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Ultrafine and nanoparticles emissions from clinical waste incineration: characterization and chemical speciation.

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Abstract

Present paper reports the main results of an extended field scale investigation of UFP and nanoparticle size fractions emitted from a clinical waste incineration facility. Measurements were conducted at stack emissions with an electric low-pressure impactor counting system for the evaluation of total particle number concentrations and size distributions in the range 7 nm - 10 μm. Sampled fractions were also evaluated for their content of trace metals of concern (As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Sb, Sn, Tl, V, Zn), analyzed in terms of total concentrations and size distributions within fine, ultrafine and nanoparticle fractions. Results obtained are reported and analyzed for total concentrations and size distributions observed, with measurements also discussed in comparative terms, in order to figure out the investigated activities in perspective within the general issue of UFP emissions from other types of sources.

Keywords: emissions, ultrafine particles, incineration, hospital waste, trace toxics.

1. Introduction

Within the last few years, focus on atmospheric particulate matter has steadily shifted towards finer size fractions, namely those particles with dimensions included from 2.5 μm down to the minimum practical detection limit of few nm. These fractions share the higher burden of health related effects arising from particle pollution, with ultrafine (UFP) and nanoparticle (NP) aerosols (size less than 0.1 and 0.05 μm respectively) actually receiving a constantly rising attention. Reference data available are mainly addressed to their presence in ambient air, whilst much less investigations have dealt with characterization of emission sources of potential interest and still fewer with their chemical speciation, in terms of the content and size distribution of some trace toxic compounds involved in health effects. This lack of information involves some activity sectors like waste to energy (WtE) that generally need to be accounted for in terms of their contribution to locally measured UFP levels, as well as in terms of their growing concern involved in health risks posed to human health.

2. Field Investigation Setup

Stack emissions measurements were performed at a clinical waste incineration (CWI) plant, equipped with a rotating kiln furnace with post-combustion chamber and an energy recovery section through electricity production with superheated steam cycle. Flue gas treatment is provided by post-combustion SNCR with NH_3 injection, two dry system scrubbers (DSI) in series with activated carbon and lime addition upstream fabric filters, SCR $DeNO_x$ and PCDD/Fs catalytic polishing reactor and final NaOH acid scrubber with Adiox® packing material. Plant design provides for a nominal operating capacity of 32000 t/y of clinical infectious waste, with average LHV of nearly 13000 kJ/kg. Particle measurements were performed with a two stage heated isokinetic sampling line, equipped with an ELPI® impactor for number concentration and size distribution evaluation in the range between 7 nm and 10 μm aerodynamic particle diameter. Single stage filters from the impactor, grouped in 3 size ranges (nanoparticle fraction, 0.02-0.08 μm; ultrafine fraction, 0.08-1 μm; fine fraction, 1-10 μm), were analyzed for their metals content, with ICP-MS plasma reference methods for target elements.

3. Results and Discussion

Particle number concentrations obtained are reported in Table 1, in terms of the statistics of interest from 1 min measurements obtained by ELPI impactor over the entire sampling duration period of two days. Average values of $2.1 \cdot 10^5$ particles/cm^3 were observed, ranging between an IQR included from $8 \cdot 10^4$ to $2 \cdot 10^5$ particles/cm^3, with oscillations in measured values considered to be reasonable when monitoring emissions from continuous operating waste combustion sources at full scale regimes. Size distributions are largely dominated by UFP and NP, with mean fractions of 92% and nearly 77%, respectively, and with corresponding geometric mode diameters around 25 nm (Figure 1). Despite no similar studies are available for CWI, recorded levels are within the range of typical literature data for urban WtE plants with similar air pollution control device configurations (Jones and Harrison, 2016; Setyan et al., 2016; Buonanno and Morawska, 2015), where the final wet scrubbing unit is reported to potentially generate a slight increase in ultrafine concentrations, arising by new particles formation from semi-volatile gas enhanced condensation with increasing moisture content (Gretscher and Schaber, 1999; Schaber et al., 2002; Ozgen et al., 2015). The corresponding particulate mass concentration measured result in a value of 0.55 mg/m^3, with size fractions, as expected, moved towards coarser ranges with respect to number concentrations (Figure 1) and with a distribution centered nearly at 1 µm (geometric mean of 1.4 µm), showing some bimodal characteristics. All measurements obtained point out a very high efficiency of particulate removal by air pollution control equipment adopted, especially fabric filters and final wet scrubber, with an almost total capture even for particles smaller than few µm.

Table 1. Particle number concentration (particles/cm^3) measurement results

Average concentration	Geometric mode diameter	IRQ	Min	Max
$2.1 \cdot 10^5$	25 nm	$1.4 \cdot 10^5$	$6 \cdot 10^4$	$8.4 \cdot 10^5$

Stack concentrations of the investigated metals in the three size fractions derived from impactor samplings are summed up in Figure 2, in terms of their partitioning and their total values. Results obtained are generally included in the very low range of levels expected for this type of source. Major contributions arise from Cr and Ni, accounting for about 90% of the total content of the metal species investigated, with all the other elements in the range between 5 to 100 ng/m^3 and with some of the more significant metals affecting health risks (including Cd, Tl and As) not detectable at all. If evaluated in terms of mass per mass basis, speciation of metals confirms the expected preferential partitioning of highly volatile elements in the finer fractions, with an appreciable enrichment of mercury and partly of lead and manganese in the ultrafine particles (< 100 nm) and with the other elements detected largely present in the coarser fractions. All metals are largely below the emission limits required for the plant, with margins of safety as high as two orders of magnitude, thus confirming the excellent efficiency of the flue gas treatment line configuration already claimed for total particulates. Despite the effects of the different waste quality and compositions, limited data available for hospital waste incinerators with similar air pollution control equipment show, on average, emission levels located on a significantly higher range of values, with total metals of interest (including As+Cr+Pb+Mn+Hg+Ni) around 0.1-0.2 mg/m^3, Cd and Tl at 4 µg/m^3 and a single data for Hg of 40 µg/m^3 (Liu et al., 2006; EU BREF, 2018).

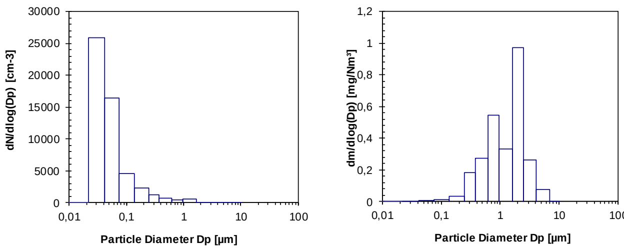

Figure 1. Particle size distributions measured for number (left) and mass (right) concentrations.

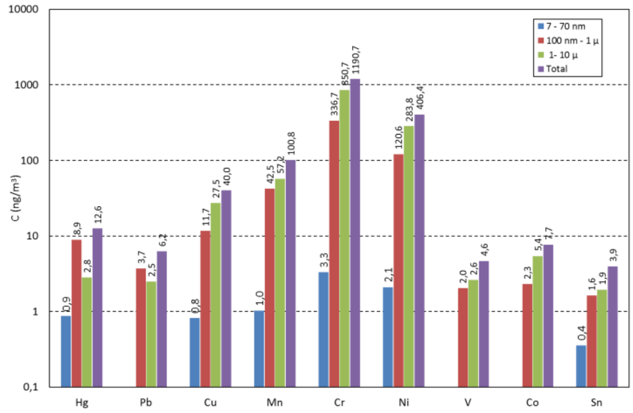

Figure 2. Total concentrations and size partitioning of trace metals investigated.

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