Emissions of PCDD/PCDF from burning of waste in developing countries

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Abstract

Municipal solid waste from two developing and two developed countries were characterized according to their main fractions and then burned under controlled conditions in burn hut chambers and in real field situations. Burn hut experiments utilizing shredded waste in well-defined open-burning environments showed that the generation of polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/PCDF) was in a narrow, one order of magnitude range. Under these artificial conditions of shredded, homogenized waste fractions, no difference in the scale of the PCDD/PCDF emissions could be detected although the waste sources were from four different countries. The field burn experiments in China and Mexico showed a larger range of emission factors but still within two orders of magnitude. The emission factors are at the higher end of the emission factors reported in the United Nations Environment Programme's Toolkit methodology for development of national PCDD/PCDF release inventories.

Introduction

A multi-national project including research institutions from China, Mexico, Sweden, and United States was initiated to study the formation and release of unintentional persistent organic pollutants (POPs) from open burning of waste in developing countries[1]. The objectives of the project were to characterize waste compositions in developing countries according to situations where such open burning might occur, to undertake controlled burn experiments to study different waste compositions with respect to their potential for formation of polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDD/PCDF), to develop field sampling equipment capable to take smoke samples from open burn sites in the field, and to determine emission factors for use in the United Nations Environment Programme (UNEP) Dioxin Toolkit[2]. With respect to application of best environmental practices, the results would contribute to the further development of the Guidelines on Best Available Techniques and Preliminary Guidance on Best Environmental Practices[3] to support the Stockholm Convention. The results would be the first PCDD/PCDF data from open waste burning in developing countries.

The project started from the hypothesis that in an urban industrialized area, waste would be well managed and includes the presence of waste collection systems, removal of precious fractions, and recycling or further processing of certain fractions. Final disposal would occur in a controlled manner; most probably engineered landfills. Open burning of waste would be highly unlikely to occur under such a scenario. Similarly, in very poor areas of developing countries, the main fraction of waste would be kitchen or food waste and would not be combustible. It is assumed that consumer goods, packaging materials, *etc.* would be reused or otherwise converted into a new use, so that there would hardly be any waste that could be ignited. Rather, this work assumed that open burning of waste would occur in small urban areas whereby the waste fractions would consist of some engineered products but that also valuables would be taken out of the waste stream and recycled. Similarly, open waste burning would occur in semi-rural and rural areas where the waste fractions would be lower in engineered products than in the urban industrialized areas but could contain higher percentages of textiles, leather, treated wood, or plastics.

Materials and Methods

Waste characterizations

Waste composition characterization was undertaken in Mexico and China according to national statistic schemes and fractions assigned. Questionnaires and national statistics have been used but also on-site characterization has been done. Where field verifications were undertaken, four to six samples of 1 m^3 each were taken from the waste disposal site applying a random number generator over the gridded field. Finally, one mixed representative sample was formed and characterized for burn testing according to these characterizations with the content of materials including cardboard and other papers such as diapers and napkins, dust, multilayer beverage container, fibers, metals, ceramic, wood, demolition waste, different types of plastics, garden waste, food waste, textile, glass, shoes, batteries, electronics, and others.

Burn hut experiments

Characteristic waste from Mexico, as identified in this project, was shipped to Research Triangle Park, NC (RTP), and Chinese waste was shipped to Umeå University, Sweden. Cross-over samples consisting of Mexican waste burned at Umeå University and Chinese waste burned at RTP were included as well.

Two different burn huts were used in this study: The burn hut at Umeå University was a temporary open-air facility for combustion testing: The waste was burned on a titanium plate, the actual fireplace. The plate was surrounded by three layers of concrete blocks to minimize the influence of the wind. A titanium hood was placed over the fire place to collect the flue gases. PCDD/PCDF sampling was done according to EN 1948; other inorganic pollutants such as CO, CO_2, and H_2O as well as temperature were monitored continuously. Weight loss was followed by a scale placed below the fireplace. The RTP burn hut has been characterized elsewhere[4,5]. Briefly it is an enclosed facility, sized 3.0 m x 2.8 m x 2.4 m, constructed with sheet metal walls on the inside. Continuous emission monitors (CEMs) for CO, CO_2, O_2, and total hydrocarbons were run throughout the experiments as well as monitoring of temperature. The fumes are captured by a high-volume air sampler, Graseby PS-1, following EPA's ambient TO9A air method.

For the burn hut experiments, solid household waste from China, Mexico, Sweden, and U.S.A. was shredded into small fractions (<2 cm), well mixed, placed on the plate, and ignited with a torch. Each burn experiment was carried out with approximately 5 kg of waste; some of the samples had 20% of water added before burning. All waste compositions were burned in duplicates.

Field sampling

A high-volume ambient air sampler consisting of a glass-fiber filter and a polyurethane foam (PUF) plug with the sampling head downwards (towards the fumes), mounted on a movable 6 m-long boom was developed and used at the field studies in China and Mexico. PUFs were prepared by Umeå University and shipped to Mexico and China where they were spiked with ^{13}C-labeled PCDD/PCDF. The field sampler is described by Zhang *et al.* [6]. Between 100 and 150 kg of waste per batch were burned and the fumes sampled; online monitoring of pressure at the sampling head as well CO and CO_2 monitoring was performed.

Chemicals analysis

All analyses for organic pollutants were performed in one laboratory, Umeå University, experienced in organic trace analysis. The analytical procedure followed standard methods according to EN 1948. Identification and quantification was done by isotope-dilution technique with capillary gas chromatography coupled to a high resolution mass spectrometer (HRGC/HRMS; Waters Corporation, Milford, MA, USA).

Reporting of emission factors

Since the UNEP Standardized Toolkit uses mass of waste burned to report emission factors, the results are presented per mass of initial waste (in kg). Where PCDD/PCDF results are given, they are presented as toxic equivalents (TEQ) using the 2005 WHO-TEF scheme [7].

Results and Discussion

Waste characterization

Waste collected and shipped to the burn hut experiments from the developing countries, China and Mexico, were representative of urban to rural sites. The wastes from Sweden and U.S.A. were urban-industrial and very similar in composition. The waste from Mexico was characterized by high contents of kitchen/garden waste (31.4%), plastic foil (low density polyethylene, LDPE, 12.4%), and disposable diapers/femine napkins (10.4%). The China waste is detailed elsewhere[6]; especially the rural waste was high in dust content (38%) but low in plastics or paper (5% each).

Results from burn huts

A total of 26 burns were undertaken in the Umeå (n=14) and the RTP (n=12) burn huts including duplicates, cross-over samples, and samples with water added (marked as "Wet" in Table below). The emission factors are compiled in Table 1 and based on the mass (in kg) of shredded waste. The results ranged from 2.1 ng TEQ kg^{-1} of initial waste to 85 ng TEQ kg^{-1} of initial waste. It should be mentioned that the highest values for each of the national waste samples were obtained in the cross-over samples. Without these, the upper value would be 30 ng TEQ kg^{-1} of initial waste.

Table 1: Results of all burn hut samples (n=26; emission factors in ng WHO_{2005}-TEQ kg^{-1} of initial waste)
* indicates cross-over samples

Origin of Waste	ng TEQ kg^{-1} waste	Origin of Waste	ng TEQ kg^{-1} waste
USA	30	SWE	3.7
USA	13	SWE	19
Mean (developed countries)	16	Median (developed countries)	12.8
MEX Dry	2.3	CHN A	5.4
MEX Dry	9.5	CHN A	3.5
MEX Dry	3.6	CHN A Wet	6.4
MEX Dry	2.5	CHN A Wet	7.5
MEX Wet	2.1	CHN B	5.6
MEX Wet	9.4	CHN B	4.0
MEX Wet	9.5	CHN B Wet	15
MEX Wet	17	CHN B Wet	19
MEX *	28	CHN C	2.9
MEX *	11	CHN C	9.1
		CHN *	85
		CHN *	37
Mean MEX	9.6	Mean CHN	18
Median MEX	6.8	Median CHN	9.4
Minimum all	**2.3**	**Mean all**	**14**
Maximum all	**85**	**Median all**	**9**
		STD all	**17**

Results from field sampling

Field sampling consisted of five waste compositions in each developing country burned in duplicate and according to local conditions. A total of 20 field burns were undertaken. The Chinese field burns are described by Zhang *et al.*[6]. The emission factors (EFs) for PCDD/PCDF ranged from 19 to 891 ng WHO_{2005}-TEQ kg^{-1} waste. The results from the Mexico burns together with the China results are summarized in Figure 1, grouped according to their origin into urban (total of ten burns), semi-urban (total of six burns), and rural (total of four burns) waste compositions. Although the emission factors overlap as can be seen in Figure 1, in general, the emission factors from Chinese waste were lower than from Mexican waste.

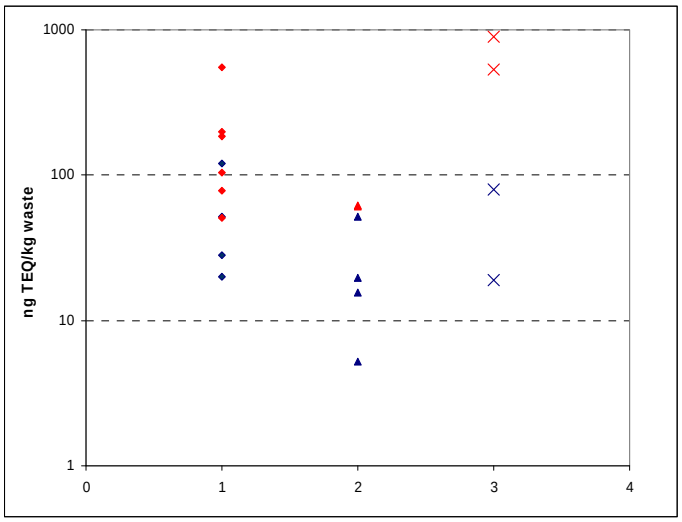

Figure 1: Results of all field burns (◆ represent urban compositions; ▲ represent semi-urban compositions, x represent rural compositions; Chinese waste are blue, Mexican waste are red)

Discussion

These are the first field data for PCDD/PCDF from open burning of waste in developing countries. Presently, the UNEP Standardized Toolkit, version 2.1, proposes one aggregated emission factor for open burning of household-like waste as investigated in this project of 300 ng TEQ kg^{-1} waste (or 300 µg TEQ t^{-1} as shown as 6.b(3) = category 6, subcategory b, and class 3). This emission factor had been derived from simulated burns because no field sampling results were available at that time. With respect to the emission factors obtained from the various experiments in this project, it should be noted that the emission factors from the burn hut experiments were designed to study compositional effects only. They are useful for intracomparison and cannot be used to estimate emissions of PCDD/PCDF in inventory development because the burn studies were designed with the objective that the variation due to the presence of large pieces in the waste fractions had been eliminated. The shredded material has different burning characteristics than the actual unaltered waste. From the quite narrow range of measured data in the burn huts in this study, it can be concluded that the composition of the waste according to main fractions does not cause large differences in the emission factors. The results from the field burns take into account that in reality waste is heterogeneous and the burn quality seems to be more important than waste composition for the range tested.

The statistical analysis and a final evaluation of the best method on how to derive emission factors from open burning of waste for use by countries in the development of their national release inventories still needs to be done. Whereas the field tests give reproducible data within the test series in Mexico and China, the differences in mass loss during the burning were large. The high ash content and low organic carbon content in the Chinese waste „dilute“ the emission factors because large fractions do not take part in the burning event. It needs to be

seen how to assign emission factors to take into account these differences and how to give practical advice in determination of the mass of waste that is burned at national level.
It is expected that the 4th meeting of the Toolkit Expert Group in December 2009 will agree on an emission factor for the Toolkit category 6(b)3.

Acknowledgments
The project has been implemented by the United Nations Environment Programme (UNEP) through Chemicals Branch and funded by the Swedish Government through Swedish International Development Cooperation Agency (SIDA) and the American Chemistry Council, Chlorine Chemistry Division, U.S.A. The authors thank the State of Mexico and their Municipalities, the local rural works in Hebei and Beijing, for assistance during the field projects as well as the support from the staff at CENICA, especially Mr. Alejandro de la Rosa and Mr. Sergio Flores; at Tsinghua University, especially Ms. Shu Wang and Dr. Jun Huang; at Umeå University, especially Dr. Lisa Lundin and Dr. Stina Jansson; and Ms. Maria Nyholm, Swedish EPA.

The work described in this paper was not funded by the United States Environmental Protection Agency and, therefore, the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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