DUST LOADS IN RAILWAY TUNNELS – RESULTS FROM IN-SITU MEASUREMENTS AND CONSEQUENCES FOR TUNNEL FACILITIES AND RAILWAY OPERATION

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ABSTRACT

Several long railway tunnels are currently under construction in Austria (e.g. the Koralm Tunnel / KAT; Semmering Base Tunnel / SBT; Brenner Base Tunnel / BBT). The project KAT is now at the beginning stage of implementation with respect to technical railway equipment. In order to complete the detailed planning several very specific topics have to be examined in detail. The ÖBB (Austrian railway corporation) has thus begun detailed research in the relevant areas in order to grapple with problems at their root, and to allow for findings to be incorporated into ongoing projects.

For example, it is known from cases in Switzerland, where several long railway tunnels have been in operation for years (Lötschberg Base Tunnel / LBT; Gotthard Base Tunnel / GBT), that technical equipment needs a lot of maintenance when it is exposed to high dust loads. The quantity and composition of the dust also play a key role here.

To assess the nature of the problem, in-situ measurements were thus carried out in an ÖBB railway tunnel under full operation in Upper Styria. The knowledge gained from these measurements is to be integrated into current and future rail tunnel projects. Specific attempts were made to derive characteristic emission factors in relation to different train types. It should then prove possible to estimate total dust emissions in current and future projects, depending on the specific operating programs, timetables, train mix etc. The overall intention is to improve filter design and to derive more relevant information concerning maintenance and repair.

Keywords: Dust loads, railway tunnels, PM emissions, filter lifetime, railway operation

1. INTRODUCTION

The so called ‘southern corridor’, which includes the Koralm railway (Koralmbahn / KAB), is part of the 1,800 km long Baltic–Adriatic rail corridor of the Trans European Network – Transport (TEN-T) [1] [2]. The KAB, with a length of about 130 km, connects the Austrian federal regions Styria and Carinthia, and their capital cities, Graz and Klagenfurt. This new, high-performance track is characterized by very low track gradients. It reduces the travel distance between the two capital cities by 100 km and the travel time by more than 2 hours.

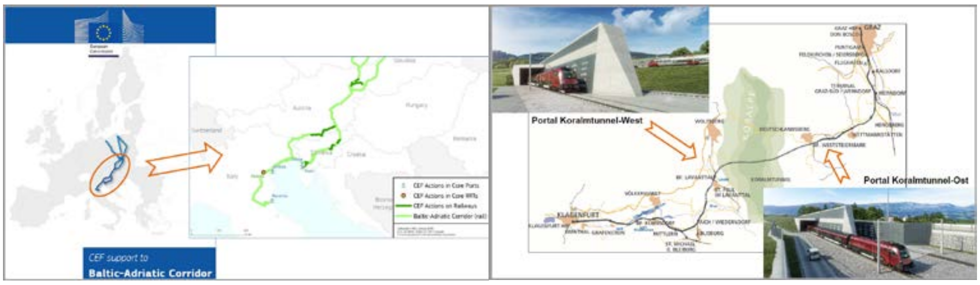

Figure 1: The Baltic-Adriatic traffic corridor [1], [2] (left);
Overview of the KAB Graz – Klagenfurt (right)

The key element of this new route is the Koralm Tunnel (KAT) with a length of 32.9 km. It is currently one of the longest railway tunnels in the world. The maximum rock overburden is some 1,200 m.

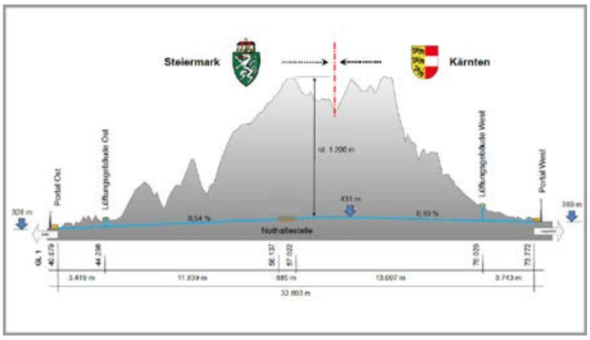

Figure 2: Longitudinal section of the Koralm Tunnel

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 900 m is situated between the two tubes roughly in the middle of the tunnel. After a period of more than 20 years of design and construction work, we are now approaching an important milestone in terms of the railway fit-out. Both the tunnel (KAT), and the railway line (KAB), should be completely ready for operation by the end of 2025.

2. GENEREAL REQUIREMENTS FOR OPERATING A RAILWAY TUNNEL

In a world of rapidly advancing technology, selecting the technical equipment for a railway tunnel calls for a delicate balancing act when attempting to satisfy all the (often conflicting) requirements. In this respect, particularly due to its length, the KAT represents a very special case in terms of equipment, operation and maintenance.

Experience from the operation of comparable rail tunnels (e.g. Gotthard-, Lötschberg Base Tunnel, the new tunnels in the Brenner approach line, or the Westline from Vienna to St. Pölten) shows how time-intensive maintenance work can be. For example, maintenance work can only be carried out at specific closure times per week in one rail tunnel. The fact that access is only possible via the portals, and that extremely long distances are involved (travel times of up to 1 h in each direction) certainly does not help to make problems any smaller.

The very dry tunnel climate often aggravates dust problems leading to disadvantageous effects on people and equipment. The dust burden – mainly due to metal wear in braking stretches – is a significant driver behind maintenance work since it entails an increased need for cleaning (Figure 3).

Figure 3: Dust load in a cross passage of the Wienerwald Railway Tunnel / ÖBB Westline

Little information is currently available concerning particulate matter (PM) emissions from electrified rail traffic. It is, however, well-known that PM from rail traffic strongly affects the operating conditions and the life of electrical equipment inside a tunnel. The massive occurrence of dust from a wide variety of abrasion, wear and resuspension processes in train tunnels poses considerable technical and economic challenges. Above all, technical systems for energy supply (switching devices, TRAFOs, etc.) as well as telecommunication systems etc. react extremely sensitively to excessive dust concentrations in the area. Metallic dusts, in particular, have a particularly high potential for interference or damage due to their electrical conductivity. This has in fact been confirmed by existing measurements [4], [5]. In order to improve the database, a research project was set up with the aim of investigating non-exhaust particle emissions for different types of freight and passenger trains and their respective effects on tunnel equipment. For this reason, the Austrian railway corporation, the ÖBB, initiated a pilot-project at Unterwalder tunnel on the Schoberpass-track in Styria. Although the focus of this project was testing electronical components under real in-situ conditions, dust concentrations inside the tunnel were also measured. In fact, dynamic measurements of particle concentrations were undertaken, as was dust composition analysis of PM samples.

3. MEASUREMENT SET-UP

3.1. Measurement location

In order to investigate the dust load from rail traffic and its impact on tunnel equipment the Austrian railway corporation (ÖBB) initiated a pilot-project in the tunnel Unterwald. This tunnel has a length of 1,075 m and a constant grade of 1.52 % from east to west. The escape gallery of Unterwalder tunnel was chosen as test location. A new utility room was constructed here for the test application. Supply air (0.2 m³/s), extracted from the railway tunnel, was provided by an axial fan and guided via DN250 pipes and fittings. Additionally, a dust filter was installed in the exhaust air duct upstream of the utility room. PM concentration was monitored within the supply air duct. Figure 4 shows the cabinet (utility room) in the escape gallery as well as the PM measurement devices inside (right), and outside the utility room (centre). The measurements started on 1st December 2018 and lasted for more than one year.

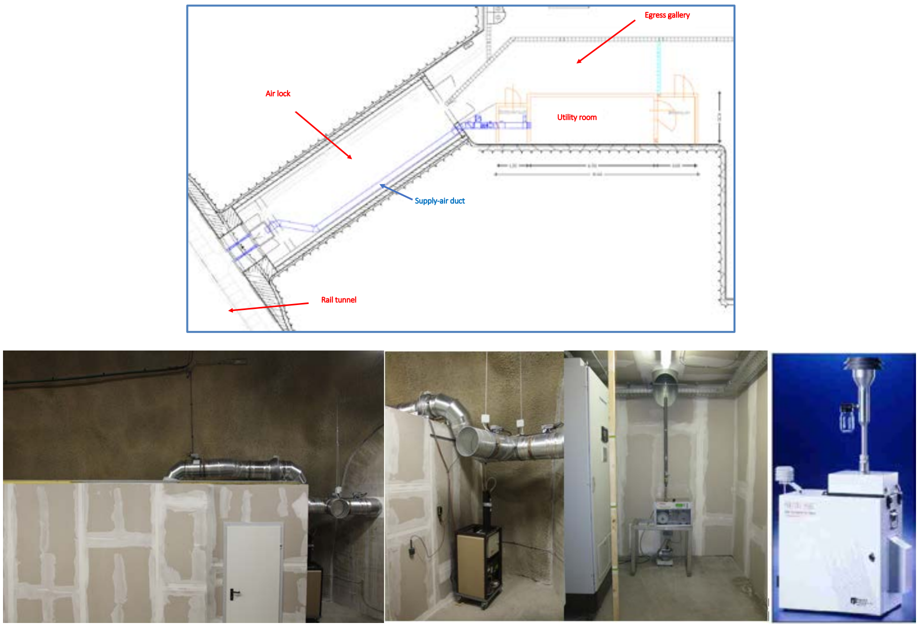

Figure 4: Test room within the Unterwald evacuation gallery – layout (above); utility room (left); PM measurement devices / TEOM, Sharp & PARTISOL (right)

3.2. PM measurement

Continuous PM concentrations were recorded by a TEOM 1400a and a Sharp 5030 monitor. While the TEOM monitor works on the basis of a micro-balance (using frequency changes as measurement signal) the SHARP monitor is a hybrid measurement system utilizing the principle of a nephelometer and a radiometer. Samples for dust composition analysis were taken with a PARTISOL PLUS 2025 sampler.

Figure 4 shows the installed TEOM device in front of the entrance to the utility room and the activated SHARP system installed at the supply air entrance into the utility room. Both systems were used without particle separators at the entrance of their extracting pipes in order to measure total suspended particles (TSP). Usually, wear effects on traction wire, breaks and rails are the main sources of particle emissions. The main particle size in this connection is PM10, and is responsible for 75% of the total particle mass.

Since the damaging potential of particles is dependent on their physical and chemical characteristics, an additional point of focus was the analysis of dust composition. Iron particles, with their magnetic attributes, have a particularly high potential for damaging electric equipment. In this connection, iron and alloy components could be expected to be the main component of chemical species within the dust. Figure 4 (right hand side) shows the PARTISOL particle sampler. In total, 32 filters with 24h sampling time were used.

3.3. Other parameters

The parameters monitored in the tunnel tube were air speed, temperature and humidity. The air speed and direction indicated indirectly the direction of the driving train (as well as the number of trains). Problems occurred in cases where trains from both directions met in the tunnel or where trains arrived within a very short time interval. In such cases no clear identification was possible and the data had to be dismissed. In order to aid differentiation of the various train types, a video-monitoring system was installed next to the tunnel portal. Although freight transport was dominated by container transport, there were also open wagons transporting bulk freight (e.g. iron ore, gravel) which caused very high particle concentrations in the tunnel air.

As humidity plays an important role in dust emissions, a meteorological station was installed near the portal tunnel for recording precipitation.

4. RESULTS

Apart from wear effects, type of freight and how it is transported (type of wagon) are also key factors in particle emissions. Since the Schoberpass line is heavily used by freight trains, the latter have a clear influence on results. It can also be noted that the measured concentrations also varied depending on the train type, train speed and on weather conditions. Train type was monitored via the installed video cameras at portal site, train speed was not directly recorded, but the influence was given due to the recorded tunnel air velocity.

4.1. PM emissions

Although PM monitoring was performed by certified PM monitors, the different measurement principles employed, as well as the existence of different measurement locations, resulted in differences in the measured values. In order to evaluate this effect both systems were employed in parallel over a duration of 18 days. However, it has to be mentioned that the measurement locations differed. While the TEOM monitor is upstream of the supply air entrance into the utility room (roughly 4 m), the SHARP monitors the air already inside the utility room. Apart from this, no further obstacles or filters were present.

Figure 5 shows the comparison of TEOM and SHARP measurements on the basis of daily mean values measured over the duration of 18 days. Except for two days, the agreement of the values is between +/-25 % (which is the accuracy level according to [7]). The higher differences in % are observed at times with low concentration levels.

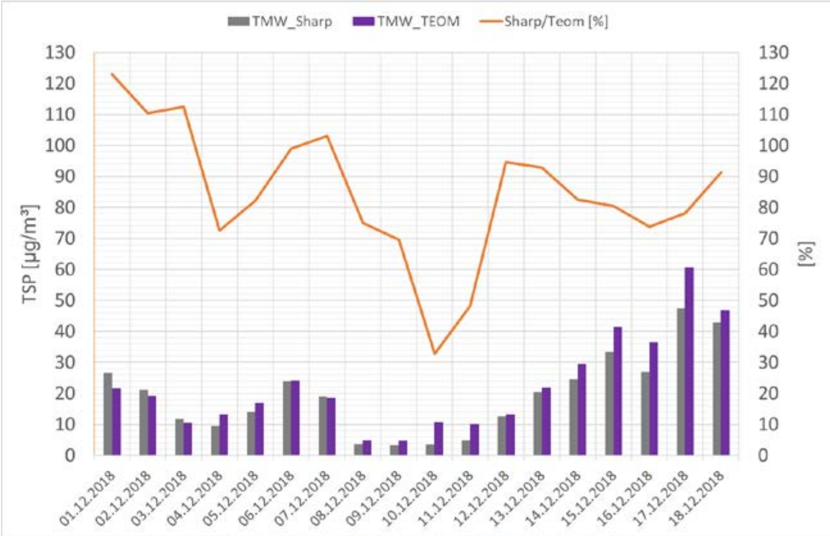

Figure 5: Comparison of TEOM and SHARP measurement systems

4.2. Emission factors

4.2.1. Methodology

Transforming measurements into appropriate emission factors calls for a clear methodology. The main problem here lies in the fact that while the measurement signal captures what happens in a tunnel due to the passage of a train, there is always a time lag between PM generation and monitoring. From the measurements, it can be assumed that the train speed is around 20 to 25 m/s while the air speed rarely exceeds 4 m/s and rapidly decays to < 1 m/s, depending on the ambient conditions. In addition, the measured value is an average value over a defined sampling time, ranging from a few seconds to several minutes.

It can be assumed that the rapid increase of the PM concentrations up to peak value is due to a passing train, while the subsequent decay is strongly influenced by the air speed in the tunnel. In order to come up with emission factors, the following approach based on the maximum increase of PM concentration Δm_{conc}, i.e. the time of first increase to peak value Δt and the average air velocity within the tunnel system v_{tunnel_avg} has to be determined [8]. If all parameters are known and allocated to single train passages, the emission factor (EMF) can be calculated based on equation (1).

$$EMF_{peak} = \frac{\Delta m_{conc} * A_{tunnel} * v_{tunnel\_avg} * \Delta t}{l_{char}} \quad [\frac{\mu g}{km}] \tag{1}$$

Figure 6 shows the graphical depiction of the evaluation regime used.

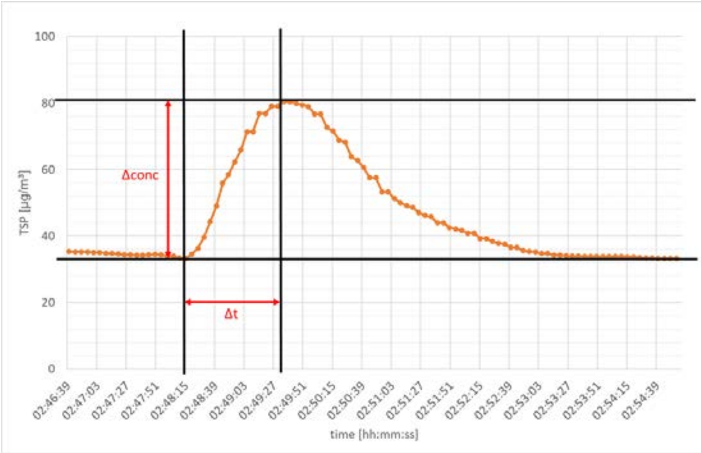

Figure 6: Concentration – time curve for a train passing the measurement location inside the tunnel

4.2.2. Factors

The methodology employed results in the emission factors as shown in Table 1. A distinction was made in terms of passenger and freight trains. With respect to passenger trains, a further distinction was also made in terms of long-distance trains (IC, EC, NJ) and regional trains (R, REX). Freight trains were subdivided mainly in terms of transport distance (trans-European, long-distance and regional), and also in terms of 'rolling highway (ROLA)' and empty trains (LZ). However, as some of these categories had only a small number of samples, there is often a large difference between mean and median emission factor values. In general, it was found that for freight trains non-exhaust emissions are higher by a factor of 4 compared to passenger trains. Trains with open freight cars, e.g. for the transport of iron ore or gravel, cause the highest emissions.

Table 1: Emission factors of different train types

	train-movements	emission-factor (avg.)	emission-factor (median)		train-movements	emission-factor (avg.)	emission-factor (median)
	#	[g/km]	[g/km]		#	[g/km]	[g/km]
total	1576	1.69	0.48				
passenger trains	803	0.62	0.26	**freight trains**	702	3.03	1.15
R	297	0.34	0.14	ROLA	29	2.42	0.86
REX	48	0.43	0.27	trans european	32	2.10	0.61
EC	160	0.63	0.35	long distance	423	3.41	1.34
IC	232	0.72	0.38	regional	201	2.69	1.15
NJ	55	1.10	0.40	LZ	54	0.51	0.18

4.3. Chemical analysis of dust composition

While the quantity of dust is one important parameter, its chemical composition is also significant in that it has a strong influence on maintenance and life-cycle costs. Depending on the chemical species, different filter materials are required. Quartz filters were used to analyse salts, and cellulose filters were used for heavy metals. Figure 7 shows the results from 5 filter samples, with a sampling time of 24 h each. Roughly 40% of the mass can be allocated to salts, while the remaining 60% are metals. In terms of metals, iron dominates, with 45% on average, followed by aluminium with 10%. However, when looking in detail, one needs to note that aluminium is already a big part of the background (see [1]), i.e. already in the air transported into the tunnel. Some samples contain non-neglectable mass fractions of titanium, chrome and zirconia. Such elements are used in certain alloys to enhance hardness and preventing abrasion effects.

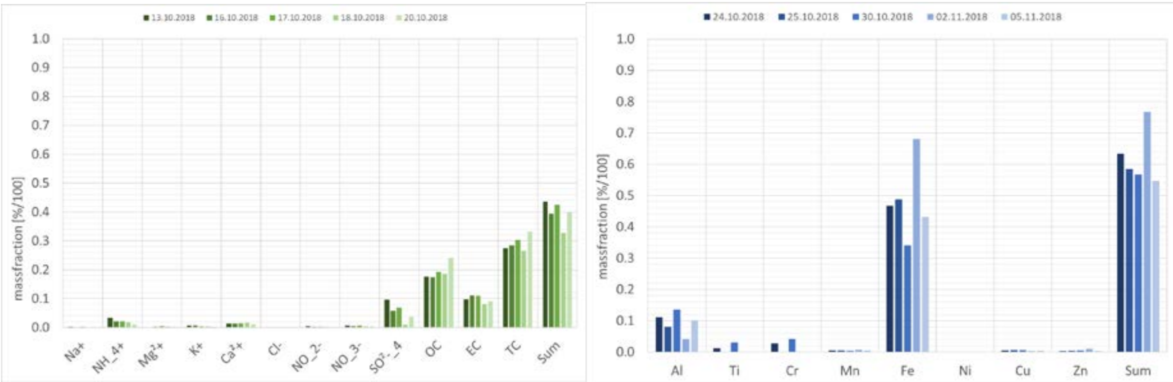

Figure 7: Results from chemical analysis – quartz filters (left); cellulose filters (right)

4.4. Filter lifetime

Owing to the high dust loads in tunnels, the air employed in cooling the equipment in utility rooms needs to be filtered. Filter life is now an essential parameter in planning maintenance intervals – and in overall system costs. Filter lifetime may in fact vary by several months, depending on in-tunnel particle concentrations.

The test installation in the tunnel Unterwald was mainly designed for performing durability tests on filter elements. In order to get some idea of the required service intervals, a so-called F7 stage filter was installed and exposed to the tunnel air. The main parameter which provides reliable information on filter dust load is the backpressure. This parameter was thus monitored and the lifetime of the filter was then defined as a function of the volume flow rate. Table 2 shows the expected filter lifetimes for two typical flow rates. While an air flow rate of 0.2 m³/s was required in the tunnel Unterwald, the same filter unit is used with an air flow rate of 1.0 m³/s in the KAT. Assuming the PM concentrations are more or less in the same range, the expected filter lifetime is between 4.5 months in the KAT and 21 months in the tunnel Unterwald. Of course, as the PM concentration in longitudinally ventilated tunnels rises with tunnel length, the numbers given here may only be taken as rough indicators.

Table 2: Expected filter lifetimes - Unterwald Tunnel and KAT

Tunnel	Air volume flow [m³/s]	Expected filter lifetime [months]
Unterwald tunnel	0.2	21
Koralmtunnel	1.0	4.5

5. SUMMARY AND CONCLUSION

One key factor behind equipment durability in railway tunnels is exposure to tunnel air dust load. Thus, as a form of protection, equipment is either located in dedicated utility rooms or in closed cabinets. Both of these need to be cooled. This is very often done by ventilation using tunnel air. Hence, air filtration is required, which in turn needs to be maintained.

The wear effects of rails, wheels, breaks, catenary systems, etc., as well as the dust from transported goods, are the main sources of particle emissions. Measurements were performed as part of a pilot project in a railway tunnel in order to obtain preliminary results with respect to the quantification of dust loads and filter lifetime. In total, more than 2,000 train movements were analysed. Numerous parameters, such as train speed, loading systems, weather conditions, precipitation, etc. were monitored. Due to the large variety of trains passing through the tunnel, and the pilot character of the project, the emission factors that were finally derived are subject to a large degree of uncertainty and should be taken as being nothing more than indicative. Nevertheless, it can be concluded that emissions from freight trains are in general 4 times higher than those from passenger trains. Bulk freight transport in open cars entails the highest emissions while the short regional passenger trains exhibit the lowest emission levels. Chemical analysis of the samples came up with a mass fraction of 60% related to metals – of which iron is the dominating component.

The main objective of the tests was to investigate the lifetime of dust filters and their components, as employed in utility room venting applications in long rail tunnels in Austria. It was found that, depending on the air flow rate required for cooling, the lifetime of the F7 stage filters investigated was between 4 and 20 months, assuming in-tunnel PM concentrations similar to those measured in the pilot project.

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