ANALYSIS OF THE VERTICAL AND HORIZONTAL CHARACTERISTICS OF THE PM PROFILE IN A MAJOR ROADWAY, IN ATHENS, GREECE

PATERAKI ST.[1], BELESIOTIS G.[2], ASIMAKOPOULOS D.N.[2], BAIRACHTARI K.[1], VASILAKOS CH.[1] and MAGGOS TH.[1]

[1] Environmental Research Laboratory/ I.N.RA.S.T.E.S., National Centre for Scientific Research "DEMOKRITOS", 153 10, Aghia Paraskevi, Athens, Greece, [2] Department of Applied Physics, Faculty of Physics, University of Athens, University Campus, building PHYS-5, 157 84, Athens, Greece.
E-mail: stella@ipta.demokritos.gr

ABSTRACT

A carefully designed monitoring study based on the PM_{10}, $PM_{2.5}$ and PM_1 monitoring was carried out at an urban roadside environment of Athens, Greece. With the principal aim to give insight to the horizontal and vertical characteristics of the traffic induced PM status, the experimental equipment was placed simultaneously on different heights of a 19m high building, both along the main road and the street canyon. The collected samples were chemically analyzed in terms of its carbonaceous and ionic content.

According to the data analysis, the vertical configured status was more complicated than the horizontal one probably due to the enhanced role of the atmospheric chemistry increasing the distance form the ground sources.

The maximum concentrations of the particles occurred along the main road indicating undiluted concentrations drawn directly from the roadway. In the adjacent of the main road, the PM values were decreased increasing the height whereas within the canyon was obtained the opposite trend, probably due to a mixing action.

The traffic related OC, EC, NO_3^- and SO_4^{2-} species were the dominant PM constituents. In general, the carbonaceous input was more sensitive to the changes, especially for the horizontal axis. As for the ionic mass, its behavior was more complicated due to its simultaneous secondary identity.

Keywords: PM_{10}, $PM_{2.5}$, PM_1, Traffic, Vertical and horizontal characteristics, ions, carbon, Mediterranean urban area

1. Introduction

Traffic is considered to be one of the major polluting sectors and as a consequence a significant cause for the monitored exceedances of ambient air quality limit values, especially in urban areas (Fameli and Assimakopoulos, 2015). This issue is of particular concern in densely populated cities, where large volume of traffic is often in close proximity to the population to enhance the people's mobility, but at the same time poses a great threat to the public health (Rakowska *et al*. 2014).

Among the important pollutants produced by the combustion of hydrocarbon fuels in vehicles, particulate matter (PM) has drawn increasing attention mainly due to its effect on both human health and environment. In addition to exhaust sources, PM from road transport is also produced by the attrition of tyres, brakes and other components (e.g. clutch), as well as road wear (Kousoulidou *et al*., 2008), with a wide range of sizes.

Despite the extensive emission control measures, PM are very often involved in severe episodes, especially in urban settings (Sasaki and Sakamoto, 2005). At traffic intersections, air quality has been emphasized due to heavy traffic flows and variations in the speed of vehicles

(Wang *et al*., 2010). Existing evidence suggests that many of the exceedences have been occurred where many roadways are lined by dense and high-rise buildings forming street canyon that greatly limits the dispersion of mobile emissions. Differences in geometry, traffic intensity/mixture and meteorology result in variable concentrations inside the street canyon (Rakowska *et al*. 2014).

In spite of the increasing worldwide literature for traffic pollution, regular roadside measurements in many cases are not representative of the real population exposure in a specific location since fuel consumption and exhaust emission of vehicles are highly dependent on road design (Wang *et al*., 2010). Moreover, despite the small number of studies investigating the vertical characteristics of the traffic originated particles, the findings that have been yielded for the mass concentrations around building envelopes are inconsistent. Some research concluded that concentrations decreased with increasing height whereas the exact opposite hypothesis is supported by other studies. A decrease in the aerosols levels to certain heights, with concentrations remaining somewhat constant beyond that has been also obtained (Quang *et al*., 2012). In the case of the chemical composition, simultaneous information for the vertical and horizontal differentiation of the ionic and carbonaceous composition of different diameter particles, to our knowledge, do not exist. The available information is mainly associated with the carbonaceous component (Chan *et al*., 2005; Sasaki and Sakamoto, 2005; Shi *et al*., 2012, Van Poppel *et al*., 2012) while for the ions the data are rare (Tian *et al*., 2013).

Given the severe air pollution problems which face the Athens Basin, due to the combination of high road traffic emissions, complex topography and local meteorological conditions (Fameli and Assimakopoulos, 2015), the principal aim of this work is to give insight to the traffic induced PM status. To be more specific, this study makes an attempt to asses, both horizontally and vertically, the profile of different diameter (PM_{10}, $PM_{2.5}$, PM_1) traffic originated particles, both in terms of mass and chemical composition.

2. Data and methodology

With the principal task to analyze the traffic originated PM behavior, PM_{10}, $PM_{2.5}$ and PM_1 samples were collected in a roadside environment, next to the busiest roads of the urban atmosphere of Athens, Mesogeion and Kifissias.

Six low-volume, controlled flow rate (2.3 m^3/h) samplers were used in parallel collecting PM on Quartz filters with diameter 47 and 50mm. Taking the advantage of the simultaneous placement of the experimental equipment on different heights of a 19m high building, both along the main road and the street canyon (H/W ratio~1.3 and 3.8, respectively), the specific campaign makes an attempt to investigate the configured PM behavior, both horizontally and vertically. For the PM_{10} and $PM_{2.5}$ scenarios, the data were collected along the main road and the street canyon on the 1^{st}, 3^{rd}, 5^{th} and 1^{st}, 5^{the} floor, respectively while the PM_1 measurements took place along the main road at the 1^{st} and 5^{th} floor as well as at the 1^{st} floor of the street canyon. Sampling periods lasted 24h. With a two days duration for each scenario (18-19/11/2013, 10-11/12/2013 and 21-29/1/2014 for PM_{10}, $PM_{2.5}$ and PM_1, respectively), a total of 26 samples were collected.
The particle mass concentration determination was conducted gravimetrically according to EN 12341. The water-soluble ions (Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, NH_4^+, K^+, Mg^{2+}, Ca^{2+}) were detected using suppressed ion chromatography while the carbon elements (OC, EC) were determined with the use of a carbon analyser. More details about the analytical techniques as well as the Na^+ calculation are given in Pateraki *et al*., 2012.

3. Results

3.1. Concentrations

The average variation of the PM_{10}, $PM_{2.5}$ and PM_1 mass is shown in Figure 1. As it can be seen, the peaks were the constant characteristic of the minimum height, along the main road due to the strength of the traffic emissions on the specific axis. The horizontal differentiation near the surface, was almost equal for PM_{10} and PM_1 (28% and 23%, respectively) and lower the one recorded for $PM_{2.5}$ (52%). On the maximum height, PM_{10} and $PM_{2.5}$ was similarly differentiated

(10% and 17%, respectively). Vertically, two opposite patterns were detected. Along the main road, the pollutants were decreased increasing the height whereas within the canyon they were accumulated, probably due to a mixing action. However, it is worthy to note the increase of the difference between the 1st and 5th floor, decreasing the particles diameter, in both cases (12%, 31% and 38% for PM_{10}, $PM_{2.5}$ and PM_1 as well as -9% and -20% for PM_{10} and $PM_{2.5}$ along the main road and the street canyon, respectively).

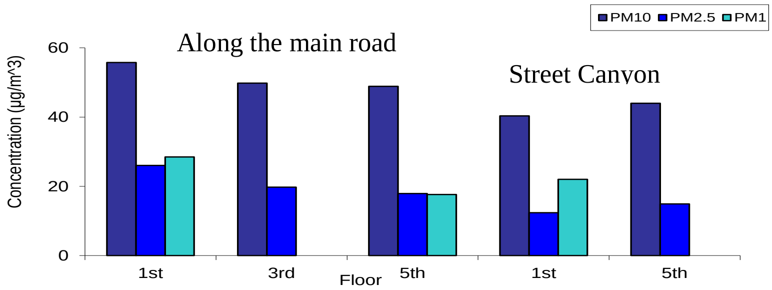

Figure 1: Average PM concentration values

The PM_{10} values on 18/11/2013 ranged from 32.8μg/m^3 to 45.1μg/m^3 while on 19/11, the recorded concentrations exceeded the daily European limit value (53.5 - 66.4 μg/m^3). The only exception was the 1st floor within the street canyon (47.9μg/m^3). $PM_{2.5}$ was generally varied between 7.70 and 33.0μg/m^3. Only on 11/12 and only in the case of the 1st and 3rd floor, along the main road (33.0 and 25.1μg/m^3, respectively) its levels exceeded the daily European limit value. On the horizontal axis, the most significant daily PM_{10} and $PM_{2.5}$ change occurred near the surface. Almost equal was the daily PM_{10} variation (27-28% and 10% on the 1st and 5th floor, respectively) despite the difference on the obtained status. It is worthy to note the more obvious $PM_{2.5}$ variation on the clean day being compared with the one of the polluted (60% and 48% as well as 24% and 12%, on the 1st and 5th floor, respectively). In the case of PM_1, it should be highlighted the almost twice differentiation (15% and 30%, respectively), despite the small variation of its daily concentration range (18.8- 27.2μg/m^3 and 16.5-29.8μg/m^3 on 28/1 and 29/1/2014, respectively). Vertically, the daily pattern was more complicated. Along the main road, the most obvious PM_{10} and $PM_{2.5}$ change occurred between the 1st and the 5th floor (11-15% and 26-34%, respectively). Within the street canyon, the vertical PM_{10} change on the polluted day was almost twice the clean one (-12% and -5%, respectively) whereas in the case of $PM_{2.5}$, the difference was more noticeable when the concentration values were lower (-40 and -11% on 10/12 and 11/12/13, respectively).

3.2. Chemical Composition

In average, even with different distribution, the particles were mainly composed of OC, EC, SO_4^{2-} and NO_3^- (Table 1). Their well-known association with traffic might be the case for the increase of the constitutional rates decreasing the particles size (75-78%, 75%-82% and 84-86% for PM_{10}, $PM_{2.5}$, PM_1). At PM_{10} and PM_1, the peaks for the dominant species were detected near the surface whereas in the case of $PM_{2.5}$ the obtained picture was complicated. It is worth commenting on the increasing trends in the OC/EC ratios with the height increase. However, this scheme was obtained only along the main road probably due to the mixing actions which prevailed within the canyon.

In general, on the horizontal axis, the most significant daily variations occurred near the surface and were associated with the carbonaceous content (up to 50%, 39% and 62% for PM_{10}, $PM_{2.5}$ and PM_1). In all the cases the differentiation was more significant on the day with the maximum concentration values. Vertically, the configured chemical behavior was complicated, especially for the secondary particles. For PM_{10}, the differences were more obvious for its carbonaceous content, between the minimum and the maximum height, both along the main road and the street canyon (32%-35% and (-31%)-(-33%), respectively). The opposite trend should be underlined. As far as $PM_{2.5}$ is concerned, the obtained picture is not clear. On the main road, the more obvious change occurred for the carbonaceous input, with an increase increasing the height during the more polluted day (15%, 38% and 47%, on the 1st, 3rd and 5th floor, respectively). Within the canyon, the differentiation of the ionic mass was more evident. In the case of PM_1, in the vicinity of the main road, the change of the carbonaceous budget was more apparent during the day with the higher concentrations (63%) while the more obvious variation of the ionic mass was associated with the more clean status (60%). In general, the more complicated behavior of the ionic mass could be probably attributed to its secondary origin since its changes are closely associated with photochemical reactions (Tian *et al*., 2013).

Table 1: Average chemical composition of the collected PM samples

		Floor	OC	EC	NO_3^-	SO_4^{2-}	Others	OC/EC
PM_{10}	Along the main Road	1st	10.5	4.32	4.89	7.21	8.80	2.39
		3rd	8.44	3.45	4.18	5.89	6.15	2.42
		5th	7.06	2.81	3.87	5.64	6.19	2.49
	Street Canyon	1st	5.80	1.96	3.59	6.13	5.67	2.94
		5th	7.58	2.62	4.01	6.21	5.95	2.88
$PM_{2.5}$	Along the main Road	1st	5.57	2.42	1.32	1.85	3.29	2.37
		3rd	4.69	1.98	1.74	2.44	2.46	2.43
		5th	4.07	1.50	1.61	2.41	2.79	2.70
	Street Canyon	1st	3.77	1.23	0.94	2.12	2.68	3.18
		5th	4.21	1.34	1.34	1.99	2.59	3.15
PM_1	Along the main Road	1st	11.2	7.51	1.57	1.96	3.68	1.51
		5th	5.18	2.43	0.83	1.19	1.58	2.16
	Street Canyon	1st	5.70	2.16	1.13	1.61	2.06	2.68

4. Conclusions

In this work it was investigated the horizontal and vertical profile of traffic generated PM_{10}, $PM_{2.5}$ and PM_1 particles.

In general, the different sized particles responded in similar ways; their mass was decreased increasing the height in the adjacent of the main road and their values were increased increasing the height within the street canyon. However, in both cases, the influence of the height was more evident at the smaller fractions since they are better indicators of traffic emissions. On the maximum height, the PM_{10} and $PM_{2.5}$ horizontal changes were almost equal.

Even with different rates, OC, EC, SO_4^{2-} and NO_3^- accounted for the largest contribution to the particles mass. The vertical OC/EC increase along the main road supports the hypothesis of the photochemical SOC formation during the transport of primary pollutants from the surface to the higher levels. Due to its local character, the carbonaceous input was more sensitive to the horizontal changes, especially near the surface. Interestingly enough, the differentiation of the ionic mass was more obvious within the canyon. However, probably due to its secondary nature, its behavior was more complicated.

Further work focusing simultaneously on different sized fractions, both horizontally and vertically is needed.

ACKNOWLEDGEMENTS

Financial support from the EnTeC FP7 Capacities programme (REGPOT-2012-2013-1, FP7, ID: 316173), is kindly acknowledged.

REFERENCES

1. Chan C.Y., Xu X.D., Li Y.S., Wong K.H., Ding G.A., Chan L.Y. and Cheng X.H. (2005), Characteristics of vertical profiles and sources of PM2.5, P M10 and carbonaceous species in Beijing, Atmos Environ,**39**, 5113–5124
2. Fameli K.M. and Assimakopoulos V.D. (2015), Development of a road transport emission inventory for Greece and the Greater Athens Area: Effects of important parameters, Sci Total Environ, **505**, 770–786
3. Kousoulidou M., Ntziachristos L., Mellios G. and Samaras Z. (2008) Road-transport emission projections to 2020 in European urban environments, Atmos Environ, **42**, 7465–7475.
4. Pateraki St., Assimakopoulos V.D., Bougiatioti A., Kouvarakis G., Mihalopoulos N. and Vasilakos Ch. (2012), Carbonaceous and ionic compositional patterns of fine particles over an urban Mediterranean area, Sci Total Env, **424**, 251-263.
5. Quang T.N., He C., Morawska L., Knibbs L.D., and Falk M. (2012), Vertical particle concentration profiles around urban office buildings, Atmos. Chem. Phys., **12**, 5017–5030.
6. Rakowska A., Chun Wong K., Townsend T., Lok Chan K., Westerdahl D., Ng S., Mocnik G., Drinovec L. and Ning Z. (2014), Impact of traffic volume and composition on the air quality and pedestrian exposure in urban street canyon, Atmos Environ, **98**, 260-270.
7. Sasaki K. and Sakamoto K. (2005), Vertical differences in the composition of PM10 and PM2.5 in the urban atmosphere of Osaka, Japan, Atmos Environ, **39**, 7240–7250.
8. Shi G.-L., Tian Y.-Z., Han S.-Q., Zhang Y.-F., Li X., Feng Y.-C., Wu J.-H. and Zhu T. (2012), Vertical characteristics of carbonaceous species and their source contributions in a Chinese mega city, Atmos Environ, **60**, 358-365.
9. Tian Y.-Z., Shi G.-L., Han S.-Q., Zhang Y.-F., Feng Y.-C., Liu G.-R., Gao L.-J., Wu J.-H. and Zhu T. (2013), Vertical characteristics of levels and potential sources of water-soluble ions in PM10 in a Chinese megacity, Sci Total Env**, 447**, 1–9.
10. Van Poppel M., Int Panis L., Govarts E., Van Houtte J. and Maenhaut W. (2012), A comparative study of traffic related air pollution next to a motorway and a motorway flyover, Atmos Environ, **60**, 132-141.
11. Wang Y., Li J., Cheng X., Lun X., Sun D. and Wang X. (2014), Estimation of PM10 in the traffic-related atmosphere for three road types in Beijing and Guangzhou, China J Environl Sci, **26,** 197–204.