



Project Summary

Emissions Assessment of Conventional Stationary Combustion Systems:

Volume IV. Commercial/Institutional Combustion Sources

N. F. Surprenant, P. Hung, R. Li, K. T. McGregor, W. Piispanen, and S. M. Sandberg

This report characterizes air emissions from commercial/institutional external combustion sources and reciprocating engines and is the fourth of a series of five project reports characterizing emissions from conventional combustion sources. The emissions characterization of commercial/institutional combustion sources was based on a critical examination of existing data, followed by a modified Level I sampling and analysis approach to resolve data gaps. The major deviation from Level I procedures was the addition of GC/MS analysis for polycyclic organic matter (POM). Tests were conducted at 22 external combustion and 6 internal combustion sites.

The results of the environmental assessment indicate that air emissions from these sources represent a potential environmental hazard. Emissions of criteria pollutants, with the exception of carbon monoxide, from most of the source categories tested are environmentally significant. Particulate sulfate and SO₃ emissions from the

coal- and wood-fires sources are also significant. In addition, emissions of several trace elements are of concern: aluminum, barium, beryllium, calcium, chlorine, cobalt, chromium, copper, fluorine, iron, potassium, lithium, sodium, nickel, phosphorus, lead, silicon, and vanadium from coal-fired external combustion sources; nickel from distillate oil sources; and nickel, chlorine, chromium, 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 one wood-fired stoker 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 commercial/institutional external combustion sources for space heating and commercial/institutional internal combustion reciprocating engines are characterized in this report. The approach involves a critical review of existing emission data, followed by the conduct of a sampling and analysis program to fill gaps in the data base and to identify additional data needs. Specifically, the objectives of this program were:

- to compile and evaluate available air emissions data from commercial/institutional stationary conventional combustion processes,
- to acquire needed new emissions data from field tests of selected sources using modified Level I procedures,
- to characterize air emissions from commercial/institutional stationary conventional combustion processes, using both the existing data base and field test results, and
- to determine additional data needs, including identification of specific areas of data uncertainty.

Level I procedures use semiquantitative (plus or minus a factor of 3) techniques of sample collection and laboratory and field analysis: (1) to provide preliminary emissions data for waste streams and pollutants not adequately characterized; (2) to identify potential problem areas; and (3) to prioritize waste streams and pollutants in those streams for further, more quantitative testing. Using the information from Level I, available resources can be directed toward Level II testing which involves specific quantitative analysis of components of those streams that do contain significant pollutant levels. The data developed at Level II are used to identify control technology needs and to further define the environmental hazards associated with emissions.

Summary

The commercial/institutional external combustion sources evaluated in this report are sources used for space heating of trade establishments, health and educational institutions, and government facilities. These application areas are identical to those used by the Department of Energy (DOE) in compiling energy consumption data for the commercial sector. Commercial combustion units have also been defined as units with heat inputs ranging from 0.42 to

13.2×10^9 Joules (J)* per hour. However, this definition excludes many smaller and larger units used in the commercial/institutional sector. Institutional units especially tend to be appreciably larger than 13.2×10^9 J/hr and account for almost 20 percent of the commercial/institutional sector fuel consumption.

Commercial/institutional fuel consumption for space heating was 5.1×10^{18} J in 1978 based on DOE data for total fuel consumption and estimates of the fraction of this fuel used for space heating. This consumption value is less than 10 percent of the estimated 1978 national fuel consumption figure of 54×10^{18} J, excluding fuel used in the transportation sector. Commercial/institutional external combustion sources for space heating primarily use oil (52 percent) and gas (44 percent). Small amounts of coal and wood are also used by the commercial/institutional sector. Internal combustion sources in the commercial/institutional sector, primarily gas- and oil-fired reciprocating engines, are used for pumping municipal water and sewage. Small amounts of fuel may also be used by internal combustion sources for auxiliary power generation.

Heating systems for commercial/institutional sources are concentrated in areas of high population density such as the Northeast, Midwest, and parts of California. Oil consumption is most heavily concentrated in the Northeast with the States of New York, Massachusetts, New Jersey, and Pennsylvania consuming about 25 percent of the U.S. total. Commercial gas consumption for space heating is more widely distributed than oil, but is still most heavily concentrated in the Midwest and Northeast.

Commercial/institutional external combustion sources can be sold as either packaged units or boilers to be constructed onsite. Most units in the commercial sector are packaged units. Field-erected units, for the most part, are restricted to larger institutional facilities. Estimates of the total number of commercial external combustion sources have been reported and, according to these estimates, there are approximately 1.5×10^6 commercial sources. Most of the smaller units ($< 13.2 \times 10^9$ J/hr) are cast iron or firetube units, and only 5 percent of these

smaller units are of watertube design. Watertube units, however, constitute 100 percent of all units above 50×10^9 J/hr input.

Air pollution control equipment is generally not installed on the smaller commercial external combustion sources, although new burner designs, atomization methods, and furnace constructions are being studied to reduce emissions of NO_x and particulates. Burner modulation during periods of fluctuating demand, instead of on/off cycling, also reduces particulate and hydrocarbon emissions from oil-fired sources.

Gaseous and particulate emissions from the flue gas stacks are emphasized in this study of commercial/institutional combustion sources. Although some of the larger institutional external combustion systems are local sources of water pollution and fugitive particulate emissions from coal pile storage and ash disposal, their contribution to the national water pollution and fugitive emission burden is negligible. It is estimated, based on the amount of coal consumed by the commercial/institutional sector, that they contribute less than 1 percent of such emissions from all stationary combustion sources.

Evaluation of existing emissions data has indicated that the data base for gas- and oil-fired external combustion sources, although limited, is adequate for nitrogen oxides (NO_x), total hydrocarbon (HC), carbon monoxide (CO), particulate, and sulfur dioxide (SO_2). However, the existing data base for specific organic emissions for these sources is inadequate and, for the oil-fired sources, the existing data base for sulfur trioxide (SO_3) and trace elements is inadequate. Emissions data from solid fuel-fired sources are generally inadequate for all pollutants.

In the case of oil-fired internal combustion sources, data are inadequate for SO_3 , trace element, and specific organic emissions. Data for gas-fired reciprocating engines are adequate; however, one unit was tested in this program to confirm data adequacy.

Modified Level I sampling and analysis procedures were used in this emissions assessment of conventional combustion systems program. These procedures were developed as an integral part of the program and were published as a separate document. Although the procedures differ to some degree from official EPA Level I procedures, they have been used throughout this program

*1055 Joules (J) = 1 Btu. Although it is EPA policy to use the metric system, this report uses certain nonmetric units for convenience.

to ensure continuity of sampling and analysis.

Because of the deficiencies in the existing emissions data base, the following 22 external combustion systems were tested: five gas-fired, three distillate oil-fired, five residual oil-fired, three anthracite stokers, three bituminous stokers, two bituminous pulverized dry units, and one wood-fired stoker. Four oil-fired, one gas-fired, and one dual-fired internal combustion reciprocating engines were also tested. Specific sites were chosen based on the representativeness of the sites as determined by the important system characteristics within each source category, including system design, size, and age. Many of the sites tested fall within the commercial size classification range, although some, particularly the pulverized bituminous-fired units, greatly exceed the upper commercial size limit of 13.2×10^9 J/hr input capacity.

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 commercial/institutional 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 have been collected. This criterion was established in conjunction with analytical technique sensitivities to ensure that any emissions that would increase the ambient loading by more than 1 µg/m³ would be detected. The cyclones were deleted for the tests at the gas- and oil-fired sites because particulate loadings were too low to provide a weighable quantity of sample from each cyclone.

In addition to the SASS train, other equipment was used to collect gaseous components not captured by the train. A gas chromatograph (GC) with a flame ionization detector was used in the field to analyze C₁-C₆ hydrocarbons collected in gas sampling bags. Additionally, these samples were analyzed for CO,

carbon dioxide (CO₂), oxygen (O₂), and nitrogen (N₂) by the GC using a thermal conductivity detector. Field sampling for NO_x and SO₃ was also conducted at selected sites using a Method 7 train for NO_x (40 CFR 60, Appendix A, Method 7) and a modified Goksoyr-Ross train for SO₃ collection.

A modified Level I sampling and analytical procedure was used in this emissions assessment program. Major deviations from Level I Procedures were the addition of gas chromatography/mass spectroscopy (GC/MS) to the 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 emissions of previously tested gas- and oil-fired utility boilers and residential heating systems.

The Level I 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 emission factors. The primary tool for Level I inorganic analysis is the Spark Source Mass Spectrograph (SSMS). SSMS data were supplemented with Atomic Absorption Spectrometry (AAS) data for mercury (Hg), arsenic (As), and antimony (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 nitric acid rinse, and the first impinger solution. Fuel was also analyzed for the solid fuel- and oil-fired sources.

Level I 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; however, 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 most instrumental techniques used by Level I procedures, the first step in the analysis was to concentrate the sample fractions from as much as 100 ml to 10 ml in a Kuderna-Danish apparatus in which rinse solvent was evaporated while the organics of interest were retained. Kuderna-Danish concentrates were then evaluated by GC, gravimetric analysis, infrared spectrometry (IR), and sequential GC/MS.* The extent of the organic analysis was determined by the stack gas concentrations found for total organics (volatile and nonvolatile). If the total organics indicated a stack gas concentration below 500 µg/m³, further analysis was not conducted. If the concentration was above 500 µg/m³, a class fractionation by liquid chromatography was conducted followed by GC, gravimetric, and IR analyses. Fractions that contained more than the equivalent of 500 µg/m³ or were of special interest were also analyzed by low resolution mass spectroscopy (LRMS).

The results of the field measurement program for flue gas emissions from commercial/institutional sources, along with supplementary values obtained from the existing data base for certain pollutants, are presented in Table 1. Also listed in this table 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.

The emission factors shown in Table 1 are uncontrolled emissions factors. However, in the case of the solid fuel-fired combustion categories, some degree of particulate control does exist in the commercial/institutional sector. Overall particulate control efficiency is estimated to be 40 percent for bituminous, pulverized dry bottom boilers and 20 percent for all stokers. Gas- and oil-fired units are essentially uncontrolled.

*The major modification in the Level I sampling and analysis procedure was the GC/MS analysis for polycyclic organic matter (POM).

Table 1. Summary of Emissions Characterization of Commercial/Institutional Combustion Sources

Pollutant ^a	Combustion source category																	
	Gas-fired boilers		Distillate oil-fired boilers		Residual oil-fired boilers		Bituminous, pulverized dry bottom		Bituminous stokers ^b		Anthracite stokers		Wood stokers		Gas-fired reciprocating engines		Oil-fired reciprocating engines	
	Emission factor (ng/J)	Ambient severity factor ^c	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor	Emission factor (ng/J)	Ambient severity factor
Particulates	2	0.0007	6	0.0022	37	0.014	3,406	2.6	1,075	0.43	145	0.05	215	0.08	5	0.001	40	0.01
NO _x	50	0.08	68	0.11	172	0.28	352	1.2	117	0.19	145	0.24	10	0.017	1,390	1.66	1,420	1.7
SO ₂	0.26	<0.0001	106	0.028	464	0.12	766	0.42	766	0.2	314	0.08	65	0.017	0.26	0.0001	97	0.017
CO	8	<0.0001	8	<0.0001	8	<0.0001	20	0.0002	195	0.0008	15	<0.0001	100	0.0004	300	0.0009	400	0.0001
HC	3	0.0026	3	0.0026	3	0.0026	6	0.01	59	0.05	5	0.004	100	0.09	400	0.25	300	0.18
Particulate sulfate ^d	—	—	—	—	0.03	0.001	2.1	0.12	3.5	0.10	27.2	0.78	3.5	0.10	—	—	—	—
SO ₃	—	—	—	—	—	—	1.0	0.07	12.2	0.44	19.3	0.07	—	—	—	—	—	—
Trace elements	—	—	0.015	<0.0001	0.156	0.009	27.5	0.323	8.7	0.048	29.5	0.163	0.031	<0.001	—	—	0.288	0.001
Al	—	—	0.0084	0.0005	0.0095	0.0006	4.24	0.517	1.33	0.077	0.278	0.016	0.010	—	—	—	0.011	<0.001
Be	—	—	0.00004	0.0005	0.00007	0.0009	0.132	4.026	0.04	0.62	0.006	0.072	—	—	—	—	—	—
Ce	—	—	0.845	0.0056	0.780	0.0050	40.7	0.497	12.8	0.074	0.872	0.006	0.627	0.004	—	—	0.107	<0.001
Co	—	—	0.0023	0.0013	0.023	0.0133	0.430	0.534	0.14	0.079	0.028	0.016	0.001	<0.001	—	—	0.0005	<0.001
Cr	—	—	0.036	0.0104	0.050	0.0144	0.825	0.563	0.26	0.084	0.376	0.109	0.004	0.002	—	—	0.006	0.001
Cu	—	—	0.205	0.0059	0.093	0.0028	0.605	0.037	0.19	0.006	0.175	0.005	0.004	<0.001	—	—	0.174	0.004
F	—	—	0.014	<0.0001	0.085	0.0003	3.245	0.079	1.02	0.012	0.270	0.003	0.015	<0.001	—	—	—	—
Fe	—	—	0.545	0.0032	0.379	0.0022	16.5	0.201	5.21	0.030	6.00	0.034	0.205	0.001	—	—	0.110	<0.001
K	—	—	0.060	0.0009	0.213	0.0031	10.5	0.320	3.31	0.048	2.856	0.041	1.48	0.021	—	—	0.144	0.001
Li	—	—	0.0015	0.0020	0.001	0.0013	1.155	3.203	0.36	0.477	0.079	0.104	0.001	0.001	—	—	0.0003	<0.001
Na	—	—	0.101	<0.0001	0.418	0.0022	20.35	0.248	0.42	0.036	0.825	0.005	0.024	<0.001	—	—	0.091	<0.001
Ni	—	—	0.112	0.0324	0.804	0.236	1.045	0.637	0.33	0.095	0.355	0.102	0.004	0.001	—	—	0.020	0.004
P	—	—	0.0057	0.0002	0.107	0.0031	4.675	2.852	1.48	0.425	2.11	0.578	0.137	0.039	—	—	0.016	0.003
Si	—	—	0.173	0.0005	1.610	0.0047	78.0	0.476	24.6	0.071	33.8	0.098	1.03	0.003	—	—	0.945	0.002
V	—	—	0.030	0.0002	3.66	2.05	1.375	0.167	0.43	0.025	0.170	0.010	0.0002	<0.001	—	—	0.004	<0.001
Total POM	0.010	—	0.020	—	0.044	—	0.002	—	0.5	—	0.003	—	26	—	—	—	0.430	—

^a = No data.

^bUncontrolled emissions.

^cEmission factors for criteria pollutants adjusted to reflect a capacity weighted distribution of stoker types.

^dAmbient severity factor is 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. A value greater than 0.05 indicates a potential problem.

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

Control measures for other criteria pollutants are not used by commercial/institutional combustion sources.

As can be seen from Table 1, the criteria pollutants of concern are particulates from all uncontrolled solid fuel-fired combustion sources, NO_x from all source categories with the exception of wood-fired stokers, SO₂ from residual oil- and coal-fired sources, and HC from bituminous- and wood-fired stokers and internal combustion reciprocating engines. Ambient severity factors are all greater than 0.05 for these pollutant/source combinations. Emissions of CO from all combustion source categories do not appear to represent an environmental problem. Emissions of particulate sulfate and SO₃ from the solid fuel-fired combustion sources tested do appear to represent a problem since ambient severity factors exceed 0.05.

The trace element data shown in Table 1 indicate that many trace elements emitted by uncontrolled fossil fuel-fired combustion sources are of concern. Chlorine emissions, although not shown in the table, should also be of concern for residual oil and coal burning sources based on the chlorine content

of these fuels. Ambient severity factors are generally greatest for bituminous, pulverized dry bottom boilers because of the larger capacity of these units. However, ambient severity factors exceed 0.05 for many trace elements emitted by the smaller stoker-fired units. Elements of greatest concern appear to be aluminum, barium, beryllium, chromium, lithium, nickel, phosphorus, and silicon. Emissions of nickel from distillate oil sources, and nickel, chromium, and vanadium from residual oil sources are also significant. Ambient severity factors based on the upper limit emission factor exceed 0.05. Information found in the existing data base would also indicate that ambient severity factors can exceed 0.05 for chlorine, cobalt, and magnesium emissions from residual oil combustion. Because many commercial/institutional fossil fuel-fired sources are totally uncontrolled or only partially controlled, further consideration of trace element emissions from these sources appears warranted.

POM emissions from some of the commercial/institutional sources tested are of significance. Of most concern were POM emissions from an underfired

stoker unit burning wood fuel during one test and bituminous coal during a second test. POM emission factors were extremely high for these tests, 15,000 and 26,000 pg/J, respectively, for coal and wood combustion. In addition, at least one active carcinogen, dibenz(a,h)anthracene, was identified, and the presence of other carcinogens (e.g., benzo(a)pyrene and benzo(g,h,i)perylene) was indicated. Level II analysis is needed to provide positive identification of the POM compounds emitted by this stoker. It should be noted that this unit was operated at low heat input levels during both test periods. This operating condition would result in lower furnace temperatures and probably inefficient combustion, factors that would favor formation of POM compounds. Emissions of POM compounds from all other external combustion sources were not significant; levels were low (0 to 50 pg/J) and the compounds identified were primarily naphthalene and its derivatives.

POM emissions from the oil-fired (and dual-fired) reciprocating engines were relatively high, in the range of 100 to 800 pg/J. However, these emission

levels were similar to those found in the existing data base for oil-fired engines, and ambient severity factors did not exceed 0.05 for any of the compounds detected. The high POM emissions measured for the dual-fired engine were somewhat surprising because the quantity of oil used represented only 5 percent of the total thermal input. No POM emissions were detected from the engine fired solely by gas.

Conclusions

Several conclusions, listed below, can be drawn from this emissions assessment of commercial/institutional combustion sources:

- Emissions of particulate, NO_x, SO₂, CO, and HC from commercial/institutional sources represent approximately 1.7 percent, 4.9 percent, 3.0 percent, 0.5 percent, and 0.7 percent, respectively, of total emissions from stationary combustion sources. Despite this relatively minor contribution to national emissions, criteria pollutant emissions from individual combustion sources can have a significant local impact as noted below.
- Flue gas emissions of NO_x from all of the commercial/institutional source categories studied in this program, with the exception of a wood-fired stoker tested at low load conditions, are of concern. Ambient severity factors exceed 0.05 and, thus, individual sources can have a significant local impact.
- Flue gas emissions of SO₂ from the coal-fired and residual oil-fired combustion sources are associated with ambient severity factors greater than 0.05 and, thus, are of environmental significance. Ambient severity factors associated with particulate sulfate and SO₃ emissions from the solid fuel-fired sources tested also exceed 0.05 and are of concern.
- Flue gas emissions of particulates from uncontrolled solid fuel-fired sources are associated with high ambient severity factors. Moderate-to-high efficiency control devices are required in many cases to reduce severity factors to 0.05. Because the application of particulate control devices to solid fuel-fired commercial/institutional combustion sources is not extensive, these sources are of practical concern.

- Flue gas emissions of total hydrocarbon are significant for commercial/institutional bituminous stokers, wood stokers, and reciprocating engines. Ambient severity factors exceed 0.05 for these combustion source categories.
- Flue gas emissions of CO do not appear to be a problem. Ambient severity factors for all source categories are 0.001 or less.
- Particle size distribution data for particulate emissions from solid fuel-fired sources are inadequate. Data collected in this study exhibit large variability and contribute little to the limited information contained in the existing particle size distribution data base.
- Trace element emissions from uncontrolled coal-fired combustion sources are of concern. Elements with ambient severity factors in excess of 0.05 include aluminum, barium, beryllium, calcium, chlorine, cobalt, chromium, copper, fluorine, iron, potassium, lithium, sodium, nickel, phosphorus, lead, silicon, and vanadium. Emissions of other elements also could be of significance given the variability of the elemental content of coals.
- Nickel emissions from distillate oil combustion sources, and nickel, chlorine, chromium, and vanadium

emissions from residual oil combustion sources are of concern. Ambient severity factors for these elements exceed 0.05.

- Flue gas emission data for POM compounds from gas- and oil-fired commercial/institutional sites appear to be adequate. Emission levels are generally low and the compounds that were detected have relatively high MATE values. Ambient severity factors for the compounds detected are all below 0.05.
- Flue gas emission data for POM compounds from solid fuel-fired combustion sources are still inadequate. Level II techniques should be used to study emissions from small coal- and wood-fired combustion sources. The effect of heat input levels, on/off operating modes, excess air levels, and other operating parameters on POM emissions should be studied in more detail. If these factors are found to contribute significantly to POM emissions, studies to determine the prevalence of contributory source operating parameters in the commercial/institutional sector should be undertaken to establish the magnitude of the problem.

N. F. Surprenant, P. Hung, R. Li, K. T. McGregor, W. Piispanen, and S. M. Sandberg are with GCA Corporation, 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 IV. Commercial/Institutional Combustion Sources," (Order No. PB 81-145 187; 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

.

.

.

.