PM_{10} non exhaust particle emissions – determination and quantification

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Abstract
Due to the current PM_{10} discussions, it is very important to understand PM_{10} emissions caused by traffic. PM emissions as a result of the combustion in the motor are well known. As motor technologies are getting cleaner, the influence of non exhaust PM_{10} particles on air quality, originating from abrasion and resuspension, raises. Currently there are several approaches to consider these emissions. However, the uncertainty of the quantification of these emissions is very high. Hence, it is necessary to improve the quality of the emission factors and to validate and verify them.

The aim of the project described here is to evaluate the influence of PM_{10} non exhaust emissions on air quality, as well as the validation of emission factors for vehicles.

Keywords *air qualitiy particulate matter, PM10 resuspension of PM10 vehicle emissions measurement tunnel*

Résumé
En raison des débats actuels concernant les émissions de PM_{10} causé par le traffic, il est nécessaire de mieux comprendre ce polluant. Les émissions PM_{10} produites dirèctement pendant la combustion dans le moteur sont bien comprises. Par contre l'influence des particules en suspension venant des processus d'abrasion et resuspension augmente. Actuellement il y a plusieures approches de mettre en compte ces émissions, mais qui sont peu sûrs. Pourtant une validation de ce polluant semble évitant.

C'est pourquoi l'objectif de ce travail est de déterminer l'influence des particules en suspension PM_{10} hors échappement sur la qualité d'air, aussi que proposer des facteurs d'émissions pour des véhicules.

Mots clé
qualité d'air particules en suspension, PM10, resuspension de PM10, émissions de véhicules, résultats de mesurage, tunnel

Definitions

PM_{10}	particulate matter with an aerodynamic diameter below 10 µm
$PM_{2.5}$	particulate matter with an aerodynamic diameter below 2.5 µm
NO_X	nitrogen oxides
PM_{10} non exhaust	PM_{10} originating from abrasion and resuspension
PM_{10} exhaust	PM_{10} originating from combustion processes
PC	passenger car
HDV	heavy duty vehicle

Methodology

The evaluation is based on detailed field measurements. These measurements were performed at different places. Not only pollutants like NO_X and PM_{10} were measured, but also traffic density, -composition and meteorological data like wind speed and wind direction were taken into consideration. Motorways as well as urban roads were investigated in open field and in a 10 km long motorway tunnel. Emission factors for vehicles can be derived from data, which were obtained in this tunnel measurement.

The employed measurement devices are able to detect concentration values in a time resolution of half hour-mean-values. For PM_{10} and $PM_{2.5}$ measurement TEOM® respectively Sharp® devices were in use. The working principles base upon a microbalance principle for TEOM® and a combination of a nephalometer and beta rays absorption for Sharp®. NO_X concentrations were detected by chemiluminescence.

The basic idea of this work is to derive emission factors and to quantify the proportion for PM_{10} non exhaust (abrasion and resuspension) based upon the measured differences of PM_{10} concentrations and calculated PM_{10} emissions. The measurement set up was based in the “windward-lee side” principle in open space and on the “entrance-out” principle in the tunnel. To define a dilution ratio, NO_X detection is necessary. Because of a good quality of simulated NO_X emissions from combustion processes within the motor, it is possible to calculate a dilution ratio by comparing simulation and measured differences of NO_X.

For a measurement set up in a tunnel, the dilution ratio can be derived directly from the known flow rates of the air (Rodler 2000). A comparison of simulated and calculated NO_X concentrations is a good indicator for the quality of the measurement data. Especially the measurements inside tunnels are very useful, because of a high concentration of measured PM_{10} biased only little by incoming air. These are preferable conditions for statistical evaluation.

With simulation software (NEMO, Rexeis, Hausberger (2005)) which was developed at the “Institute for Internal Combustion Engines and Thermodynamics” at Graz University of Technology, PM_{10} and NO_X emissions originating from combustion processes, can be calculated based on traffic data. There should be only little difference between simulated and measured NO_X concentrations, which is a good indicator for the quality of the measurement. The differences of PM_{10} are an indicator for the emissions originating from abrasion and resuspension. Emission factors for those PM_{10} non exaust emissions can be derived by a multiple regression analysis considering traffic data. In Equation 1 the mathematical model is described.

Equation 1: basics for the evalutaion of PM_{10} non exhaust emissions in tunnels

$$PM_{10\ldots non\ldots exhaust} = \frac{\left(PM_{10\ldots measured} - PM_{10\ldots background}\right)\cdot \dot{V}}{length \cdot time} - PM_{10\ldots simulated}$$

$\dot{V}$ flow rate through the tunnel

Length distance of the set-up from the entrance portal

Time time resolution of the measurement values

Complementary to this first approach, an additional evaluation of $PM_{2.5}$ concentration allows to analyse PM_{10} non exhaust emissions. Based on the fact that internal combustion in the motor produces particles with a diameter smaller than 2.5 µm, the difference between measured PM_{10} and $PM_{2.5}$ concentrations is an indicator for abrasion and resuspension.

Contrary to tunnels, background influences must be considered while evaluating open roads. For those measurement set ups the windward-lee principle is used. On both sides of the road PM_{10} and NO_x concentrations are detected whereas, depending on wind situations, one side represents the background, and the other the roadside. The NO_X detection is necessary to derive a dilution ratio. In Equation 2, the principle is described.

Equation 2: principle of a windward-lee measurement

$$PM_{10\ldots non\ldots exhaust} = \frac{NO_{X\ldots simulated} \cdot \Delta PM_{10}}{\Delta NO_X} - PM_{10\ldots simulated}$$

ΔNO_X NO_X difference windward and lee side

ΔPM_{10} PM_{10} difference windward and lee side

Results

Tunnel measurement

Road type: tunnel with two bores, unidirectional traffic, motorway, speed limit: 100 km/h

The Plabutschtunnel is a 10 km long motorway tunnel by passing the city of Graz. It has two tubes with unidirectional traffic. Because of its length a rather high air flow in the tunnel of 6-8 m/s leading in a volume flow of about 330 m³/s can be detected. The measurement set up was situated 5046 m after the entrance portal. Reference values from outside the tunnel were obtained by a nearby measurement station of the Styrian Government. The set up in the tunnel is shown in

Figure 1.

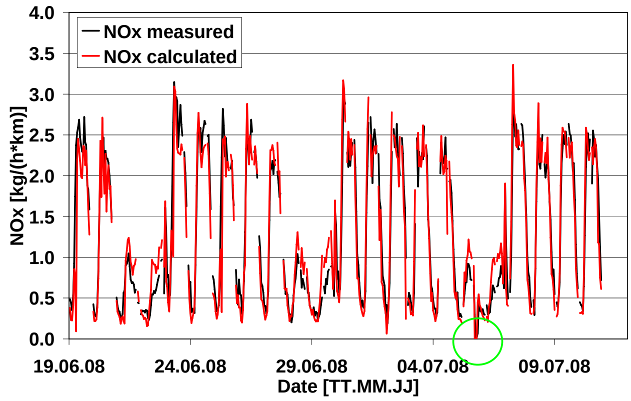
Figure 1: Measurement set up in the Plabutschtunnel

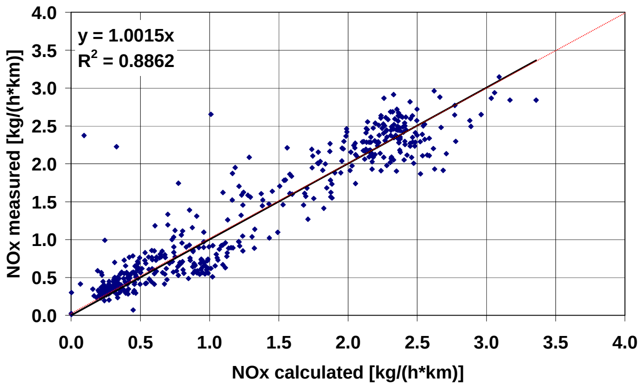
In Figure 2 the comparison between NO_X measurement and calculation is plotted.

It is evident, that both curves are nearly identical. The high peaks are significant for the rush hours during a day, whereas during the weekends the concentrations are lower. On 07-05-2008 (green circle), due to maintenance work the tunnel was closed for some hours. The calculated NO_X emissions are 0, because there was no traffic in the tunnel. As there are always concentrations of PM_{10} and NO_X in the tunnel, the measured NO_X values are a little bit higher than 0. Gaps in the graph are the result of some short breakdowns of the measurement devices.

The regression coefficient for calculated and measured NO_X is about R^2= 0.89, and the gradient of the regression line is 1.0, which shows a good correlation between measurement and calculation. The red dotted line in the graph represents the 1:1 line.

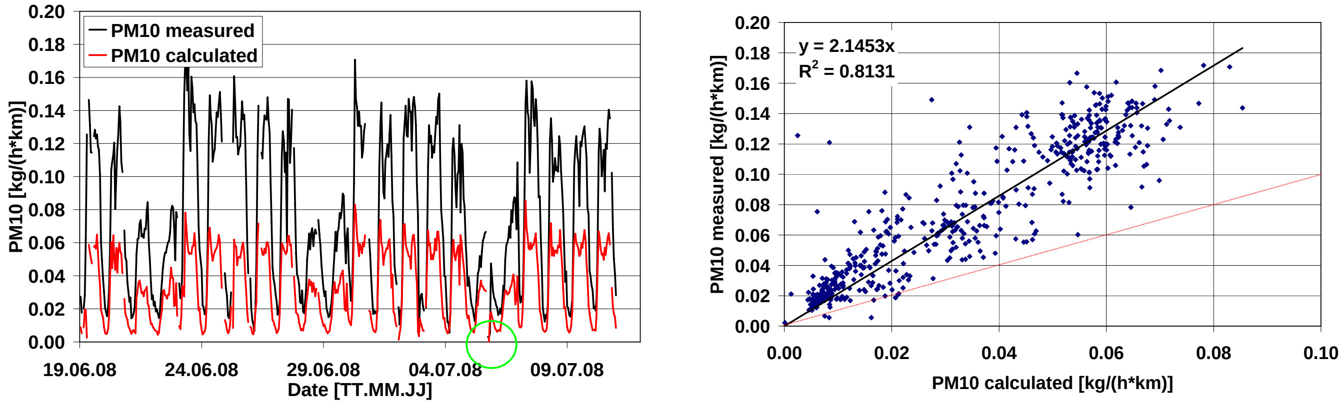
Figure 2: Comparison of measured and calculated NO_X emissions in the Plabutsch Tunnel





Contrary to the NO_X values described above, the graphs for PM_{10} show significant differences. Figure 3 shows the graphs for calculated and measured PM_{10} values and its regression. The tunnel closure on 07-05-2008 (green circle) is detected too.

Figure 3: Comparision of measured and calculated PM_{10} emissions in the Plabutsch Tunnel



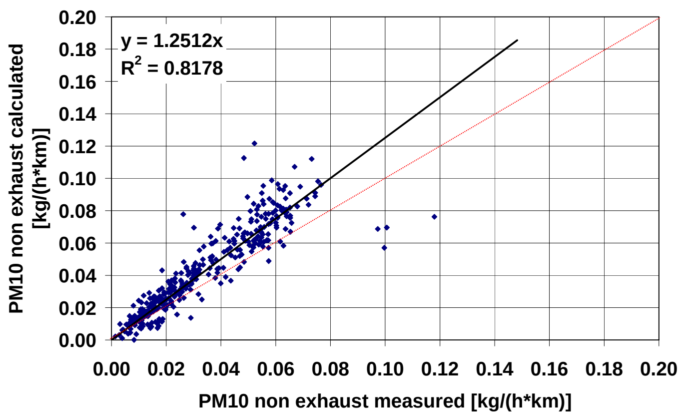
Calculated PM_{10} emissions have the same trends as measured ones, but the absolute values are about 40 to 50 % lower. The regression coefficient shows a R^2=0.81 which is a little bit weaker than the NO_X regression. This is caused by higher scattering in PM_{10} measurement. The red dotted line represents the 1:1 line, which stands for an equal division of measured and calculated PM_{10} emissions. The gradient of the regression line is about 2.1, which shows that the measured PM_{10} concentrations are twice as high as the calculated ones. As PM_{10} shows the same dispersion behaviour as a gas (NO_X), the difference between measured and calculated PM_{10} emissions are a measure for PM_{10} emissions coming from abrasion and resuspension. With a multiple regression these emissions can be classified into the vehicle categories passenger cars (PC) and heavy duty vehicles (HDV). The emission factors derived from the measurements are shown in Table 1.

Table 1: Emission factors PM_{10} non exhaust (comparison simulation - measurement)

category	Emission factor PM_{10} non exhaust [g/(km*vehicle)]
Passenger car (PC)	0.035
Heavy duty vehicle (HDV)	0.158

Simultaneous to the PM_{10} measurement, a $PM_{2.5}$ detection was made. With a second approach (cf. chapter 2), the differences between PM_{10} to $PM_{2.5}$ can be an indicator for PM_{10} non exhaust emissions too. A comparison of these emission factors is shown in Figure 4. The partial regression line shows a good R^2 of 0.8. The gradient of 1.25 represents a drift to emission factors carried out of the calculation. This drift is to be expected as non exhaust PM contributes also (but to a smaller extent) to $PM_{2.5}$ and measurement inaccuracies distort the results.

Figure 4: Comparison between PM_{10} non exhaust emission factors from measurement (PM_{10}-$PM_{2.5}$) and calculation (comparison of NEMO values and measured PM_{10} values)



In Table 2 the emission factors for PM_{10} non exhaust, coming out from the direct comparison of PM_{10} and $PM_{2.5}$ are shown.

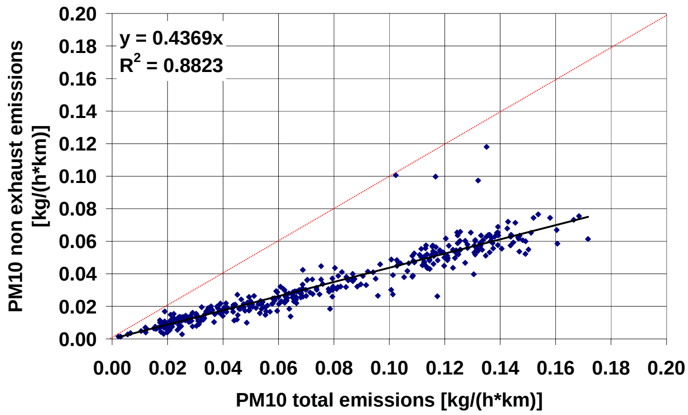
Table 2: Emission factors PM_{10} non exhaust (comparison PM_{10} – $PM_{2.5}$)

category	Emission factor PM_{10} non exhaust [g/(km*vehicle)]
Passenger car (PC)	0.026
Heavy duty vehicle (HDV)	0.142

Although there are differences concerning the way how to derive the factors, the results are comparable.

A comparison of PM_{10} emissions for abrasion and resuspension with the total PM_{10} emissions shows, that the fraction of PM_{10} non exhaust emissions represent some 40 % of the total PM_{10} emissions (cf. Figure 5).

Figure 5: Comparison between PM_{10} total emissions and PM_{10} non exhaust emissions

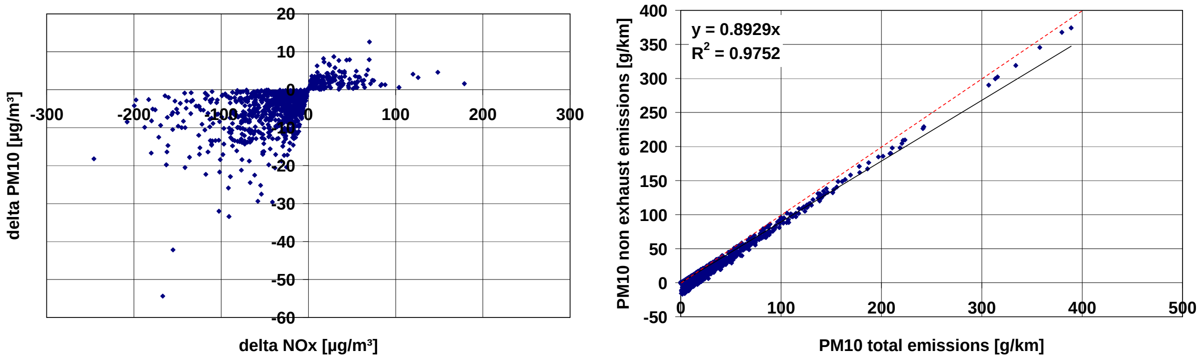


Field measurement motorway A2

Road type: feeder road with two lanes and two-way traffic, interurban, speed limit: 100 km/h

The feeder road Mooskirchen A2 is a ramp, operated with a two-way-traffic. It represents a typical interurban road with a speed limit of 100 km/h. On both sides of the road air quality measurement stations for PM10 and NOX were installed. In order to focus on traffic emissions only these data were filtered. It turned out that a ratio of NOX to PM10 emissions of > 1 is necessary in order to avoid bias from non traffic related PM10 contributions. Using this filter a background influence can be avoided. Correlation fo. Although the variation is rather high, emission factors for PM10 non exhaust can be derived by a multiple regression, using the evaluated traffic data. The fraction of PM10 non exhaust emissions is about 80 to 90 % of the total emissions (cf.Figure 6)

Figure 6: Correlation of delta NO_X and delta PM_{10} and comparison between PM_{10} non exhaust and PM_{10} total emissons



The fact that the evaluation was made during the winter period must be taken into consideration. Therefore the influence of seasonal cycles is evident which means that the annual mean of PM10 emissions is expected to be about 20 % lower than during the winter period.

PM10 non exhaust emission factors considering the winter period are presented in Table 3

Table 3: emission factors PM10 non exhaust (extra urban road)

Category	Emission factor PM_{10} non exhaust [g/(km*vehicle)]
Passenger car (PC)	0.051
Heavy duty vehicle (HDV)	0.273

Field measurement, city road

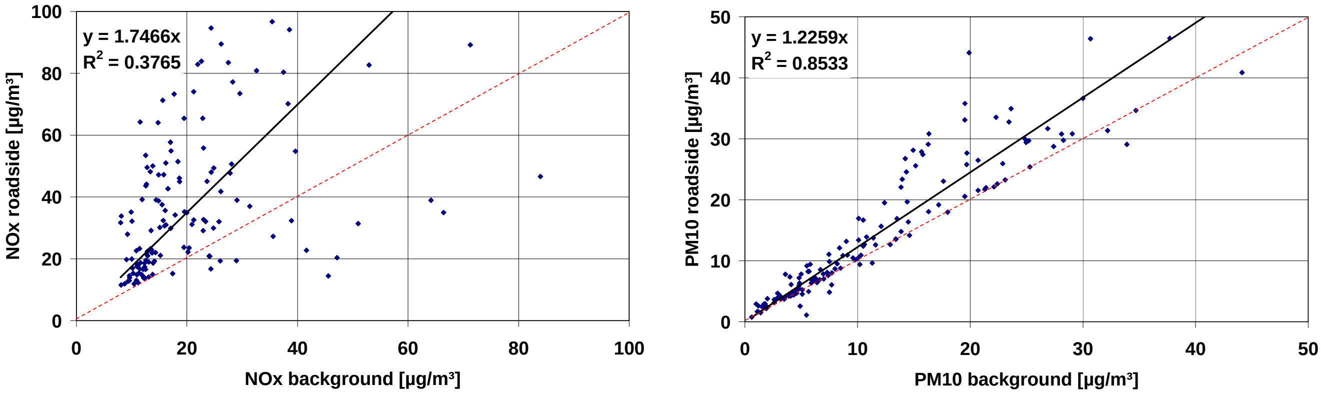
Road type: urban street with two lines and two-way-traffic, speed limit: 50 km/h

On both sides of main street in Klagenfurt, two air quality stations were installed. The measured concentrations of PM_{10} and NO_X were compared as described in chapter 0. The measurement set-up is shown in Figure 7. The yellow point marks the background station, about 120 m from the road (and during most situations at the windward side), the red point represents the roadside station, about 8 m from the leeward side.

Figure 7: Measurement set up in Klagenfurt; yellow=background, red=roadside

Contrary to the measurements in a tunnel, the meteorology in open areas is very important. A comparison of background and roadside values as described in chapter 0 is only possible, if the wind situation allows a clear classification of background and roadside. gives an overview about the regressions for NO_X and PM_{10} already filtered for appropriate wind situations.

Figure 8: Comparison of NO_X and PM_{10} values for background and roadside locations



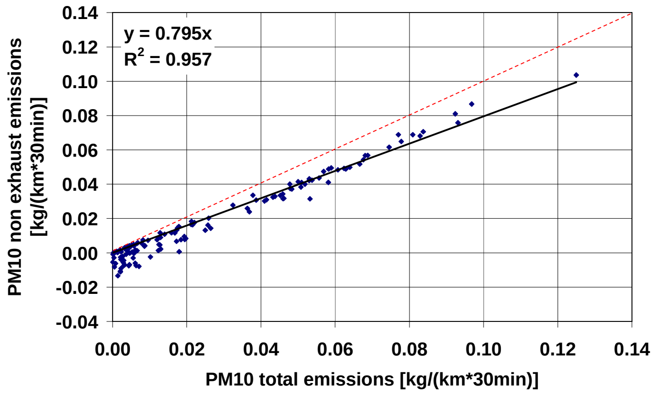
The regression coefficient for PM_{10} of R^2=0.86 is quite good while that for NO_X with R^2=0.38 is very weak. Nevertheless, kerb side NO_X is much higher in almost all cases. This is also indicated by the slope value of 1.7. This high value shows clearly the dominance of traffic in NO_X emission, whereas the direct traffic related PM_{10} contribution is much smaller. With the approach in Equation 2, considering the traffic and a multiple regression, PM_{10} non exhaust emission factors can be found as shown in Table 4

Table 4: Emission factors PM_{10} non exhaust (city road)

Category	Emission factor PM_{10} non exhaust [g/(km*vehicle)]
Passenger car (PC)	0.082
Heavy duty vehicle (HDV)	0.405

A comparison of PM_{10} total emissions and PM_{10} non exhaust emissions shows, that the proportion of PM_{10} non exhaust originating from abrasion and resuspension at urban streets is up to 80 % (cf: Figure 9).

Figure 9: Comparison between PM_{10} total emissions and PM_{10} non exhaust emissions



Conclusion and discussion

The contribution of road traffic to PM_{10} emissions is ambivalent, while PM_{10} from combustion of fuel can be quantified with a quite good accuracy, this is absolutely not the case for PM_{10} from abrasion and resuspension. In order to get a better understanding of PM_{10} non exhaust emissions a measurement program was set up. The investigations were performed in a road tunnel, an extra urban road and a city road. The three locations showed quite different results. Assuming that NO_X and PM_{10} exhaust emissions from vehicles can be estimated to a sufficiently good extent the PM_{10} non exhaust part can be derived from the comparison of the performed measurements.

The analyses from the three measurements sets yielded the following values:

Table 5: PM_{10} non exhaust emission factors

Site	PC [g/(km*veh.)]	HDV [g/(km*veh.)]	remark
Tunnel	0.035	0.158	
Tunnel	0.026	0.142	PM_{10} – $PM_{2.5}$
Extra urban	0.051	0.273	Speed limit: 100 km/h; winter time
Urban	0.082	0.405	Speed limit 50 km/h

The emission factor for PC in tunnels has the lowest value. The inner city examinations result in quite high emission factors. For HDV the situation is similar. While the tunnel situation result in the lowest values, city driving lead to the highest factors.

The fact that city driving results for PC and HDV in higher values than driving on extra urban roads can be attributed to the fact that resuspended particles in extra urban situations are more likely to deposit on other locations than on a road compared to city situations.

Compared to PM_{10} non exhaust emission factors in literature, the values derived by the above described measurements show similar values. In Table 6 emission factors out of literature for PM_{10} non exhaust are shown.

Table 6: PM_{10} non emission factors out of literature research

Site	Speed limit [km/h]	PC [g/(km*veh.)]	HDV [g/(km*veh.)]	reference
Tunnel	100	0.01	0.2	Lohmeyer et al (2004)
Motorway	100-120	0.022	0.200	Lohmeyer et al (2004)
Motorway	100-120	0.047	0.074	EMPA, Gehrig et al (2003)
Extra urban	100	0.022	0.200	Lohmeyer et al (2004)
Extra urban	100	0.051	0.272	EMPA, Gehrig et al (2003)
Urban	50	0.057	0.523	Lohmeyer et al (2004)
Urban	50	0.055	0.470	EMPA; Gehrig et al (2003)

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