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Evaluating near highway air pollutant levels and estimating emission factors: Case study of Tehran, Iran

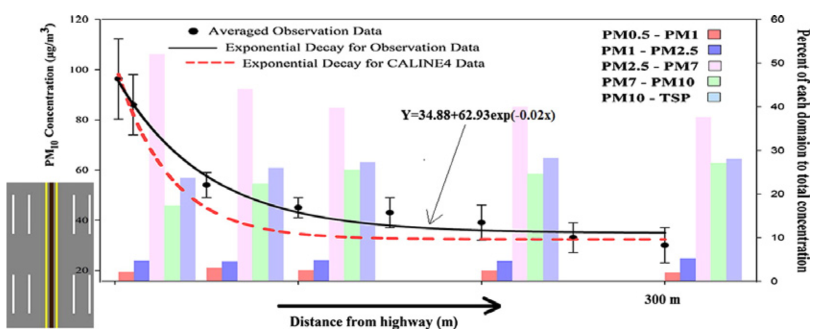
Mohammad Nayeb Yazdi, Maryam Delavarrafiee, Mohammad Arhami *

Department of Civil Engineering, Sharif University of Technology, Azadi Ave, P.O. Box 11155-9313, Tehran, Iran

HIGHLIGHTS

- Size segregated PM and CO were measured on a highway roadside and in a tunnel.
- Sharp increase of pollutant levels found in 100–150 m downwind of highway shoulder
- The EFs for CO and PM_{10} were estimated to be ~4–12 and 0.1–0.2 g/km, respectively.
- Variation of EFs under real working condition with speeds was determined.
- Particle aging and size change by distancing downwind of highway were evaluated.

GRAPHICAL ABSTRACT



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ABSTRACT

A field sampling campaign was implemented to evaluate the variation in air pollutants levels near a highway in Tehran, Iran (Hemmat highway). The field measurements were used to estimate road link-based emission factors for average vehicle fleet. These factors were compared with results of an in tunnel measurement campaign (in Resalat tunnel). Roadside and in-tunnel measurements of carbon monoxide (CO) and size-fractionated particulate matter (PM) were conducted during the field campaign. The concentration gradient diagrams showed exponential decay, which represented a substantial decay, more than 50–80%, in air pollutants level in a distance between 100 and 150 meters (m) of the highway. The changes in particle size distribution by distancing from highway were also captured and evaluated. The results showed particle size distribution shifted to larger size particles by distancing from highway. The empirical emission factors were obtained by using the roadside and in tunnel measurements with a hypothetical box model, floating machine model, CALINE4, CT-EMFAC or COPERT. Average CO emission factors were estimated to be in a range of 4 to 12 g/km, and those of PM_{10} were 0.1 to 0.2 g/km, depending on traffic conditions. Variations of these emission factors under real working condition with speeds were determined.

1. Introduction

In many large urban areas, vehicular emissions are predominant cause of high levels of air pollutants. Several epidemiological studies have shown positive associations between adverse health effects such as heart attacks, increased risk of asthma, coronary heart disease and lung cancer with elevated level of air pollutants (Tong et al., 2014; Gan et al., 2011; Yamazaki et al., 2014; Bowatte et al., 2014; Hystad et al., 2013). Exposure to high level of pollutants could rises morbidity and mortality rate particularly in infants, children and elderly (Cao et al., 2011; Zhou et al., 2014). Among different microenvironments,

* Corresponding author.
E-mail address: arhami@sharif.edu (M. Arhami).

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habitats in adjacent of roadways with high traffic volumes are exposed to high level of air pollutants (Heck et al., 2013; Brandt et al., 2014; Bentayeb et al., 2010). Roadside air pollution exposure assessment is crucial for residents and business personnel often found along highways. In a series of studies by taking measurements at 8 stations located in distances of 2 m to 350 m on vicinity of 405 and 710 interstates freeways in southern California, exponential increase of particle number, CO and PM compared to the background levels were found (Zhu et al., 2002a, 2002b). However, more information such as different sites including roadways with highly polluting vehicles at different climate conditions is still required to better understand the behavior and properties of pollutants near roadways in various urban areas. Such information could be obtained by studies on assessing and modeling pollutants trends in near roadways.

The levels of air pollutants near a busy highway and within a tunnel in Tehran, Iran which are known to have significantly high level of pollutants were evaluated, in this study. Field measurements of carbon monoxide (CO) and particulate matter (PM) were implemented to characterize roadside levels of these pollutants, and to generate input data for modeling. These two pollutants generally have major emissions from mobile sources in urban areas. PM exposure could increase the risk of acute and chronic respiratory infection, pulmonary cancer, arteriosclerosis and cardiovascular diseases (Englert, 2004; Kappos et al., 2004). CO causes major detrimental effects on human physiological functioning, cardiovascular effects, neural behaviors, and fibrinolysis effect (Raub, 1999; Tao et al., 2011). The 12.4 million population of metropolitan Tehran has experienced high levels of air pollution and serious environmental damages leading to steady mortality increase in recent years (Statistical Centre of Iran, 2012). Air pollution crisis in Tehran is attributed to many different factors, including but not limited to the low standard vehicles, low fuel quality, ineffective public transportation infrastructures, as well as non-efficient control management and policies (Sotoudeheian and Arhami, 2014; Kamali et al., 2015). Despite the significance of pollution problem attributed to mobile sources in this city, still little information on vehicular emission at the real world working condition is available. Besides, several major roadways with considerable population residing in their vicinity are located in this city. Sufficient studies were not conducted in order to produce the practical data required to take proper actions and protect these residents.

In the present study vehicular emission and the pollutants levels in the vicinity of major roadways in Tehran were assessed by conducting a near roadway and in tunnel experimental campaign followed by a modeling procedure. Experimental studies and emission models were conducted to evaluate variations in level of air pollutants and emission factor estimation. The air sampling was performed simultaneously while the meteorology data and vehicle flows were recorded (Giang and Oanh, 2014). In order to estimate traffic originated air pollutant levels near roadways and within tunnels, and emission factors, dispersion models such as CALINE4 (California LINE Source Dispersion Model, version 4), emission factor models including COPERT (Computer Program to Calculate Emissions from Road Transport), CT-EMFAC (CARB, 2000; Kouridis et al., 2000) and box modeling were used. Intra-urban variability in dispersion of ambient pollutants are caused by various factors, including the mixing scheme of pollutants, land use, local wind configurations (Seaman, 2000), traffic pattern, temperature and amount and type of precipitation (McGregor, 1999). One of the many advantages of these models is providing a framework for evaluating the effects of meteorological condition (wind speed and direction, mixing height) as well as traffic attributed variables, such as traffic counts, road length, and inverse distance to highway and reactions on air pollutants downwind of sources (Jerrett et al., 2005; Gramotnev et al., 2004). In addition, for estimating regional on-road vehicle emissions, various cars with different standard levels and speed were examined to categorize and quantify the emission from the studied fleet. Results of this study could be beneficial for policy makers to take proper actions to protect residents' health.

2. Methodology

2.1. Field measurements & sampling site

The measurements were carried out near the Hemmat highway as well as inside Resalat tunnel in Tehran. CO and size-segregated particulate matter concentration including PM_1, $PM_{2.5}$, PM_7, PM_{10} and TSP (Total Solid Particles) were measured at these sites. The fleet in Hemmat highway and Resalat tunnel represents almost the average fleet and traffic condition of major roadways in the city characterized by varying traffic condition during the day, including heavily congested traffic conditions during the rush hours.

Field study was carried out near Hemmat highway in a rather flat landscape area. This landscape area with length of 1.5 km (almost perpendicular to highway) and average width of 300 m was located on north side of highway. Except for Hemmat highway, other major anthropogenic PM and CO emission sources were not anticipated near the study field. Since the landscape area did not include considerable sized buildings, large trees, and other barriers, the sampling was performed with low effect of micro-scale turbulences and other sources. Distance from highway, traffic rate, traffic speed and meteorological parameters were also recorded since they are influential factors on air pollutant emission (Phuleriaa et al., 2007; Zhu et al., 2009a, 2009b).

PM was monitored using Met One GT-531 particle counter, which measures particles concentration in multiple size ranges including PM_1, $PM_{2.5}$, PM_7, PM_{10} and TSP. CO was measured by Aeroqual Series S-900. These monitors were used in this study for both roadside and in tunnel measurements since high sampling frequency and portability were required. Several previous studies were conducted using these instruments and confirmed their performance (Moltchanov et al., 2015; Cattaneo et al., 2010; Ikram et al., 2012). A quality assurance procedures was applied during sampling collection, and data filtering and collection. The zeroing and calibration of the instruments were carried out regularly using certified and known concentrations based on manufacturer recommendation and protocols. Measurements were performed at different stations in a way that the stations adjacent to the highway were selected to be closer to each other in order to assess emission effect and rate of pollutants emission, and further stations were located further from each other (Zhang et al., 2004b). In this regards, measurements were conducted at 8 stations at distances of 2, 10, 50, 100, 150, 200, 250 and 300 meters (m) from the highway side. The distances were chosen based on preliminary measurements and previously published literature (Hitchins et al., 2000). Stations and sampling site locations are shown in Fig. 1. Measurements were performed at height of about 1.5 m above the ground level to represent the human exposure condition. Hemmat highway has western–eastern direction and the stations were selected in its perpendicular direction; i.e. northern − southern. During the sampling period, the prevalent wind direction was southwest to northeast that carried pollutants downwind to the background site. Samplings were conducted from February 2012 to April 2012. Due to substantial differences in traffic conditions of Hemmat highway throughout a day, samplings were performed during three intervals, morning (7:00–9:00), afternoon (13:00–15:00), and evening (17:00–19:00). All the data collected during 7:00–9:00 and 17:00 to 19:00 were aggregated for heavy traffic conditions and similarly data collected during 13:00–15:00 were aggregated to reflect the light traffic condition. These three time frames provided opportunity for studying the highway pollutants at different traffic conditions and captured the fluctuations in the vehicle flows that were required for the CALINE inverse modeling. The measurements were taken by starting from the closest station (2 m of highway) to the furthest station (350 m of highway) and returning to the first point. At least three readings were taken at each point and this whole process was repeated three times at each day. However when the results in a station were much different from the previous readings at the same stations, 3 extra measurements were taken in that station. In total, sampling time