

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*Carter, W. A., and Buening, H. J., "Thirty-Day Field Tests of Industrial Boilers, Site 1—Coal-Fired Spreader Stoker," EPA-600/7-80-085a (NTIS PB 80-211386), April 1980.

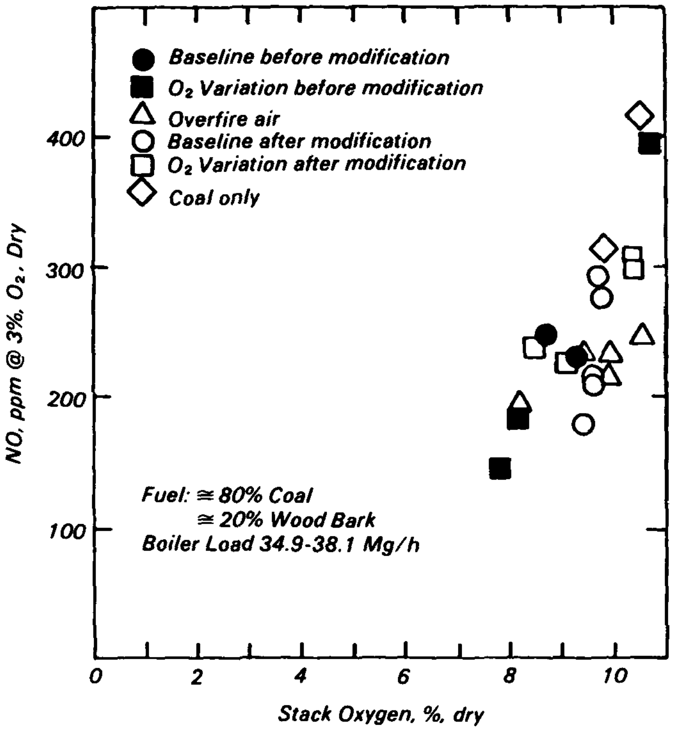

Figure 2. Location 3—NO emissions as a function of stack O_2.

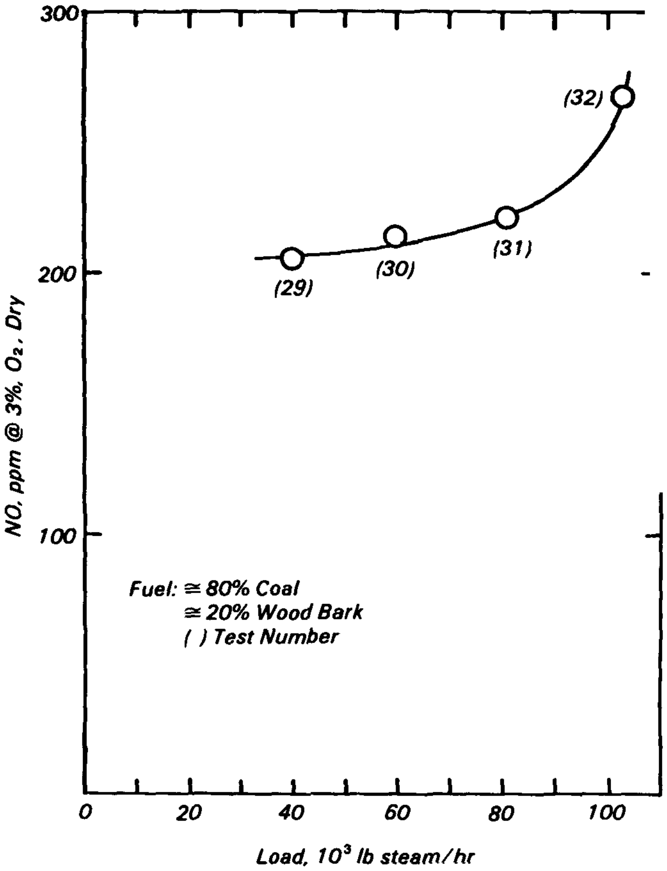

Figure 3. Location 3—NO emissions as a function of load.

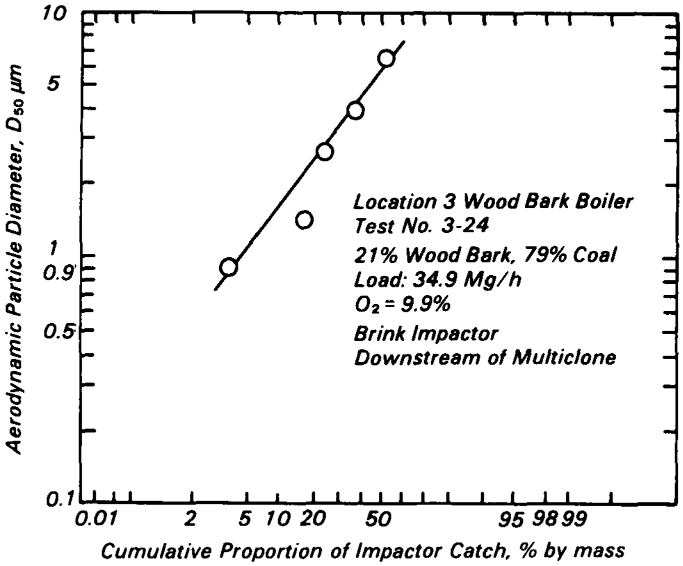

Figure 4. *Aerodynamic particle diameter—low-NO$_x$ conditions.*

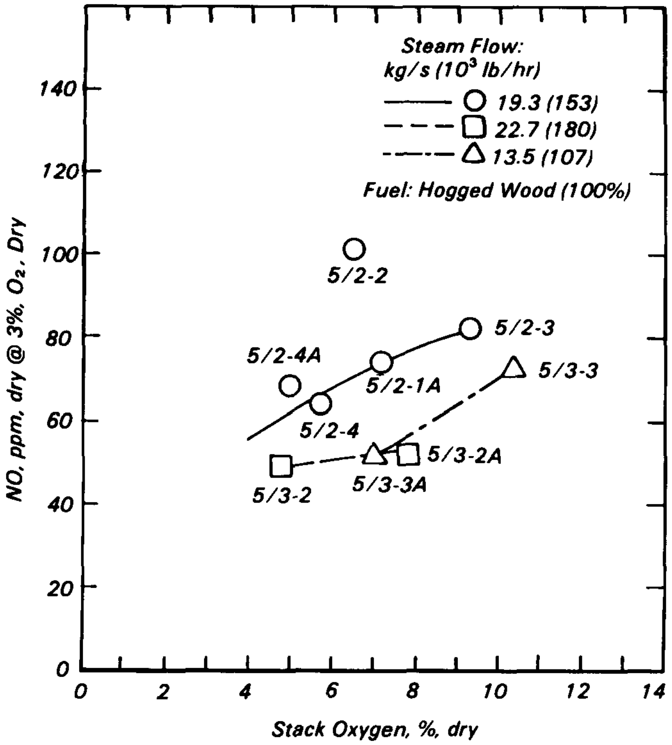

Figure 5. *NO emissions as a function of stack oxygen for three loads in a hogged fuel boiler.*

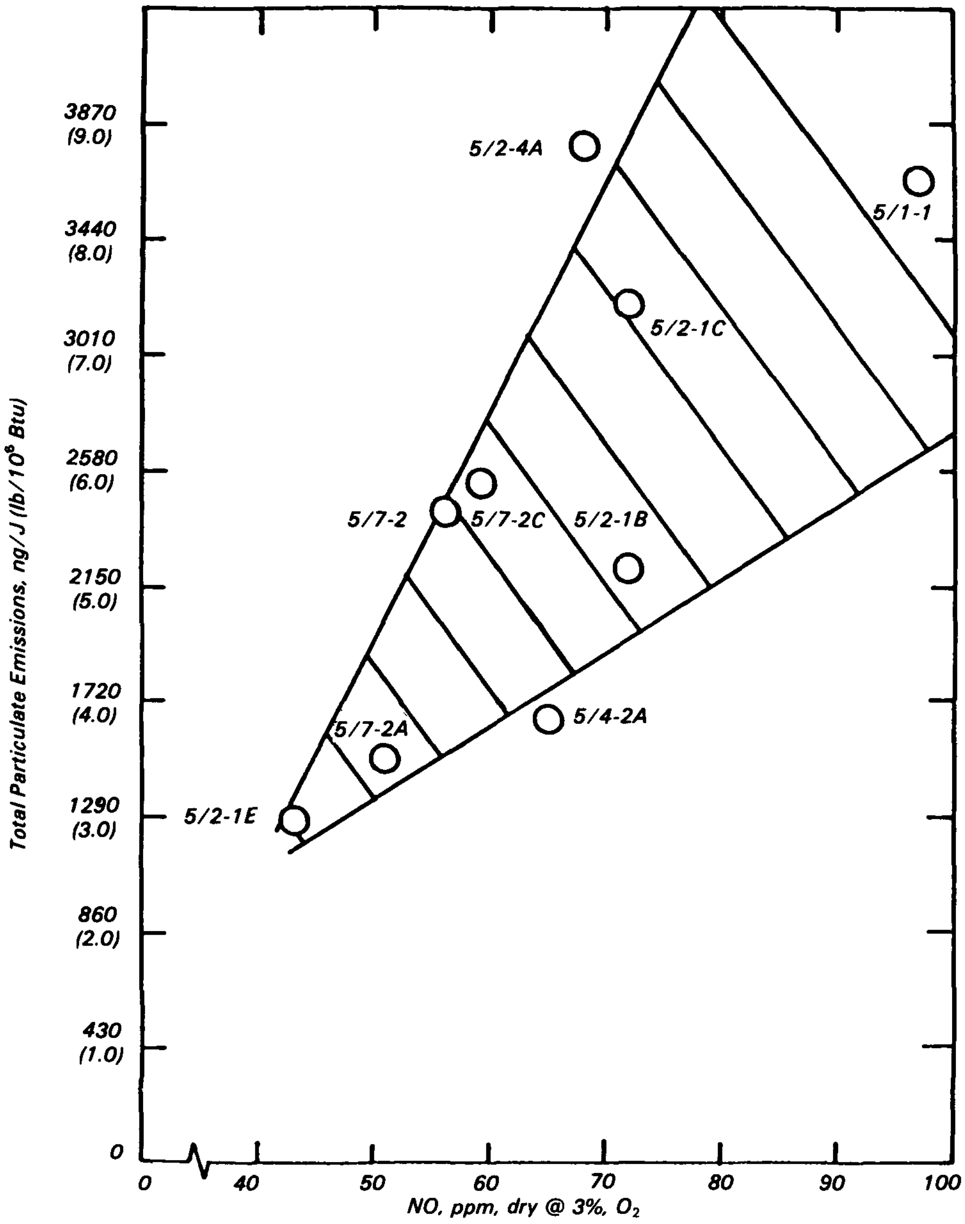

Figure 6. Location 5—Boiler total particulate emissions as a function of NO emissions.

Table 4. *Summary of POM Analyses For Location 5—Wood-Fired Spreader Stoker*

	Low NO_x Test						Baseline Test					
	XAD-2		Probe Rinse, Cyclone & Filter		Total		XAD-2		Probe Rinse, Cyclone & Filter		Total	
POM	μg	μg/m³	μg	μg/m³	μg	μg/m³	μg	μg/m³	μg	μg/m³	μg	μg/m³
Phenanthrene	0.7	0.70	2.5	2.5	3.2	3.2	0.9	0.7	1.6	1.0	2.5	1.7
Anthracene	ND[a]	ND	<0.4	<0.4	<0.4	<0.4	ND	ND	ND	ND	ND	ND
Methyl Anthracenes/ Phenanthrenes	0.7	0.70	2.7	2.7	-3.4	3.4	1.0	0.8	1.1	0.8	2.1	1.6
Fluoranthene	<0.5	<0.5	0.8	0.8	0.8<1.3	0.8<1.3	ND	ND	<0.5	<0.4	<0.5	<0.4
Pyrene	ND	ND	1.0	1.0	1.0	1.0	ND	ND	<0.5	<0.4	<0.5	<0.4
Methyl Pyrene/Fluoranthene	<0.5	<0.5	0.7	0.7	0.7<1.2	0.7<1.2	<0.5	<0.4	<0.5	<0.4	<1.0	<0.8
Benzo(c)phenanthrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benz(a)anthracene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chrysene	ND	ND	<0.5	<0.5	<0.5	<.05	ND	ND	ND	ND	ND	ND
Methyl Chrysenes	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dimethylbenz anthracenes	ND	ND	ND	ND	ND	ND	<0.5	<0.4	ND	ND	<0.5	<0.4
Benzofluoranthenes	ND	ND	ND	ND	ND	ND	<0.5	<0.4	ND	ND	<0.5	<0.4
Benzo(a)pyrene	ND	ND	<0.6	<0.6	<0.6	<0.6	ND	ND	ND	ND	ND	ND
Benzo(e)pyrene	ND	ND	0.6	0.6	0.6	0.6	ND	ND	ND	ND	ND	ND
Perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methylcholanthrenes	<1.2	<1.2	<1.2	<1.2	<2.4	<2.4	<1.2	<0.9	<1.2	<0.9	<2.4	<1.8
Indeno(1,2,d-cd)pyrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(g,h,i)perylene	ND	ND	<1.2	<1.2	<1.2	<1.2	ND	ND	ND	ND	ND	ND
Dibenz anthrancenes	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibenzpyrenes	ND	ND	0.1	0.1	0.1	0.1	ND	ND	ND	ND	ND	ND
Coronene	ND	ND	2.2	2.2	2.2	2.2	0.1	0.1	ND	ND	0.1	0.1
TOTAL[b]		1.4<3.6		10.6<14.5		12.0<18.1		1.6<3.7		1.8<3.9		3.4<7.6
Sample volume, m³	0.993						1.280					

[a] ND =Not Detected, less than 0.1 μg.

[b] Two totals are shown; e.g., 1.4<3.6 where 1.4 is total of all quantified amounts and 3.6 is total of quantified amounts plus all values indicated as <, which indicates that a compound was observed but cannot be quantified at a value below the amount shown.

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

The complete report, entitled "Evaluation of Combustion Modification Effects on Emissions and Efficiency of Wood-Fired Industrial Boilers," (Order No. PB 83-245 837; Cost: $11.50, subject to change) will be available only from:

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