Available online at www.sciencedirect.com
ScienceDirect
Atmospheric Environment 42 (2008) 3099–3114
ATMOSPHERIC ENVIRONMENT
www.elsevier.com/locate/atmosenv

Emission factors of PM species based on freeway measurements and comparison with tunnel and dynamometer studies

Zhi Ning[a], Andrea Polidori[a], James J. Schauer[b], Constantinos Sioutas[a,*]

[a]*Department of Civil and Environmental Engineering, University of Southern California, 3620 South Vermont Avenue, Los Angeles, CA 90089, USA*

[b]*Environmental Chemistry and Technology Program, University of Wisconsin-Madison, Madison, WI 53706, USA*

Received 7 August 2007; received in revised form 10 December 2007; accepted 12 December 2007

Abstract

Emission factors of various particle species from light- and heavy-duty vehicles (LDVs and HDVs, respectively), including organic and elemental carbon (OC and EC), sulfate, polycyclic aromatic hydrocarbons (PAHs), hopanes, steranes, trace metals, elements, and particle number (PN), were estimated based on roadway measurements. Sampling campaigns were conducted at two different roadways: the CA-110 highway (where only gasoline-powered vehicles are allowed), and the I-710 freeway (where about 20% of the total number of vehicles are diesel-powered trucks). The particulate matter (PM) emission factors determined in these roadways were compared to those reconstructed from recent source emission data from the Caldecott tunnel [Phuleria, H.C., Geller, M.D., Fine, P.M., Sioutas, C., 2006. Size-resolved emissions of organic tracers from light- and heavy-duty vehicles measured in a California roadway tunnel. Environmental Science and Technology 40 (13), 4109–4118], and those from previous tunnel and chassis dynamometer studies. Very good agreement between estimated and reconstructed emission factors was found for PN, EC, sulfate, high-molecular-weight (MW) PAHs, hopanes and steranes. This suggests that PM-speciated chemical data collected at roadsides can be used to calculate reliable emission factors for several important particle species at other locations characterized by a similar mix of on-road motor vehicles. The agreement between our results and other studies in the emission factors of trace elements and metals varied from very good (for species such as Cu, Mo, Ba, Pb) to poor (for species such as Mg, Fe, Ca), probably because the atmospheric concentrations of the latter elements are associated with both traffic and non-traffic sources, and the relative abundances of Mg, Ca, and Fe in road dust varies considerably across locations. The emission factors of OC and EC were clearly the highest for HDVs, and those of PAHs, hopanes, and steranes from our roadway measurements were well within the range of values reported in the literature from tunnel and dynamometer studies. The approach presented in this paper allows for a straight-forward estimation of PM emission factors from ambient, near-freeway measurements. Although the uncertainties inherent in the method proposed here must be acknowledged (e.g. assumptions were made to estimate the average fleet composition and the total carbon content in the vehicles' exhaust), our results are generally in very good agreement with those in the available literature for most non-labile PM species.

Keywords: Emission factors; Heavy-duty vehicles; Light-duty vehicles; Freeway; Tunnel; OC and EC; Sulfate; PAHs; Hopanes; Steranes; Trace metals and elements; CO_2

*Corresponding author. Tel.: +1 213 740 6134.
E-mail address: sioutas@usc.edu (C. Sioutas).

1352-2310/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.atmosenv.2007.12.039

1. Introduction

Numerous epidemiological studies have found positive associations between adverse respiratory and cardiovascular effects and exposure to atmospheric particulate matter (PM) (Samet et al., 2000; Pope et al., 2002; USEPA, 2004). In addition, toxicological experiments on human volunteers, laboratory animals, and tissues have provided some evidence of adverse effects for ultrafine particles (aerodynamic diameter <0.1–$0.2\,\mu m$) and outdoor fine PM ($PM_{2.5}$; aerodynamic diameter $<2.5\,\mu m$) (Oberdorster et al., 2004; Nel, 2005). Although the biological mechanisms responsible for the toxicity of PM are still uncertain, researchers have recently attempted to link the toxicity of PM with several of its chemical components, including organic and elemental carbon (OC and EC, respectively) (Mar et al., 2000; Metzger et al., 2004), trace metals (Saldiva et al., 2002; Wellenius et al., 2003) and polycyclic aromatic hydrocarbons (PAHs) (Dejmek et al., 2000).

In urban environments, light- and heavy-duty vehicles (LDVs and HDVs) have become the major source of ultrafine, fine and in some cases coarse PM (Gertler et al., 2000) via fuel combustion, mechanical and tire wear, and secondary aerosol formation from chemical reactions involving both organic and inorganic gaseous precursors (Schauer et al., 1996; Mysliwiec and Kleeman, 2002). It is therefore essential to characterize and quantify vehicle emissions in order to evaluate the impact on human health and the environment, and also to assess the overall effectiveness of exhaust control technologies.

Different approaches have been used to characterize vehicular emissions, including chassis dynamometer tests (Schauer et al., 1999, 2002; Zielinska et al., 2004; Riddle et al., 2007a, b; Fujita et al., 2007), roadway tunnel studies (Geller et al., 2005; Phuleria et al., 2006; Lough et al., 2005) and roadside pollutants concentration measurements (Kuhn et al., 2005a; Ntziachristos et al., 2007a). Chassis dynamometer experiments have the ability to examine vehicle emissions under different driving/loading settings and to effectively evaluate exhaust control technologies. However, a controlled laboratory environment may not necessarily be representative of real-world driving conditions (Zhang and Morawska, 2002), and non-tailpipe emissions such as those from tire wear, the wear of brake linings and re-suspended road dust (Allen et al., 2001) are not accounted for by these types of studies. Roadway tunnel experiments characterize a large portion of all on-road vehicles, providing a detailed analysis of the overall vehicle fleet emissions (Phuleria et al., 2006). However, a limitation of these studies is that they provide information that is specific to a particular tunnel under restricted driving conditions. Thus, these results may not be broadly applicable to open roadways. Finally, although roadside pollutant concentration measurements characterize freeways emissions under actual ambient and driving conditions well, they may be influenced by changes in the local meteorological and environmental conditions (Ntziachristos et al., 2007b). This could complicate a direct comparison of the pollutant levels at different locations.

In the present study, the concentrations of several gas- and particle-phase species were measured near two major roadways in the Los Angeles Basin and at selected background sites to determine fuel-based roadway emission factors for specific PM components (i.e. OC, EC and sulfur), organic constituents (PAHs, hopanes and steranes), trace metals and elements, and particle number (PN). The calculated factors were compared to those reported in previous works, as well as those reconstructed from size-segregated emission profiles obtained at the Caldecott tunnel, California, by Geller et al. (2005) and Phuleria et al. (2006). Our study thus provides a convenient methodology to derive emission factors for PM species that can be used to characterize on-road motor vehicle emissions under real-world driving conditions. This information is crucial in evaluating the effectiveness of emission control strategies and legislature, as well as in assessing PM exposure from roadway traffic emissions.

2. Experimental methods

2.1. Sampling locations

The present study was carried out near two major freeways in the Los Angeles Basin, the California State Highway (CA-110) and the Long Beach Freeway (I-710). The former connects Pasadena to downtown Los Angeles, where it merges into the I-110, which runs southbound towards San Pedro and represents one of the main freeways in the Los Angeles County. Only light-duty gasoline-powered vehicles are allowed on the CA-110. The sampling site was located downwind of the highway at 3 m from the edge of the northbound lanes on the east