Parameters Controlling Rail Subway Air Quality

T. Moreno[1], V. Martins[1], N. Pérez[1], C. Reche[1], E. de Miguel[2], M. Capdevila[2], S. Centelles[2], MC. Minguillón[1], F. Amato[1], A. Alastuey[1], X. Querol[1] and W. Gibbons[3]*

[1] Institute of Environmental Assessment and Water Research, IDAEA, CSIC, C/Jordi Girona 18-24, 08034 Barcelona, Spain. teresa.moreno@idaea.csic.es
[2] Transports Metropolitans de Barcelona, TMB, Santa Eulalia, Av. del Metro s/n L'Hospitalet de Llobregat, 08902, Spain
[3] WPS, C/Major 13, 08870 Sitges, Spain

Introduction

Commuting by underground rail is a transport mode used daily by over one hundred million people worldwide and in large cities is a key to efficient urban development. There is however a major air quality problem, with PM levels in subway systems worldwide commonly far above the limit values applied to outdoor air (Nieuwenhuijsen et al., 2007). The air quality of a given subway platform involves a complex interplay of the ventilation system, station depth and design, train speed and frequency, wheel materials and braking mechanisms, and number of passengers being transported (Moreno et al., 2014). Most of the particles are produced locally by mechanical friction between train wheels, rail tracks and brakes, with additional contribution from the catenary system that supplies electrical power to the train. Other particles produced underground can be related to activities such as cleaning and maintenance work, and there is always some contribution from road traffic and other external sources as city air infiltrates the subway via access tunnels and ventilation systems. Thus studies carried out in subway systems show a very wide variability of PM levels consistently reporting average levels on platforms that can exceed 100 $\mu gPM_{10}/m^3$ and in some cases 300 $\mu gPM_{10}/m^3$ (Table 1). Furthermore, in addition to relatively coarse abrasion particles derived from brakes, rails and wheels, recent studies have demonstrated the presence of highly respirable ultrafine particle emissions connected to train movements in railway tunnels (Loxham et al., 2013).

Table 1: Average values registered at subway systems worldwide.

	PM_{10}	$PM_{2.5}$	Reference
On platforms			
Barcelona	87-325	21-96	Querol et al. 2012
Barcelona	133	104	Moreno et al. 2014
Budapest	155	51	Salma et al. 2007
London	1000–1500	270–480	Seaton et al. 2005
Los Angeles	78	57	Kam et al. 2011
Paris	200	61	Raut et al. 2009
Seoul	359	129	Kim et al. 2008
Stockholm	357	199	Johansson & Johansson 2003
Taipei	51	35	Cheng et al. 2008
Inside trains			
Barcelona	36-100	11-32	Querol et al. 2012
Los Angeles	31	24	Kam et al. 2011
Taipei	41	32	Cheng et al. 2008

Air movements on the platform show constantly repeated cycles involving 3-dimensional turbulent flow through some combination of mechanically forced ventilation systems, blast shafts, and platform access points, driven to a large extent by the piston effect of the trains moving through the tunnels (e.g. Lin et al., 2008; Jia et al., 2009, Pan et al., 2013; López-González et al., 2014). A perceived virtue of these piston winds lies in their ability to ventilate the tunnels and platforms, thus possibly reducing the need for additional mechanically forced ventilation, and offering the possibility of making significant energy savings.

To investigate the parameters controlling rail subway air quality we are carrying out measurement campaigns for indoor air quality and passenger exposure in the Barcelona (NE Spain) subway system. The impact of platform screen door and ventilation systems on the reduction of PM levels on the platforms is also being evaluated (Querol et al., 2012) considering the influence of the piston effect for both ventilation and abatement of PM concentrations on platforms. Air quality is being monitored across a range of station designs under (i) normal ventilation conditions, with mechanical forced ventilation running in the tunnels, and (ii) experimental ventilation conditions, when the forced ventilation of the tunnel is turned off during daytime so that the train piston effect is emphasized. During the sampling periods we monitor ambient PM concentrations in different size fractions at high time resolution (every six seconds) and at different platform locations, along with coeval concentrations of CO and CO_2.

Methodology

Measurements on platforms from 24 stations so far, as well as inside the trains (during a one-way trip to and from the beginning of the line) from six subway lines have been carried out using a light-scattering laser photometer (TSI DustTrak 8533) to obtain real-time measurements of levels of PM_1, $PM_{2.5}$ and PM_{10} with data logging interval of 5 seconds. Stations have been selected according to different designs including stations with two platforms in the same tunnel with the two rail tracks in the centre running in parallel (one for each direction), two platforms separated by a middle wall, or built in different tunnels and stations with single platforms in different tunnels with the platform being separated from the rail track by a wall with mechanical doors that are opened simultaneously with the train doors (known as platform screen door systems).

Measurements are being performed at each selected station for one hour, divided into periods of 15 minutes in 4 positions approximately equidistant along the platform (Figure 1) for greater representativeness and to observe possible spatial differences depending on the position on the platform. A manual control of the exact arrival and departure times of each train is performed to assess possible correlations with the variability of the registered concentrations. The PM concentrations inside the trains are monitored in the middle of the central car of the subway and, in this case, a manual control of the time when train doors open and close was performed. Levels of PM are then corrected after intercomparison with a reference high volume PM sampler.

Figure 1: Example of the locations for PM measurements in 4 equidistant points along each platform.

Results

Several parameters have been observed to clearly influence the air quality in the subway system. PM levels are markedly lower during weekends compared to week days, probably due to the lower frequency of trains, as it has already been described by Johansson and Johansson (2003) for the Stockholm metro. Also PM levels are much lower during the night but doubled during the day except on weekends when night levels are also high due to the fact that the Barcelona metro systems work continuously from early Saturday to Sunday night (Querol et al., 2012).

Overall when considering variations in type of ventilation, PM concentrations averaged for all stations with forced mechanical tunnel ventilation operating are PM_1 = 50 µg/m^3, PM_3 = 124 µg/m^3, PM_{10} = 159 µg/m^3. These average figures rise when tunnel ventilation is switched off: PM_1 = 59 µg/m^3 PM_3 = 144 µg/m^3, PM_{10} = 178 µg/m^3. However, such global averages obscure the fact that levels of inhalable particulates vary enormously depending on the station design and platform location. However, it can be observed that narrow platforms with single-track tunnels are strongly dependent on forced tunnel ventilation and cannot rely on the train piston effect alone to reduce platform PM concentrations. In contrast in wider stations with spacious double-track tunnels ambient PM levels can actually improve when tunnel ventilation is switched off (Table 2).

Table 2: Average values registered at platforms with and without forced ventilation in the tunnels.

		PM_1	PM_3	PM_{10}	CO_2	CO
			$\mu g/m^3$		ppm	
Stations with> 1 rail track	Forced ventilation	56	147	172	449	0.3
	Piston effect only	53	139	165	451	0.2
Stations with 1 rail track	Forced ventilation	38	93	117	479	0.7
	Piston effect only	71	175	209	472	0.5

Platform ventilation also affects PM levels, being clearly lower (half in some cases) during the summer period (April to October in the Barcelona subway system) when stronger ventilation is operating in the stations. The influence of air conditioning is also very evident when measuring inside the trains, in this case with values increasing more than 3 times when air conditioning is switch off (Martins et al., 2014).

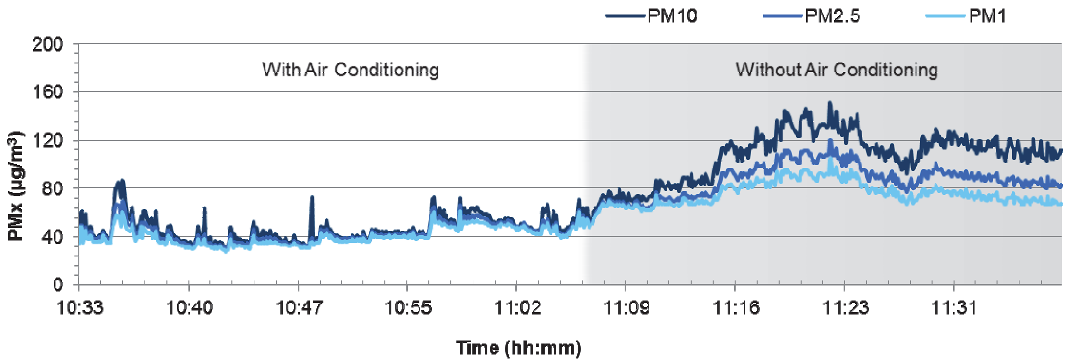

Figure 2: PM measurements inside a subway train with and without air conditioning during the same trip.

Another parameter affecting the variability of PM levels is that occurring spatially along the platform. Thus platforms with one end exit show an increase in PM concentrations at the opposite end of the platform, both with and without forced ventilation, this being particularly clear in the case of coarser particles, indicating worse air quality conditions at the farthest end from the entrance/exit point (see top platform in Figure 3). The effect of the arrival or departure of trains in the stations is more visible in the stations with one rail track/one platform in the entrance point of the train at the station (bottom platform Figure 3), especially when forced ventilation in the tunnel is being applied.

Access tunnels to platforms can help dilute PM concentrations by introducing cleaner air from outside, although lateral accesses are less effective than those parallel to the train entry point. Concentrations of CO vary by an order of magnitude and are probably controlled by the amount of traffic-contaminated air, with values of up to 1 ppm CO presumably reflecting air being brought down from street level. Finally, the commuters themselves influence air quality, as demonstrated by the regular rise and fall of CO_2 levels during the build-up and exchange of passengers with each passing train (Figure 4). The amplitude of such variations will depend on passenger numbers, train frequency, and therefore time of day.

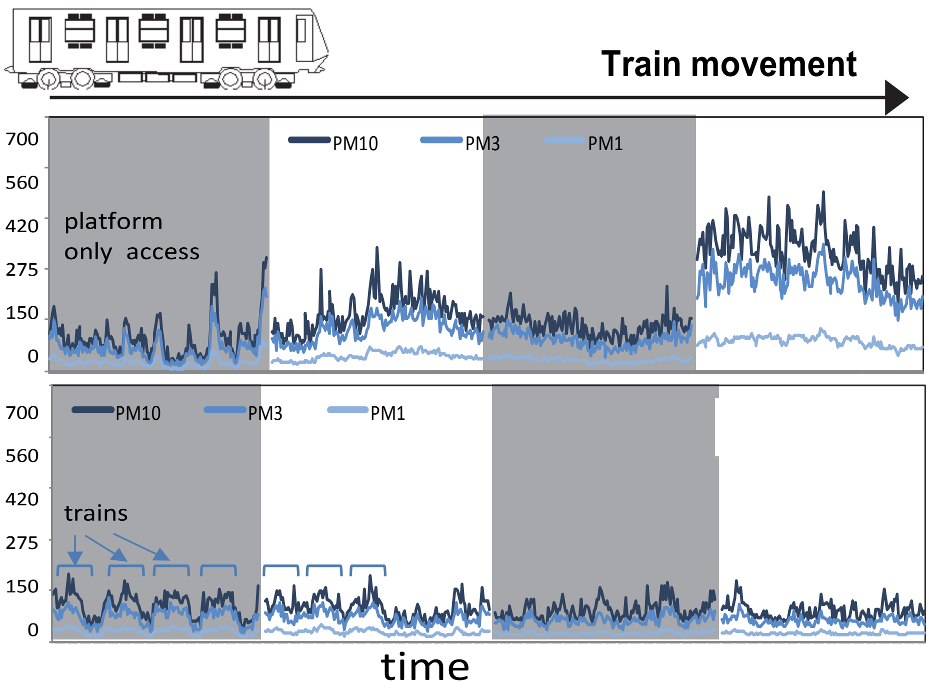

Figure 3: Examples of PM concentrations (µg/m^3) measured every 6 s. during 1-h in 4 equidistant points along each platform.

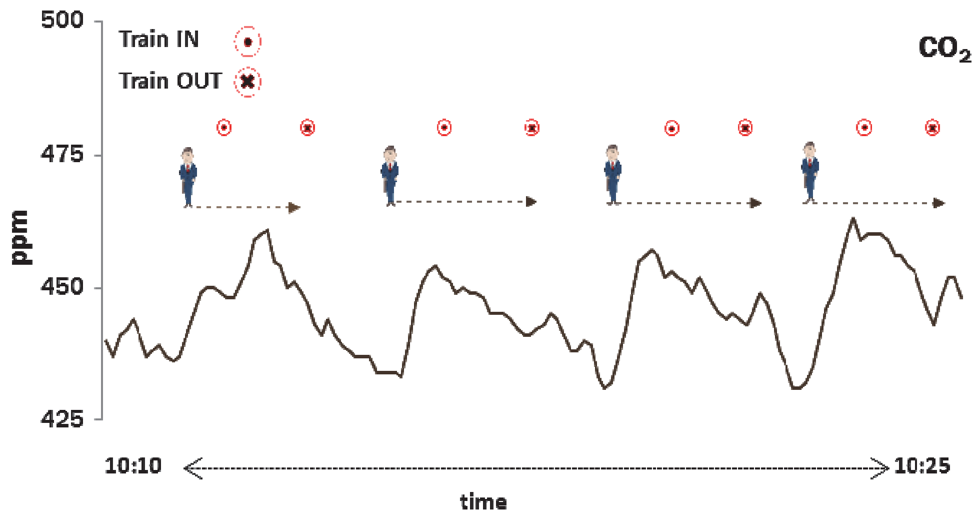

Figure 4: Carbon dioxide concentrations measured in a platform, note the regular rise and fall of CO_2 concentrations due to passenger build-up and exchange with each passing train.

In conclusion, air quality in the subway environment is an issue of concern due to the high concentrations usually registered, especially in platforms. Several variables influence these concentrations including type and intensity of ventilation, station design, number and location of accesses to platforms and number of trains and passengers. The detailed study of these parameters in a large number of stations is helping us to discern which characteristics are better for more desirable PM concentrations. The ongoing research projects METRO and IMPROVE LIFE, both based in Barcelona (teresa.moreno@idaea.csic.es), are currently producing a large amount of new data, as well as developing protocols specifically aimed at producing discernable improvements to rail subway air quality.

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