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VEHICLE AEROSOL EMISSIONS FROM ROAD TUNNELS IN SAO PAULO, BRAZIL

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Abstract

Vehicular emissions can be determined by measurements inside road tunnels. Such studies can provide information about emissions factors of in-use vehicles. Emission factors (EFs) are used to estimate vehicular emissions and are described as the amount of species emitted per vehicle distance driven or per volume of fuel consumed. This work presents tunnel measurements results of fine particles ($PM_{2.5}$), coarse particles ($PM_{2.5-10}$), inhalable particulate mater (PM_{10}), black carbon (BC) and size distribution of PM_{10} performed in two tunnels in Sao Paulo, Brazil, namely Janio Quadros (JQ) and Maria Maluf (MM), on March and May 2004 respectively. Concentrations of $PM_{2.5}$ and $PM_{2.5-10}$ were measured with a MiniVOL sampler and PM_{10} size distribution with a MOUDI cascade impactor, while concentrations of BC were estimated by reflectance analysis of each sampled filter. JQ tunnel carried mainly light-duty vehicles (LDVs), whereas MM tunnel carried both LDVs and heavy-duty vehicles (HDVs). EFs for HDVs and LDVs were derived based on measurements of particles, CO and CO_2. In JQ tunnel, 84.7% of the fleet consisted of cars; 7.5%, motorcycles, 3.9%, taxis and 3.8% HDV (vans and light trucks). In MM tunnel there was a different distribution: 74% cars, 12.5% motorcycle, 1.5% taxi and 12.3% HDVs. The EFs estimated by this work for BC, PM_{10}, $PM_{2.5-10}$ and $PM_{2.5}$ in the JQ tunnel were 16.4, 226.3, 133.6 and 93.2 mg $.km^{-1}$, respectively. The contribution of HDVs in emissions of BC, PM_{10}, $PM_{2.5-10}$ and $PM_{2.5}$ was in average 27, 3, 5, and 4.8 times higher than LDVs. PM_{10} EF for HDVs was 1.2 times higher than that found during dynamometer test and generally, the particles emissions are higher in São Paulo tunnels compared to other cities of the world. In a California roadway tunnel, in the United States, HDVs also emitted 37 times more BC mass per unit mass of fuel burned compared to LDVs.

1. INTRODUCTION

Road traffic is one of the largest emission sources of air pollutants. To be able to characterize the different vehicles types contribution to air pollution, detailed information regarding the emission is needed. For this purpose, emission factors (EFs), which describe the emitted mass (g) of a compound per driven distance (km), are being used (Colberg et al., 2005).

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The Metropolitan Area of São Paulo (MASP), Brazil, has an unconventional mixture of vehicle types, burning a variety of gasoline blends, including oxygenated ones. In the MASP, the fleet is about

7.2 million automotive vehicles, heavy-duty vehicles (HDV) fueled with diesel, light-duty vehicles (LDV) using a mixture containing 75-78% (in volume) gasoline and 22-25% ethanol, which is refereed to as gasohol, and some cars using ethanol as fuel (95% v/v) (CETESB, 2005).

In this paper it is reported the results of field measurements of air aerosols made in road tunnels. Tunnel studies allow assessing traffic emission. The main objectives of this study were: (1) to measure on-road particulate mater emission factors for vehicles, and (2) to characterize the particle-size distribution of vehicle emission.

2. MEASUREMENT OF AEROSOL

Field measurements were carried out in two roadway tunnels within the MASP, Janio Quadros (JQ) and Maria Maluf (MM) tunnels, to quantify the emissions of particulate-phase aerosol from different types of vehicles. The JQ tunnel is located southwest of São Paulo. It is 1900 m long, where emissions are from gasohol and ethanol fueled vehicles. MM tunnel is located in the southeast side of the city. It has a length of 845 m, in which runs light- and heavy-duty vehicles. Two-hour inside tunnel sampling was performed on workdays from 0800 LT (local time) to 1800 LT in JQ tunnel, on March 2004, and from 0800 LT to 1800 LT in MM tunnel, on May 2004.

3. METHODOLOGY

Coarse (PM2.5-10μm) and fine particles (PM2.5 μm) were collected using the MiniVOL portable air sampler instrument. It was operated at a 5 L min^{-1} rate. In addition, the black carbon (BC) or elemental carbon (EC) concentration was evaluated by means of a reflectance analysis of each sampled filter (Artaxo and Hansson, 1995). Finally, the tunnel PM size distribution measurements were undertaken, employing cascade impactors called Micro-Orifice Uniform Deposit Impactor (MOUDI) instruments which separates the PM in 10 different stages whose nominal 50% cut-off points (D50) are after-filter, < 0.1, 0.32, 0.56, 1.0, 1.8, 3.2, 5.6, 10 μm, and inlet at cut-size 18 μm (Marple et al., 1991).

3.1. Emission Factors

Particle-phase light-duty vehicle emission factors were computed directly from the light duty measurements of PM, CO_2, and CO concentration using the following equation (McGaughey et al., 2004):

$$E_{pm} = 1000x\left(\frac{\Delta[p]}{\Delta[CO_2]+\Delta[CO]}\right)wc, \quad (1)$$

where E_{pm} is the emission factor, Δ[p] is the background-subtract of particle-phase concentration of PM inside the tunnel (μg m^{-3}). $\Delta[CO_2]$ and Δ[CO] are the background-subtracted concentrations of CO_2 and CO given in μg of carbon m^{-3} (i.e., when converting concentrations of CO_2 and CO from mol fraction to mass units, a molecular weight of 12 gmol^{-1} was used instead of 44 and 28 gmol^{-1}

for CO_2 and CO, respectively) and w_c is the carbon weight fraction of the fuel (considered 0.87 for diesel and 0.85 for light-duty gasohol).

The contribution from heavy-duty diesel must not be computed directly from measurement in the MM tunnel because in this tunnel the traffic comprised both light-duty vehicles and heavy-duty diesel buses and trucks (Marr et al., 1999).

4. RESULTS

Table 1 presents the results of the vehicle traffic counts by vehicle types (LDVs, HDVs, motorcycle and taxis) for each 2-hour sampling period. Table 1 also presents the total traffic volumes and percentage of heavy-duty vehicles for each 2-hours sampling period, in the JQ tunnel. In this tunnel, 84.7% (5064 vehicles) of the fleet consisted of cars; 7.5% (450 vehicles), motorcycles; 3.9% (230 vehicles), taxis; and 3.8% (238 vehicles) HDV (vans and light trucks).

Pollutant concentrations measured inside the tunnel were consistently above background levels for CO, NOx , PM2.5, PM2.5-10, PM10 and BC, as shown in Table 2. This result is in agreement with the study in the JQ tunnel by Sánchez-Ccoyllo (2002), and with other studies in tunnels. In Caldecott tunnel, San Francisco, USA, Kirchstetter et al. (1999) observed that the tunnel/background ratio for PM2.5 was 8. In the Kaisermuhlen tunnel, in Austria, Laschober et al. (2004) found the ratios for PM10 and BC of 2 and 9 respectively.

Emission factors were calculated by carbon balance for each 2-hour sampling period, and are presented in Table 3 for JQ tunnel and for MM tunnel. For light duty fleet it is noticed a maximum value of 416.8 mg km^{-1} for PM10 and a minimum value of 97.4 mg km^{-1}. Kristensson et al. (2004) found an average value of EFs of 236 mg km^{-1} for PM10 in the Stockholm tunnel, Switzerland. For LDVs, observed maximum and minimums value of EFs were 216.0 and 18.2 mg km^{-1} for PM2.5, respectively.

Vehicle emission factors in the MM tunnel (heavy-duty vehicles) are reported also in Table 3. Compared to light-duty vehicles, heavy-duty vehicles have higher emission factors for every pollutant studied. The EFs estimated by this work for BC, PM_{10}, $PM_{2.5\text{-}10}$ and $PM_{2.5}$ in the JQ tunnel were 16.4, 226.3, 133.6 and 93.2 mg .km^{-1}, respectively. The contributions of heavy-duty vehicles in emissions of BC, PM_{10}, $PM_{2.5\text{-}10}$ and $PM_{2.5}$ were in average 27, 3, 5, and 4.8 times higher than LDVs.

The size distribution obtained from the MOUDI cascade impactor data is presented in Figure 1 for JQ tunnel. In the legend, morning values indicate an average mass concentrations from 10 to 14 HL, while, afternoon values indicate average from 14 to 18 HL. In Figure 1 it is also observed that the mass concentrations in the morning were higher than the mass concentrations in the afternoon, in all the MOUDI.

Table 1. Traffic volumes (total vehicles) and percent (%) heavy-duty vehicles in the Janio Quadros tunnel by time of day

Date	Time (LT)	LDVs	HDVs	Motorcycle	Taxi	Total traffic volume	% HDVs
3/23/2004	0800-1000	4128	52	342	188	4710	1.1
	1000-1200	4244	136	334	222	4936	2.8
	1200-1400	4866	194	328	252	5640	3.4
	1400-1600	5004	234	446	182	5866	4.0
	1600-1800	6804	442	604	260	8110	5.5
3/24/2004	0800-1000	4358	100	384	204	5046	2.0
	1000-1200	4008	122	390	250	4770	2.6
	1200-1400	5790	214	418	234	6656	3.2
	1400-1600	5250	384	492	254	6380	6.0
	1600-1800	6998	528	674	230	8430	6.3
3/25/2004	0800-1000	4404	110	392	208	5114	2.2
	1000-1200	4116	202	424	230	4972	4.1
	1200-1400	5376	168	384	220	6148	2.7
	1400-1600	5104	244	548	248	6144	4.0
	1600-1800	6834	226	622	284	7966	2.8
3/26/2004	0800-1000	4116	208	386	180	4890	4.3
	1000-1200	4120	300	450	222	5092	5.9
	1200-1400	5632	426	486	278	6822	6.2

LDVs= light-duty vehicles; HDVs= heavy-duty vehicles

Table 2. Ratios of pollutant concentrations measured inside the tunnel to those measured in ambient air.

Pollutant	Tunnel/background concentration ratio				
	0800-1000	1000-1200	1200-1400	1400-1600	1600-1800
CO	7.7±1.8	5.9±5.8	5.9±2.7	5.0±1.3	4.9±2.5
NOx	5.5±1.1	6.1±6.7	6.8±5.7	5.1±1.0	4.7±2.1
$PM_{2.5}$	2.4±0.3	2.3±2.9	2.5±1.9	2.6±2.0	2.0±1.1
$PM_{2.5}$-PM_{10}	1.7±0.8	3.0±1.2	2.2±0.5	1.8±0.5	2.1±0.4
PM_{10}	1.9±0.6	2.7±0.8	2.4±0.7	1.9±0.8	2.4±1.3
BC	2.4±0.5	2.0±0.2	2.0±0.3	2.2±0.8	1.6±0.4

$PM_{2.5}$ =fine particles, $PM_{2.5}$-PM_{10}=coarse particles, PM_{10} = inhalable particulate mater

Table 3. Calculated emission factors (and standard deviation) in the JQ and MM tunnel by sampling period (in mg km^{-1})

	BC ($mgkm^{-1}$)	PM_{10} ($mgkm^{-1}$)	$PM_{2.5-10}$ ($mgkm^{-1}$)	$PM_{2.5-10}$ ($mgkm^{-1}$)
Light-duty – Jânio Quadros tunnel	17 (5)	227 (118)	134 (67)	93 (20)
Heavy-duty Maria Maluf tunnel	457 (112)	754 (401)	715 (585)	449 (364)

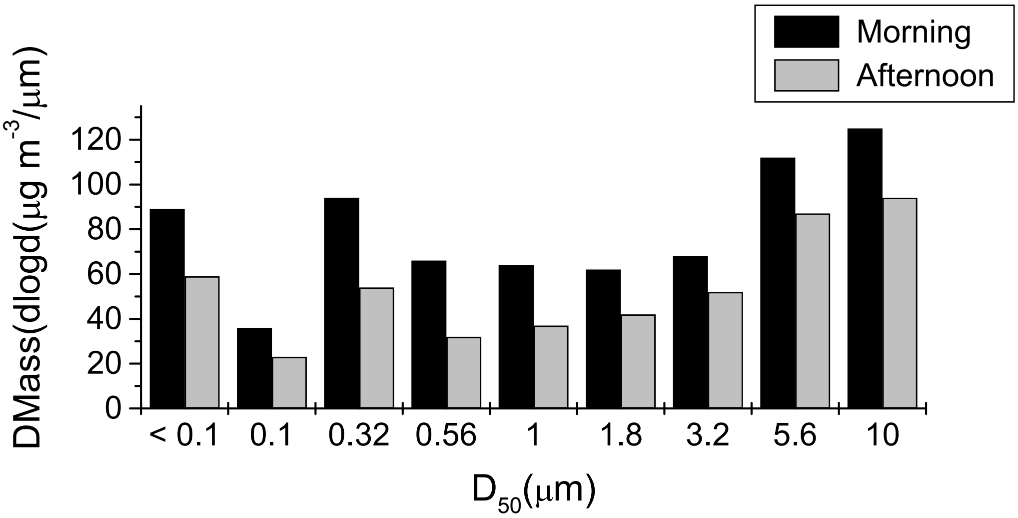

Figure 1. Size distribution of average mass concentration measured in 2004 with the MOUDI impactor stages in the JQ tunnel. Morning values represents an average from 10 to 14 LT, while, afternoon values is average from 14 to 16 LT.

5. CONCLUSIONS

A measurement of the particulate matter (PM) was made in two tunnels in the MASP, Brazil. These investigations carried out so far can be summarized as follows: Fine particle black carbon, inhalable (PM10), coarse (PM2.5-10μm) and fine (PM2.5 μm) particles were analyzed to have the emissions factors calculated. Compared to light-duty vehicles (in the Janio Quadros tunnel), heavy-duty vehicles (in the Maria Maluf tunnel) have higher emission factors for every pollutant studied. The EFs estimated by this work for BC, PM_{10}, $PM_{2.5-10}$ and $PM_{2.5}$ in the JQ tunnel were 16.4, 226.3, 133.6 and 93.2 mg .km^{-1}, respectively. The contributions of heavy-duty vehicles in emissions of BC, PM_{10}, $PM_{2.5-10}$ and $PM_{2.5}$ were in average 27, 3, 5, and 4.8 times higher than LDVs.

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