5.04 PM_{10}, CO AND NO_X CONCENTRATIONS IN THE TUHOBIĆ ROAD TUNNEL, CROATIA

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INTRODUCTION

Airborne pollutants, and in particular, particulate matter (PM) continue to give a rise to concern as a result of their adverse effects on human health (D'Amato et al., 2001; Fisher et al., 2004; Stedman, 2004). A number of studies suggest that not all particles are equal with respect to health effects (e.g., Schwartz et al., 1996, Englert 2004). These findings have led to the introduction of size specific particulate mass concentrations, where PM_{10} and $PM_{2.5}$ correspond to thoracic and alveolar particles, respectively.

In urban areas, vehicular transport is recognized as an important source of, among other, PM_{10}, $PM_{2.5}$ and trace gases, such as, carbon monoxide (CO) and nitrogen oxides (NO_x) (*Gertler et al.,* 2000; *Querol et al*., 2001; *Paoletti,* 2003; *Rodriguez et al.,* 2004). Therefore, various recent studies focus on emission factors, i.e. amounts of species emitted per vehicle km driven or per volume of fuel consumed (*Abu-Allaban et al*., 2003; *Hausberger et al*., 2003; *Kristensson et al*., 2004). In this study we investigated air quality conditions found in the in real-world traffic situations during a summertime touristic season, which is characterized with an intensive vehicular transport. Namely, we collected and analyzed data for a tunnel located on the main road connecting Croatian inland with the Northern Adriatic. Specifically, we examined a dependence of pollutant levels (PM_{10}, CO, NO and NO_2) on traffic density. Additionally, we investigated a relationship between PM_{10} and trace gases concentrations. Weekend and weekdays data were analyzed separately due to noticeably different traffic densities.

EXPERIMENTAL

PM_{10} particle fraction and trace gases CO, NO and NO_2 have been sampled during 6 weeks (21.07.2002 - 01.09.2002) in the third longest tunnel in Croatia (Tuhobić, 2140 m). It is located on the Zagreb-Rijeka road, with an inlet at $\varphi = 45°19'39.5''$ and $\lambda = 14°39'42.1''$. The tunnel has two lanes separated by the centreline, one for each direction. Eight mini portable air samplers (Air Metrics, USA) were placed in the centre of the tunnel, at the height of 1.70 m above the ground. PM_{10} samples were collected on a Whatman quartz fibre filters with the diameter of 47 mm. Gases were collected in Tedlar bags. The ventilation system was operating during the measurement.

Weekend samples (from Friday at 8 LST to Sunday at 24 LST) were collected for 8-hour sampling intervals. During the weekdays, 4-hour cumulative samples were collected throughout the whole week. In other words, pollutant concentration for weekday for the sampling interval from 0 to 4 LST, for example, corresponds to an average 0-4 LST concentration for five consecutive days (Monday-Friday). For every sample corresponding number of vehicles was recorded. Data on particular vehicle specification and speed were not available. Out of the total 82 PM_{10} samples 46 and 36 were collected during weekends and the weekdays, respectively. The total number of trace gases samples was 62, where 34 were collected during weekends.

RESULTS

A summary of the measurements is given in Table 1. They show that concentrations of all pollutants are on the average higher during the weekend compared to weekdays. The same is also valid for the diurnal variations of pollutant concentrations (Figure 1). This may be attributed to substantially higher average traffic density compared with the weekdays (about 730 and 420 vehicles per hour, respectively). Since concentrations at any time depend on the concentrations and other events that have taken place at previous time intervals (*Abu-Allaban et al.*, 2003), this implies lower background concentrations for the weekdays. In addition, for PM this also implies less intensive resuspension caused by vehicular traffic. The effects of the 'history' on pollutants concentrations are the most clearly illustrated with the pattern of the diurnal variation for the weekdays (Figure 1, left), where a time interval with maximum traffic density (16-20 LST) precedes the interval with maximum concentrations per vehicle (20-24 LST). Similarly, the time interval with minimum traffic density (0-4 LST) is followed by the interval with minimum concentrations of trace gases per vehicle and with substantial decrease in PM_{10} concentration per vehicle (4-8 LST).

Table 1. Summary of measurements. E and D correspond to weekend and weekday samples (i.e. 8-hour and 20-hour sampling interval, respectively), N is the number of samples and nv is the average number of vehicles per sample.

	SAMPLE	N	MEAN	MEDIAN	MIN.	MAX.	ST. DEV.
PM_{10} (μG/M3)	E	46	272.3	285.8	35.8	749.2	140.4
	D	36	244.5	217.3	17.9	504.6	133.6
CO (MG/M3)	E	34	6.5	5.6	0.0	17.5	4.6
	D	28	4.1	4.4	0.0	11.3	3.4
NO (μG/M3)	E	34	513.7	485.1	233.2	1002.3	185.7
	D	28	308.4	303.5	175.5	466.3	87.7
NO_2 (μG/M3)	E	34	1007.0	911.2	110.7	2498.9	645.5
	D	28	846.3	843.6	51.3	1873.7	522.9
NV (PM_{10})	E	46	5850.1	5865.5	1596.0	10267.0	2104.5
	D	36	8469.9	10316.0	2295.0	12700.0	3334.8
NV (TRACE GASES)	E	34	5846.1	5842.5	1596.0	10267.0	1994.1
	D	28	8310.3	9163.0	2536.0	11847.0	3286.2

To examine the relationship between the traffic density and pollutant concentrations, an approach of *Kukkonen et al.* (2001) was employed, where near-ground-level concentrations originate from local traffic and stationary sources, background contribution and the resuspension of particles from street surfaces. For the tunnel we may neglect the contribution of stationary sources. Further, we assume a linear dependency between the pollutant concentrations due to the local traffic and the traffic density:

$$C_I = A_I\, N + C_I^{BG}, \qquad (1A)$$

$$PM_{10} = B\, N + PM_{10}^{RES} + PM_{10}^{BG}, \qquad (1B)$$

where C_i and PM_{10} are the total (measured) near-ground-level concentrations of i-th trace gas and thoracic particles, respectively, n is the number of vehicles per hour, while a_i and b are constants to be determined empirically. The superscripts 'bg' and 'res' refer to the background pollution and resuspension of particles from street surfaces, respectively. A set of corresponding regression equations is listed in Table 2, while a scatter plot for PM_{10} vs. traffic density for all samples is illustrated in Figure 2.

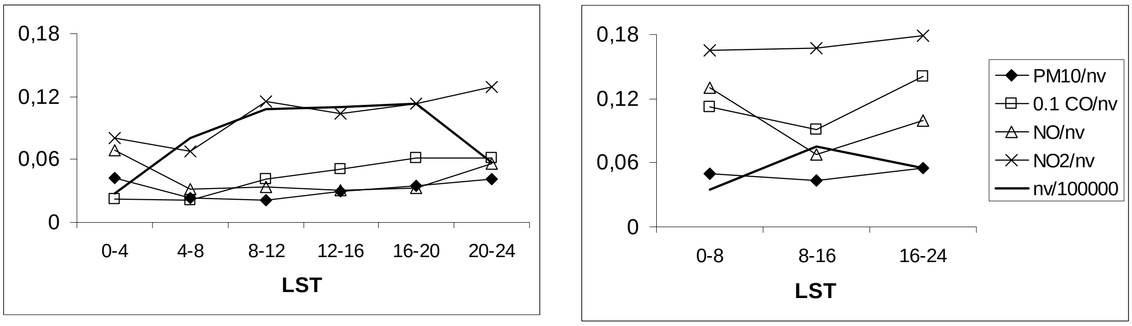

Figure 1. Diurnal variations of pollutant concentrations per vehicle (µg/m³) and number of vehicles (nv) for weekdays (left) and weekend (right).

The best correlation between the PM_{10} and trace gases was obtained for NO_2 (Figure 3), where correlation coefficients for all, weekend and weekday samples were following: 0.85, 0.83 and 0.91. Corresponding figures for CO were 0.53, 0.51 and 0.60, while for NO they were 0.25, 0.15 and 0.63, respectively. Further, assumed linear dependency between the concentrations of PM_{10} and NO_2 ($PM_{10} = k\ NO_2 + PM_{10}^{bg} + PM_{10}^{res}$) yielded to $k =$ 0,19, 0,18 and 0,22 for all, weekend and weekdays, which agrees reasonably with the value 0,11 obtained for urban NO_x caused by vehicular transport (*Kukkonen et al.,* 2001). Background PM_{10} values for the tunnel were 101 (all), 108 (weekend) and 84 µg/m³ (weekdays) again suggesting the influence of the pollution history on background levels.

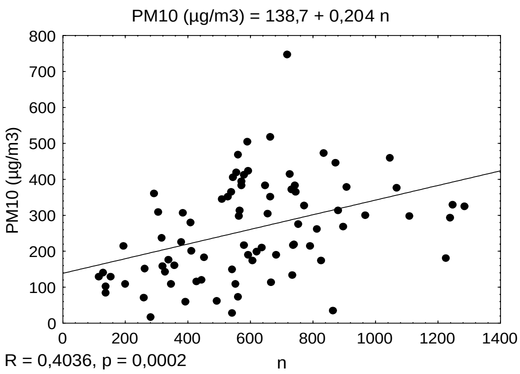

Figure 2. PM_{10} vs. number of vehicles per hour (n) for all samples.

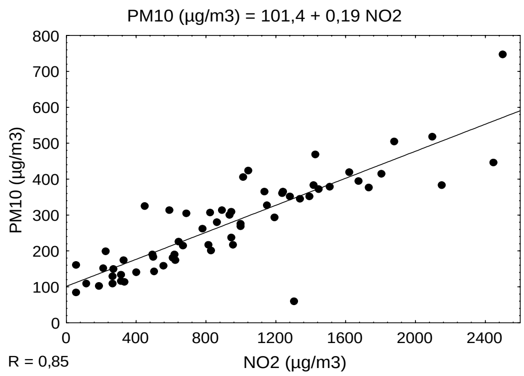

Figure 3. PM_{10} vs. NO_2 for all samples.

Table 2. Dependence of pollutants concentrations (µg/m3) on the traffic density for all (A), weekend (E) and weekday samples (D). N is the number of samples and n is the number of vehicles per hour. Correlation coefficients (R) which are significant at the level p = 0.05 are underlined.

SAMPLE	N	*R*	REGRESSION EQUATION
A	82	<u>0.40</u>	$PM_{10} = 138.7 + 0.204\,N$
E	46	<u>0.37</u>	$PM_{10} = 129.0 + 0.196\,N$
D	36	<u>0.56</u>	$PM_{10} = 53.7 + 0.451\,N$
A	62	<u>0.37</u>	$CO = 1984.5 + 5.800\,N$
E	34	0.14	$CO = 4716.4 + 2.500\,N$
D	28	<u>0.53</u>	$CO = -509.9 + 11.000\,N$
A	62	<u>0.42</u>	$NO = 251.7 + 0.288\,N$
E	34	0.04	$NO = 490.1 + 0.032\,N$
D	28	<u>0.46</u>	$NO = 206.6 + 0.245\,N$
A	62	<u>0.36</u>	$NO_2 = 463.7 + 0.800\,N$
E	34	0.21	$NO_2 = 596.0 + 0.562\,N$
D	28	<u>0.65</u>	$NO_2 = -16.2 + 2.076\,N$

CONCLUSIONS

Tunnel measurements offer the possibility of investigating real-world conditions, since they are representative for a huge variety of vehicles. Results of this study suggested a correlation between the pollutants concentrations and the traffic density, which is in contrast with the results *Abu-Allaban et al.* (2003) and *Martuzevicius et al*. (2004). However, apart from the fact that both above studies investigated open road data, in the first study a real-time concentrations, with the time resolution of 1 s, where measured, and, thus, they exhibited a strong 'memory' of previous concentrations and vehicle counts. On the other hand, second study employed a daily values, which were accompanied with low variations of traffic intensity.

Though correlation between pollution levels and traffic density was generally weak for all pollutants, it was stronger for weekday samples, i.e. for lower traffic densities. The latter, together with the pattern of diurnal variations of pollutants concentrations strongly suggests influence of pollution history on background values if the timescale < 1 day is considered. For the 8-hour samples investigated in this study, background contributions for PM_{10}, CO and NO_2 were of the same order of magnitude as the contributions from traffic, while for NO they were even about 20 times higher. This implies that a time-series data analysis is needed in further investigation.

PM_{10} concentrations exhibited the strongest correlation with NO_2 (better than with NO_x). Assumed linear dependency $PM_{10} = k\ NO_2 + PM_{10}^{bg} + PM_{10}^{res}$ resulted in $k \approx 0.2$, which reasonably agrees with the results of Kukkonen *et al.* (2001).

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