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Evolution of particle number distribution near roadways. Part III: Traffic analysis and on-road size resolved particulate emission factors

K. Max Zhang[a], Anthony S. Wexler[a,b,c,*], Debbie A. Niemeier[b], Yi Fang Zhu[d], William C. Hinds[d], Constantinos Sioutas[e]

[a]*Department of Mechanical and Aeronautical Engineering, University of California, Davis, CA 95616, USA*
[b]*Department of Civil and Environmental Engineering, University of California, Davis, CA 95616, USA*
[c]*Department of Land, Air, and Water Resources, University of California, Davis, CA 95616, USA*
[d]*Department of Environmental Health Sciences, University of California Los Angeles, 650 Charles E. Young Drive South, Los Angeles, CA 90095, USA*
[e]*Department of Civil and Environmental Engineering, University of Southern California, 3620 South Vermont Avenue, Los Angeles, CA 90089, USA*

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Abstract

On-road size-resolved particulate emission factors were computed using concurrently measured carbon monoxide (CO) as a freeway dilution indicator and correlating roadside particle measurements to CO measurements. The emission factors derived for the total particle number agree well with previous on-road investigations. However, this study extends this analysis to produce unique receptor-dependent, size-resolved, road and grid-level emission factor distributions. Both mileage- and fuel-based particle number and mass emission factors at road and grid levels, along with CO emission factors, are presented and the results from freeways with distinctly different percentages of heavy-duty diesel truck traffic are compared. The effects of plume processing on particle number near roadways are shown to be much more profound than on particle mass, further indicting that the adverse health effects observed near roadways are at least partially related to particle numbers.

Keywords: Carbon monoxide; Mobile emissions; Traffic; Transportation; Ultrafine particles; Aerosol

1. Introduction

Accurate motor vehicle emission inventories are critical for understanding and controlling air pollution problems. Vehicle emissions inventories are produced by multiplying emission factors by associated travel activity. While emission factors can be directly measured in the laboratory using dynamometer tests (Rickeard et al., 1996; Graskow et al., 1998; Hall et al., 2000; Hall and Dickens, 2000; Maricq et al., 2002a, b), there is an ongoing debate over whether such tests are able to replicate the real world emissions (Graskow et al., 1998; Hall and Dickens, 2000; Hall et al., 2000; Maricq et al.,

*Corresponding author. Department of Mechanical and Aeronautical Engineering, University of California, Davis, CA 95616, USA. Tel.: +1 530 754 6558; fax: +1 530 752 4158.
E-mail address: aswexler@ucdavis.edu (A.S. Wexler).

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2002b). Largely as a result of this debate, in recent years, many researchers pursued a so-called ''on-road'' approach—deriving emission factors from real-world observations. A brief introduction to four general approaches found the in the literature is given here.

Control volume. Hlavinka and Bullin (1988) proposed using a mass balance model to determine emission factors of gaseous pollutants and calculated carbon monoxide (CO) emissions factors using this method. Jamriska and Morawska (2001) adopted a similar approach and extended it to estimating particle number emission factors. Both of these models select a representative portion of the roadway as a control volume, and assume that the two main processes affecting the pollutant concentration—emissions that originate from traffic traveling in the control volume and losses due to airflow carrying the pollutant out of the control volume—are in equilibrium. The effects of sinks, such as gravitational deposition of particles, or of other processes affecting pollutant characteristics are assumed negligible. With controlled ventilation, road tunnels provide a well-defined control volume to study mobile emissions (Abu-Allaban et al., 2002; Gidhagen et al., 2003). The emission factors can then be calculated, in a straightforward manner, from outlet and inlet concentrations, length and cross-sectional area of tunnel, traffic volume and wind speed inside of tunnel.

Correlation with carbon (fuel-based emission factors). Fuel-based pollutant emission factors are generally computed by relating the increase in pollutant concentration to the increase in the total carbon emissions (mostly in forms of carbon dioxide (CO_2) and CO) in a tunnel (e.g. Kirchstetter et al., 1999) or on roads (e.g. Kittelson et al., 2004), which are then in turn related to the carbon content of fuel. The emission factors, expressed as mass of pollutant emitted per unit of fuel consumed, can be combined with fuel sales data to estimate total pollutant emissions (Singer and Harley, 1996). The advantages and drawbacks of this approach were discussed in Sawyer et al. (2000). Assuming vehicle fleet average fuel consumption, distance-based emission factors in particles km^{-1} can be determined.

Correlation with NO. Janhäll et al. (2004) found that nitric oxide (NO) was a better tracer for traffic related ultrafine particles, than traffic intensity itself after analyzing their measurements of gases (NO, NO_x, SO_2 and O_3) and particles near Göteborg, Sweden. Although NO_x emission rates were not given explicitly in Janhäll et al. (2004), if they are available, the particle emission factor size distribution can be calculated by multiplying their NO-based emission factors by the actual NO emission factors.

Particle dispersion (inverse modeling). Inverse modeling can also be used to determine emission factors (Mulholland and Seinfeld, 1995; Palmgren et al., 1999). Gramotnev et al. (2003) assumed that the total number concentration of particles ranged from ~15 nm to ~1 μm and the average emission factors for vehicles on a road can be approximately described by a Gaussian plume. For example, this type of analysis was used in the Brisbane area, Australia, where CALINE 4 (Benson, 1992) was adapted to obtain the emission factors near a busy road (Gramotnev et al., 2003).

For the remainder of this paper, we will refer to the methods discussed above as control volume, particle-carbon, particle-NO and particle dispersion, respectively. The values of emission factors derived from studies using each of those methods are listed in Table 5. Particulate pollutants' physico-chemical properties and health effects are closely associated with their size, therefore ideally particle emission factors should be size-resolved. Note only those results from Janhäll et al. (2004) were size resolved, however, the emission rate was implicitly defined (i.e., in terms of particles per ppb NO).

Since evolution of particle distributions is a dynamic process (Zhang et al., 2004), size-resolved particle emission factors (or particle emission factor distributions) are also receptor dependent. In our previous study, we have shown this dynamic process can be divided into two stages, i.e., 'tailpipe-to-road' and 'road-to-ambient', based on their distinct dilution natures (Zhang and Wexler, 2004). Accordingly, there are three major types of emission factors: tailpipe-level EF, road-level (or curb-level) EF and grid-level EF as described in Table 1. Typical urban and regional air quality models usually employ grid-level EFs as their inputs, while 'plume-in-grid' models require tailpipe or road-level EFs. In the field of highway design and planning, information on both road-level and grid-level EFs are necessary to evaluate the impacts of highway traffic on the exposure of commuters, pedestrians and nearby communities. However, none of previous studies have clearly distinguished those EFs.

Table 1
Three major types of emission factors and their descriptions

EF	Description
Tailpipe-level	The emission profiles near the exit of the tailpipe
Road-level	The emission profiles on or near the roadway curb
Grid-level	The emission profiles near the end of plume processing (particle dynamics slows down significantly at this point)