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Ultrafine particle emission of waste incinerators and comparison to the exposure of urban citizens

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ABSTRACT

On the basis of the growing interest on the impact of airborne particles on human exposure as well as the strong debate in Western countries on the emissions of waste incinerators, this work reviewed existing literature to: (i) show the emission factors of ultrafine particles (particles with a diameter less than 100 nm) of waste incinerators; and (ii) assess the contribution of waste incinerators in terms of ultrafine particles to exposure and dose of people living in the surrounding areas of the plants in order to estimate eventual risks. The review identified only a limited number of studies measuring ultrafine particle emissions, and in general they report low particle number concentrations at the stack (the median value was equal to 5.5×10^3 part cm^{-3}), in most cases higher than the outdoor background value. The lowest emissions were achieved by utilization of the bag-house filter which has an overall number-based filtration efficiency higher than 99%. Referring to reference case, the corresponding emission factor is equal to 9.1×10^{12} part min^{-1}, that is lower than one single high-duty vehicle. Since the higher particle number concentrations found in the most contributing microenvironments to the exposure (indoor home, transportation, urban outdoor), the contribution of the waste incinerators to the daily dose can be considered as negligible.

1. Introduction

Particulate matter, a major component of air pollution, has recently been classified as carcinogenic to humans (Group 1). This classification came from the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), based on sufficient evidence that exposure is associated with an increased risk of lung cancer (Loomis et al., 2013). Airborne ultrafine particles (UFPs, referring here to those below 300 nm in diameter to include over 99% of total particle number concentration, PNC, (Heal et al., 2012)) are of large concern to the air quality management due to their associations with adverse health effects. Scientific relevance has significantly increased in the past few years since epidemiological and toxicological studies indicated that inhalation and subsequent deposition of ultrafine particles into the lungs induced adverse health effects (Pope and Dockery, 2006; Schmid et al., 2009; Buonanno et al., 2013a). Indeed, the harmful potential of ultrafine particles is associated to their capability in depositing in the deepest region of the human respiratory system that represents the most defenceless regions of the lung, by carrying with them a number of toxic compounds.

Particles are unfortunately produced by many indoor and outdoor sources leading to large doses regardless of people's lifestyle and to a difficulty in performing comprehensive particle assessments. In fact, the major difficulty facing epidemiological studies of UFPs is mostly related to the estimation of individual exposure levels (Buonanno et al. 2014). The most common current approach assumes that each person in a given region has the same exposure level, which is often obtained from a few air quality monitors and reflects the mean concentrations in the entire urban area or community. This approach could lead to significant errors in the estimation of individual exposure to air pollutants because the actual exposure is strongly related to the time activity of the individuals (Buonanno et al., 2011a, 2012a, 2013b). Furthermore, the use of mean air pollution levels smoothes peak air pollution concentrations and thus, may result in unreliable estimates of exposure (Manigrasso et al., 2013). Therefore, current understanding of which characteristics of airborne particles by source, composition and size have the greatest impact on public health is limited and not definitive despite significant progress being made in the recent years. The case for ultrafine particles is even

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less addressed and their contribution to the exposure to urban airborne particles and the consequent dose is hardly known (Kumar et al., 2013).

In the waste management, incineration is considered a good practise for reducing the waste volume and recovering its energy to produce electricity and district heating. Nevertheless, incinerators have generated a strong debate in Western countries about their emissions of UFPs. Currently, as well as other industrial plants, only a mass-based threshold limit value is imposed as stated by the Directive 2010/75/EU (European Parliament and Council, 2010). In particular, total dust values (total amount of particle emitted in terms of mass) at the stack of the incinerators have to be lower than 10 mg m^{-3} on daily basis. However, the total particle mass is an inadequate measure of the lung penetrating particle fraction, as larger particles, mostly contributing to mass concentration, precipitate in the nose or throat region upon inhalation. Within the past decade many efforts were carried out by European countries to decrease toxic emissions from waste incinerators: thanks to these efforts, nowadays waste incineration in Western countries represents a relatively clean process (Ragazzi and Rada, 2012), equipped with some of the most recent flue gas treatments, such as wet scrubbers, fabric dust filters, absorbers, or electrostatic dust precipitators (ESP). On the other hand, the risk perceived by people living near waste incinerators is very high because of the bad reputation of previous waste processing plants with a diffuse social response like the Not In My Backyard (NIMBY). This opinion is reinforced by a handful of scientific papers on the characterisation of particles emitted by waste incinerators at full scale real operating conditions: furthermore, no papers estimated the contributions of these emissions to the daily ultrafine particle exposure or dose. This is a crucial aspect since throughout their entire lives, each and every person is exposed to the aerosols omnipresent in indoor air. As regards this topic, there are still major challenges to be addressed to fully understand and quantify the magnitude of both individual and population exposure to air pollution in different types of outdoor and indoor microenvironments. In fact, exposure is a product of the ultrafine particle concentration and the time over which a person is in contact with that pollutant: the corresponding dose is a product of exposure and dosimetry factors, and it estimates the quantity available for interference with metabolic processes or biologically significant receptors (Morawska et al., 2013).

The aim of this paper was to review the existing literature on the ultrafine particle emissions of waste incinerators with a special focus on the contribution of these emissions to the overall human exposure and daily dose. Exposure in typical important microenvironments has already attracted separate review (Morawska et al., 2008). In addition, we included in this review other more recent studies and identified studies published in English, using ScienceDirect, EBSCOhost, Web of Science and Wiley Interscience search engines. The following key words were used: incinerator, ultrafine particles, nanoparticles, waste. Additional studies were identified in the references of these publications, and on the basis of personal knowledge of the authors of this review.

2. Material and methods

As discussed above, ultrafine particle emissions from waste incinerators have not received adequate scientific attention. It should be noted that articles included in this review varied in their design and approach, also because different instrumentation was used. Consequently, most of the available data derive by different measurement procedures and instruments, leading to significant difficulties in the comparison. Moreover, even less information is reported about particle formation and changes in size arising from possible condensation of semivolatile flue gas components due to dilution and cooling effects. Table 1 summarizes exposure monitoring studies on ultrafine particle emissions of waste incinerators considered in this review.

Table 1
Summary of exposure monitoring studies on ultrafine particle emissions of waste incinerators.

Flue gas treatment	Instrumentation	Measurement range (nm)	Dilution ratio	References
1 waste incinerator: BH, WS, SCR	CPC (Grimm 5403) Vienna-type DMA (Grimm 55,706)	5.5–350	1:7	Ragazzi and Rada (2012) (10,000)
3 waste incinerators: BH, SCR	ELPI™ (Dekati Ltd.)	7–10,000		Ozgen et al. (2012) 14,000, 5000, 60,000
1 waste incinerator: WS, BH	LPI (Hauke GmbH) DMA (TSI Inc. 3071) CPC (TSI Inc. 3010)	14–800	1:5–1:200	Zeuthen et al. (2007)
1 waste incinerator: BH, WS, ESP	DMA (TSI Inc. 3071) CPC (TSI Inc. 3022)	17–600	1:10,000	Maguhn et al. (2003)
4 waste incinerators: • ESP, DA, BH, SCR • SCR, DA, BH • Quencher, DA, BH, WA SCR • SNCR, DA, BH, WA	ELPI™(Dekati Ltd.)	7–10,000	1:10–1:50	Cernuschi et al. (2012)
1 waste incinerator: SNCR, ESP, BH	ELPI™ (Dekati Ltd.)	7–10,000	1:20–1:200	Buonanno et al. (2009a)
1 waste incinerator: SNCR, BH	EC (TSI Inc. 3080L) CPC (TSI Inc. 3775)	14–700	1:25	Buonanno et al. (2010a) and Buonanno et al. (2011b)
4 waste incinerators: • SNCR, BH • SNCR, BH • WS, BH, SCR • 2 BH, SCR	EC (TSI Inc. 3080L) CPC (TSI Inc. 3775) DMA (Grimm 55,706)	6–800 nm 5.5–350 nm	1:10–1:20	Buonanno et al. (2012b)

SCR: selective catalytic reduction, SNCR: selective non catalytic reduction, ESP: electrostatic precipitation, DA: dry absorption system, WA: wet absorption system, BH: baghouse, AC: activated carbon, CPC: condensation particle counter, DMA: differential mobility analyzer, EC: electrostatic classifier, ELPI: electrical low pressure impactor, LPI: low-pressure cascade impactor.