ESTIMATION AND VALIDATION OF $PM_{2.5}$/PM_{10} EXHAUST AND NON-EXHAUST EMISSION FACTORS FOR STREET POLLUTION MODELLING

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ABSTRACT
This paper is collecting and comparing current available emission factor estimates for PM_{10} and $PM_{2.5}$ from emission databases, and validating these with street pollution measurements in Denmark, Sweden and Germany. Results from presently ongoing studies on PM emission factors in these countries have been included. All models consistently indicate that a large part (about 50% - 85% depending on the location) of the total PM_{10} emissions originates from non exhaust emissions. This implies that measured reducing the exhaust part of the vehicle emissions can have a very limited effect on ambient PM_{10} levels.

1. INTRODUCTION

The assessment of sources for local and regional PM (suspended particulate matter, measured in mass units) levels has high priority in the political and scientific discussions due to stringent EU limit values that have to be met and the association of PM to health effects and climate effects. For the design of efficient reduction strategies, e.g. environmental zones with traffic restriction a source apportionment of PM concentrations is necessary. This requires the estimation of correct emission factors for PM separated into exhaust and non-exhaust contributions, since technological improvement will typically only affect the exhaust part of the emissions.

This work aims at collecting and comparing the current available emission factor estimates for PM_{10} and $PM_{2.5}$ from emission databases, and validating these with street pollution measurements in Denmark, Sweden and Germany. Results from presently ongoing studies on PM emission factors in these countries have been included (Lohmeyer et al. 2004, Omstedt et al. 2005, NORPAC).

2. PM EMISSION CONTRIBUTIONS AND MEASURENTS

PM emissions from traffic can be divided into three main groups: **A)** Direct exhaust emissions that are predominantly found in the fine fraction ($PM_{2.5}$) and are documented in different emission databases (e.g. COPERT, UBA, TNO, CORINAIR, UK-TLR). **B)** Emissions from brakes wear that are to about equal amount present in the fine and coarse (PM_{10}-$PM_{2.5}$) fraction and correlate well with the direct emissions and other vehicle emissions e.g. NO_x. Most difficulties are connected with **C)** emissions from road abrasion, tyre wear and road dust re-suspension that are found partly in the fine fraction and mostly in the coarse fraction. This PM source is often less correlated with the exhaust emission due to an influence from 'external factors' as road condition (wetness, salting, sanding, road material) and use of studded tyres. A comparative analysis of PM measurements is shown in Fig. 1 plotting the monthly averages of PM_{10} and $PM_{2.5}$ normalised by NO_x for streets in Denmark, Sweden and Germany. Only the local street contributions are considered, i.e. the urban background was subtracted. Figure 1 shows the large variability of PM/NOx both between different locations and in a seasonal pattern with typically higher values during winter/spring.

During summer months (June-Oct.) the ratios for $PM_{2.5}$ are about 0.03-0.05 [g/g] and for PM_{10} about 0.06-0.15 [g/g]. The summer month ratio for PM_{10} is generally higher at two of the streets, LUET and HCAB. While for LUET the bad condition of the road surface is the likely reason no comprehensive explanation for the elevated values at HCAB could be found so far (higher HDV share, higher vehicle speed, road conditions).

Under winter/early spring conditions the use of studded tyres and salting leads to a dramatic increase of PM_{10} and $PM_{2.5}$ emissions, that are very depending on the local conditions at the measuring site and are more difficult to predict. Most pronounced increases are found for HORG (Fig.1), but all streets show some kind of increase. During periods when the roads are wet the coarse emissions are reduced while in the process of drying of the road surface elevated emissions are observed. An empirical model accounting for these effects was developed by Omstedt et al. (2005) and is briefly described in the following section.

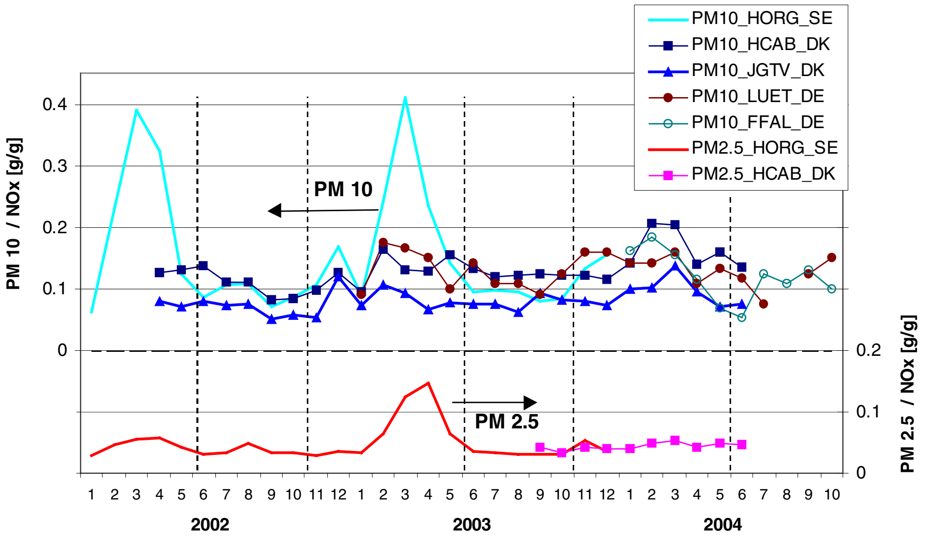

Figure 1: Ratios of the monthly averages of PM_{10} / NO_x and $PM_{2.5}$ / NO_x, street contributions only, i.e. the urban background was subtracted. HCAB= H.C. Andersens Boulevard, JGTV= Jagtvej, both in Copenhagen; HORG= Hornsgatan, Stockholm; LUET=Lützner Str., Leipzig; FFAL= Frankfurter Allee, Berlin. For all stations direct results from TEOM / Beta absorption methods are used without correction factors. Summer periods are marked.

3. SWEDISH EMPIRICAL EMISSION MODEL

A new model for calculation of emissions from vehicle induced non-tailpipe particles (PM_{10} and $PM_{2.5}$) has been developed (Omstedt et al., 2005). Road surface moisture is important for particle re-suspension of road dust and it is calculated every hour from energy and water mass balance equations. A road dust depot is built up from road wear (depending on the use of studded tires), frequency of road sanding or salting and re-suspension due to vehicle-induced turbulence and wash-off due to precipitation continuously reduce it. Other direct non-tailpipe vehicle emissions are accounted in the traditional way as mass emitted per vehicle kilometre. The particle exhaust emissions at Hornsgatan in Stockholm is 20-30 mg vkm^{-1}. This can be compared with the non-exhaust emissions mainly due to road wear of 205 mg vkm^{-1}. The model is compared with measurements, both from a narrow street canyon, Hornsgatan (Figure 2), and for an open highway, with good results. The model is able to account for the main features in the PM_{10} variability, especially the peak in PM_{10} concentrations in late winter and early spring that is commonly experienced in the Nordic countries where studded tires are used. An analysis showed that using a simple emission factor for PM_{10} or relating PM_{10} emissions to NO_x can not be used for prediction of PM_{10} concentration in the traffic environments studied here. In stead the suggested model describes variations in road dust emissions, the wetness of the road and how re-suspension interacts with these processes.

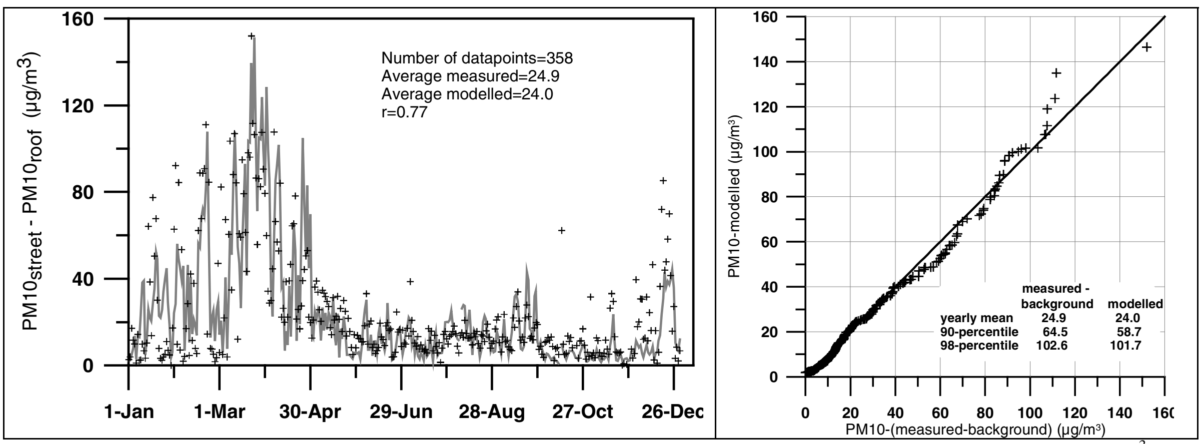

Figure 2: Comparison of measured (+) and modelled (solid line) daily mean concentrations of PM_{10} ($\mu g/m^3$) at Hornsgatan/ Stockholm for year 2000. The right figure shows the same results as the lefts but sorted according to rank.

4. EMISSION FACTOR APPROACH

4.1 'German' Method

For German conditions Düring et al., (2002) formerly used the modified US EPA model to determine the PM_{10} emissions. Lohmeyer et al., (2003) found in a research project, using the results of the roadside measurements of the regular German State Monitoring Stations, that this model over predicts the emissions significantly at motorways. This was confirmed by analysis of datasets from the B10 project (Lohmeyer et al., 2004). These findings together with results of Gehrig et al. (2003) led to the presently suggested German procedure (Tab.1). It can be seen, that the basic way of the US-EPA (2003) was completely abandoned, i.e. to determine the emissions by an equation, containing the parameters silt load of the street surface, weight of the vehicle fleet etc. Instead the new method follows the general procedure in the INFRAS emission factor handbook (UBA, 2004) for all exhaust emissions and the procedure of Gehrig et al. (2003), that is to provide the emission factors as a function of the so called "traffic situations". For a description of these traffic situations see Tab. 1 or UBA (2004).

Table 1: Simplified version of the proposed German PM_{10} emission factors for non exhaust emissions (last two columns) in dependence on the traffic situation. Values for a fleet mix with 4% heavy duty traffic and exhaust emissions according to (UBA , 2004) are given. For comparison the emission factors are given for specific streets applying the Danish and Swedish methods.

Method/ Traffic situation	average Speed [km/h]	Share of constant speed driving[%]	exhaust emiss. factor (fleet-mix) [mg/km veh]	non-exhaust emission factor (fleet-mix) [mg/km veh]	non exhaust emission factor* [mg/km veh] cars / vans	trucks
German method:						
motorways or outside cities	60-130				22	200
tunnel	60-100				10	200
city main road (HVS1)**	56	46	19	29	22	200
city main road (HVS2)**	44	52	20	41	30	300
city main road (HVS3)**	34	44	22	54	40	380
city main road (HVS4)**	28	37	26	66	50	450
city traffic lights (LSA2)**	24	32	28	82	60	600
city slow traffic (IO_Kern)**	17	23	32	118	90	800
Danish method for JGTV	45		66	57	50 / 70	230
Swedish method for HORG	40		37	205***		

* Values for good quality of the road surface, flat terrain and conditions of rain as usual in Germany.
** Speed limit = 50 km/h; ***annual average for the year 2000

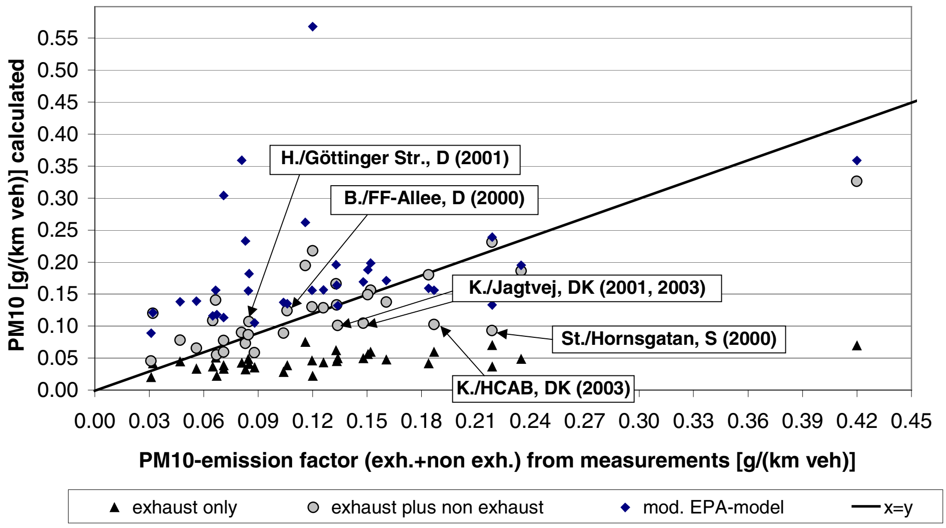

Figure 3: Total PM_{10} emission factors of roads (exhaust plus non-exhaust, calculated on the basis of information of Tab. 1, *German method*) and exhaust emission only, compared to total emission determined from measurements.

Fig. 3 displays the comparison of the emissions modelled according to the 'German' method (circles) to those, derived from concentration measurements at several streets. Quite substantial deviations can be detected. But it can be seen, that the formerly used modified EPA-model (diamonds) performs worse and that the exhaust emissions only (triangles) are considerably lower than the observed emissions. The 'German' method shows also fair agreement for Jagtvej (JGTV), while it considerable underestimates the elevated emission levels at Horngsgatan and HCAB.

4.2 'Danish' Method

The Danish approach presently used in the OSPM model was adopted from the UK-TLR method for the exhaust part and a method according to the EMEP CORINAIR Emission Inventory Guidebook (2003) for the non-exhaust part. The method has been validated with several roadside measurements and results from receptor analyses (Palmgren et al., 2003). Emission estimates from this method for Jagtvej are given in Tab. 1 showing a good agreement with the 'German' method for non exhaust emissions if traffic situation HVS3 is assumed. The Danish method seems to over estimate the exhaust emissions compared to the other two methods.

5. CONCLUSIONS

Three PM emission methods are described and compared here. In northern Scandinavian countries much higher PM_{10} emissions occur, especially during the spring due to the use of studded tyres in combination with the application of road salt and traction sand on the roads. The empirical model described in section 3 is able to reproduce this strong seasonal variation of non-exhaust emissions. This model requires detailed meteorological information in order to model road surface moisture and road dust depot.

However, the less pronounced annual variation for Danish and German conditions might allow the application of simpler methods based on constant emission factors. These methods represent an annual average emission and can not reproduce the seasonal variations. The German method was tested for a large number of streets. The variation of emissions factors in-between different street locations is large and can be well explained by the present emission model for most of the locations. The model is not applicable for conditions when studded tyres are used.

All models consistently indicate that a large part (about 50% - 85% depending on the location) of the total PM_{10} emissions originates from non exhaust emissions. This implies that measures relying on reducing the exhaust part of the vehicle emissions can have a very limited effect on ambient PM_{10} levels.

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