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Project Summary

Evaluation of Emissions from the Open Burning of Land-Clearing Debris

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The exposure of persons to combustion emissions during land clearing has become an issue of increasing concern. This study identifies and quantifies a broad range of pollutants that are discharged during small-scale, simulated, open combustion of land-clearing debris and reports these emissions relative to the mass of material combusted. Two types of land-clearing debris (representing the typical land-clearing debris found in Florida and Tennessee; primarily wood and other organic debris) were combusted in a facility designed to simulate open burning. One debris sample was also combusted in the same facility using a simulated air curtain incinerator. Volatile, semivolatile, and particulate-bound organics were collected and analyzed by gas chromatography/mass spectrometry. The emphasis of the analyses was on the quantification of hazardous air pollutants listed in Title III of the Clean Air Act Amendments of 1990 (CAAA), although further efforts were made to identify and quantify other major organic components. Fixed combustion gases (carbon dioxide, carbon monoxide, nitric oxide, oxygen, and total hydrocarbons) were monitored continuously throughout the test period.

This project produced estimated emissions data for a broad range of atmospheric pollutants from a simulated open debris combustion process. Both air pollutant concentrations within the facility where combustion was taking place, and estimated emissions expressed as mass of pollutant per mass of debris material consumed by combustion were reported for volatile, semivolatile, and particulate bound organics, typical combustion gases, and particulate. Substantial emissions of a large number of pollutants including carbon monoxide, PM_{10}, $PM_{2.5}$, benzene, acetone, toluene, ethyl benzene, pinene, naphthalene, phenol, and 14 polycyclic aromatic hydrocarbons were observed. QA/QC requirements apply to this project. Data are supported by QA/QC documentation as required by the US EPA's QA Policy.

These tests did not provide conclusive evidence of the effectiveness of air curtain combustors in reducing emissions. While the emissions of some pollutants seemed to be decreased, others were unchanged or, in a few cases, appeared to increase.

This Project Summary was developed by EPA's National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, 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

Disposal of debris generated by land clearing or landscaping has long been problematic. Land clearing is required for a wide variety of purposes such as construction, development, and clearing after natural disasters. The resultant debris is primarily vegetative, but may include inorganic material. Landscaping such as pruning often generates similar vegetative de-

bris. This debris is often collected and disposed of by municipalities. Open burning or burning in simple air curtain incinerators is a common means of disposal for these materials, and has long been a source of concern. Air curtain incinerators use a blower to generate a curtain of air, (for brevity, in this document "with blower" is used to describe tests in which an air curtain incinerator was used) to enhance combustion taking place in a trench or a rectangular shaped, open-topped refractory box. For instance, in Detroit, the problem of municipal burning of brush, logs, and stumps became so severe that in September 1958, the mayor appointed a committee to study this problem among others. This eventually led to the design and construction of a specially designed incinerator in 1961-62 for brush and log burning, which was more complex than an air curtain incinerator, at a cost of $250,000. In many locations open burning or the use of simple air curtain incinerators is still the method of choice for the disposal of these materials.

An evaluation of literature on emissions from open air burning of debris shows a limited amount of information on emission factors for specific pollutants measured in such a way that emissions could be estimated and therefore modeled. Several similarities can be drawn from the literature reviewed. Most of the available data focus on only a few classes of pollutants. The list of pollutants for which emission factors are available does not include most of the air toxic compounds listed in the Clean Air Act Amendments of 1990 (CAAA). However, the rough order of magnitude agreement in the total particulate and total hydrocarbon (THC) emission factors reviewed over a wide variety of source types is notable.

Local air regulatory agencies, including those in Tennessee and Broward County (Florida), requested that more detailed information on the emissions from these processes be made available. Therefore, EPA's Control Technology Center (CTC) steering committee proposed a research project examining emissions from the open burning of debris.

In response to these concerns, through the guidance of EPA's Air Pollution Prevention and Control Division (APPCD), a study was undertaken to measure emissions from the simulated open combustion of land-clearing debris. This study included replicated simulated open burning tests of debris from Florida and Tennessee and replicate tests with a simulated air curtain incinerator for the Tennessee debris. The study was designed to collect, identify, and quantify a wide range of air emissions and to report these emissions per mass of debris material combusted. The emphasis of these analyses was on the quantification of air toxics compounds listed in the CAAAs, although further efforts were made to identify and semiquantify other major organic components.

Experimental

The project consisted of a replicate study to collect and qualitatively and quantitatively characterize organic and particulate emissions resulting from the simulated open combustion of land-clearing debris. Small quantities (11.3 to 17.8 kg [25 to 39 lb]) of wood, sticks, twigs, leaves, and other organic matter were combusted in a refractory lined pit within a test facility designed to simulate open-combustion conditions. Sampling was conducted within the facility through a modified dichotomous sampler using 142 mm filter heads for particulate with an aerodynamic diameter < 2.5 μm ($PM_{2.5}$) and particulate with an aerodynamic diameter < 10 μm (PM_{10}). Volatile organics were sampled using SUMMA® canisters, and semivolatiles were sampled using a PUF/XAD TO-13 sampling train. A portion of the combustion effluent was diverted to an adjacent sampling facility via an induced draft duct. A portion of the sample from the induced draft duct was also analyzed by a series of continuous emission monitors for carbon dioxide (CO_2), carbon monoxide (CO), nitric oxide (NO), oxygen (O_2), and THC. The organic constituents were analyzed both qualitatively and quantitatively using a gas chromatograph/mass spectrometer (GC/MS). Measured concentrations were related to dilution air volumes and measured net mass of debris combusted to derive emission rates.

The EPA's Open Burning Simulation Facility was used in this study. A simulated air curtain combustor was constructed for the tests of this system based on an analysis of specifications of pilot- and full-scale units of this type.

Before each test, a sample of debris was removed from the crate of either Florida or Tennessee samples provided by cooperating state and local government personnel and placed in the refractory burn box (RBB). The wood and other materials were arranged in the RBB to allow for easy lighting and total consumption of burn material. For these tests, 11.3 to 17.8 kg (25 to 39 lb) of material was placed in the RBB. Before and after each test, or before and after each change of sample media (if this occurred more frequently), all sampling trains were leak checked. Before the beginning of each test day, at least 15 min of background data were acquired on the continuous emission monitors (CEMs), thermocouples, and the scale platform. The burn was then ignited by a brief application of a handheld propane torch, which was removed before sampling began. During a typical test, sufficient combustion began after less than 5 min of torch operation. The air curtain was started immediately after the removal of the lighting torch in tests involving this system. All sampling started 2-min after removal of the torch from the burn hut. This 2-min period was designed to ensure exhaust of any propane combustion vapors.

To allow adequate time for all necessary emissions samples to be obtained, some tests had another charge of debris added. Combustion of charge was allowed to go to apparent completion (as signified by unchanging weight and near background concentrations of combustion gases) before completion of the run. Combustion of one charge was allowed to go to apparent completion before another charge was introduced.

A "hut blank" test, in which the propane torch was briefly introduced into the facility but no debris was combusted, was conducted for comparison purposes. In addition, various field and laboratory blank samples were collected for each sampling train.

After completion of the chemical analyses, analyte concentration data were coupled with sample volume, facility air flow, and combustible material mass loss data to derive estimated emissions (expressed as mass of analyte produced per mass of debris material consumed in the combustion process).

Results and Discussion

Estimated emissions on a mass emitted per mass consumed by combustion basis of CO and THC appear broadly similar for the Tennessee and Florida materials in the no-blower case (Table 1). These values appear to agree within a factor of two with those measured by Gerstle and Kemnitz for "Landscape Refuse." Estimated emissions of CO and THC for the Tennessee material appear to be little impacted or at best slightly decreased by the use of the air curtain incinerator.

Substantial emissions of PM_{10} and $PM_{2.5}$ particulate matter were observed with both types of debris materials combusted (Table 2). Particulate catches on a mass/volume basis during hut blank tests were at least tenfold lower than during any actual com-

Table 1. *Targeted Volatile Compounds Estimated Emissions (mg/kg)*

Test No.	1	2	3	4	5	6	7	8
Sample ID	TN	TN	FL	FL	Hut	TN	TN	Hut
Compound	nb	nb	nb	nb	Blank	wb	wb	Blank
dichlorodifluoromethane	<2	<3	<2	<2	NA	<1	<2	NA
dichlorotetrafluoroethane	<7	<8	<6	<6	NA	<4	<4	NA
chloromethane	6	6	133	55	NA	4	5	NA
vinyl chloride	<1	<1	<1	<1	NA	<1	<1	NA
1,3-butadiene	141	116	108	41	NA	135	140	NA
bromomethane	<2	<2	2	<2	NA	<1	<1	NA
chloroethane	<2	<2	<1	<1	NA	<1	<1	NA
trichlorofluoromethane	<3	<3	<2	<2	NA	< 1	<2	NA
dichlorotrifluoroethane	<3	<3	<3	<2	NA	<2	<2	NA
trichlorotrifluoroethane	<4	<4	<3	<3	NA	<2	<2	NA
1,1-dichloroethene	<2	<2	<2	<2	NA	<1	<1	NA
acetone	224	198	209	84	NA	180	123	NA
carbon disulfide	<1	<2	<1	<1	NA	<1	<1	NA
methylene chloride	4	4	<2	2	NA	<2	<2	NA
3-methylpentane	<2	<2	<2	<1	NA	<1	<1	NA
1,1-dichloroethane	<2	<2	<2	<2	NA	<1	<1	NA
butyl methylether	<2	<2	<2	2	NA	<1	<1	NA
cis-1,2-dichloroethene	<2	16	31	33	NA	28	13	NA
2-butanone	42	36	40	16	NA	30	19	NA
ethyl acetate	42	36	40	16	NA	30	19	NA
chloroform	<2	<3	<2	<2	NA	<1	<2	NA
1,1,1-trichloroethane	<3	<3	<2	<2	NA	<1	<2	NA
carbon tetrachloride	<3	<4	<3	<3	NA	<2	<2	NA
benzene	346	325	258	132	NA	273	270	NA
1,2-dichloroethane	<2	<2	<2	<2	NA	<1	<1	NA
trichloroethene	<3	<3	<2	<2	NA	<1	<2	NA
1,2-dichloropropane	<2	<2	<2	<2	NA	<1	<1	NA
cis-1,3-dichloropropene	<2	<2	<2	<2	NA	<1	<1	NA
dimethyl disulfide	<2	<2	<2	<2	NA	<1	<1	NA
4-methyl-2-pentanone	<2	<2	<2	<2	NA	<1	<1	NA
octane	8	6	5	3	NA	<1	5	NA
toluene	207	179	147	65	NA	165	212	NA
trans-1,3-dichloropropene	<2	5	<2	<2	NA	<1	<1	NA
1,1,2-trichloroethane	<3	<3	<2	<2	NA	<1	<2	NA
tetrachloroethene	<3	<4	<3	<3	NA	<2	<2	NA
butyl acetate	<2	<3	<2	<2	NA	<1	<1	NA
1,2-dibromoethane	<4	<4	<3	<3	NA	<2	<2	NA
chlorobenzene	<2	<2	<2	<2	NA	<1	<1	NA
nonane	<2	<3	<2	<2	NA	<1	<1	NA
ethyl benzene	37	29	21	9	NA	27	35	NA
m,p-xylene	89	70	46	18	NA	86	151	NA
o-xylene	21	17	15	7	NA	17	19	NA
styrene	76	70	40	17	NA	59	86	NA
pinene	54	137	<2	<2	NA	80	124	NA
1,1,2,2-tetrachloroethane	<3	<4	<3	<3	NA	<2	<2	NA
decane	<3	<3	<3	<2	NA	<2	2	NA
4-ethyltoluene	29	23	12	5	NA	27	51	NA
1,3,5-trimethylbenzene	5	4	3	<2	NA	4	5	NA
1,2,4-trimethylbenzene	18	14	11	4	NA	15	25	NA
limonene	99	84	<2	<2	NA	51	92	NA
1,3-dichlorobenzene	<3	<3	<3	<2	NA	<2	<2	NA
1,4-dichlorobenzene	<3	<3	<3	<2	NA	<2	<2	NA
benzyl chloride	2	<3	<2	<2	NA	2	3	NA
undecane	4	4	<3	<3	NA	2	6	NA
1,2-dichlorobenzene	<3	<3	<3	<2	NA	<2	<2	NA
dodecane	4	<4	<3	<3	NA	2	4	NA
1,2,4-trichlorobenzene	<3	<4	<3	<3	NA	<2	<2	NA
hexachlorobutadiene	<5	<6	<5	<4	NA	<3	<3	NA
naphthalene	69	73	48	24	NA	42	53	NA

nb = no blower, wb = with blower, NA = not applicable, nd = not detected.

Table 2. *Particulate Data*

Test No.	Test Conditions	Concentration $PM_{2.5}$ (mg/m^3)	Concentration PM_{10} (mg/m^3)	Estimated Emission $PM_{2.5}$ (g/kg)	Estimated Emission PM_{10} (g/kg)
1	TN No Blower	30.51	36.30	14.13	16.81
2	TN No Blower	18.75	19.13	10.04	10.25
3	FL No Blower	3.95	17.54	1.75	7.75
4	FL No Blower	11.63	11.90	4.56	4.66
5	Hut Blank	0.11	0.29	NA	NA
6	TN With Blower	45.15	45.77	12.07	12.23
7	TN With Blower	35.73	37.82	8.33	8.82
8	Hut Blank	0.07	0.26	NA	NA

bustion test (Table 2). This indicates that most of the particulate collected was actual combustion emissions and not particulate being resuspended from the burn hut walls or present in the ambient air fed into the facility. Estimated emissions on a mass particulate per mass material combusted basis from the Tennessee material appeared to be substantially higher than those from the Florida material. The Tennessee material without the blower gave fairly consistent values in replicate tests. The Tennessee material with the blower, in one case, gave a value that appeared similar to the value without the blower. In the next (duplicate) test, it gave values somewhat lower than those typical without the blower. However, in this test the sample was obtained for only a short period due to an equipment malfunction, and the flow rate did not meet data quality indicator goals. In other tests, data quality was acceptable for this measurement. In almost all cases, regardless of source of material or use of blower, most of the PM_{10} appears to be composed of very fine material (<2.5 μm diameter). This is an important observation because many believe that fine particulate is more strongly associated with health effects than coarse particulate. Our average estimated PM_{10} emissions agree within ±25% with those measured by Gerstle and Kimnitz for total particulate, perhaps due to this predominance of fine particulate.

The volatile organic data set produced from these tests included concentration measurements for more than 55 targeted and several dozen tentatively identified species. Targeted species are defined as those for which the analytical instrument was calibrated. Tentatively identified species are other compounds found in the sample that can be tentatively identified through searches of mass spectral libraries checked by investigator examination of the mass spectral match. Approximately 19 of the targeted species were consistently detectable. Results of the volatiles analyses of the targeted analytes are presented in Table 1 as estimated emissions on a mass of pollutant per mass of material consumed by combustion basis.

Various hydrocarbon, aromatic, and oxygenated species, such as benzene, acetone, toluene, ethyl benzene, m, p-xylene, pinene, limonene, naphthalene, and styrene, were among the highest concentration targeted volatiles observed. In general, emissions of these species were higher with the Tennessee material than with the Florida material. This trend was most dramatic for pinene and limonene, two compounds that belong to the terpene group that is often isolated from plants.

The data set is inconclusive on the effect of the air curtain incinerator on volatiles emissions. Emissions of many compounds appear unchanged and, while some species appear to be emitted at a lower rate with the air curtain in operation, emissions of others may be increased.

Alkenes, ketones, heteroaromatics, and alkyl-substituted aromatics are prominent among the tentatively identified volatile compounds.

More then 100 semivolatile species were targeted in these analyses. Approximately 23 of these species were consistently detected in the combustion samples at levels significantly above blank levels. Of these 23 species, 14 are polycyclic aromatic hydrocarbons (PAHs). These have been detected in numerous studies of wood combustion, so their appearance in a study of the combustion of land-clearing debris is expected. The range of estimated emissions reported in this document agree broadly with those reported by Cooper for various PAH species from wood combustion in fireplaces. Of the 23 species detected, 4 were phenol and its methyl substituted derivatives. Phenols have also been previously established as wood combustion byproducts. The values measured here for estimated emissions of phenol are slightly higher then those measured by Cooper for wood combustion in fireplaces. The remaining five consistently detected species were biphenyl, styrene, cumene, 2-methylnaphthalene, and dibenzofuran.

The results of the tests without the air curtain incinerator showed that concentrations of individual semivolatile species were usually similar for the Florida and Tennessee materials, but a few species were emitted at a moderately higher rate from combustion of the Tennessee material. A brief analysis of this data set suggests that, for most semivolatile species, no discernible difference in emission factor between the with and without air curtain incinerator tests can be observed. However for a few species, such as pyrene, benzo(a)pyrene, and biphenyl, use of the air curtain does appear to reduce emissions.

Numerous tentatively identified species were also identified in the semivolatile analyses. These species consist primarily of alkylated and oxygenated aromatics, heteroaromatics, and polyaromatics.

Summary and Conclusions

This project produced estimated emissions data for a broad range of atmospheric pollutants from a simulated open

debris combustion process. Both air pollutant concentrations within the facility where combustion was taking place and estimated emissions expressed as mass of pollutant per mass of debris material consumed by combustion were reported for volatile, semivolatile, and particulate-bound organics, typical combustion gases, and particulate. Substantial emissions of a large number of pollutants including CO, PM_{10}, $PM_{2.5}$, benzene, acetone, toluene, ethyl benzene, pinene, naphthalene, phenol, and 14 PAHs were observed. These tests did not provide conclusive evidence regarding the effectiveness of air curtain blowers in reducing emissions. While the emissions of some pollutants seemed to be decreased slightly, others were unchanged or, even in a few cases, appeared to increase. A definitive assessment of the value of the air curtain device cannot be made without a detailed statistical and relative risk analysis. Measurements of a variety of pollutants in the emissions of full-scale models of this device operating under realistic work site conditions would also be helpful.

This project has yielded estimated emissions values for open debris combustion processes that can be used to assess the risks of these processes.

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***Paul M. Lemieux** is the EPA Project Officer (see below).*
The complete report, entitled "Evaluation of Emissions from the Open Burning of Land-Clearing Debris," (Order No. PB97-115356; Cost: $28.00, subject to change) will be available only from:
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