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Original article

Emissions from burning municipal solid waste and wood in domestic heaters

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ABSTRACT

Waste burning is globally important emission source of several toxic compounds. The objective of this study was to acquire emission factors (EF) for PCDD/Fs, HCBs, PAHs, PMx and for several gaseous pollutants from the residential combustion, where wood is burned with municipal solid waste (MSW). In addition to the wood, paper and cardboard waste, people also tend to burn MSW. As the burnable waste content in MSW has changed during the past years, it is important to assess the effect of this factor for air emissions nowadays and in the past. Therefore an attempt was made to derive EF for the past emissions. 18 experiments including samples of firewood and MSW were burned using Estonian most common old type masonry heater, measuring PMx, PCDD/F, HCB, PAH-s and gaseous pollutants.

Significant correlation was found between PCDD/F, HCl, HCB and CO and between HCl and HCB in all 18 experiments. In three experiments (years 1990, 1995, 2000), the mean levels of PCDD/F were higher than the legislative limit value for combustion of MSW in waste incineration plants. The mean PCDD/F concentrations during the experiments was 0.0833 (0.0116–0.1550 95% Cl) ng I-TEQ Nm^{-3} 11% O_2. Since low chlorine levels in used fuel caused high emissions of PCDD/F and HCB, it indicates that the habit of burning these kinds of waste in residential heaters should be avoided.

We can conclude that RWC is significant source of PCDD/F, HCB and PAH. In general, EF measured within this study are in accordance with literature data. There was remarkable difference in EF between different years. EF of PCDD/F and HCB found confirm the trend of development of MSW collection system leading to an increasing usage of MSW recycling. Nevertheless, people's awareness about the negative impacts of waste burning in household heaters, should be raised.

1. Introduction

Burning waste, whether at individual residences, businesses, or dump sites, is a large source of air pollutants. However, waste burning is not included in many current emission inventories used for chemistry and climate modelling applications (Wiedinmyer et al., 2014). Trash burning can be an important organic aerosol source and there are only few studies available (Mohr et al., 2009). There is an estimation that emissions of PM_{10} from open burning of domestic waste in China is equivalent to 22% of China's total reported anthropogenic PM_{10} emissions (Wiedinmyer et al., 2014). Waste burning is one important source of aerosols, which has been largely overlooked. It is estimated, that around 40 percent of the world's waste is disposed in this reckless and toxic way (Wiedinmyer et al., 2014).

Incomplete combustion occurs often during domestic heating, wherein organic material in the presence of chlorine causes the formation of chlorinated organic by-products, such as polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polychlorinated biphenyls (PCBs), and hexachlorobenzene (HCB) (Hedman et al., 2006). In general, considerable PCDD/F emission reduction has been achieved with

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respect to the industrial emission sources, whereas emissions from non-industrial sources hardly decreased (Quaß et al., 2004). According to the European Emission Inventory, wood combustion is one of the most important air emission sources for dioxins (Quaß et al., 2000). Based on the analyses of PCDD/F and PCBs in oil shale and fly ash from oil shale fired power plants in Estonia (covering more than 90% from Estonian electricity needs), it was concluded, that the power plants are probably not the major sources of dioxins in Estonia (Roots, 2004; Roots et al., 2015). Residential wood combustion (RWC) in wood heaters and fireplaces is estimated to account for 78% of PAH, 53% of PCDD/F 70% of HCB and 50% of $PM_{2.5}$ emissions in Estonia in 2010 (EEIC, 2012).

Biomass combustion is a major global source of fine PM in the atmosphere with significant impacts on regional air quality, visibility, ecosystems, human health, and global climate (Hobbs et al., 1997). Fine particulates, especially fine particulates ($PM_{2.5}$ and smaller), are particularly risky to human health, causing various respiratory and cardiovascular diseases, even lung cancer (Delfino et al., 2005; Pope et al., 2002). Estonia's health impact assessment study showed, that fine PM in ambient air has shortened the life expectance up to 13 months, with the highest decrease in city centres or areas with extensive domestic heating (Orru et al., 2011). Additionally, polycyclic aromatic hydrocarbons (PAH-s) are emitted during the biomass combustion, that have been proposed to cause high toxicity (Fernandez et al., 2001).

There is, however, lack of information concerning the characterisation of emissions from small scale biomass combustion systems. According to the Estonian Construction Registry there are around 164,000 households (30% from the total households) using wood for heating purposes, whereby more than 80% of them exploit old type masonry heaters. In Estonia wood and wood chips account >90% of the fuel used for residential heating (TUT, 2008). According to the members of Estonian Chamber of Chimney Sweepers evaluation (Kupri, 2014), in addition to the wood, paper and cardboard waste, people also tend to burn Tetra Pak's®, sanitary napkins, diapers, various plastic packages, shoes, textile etc. It is difficult to assess the exact number of people who still practice burning MSW since such activities are done clandestinely (Kupri, 2015b). PMF analysis of Aerosol Chemical Speciation Monitor (ACSM, Aerodyne Inc.) dataset showed that during the heating season, plastic burning aerosols can be identified in residential areas (Maasikmets et al., 2015). Presumable, some households burn MSW on their domestic fires either to reduce fuel costs or to avoid disposal fees (Watson, 2012). Nevertheless, the issue of burning waste remains an important topic to address. The available evidence indicates that waste combustion in domestic conditions can be a significant generator of dioxins and, particularly, of PAHs. These emissions should therefore be reduced and eliminated where possible (Watson, 2012).

In addition to health effects caused by emissions from the MSW burning in households, quality of country specific emission inventories depend on reliable activity and emission data. Therefore verified EFs are needed for the annual emission reporting to the 1979 Convention on Long-range Transboundary Air Pollution (LRTAP) and to estimate the compliance with the Persistent Organic Pollutants (POPs) Protocol. At the moment, Estonia is not in compliance with the referred protocol. The main reason for being in non-compliance is caused by the fact, that during the past years the biomass, as an energy source, has been favoured due the climate policy and this has led to higher PCDD/F, HCB, PAHs and PMx emissions from the wood combustion sector, e.g. small scale combustion. On the other hand, used EF for national emission reporting are based on EMEP/EEA air pollutant emission inventory guidebook (EEA, 2013), where the given EF are highly uncertain and may differ from Estonia's conditions. In-field measurements make a better database for inventory EF as they take into account a several important factors for the level of the pollutant emissions, which include the co-incineration of wastes, the complete system consisting of combustion unit, flue pipe and chimney, memory effects in the chimney and the habitual practice of the operators (Hübner et al., 2005). These factors should be considered when compiling the national emission inventories and therefore, it is crucial to have EF which are representing, in more accurate way, the real situation in Estonia.

The burnable waste content in MSW has changed during the past 15 year; nevertheless our study enables to assess the possible effect of this factor for air emissions nowadays and in the past. Therefore an attempt was made to derive EF for years 1990, 1995, 2000, 2005, 2010 and 2013 using the amount of MSW generated during those years. The most common heater type (batch fuelled old type masonry heater) was used for measuring emissions from the 18 experiments carried out in EERC stove laboratory.

2. Methods and materials

According to Statistics Estonia, between 2000 and 2005, organized MSW collection systems covered 79% of the Estonia's population. By 2010 the percentage increased to 90% and by 2012 95% of Estonia's population was connected with the organized waste collection system (Statistics Estonia, 2015). MSW is an extremely heterogeneous material and the composition varies greatly between countries and even seasons (Lundin et al., 2013). For estimating the MSW generated, sorting studies of 2002 (Oras, 2002), 2007/2008 (SEI, 2008) and 2012/2013 (SEI, 2013) were taken into account for precise preparing the MSW content for the experiments. MSW burning experiments are based on the amount of MSW generated by Estonia's average household. Estonian average households are relatively small—according to Estonia's Statistics information in 2011, the average size of households consisted of 2.13 people (Statistics Estonia, 2014). For calculating the amount of MSW burned per household, a family of three as an average is taken into account in any observed year. It can be assumed, that people tend to burn flammable materials consisting plastic, paper and cardboard, wood, other flammable wastes and textile. Burning biodegradable waste is not included to this study, because biological treatment of solid waste is practiced widely. For determining year's specific EFs, MSW from Table 1 was burned together with firewood. More detailed overview about the content of MSW included to the experiments is described by Kupri (2015a).

Six experiments with three tests for each year (1990, 1995, 2000, 2005, 2010 and 2013) were prepared using firewood (alder, Alnus incana) mixed with common MSW in a way that different types of materials within the combustible waste material group were present. In each case, the wood was cut into pieces of 0.4–0.5 m length and split into halves or quarters. The wood was stored in a conventional way in an outdoor woodshed and was brought to heater laboratory at least 1 day prior to combustion experiment. The wood moisture content ranged between 14 and 18% on wet basis. The fuel net calorific value measured in all 18 experiments was 20.399 ± 0.662 MJ kg^{-1}. Analysis showed that the average chlorine content of the mixed fuel was 0.101 ± 0.034%. Fuel was ignited from the bottom, as this is the most common method used by the most of the heater users in Estonia. MSW was sourced from the Estonian Environmental Research Centre's kitchen, different households and a package waste receptacle of an apartment building.

Statistical variation between the data was analyzed by statistical software SPSS Statistics 17.0 (IBM SPSS Statistics), using Bivariate Correlation procedure to calculate Spearman Correlation Coefficient (Spearman's rho ρ, nonparametric correlations algorithm). Additionally descriptive statistics like mean, standard deviation