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Project Summary

Evaluation of Emissions from the Open Burning of Household Waste in Barrels

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The report gives results of a detailed emissions characterization study to examine, characterize, and quantify emissions from the simulated burning of household waste materials in barrels. The study evaluated two experimental conditions: that of an avid recycler, who removes most of the recyclable content from the waste stream prior to combustion; and that of a non-recycler, who combusts the entire stream of household waste. Estimated emissions were developed in units of mass emitted per mass of waste burned. Continuous gas samples were analyzed for oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2), nitric oxide (NO), and total hydrocarbons (THCs). Gas-phase samples were collected using SUMMA® canisters and analyzed by gas chromatography/mass spectrometry (GC/MS) for volatile organic compounds (VOCs). Extractive samples from the combined particulate- and gas-phase were analyzed for semivolatile organic compounds (SVOCs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorobenzenes (CBs), polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs), aldehydes and ketones, hydrogen chloride (HCl), hydrogen cyanide (HCN), and metals. Emissions of particulate matter (PM) with aerodynamic diameters of 10 m or less (PM_{10}) and of 2.5 μm or less ($PM_{2.5}$) were also measured. Ash residue samples were analyzed for SVOCs, PCBs, PCDDs/PCDFs, and metals.

For most of the non-chlorinated compounds, including VOCs, SVOCs, PAHs, and aldehydes and ketones, emissions from the non-recycler were higher, both on a per mass burned basis and on a per day basis (using waste generation estimates from New York State). However, emissions of many of the chlorinated organics, particularly CBs and PCDDs/PCDFs, were higher from the avid recycler, on a per mass burned basis. From estimates of waste generated each day by New York households for the avid recycler and non-recycler scenarios, emissions per day of PCDDs/PCDFs are significantly higher for the avid recycler. Emissions of PCBs were higher from the non-recycler: although its cause is not known for certain, this phenomenon is likely the result of several factors, including the higher mass fraction of PVC in the avid recycler's waste. It is also possible that some component of the non-recycler's waste may poison the metallic catalysts believed to be responsible for enhancing formation rates of PCDDs/PCDFs. Results from HCl sampling indicated much higher HCl emissions from the avid recycler, which is consistent with the higher emissions of chlorinated organics, and ash residue analysis indicated that the avid recycler's residue had more copper, which could contribute to higher emissions of PCDDs/PCDFs. The temperature at the base of the burning bed was significantly lower for the avid recycler than for the non-recycler. Gas-phase emissions of metals were

not a strong function of the test conditions. PM emissions were much higher from the non-recycler. Almost all of the PM emissions from both test conditions were < 2.5 μmin diameter.

This Project Summary was developed by the 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

In many areas of the country, residential solid waste disposal practices consist of open-burning using barrels or other similar devices instead of, or in addition to, disposal to municipal landfills or municipal solid waste combustors. The motivations for households that open-burn their garbage may include convenience, habit, or landfill and cost avoidance. Some communities have regulations which ban the open burning of garbage. Emissions from backyard burning of residential solid waste are released at ground level resulting in decreased dilution by dispersion. Additionally, the low combustion temperature and oxygen-starved conditions associated with backyard burning may result in incomplete combustion and increased pollutant emissions. In contrast, modern refuse combustors have tall stacks and specially designed combustion chambers, which provide high combustion temperatures, longer residence times, and better waste agitation while introducing air for more complete combustion.

The New York State Departments of Health (NYSDOH) and Environmental Conservation (NYSDEC), as well as regulatory agencies in other states, requested that the EPA's Control Technology Center (CTC) characterize emissions due to open burning of residential waste in burn barrels using techniques that would minimize the limitations of previous studies. The CTC, NYSDOH, and NYSDEC performed a cooperative study to: 1) characterize and fabricate the waste to be burned (in duplicate), 2) measure the emission rates of many pollutants of concern, 3) measure these pollutant concentrations in the residual ash (except for the VOCs), 4) measure the volume of ambient air entering the burn facility, and 5) be representative of the combustion conditions typically found in a backyard burner. The study was conducted under the direction of the EPA's National Risk Management Research Laboratory, Air Pollution Prevention and Control Division (APPCD). The combustion tests were conducted by APPCD's on-site contractor, Acurex Environmental Corporation with the oversight of representatives from APPCD and NYSDOH. Analytical chemistry work was divided between Acurex and NYSDOH staffs.

Experimental Approach

The study qualitatively identified and quantitatively measured the emissions of hazardous air pollutants from the open burning of household residential refuse in barrels. A secondary objective was to evaluate the concentrations of hazardous compounds in the residual ash. The target audience for this work is the scientific community at large as well as state and local regulatory agencies. The major intended end use of the data is to place the emissions from these processes in proper perspective with respect to other point and area sources and to provide estimated emissions values that can serve as inputs to a risk assessment for the barrel burning process. This work is intended to provide a sufficiently broad survey of the emissions from this process to allow evaluation of the need for further study of this practice. It should be noted that most risk assessment exercises currently include sources of uncertainty so great that the true risk can only be stated to be within a range of one or more orders of magnitude. Thus, the formal data quality objective for this study was stated as follows.

Emissions from two categories of waste were analyzed in this study (Table 1): waste from avid recycling and non-recycling families of four. To reduce the amount of different types of material to be collected for the tests, percentages for like materials were combined (e.g., percentages for newspaper, books, and office paper have all been combined) and percentages for "miscellaneous" items for each category were added to the items that make up the largest percent for that category. Household hazardous waste (e.g., household chemicals, paint, grease, oils, tires and other vehicle parts) were not included in the waste to be burned. For the recycling and non-recycling scenarios, 6.4 - 13.6 kg (14 - 30 lb) of waste were combusted (in duplicate) in a specially designed vessel in the EPA's Open Burning Simulation Test Facility. The pollutants targeted in this study were VOCs, HCN, HCl, $PM_{2.5}$, PM_{10}, aldehydes, combined particulate- and vapor-phase SVOCs (including PAHs, PCBs, and PCDDs/PCDFs), particulate-phase metals, and vapor-phase mercury. Additionally, SVOCs (including PAHs, PCBs, and PCDDs/PCDFs), and metals were measured in the residual ash. Continuous emission monitors (CEMs) for O_2, CO_2, CO, THCs, and NO were also operated. Measured concentrations were related to dilution air volumes and measured net mass of debris combusted to derive emission rates. Emission rate data and ash sampling results are intended to be useful in evaluating the potential exposure due to pollutant emissions associated with the backyard burning of household refuse in barrels.

Results

For most of the non-chlorinated compounds, including VOCs, SVOCs, PAHs, and aldehydes and ketones, emissions from the non-recycler were higher, both on a per mass burned and on a per day basis (based on waste generation statistics provided by NYSDOH). However, emissions of many of the chlorinated organics (on a per mass burned basis), particularly chlorobenzenes and PCDDs/PCDFs, were higher from the avid recycler. Emissions of PCBs were higher from the non-recycler, although the cause of this phenomenon is not known. On a per day basis, emissions of PCDDs/PCDFs are significantly higher for the avid recycler. This phenomenon is likely due to several factors, including the higher mass fraction of PVC in the avid recycler's waste. It is also possible that some component of the non-recycler's waste may poison the metallic catalysts believed to be responsible for enhancing formation rates of PCDDs/PCDFs. Results from HCl sampling indicated much higher HCl emissions from the avid recycler, which is consistent with the higher emissions of chlorinated organics; and ash residue analysis indicated that the avid recycler's residue had more copper, which could contribute to higher emissions of PCDDs/PCDFs. The temperature at the base of the burning bed was significantly lower for the avid recycler than for the non-recycler. Gas-phase emissions of metals were not a strong function of the test conditions. PM emissions were much higher from the non-recycler. Almost all of the PM emissions from both test conditions were < 2.5 μm in diameter.

It may be useful to compare emissions from open burning of household waste to emissions from a full-scale municipal waste combustor (MWC) operating with good combustion and flue gas cleaning technology. Based on data from a field test at a MWC, and averaging the "Normal Good" PT-08, PT-09, and PT-11 test conditions described in a detailed field test published in 1994, using the samples taken at the pollution control device outlet, the data in Table 2 were generated. For the results

Table 1. Composition of household wasted prepared by EPA.

	Non-Recycler (%)	Avid Recycler (%)
PAPER		
Newspaper, books and office paper	32.8	3.3
Magazines and junk mail	11.1	—
Corrugated cardboard and kraft paper	7.6	—
Paperboard, milk cartons, and drink boxes	10.3	61.9
PLASTIC RESIN[a]		
PET #1 (bottle bill)	0.6	—
HDPE: #2, LDPE #4, and PP #5	6.6	10.4
PVC: #3	0.2	4.5
PS: #6	0.1	0.3
MIXED #7	0.1	0.3
FOOD WASTE	5.7	—
TEXTILE/LEATHER	3.7	—
WOOD (treated/untreated)	1.1	3.7
GLASS/CERAMICS		
Bottles/jars (bottle bill)	9.7	—
Ceramics (broken plates and cups)	0.4	6.9
METAL - FERROUS		
Iron - cans	7.3	4.0
NON-FERROUS		
Aluminum - cans (bottle bill), foil, other	1.7	1.0
Other non-iron (wire, copper pipe, batteries)	1.1	3.7
TOTAL WEIGHT GENERATED PER HOUSEHOLD FOR DISPOSAL IN BURN BARRELS (kg/day)	4.9	1.5

[a]PET=POLYETHYLENE TEREPHTHALATE; HDPE=high-density polyethylene; LDPE=low density polyethylene; PP=polypropylene; PVC=polyvinyl chloride; and PS=polystyrene

Table 2. Comparison between open burning of household waste and controlled combustion of municipal waste in a MWC; emissions are in μg/kg waste burned.

	Avid Recycler	Non-Recycler	MWC
PCDDs	46.7	38.25	0.0016
PCDFs	222.9	6.05	0.0019
CBs	1,007,450	424,150	1.16
PAHs	23,974.7	66,035.65	16.58
VOCs	2,052,500	4,277,500	1.17

from this study, concentrations of all target VOCs were summed to give total VOC emissions (concentrations below detection limit were set at zero). A similar treatment was taken for PAHs, CBs, PCDDs/PCDFs, and PCBs. Figure 1 graphically depicts these results.

It is readily apparent that even the significant differences between the avid recycler and non-recycler's emissions are minor in comparison to the difference between open burning of household waste and the controlled combustion of municipal waste at a dedicated MWC facility. The emissions from open burning can be several orders of magnitude higher than controlled combustion.

As an additional comparison of open burning versus controlled combustion in a properly designed combustion device, Table 3 was created by calculating the total air pollutants produced per day using the estimated emissions from Table 2, the waste generation rates described in Table 1, and comparing those values to a hypothetical 182,000 kg/day (200 ton/day) MWC facility emitting air pollutants at the rate described in Table 3. (NOTE: This size facility processes the equivalent waste from 37,000 non-recycling and 121,000 recycling households.) By dividing the daily estimated emissions from the MWC by the daily estimated emissions from open burning, it is possible to estimate how many open-burning households it would take to equal the air pollution produced by a moderately sized MWC facility. The number is surprisingly low; in fact, for certain pollutants such as VOCs and CBs, a single household that burns their trash in barrels produces more pollutants than a full-scale MWC facility.

Table 4 illustrates which test condition resulted in higher emissions. The first two columns are based on the mass/mass emissions, and the second two columns are based on mass/day emissions, using the waste generation rates reported by NYSDOH in Table 1. For the ash residue, estimates per person were based on both the waste generation rates reported by NYSDOH and the mass of material remaining after combustion.

Table 5 summarizes all the test data, showing the average results for the various pollutants that were measured, along with the ratio between the avid recycler and the non-recycler.

Emissions from backyard burning of residential solid waste are released at ground level, resulting in decreased dilution by dispersion. This could potentially exacerbate potential impacts beyond what is apparent from the magnitude of the emissions alone. The large magnitude of the emissions, coupled with the concentration of these emissions in the local neighborhoods due to poor dispersions, will lead to increased direct inhalation exposure.

Another issue related to this particular source is that it could potentially be a significant overall source of PCDDs/PCDFs. A 1994 EPA document attempted to conduct a mass balance for dioxin emissions in the U.S. and identified a significant gap between current deposition estimates and emission estimates, with the former considerably higher than the latter. EPA speculated that this indicated that there were unknown dioxin emission sources. The dioxin emissions from burn barrels may be a missing link to help account for the gap between measured deposition rates and emission inventories.

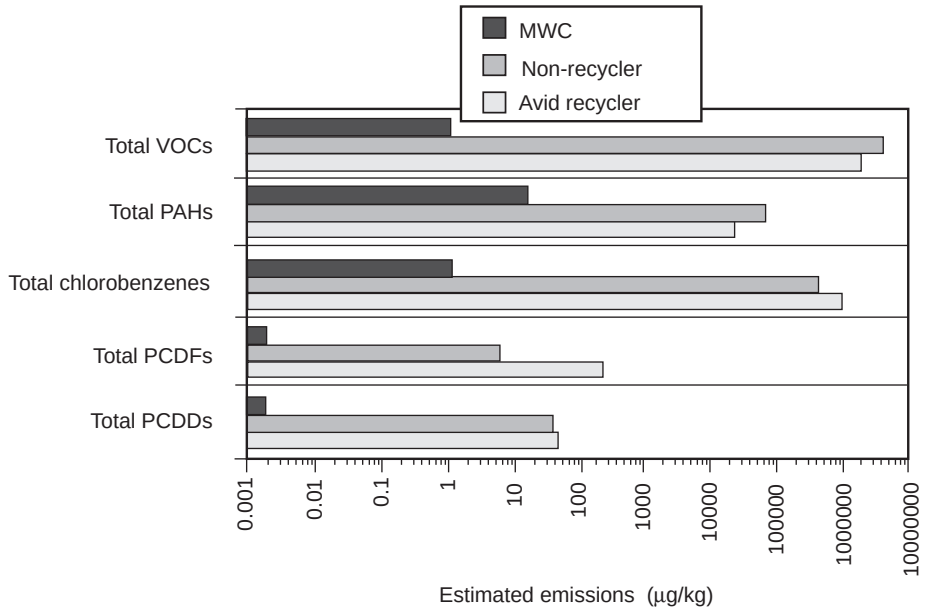

Figure 1. Composition between open burning and controled combustion.

Table 3. Number of open-burning households to equal the air pollution from a full-scale MWC facility[a]

	Avid Recycler	Non-Recycler
PCDDs	4.15	1.55
PCDFs	1.03	11.65
CBs	0.14	0.10
PAHs	83.8	9.31
VOCs	0.07	0.01

[a]Using refuse generation rate supplied by NYSDOH, shown in Table 1; MWC burns 182,000 kg/day (200 tons/day)

Table 4. Which test condition resulted in higher emissions?

		Mass Emitted/Mass Burned		Mass Emitted/Person[a]	
	Pollutant	Recycler	Non-Recycler	Recycler	Non-Recycler
Gas-Phase					
	VOCs		X		X
	SVOCs		X		X
	PAHs		X		X
	PCBs		X		X
	CBs	X		X	
	PCDDs/PCDFs	X		X	
	Aldehydes & ketones		X		X
	HCl	X		X	
	HCN		X		X
	PM		X		X
	Metals	–	–	–	–
Ash Residue					
	SVOCs		X		X
	PCBs	X			X
	PCDDs/PCDFs	X		X	
	Metals	–	–	–	–

[a]*Using refuse generation rate supplied by NYSDOH, shown in Table 1.*

Table 5. Summary of all test data

Parameter	Average, per mass lost			Average, per household		
	Recycler	Non-Recycler	Ratio	Recycler	Non-Recycler	Ratio
WASTE COMPOSITION						
total daily waste (kg)	1.5	4.9	0.31	1.5	4.9	0.31
PVC in waste (kg)	0.07	0.01	7.00	0.07	0.01	7.00
paper waste (kg)	0.98	3.02	0.32	0.98	3.02	0.32
all plastics (kg)	0.23	0.36	0.64	0.23	0.36	0.64
food (kg)	0	0.28	0.00	0	0.28	0.00
textiles, leather (kg)	0	0.18	0.00	0	0.18	0.00
wood (kg)	0.06	0.05	1.20	0.06	0.05	1.20
glass/ceramics (kg)	0.1	0.5	0.20	0.1	0.5	0.20
metals (kg)	0.14	0.49	0.29	0.14	0.49	0.29
COMBUSTION RESULTS						
max. bed temp (°C)	370	740	0.50	370	740	0.50
fractoin burned (%)	66.7	49.1	1.36	66.7	49.1	1.36
unburned residue (kg)	0.50	2.49	0.20	0.50	2.49	0.20
AIR CONTAMINANT EMISSIONS		(mg/kg burned)			(mg/household·day)	
benzene	725	1240	0.58	725	2983	0.24
acetone	190	940	0.20	190	2262	0.08
styrene	310	740	0.42	310	1780	0.17
total TICs[a]	4000	14400	0.28	4002	34645	0.12
naphthalene[b]	40	48	0.83	40	115	0.35
phenol	85	140	0.61	85	337	0.25
dichlorobenzenes	320	160	2.00	320	385	0.83
trichlorobenzenes	400	110	3.64	400	265	1.51
tetrachlorobenzenes	140	74	1.89	140	178	0.79
pentachlorobenzene	100	53	1.89	100	128	0.78
hexachlorobenzene	48	22	2.18	48	53	0.91
acenaphthylene	3.4	11	0.31	3.4	26	0.13
naphthalene[c]	5.2	18	0.29	5.2	43	0.12
phenanthrene	3.3	7.3	0.45	3.3	18	0.19
aldehydes & ketones	140	2800	0.05	140	6737	0.02
total PCDD	0.047	0.038	1.24	0.047	0.091	0.51
total PCDF	0.22	0.0061	36	0.220	0.015	15
total PCB	0.97	2.86	0.34	0.97	6.87	0.14
PM10	5800	19000	0.31	5803	45712	0.13
PM2.5	5.3	17.4	0.30	5.3	42	0.13
HCl	2400	284	8.47	2401	682	3.52
HCN	200	468	0.43	200	1126	0.18
RESIDUALS IN ASH	µm (or ng) per kg ash					
PCDD, ng/kg	14851	1556	9.54			
PCDF, ng/kg	34040	5800	5.87			
PCB, µg/kg	220	122	1.80			
Cr	300	92	3.26			
Cu	4910	343	14			
Pb	164	32	5.13			
Zn	11500	721	16			

[a]Tentatively identified (VOC) compounds.
[b]Semi-volatile organics analysis.
[c]PAH specific analysis.

Paul M. Lemieux *is the EPA Project Officer (see below).*
The complete report consists of two volumes, entitled "Evaluation of Emissions from the Open Burning of Household Waste in Barrels:"
Volume 1. Technical Report (Order No. PB98-127343; Cost: $25.00)
Volume 2. Appendices (Order No. PB98127350-; Cost: $31.00)
The above reports will be available only from: (cost subject to change)

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