



Project Summary

Emissions Assessment of Conventional Stationary Combustion Systems: Volume V. Industrial Combustion Sources

N. F. Surprenant, W. Battye, D. R. Roeck, and S. M. Sandberg

This report characterizes air emissions from industrial external combustion sources and is the last of a series of five project reports characterizing emissions from conventional combustion sources. The emissions characterization of industrial combustion sources was based on a critical examination of existing data, followed by a modified Level 1 sampling and analysis approach to resolve data gaps. The major deviation from Level 1 procedures was the addition of GC/MS analysis for polycyclic organic matter (POM). Tests were conducted at 32 external combustion sites.

The results of the emissions assessment indicate that air emissions from these sources represent a potential environmental hazard. Criteria pollutants emissions, with the exception of CO, from most of the source categories tested are environmentally significant. Particulate sulfate emissions from the coal- and wood-fired sources and SO₃ emissions from the two coal-fired sources tested are also significant. In addition, emissions of several trace elements are of concern: arsenic, beryllium, chlorine, cobalt, chromium, iron, potassium, lithium, sodium, nickel, phosphorus, and lead from coal-fired external combustion sources; nickel, chromium, phosphorus, and

vanadium from distillate oil sources; and chlorine, chromium, sodium, nickel, silicon, and vanadium from residual oil sources. Several potentially hazardous POM compounds were tentatively identified in the emissions from solid-fuel-fired sources, particularly from the wood-fired combustion sources tested. Flue gas emissions of POM from solid-fuel-fired sources will require further study to positively identify the POM compounds emitted.

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

Emissions from industrial external combustion sources used for the purposes of electricity generation, production of process steam, and space heating are characterized in this report. Emissions resulting from the direct firing of industrial process operations or from the use of fuel as feedstock were not considered. Emphasis was placed on the characterization of air emissions from flue gas stacks, although samples

of ash from wood combustion were collected and analyzed during the study for the purpose of supplementing a limited data base.

The approach to the characterization of emissions from industrial combustion sources involved a critical review of existing data, followed by a sampling and analysis program to fill gaps in the data base. Data acquired as a result of the measurement program, in combination with the existing data, were further evaluated. Data inadequacies identified at the completion of the current program are discussed with respect to the need for additional study. Specifically, the objectives of this program were:

- To compile and evaluate all available air emissions data on pollutants from selected industrial stationary conventional combustion processes,
- To acquire new emissions data from field tests,
- To characterize air emissions from selected stationary conventional combustion processes and ash from wood combustion, using combined data from existing sources and field tests,
- To determine additional data needs, including specific areas of data uncertainty.

The emissions characterization was based on modified Level 1 sampling and analysis procedures, the principal modification being the use of gas chromatography/mass spectroscopy to analyze for polycyclic organic material (POM). Level 1 procedures use semiquantitative (plus or minus a factor of 3) techniques of sample collection and laboratory and field analysis to: (1) provide preliminary emissions data for waste streams and pollutants not adequately characterized; (2) identify potential problem areas; and (3) set priorities for waste streams and pollutants in those streams for further, more quantitative testing. Using the information from Level 1, available resources can be directed toward Level 2 testing, which involves specific quantitative analysis of components of these streams that do contain significant pollutant levels. The data developed at Level 2 are used to identify control technology needs and to further define the environmental hazards associated with emissions.

Summary

Stationary external combustion sources used in the industrial sector for electricity generation, production of

steam for process heating, and space heating can be classified according to the type of fuel used and furnace and boiler design. Fuels used in industrial combustion systems include bituminous coal, anthracite coal, lignite coal, wood, residual oil, distillate oil, and natural gas. Pulverized dry bottom furnaces and stoker furnaces are the major furnace designs used by the industrial sector for the combustion of bituminous coal. Stoker furnaces predominate for wood-fired combustion sources and for the combustion of lignite and anthracite coals. Although a large percentage of industrial boilers are cast iron systems, these systems constitute only about 7 percent of total industrial boiler capacity. Firetube boilers, in which the combustion gases pass through tubes submerged in water, make up about 24 percent of total industrial capacity. These units generally are smaller than about 21 GJ/hr* input capacity. Watertube boilers constitute about 69 percent of the industrial boiler capacity. In a watertube system the combustion gases transfer heat to tubes into which water is fed to be converted to steam. Boiler systems larger than about 53 GJ/hr input capacity and systems with steam pressures exceeding about 65 kPa are almost exclusively watertube systems.

There are approximately 500,000 industrial boilers in the United States with an estimated capacity of about $4,000 \times 10^{12}$ J/Hr. Natural gas is the primary fuel, accounting for about 63 percent of the total industrial fuel use in 1978; oil and coal account for about 18 and 15 percent, respectively. Wood and other miscellaneous fuels are minor fuel sources. Total fuel consumption by the industrial external combustion sources considered in this study was 8700×10^{15} J/yr in 1978, about 25 percent of total national fuel consumption by the stationary combustion sources studied in this program. The overall growth rate during the 1978 to 1985 period should be about 3 percent per year. Coal consumption by 1985 could account for 30 percent of industrial fuel use in 1985, if provisions of the National Energy Plan are fully implemented. This increase, however, could be a gross overestimate because of the influence of regulatory actions limiting, for example, sulfur content of the coal fuel.

*One Btu = 1,055 Joules (J). Although it is EPA policy to use the metric system, this publication uses certain nonmetric units for convenience.

Air, water, and solid waste pollutants are emitted from many sources constituting an industrial boiler facility. The major source of air emissions is flue gas emissions from stacks. Other potential sources of air emissions, depending on the size of the facility and the type of fuel burned, are ash handling and storage, fuel handling and storage, and drifts and vapors from cooling systems. Wastewater emissions streams and sources of solid wastes vary in number and volume, depending again on facility size and type of fuel burned. Emphasis in this study was placed solely on air emissions from stacks, with the exception of the characterization of bottom ash and fly ash from the wood-fired systems tested in this study.

Air pollution control on industrial boilers is mainly directed at reducing particulate flue gas emissions from solid-fuel-fired sources. The estimated overall efficiency of particulate removal in the industrial sector, based on data in the National Emissions Data System (NEDS), is 81 percent for pulverized units and 53 percent for stokers. Application of control measures for SO₂ and NO_x is not extensive in the industrial sector, but will increase with the promulgation of regulations for control of such emissions from industrial boilers.

This study emphasized gaseous and particulate emissions from industrial sources. Existing flue gas emissions data were evaluated before conducting the sampling and analysis program. As a result of the data evaluation effort, many data inadequacies were identified. The status of the existing data base can be summarized as follows:

- The existing data base for criteria pollutants** is generally adequate, with the exception of that for emissions from wood-fired combustion sources.
- The existing data base for particulate sulfate and sulfuric acid emissions is inadequate for the oil- and solid-fuel-fired combustion source categories.
- The existing data base for particulates by size fractions and trace elements is adequate only for gas-fired sources.
- The existing data base for specific organics is inadequate for all industrial source categories.

**Criteria pollutants are those for which a National Ambient Air Quality Standard (NAAQS) exists; e.g., particulate, sulfur dioxide, nitrogen oxides, carbon monoxide, and hydrocarbon. The criteria pollutant, lead, is categorized in this study as a trace element.

As noted previously, industrial boilers are also sources of water pollution and solid waste. However, these sources, particularly in the case of large industrial boilers used for electricity generation, are similar to those at electric utilities. These sources of pollution were characterized for electric utilities earlier in this program; results are in Volume III of this report series.

To overcome some of the deficiencies in the existing emissions data base, the following 32 external combustion systems were tested: 10 gas-fired, 4 distillate-oil-fired, and 5 residual-oil-fired boilers; 3 bituminous pulverized wet-bottom and 2 bituminous pulverized dry-bottom units; 3 bituminous stokers; and 5 wood-fired stokers. Specific sites were chosen based on the representativeness of the sites as measured against the important system characteristics in each source category, including system design, size, and age.

The Source Assessment Sampling System (SASS) train, developed under contract to EPA, was used to collect both gaseous and particulate emissions in quantities sufficient for the wide range of analyses needed to adequately characterize emissions from the industrial combustion sources. The SASS train consists of a conventional heated probe, three cyclones and a filter mounted in a heated oven, a gas conditioning system, an XAD-2 polymer adsorbent trap, and a series of impingers. Particulate matter is size-fractionated and collected in the cyclones and on the filter, gaseous organics and some inorganics are collected by the XAD-2 adsorbent, and the remaining gaseous inorganics and trace elements are captured by the impingers. The train is run until at least 30 m³ of gas has been collected. This criterion was established in conjunction with analytical technique sensitivities to ensure that any emission that would increase the ambient loading by more than 1 µg/m³ would be detected. The cyclones were deleted for the gas- and oil-fired sites because particulate loadings were too low to provide weighable quantities of samples from each cyclone.

In addition to using the SASS train for stack gas sampling, other equipment was employed to collect components that could not be analyzed from the train samples. A gas chromatograph (GC) with flame ionization detection was used in the field to analyze C₁-C₆ hydrocarbons collected in Tedlar gas sampling bags. Additionally, these samples were

analyzed for CO, CO₂, O₂, and N₂ by GC using thermal conductivity detection. Field sampling for NO_x and SO₃ was also conducted at selected sites using a Method 7 train (40-CFR-60, Appendix A, Method 7) for NO_x and a controlled condensation sampling train for SO₃ collection.

A modified Level 1 sampling and analytical procedure was used in this emissions assessment program. Major deviations from Level 1 procedures included the use of gas chromatography/mass spectroscopy (GC/MS) for organic analyses, the combination of certain SASS train fractions before analysis, and the deletion of inorganic analysis of SASS train samples collected from gas- and oil-fired sources. The combination and deletion guidelines were instituted as a result of low levels of pollutants found in the flue gases of previously tested gas- and oil-fired utility boilers and residential heating systems.

Level 1 inorganic analysis was designed to identify all elemental species collected in the SASS train fractions and to provide semiquantitative data on the elemental distributions and total emissions factors. The primary tool for Level 1 inorganic analysis is Spark Source Mass Spectrography (SSMS). SSMS data were supplemented with Atomic Absorption Spectrometry (AAS) data for Hg, As, and Sb, and with standard method determinations for sulfates.

The following SASS train fractions from the solid-fuel-fired sources were analyzed for their elemental composition: (1) the cyclone catches, (2) the particulate filter, (3) the XAD-2 sorbent, and (4) a composite sample containing portions of the XAD-2 module condensate and HNO₃ rinse, and the first impinger solution. Fuel was also analyzed for the solid-fuel- and oil-fired sources.

Level 1 organic analysis provides data on volatile (C₇-C₁₆) and nonvolatile (>C₁₆) organic compounds to supplement data for gaseous organics (C₁-C₆) measured in the field. Organics in the particulate fractions, the XAD-2 sorbent, and XAD-2 module condensate trap were recovered by methylene chloride extraction. SASS train components including the tubing were carefully rinsed with methylene chloride or methylene chloride/acetone solvent to recover all organics collected in the SASS train. SASS train rinses and extracts recovered from the gas- and oil-fired sites were combined for analysis; how-

ever, samples collected from solid-fuel-fired sources were analyzed separately.

Because all samples contain significant quantities of solvents from rinsing and are too dilute to detect organic compounds by the majority of instrumental techniques employed by Level 1 procedures, the first step in the analysis was to concentrate the sample fractions from as much as 1000 ml to 10 ml in a Kuderna-Danish apparatus in which rinse solvent is evaporated while the organics of interest are retained. Kuderna-Danish concentrates were then evaluated by GC, gravimetric analysis, infrared spectrometry (IR), and sequential GC/MS. The extent of the organic analysis is determined by the stack gas concentrations found for total organics (volatile and nonvolatile). If the total organics indicate a stack gas concentration below 500 µg/m³, further analysis is not conducted. If the concentration is above 500 µg/m³, a class fractionation by liquid chromatography is conducted followed by GC, gravimetric, and IR analyses. Low resolution mass spectroscopy analysis was also conducted on individual fractions which contained an equivalent concentration of 500 µg/m³ or which were of special interest.

The results of the field measurement program for flue gas emissions from industrial sources, along with supplementary values obtained from the existing data base for certain pollutants, are presented in Table 1. Results of analyses of ash samples from wood-fired systems are also presented in the table. Also listed in Table 1 are ambient severity factors, defined as the ratio of the calculated maximum ground-level concentration of the pollutant species to the level at which a potential environmental hazard exists. An ambient severity factor of greater than 0.05 indicates a potential problem requiring further attention. For the ash samples collected during tests of the wood-fired sources, discharge severity (the ratio of the elemental concentration in the ash to the health Minimum Acute Toxicity Effluent [MATE] value of the element) was used as a measure of potential hazard. A discharge severity exceeding 1 is considered to warrant concern regarding the impact of emissions on health.

The particulate, elemental, and particulate sulfate emission factors shown in Table 1 are the mean values of those measured in this study. One bituminous, pulverized wet-bottom unit and one bituminous stoker were controlled by

Table 1. Summary of Emissions Characterization of Industrial Combustion Sources

| Pollutant | Combustion source category | | | | | | | | | |
|----------------------------------|----------------------------|--------------------------------------|------------------------------|--------------------------------------|----------------------------|--------------------------------------|---|--------------------------------------|--|--------------------------------------|
| | Gas-fired boilers | | Distillate oil-fired boilers | | Residual oil-fired boilers | | Coal-fired bituminous pulverized dry bottom boilers | | Coal-fired bituminous pulverized wet bottom ^a boilers | |
| | Emission factor (ng/J) | Ambient severity factor ^b | Emission factor (ng/J) | Ambient severity factor ^b | Emission factor (ng/J) | Ambient severity factor ^b | Emission factor ^a (ng/J) | Ambient severity factor ^b | Emission factor ^a (ng/J) | Ambient severity factor ^b |
| Particulate | 2 | <0.01 | 6 | <0.01 | 30 | 0.05 | 12 | 0.02 | 20 | 0.03 |
| NO _x | 70 | 0.35 | 70 | 0.35 | 170 | 0.85 | 350 | 1.8 | 586 | 2.9 |
| SO ₂ | 0.26 | <0.01 | 106 | 0.11 | 464 | 0.52 | 766 | 0.85 | 766 | 0.85 |
| CO | 8 | <0.01 | 15 | <0.01 | 15 | <0.01 | 20 | <0.01 | 20 | <0.01 |
| HC | 1 | <0.01 | 3 | 0.01 | 3 | 0.01 | 6 | 0.02 | 6 | 0.02 |
| Particulate sulfate ^c | — | — | — | — | — | — | 1.8 | 0.15 | 0.12 | 3.2 |
| SO ₃ | — | — | — | — | 5.7 | 0.87 | 4.1 | 0.60 | — | — |
| <i>Trace Elements</i> | | | | | | | | | | |
| Al | — | — | 180 | <0.01 | 175 | <0.01 | 930 | 0.02 | 1100 | 0.03 |
| As | — | — | 4 | <0.01 | <1 | <0.01 | 50 | 0.12 | 14 | 0.03 |
| Ba | — | — | 1 | <0.01 | <1 | <0.01 | 21 | <0.01 | 70 | 0.02 |
| Be | — | — | <1 | <0.01 | <1 | 0.01 | <1 | 0.03 | <1 | <0.01 |
| Ca | — | — | 75 | <0.01 | 228 | <0.01 | 70 | <0.01 | 400 | <0.01 |
| Cd | — | — | 1 | <0.01 | <1 | <0.01 | <1 | <0.01 | <1 | <0.01 |
| Co | — | — | 4 | 0.01 | 11 | 0.03 | 20 | 0.05 | 6 | 0.01 |
| Cr | — | — | 24 | 0.06 | 29 | 0.07 | 28 | 0.07 | 5 | 0.01 |
| Cu | — | — | 38 | <0.01 | 10 | <0.01 | 22 | <0.01 | 19 | <0.01 |
| Fe | — | — | 380 | 0.01 | 55 | <0.01 | 660 | 0.02 | 1400 | 0.03 |
| K | — | — | 85 | <0.01 | 260 | 0.01 | 160 | <0.01 | 200 | 0.01 |
| Li | — | — | <1 | <0.01 | <1 | 0.01 | <1 | <0.01 | <1 | <0.01 |
| Mn | — | — | 42 | <0.01 | 8 | <0.01 | 62 | <0.01 | 6 | <0.01 |
| Na | — | — | 62 | <0.01 | 1235 | 0.06 | 240 | 0.01 | 974 | 0.05 |
| Ni | — | — | 255 | 0.32 | 730 | 0.89 | 15 | 0.02 | 16 | 0.01 |
| P | — | — | 46 | 0.05 | 18 | 0.02 | 28 | 0.03 | 89 | 0.11 |
| Pb | — | — | 24 | 0.02 | 1 | <0.01 | 6 | <0.01 | 88 | 0.11 |
| Si | — | — | 735 | <0.01 | 5790 | 0.07 | 1350 | 0.02 | 713 | <0.01 |
| V | — | — | 195 | 0.05 | 365 | 0.09 | 15 | <0.01 | 5 | <0.01 |
| Total POM | — | — | 0.015 | — | <0.001 | — | ND | — | — | 0.003 |

electrostatic precipitators. Multiclones were used on the remaining bituminous-coal-fired units, except one pulverized dry unit, which was controlled by a double alkali flue gas desulfurization (FGD) unit (measured particulate efficiency—99.47 percent). Emissions from two wood-fired boilers were controlled by particulate scrubbers; the remaining three wood-fired units were uncontrolled. Emission factors for gas- and oil-fired units presented in the table represent uncontrolled emission factors. As noted previously, the overall efficiency of particulate control in the industrial sector is 81 percent for pulverized units and 53 percent for stokers. Gas- and oil-fired units are essentially uncontrolled. Control measures for criteria pollutants other than particulates are not widespread in the industrial sector.

As can be seen from Table 1, the major criteria pollutants of concern are: particulates from residual oil sources and all uncontrolled solid-fuel-fired units; NO_x from all source categories; SO₂ from oil- and solid-fuel-fired sources, including wood-fired units (assuming a sulfur content of 0.1 percent and 95 percent conversion to SO₂); and HC from bituminous stokers and wood-fired boilers. Ambient severity factors are all greater than 0.05 for these pollutant/source combinations. Emissions of CO from all the combustion source categories tested do not represent an environmental problem.

Particulate sulfate and SO₃ emissions from the solid-fuel-fired sources tested are associated with ambient severity factors in excess of 0.05 and, thus, represent a potential environmental

hazard. Also, SO₃ emissions, measured in one test of a unit burning residual oil, are significant despite the use of a double alkali FGD unit to control emissions from this source. Although the SO₂ removal efficiency of this FGD unit was 97.5 percent, only 28.5 percent of the SO₃ was removed from the flue gas.

The trace element data shown in Table 1 indicate that many trace elements emitted by controlled bituminous-coal-fired sources are of concern. Elements of greatest concern appear to be arsenic, beryllium, cobalt, chromium, iron, potassium, lithium, sodium, nickel, phosphorus, lead, and silicon. Chlorine, on the basis of its concentration in coal, and other elements in addition to those listed above, may also be of concern because of variations in the elemental content of bituminous coals. Because

Table 1. (Continued)

| Pollutant | Combustion Source Category | | | | | | | | | |
|---------------------|-------------------------------------|--------------------------------------|-------------------------------------|--------------------------------------|--------------------------|---------------------------------|---------------------|---------------------------------|---------------------|---------------------------------|
| | Coal-Fired Bituminous Stokers | | | | Ash from Wood Combustion | | | | | |
| | Coal-Fired Bituminous Stokers | | Wood Stokers | | Bottom Ash | | Cinder Ash | | Scrubber Ash | |
| | Emission factor ^a (ng/J) | Ambient severity factor ^b | Emission factor ^a (ng/J) | Ambient severity factor ^b | Concentration (ppm) | Discharge Severity ^d | Concentration (ppm) | Discharge severity ^d | Concentration (ppm) | Discharge Severity ^d |
| Particulates | 84 | 0.1 | 70 | 0.11 | — | — | — | — | — | — |
| NO _x | 290 | 1.1 | 50 | 0.25 | — | — | — | — | — | — |
| SO ₂ | 766 | 0.64 | 65 | 0.07 | — | — | — | — | — | — |
| CO | 40 | <0.01 | 400 | <0.01 | — | — | — | — | — | — |
| HC | 20 | 0.05 | 100 | 0.36 | — | — | — | — | — | — |
| Particulate Sulfate | 4.5 | 0.38 | 3.1 | 0.35 | — | — | — | — | — | — |
| SO ₃ | — | — | — | — | — | — | — | — | — | — |
| Trace Elements | | | | | | | | | | |
| Al | 890 | 0.02 | 577 | 0.01 | 11,270 | 0.70 | 9,700 | 0.61 | 8,900 | 0.56 |
| As | 144 | 0.35 | 12 | 0.03 | 10 | 0.19 | 7 | 1.4 | 18 | 0.36 |
| Ba | 66 | 0.22 | 90 | 0.21 | 1,640 | 1.6 | 2,800 | 28 | 560 | 0.56 |
| Be | 2.8 | 0.13 | <1 | 0.01 | <1 | 0.06 | <1 | 0.01 | <1 | 0.08 |
| Ca | 820 | <0.01 | 14,280 | 1.8 | 119,000 | 2.5 | 416,670 | 8.7 | 110,000 | 2.3 |
| Cd | <1 | <0.01 | 3 | <0.01 | <1 | 0.03 | 1 | 0.10 | <1 | <0.01 |
| Co | 34 | 0.08 | <1 | <0.01 | 17 | 0.12 | 15 | 0.10 | 20 | 0.15 |
| Cr | 58 | 0.14 | 6 | 0.015 | 2,300 | 46 | 28 | 0.55 | 260 | 5.2 |
| Cu | 270 | 0.03 | 106 | 0.01 | 129 | 0.13 | 280 | 0.28 | 90 | 0.09 |
| Fe | 2,660 | 0.06 | 876 | 0.02 | 32,670 | 109 | 47,030 | 157 | 22,000 | 73 |
| K | 1,370 | 0.08 | 18,750 | 1.1 | 28,530 | 6.8 | 38,330 | 9.1 | 14,000 | 3.3 |
| Li | 13 | 0.07 | 3 | 0.03 | 6 | 0.08 | 5 | 0.08 | 7 | 0.10 |
| Mn | 37 | <0.01 | 314 | <0.01 | 9,230 | 185 | 4,900 | 98 | 5,000 | 112 |
| Na | 990 | 0.05 | 66 | <0.01 | 4,330 | 0.03 | 12,100 | 0.08 | 4,200 | 0.03 |
| Ni | 184 | 0.22 | 29 | 0.04 | 185 | 4.1 | 94 | 2.1 | 140 | 3.1 |
| P | 810 | 1.0 | 1,190 | 1.5 | 9,770 | 3.3 | 5,620 | 1.9 | 6,200 | 2.1 |
| Pb | 127 | 0.10 | 50 | 0.04 | 23 | 0.46 | 52 | 1.0 | 30 | 0.60 |
| Si | 1,875 | 0.02 | 750 | <0.01 | 91,330 | 3.0 | 140,670 | 4.7 | 75,000 | 2.5 |
| V | 54 | 0.01 | 5 | <0.01 | 69 | 0.14 | 72 | 0.14 | 65 | 0.13 |
| Total POM | 0.18 | — | 0.18 | — | ND | — | ND | — | — | 0 |

^aControlled emissions of particulates, particulate sulfate, and trace elements.

^bAmbient severity is defined as the ratio of the calculated maximum ground level concentration to the level at which a potential hazard exists. A value equal to or greater than 0.05 is considered significant.

^cDetermined turbidimetrically following hot water extraction of sulfate from the collected particulate.

^dDischarge severity is defined as the ratio of the concentration in the ash to the health MATE value of the pollutant. A value equal to or greater than 1.0 is considered significant.

— = Not measured.

ND = Not detected.

many industrial sources are totally uncontrolled or only partially controlled, further consideration of trace element emissions is warranted.

Trace element emissions of concern from the wood-fired sources tested include barium, calcium, potassium, and phosphorus. Ambient severity factors calculated from the mean of the emission factor from these sources exceed 0.05 for these elements. Overall removal efficiency of particulates and

nonvolatile trace elements from the five wood-fired units tested is estimated to be 36 percent.

Chromium, nickel, phosphorus, and vanadium emissions from distillate-oil-fired sources, and chromium, sodium, nickel, silicon, and vanadium emissions from residual-oil-fired sources are significant. Ambient severity factors, based on mean emission factors measured in this study, exceed 0.05. In addition, information in the existing

data base indicates that ambient severity factors can exceed 0.05 for chlorine, cobalt, fluorine, and magnesium emissions from residual-oil-fired boilers.

POM emissions from bituminous stokers and wood-fired boilers are potentially significant. Mean emission factors for total POM were 180 and 210 pg/J, respectively, for these sources. Although no active carcinogens were positively identified and ambient severity factors for most compounds were less

than 0.05, the possible presence of benzo(a)pyrene in significant amounts was indicated in the emissions of two wood-fired boilers and one bituminous stoker. Level 2 testing is needed to provide positive identification of the POM compounds emitted from these sources.

The samples of ash collected from the wood-fired sources were analyzed: for trace elements by SSMS; and for organic compounds, including POM, by GC/MS. Three types of samples were collected: bottom ash, cinder ash collected downstream of the combustion chamber, and fly ash collected by a particulate scrubber control device. Discharge severity, the ratio of the elemental concentration in the ash to the elemental health MATE value for solids, was used to evaluate the impact of ash disposal. A value in excess of 1 indicates that a potential environmental problem exists.

As shown in Table 1, the discharge severity is in excess of 1 for several trace elements. Elements of concern in bottom ash are barium, calcium, chromium, iron, potassium, manganese, nickel, phosphorus, and silicon. For cinder ash, discharge severities in excess of 1 were found for arsenic, barium, calcium, iron, potassium, manganese, nickel, phosphorus, and silicon. Fly ash elements of concern include calcium, chromium, iron, potassium, manganese, nickel, phosphorus, and silicon. If ecological effects are considered, several other elements will warrant concern because the ecology Discharge Multimedia Environmental Goal (DMEG) or MATE values for the pollutants of interest are generally lower than those for health. DMEG values are equivalent to MATE values and are derived through a series of models which use available data relating to properties of chemical toxicants for both health and ecological effects. DMEG values represent concentrations that will cause minimal adverse effects on either a human (health DMEG) or an ecological (ecological DMEG) receptor.

As anticipated, TCO and gravimetric organics were not present in significant amounts in bottom ash. Organics were generally found in greater amounts in cinder ash and fly ash, but are not of environmental concern. Although POM compounds were not found in the samples of bottom ash and cinder ash, they were found in the one sample of fly ash collected by a particulate scrubber. The POM compounds were identical to POM compounds collected downstream of

the scrubber by the SASS train at this site. Further, the relative distribution of these compounds in the scrubber ash and in the SASS samples was similar. Based on this, wood fly ash will present a definite hazard at sites emitting POM compounds such as benzo(a)pyrene. The compound benzo(a)pyrene was tentatively identified in the flue gas emissions of two uncontrolled wood-fired boilers during this study.

Conclusions

Several conclusions can be drawn from the characterization of emissions from industrial external combustion source:

- Industrial combustion sources in 1978 accounted for 25, 15, 9, 24, and 28 percent, respectively, of total nationwide emissions of particulates, NO_x, SO₂, CO, and HC emissions from external combustion sources.
- Flue gas emissions of NO_x from industrial boilers are environmentally significant. Ambient severity factors exceeded 0.05 for all of the source categories tested in this study, ranging from 0.25 for wood-fired stokers to 2.9 for bituminous, pulverized wet-bottom units.
- Flue gas emissions of SO₂ from the residual-oil- and bituminous-coal-fired sources are associated with ambient severity factors greater than 0.05 and, thus, are of environmental concern. The calculated SO₂ ambient severity factor of 0.07 for wood, shown in Table 1, is based on a fuel sulfur content of 0.1 percent. Normally the wood sulfur content will be lower than the assumed value of 0.1 percent and emissions from wood fuels containing less than 0.07 percent sulfur would not be of concern. Ambient severity factors for particulate sulfate from bituminous coal and wood combustion, and for SO₃ from the two source categories tested (bituminous, pulverized dry-bottom boilers and residual oil boilers) are in excess of 0.05 and warrant concern.
- Flue gas emissions of CO from industrial sources are of little concern. Ambient severity factors are less than 0.01 for all source categories.
- Flue gas emissions of HC are significant for bituminous stokers and wood boilers; ambient severity

factors determined in this study are 0.05 and 0.35, respectively.

- Flue gas emissions of particulate from uncontrolled solid-fuel-fired sources are of definite concern. Uncontrolled emissions of particulates from residual-oil combustion (ambient severity factor of 0.05) may also be significant. Well controlled sources are not expected to be a problem. High efficiency devices, such as ESPs, should adequately control particulate emissions from large bituminous pulverized units and stokers. Ambient severity factors less than 0.05 are achievable with control devices with efficiencies of 80 to 90 percent for wood-fired units of 50 x 10⁹ J/hr input capacity.
- Particle size distribution data for particulate emissions from solid-fuel-fired boilers are inadequate. The data generally exhibited high variability. Further study of source category/control device combinations is needed.
- Trace element emissions from controlled bituminous coal combustion sources are of concern. Bituminous stokers, probably because of less efficient control of particulates, were the largest emitters of trace elements and particulates. Elements of principal concern are arsenic, beryllium, chlorine, cobalt, chromium, iron, potassium, lithium, sodium, nickel, phosphorus, and lead.
- Trace element emissions of concern from wood-fired boilers are barium, calcium, potassium, and phosphorus. Mean ambient severity factors exceed 0.05.
- For distillate oil sources, trace element emissions of concern are chromium, nickel, phosphorus, and vanadium; for residual oil sources, chlorine, chromium, sodium, nickel, silicon, and vanadium are also associated with mean ambient severity factors in excess of 0.05 and, thus, are environmentally significant.
- Analysis of organic emissions from industrial sites indicates that the principal organic constituents are esters, ethers, glycols, and aliphatic and aromatic hydrocarbons. The most prevalent constituents are generally associated with MATE values in the 10 to 1000 mg/m³ range. Ambient severity factors will not exceed 0.05 at these MATE

levels. However, more detailed Level 2 analysis would be required to definitely identify compounds and establish their environmental significance.

- Flue gas emissions of POM from gas-fired sources were not significant. Compounds identified in highest concentrations were naphthalene and phenanthrene. The data base for POM emissions from gas-fired industrial sources is adequate.
- POM emissions from oil-fired sources were not significant. Biphenyl was emitted in small amounts from two residual-oil-fired boilers but the associated ambient severity factor was less than 0.001. The POM data base for oil-fired sources is adequate.
- POM compounds of potential environmental significance may be present in the flue gas emissions from bituminous stokers and wood-fired boilers. A compound, tentatively identified as benzo(a)pyrene, was found at some of these sites. Phenanthrene was also emitted in significant amounts from one of the wood-fired boilers. Level 2 GC/MS analysis is required to positively identify POM compounds and to establish the impact of the POM emissions from these source categories.
- The disposal of fly ash from wood combustion poses a potential hazard. Compounds, such as benzo(a)pyrene, if present in flue gas emissions, could be collected by the control device. The discharge severity of this compound in the ash could well exceed unity. In addition, discharge severities for several trace elements are appreciably greater than unity.

N. F. Surprenant, W. Battye, D. R. Roeck, and S. M. Sandberg are with GCA/Technology Division, 213 Burlington Road, Bedford, MA 01730.

Michael C. Osborne is the EPA Project Officer (see below).

The complete report, entitled "Emissions Assessment of Conventional Stationary Combustion Systems; Volume V. Industrial Combustion Sources," (Order No. PB 81-225 559; Cost: \$17.00, subject to change) will be available only from:

National Technical Information Service

5285 Port Royal Road

Springfield, VA 22161

Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Industrial Environmental Research Laboratory

U.S. Environmental Protection Agency

Research Triangle Park, NC 27711

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Postage and
Fees Paid
Environmental
Protection
Agency
EPA 335



Official Business
Penalty for Private Use \$300

PS 0000329
U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604