# DIFFUSE PM10 EMISSION FROM CONSTRUCTION ACTIVITIES

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## ABSTRACT

*Diffuse PM10 emissions are a main source of high PM10 concentrations in urban as well as in rural areas. However the knowledge of the source strength of such emissions is not easy to be determined. In order to improve the data base on emission factors for such sources on-site measurements of PM10 were adjacent to a stone quarry as well as in the ambient air of the Tradenberg tunnel during its construction. A typical fleet of construction machinery was applied to both areas. The air pollution measurements were compared to the PM10 emission factors, calculated using the mathematical models proposed by guidelines Austrian and German guidelines for the calculation of emissions from storage, transhipment and transportation of bulk materials. Because of the high deviation between calculated and measured ambient air pollution, it can be considered that the values given by guidelines strongly overestimate real world situations.*

***Keywords:*** *Diffuse PM10 emission, stone quarry activity, transportation of bulk materials, PM10 emission factors*

## 1. INTRODUCTION

The intention of the performed measurements is to verify the technical guidelines for the calculation of diffuse dust emissions and calculation of dust dispersion (BMWA, 1999). Therefore two measurement setups were designed. On-site measurements of PM10 close to a stone quarry, as well as in ambient air close to tunnel portal during construction, have been performed.

## 2. ESTIMATION OF DIFFUSE PM10 EMISSION IN A STONE QUARRY

### 2.1. Description of construction site

The researched stone quarry is situated in eastern Styria. Its location is characterized by the Naintsch gorge which is approximately 100 meters deep. The meteorological wind system is dominated by an alternated katabatic wind system. Its wind direction is determined by the trench and the wind speed is frequently low (96 % below 2.5 m/s), which causes a poorly aerated zone. The stone quarry itself is characterized by surface mining gathering lime, schist and silicate. Annually 500,000 tons are mined and processed to gravel and chippings.

After blasting, the material takes a route through various machines and processing steps before it ends on the loading space of a truck ready to deliver. The material passes through the following processing steps before being released to the consumer. A backhoe loads the bulk material on skips which transport it to pre-crushing. 20% of the material is directly forwarded and delivered, the remaining 80% is passed to the secondary crusher. From this 80% two-thirds are processed to a sub-base material for construction. The remaining third is reprocessed to special chippings. All of the inserted crushing and sifter equipment is completely enclosed and powered by two diesel engines (power-set), with the second engine in-place to handle peak loads. In case of bulk overspill the conditioned material is stored in the quarry area. On days where large quantities are transported, the trucks are loaded directly from these disposals via a wheel loader. Figure 1 shows the stone quarry from an aerial view as well as the loading zone. The machinery details are listed in Table 1. The quoted emission factors were taken from Pischinger (2000), the factor for load from EWE/BUWAL (2000).

**Figure 1:** Overview of the stone quarry and impression of the processing equipment

**Table 1:** Mining and conditioning Machinery

| machinery | type | year of manufactory | quantity | emission class | emission factor g/kWh | power kW | load % | hours per year h/a |
|---|---|---|---|---|---|---|---|---|
| drilling maschine | Montalbert 125 CL | 1996 | 1 | AG 2 | 1.100 | 110 | 100 | 1500 |
| power set | CAT F 800 | 2000 | 1 | Stage I | 0.300 | 500 | 100 | 2125 |
| power set | CAT D 348 | 2000 | 1 | Stage I | 0.300 | 700 | 100 | 500 |
| backhoe | CAT 365 B | 2000 | 1 | Stage I | 0.300 | 400 | 50 | 2125 |
| skip | CAT 775 D | 2000 | 2 | Stage I | 0.300 | 550 | 50 | 1800 |
| wheel loader | Caterpillar 988 B | 1991 | 2 | AG 1 | 1.500 | 700 | 50 | 1800 |

### 2.2. Sampling campaign and methods

Between 30th August and 7th February continuous sampling was been carried out with standard air-quality monitoring equipment (low volume air sampler for PM10 – Tecora Sky Post) close to the stone quarry. The location of the measuring point was selected to be dominated by the activities in the stone quarry. The position near the gateway was selected because of the marked airflow out of the quarry into the Naintsch gorge. PM10 filters were sampling for 24 hours, deriving dust content gravimetrically. For about one month the filter changing rate was set equal to the operation time of the quarry. Figure 2 shows the chosen position at cadastral survey and the used PM10 sampler.


**Figure 2:** Position and equipment of the measurement site

To analyse and appraise the measured PM10 concentrations, the emissions for each day of the measurement period were calculated. To compare emissions with dust dispersion concentrations the application of dispersion modelling is necessary. In this study the GRAMM and GRAL (Öttl, 2000) were used to compute the PM10 concentrations.

The used model has been developed at our Institute since 1999. It has been specially designed to have a reliable dispersion model for calm wind conditions. It consists of two main modules:

1. The prognostic wind field model GRAMM used for analysing stationary wind fields, serving the pollution dispersion in complex terrain or in build up areas.
2. The dispersion model GRAL developed for specific dispersion situations, both in calm wind conditions (the occurrence of large horizontal eddies) and from tunnel portals (effect of the jet streams).

The analysis of wind fields with GRAMM offers the advantage to take into account dynamic effects in a realistic manner. GRAL can simultaneously calculate line sources, area and point sources as well as tunnel portals. The quality assurance is documented by publications in international journals and presentations at international conferences. In this way, model development and validation undergo a rigorous scientific control. The validation is performed on the basis of field experiments and air quality measurements. The results of validation work has been published by Almbauer (2000), Öttl (2000, 2001, 2002, 2003, 2004 and 2005) and Anfossi (2005).

### 2.3. Results

First reviews of the measurement results show a clear connection between the activities in the stone quarry and the PM10 impact at the measurement location. Naturally all effects are swayed by rainfall but there are clearly marked differences between weekend and working days PM10 levels. On weekends the average PM10 level during the measurement period is 15 $\mu g/m^3$, for a working day it is rises up to 24 $\mu g/m^3$. This is leading to a PM10 annual average value of 22 $\mu g/m^3$. This scale of PM10 concentration increase is in the range of the published measurement data from Grabowski (2007). The analysis of the measurement period with equal changing rate to operation time show similar results. On weekends the differences of PM10 level between 7 am to 5 pm and the rest of the day is on average approximately 4 $\mu g/m^3$ - on working days it amounts to 16 $\mu g/m^3$. On days with rainfall, it is not possible to find a relationship, especially when it wasn't raining for the whole day. Figure 3 shows the differences between the operation and down-time periods.

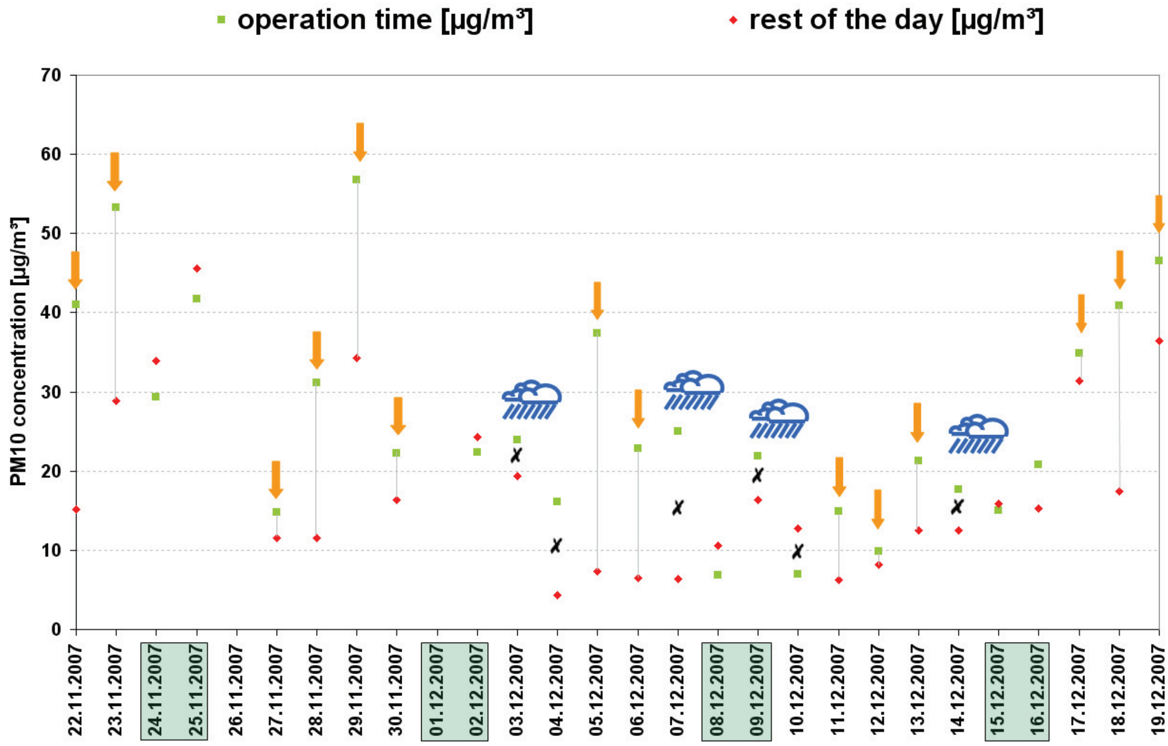


**Figure 3:** Difference in PM10 concentration level between operation time and the rest of the day. The data marked with an x were excluded from analysis because of rainfall, the ones marked with an arrow are the available datasets for weekdays

Because of these differences in concentration levels it's clear that the PM10 levels are strongly influenced by the activities in the stone quarry. For further calculations with GRAL the weekend average of 15 µg/m³ is used as background concentration.

All further analysis of the data takes the calculated emission rates into account. For emission calculation the technical guideline of BMWA (1999) were used. Only the calculation of the PM10 emissions from the blasting periods were based on US EPA AP42.

**Table 2:** Emission factors used for the calculation of emission rates from the stone quarry

| Process | emissionfactor TSP | emissionfactor PM10 |
|---|---|---|
| blasting [kg/basting/drill hole] | 2.70 | 1.41 |
| driving activity skip [g/km] | 604.50 | 151.13 |
| driving activity backhoe [g/km] | 593.00 | 148.19 |
| driving activity trucks [g/km] | 746.00 | 186.50 |
| driving activity load wheeler [g/km] | 535.00 | 133.75 |
| pick up wheel loader [g/to] | 14.65 | 3.66 |
| dumping wheel loader [g/to] | 7.67 | 1.92 |
| pick up backhoe [g/to] | 28.06 | 7.01 |
| dumping backhoe [g/to] | 14.69 | 3.67 |
| dumping skip [g/to] | 4.02 | 1.01 |
| dumping band-convayor [g/to] | 1.15 | 1.15 |
| dumping trucks [g/to] | 7.67 | 1.92 |

When considering the ambient measurements and calculated emission rates together, it is clear that there is a close connection between measured PM10 level and the calculated emissions from blasting, processing and transport. It appears that digging and conditioning activities (except blasting) have a low influence on the PM10 measurement. Figure 4 shows the trend between calculated emission amount, measured PM10 concentration and modelled PM10 concentration (GRAL).

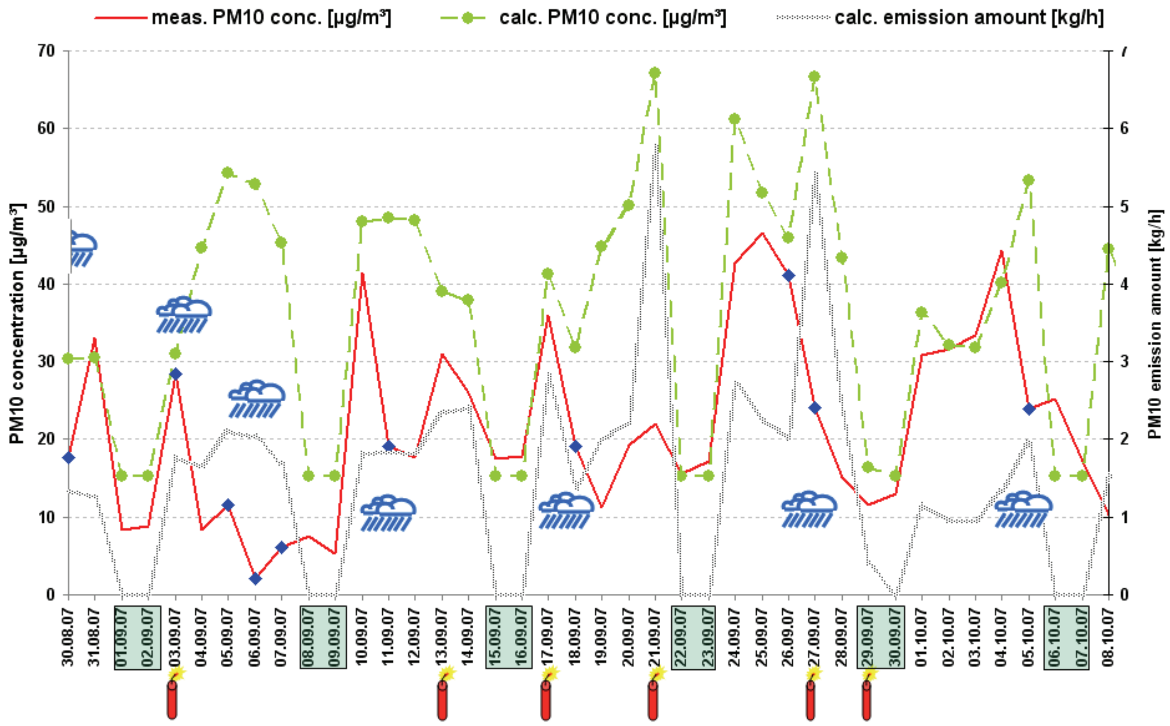


**Figure 4:** Illustration of calculated emission rate, measured PM10 concentration and modelled PM10 concentration (GRAL). Below the x-axis the days with blasting activities are marked

Comparing the measured PM10 concentration with the calculated ones at the point of measurement, it is demonstrated that the model results are considerably higher than the monitored concentrations. Statistical evaluation shows that days without rainfall are overestimated by 33% and those with rainfall nearly by 50%. As it is assumed there are 95 days with rainfall during a year, this could lead to an overestimation of concentration level of 37%. Accepting the method of dispersion calculation with GRAMM/GRAL would require a reduction of the emission rates from BMWA (1999) to represent reality.

## 3. ESTIMATION OF DIFFUSE PM10 AND NOX EMISSION IN TUNNELS DURING CONSTRUCTION

### 3.1. Description of construction site

The Tradenberg tunnel is under construction as part of the S1 Wiener Außenring Schnellstraße in the north of Vienna. The geology is typical for the flysch zone in this area with mainly fractured sandstone, marl, silt and clay. The excavation method varies between traditional methods (hammer and bucket) in the rock with soft to medium resistance and drilling and blasting in hard rock.

A typical fleet of tunnel construction machines is applied with excavators equipped with backhoe buckets, ripper buckets and hydraulic breakers for mechanical excavation and a rocket boomer three-arm drill rig with basket for drilling and blasting. Because of the varying geological realities the specific consumption of explosives ranges between 0.04 and 0.64 kg/m³.

Excavation started in August 2007 and is planned to be completed within 11 months followed by lining, road and infrastructure works. When starting the sampling campaign, the tunnel had advanced 327m from the northern portal. The tunnel cross section is around 126 m². An average tunnel drifting of 4 m per day is achieved yielding around 600 – 700 m³ of loose bulk material to be handled every day. A blowing ventilation system (around 52.000 m³/h) is used to maintain the air quality in the tunnel in accordance with health and safety regulations. Additionally all machinery is equipped with diesel particulate filters.

### 3.2. Sampling campaign and methods

Between 10$^{th}$ and 16$^{th}$ December 2007 tunnel air sampling was performed continuously with standard air-quality monitoring equipment (high volume air sampler for PM10 (Digitel DHA 80) and ambient NOx monitor HORIBA Instruments Inc., Model APNA-360 NO-NO2-NOx chemiluminescence monitor). PM10 filters were sampled for 12 hours and dust content was determined gravimetrically. All necessary features have been implemented into a monitoring vehicle that was situated close to the portal located 20 m inside the tunnel (see Figure 5).

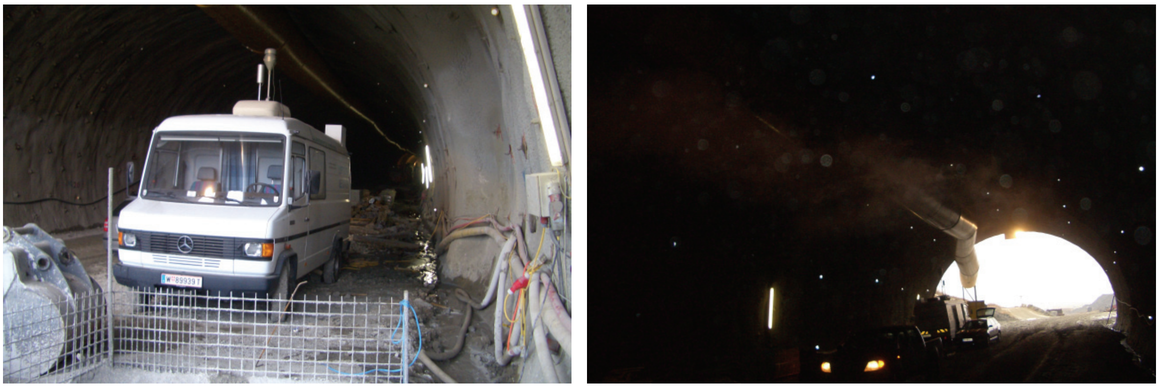

**Figure 5:** Location of the monitoring car equipped with PM10 high volume sampler and NOx monitor at the Tradenberg tunnel portal

### 3.3. Results

Table 3 presents the emission rate for PM10 derived from the monitoring during the sampling period. Additionally, an emission factor was calculated on volume of bulk material excavated and handled. The emission rate was rather constant corresponding to the steady tunnel excavation. For NOx, an average emission rate of 2.1 kg/d was determined with a higher daily variation according to the frequency of blasting and amount of explosives needed.

**Table 3:** Emission rate (mean value and range) for PM10 at the Tradenberg tunnel portal during construction, sampling period: 10$^{th}$-16$^{th}$ December 2007

| PM10 | mean | range |
|---|---|---|
| kg/d | 1.1 | 0.95 - 1.3 |
| $g/m^3_{exc}$ | 1.6 | 1.4 - 1.9 |

Generally, emissions during heavy construction operations have to be estimated by empirical equations as recommended by technical guidelines. In Austria the Federal Ministry of Economics and Labour has published a guideline in 1999 as a standard for estimation of diffuse dust emissions from heavy construction operations referring to international guidelines such as US-EPA AP 42 and VDI 3970 (BMWA, 1999).

Using the equations as recommended by BMWA (1999) PM 10 emissions were calculated for the tunnel construction operations taking into account the following processes:

- dust emissions from vehicles travelling on unpaved roads (Table 4)
- dust emissions from bulk material pick-up and dumping (Table 5)

**Table 4:** Calculated PM10 emissions from offroad traffic inside the tunnel. Calculation according to BMWA (1999)

| | **vehicles traveled per day** number/day | | | **weight** tons | | | **PM10 emission factor** kg/km | | | **emission** PM10 kg/day |
|---|---|---|---|---|---|---|---|---|---|---|
| | LDV | HDV | dumper | LDV | HDV | dumper | LDV | HDV | dumper | |
| drive in | 8 | 2 | 45 | 1.2 | 25.0 | 27.5 | 0.06 | 0.20 | 0.21 | 3.1 |
| drive out | 8 | 2 | 45 | 1.2 | 25.0 | 55.0 | 0.06 | 0.20 | 0.27 | 4.0 |

additional parameters: silt loading: 5%, moisture content: 10%, travel way per vehicle and direction: 300 m

**Table 5:** Calculated PM10 emissions for excavation, pick-up and dumping. Calculation according to BMWA (1999)

| **Process Equipment** | **variable** | **unit** | **excavating excavator** | **pick-up wheel loader** | **dumping wheel loader** |
|---|---|---|---|---|---|
| material property (low dust generation) | a | | 31.6 | 31.6 | 31.6 |
| picked-up / dumped quantity per bucket | Q | t/bucket | 3.0 | 7.2 | 7.2 |
| standardized emission factor | $q_{norm}$ | g/t | 49.3 | 31.8 | 31.8 |
| free-fall height | $H_{free}$ | m | 2.0 | 2.0 | 1.0 |
| effect factor $k_H$ | $k_H$ | | 0.7 | 1.0 | 0.4 |
| factor $k_{equip.}$ | $k_{equip.}$ | | 1.5 | 1.5 | 1.5 |
| bulk density | $q_S$ | t/m³ | 1.8 | 1.8 | 1.8 |
| local factor $k_u$ | ku | | 0.9 | 0.9 | 0.9 |
| standardized emission factor, corrected | $q_{norm\ korr}$ | $g/t_{mat}$*m³/t | 25.8 | 23.9 | 10.0 |
| emission factor | q | g/t | 41.8 | 38.7 | 16.3 |
| bulk material handled | | m³/d | 680.0 | 680.0 | 680.0 |
| emission total dust | PM500 | kg/d | 73.3 | 47.3 | 19.9 |
| emission PM10 (particle size factor: 0.1) | PM10 | kg/d | 7.3 | 4.7 | 2.0 |

As comparison in Table 6 shows a high deviation between calculated and measured PM10-emissions. The calculation exceeds the actual emission rate by a factor of around 20.

**Table 6:** Comparison of calculated and measured PM10 emissions

| **PM10 emission** kg/d | **calculation** | **measurement** | **relation calculation-measurement** |
|---|---|---|---|
| exhaust emissions, vehicles (without dumper) | neg. | | |
| exhaust emissions, maschinery (negligible because of particulate filter) | neg. | | |
| offroad emissions by vehicles travelling on unpaved roads | 7.0 | | |
| dust emission by transshipment of bulk material | 14.1 | | |
| blasting emissions (not covered by BMWA, 1999) | ? | | |
| **total** | **21.1** | **1.1** | **19.0** |

## 4. CONCLUSION

Both sets of measurements have demonstrated that the calculated emissions based on the technical guideline for calculating diffuse dust emissions (BMWA, 1999) causes overestimation of the pollution load. These two measurement campaigns indicate that it is necessary to reduce calculated emission factors to represent reality. Despite these results further investigations should be carried out to verify which procedures are properly covered by the guidelines and which are even not nearly comprehended.

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