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Benchmark study on fine-mode aerosol in a big urban area and relevant doses deposited in the human respiratory tract☆

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ABSTRACT

It is well-known that the health effects of PM increase as particle size decreases: particularly, great concern has risen on the role of UltraFine Particles (UFPs). Starting from the knowledge that the main fraction of atmospheric aerosol in Rome is characterized by significant levels of $PM_{2.5}$ (almost 75% of PM_{10} fraction is $PM_{2.5}$), the paper is focused on submicron particles in such great urban area. The daytime/nighttime, work-/weekdays and cold/hot seasonal trends of submicron particles will be investigated and discussed along with NO_x and total PAH drifts demonstrating the primary origin of UFPs from combustion processes. Furthermore, moving from these data, the total dose of submicron particles deposited in the respiratory system (i.e., head, tracheobronchial and alveolar regions in different lung lobes) has been estimated. Dosimeter estimates were performed with the Multiple-Path Particle Dosimetry model (MPPD v.2.1). The paper discusses the aerosol doses deposited in the respiratory system of individuals exposed in proximity of traffic. During traffic peak hours, about 6.6×10^{10} particles are deposited into the respiratory system. Such dose is almost entirely made of UFPs. According to the greater dose estimated, right lung lobes are expected to be more susceptible to respiratory pathologies than left lobes.

1. Introduction

In 2015 the International Agency for Research on Cancer (IARC) considered the airborne Particulate Matter (PM) (WHO, 2007; Fuzzi et al., 2015; Zhang et al., 2015) as a leading environmental cause of cancer deaths and classified it as carcinogenic to humans in the group I (IARC, 2015). The basis of this decision was the different epidemiologic studies performed on populations exposed to either PM_{10} or $PM_{2.5}$ (Russell and Brunekreef, 2009; HEI, 2013; Philip et al., 2014; Loomis et al., 2013; Hamra et al., 2014) and thus PM is presently regulated throughout the European Community on a mass basis through the PM_{10} and $PM_{2.5}$ conventions (Directive EC, 2008). These evidences have been related both to particles themselves and their chemical composition: a) inorganic ions (sulphates, nitrates, ammonium, chloride), b) carbonaceous components (Organic Carbon, OC and Elemental Carbon, EC) (Avino et al., 2000, 2015a), c) mineral particles and unknown compounds (Avino et al., 2006, 2008, 2013b). $PM_{2.5}$ is richer in organic ions and carbonaceous components, but less in mineral particles (Avino et al., 2013c).

Basically, airborne particulate matter is a complex particle mixture at different size and chemical composition (Avino et al., 2013a) deriving from several processes, mainly represented by combustion and/or atmospheric gas-to-particle conversion. As regard to size, particles in urban atmosphere generally range between 0.01 and 100 μm: UltraFine Particles (UFPs) 0.01–0.10 μm, fine particles (fine) 0.10–2.5 μm, coarse particles (coarse) 2.5–10 μm. Different studies have provided evidence that some particles become more toxic per unit mass as their size decreases and, consequently, have drawn the attention on particle surface area or particle number rather than mass, emphasizing the role of UFPs (Oberdorster, 1996; Oberdörster, 2001; Huang et al., 2004; Warheit, 2004; Salata, 2004; Yang and Watts, 2005; Oberdörster et al., 2005a, 2005b; Buonanno et al., 2011; Manigrasso and Avino, 2012; Stabile et al., 2013; Canepari et al., 2013; Manigrasso et al., 2013; Marini et al., 2015). While particles greater than 2.5 μm are quickly removed through dry and wet deposition on the

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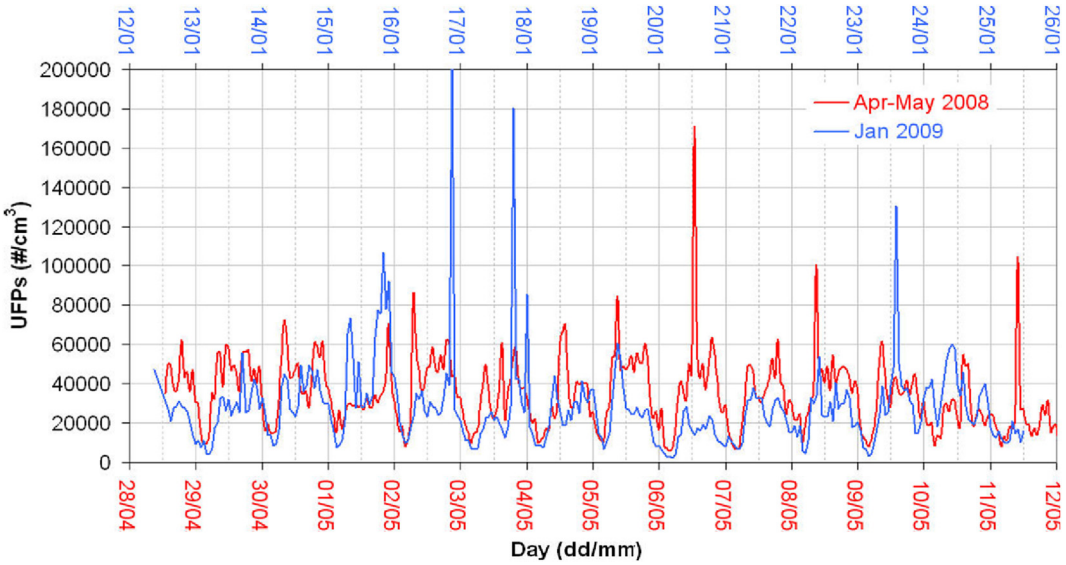

Fig. 1. Typical daily trends of total UFP number concentrations in April–May 2008 and January 2009.

time scale of hours, submicron particles (PM_1) could reside in atmosphere for long time, penetrate in indoor environments (Brauer et al., 1989) and/or be transported long-range.

The small size of UFPs in comparison with cellular structures' dimensions, their high particle number concentration and the very high surface area allow a great ability of both absorption of organic molecules and penetration into cellular targets in the lung and systemic circulation (Pagano et al., 1996; Li et al., 2003; Cuomo et al., 2013). Thus, the number particle concentration provides a better UFPs exposure index to be correlated with the observed health effects compared to their mass concentration. While databases for PM_{10} and $PM_{2.5}$ are available for many urban centers worldwide, UFPs data in terms of number particle concentration are still limited (Vu et al., 2015). Further, a very important issue regards the contribution of submicron fraction to the fine-mode fraction. Starting from $PM_{2.5}$ measurement, this paper investigates the relevance of the submicron particles on the *fine*-mode aerosol. Moreover, the UFPs behavior as well, in big urban areas, such as Rome, has been studied.

2. Materials and methods

Aerosol and gas-phase pollutants measurements were carried out at the INAIL's Pilot Station located in downtown Rome in an area characterized by high density of autovehicular traffic. The street where the measurements were performed can be considered a canyon: a narrow double lane street and high buildings on both sides (height/width ratio 3:1) are conditions important for describing the sampling site. Rome represents an interesting study for its characteristics: in fact, its urban area is characterized by both intense and heavy traffic (buses, trucks). According to the Automobile Club Italia (ACI) statistics (2013), three millions of vehicles circulate in Rome with a ratio of 706 vehicles per 1000 inhabitants (for comparison Milan, another important big Italian city, shows a ratio of 530 vehicles per 1000 inhabitants, whereas the European average ratio is 582 per 1000 inhabitants) in an area of 1287 km^2. These data evidence the strong influence of autovehicular traffic in Rome and why its metropolitan area can be considered a relevant study scenario. Furthermore, diesel fueled vehicles are steadily increasing, reaching almost the 40% of the total vehicle park (ACI, 2013).

All the measurements were performed at street level, except the measurements for determining carbonaceous particulate matter that were carried out at 20 m-height as well. The measurements cover about five years (2008–2013), and divided in two groups representative of the hot and cold periods. In the present research we selected and evaluated a set of data obtained during some specific periods, for describing peculiar characteristics of aerosol pollution in a big urban areas such as Rome.

The hourly PM_{10} and $PM_{2.5}$ measurements were simultaneously performed by an instrument based on β-attenuation technique (SWAM 5a Dual Channel Monitor, FAI Instruments, Fonte Nuova, Italy) whereas the aerosol number size distributions (2.5–1000 nm) were measured using a Scanning Mobility Particle Sizer (SMPS, model 3936, TSI, Shoreview, MN, USA) equipped with an Electrostatic Classifier (model 3080, TSI) and a Differential Mobility Analyzer (DMA, model 3085, TSI) and a water-based Condensation Particle Counter (model 3786, TSI), for the electrical mobility diameter size classification of the particles with measurement time of 5 min. Further, highly time-resolved particle number size distributions (1 s time) were measured by means of a Fast Mobility Particle Sizer (FMPS, model 3091, TSI) in the range from 5.6 to 560 nm electrical mobility diameter.

Ozone, NO and NOx concentrations were determined both by API instruments (400 series and 200 series, San Diego, CA) and DOAS (Opsis, Opsis, Sweden) (Platt et al., 1979; Platt and Perner, 1980; Karlsson, 1990; Avino and Manigrasso, 2008). Carbonaceous fractions (OC, EC and Total Carbon, TC) and PM nitrate were measured by means of 5400 ACPM and 8400 Nitrate, respectively (Rupprecht and Patashnick, Albany, New York). Total particle bound Polycyclic Aromatic Hydrocarbons (PAHs) were measured by means of realtime monitor PAS 2000 (Ecochem, League City, TX). The secondary Organic Carbon (OC_{sec}) was calculated according to Turpin and Huntzicker (1995) and Castro et al. (1999): it was assessed using EC as a tracer of primary OC (Turpin et al., 1991; Lee and Huang, 1993; Turpin and Huntzicker, 1995; Castro et al., 1999).

For evaluating the mixing properties of the atmosphere and the relative conditions favoring and unfavoring the pollutant dispersion, the Planetary Boundary Layer (PBL) (Allegrini et al., 1994; Shweikani et al., 1995; Perrino et al., 2001; Avino et al., 2003, 2008; Buonanno et al., 2010; Manigrasso et al., 2012; Avino et al., 2015b) was studied by means measuring the natural radioactivity

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