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Particle Mass Size Distribution Relation to Train Traffic and Type in a Railway Tunnel

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Abstract

Concentrations of inhalable particles (PM10) have been shown to be exceptionally high in railroad and subway tunnel environments. The elemental composition usually indicates that particles originate in wear from rails, wheels, brake systems and pantographs. To be able to study and abate the contribution to PM10 from different train types, or even individual train sets, detailed traffic data is needed. Most studies are from subways where train types are rather uniform. This study was made in a rail road tunnel, where five different train types traffic the platform. A measurement system for train passages was set up and the data combined with traffic data from the Swedish Transport Administration to pinpoint if certain train types or individual train sets are more important than others for high PM10 concentrations. The results show that an older type of train, with mechanically braking wagons seem to produce most peaks of high PM10 concentrations.

Keywords: railroad, PM10, size distribution, train type.

1 Introduction

Even though not trafficked by combustion vehicles, high levels of particulate air pollution have been recognized in several railroad environment, especially in subway stations, e g Stockholm, London, New York city, Tokyo, Helsinki, Mexico City, Taipei, Prag, Budapest, Seoul and Rome (Aarnio et al., 2005; Birenzvige et al., 2003; Johansson and Johansson, 2003; Ripanucci et al., 2006; Seaton et al., 2005, Nieuwenhuijsen et al 2007, Kim et al, 2008, Raut et al.,2009; more references are given in Abbasi et al. (2013) and Järvholm et al., 2013). Typically, super-micron particles generated during mechanical wear dominate the particle mass concentration. Wheels, rails and brake systems are dominating sources

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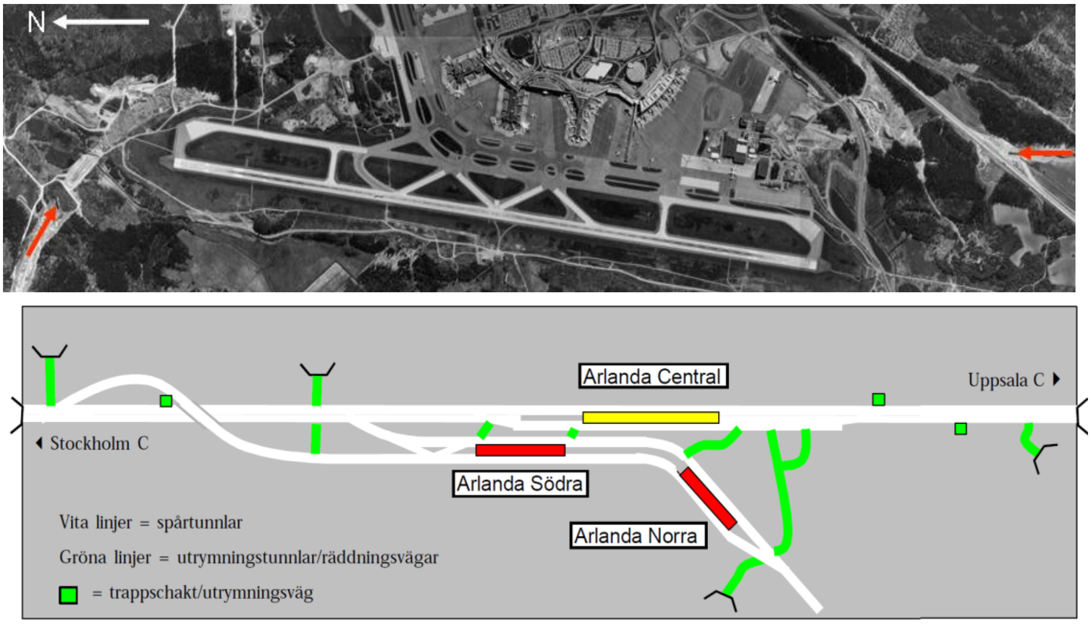
and particles consist to a large part of different oxidized forms of iron. In a Stockholm subway station around 60% of the PM10 was found to be iron or iron oxides, both magnetite (Fe_3O_2) and hematite (Fe_2O_3) (Johansson, 2005). Many other trace metals and metalloids have been found in elevated concentrations in subway environments, e g chromium, nickel, arsenic, calcium, barium, copper, antimony and aluminium (e g Querol et al., 2012). Also organic material has been identified.

While rails and wheels mainly consist of iron, brake wear systems have diverse techniques and compositions with potential to emit both different amounts of wear particles and with different compositions. The variation in contribution to PM10 from different trains and even from individual train sets might be high depending on brake system and brake materials used as well as on the maintenance state of the systems.

The aim of this study was to investigate the relation between particle emission and properties and train types trafficking a railroad tunnel.

2 Methods

The subterranean station Arlanda Central (C) is situated north of Stockholm below Arlanda airport. The platform is 400 m long with one track on both sides with traffic in opposite directions. The tunnel is approximately 5 km long and the station is trafficked by mixed long distance, regional and commuter trains passing the airport. The tunnels are self-ventilated. The only active ventilation is smoke evacuation fans only activated if fire occurs.



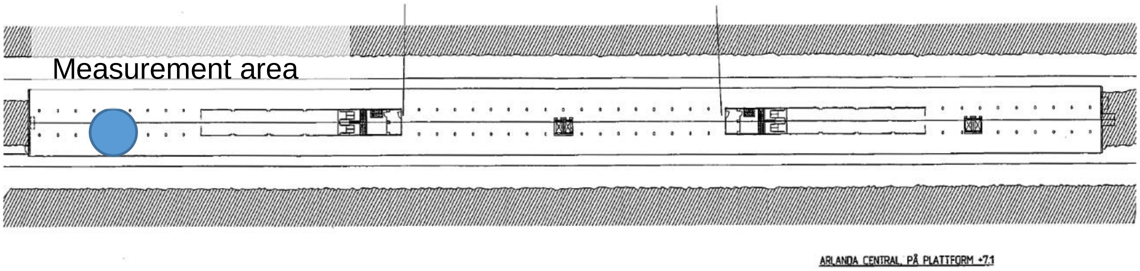


Figure 1: Arlanda tunnel and its entrances (upper) and Arlanda C platform with placement of the measurements.

The traffic in the tunnel is a mix of electrical trains, from long distance to commuter trains of different age and construction (Figure 2).

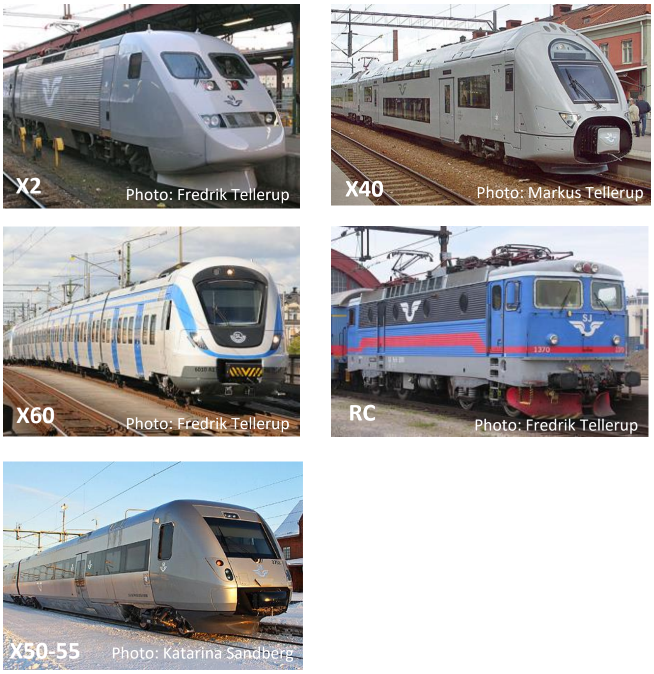


Figure 2: Train types trafficking Arlanda C. All photos from järnväg.net.

Apart from these electric trains, different types of maintenance vehicles traffic the tunnel, mainly in night time, when there is no regular train operations ongoing. These vehicles can be either electrically or diesel driven.

The train traffic at Arlanda C was detected by a photocell equipment designed at VTI registering each train arrival approximately 10 meters before the Arlanda C train station platform at each track (track 1= northbound, track 2 = southbound). The two rays were placed perpendicular to the rail, two meters apart, why the speed could be calculated. Since both the train front speed (by disrupting the rays) and train aft speed (by resuming the rays) could be calculated, the train length and speed retardation could be calculated. The photocells (brand: IR transmitter IFM Efector 200 OA5101, IR receiver IFM Efector 200 OA5102) were fixed two meter apart on aluminum rods held by two tripods at approximately 130 cm above the rails (Figure 3). The timing of ray disruption and resuming was logged by a TA89-logging equipment (VTI notat T147). During the measurement period 2013-01-28–2013-02-11, a total of 885 northbound and 959 southbound train arrivals were registered. Train definitions are: Length 20–400 m, acceleration/retardation between 2 and -2 m s^{-2}, front speed above 2 m^{-s}. Using the traffic system LUPP (access provided by the Swedish Transport Administration), it was possible to identify each train registered by the traffic measurements system.

Figure 1: Train traffic counting equipment in the tunnel. Measurement rays across the rail is indicated by red lines in the photo.

Monitoring of PM10 was performed using tapered element oscillating microbalance (TEOM) instruments (Thermo Fischer Inc., USA, model 1400a). The inlet at Arlanda were placed 2 m above the platform. Particle size distributions over the range 0.523-14.6 µm were measured using TSI Aerodynamic Particle Sizer (TSI APS 3321) and are presented as mass distribution. The time resolution for APS was 20 s. In the conversion from number to mass, a particle density of 5.0 kg m^{-3} is used for particles > 0.5 µm (density of iron oxide). For APS the Stokes correction was used which corrects for APS's overestimate of the particle size when the particle density is much higher than 1.0 kg m^{-3}.

3 Results

Traffic density shows obvious traffic peaks in the morning and afternoon (Figure 4), with a main minimum during late night and a secondary during mid-day. PM10 concentration correlates reasonably well with traffic density (R^2=0.58 for hourly mean values).

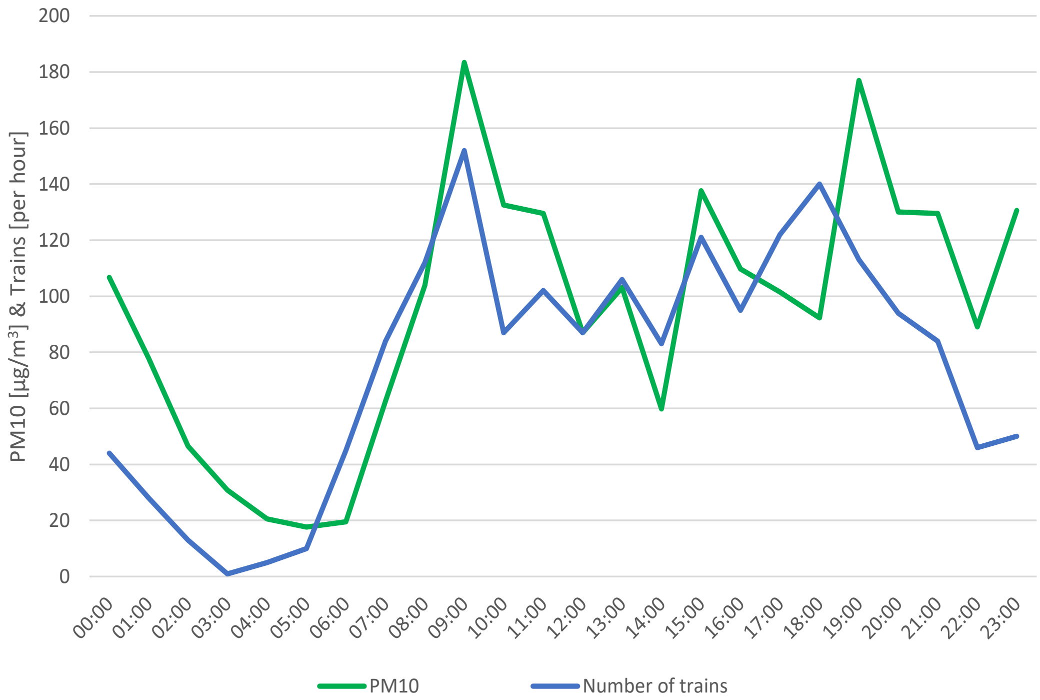


Figure 4: Mean traffic density and mean hourly PM10 concentration at Arlanda C.

The average mass size distribution of PM10 at Arlanda C is unimodal and peaks at slightly above 2 µm (Figure 5). From data on time series of particle size distributions, trains related to peaks in mass size distributions of PM10 have been identified on individual level using the LUPP-system and traffic data collected during the measurements. In Figure 6, a size distribution time series from the APS instrument during one day (February 3rd, 2013) is shown. On this scale, pinpointing the arrival of RC-trains (older trains with locomotive and coaches) seem to initiate mass peaks of the coarse fraction detected by the APS. It can also be seen that the arrival of the specific train set RC6 1419 three times during the day in Figure 6 results in similar particle mass peaks with a maximum around 3-4 µm, while other RC trains are connected to finer mass peaks.

In opposite to the irregular arrival pattern of the regional trains (RC, X40 and X55), the X60 commuter trains arrive almost simultaneously from both directions every 30 minutes between 8 AM to 11 PM. The lack of periodically recurring mass concentration peaks that coincide with the periodical commuter traffic indicates that these train sets are not major particle sources. Also the X50/X55 and the X40 train sets seldom coincide with particle peaks, but are harder to discern from the RC arrivals.

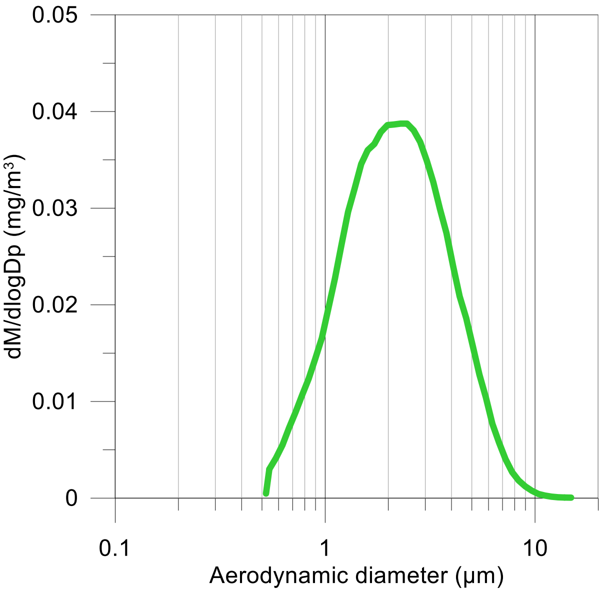


Figure 5: Mean mass size distribution for PM10 at Arlanda C.

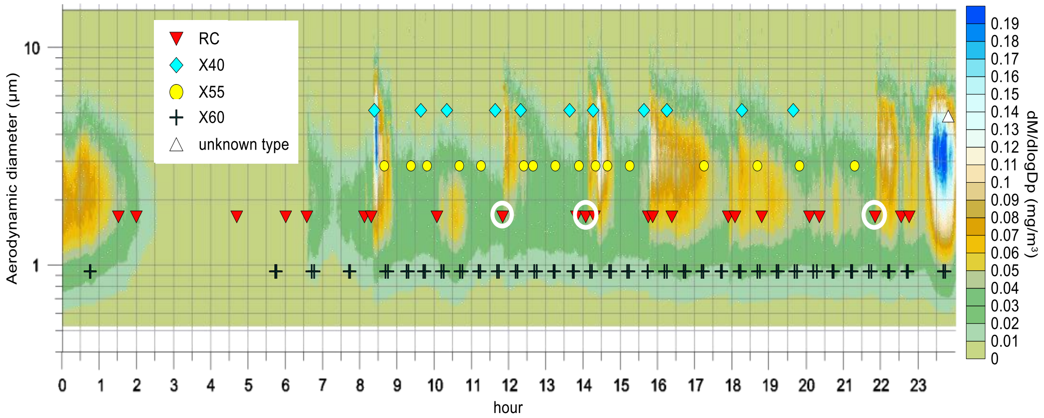


Figure 6: Mass size distributions and train type passages at Arlanda C during February 3rd, 2013. White rings indicate passages of the train RC6 1419.

4 Discussion

This study shows that electric train sets emit PM10 when trafficking an underground station and different train types and individuals are connected to different concentration peaks. The older type of trains (RC) are more often connected to high particle concentrations than other, more modern train sets.

A possible explanation for the connection between particle peaks and RC trains, is that the RC trains have longer braking time and also more individual behaviour since braking time depends on the number of wagons that are mechanical braked. Also in terms of electrical braking the RC locomotives are different since the locomotive itself is electric braked and the wagons are mechanically braked. The longer braking time may also make the particle emissions from the RC trains longer and therefore also easier to detect depending on the sampling time of the instruments.

It is likewise obvious though, that not all RC trains are connected to high PM10 concentrations and that some other train types occasionally are connected to particle concentration peaks, indicating that there are differences in the systems emitting the particles and/or how systems are used during the deceleration before finally stopping at the station. Differences could be associated to materials, state of system maintenance or differences in driving pattern.

Even though not studied in this work, it is probable that emissions made in other parts of the tunnel might result in contaminated air pulses that are moved to the platform due to piston effects (Coke et al., 2000) and natural ventilation, which makes the interpretation of the data more complex.

From an air quality abatement perspective, it would be beneficial to reduce stops of RC trains in the tunnel, through exchanging them for more modern trains with electrical brakes or to modernize the wagon brake systems.

5 Conclusion

Electrical trains cause high concentrations of PM10 in tunnel platform environment. PM10 has a unimodal, mean mass distribution peaking at 2-3 μm. Data support that the older type of trains (RC), with mechanically braked wagons and longer braking time are responsible for most PM10 emission peaks. Since not all RC trains cause high PM10 concentrations, data could be used to identify the individual high- emitters to investigate the origin of particle sources. PM10 concentrations in the tunnel could be improved by reducing RC train stops or by identifying and abate high-emitting train sets.

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