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Characterization of particle emission from laser printers

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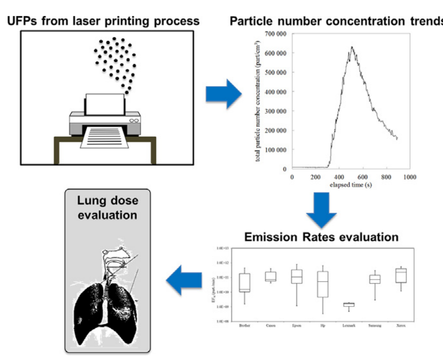
HIGHLIGHTS

- 110 laser printers from 7 manufacturers were analyzed in an experimental chamber.
- Particle number and mass concentrations, and size distributions, were measured.
- Emission rates for all the printers were calculated under fixed operational conditions.
- Daily surface area dose received by employees was estimated from emission rates.
- Relatively low total surface area dose (2.7 mm^2) was estimated for office employees.

GRAPHICAL ABSTRACT



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ABSTRACT

Emission of particles from laser printers in office environments is claimed to have impact on human health due to likelihood of exposure to high particle concentrations in such indoor environments. In the present paper, particle emission characteristics of 110 laser printers from different manufacturers were analyzed, and estimations of their emission rates were made on the basis of measurements of total concentrations of particles emitted by the printers placed in a chamber, as well as particle size distributions. The emission rates in terms of number, surface area and mass were found to be within the ranges from 3.39×10^8 part min^{-1} to 1.61×10^{12} part min^{-1}, 1.06×10^0 mm^2 min^{-1} to 1.46×10^3 mm^2 min^{-1} and 1.32×10^{-1} μg min^{-1} to 1.23×10^2 μg min^{-1}, respectively, while the median mode value of the emitted particles was found equal to 34 nm.

In addition, the effect of laser printing emissions in terms of employees' exposure in offices was evaluated on the basis of the emission rates, by calculating the daily surface area doses (as sum of alveolar and tracheobronchial deposition fraction) received assuming a typical printing scenario. In such typical printing conditions, a relatively low total surface area dose (2.7 mm^2) was estimated for office employees with respect to other indoor microenvironments including both workplaces and homes. Nonetheless, for severe exposure conditions, characterized by operating parameters falling beyond the typical values (i.e. smaller office, lower ventilation, printer located on the desk, closer to the person, higher printing frequency etc.), significantly higher doses are expected.

1. Introduction

Indoor activities could expose people to high concentrations of ultrafine particles due to the insufficiently fast removal of particles from the buildings where particle sources operate, and in turn causing a range of

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diseases (Alfano et al., 2012; Fuoco et al., 2015; Morawska et al., 2013; Stabile et al., 2016a). The main particle sources in indoor environments have been identified as cooking activities (Buonanno et al., 2011c; Buonanno et al., 2009b; Stabile et al., 2014), biomass burning for heating purposes (Salthammer et al., 2014), or particle re-suspension due to walking or cleaning activities (Kim et al., 2010). In workplaces, such as office buildings, in the absence of combustion or manufacturing processes, particle sources mainly include printers and photocopiers (Destaillats et al., 2008; Lee and Hsu, 2007; Schripp et al., 2008).

1.1. Particle emission from printers: state-of-art

The particle formation in a laser printing process is likely related to the evaporation of VOCs (volatile organic compounds) and SVOCs (semi-volatile organic compounds) released during the heating and fusing of the toner on the paper. After the evaporation of these compounds, Morawska et al. (2009) hypothesized two possible particle formation processes: i) primary particle formation due to homogeneous nucleation of SVOC and ii) secondary particle formation from SVOC species, formed through a reaction between VOC and ozone. As reported in their paper, the authors pointed out that such evaporation and nucleation processes depend on a range of factors, including fuser temperature, vapor pressure of the VOCs, amount of material deposited and water vapor content. He et al. (2010) quantified the relationship between fuser roller temperature and particle formation by measuring emissions from 30 laser printers in a chamber, using a standardized printing sequence, as well as monitoring the fuser roller temperature. They found that the temperature is the strongest factor controlling particle formation. In addition, they also found that almost all the investigated printers were high emitters in terms of particle number ($>1 \times 10^{10}$ part min^{-1}). The same relationship between the emission rate and the fuser unit temperature was showed in Park and Park (2013) by analyzing 11 printers with different fuser units from a variety of manufacturers. Betha et al. (2011) examined the characteristics of ultrafine particles and VOCs emitted from laser printers in a commercial printing center, and found that the number concentration of ultrafine particles (UFPs, particles smaller than 100 nm) in ambient air was influenced by the printer-related parameters and by indoor ventilation conditions: in particular UFP concentrations were high at lower air change rate. He et al. (2007) investigated particle emission from 62 laser printers in an office building, and classified the printers as "low", "medium" or "high" emitters. In particular, they showed that approximately 40% of the analyzed printers emitted UFPs, and that 27% of that 40% were high particle emitters. Nonetheless, the authors characterized only three printers in terms of emission rates, showing values up to 1.6×10^{11} part min^{-1} and negligible $PM_{2.5}$ emission rates of 0.75 ± 0.18 μg min^{-1}. McGarry et al. (2011) presented experimental evidence on temporal and spatial particle number concentrations measured during operation of 107 laser printers within open plan offices of five buildings in Australia, as part of their research aimed to evaluate the impact of the printers on exposure levels of the office workers during a typical working day. The authors found that the exposure to the printer-generated particles was significantly lower than the local background particle exposure, but that the exposure due to the peak concentrations resulting from printer emissions can be two orders of magnitude greater than the local background particle exposure. Similar results were shown for German offices by Tang et al. (2012). In that case, the authors measured UFP concentrations before, during, and after the operation of laser printing in 63 offices. They found "significant increase" of particle fractions between 0.23 and 20 μm in the offices during and after the printing processes: $PM_{0.23–20}$, $PM_{2.5}$ and PM_{10} concentrations increased in 43 out of the 62 investigated offices. An increase was also observed in the same offices for sub-micrometer particles, with the median number concentration of about 6.5×10^3 part cm^{-3} before, and 1.8×10^{-4} part cm^{-3} during the printing process.

1.2. Aim of the work

Despite the body of information presented from the above mentioned studies, there is a lack of information in the scientific literature regarding the characterization of particle emission: in fact, no studies exhaustively evaluated particle emission rates or particle sizes. To this end, in the present paper 110 laser printers from 7 different manufacturers, produced after 2006, were tested in an experimental chamber specifically designed for investigations of printer emission. The experimental analysis, aimed to assess the number, mass and surface area particle emission rates, as well as particle distributions, was performed based on printer emission testing under fixed operational conditions. This was done for the very first time on such a large number of laser printers. In addition to the emission characterization, the exposure to printer-generated UFPs of the people working in office environments was evaluated by estimating the surface area dose received by office workers (alveolar and tracheobronchial) on the basis of (i) the evaluated emission characteristics (emission rates) and (ii) the typical exposure scenario in the office. The estimated doses were compared to those received due to other indoor activities or indoor microenvironments.

2. Material and methods

2.1. Printers and media description

Laser printers from 7 different manufacturers were tested (Brother, Canon, Epson, HP, Lexmark, Samsung and Xerox). For each manufacturer, a minimum of 3 different models were considered, with a total of 110 printers. Listing of the number of printers for each manufacturer is provided in Table 1.

All the investigated printers work on the same three-phase principle: (i) selective collection of electrically charged toner on a drum; (ii) transfer of the image/text from the drum to the paper, (iii) heating of the paper in order to permanently fix the image/text on it. The firmware of all the printers was updated to the latest available version and original toner cartridges were used for all the tests. A single type of printer paper was used, which is a standard A4 paper for laser printing/fax/copy, with a density of 80 g m^{-2}. Tests were performed by printing 50 pages with a monochromatic toner coverage of 5% for each page, with a printing speed/quality according to the standard setting for each printer.

2.2. Instrumentation and quality assurance

The emissions of the investigated laser printers were characterized by measuring different particle metrics, using specific instrumentation:

- particle number concentrations (for particles >4 nm in diameter) were measured with a butanol-based Condensation Particle Counter (CPC model 3775, TSI Inc.), able to measure concentrations up to 1×10^7 part cm^{-3} with 1-s sampling time;
- particle mass concentrations in terms of PM_1, $PM_{2.5}$, PM_{10} were measured with a light-scattering laser photometer (DustTrak aerosol

Table 1
Number of printers tested for each manufacturer.

Manufacturer	Number of printers analyzed
Brother	4
Canon	3
Epson	16
HP	42
Lexmark	3
Samsung	31
Xerox	11