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Chemical emissions from residential dryer vents during use of fragranced laundry products

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Abstract Common laundry products, used in washing and drying machines, can contribute to outdoor emissions through dryer vents. However, the types and amounts of chemicals emitted are largely unknown. To investigate these emissions, we analyzed the volatile organic compounds (VOCs) both in the headspace of fragranced laundry products and in the air emitted from dryer vents during use of these products. In a controlled study of washing and drying laundry, we sampled emissions from two residential dryer vents during the use of no products, fragranced detergent, and fragranced detergent plus fragranced dryer sheet. Our analyses found more than 25 VOCs emitted from dryer vents, with the highest concentrations of acetaldehyde, acetone, and ethanol. Seven of these VOCs are classified as hazardous air pollutants (HAPs) and two as carcinogenic HAPs (acetaldehyde and benzene) with no safe exposure level, according to the US Environmental Protection Agency. As context for significance, the acetaldehyde emissions during use of one brand of laundry detergent would represent 3% of total acetaldehyde emissions from automobiles in the study area. Our study points to the need for additional research on this source of emissions and the potential impacts on human and environmental health.

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Background

Fragranced laundry detergents and dryer sheets emit chemicals into the environment through air vented outdoors as well as through laundry wastewater, residue on laundered items, and other routes. Little is known about chemicals in laundry products because their labels are not required to list any or all ingredients (Steinemann 2009). The fragrance alone in a product can contain up to several hundred chemicals among more than 2,600 chemicals documented as fragrance ingredients (Ford et al. 2000; Bickers et al. 2003). Some of these chemicals are classified as toxic or hazardous under federal laws (Steinemann et al. 2011). Given their widespread use, fragranced laundry products represent a potentially significant source of emissions.

Limited prior work has investigated fragranced consumer product ingredients and their fate and transport in the environment. Some studies have analyzed volatile organic compounds (VOCs) in the products themselves (Steinemann et al. 2011; Wallace et al. 1991; Cooper et al. 1992; Rastogi et al. 2001; Jo et al. 2008), while others have examined the generation of secondary pollutants due to reactions between product VOCs and ozone (Nazaroff and Weschler 2004; Sarwar et al. 2004; Destaillats et al. 2006). Other work has focused on synthetic musks and their presence in water, sediment, air, sewage sludge, wastewater treatment facilities, aquatic organisms, and household products (Rimkus 1999; Peck and Hornbuckle 2006; Alvarez et al. 1999; Simonich et al. 2000, 2002; Reiner et al. 2007; Reiner and Kannan 2006).

This paper represents the first study (to our knowledge) to identify and quantify emissions from residential dryer vents during the use of fragranced laundry products. The goals of this study were to determine the identities and concentrations of compounds in air vented outdoors from residences during typical use of laundry products, to assess the potential significance of the emissions, and to provide a foundation and direction for future study.

Approach

A detailed protocol was developed for this study (see Table 1). The machines and laundry were prepared, and the samples collected and analyzed, using the same procedure at each residential site. Dryer vent emissions were sampled during the use of (a) no products, (b) detergent only, and (c) detergent and dryer sheets.[1] Grab samples of the dryer vent emissions, one for each of the three usage conditions at each site, were collected approximately 15 min into the drying cycle using evacuated 400-mL fused-silica lined stainless steel canisters. To minimize the collection of ambient air (i.e., air not coming from the dryer vent), the canister inlet was placed directly in the stream of air exiting the vent.

This study was conducted over 2 days at two homes in Seattle, Washington. Homeowners volunteered the use of their laundry machines. Machines at both sites were in good working condition, and dryers were vented to the outdoors through flexible aluminum tubing. Both homeowners had previously used fragranced products in the machines; however, this was an occasional use at site 1 and typical use at site 2.

The laundry products selected for use were those with the highest annual US sales in their market categories (MarketResearch.com 2007). The same brand of fragranced liquid laundry detergent was used at both sites in the appropriate formulation (regular for top loading at site 1 and high efficiency for front loading at site 2) as well as the same brand of dryer sheets.

Methods

Headspace samples were prepared by placing approximately 2 g of each consumer product (laundry detergent and dryer sheet) in individual, clean 0.5-L glass flasks that initially contained only ambient laboratory air, followed by equilibration for at least 24 h at room temperature. Canisters containing dryer vent emissions were pressurized with hydrocarbon-free air to facilitate analysis. Headspace and canister samples were then each analyzed once for VOCs. Sample analysis and data reduction procedures were nominally identical to those presented in Steinemann et al. (2011). Analysis was performed using an Agilent 6890/5973 gas chromatograph/mass spectrometer (GC/MS) system interfaced to an Entech 7100A cryogenic preconcentrator and generally followed the guidelines found in US EPA Compendium Method TO-15 (US EPA 1999). The preconcentration system was operated in the microscale purge-and-trap mode; either 2 mL (for the headspace vapors) or 200 mL (for the dryer vent canisters) was concentrated. The top 20 peaks by total ion current area were selected from each chromatogram and identified based on mass spectral library matching and consideration of the consistency of the proposed structure and molecular weight with the observed retention time. Concentrations were estimated using relative response factors of selected surrogate compounds, and levels in the canisters were dilution-corrected. Only VOCs with headspace concentrations of greater than 100 μg/m^3 and dryer vent sample concentrations greater than 2 μg/m^3 were reported.[2]

Results

The VOCs in the dryer vent emissions varied by site and by samples taken during use of (a) no products, (b) detergent only, and (c) detergent and dryer sheets (Table 2). During the use of the detergent product, 21 unique VOCs were identified among both sites (13 VOCs at site 1 and 19 VOCs at site 2). The following VOCs were found at one or both sites during the use of "detergent only" but not during "no products": acetaldehyde, acetone, benzaldehyde, butanal, dodecane, hexanal, limonene, nonanal, 1-propanal, and 2-butanone. Of the VOCs found in the "detergent only" samples, four were found in the GC/MS headspace analysis of the detergent product (Table 3): dodecane, ethanol, limonene, and 2-butanone.

During use of detergent and dryer sheets, 25 unique compounds were identified among both sites (16 VOCs at site 1 and 24 VOCs at site 2). The following VOCs were found at one or both sites during the use of "detergent and dryer sheets" but not during "no products": acetaldehyde, acetone, benzaldehyde, butanal, dodecane, hexanal, limonene, nonanal, octanal, tetramethylpropylidene cyclopropane, 1-(1,1-dimethylethyl)-4-ethylbenzene, 1-propanal, 2-butanone,

[1] We use the term "during" to refer to the entire wash and dry cycle.

[2] These thresholds were established to better ensure that only those compounds emitted from the products or from the dryer vents were reported.

Table 1 Protocol for laundry cycles and air sampling

Preparation	Each washer and dryer was wiped on the inside with white vinegar and unbleached paper towels to remove residue. Each washer was run empty through a full wash/rinse cycle and each dryer was run empty for 10 min. A new set of six dye-free, 100% organic cotton bath towels was used for each site. Each set was pre-rinsed in water only and dried using an off-site washer and dryer that had no prior fragranced product use.
Sample a	No products. Using only towels in the wash and dry cycle, samples were taken at dryer vent in air stream, after 15 min into the dry cycle, to measure baseline concentrations of compounds.
Sample b	Fragranced liquid laundry detergent. Two capfuls of detergent were used with the towels in the washing machine, as recommended by product packaging for larger loads. Samples were taken at dryer vent in air stream after 15 min.
Sample c	Fragranced liquid laundry detergent and dryer sheet. After detergent was used in the wash, two fragranced fabric softener dryer sheets were used with the towels in the dryer, as recommended by product packaging for larger loads. Samples were taken at dryer vent in air stream after 15 min.

and 2,7-dimethyl-2,7-octanediol. Of the VOCs found in the "detergent and dryer sheets" samples, four were found in the GC/MS headspace analysis of the detergent product (Table 3): dodecane, ethanol, limonene, and 2-butanone, and eight were found in the GC/MS headspace analysis of the dryer sheet product (Table 4): acetaldehyde, acetone, butane, ethanol, isopropyl alcohol, limonene, methanol, and 2,7-dimethyl-2,7-octanediol.

Table 2 Compounds found in dryer vent samples (concentrations in micrograms per cubic meter)

Compound[a]	CAS #	1(a)	1(b)	1(c)	2(a)	2(b)	2(c)
Acetaldehyde	75-07-0		36	22	41	47	36
Acetone	67-64-1		36	24	28	32	31
Benzaldehyde	100-52-7					5.8	4.9
Benzene	71-43-2				2.7		2.2
Butanal	123-72-8		3.8	2.6	3.5	4.0	3.0
Butane	106-97-8	5.2	5.2	5.3	5.9	4.5	4.6
Dodecane	112-40-3			2.6		3.0	3.7
Ethanol	64-17-5	22	32	50	14	25	15
Ethylbenzene	100-41-4				3.8	2.3	2.2
Formic acid hydrazide	624-84-0	6.0	5.6	4.7	7.9	8.2	6.4
Hexanal	66-25-1		2.4	2.3		5.7	3.2
Isobutane	75-28-5	3.2					
Isopropyl alcohol	67-63-0	4.2	2.9	3.0			
Limonene	138-86-3			9.3		3.5	14.7
m/*p*-Xylene	106-42-3				12	8.8	9.4
Methanol	67-56-1	6.5	12	10	15	21	14
Nonanal	124-19-6			2.1		4.0	3.7
Norfiorane	811-97-2	31	3.7				
o-Xylene	95-47-6				4.8	3.4	3.6
Octanal	124-13-0			2.4			4.7
Pentanal	110-62-3				3.2	3.8	
Tetramethylpropylidene cyclopropane	24519-04-8						2.1
Toluene	108-88-3	4.3	4.2	2.9	7.1	9.5	5.0
1-(1,1-Dimethylethyl)-4-ethylbenzene	7364-19-4						2.3
1-Propanol	71-23-8		3.5	3.0	3.7	4.8	4.0
2-Butanone (methyl ethyl ketone)	78-93-3		4.3	3.0	5.9	5.9	4.9
2-Methylbutane	78-78-4	6.4					
2,2-Dimethylhexane	590-73-8				2.2		2.1
2,7-Dimethyl-2,7-octanediol	19781-07-8						4.0

Site 1: 1(a) no products, 1(b) detergent only, and 1(c) detergent and dryer sheets. Site 2: 2(a) no products, 2(b) detergent only, and 2(c) detergent and dryer sheets

[a]Compounds listed in alphabetical order

Table 3 Compounds found in headspace analysis of detergent (listed in decreasing order of headspace concentration)

Compound	CAS #
Ethanol	64-17-5
Limonene	138-86-3
2-Methyl-2-propanol (*t*-butyl alcohol)	75-65-0
1,4-Dioxane	123-91-1
3,7-Dimethyl-1,6-octadiene	10281-56-8
Ethyl acetate	141-78-6
alpha-Pinene	80-56-8
beta-Pinene	127-91-3
2-Butanone (methyl ethyl ketone)	78-93-3
1-Methyl-3-(1-methylethyl)-cyclohexene	13828-31-4
2,4-Dimethyl-3-cyclohexene-1-carboxaldehyde (Triplal 1)	68039-49-6
Undecane	1120-21-4
beta-Terpinene	99-84-3
Benzyl acetate	140-11-4
Dodecane	112-40-3
alpha-Terpinene	99-86-5
Carene isomer	e.g., 13466-78-9
Bornane	464-15-3

Among all chemicals detected in dryer vent samples collected during the use of fragranced products, the highest concentrations were of acetaldehyde, acetone, and ethanol. Acetaldehyde ranged from 22 to 47 μg/m^3, acetone ranged from 24 to 36 μg/m^3, and ethanol ranged from 15 to 50 μg/m^3. Average annual ambient levels of acetaldehyde and acetone,[3] respectively, in the study area, during this sampling period, were 0.8 μg/m^3 (monthly averages range from 0.5 to 1.2 μg/m^3) and 2.3 μg/m^3 (monthly averages range from 1.4 to 3.0 μg/m^3). Thus, concentrations of acetaldehyde in the emissions from the dryer vents are more than 25 times the average annual ambient level and more than 10 times for acetone (US EPA 2008).

We also detected seven VOCs in the dryer vent emissions that are classified as hazardous air pollutants ("HAPs"; US EPA 1994): acetaldehyde, benzene, ethylbenzene, methanol, *m*/*p*-xylene, *o*-xylene, and toluene. Concentrations of each of these HAPs were greater in dryer vent samples than in typical mean ambient concentrations, suggesting that dryer vent emissions are a potential source of these compounds.[4] Two of these compounds (acetaldehyde and benzene) are classified as carcinogenic HAPs, with no safe exposure level (US EPA 2005, 2010).

[3] Ethanol data not available.

[4] Mean ambient concentrations (micrograms per cubic meter), from the study area site (Seattle, Beacon Hill), 2008, are as follows: acetaldehyde, 0.81; benzene, 0.76; ethylbenzene, 0.27; toluene, 1.36; *m*/*p*-xylene, 0.78; *o*-xylene, 0.29; and methanol, not available (US EPA 2008).

Table 4 Compounds found in headspace analysis of dryer sheet (listed in decreasing order of headspace concentration)

Compound	CAS #
Limonene	138-86-3
Methanol	67-56-1
2,7-Dimethyl-2,7-octanediol	19781-07-8
Butane	106-97-8
(*Z*)-2-(3,3-Dimethylcyclohexylidene)ethanol	26532-23-0
Acetone	67-64-1
Acetaldehyde	75-07-0
beta-Pinene	127-91-3
Carbonyl sulfide	463-58-1
Isopropyl alcohol	67-63-0
Ethanol	64-17-5

Significance of emissions

To provide context for the significance of dryer vent emissions, we estimated the mass of annual emissions of acetaldehyde during use of the laundry detergent tested in this study and compared that to annual emissions of acetaldehyde from motor vehicles in King County, Washington. The annual emissions of acetaldehyde, during use of only this laundry detergent, would be approximately 1,660 lb/year. Compared to automobile emissions of approximately 56,000 lb/year, the dryer vent emissions during use of only this laundry detergent would represent 3% of automobile emissions. If we consider potential emissions from households using one of the five top-selling laundry detergents, assuming emissions from the other four fragranced laundry products are similar to this top-selling product, the estimated dryer vent emissions would be 3,545 lb/year, representing 6% of automobile emissions.[5]

[5] Calculations, assumptions, and sources: data based on the year 2005: 746,109 households in King County (US Census Bureau 2005); acetaldehyde emissions from automobiles in King County=56,000 lb/year (Washington State 2005); 453.59 g=1 lb; 187.5 cfm dryer vent flow rate=5.6 m^3/min=336 m^3/h (State of Wisconsin Department of Commerce 2001; Hardin County 2008); 268 h drying/year per household (US DOE 2009; Efficiency Vermont 2010); 41.5 μg/m^3 emissions of acetaldehyde after using laundry detergent (average of each site, 47 and 36 μg/m^3, from this study), assuming negligible contribution from ambient air; 37% of households use the top-selling laundry detergent tested in this study (MarketResearch.com 2007, based on data for 2006, assume similar market penetration as 2005); 79% of all households use one or more of the five top-selling laundry detergents (MarketResearch.com 2007); 73% of all households have clothes dryers (CPSC 2000), multiplied by 37% and 79%, respectively, for conservative calculations.

Discussion

This study investigated dryer vent emissions from individual households during typical use of fragranced laundry products. Between the two sites, over 25 VOCs were found in the dryer vent emissions, including seven HAPs and two probable carcinogens. Thus, a key result is the identification and quantification of potentially hazardous emissions from dryer vents. Of interest, acetaldehyde was found in the headspace analysis of the dryer sheet product, but not in the detergent product, even though acetaldehyde was identified in dryer vent samples at both sites during the use of the detergent. Thus, acetaldehyde could be a secondary pollutant resulting from a reaction between product ingredients (e.g., terpenes, such as limonene) and ambient compounds (e.g., ozone) (Nazaroff and Weschler 2004). It also could be a residual from prior use of products, from heating and reactions of fragranced products in machines, or other factors.[6]

Virtually none of the VOCs identified in the GC/MS headspace analysis of the products were listed on the product label or the product MSDS (only ethanol was listed on the MSDS of the laundry detergent). Instead of listing chemical ingredients, the product labels and MSDSs used only general terms, such as “biodegradable surfactants,” “softeners,” or “perfume.” Thus, consumers may not be aware of potentially hazardous chemicals emitted from the products.

This study, the first to characterize dryer vent emissions during the use of fragranced laundry products, found that many chemicals are emitted from dryer vents, including some classified as hazardous (US EPA 2010). Furthermore, in the case of acetaldehyde, such emissions potentially represent a non-trivial contribution to overall concentrations in populated areas.

The goal of the study was to elucidate the types, concentrations, and potential significance of the emissions, rather than to explain why emissions varied among the sites, or the precise sources of the compounds identified. In light of these results, additional research is warranted to investigate the potential impact of emissions from such products from dryer vents on the environment and on human health. Future research can investigate the following: the persistence of fragranced laundry product chemicals and their contributions to emissions (i.e., residual compounds from prior use of products in machines), a comparison of emissions between fragranced and fragrance-free products, emissions of semivolatile organic compounds and secondary organic aerosols, and the additional burden of dryer vent emissions on ambient air.

[6] Similarly, VOCs in the “no products” samples could be from residual VOCs in machines from prior use of products, offgassing of machine components, entrained indoor air, reactions between residual VOCs and ambient compounds, or other factors.

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References

Alvarez FR, Shaul GM, Krishnen ER, Perrin DL, Rahmen M (1999) Fate of terpene compounds in activated sludge wastewater treatment systems. J Air Waste Manag Assoc 49 (6):734–739

Bickers DR, Calow P, Greim HA, Hanifin JM, Rogers AE, Saurat JH, Sipes IG, Smith RL, Tagami H (2003) The safety assessment of fragrance materials. Regul Toxicol Pharmacol 37(2):218–273

Cooper S, Raymer J, Pellizzari E, Thomas K, Castillo N, Maewall S (1992) Polar organic compounds in fragrances of consumer products. Final report, contract # 68-02-4544, US EPA, Research Triangle Park

CPSC (2000) U.S. Consumer Product Safety Commission. Electric & gas clothes dryers—staff evaluation (0101), February 2000. http://www.cpsc.gov/library/foia/foia00/os/clothes.pdf. Accessed 20 Apr 2011

Destaillats H, Lunden MM, Singer BC, Coleman BK, Hodgson AT, Weschler CJ, Nazaroff WW (2006) Indoor secondary pollutants from household product emissions in the presence of ozone: a bench-scale chamber study. Environ Sci Technol 40 (14):4421–4428

Efficiency Vermont (2010) Your guide to electrical usage in your home. http://www.efficiencyvermont.com/pages/Residential/SavingEnergy/HighElectricBills/. Accessed 16 Apr 2010

Ford RB, Domeyer O, Easterday KM, Middleton J (2000) Criteria for development of a database for safety evaluation of fragrance ingredients. Regul Toxicol Pharmacol 31(2):166–181

Hardin County (2008) Hardin County Planning and Development Commission. Building code clarification handout, #2008.004, January 2008. http://www.hcpdc.com/KYbuildingcode.asp. Accessed 16 Apr 2010

Jo WK, Lee JH, Kim MK (2008) Head-space, small-chamber and in-vehicle tests for volatile organic compounds (VOCs) emitted from air fresheners for the Korean market. Chemosphere 70(10):1827–1834

MarketResearch.com (2007) Laundry care products in the U.S. Packaged Facts, Rockville, MD

Nazaroff WW, Weschler CJ (2004) Cleaning products and air fresheners: exposure to primary and secondary air pollutants. Atmos Environ 38(18):2841–2865

Peck AM, Hornbuckle KC (2006) Synthetic musk fragrances in urban and rural air of Iowa and the Great Lakes. Atmos Environ 40 (32):6101–6111

Rastogi SC, Heydorn S, Johansen JD, Basketter DA (2001) Fragrance chemicals in domestic and occupational products. Contact Dermat 45(4):221–225

Reiner JL, Kannan K (2006) A survey of polycyclic musks in selected household commodities from the United States. Chemosphere 62 (6):867–873

Reiner JL, Berset JD, Kannan K (2007) Mass flow of polycyclic musks in two wastewater treatment plants. Arch Environ Contam Toxicol 52(4):451–457

Rimkus GG (1999) Polycyclic musk fragrances in the aquatic environment. Toxicol Lett 111(1):37–56

Sarwar G, Olson DA, Corsi RL, Weschler CJ (2004) Indoor fine particles: the role of terpene emissions from consumer products. J Air Waste Manag Assoc 54(3):367–377

Simonich SL, Begley WM, Debaere G, Eckhoff WS (2000) Trace analysis of fragrance materials in wastewater and treated wastewater. Environ Sci Technol 34(6):959–965

Simonich SL, Federle TW, Eckhoff WS, Rottiers A, Webb S, Sabaliunas D, de Wolf W (2002) Removal of fragrance materials during U.S. and European wastewater treatment. Environ Sci Technol 36(13):2839–2847

State of Wisconsin Department of Commerce (2001) Optional Uniform Dwelling Code (UDC) makeup and combustion air worksheet, April 2001. http://commerce.wi.gov/sb/. Accessed 16 Apr 2010

Steinemann AC (2009) Fragranced consumer products and undisclosed ingredients. Environ Impact Assess Rev 29(1):32–38

Steinemann AC, MacGregor IC, Gordon SM, Gallagher LG, Davis AL, Ribeiro DS, Wallace LA (2011) Fragranced consumer products: chemicals emitted, ingredients unlisted. Environ Impact Assess Rev 31(3):328–333

US Census Bureau (2005) American FactFinder, Data Set: 2005 American Community Survey. http://factfinder.census.gov/servlet/DatasetMainPageServlet?_program=ACS&_submenuId=datasets_1&_lang=en&_ts=. Accessed 11 May 2010

US DOE (2009) 2009 Buildings energy data book. US Department of Energy, Energy Efficiency and Renewable Energy, Washington, DC

US EPA (1994) Environmental Protection Agency, technical background document to support rulemaking pursuant to the Clean Air Act, Section 112(g), ranking of pollutants with respect to hazard to human health, EPA-450/3-92-010, February

US EPA (1999) Determination of volatile organic compounds (VOCs) in air collected in specially-prepared canisters and analyzed by gas chromatography/mass spectrometry (GC/MS). Method TO-15. Compendium of methods for the determination of toxic organic compounds in ambient air, 2nd ed. EPA/625/R-96/010b. US Environmental Protection Agency, Office of Research and Development, Cincinnati. http://www.epa.gov/ttnamti1/airtox.html. Accessed 4 Feb 2010

US EPA (2005) Guidelines for carcinogen risk assessment. EPA/630/P-03/001F, Washington, D.C., March 2005

US EPA (2008) United States Environmental Protection Agency, air quality system, raw data report (AMP350). Beacon Hill site, Seattle, WA. Report generated March 29, 2011

US EPA (2010) Table 1, prioritized chronic dose-response values for screening risk assessments (4/27/2010). http://www.epa.gov/ttn/atw/toxsource/summary.html. Accessed 26 Apr 2011

Wallace L, Nelson W, Pellizzari E, Raymer J, Thomas K (1991) Identification of polar volatile organic compounds in consumer products and common microenvironments. Paper #91-62.4 presented at the 84th Annual Meeting of the Air and Waste Management Association, Vancouver, BC, June

Washington State (2005) WA Emissions Inventory 2005, King County. Washington State Department of Ecology, Olympia