

SIZE DISTRIBUTION OF THE SUBMICRONIC AEROSOL IN A PARISIAN METRO STATION

Sophie Mazoué ⁽¹⁾, Nicolas Fischer ⁽¹⁾⁽³⁾, Evelyne Gehin⁽²⁾, André Renoux ⁽³⁾

⁽¹⁾ RATP, Environment and Security Department, 13 rue Jules Vallès, 75547 Paris cedex 11,
France, sophie.mazoue@ratp.fr

⁽²⁾ CERTES, ⁽³⁾ LPATC, Paris 12 University, 61 av. du Général de Gaulle, 94010 Créteil cedex,
France, gehin@univ-paris12.fr, renoux@univ-paris12.fr

INTRODUCTION AND CONTEXT OF THE STUDY

For many years, RATP¹ has been monitoring air quality in the underground stations of its railway system. This monitoring consists in a continuous follow-up of the levels of several gaseous parameters and of the weight concentration of the PM₁₀ fraction of the aerosol taken in two stations. Besides, since last year, RATP is launching a broad survey aiming at enhancing its knowledge of the atmospheric aerosol in its underground premises. Measurements of weight concentrations and takings on filters are carried out during four weeks in some especially representative RATP RER and Metro stations. Those takings are followed by lab chemical analyses. An outside location is monitored in parallel and in the same way as the underground site to make up a reference point. Such a survey makes it possible to quantify the PM₁₀ levels and to assess which kind of aerosol RATP employees and passengers are submitted to. During one of those tests, two additional analysers were implemented at platform level to assess the granulometric distribution of particles in suspension in the air of the selected station.

EXPERIMENTAL PROTOCOL

1. Selection of the station to be equipped

During recent years, aerosol survey campaigns were already carried out in three underground stations [1][2]. The station selected for our investigation differs from those formerly surveyed by a few criteria likely to alter the physical and chemical nature of its aerosol.

- ✓ A 60-m³/s extracting fan is located in the tunnel adjacent to the station
- ✓ Trains are steel-wheeled
- ✓ Braking shoes are made of a composite material

Besides, the station layout is simple and the station is located under a fairly busy road in Paris. At last, it belongs to a 20-station panel selected for their representativeness and the aerosol taken inside should be featured on the occasion of a broad measurement campaign. Our survey has been carried out in that context.

¹ Parisian public transport

2. Experimental protocol

The selected station has been equipped during four weeks. Two sites were installed : one in the middle of the platform and the second at the street level, close to a station entrance and less than 10 meters apart from a very busy crossing in Paris. Measurements tools implemented on both sites are identical and detailed hereafter.

2.1 Continuous measurement of the PM₁₀ level

A Rupprecht and Patachnik TEOM (Tapered Element Oscillating Microbalance), carrying out a dynamic measurement of the aerosol weight by means of an oscillating microbalance, is programmed to record PM₁₀ concentrations at 15-min intervals.

2.2 Takings of filters and physical-chemical analysis

A Rupprecht and Patachnik Partisol + sequential sampler takes the PM₁₀ aerosol and dissociates the fine (PM_{2,5}) and coarse (PM_{2,5-10}) fractions by means of a dichotomic separator. Each taking is 24-hour long. Chemical analyses subsequent to those samplings require the implementation of three different filter types according the chemical species to be analysed.

- ✓ Pallflex PTFE coated fibreglass filters, for a capillary electrophoresis analysis in order to determine the anionic and cationic concentrations (analysis performed by the Paris City Hygiene Laboratory).
- ✓ Whatman quartz filters to determine organic and elementary carbon by infra-red spectrometry (analysis performed by the Paris City Hygiene Laboratory).
- ✓ Polycarbonate filters (porosity = 0,8 µm) for the multi-element analysis of non-soluble elements by the PIXE process (Particle induced X-ray emission, analysis performed by the Nuclear Survey Centre at Gradignan, near Bordeaux).

Each third day, each type of filter is used as a filtering medium in accordance with the outside takings.

2.3 Analysis of the granulometric distribution of the aerosol [3]

During twelve days, two additional analysers were located along the TEOM and the Partisol + at the platform level. Indeed, it sounded necessary to enhance our knowledge on the metro aerosol by investigating its granulometric distribution and concentrations in submicron sizes.

For that purpose, we implemented :

- ✓ A *Dekati* ELPI (electrical low pressure impacter). The operation of this appliance can be broken down into three phases. First, the aerosol, sampled through a PM₁₀ taking head, is loaded by corona effect. Then, it is submitted to an inertial low-pressure ranking through a cascade impacter. This impacter is made of twelve stages which make it possible to separate particles from 30 nm to 10 µm in diameter. Finally, loaded particles are detected on each stage by means of an electrometer. Therefore, this appliance is able to provide a response in real time. For our study, the acquisition period was set to 15 s.

✓ A *TSI* SMPS (differential analyser of electrical mobility). This appliance associates two successive measurement media. The sampled aerosol is equally loaded by passing through a cloud of bipolar ions and then it is separated into an hundred of classes by means of a differential mobility analyser (DMA) which selects particles according to their electrical mobility, while the numerical concentration of the range is measured immediately after each separation by means of a condensation nuclei counter. We programmed the SMPS to make it sweep the range in 180 s, and then to acquire the mean distribution of five successive distribution ($t = 15$ min).

RESULTS

1. Weight measurement and chemical speciation

1.1 Weight concentration

Thanks to the 15-min interval follow up of the PM_{10} weight concentration in an underground station, it is possible to get the average profile of each environment from Monday to Friday. The outside profile matches those conventionally measured on Parisian sites with a steady increase from 6:00 to 10:00, to reach values slightly greater than $50 \mu\text{g}/\text{m}^3$ and culminating between 40 and $50 \mu\text{g}/\text{m}^3$ in the afternoon. Inside the station, the concentration follows the conventional profile systematically noticed during former measurement campaigns in underground. Two $200\text{-}\mu\text{g}/\text{m}^3$ peaks respectively appear at morning and evening rush hours, while during slack hours the concentration comes back below $150 \mu\text{g}/\text{m}^3$. During night stoppage of traffic, PM_{10} concentration tends to catch up the outside one which is then a few tens of $\mu\text{g}/\text{m}^3$. It should be noted that during this test, the fine fraction ($PM_{2,5}$) counts for less than half of the PM_{10} concentration.

RATP matches train traffic to the attendance of each line. Thanks to internal statistical data, it has been possible to show a correlation on a 30-min time period between the PM_{10} concentration and the operating parameters of the station. This is valid for the number of passengers entering the station and for the number of trains passing by the station too. Indeed, there are respective correlation coefficients of 0,88 and 0,82 between the PM_{10} concentration and each of these two series of data.

1.2 Chemical composition

The three types of chemical elements analysed during that campaign have made it possible to explain a major part of the chemical composition of $PM_{2,5}$ and PM_{10} aerosols. The aerosol taken outside shows the composition usually found in the Paris air, i.e. ionic and carbon fractions counting for more than 2/3 of its weight. However, the function of the trace elements is lower than 10 %. If we consider the aerosol taken inside the station, the weight contribution of ionic and carbon elements drops in spite of a light increase of the organic carbon content. Globally, only the metallic elements are more present in the station aerosol than in the outside one. This observation seems to indicate that particles are generated underground.

1.3 Signature of the PM_{10} aerosol by the emissions generated by braking

An aerosol survey [1] has shown that, as far as we refer to the PM_{10} concentration braking is really an internal source. It is desirable to compare the elementary composition of emissions

by the braking shoes and of that one of the aerosol sampled during of our test, in order to consider the contribution of the braking to the dust deposited in station. It appears that every element generated by braking is detected in station. However, elementary fractions of the aerosol in station are not identical to those of the emission. That is the reason why braking is not sufficient to explain concentration of every metallic element. There is at least one additional network-related PM₁₀ source, which should explain the presence of elements such as titanium or lead which are present neither in the composition of the composite material of the braking shoes nor in the aerosol taken outside.

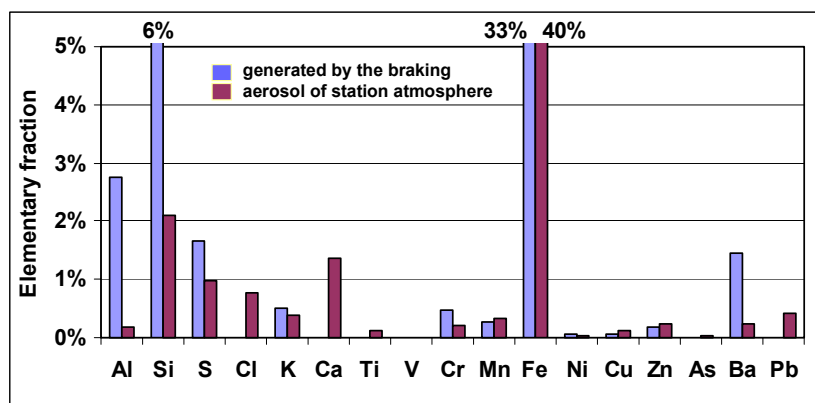


Fig. 1 - Weight fraction of metallic elements in the aerosol

2. Numerical granulometric distribution [3]

2.1 Three-hour distribution

The selection of the SMPS measure range – partly made on the basis of the first outputs given by the ELPI – between 7 and 305 nm, has enabled us to define the granulometric distribution of the aerosol accurately. The first observations of three-hour distributions on a day show a decrease in the numerical concentration during night stoppage of traffic for every analysed dimension. Besides, as it could be imagined, maximum concentrations occur between 6:00 and 12:00. The most significant fact, resulting from the survey of those eight curves representing the average three-hour distribution, is that the mode remains roughly steady, i.e. always comprised between 35 and 40 min during a day.

2.2 Comparison of the responses of the two methods

This test was a first investigation of the granulometric distribution of the aerosol in the atmosphere of a station of our network and with two appliances operating according to different concepts. It was decided to compare the global numerical concentration on a shared part of their measurement range, i.e. between 29 and 259 nm. Data processing was carried out for one day from the 15-min data. Profiles follow each other practically perfectly, since the correlation coefficient linking the two series is 0,98. However, there is a difference in amplitude between the two responses, which is likely due to the lack of knowledge of the density of the aerosol in the station atmosphere. Indeed, both appliances require this parameter entered before calculating distributions. In both cases, it was decided to take $d = 1$. Then, responses of both appliances follow the law $[ELPI] = 0,67 [SMPS]$.

2.3 Comparison of concentrations inside and outside the station

On the occasion of this 12-day test, it was decided to install the SMPS during 48 hours in the lab truck in order to assess the granulometric distribution of the aerosol outside the station. Drawing on a same figure profiles of the numerical concentration outside the station in the 29 – 259 nm range and of the concentration inside the station simultaneously measured by the ELPI and multiplied by the inverse of the here above coefficient shows that the sudden changes measured outside by the SMPS are not passed on to the underground station. Indeed the amplitude of variations in station is very smoother. However, profiles follow each other. Apparently a transfer exists from an atmosphere to the other. Granulometric distributions should be compared to each other.

2.4 Comparison of granulometric distributions inside and outside the station

Figure 2 shows the mean profiles obtained by means of SMPS in both environments. The profile of the underground aerosol represents a 12-day mean while the profile of the outside one has been calculated from the 15-min data of two days.

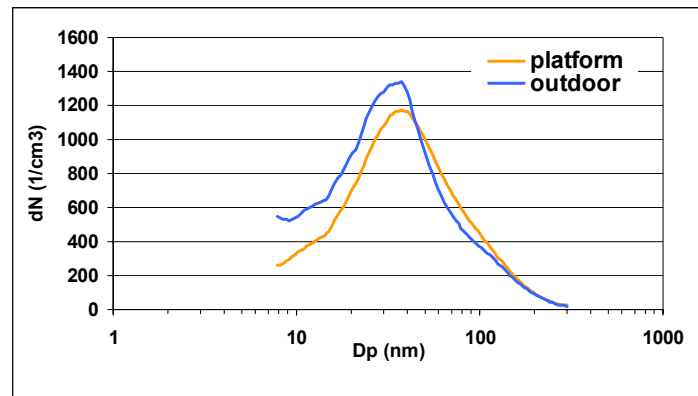


Fig.2 – Numerical granulometric distribution

However, profiles are very close to each other in terms of amplitude and, therefore, of concentration for each granulometric range. It can be seen too that mode values of respective aerosol profiles are close to each other. Those remarks reinforce the assumption of a link between the environments and of an aerosol transfer, at least in this size range.

2.5 Correlation between traffic and numerical concentration

The PM₁₀ concentration continuously measured in metro stations has the advantage of being well correlated to some operating parameters such as train traffic or the number of passengers entering the station.

We took advantage of this survey to look whether a correlation exists between the increase in numerical concentration in particles underground and that one of the number of trains passing through the station. This part of the test was implemented early on in two mornings (May 27th and 28th, 2002) when the operation is resuming. Considering the line of the variation of the correlation coefficient according to the granulometry, it can be noticed a low correlation for particles smaller than a score of nm. This observation should be relativized since the SMPS condensation nuclei counter has not an optimum counting efficiency below 20 nm. This could

be the origin of the lack of apparent correlation. However, as soon as the size exceeds a few tens of nm, a very better correlation is noticed between the numerical concentration in particles in suspension and the number of trains passing through the station. This verified with ELPI data too for bigger granulometries.

CONCLUSION

Thanks to this four-week long test, we were able to measure that PM_{10} concentration is higher inside the station than outside. Besides, a marked correlation can be noticed between PM_{10} concentration and the metro operation. As far as the chemical composition of this aerosol of the station atmosphere is concerned, it is very little altered by soluble elements such as sulphates and nitrates featuring the aerosol of the outside atmosphere. An enhancement in organic carbon featuring the presence of an internal source has also been noticed. The PM_{10} aerosol mainly contains metallic elements partly due to the emissions by train braking. However there are unidentified sources which should likely contribute to the remainder of those elements and explain the presence of other elements, such as lead for instance.

The implementation during 12 days of ELPI and SMPS at the platform level has for the first time made it possible to define the numerical granulometric distribution of the aerosol of the atmosphere of a network station. It features a peak between 35 and 40 nm all the day long and is similar to the distribution of the aerosol of the outside atmosphere, which evokes a transfer of the submicronic aerosol from an atmosphere to the other. Finally, we were able to show that operation resumption leads to an increase in numerical concentrations of the aerosol above a score of nm. It will be necessary to perform at least one additional test to accurately confirm that the aerosol of the outside atmosphere is truly the main contributor to the submicronic aerosol in RATP underground network.

ACKNOWLEDGEMENTS

The authors wish to thank A. Person (LHVP) and H. Guegan (CENBG) for their contribution to this work.

REFERENCES

- [1] Lesaint, T. (1999). *Caractérisation de l'empoussièrement du métro parisien : contribution des organes de freinage du matériel roulant*. Rapport d'essai interne RATP.
- [2] Fischer N. (2002). *Underground/outdoor aerosol study in a Parisian Metro station*, International Aerosol Conference.
- [3] Fischer N. (2003). *Compréhension des mécanismes d'aérocontamination croisés (gaz et aérosols) dans les espaces souterrains d'une station du métro parisien*. Ph.D.