EXPERIENCES FROM FIVE YEARS OF PM MONITORING IN RAILWAY TUNNELS OF AUSTRIAN FEDERAL RAILWAYS (ÖBB)

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ABSTRACT

Railways are considered a green transport system due to a high degree of electrification. However, due to abrasive- and wear processes railways do emit non-exhaust particles. On the one hand these particles represent a special concern related to the consequences on human´s health and the environment. On the other hand, particles emitted from railways comprise a high share of conductive material, which potentially causes issues in the operation of railway infrastructure. In order to gain more information about the quantity of emissions and PM loads in railway tunnels, extensive measurement campaigns have been conducted in Austrian railway tunnels. The results show large differences in the hourly and daily average PM concentrations, which result from differences in the tunnel characteristics, traffic volume and the position in the tunnel. Iron, copper and manganese have been identified to represent the major share in the emitted particles. Furthermore, PM filter service life has been evaluated in an in-situ installation. The nominal end of filter service life was achieved within a period of two to three months.

Keywords: non-exhaust emissions, particulate matter, railway Tunnel, filter service life, Koralmbahn, Koralmtunnel, railway operation

1. INTRODUCTION

Particle emissions from road transport are well investigated and subject to strict regulations. In particular, this refers to the particle emissions from combustion processes, but non-exhaust emissions are also the focus of research, legislation and industry. The emissions from railways are not investigated in the same level of detail, although some researchers [1][2][6][9][11] carried out investigations in order to quantify the emission. However, depending on the applied methodology, PM10 emission factors vary by a factor of 10 (0.2 g/km to 23 g/km). Brakes, wheels, rails as well as the contact strip and the contact wire represent the main sources of non-exhaust particle emission in rail transport.

In a tunnel environment, the PM concentrations can be expected high, due to a limited dilution of pollutants. This expectation is confirmed by many studies which identified metro systems to be the highest polluted urban places. [4] investigated the PM loads in the metro system in Milan and determined daily average concentrations up to 300 $\mu g/m^3$. Similar results were obtained in the study of [10] who investigated the air quality in Barcelona´s metro system.

PM loads in railway tunnels were assessed by [3], who conducted measurements in the Arlanda airport tunnel in Stockholm. During rush hour the PM10 concentration reached values up to 260 $\mu g/m^3$. Due to a lack of information an assignment to exhaust and non-exhaust emissions cannot be made. However, these results show that particle emissions from rail transport can cause a severe problem due to the particles conductive properties and the quantity of emitted particles.

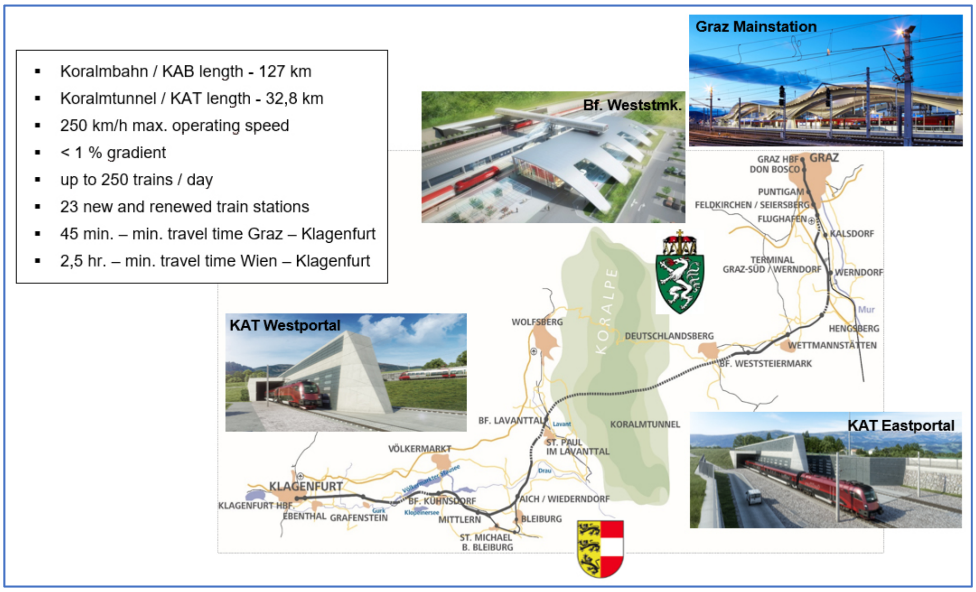
Long subsurface structures become more and more often part of modern transport infrastructure. A safe and reliable operation of such structures requires a variety of technical installations. Some of these installations release significant off-heat, which has to be removed in order to keep room air temperatures on an acceptable level [5]. Hence, cooling systems are required, which most commonly utilize tunnel air for re-cooling. In case of a mechanical ventilation system, the tunnel air is directly guided into the utility rooms. Another option is to use means of air conditioning in order to avoid from a direct utilization of polluted tunnel air. However, the re-cooling unit as well has to be protected from the dust loads. Thus, in both cases tunnel air has to be specially treated by the utilization of filter systems that are characterized by a service life, which depends on the collected particle mass.

In order to determine the PM filter service life in a railway tunnel environment, extensive PM monitoring has been conducted in recent years. This includes the observation of PM mass-concentrations, the derivation of PM emission factors, chemical analysis of particle composition and in-situ testing of PM filters in order to determine the service life. This paper summarizes the experiences and the main findings from the past five years.

2. KORALMBAHN AND KORALMTUNNEL

In the future the Austrian Federal railways will face the issue of dust loads, as three very long (longer than 27 km) railway tunnels (Koralmtunnel / KAT; Semmering Base Tunnel / SBT; Brenner Base Tunnel / BBT) will be set in the next 10 to 15 years into operation.

The so called ‘southern corridor’, which includes the Koralm railway (Koralmbahn / KAB – see Figure 1), is part of the 1,800 km long Baltic–Adriatic rail corridor of the Trans European Network – Transport (TEN-T). The KAB, with a length of about 130 km, connects the Austrian federal regions Styria and Carinthia, and their capital cities Graz and Klagenfurt.



- Koralmbahn / KAB length - 127 km
- Koralmtunnel / KAT length - 32,8 km
- 250 km/h max. operating speed
- < 1 % gradient
- up to 250 trains / day
- 23 new and renewed train stations
- 45 min. – min. travel time Graz – Klagenfurt
- 2,5 hr. – min. travel time Wien – Klagenfurt

Figure 1: Overview of the Koralmbahn (KAB) Graz - Klagenfurt

The key element of this new route is the Koralm Tunnel (KAT) with a length of 32.9 km and a maximum rock overburden about 1,200 m. The two single-track rail tunnels are connected via cross-passages every 500 m. These serve as escape routes and also house the necessary equipment required for tunnel operation. An emergency stop station with a length of about 1 km is situated between the two tubes roughly in the middle of the tunnel. Both the tunnel (KAT), and the railway line (KAB) should be completely ready for operation by the end of 2025.

3. TEST SITES AND MEASUREMENT SETUP

3.1. Test-sites

Three different test sites have been selected for the PM monitoring. The selection was made based on the tunnel characteristics, which is mainly expressed by the length of the tunnel, the traffic volume and the speed limit. In order to obtain information about the range of PM loads tunnels with different characteristic have been selected. Table 1 shows the tunnel test-sites including their characteristic. All tunnels are single-bore double track tunnels equipped with a solid track (slab track). The tunnels cross-section are similar (~ 65m²). Figure 2 shows the location of the test sites on the Austrian railway network.

Table 1: Test-sites including information of tunnel characteristics.

Tunnel	Length [m]	Traffic volume [#/day]	Speed limit [km/h]
Tunnel Unterwald	1.075	50 – 85	100
Burgstaller Tunnel	2.500	160 -210	250
Münsterer Tunnel	15.990	80 – 135	250

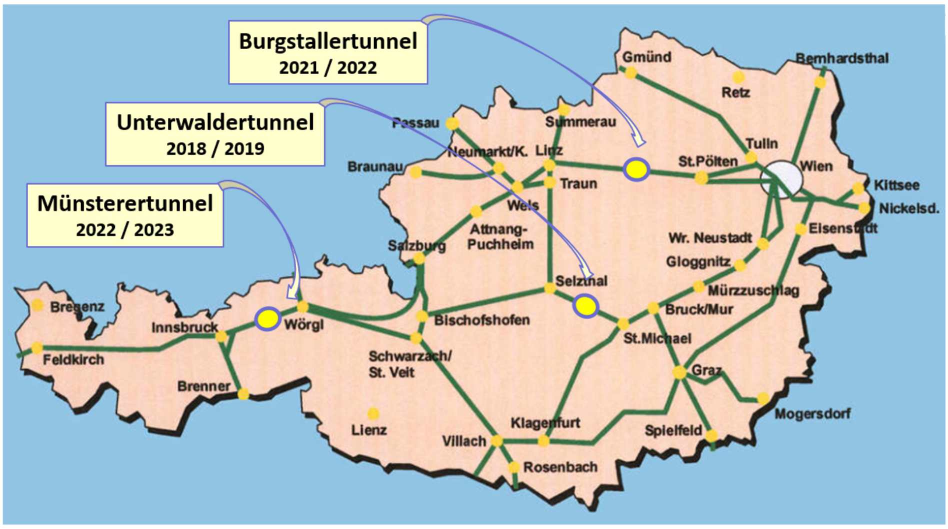


Figure 2: Location of test sites on the Austrian railway network.

3.2. Measurement setup

The measurement setup differed slightly between the measurement campaigns. In particular, the test setup in the tunnel Unterwald (Figure 3) had a special design, as the PM monitoring was implemented in supply air system that was used for cooling purposes. This system was designed to extract tunnel air (0.25 m³/s) and to guide the supply air via ventilation ducts into a dedicated utility room. The PM monitor was located in the egress way and extracted the sample flow from the supply air duct. Isokinetic extraction was applied in order to minimize particle losses. However, due to several fittings, redirections and the length of the supply air system (~ 15 m), particle losses due to deposition could not be prevented. A tapered element oscillating micro balance monitor (TEOM 1400i) was employed to continuously monitor the TSP concentration in the supply air duct. TEOM 1400i uses a gravimetrical principle to determine changes of collected particle mass on a filter.

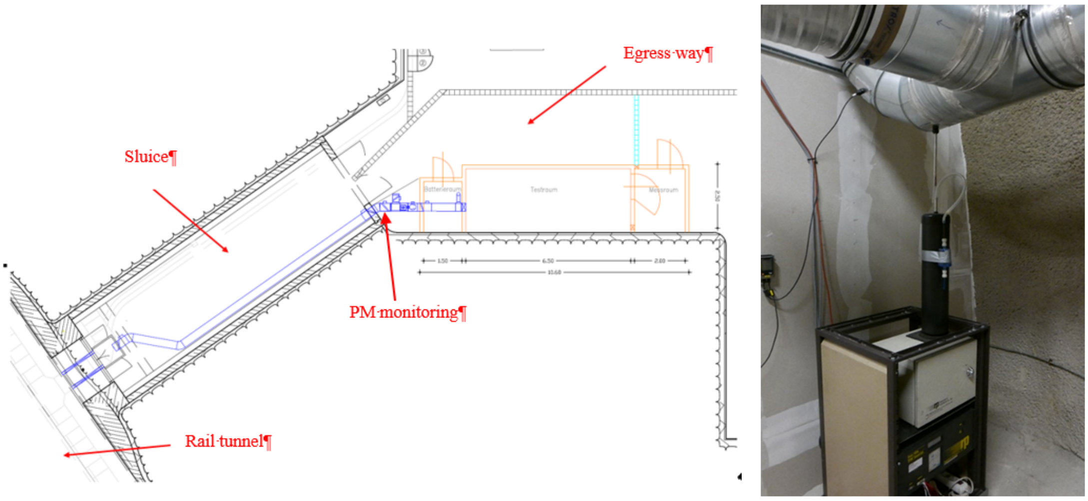


Figure 3: left - scheme of the test setup at Unterwalder Tunnel,
right – position of the TEOM 1400

In contrast, in Burgstaller- and Münsterertunnel the PM monitors were situated directly in the rail tunnel, thus, providing more precise information about the PM loads in the tunnel. In both tunnels two PM monitors were employed, which use different measurement principles. One is an optical particle monitor (EDM180), which uses light scattering technique to count particles in the size range of 250 nm to 32 µm. An internal algorithm transforms the particle count into information of particle mass concentration. Hence, a certain particle density has to be applied, which by default is set at a level of 2.6 to 2.8 g/cm³ in order to account for ambient aerosols. In a railway tunnel environment, the share of heavy metals in the aerosol is expected much higher, thus requiring the application of a density correction. For this reason, in both tunnels a sequential air sampler PARTISOL Plus, which uses a gravimetric principle was operated in parallel for a period of one month. The drawback of a gravimetric device is the limitation related to the resolution in time, which depends on the collected particle mass on the filter. In order to overcome this issue, daily average values were determined and compared to the results of the EDM180 monitor, which gives information about the PM concentration every sixth second. Subsequently, the data of EDM180 were corrected by the quotient of daily average values (PARTISOL/EDM180). Figure 4 shows the PM monitoring positions in both Burgstall- and Münster Tunnel as well as an image of the installed PM monitors.

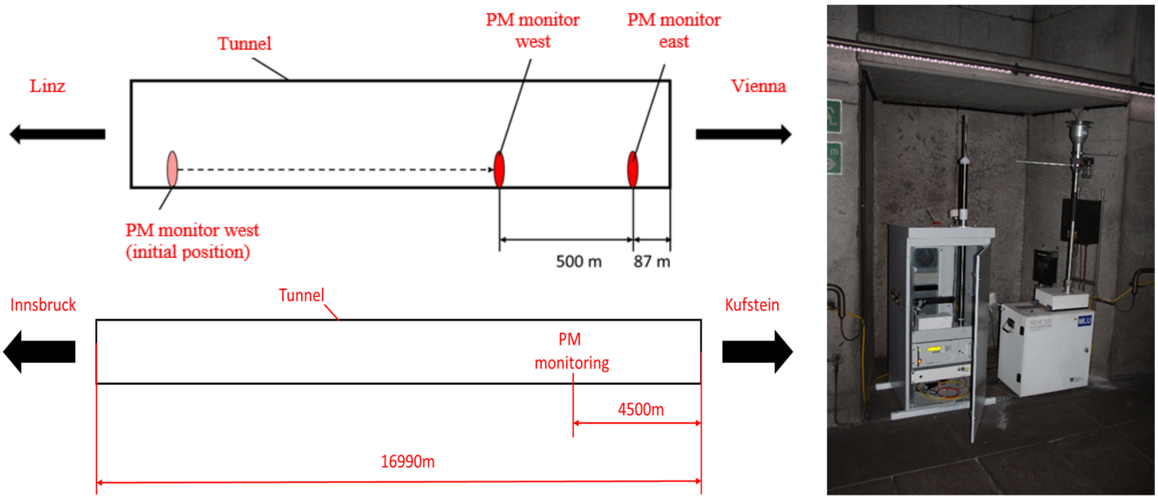


Figure 4: top left - scheme of the test setup in the Burgstaller Tunnel,
bottom left - Scheme of the test setup in the Münsterer Tunnel,
right – installation of PM monitors in the Tunnel Burgstall

In addition to the monitoring of PM concentrations, the service life of PM filters in a railway tunnel environment has been evaluated. For this reason, a supply air system comprising a supply air fan, ventilation ducts, fittings and a two-stage filter were installed in the Münster tunnel. This installation was operated for half a year, thus, enabling the sequential testing of three filter sets. These filter sets (coarse dust and PM filter) were covered in a filter box. Figure 5 shows the installation in a niche next to the PM monitoring station. There was no fan control in dependency on the air flow. However, the initial supply air flow was set slightly higher than the nominal air flow (1 $m^3/2$) through the filters. With increasing particle mass on the filters, the total pressure difference across the filters increased as well, thus, leading to a decrease of air volume flow. This effect was negligible for most of the time, but with very high pressure differences, the air flow decreased to 0.85 m^3/s. The observed quantities comprised the supply air speed and the pressure difference across every filter stage.

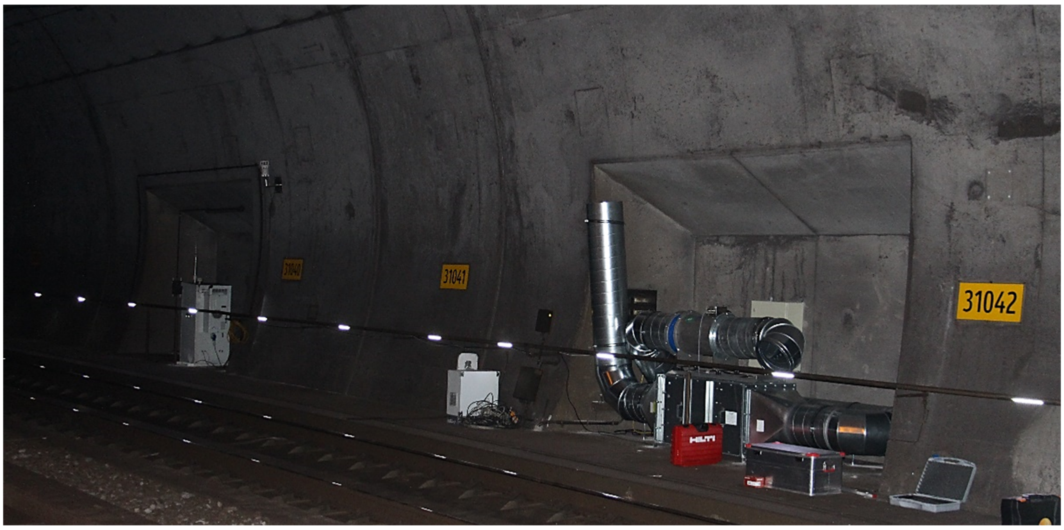


Figure 5: Tunnel Münster - installation of ventilation system including double-stage filter.

4. RESULTS

4.1. Particle mass-concentration in the railway tunnels

The observation of PM concentrations in three different ÖBB railway tunnels showed large differences that result from different tunnel characteristics as well as from different monitoring positions in the tunnels. Figure 6 illustrates these differences in a comparison of daily average particle mass-concentrations for selected periods. In addition, data from tunnel Burgstall and tunnel Münster show a comparison of mean PM10 concentrations recorded by EDM180 (optical device) and PARTISOL Plus (gravimetric device). One can see that daily average particle mass-concentrations in a short tunnel (Unterwald) and in a monitoring position close to the portal (Burgstall) are significantly lower compared to a monitoring position away from the portal of a long tunnel (Münster). Furthermore, daily average concentrations varied by a factor of 10 – 15 in every tunnel. The main reasons for that are variations in the daily traffic volume as well as the influence of precipitation. The latter causes a reduction of background concentrations as well as of particle emissions from trains. In humid conditions, it is more likely that the particles will settle on the floor as well as on the surfaces of the train. Hence, precipitation has a strong impact that in particular can be observed in short tunnels as well as in portal regions.

A second aspect to be mentioned are the deviations between optical and gravimetrical measurements, which were different at tunnel Burgstall and tunnel Münster. While the daily average values recorded by EDM180 covered 64% of the collected particle mass of

PARTISOL Plus, in the tunnel Münster the share was only 32%. These deviations are a result of differences in the effective density of the tunnel aerosols. In this context it is important to understand the influence of ambient air in tunnel sections close to the portals and in some distance to the portals. Moving trains will cause ambient, thus lower polluted air to enter the tunnel in driving direction and reaches PM monitoring stations close to the portal. In contrast, some time is required in which ambient air will reach tunnel sections in some distance to the portals. In longer single tube tunnel characterized by bi-directional traffic, it is most likely that another train will enter the tunnel from the opposite side. The piston effect of trains in both directions, cause highly polluted tunnel air to remain inside the tunnel for a long time. Thus, in average, PM loads are higher in the tunnel centre than close to the portals. This statement is confirmed by the results depicted in Figure 6, as PM loads in tunnel Müntser are significantly higher than in tunnel Burgstall, although, the traffic volume usually is higher in tunnel Burgstall.

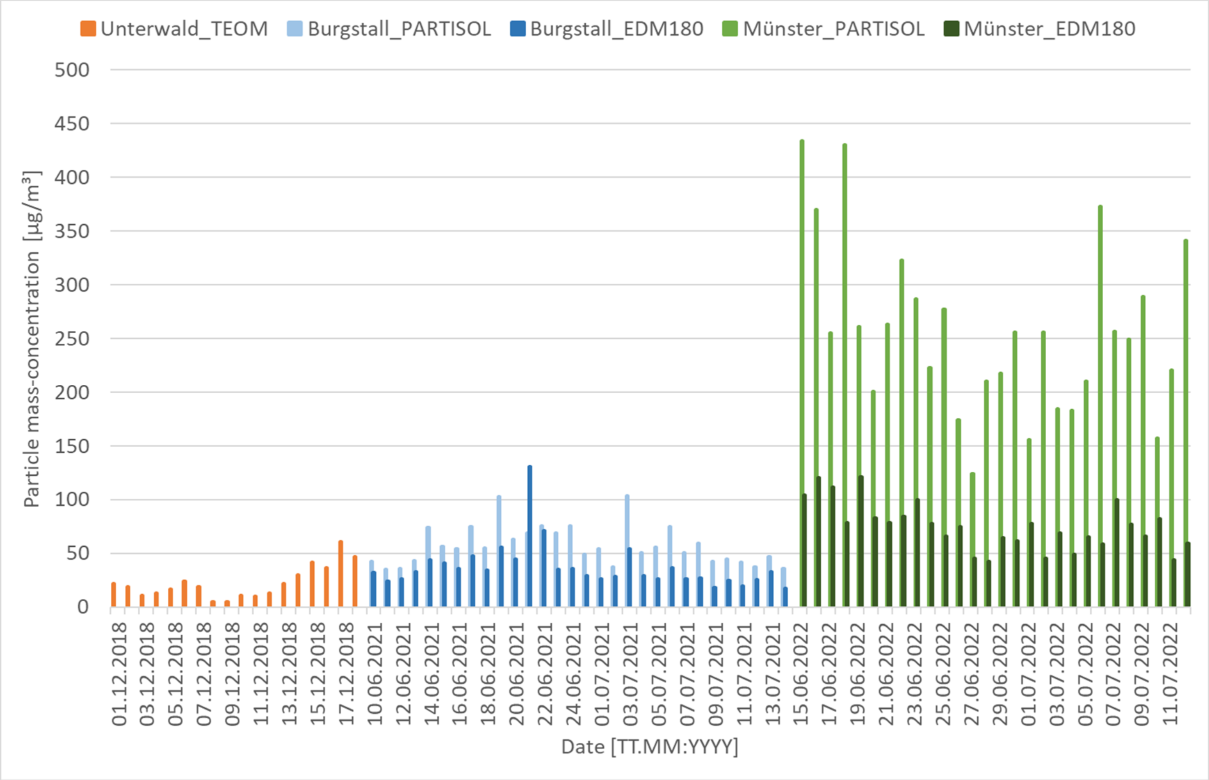


Figure 6: Daily average TSP (Unterwald) and PM10 (Burgstall and Münster) concentrations.

In order to quantify aforementioned differences, Table 2 shows the average particle mass-concentration of the entire monitoring period for each of the tunnels. In addition, minimum and maximum daily average values of the monitoring periods are added. The average PM10 concentration in the tunnel Münster was roughly six times higher than in tunnel Burgstall and roughly 19 times higher than in Tunnel Unterwald. While the minimum value is five times lower compared to the average value, the maximum daily average value is three times higher. Similar relations could be observed as well for tunnel Unterwald and tunnel Burgstall.

Table 2: Comparison of daily mean PM concentrations at every test-site

	Münster			Burgstall	Unterwald
	PM10	PM2.5	PM1	PM10	TSP
Average	407.3	215.1	126.2	70.8	22.5
Minimum	80.5	60.2	44.0	21.2	4.7
Maximum	1297.9	479.5	240.2	205.3	60.7

4.2. Monitoring of filter service life

Obviously, the PM loads have an impact on the filter service life of PM filters. In order to extend the service life of a PM filter, usually a coarse dust filter is arranged in front of the PM filter. Such an arrangement has been tested in the tunnel Münster. The filter status has been monitored by recording the total pressure differences across each filter stage. Figure 7 illustrates the development of pressure differences across each filter stage as well as the total pressure difference for three filter sets, which were tested sequentially. Additional information is provided by the daily average PM10 concentrations during the test period. The end of service life is indicated by a total pressure difference of 450 bar (defined by manufacturer), which was reached after 1.5 to 2 months. One aspect to be emphasized is the development of the pressure difference across the PM filter. After some time, the expected increase of pressure difference turned into a decrease. This decrease was a result of massive particle mass collected on the coarse dust filter, which caused smaller particles as well to be caught by the coarse dust filter. Hence, the decrease of volume flow led to a reduction of the pressure difference across the PM filter.

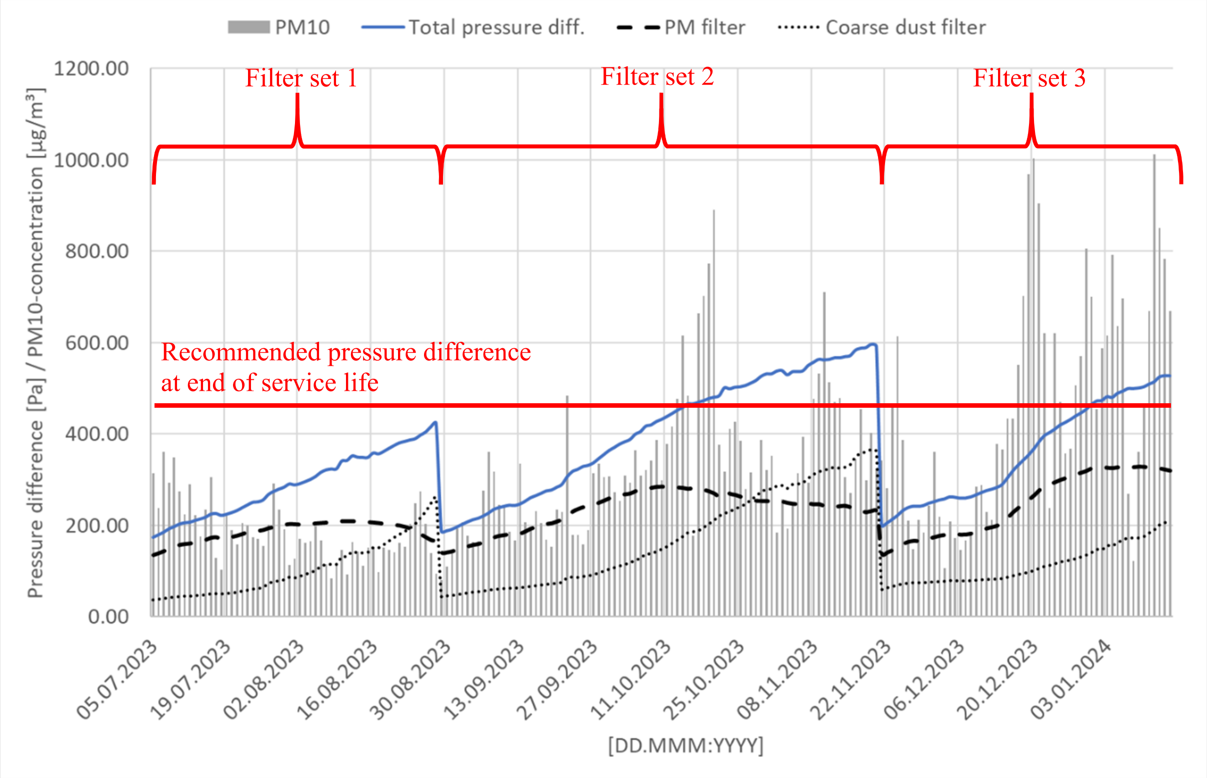


Figure 7: Development of Pressure difference across 2 stage filter and daily average PM10 concentrations – Münster Tunnel

4.3. Particle composition

Ultimately, filter samples collected by PARTISOL PLUS air sampler were analyzed for the heavy metal and total carbon mass deposited on them. The information gained by this analysis shows the mass-fractions of selected elements in the total PM10 mass collected on the filter samples. These mass-fractions are expressed as average values of 32 filter samples for each of the tunnel sites. As one could assume, iron, carbon, and carbon represented the major shares in the collected particle mass. Furthermore, copper, chromium, manganese, magnesium and nickel were identified to represent minor shares of the particle mass. It has to be mentioned that the analysis was made for selected elements and does not provide full information about the particle composition. However, a comparison of mass-fractions determined individually for each of the test tunnels (see Table 3) shows differences in the particle composition. On the one hand these differences are caused by the already mentioned differences related to the influence of ambient air and on the other hand the emission of the rolling stock as well as other railway components (e.g. contact wire) may varies dependent on the utilized materials. As an example, contact wires usually consist of pure copper or copper and alloy additives such as magnesium or silver. Hence, there are local variations in the non-exhaust emission of moving trains.

Table 3: Results of chemical analysis of particle composition – (mass %)

	TC	Cr	Cu	Fe	Mg	Mn	Ni
Unterwald **	29.20	1.38	0.45	48.16	<<	0.51	0.103
Burgstall	*	0.01	1.12	25.09	3.18	0.15	0.94
Münster	10.44	1.10	9.20	38.00	<<	0.30	0.11

* not analyzed << below detection limit **already published in [7]

5. SUMMARY AND CONCLUSION

The presented study provides information about OM loads in railway tunnels caused by non-exhaust emissions from moving trains. The provided data are derived from extensive measurement campaigns in tunnels of Austrian Federal Railways, which were carried out for more than five years. The aim of the study was to determine the PM loads, to derive PM emission factors (see [8][12]), to gain information about the particle composition as well as to determine the service life of PM filters in a railway tunnel application. The main findings can be summarized as follows:

- PM loads in railway tunnels depend on the traffic volume, the tunnel characteristics as well as on the position inside the tunnel. Test results show that the latter is dominant over the other parameters.
- In tunnel sections close to the portals significantly lower PM loads could be observed compared to tunnel sections in some distance to the portals. In particular, this conclusion is valid for single-bore double-track tunnels.
- Due to significant changes in the effective particle density, data from optical particle monitors have to be corrected in a railway tunnel environment.
- The service life of two-stage particle filters at an air flow of 1 m^3/s could be determined by 1.5 to 2 months (away from tunnel portals).
- The main mass-fractions in the PM10 fraction are iron and carbon. Smaller amounts of copper, chromium, manganese, magnesium and nickel were identified as well.
- The particle composition will vary dependent on the impact of ambient air (position inside the tunnel) and differences in the utilized materials in the rolling stock as well as in additional railway components such as rails and contact wires.

6. ACKNOWLEDGMENTS

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