Geochemistry of Respirable Particles in Barcelona's Subway: How Reducing Commuting Exposure?

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INTRODUTION

Subway systems are one of the cleanest public transport systems in large urban agglomerations. The energy efficiency and reduced urban atmospheric emissions make this kind of collective transport a powerful tool to reduce energy demands and improve air quality in urban environments.

Concerning indoor air quality into the subway systems two aspects are considered. The first is the air quality on the platform of the stations and the second the air quality inside the train units. In both cases, suspended atmospheric Particulate Matter (PM) is the main critical parameter (Nieuwenhuijsen et al., 2007). This arises mostly from the abrasion products of rail track, wheels, and brake pads, as well as from sparkling in the catenaries.

On the platforms, PM levels are usually higher than those inside wagons, especially if air conditioning is implemented. Also rubber wheel trains cause less air quality impairment than metal wheels (Nieuwenhuijsen et al., 2007). Furthermore, the platform and tunnel ventilation systems also decisively influence air quality.

In Europe we have old metro systems with metal wheel trains and obsolete ventilation systems. Consequently, metro commuting PM exposure may reach relatively high levels during the few minutes the traveler is on the platform (Johansson & Johansson, 2003, Aarnio et al., 2005, Adams et al., 2001, Ripanucci et al., 2006, Salma et al., 2007). However, we have to bear in mind that we can not compare the PM exposure levels during metro commuting with ambient air quality standards, but with other commuting systems, such as bus, private car, bicycle or pedestrian, during which similar or even higher PM exposure levels than in metro commuting are reached.

In the present study we evaluate the impact of different features of the new metro lines in Barcelona´s subway system on PM levels on the platform and into the wagons with the aim of evidencing possible settings to reduce exposure to travelers.

To this end we selected the platforms from the old Fontana metro station in the green line (L3) and the new Sagrera station in the new blue line (L9), as well as the trains from L9, L3 and old blue line (L5) to perform simultaneous measurements in order to: 1) measure PM levels inside both trains and on platforms and compare the old L3 and new L9 stations and trains; 2) perform a detailed geochemical and mineralogical characterization of PM on the platforms to identify source origins of particles, 3) evaluate the influence of the new platform screen door systems (automated systems with closed rail tracks and platforms) and different type of ventilation settings in the tunnels and platforms on PM levels and composition.

METHODOLOGY

As previously stated two highly contrasting underground stations within the Barcelona metro system were selected for air quality measurements from 5th to 25th July 2011, these being Sagrera L9 (S-L9) and Fontana L3 (F-L3) stations. At S-L9 measurements of PM levels were repeated from 6th to 24th February 2012. The following instruments were placed at the far end of the platform at the train entry point, and were in operation in each station: 1) high volume sampler (30 m^3/h) MCVPM1025, equipped with quartz microfiber filters to sample PM10 or PM2.5 (PM finer than 10 or 2.5 μm respectively); and 2) two optical counters (GRIMM 1107 and DustTrak DRX TSI) for real-time measurements of levels of PM10, PM2.5 and PM1 performed on a continuous basis.

Furthermore, real time measurements of PM10, PM2.5 and PM1 levels were obtained also from within trains of metro lines L3, L5 and L9 during different travel distances.

Filter samples were analyzed using classical geochemical sample treatment and analytical tools, including Inductively Coupled Plasma Atomic Emission and Mass Spectrometry Mass Spectrometry (ICP-AES and ICP-MS), ion chromatography, and organic (OC) and elemental carbon (EC) thermo-optical analyzers. Furthermore, X-ray powder diffraction (XRD) and Scanning electron Microscope equipped with an energy dispersive X-ray analyzer (SEM-EDX) were also used to characterize mineralogy and morphology of PM.

During measurements performed at S-L9 there was a change of the platform and tunnel ventilation conditions in such a way that both winter (PW) and summer (PS) platform ventilation setting up were tested in combination with two sets up of tunnel ventilation: 1) outdoor air uptake with 2 ventilation systems being operative (T2) and only one ventilation system in operation (T1) in the tunnel. Thus we measured and sampled PM in the following ventilation schemes: PW-T2, PW-T1, PS-T2 and PS-T1. Each ventilation scheme was maintained at least during one week.

RESULTS

Levels on the platforms

The new metro system of S-L9 in the Barcelona city subway was able to reach ambient particulate pollution lower than

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in the conventional system (F-L3) by a factor of 4, which is probably attributable to the advanced ventilation set up, to the platform screen door system and other design features of the platform and trains, which reduce the contribution of metallic abrasion dust to ambient PM on the platform. If PW-T2 and PS-T2 ventilation schemes are implemented the PM reduction factor is increased from 4 to 7 times. Experiments performed in February 2012 confirmed the magnitude of the reduction of PM levels by changing the tunnel ventilation power from T1 to T2.

PM Geochemistry and Mineralogy

Geochemical and XRD mineralogical studies of the PM sampled allowed identifying laminar hematite (Fe_2O_3) as the dominant particle accounting for around 50-60% of the PM mass, being mainly originated by mechanical abrasion of the rail track and wheels. Furthermore, calcite ($CaCO_3$), dolomite ($CaMg/(CO_3)_2$), clinochlore ($(Mg,Al)_6(Si,Al)_4O_{10}(OH)_8$), quartz ($SiO_2$), illite ($(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$) and traces of gypsum ($CaSO_4\ 2H_2O$) were detected in much lower concentrations. These PM point to infiltrated outdoor dust resuspension, construction dust, or dry and resuspended mud introduced by convective dynamics during the air uptake from outdoor into the tunnel and subsequent channelling of wind flows to the platform throughout lateral ventilation outlets. Finally, halite (NaCl), rounded C-Fe particles, discrete barite ($BaSO_4$,) and rough-surface Fe-particles containing traces of barite and Cu are frequently detected in the PM fractions at F-L3 platform.

Factor analysis evidenced 3 major sources of particles in the metro´s system: a) Brake wear; b) Outdoor air introduced into the metro; c) Metal wear.

Although, during the approach to the platform, braking is electric, trains of both old (L3-L5) and new (L9-L10) systems use pneumatic braking after deceleration to a certain velocity to finally stop on the platform. The different composition of brake pads of these braking systems is responsible for much higher levels (by factors from 5 to 200) of specific metals, such as Ba, As, Sr, Mo, Cu, among others, in the conventional line 3. Low metal specifications for brake pads would reduce considerably commuter's exposure to metals.

Concerning the levels of trace elements, much higher mean levels in PM10 were measured at F-L3 with respect to S-L9. The following grouping of elements was obtained according to the degree of their enrichment in the former versus the later with the optimal ventilation conditions (PW-T2):

- Ba is enriched in PM10 at F-L3 near 200 times with respect S-L9.
- Most of heavy metals and other trace element levels, from 4 to 40 times higher.
- Only Na, K, V, Se and Rb were present in similar levels at both stations, these mostly arising from the contribution from outdoor air.

PM Levels in the Trains

PM levels inside trains (where most of the travelling time is spent) from L9, L5 and L3 were lower, by a factor of 5, than those measured at the platforms. Also, levels were lower for L9 trains than for L3 and L5 ones, and most probably lower than if commuting was done by bus or by car.

The low levels recorded inside the train wagons are attributed to the PM filtering efficiency of the air conditioning working both in the cold and warm seasons.

Levels of PM inside trains of the Barcelona city subway are amongst the lowest reported for worldwide metro systems (reaching down to 15-25 $\mu g/m^3$ PM2.5, wile many subway systems exceed 50 $\mu g/m^3$). This is most probably related to the air conditioning system working in all carriages of the Barcelona metro. In Europe only a few metro systems have continuous air conditioning operating into the train wagons (Nieuwenhuijsen et al., 2007).

CONCLUSIONS

Comparison with the few studies performed in worldwide subway systems evidenced that PM exposure during metro commuting in Barcelona is amongst the lowest of the exposure levels in worldwide metro systems.

Both mass concentrations and metal loads are clearly reduced in the case of the new L9 with respect to L3, but also at L9 a very high reduction of exposure is reached by setting up the ventilation conditions as PW or PS with T2, compared to T1.

A high PM exposure lowering effect is evidenced into the wagon trains due to air conditioning operation, resulting on low PM exposure levels.

Finally, by controlling the composition of the brake pads it may also highly reduce the exposure levels of specific heavy metals and trace elements during the stay of commuters on the platforms.

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