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Environmental and traffic-related parameters affecting road dust composition: A multi-technique approach applied to Venice area (Italy)

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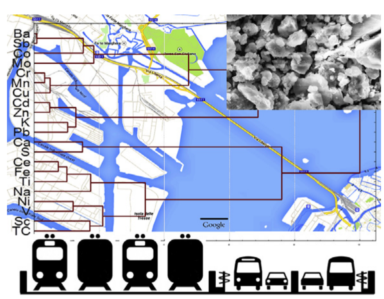
HIGHLIGHTS

- Road dust of Venice is characterized by a multi-technique approach.
- Road dust composition changes as a function of the driving conditions.
- Six pollutant sources are identified by cluster analysis.
- Sources: brake, railway, tire, asphalt, soil + marine, mixed combustions.

GRAPHICAL ABSTRACT



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ABSTRACT

Road dust is a non-exhaust source of atmospheric particulate by re-suspension. It is composed of particles originating from natural sources as well as other non-exhaust source such as tire, brake and asphalt wear. The discrimination between atmospheric particles directly emitted from abrasion process and those related to re-suspension is therefore an open issue, as far as the percentage contribution of non-exhaust emissions is becoming more considerable due also to the recent policy actions and the technological upgrades in the automotive field, focused on the reduction of exhaust emissions.

In this paper, road dust collected along the bridge that connects Venice (Italy) to the mainland is characterized with a multi-technique approach in order to determine its composition depending on environmental as well as traffic-related conditions. Six pollutant sources of road dust particles were identified by cluster analysis: brake, railway, tire, asphalt, soil + marine, and mixed combustions.

Considering the lack of information on this matrix in this area, this study is intended to provide useful information for future identification of road dust re-suspension source in atmospheric particulate.

1. Introduction

In the last few years, several reviews report that road traffic emissions contribute significantly to atmospheric particulate

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matter (PMx, where x is the aerodynamic diameter measured in μm) in urban and industrialized areas (e.g., Thorpe and Harrison, 2008; Wik and Dave, 2009; Franco et al., 2013; Kumar et al., 2013a; Pant and Harrison, 2013; Amato et al., 2014a). This particular source includes exhaust and non-exhaust emissions. The former are related to the tailpipe emissions, the others are due to wear of vehicle parts such as brake system (pads and disc) and tires, road surface abrasion and re-suspension of road dust (RD) finer particles made of natural and anthropogenic material that accumulates on the road surface mainly close to the pavements (Pant and Harrison, 2013, and references therein).

Most of the recent policy actions and technological upgrades in the automotive field were focused on finer PMx emitted by exhaust emissions, whereas the relative contribution to environmental PMx of non-exhaust emissions is becoming more and more relevant (Denier van der Gon et al., 2012). For example, Rexeis and Hausberger (2009) estimated that nearly 90% of the total emissions from road traffic will come in the next few years from non-exhaust sources. Instead, Bukowiecki et al. (2009) estimated that the sum of direct abrasion sources and vehicle induced road dust resuspension included 60% of the total traffic related PM_{10} emissions.

Beside the issue of the overcoming of guidelines limits for the air quality, the characterization of non-exhaust emission source is of crucially high interest for the inherent toxicity of emitted particles, that can act as carriers of heavy metals and carcinogenic components (Pant and Harrison, 2013).

Size and chemical composition of particles emitted by non-exhaust sources may differ significantly and their percentage contributions to the atmospheric particulates is quite site-specific. Some of the conditions and the environmental parameters that drive the non-exhaust emission characteristics are: fleet composition (higher emissions are reported for heavy duty vehicles (EMEP/EEA, 2013a; Grigoratos and Martini, 2014)); traffic flow (the wear of brake and related particles emission is higher with stop-and-go driving conditions (Bukowiecki et al., 2009)); number of vehicles and related mean speed; composition of tires and brake of vehicles; moisture/humidity of surface; type of roads (unpaved road are characterized by higher emission of re-suspended road dust, and asphalt surfaces cause less tire wear than concrete pavements); climate conditions (the use of anti-skid materials on the road surface during the cold seasons increases the re-suspension of road dust even in the following warmer seasons); geology of the sampling site (Pant and Harrison, 2013 and references therein).

The technical guidance to prepare national emission inventories of EMEP/EEA air pollutant emission inventory guidebook (2013a) includes tire wear, brake abrasion and road surface wear as source emissions categories, but ignores the re-suspension process which dominates PMx emissions in some European areas (Weinbruch et al., 2014; Amato et al., 2014a and references therein). In some cities, the efficiency of street wash activities and the use of dust suppressants (such as calcium–magnesium acetate or $MgCl_2$) to limit the re-suspension were characterized (Amato et al., 2014b; Karanasiou et al., 2014).

Presently, detailed information on non-exhaust PMx emissions including sources, spatial and temporal variations of chemical characteristics, evolution of particles emitted from vehicles, impact upon human health and quantitative contributions of different sources are rather scarce (Pant and Harrison, 2013). In particular, since RD is also composed of particles originated from non-exhaust, the discrimination between particles directly emitted from abrasion process and those related to the re-suspension is lacking; accordingly, the scientific community is paying an increasing interest in the topic at issue (e.g.: Grigoratos and Martini, 2014, 2015).

In the last decade several works were focused on the characterization of RD samples collected worldwide: Asia (e.g: Fang et al., 2004; Liu et al., 2007; Han et al., 2009; Wei and Yang, 2010; Huang et al., 2012; Wijaya et al., 2012; Du et al., 2013; Kumar et al., 2013b; Liu et al., 2014; Sakata et al., 2014; Zhang et al., 2015a), Europe (Amato et al., 2011; Bardelli et al., 2011; Varrica et al., 2013; Zhang et al., 2015b), Americas (McKenzie et al., 2008; Apeagyei et al., 2011; Fujiwara et al., 2011a, 2011b, 2011c; Quiroz et al., 2013), Australia (Gunawardana et al., 2012) and Africa (Hassanien and Abdel-Latif, 2008). Most of them are based on the study of the elemental composition (e.g: McKenzie et al., 2008; Amato et al., 2011; Han et al., 2011; Fujiwara et al., 2011b, 2011c; Gunawardana et al., 2012; Huang et al., 2012; Wijaya et al., 2012; Du et al., 2013; Liu et al., 2014; Zhang et al., 2015a), some other on the characterization of the organic compounds (e.g: Omar et al., 2007; Fang et al., 2004; Liu et al., 2007; Hassanien and Abdel-Latif, 2008; Han et al., 2009; Zhang et al., 2015b). X-ray powder diffraction (XRD), X-ray fluorescence (XRF), X-ray absorption spectroscopy (XAS) and Ion Beam Induced Luminescence (IBIL) techniques were also used to study RD samples (e.g: Fujiwara et al., 2011a; Apeagyei et al., 2011; Barrett et al., 2010; Bardelli et al., 2011; Varrica et al., 2013; Sakata et al., 2014; Valotto et al., 2014a); however, the use of a multi-technique approach to characterize this matrix is quite rare.

Usually, RD samples are collected to determine the chemical differences among different areas of the same city such as industrial, urban, residential and background (e.g: Liu et al., 2007; Huang et al., 2012; McKenzie et al., 2008; Fujiwara et al., 2011a, 2011b, 2011c; Gunawardana et al., 2012; Du et al., 2013; Kumar et al., 2013b; Hassanien and Abdel-Latif, 2008; Zhang et al., 2015b). In other work,s the sampling campaigns are performed to point out the difference among different cities (e.g: Amato et al., 2011; Wiljaya et al., 2012) or among streets of the same city characterized by significantly different traffic flows (e.g: Apeagyei et al., 2011; Liu et al., 2014; Quiroz et al., 2013). Instead, few works focused on small areas but with an higher spatial resolution (Zhang et al., 2015a).

In this work, RD samples were collected every 200 m along the only bridge that connects the Venice island (Italy) to the mainland, and characterized by a multi-technique approach to determine the different composition depending on environmental as well as traffic-related conditions. The sampling site is an ideal area for the characterization of non-exhaust sources because the presence of crustal particles is lower than in other continental sites. Moreover, this study, the first one on this non-exhaust source in Veneto Region, will provide topical information for future identification in the Venice district of RD re-suspension source in atmospheric particulate.

Elemental and molecular composition as well as morphology of sub-samples most subjected to re-suspension process (characterized by particle size lower than 37 μm) were determined by: Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), Total Carbon (TC) analysis, Scanning Electron Microscopy – Energy Dispersive X ray spectroscopy (SEM–EDX), X-ray Photoelectron Spectroscopy (XPS). Furthermore, in order to identify the main pollutant sources of road dust particles, the relation between elemental concentration values was studied by Cluster Analysis.

2. Materials and methods

2.1. Study area and sampling sites

The municipality of Venice, located between the Adriatic Sea and the Po Valley, is the most industrialized district of Italy. As mentioned in Valotto et al. (2014b), this area is influenced by several anthropogenic emission sources such as the urban areas of Mestre and Venezia, the industrial area of Porto Marghera, private