ESTIMATION OF THE "NON EXHAUST PIPE" PM10 EMISSIONS OF STREETS FOR PRACTICAL TRAFFIC AIR POLLUTION MODELLING

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INTRODUCTION

EC Council Directive 1999/30/EC sets a limit for the concentration of PM10 in the ambient air. Field measurements show an exceedance of this limit in the vicinity of streets (Lenschow et al., 2001), thus the problem has to be addressed and the reasons for the exceedances detected. However, PM10 pollution modelling in the vicinity of a paved street is deficient because the understanding and the modelling of the PM10 emissions are vague. For the vehicle fleet in Germany, there is comparatively good information on the contribution coming out of the exhaust pipe, but the quantification of the PM10 emissions resulting from abrasion of vehicle components and especially from the street surface is not satisfactorily solved. A critical examination by Venkatram (2000) of the AP-42 model, published by the US-EPA (1997) for paved street emissions, came to the conclusion, that there are lots of open questions.

In the year 2000 a project for non exhaust pipe PM10 emission modelling for paved streets in Germany was launched. The modelling was aimed to be applicable for operational purposes by state and city authorities and consultants and it should be based on easily available input parameters. Therefore the project consisted of a literature survey for identification of a may be already available model and of field measurements in heavily trafficked street canyons in Leipzig and in Berlin to check the performance of the model. A first proposal for possible modifications of the model to improve its performance for use in Germany was set up.

Based on this project, measurements of PM10 and NO_x in several streets of Berlin were analysed to determine the influence of precipitation on PM10 emissions. With the results, the newly proposed EPA-formula (EPA 2001) that contains a factor for the influence of rain should be proved and if necessary modificated regarding local circumstances.

PROCEDURE

Literature survey

The only operational models were found to be a model in Sweden (SMHI-model, Bringfelt et al., 1997) and the model of the US-EPA (EPA, 1997). For the EPA model, Rauterberg-Wulff (2000) showed the way it needed to be modified in order to describe the results of field measurements in Frankfurter Allee, Berlin. Landesumweltamt Brandenburg (LUA, 2000) modified it further for application in the State of Brandenburg.

Other countries for example Austria, UK, France were found to determine the PM10 emissions of streets from the exhaust pipe emissions of NO_x, soot or particles or were found to neglect the non-exhaust-pipe emissions.

The survey shows a large uncertainty concerning the PM10 emission of streets by dust re-suspension and abrasion and much complaints about the lack of a decent model is found. The performance of the EPA model is considered not to be suitable by an expert group in the US

(Venkatram, 2000), and the UK Airborne Particle Expert Group (APEG, 1999) considers the model not to be applicable in the UK. Nevertheless, as an operational model has to be provided to deal with the EC Directives and as there is presently nothing else than the EPA model, this model was used as the basis for the project. The EPA version of the model is

$$e = 0.56(sL)^{0.65}(W)^{1.5}$$

where *sL* is the silt load (PM75) in g/m^2, *W* is the average weight of a vehicle of the fleet in tons and *e* is the PM10 emission in g/VKT for days without rain, VKT means Vehicle Kilometre Travelled. The calculated emission contains all contributions, i.e. exhaust pipe emissions plus emissions by dust re-suspension and abrasion. No emission is supposed to occur during days with rain.

Recently (2001), the EPA made a proposal for a modified model that regards the emission during raining days half the emission during dry days.

Concerning the importance of the non exhaust pipe emissions it could be derived from PM10 immission data, found in the literature (Hueglin 2000) and own data, that the total PM10 emission in g/VKT of these streets was in the order of 2 (or even more) times the exhaust pipe PM emission.

Field Measurements in Leipzig and Berlin

Field measurements in the street canyon Lützner Strasse in Leipzig and measurements in the street canyon Schildhornstrasse in Berlin were done including determination of the silt load of the street, traffic counts (passenger cars and trucks), PM10 and PM2.5 concentrations including analysis of the PM components on the filters and PM10 and PM2.5 background concentrations.

Based on the results, emission of the streets caused by passenger cars and heavy trucks were analysed both for working days and weekends, showing e.g. the emissions of a truck being roughly 25 times the emissions of a passenger car in the Schildhornstraße. There, the problem of the modification of the emission factors by rain was also addressed. Astonishingly they were not significantly reduced during rainy days, a finding that needed further examination, see Lohmeyer et al. (2001).

MODIFIED EPA MODEL (SHORT TERM SOLUTION) AND APPLICATION

A first modification of the EPA model was done, dividing the emission e into exhaust pipe emission and emission by re-suspension

$$e = e_{\text{exhaust pipe}} + e_{\text{re-suspension}}$$

with re-suspension being defined as contributions from abrasion of street surface, abrasion of vehicle components (clutch, brakes, tyres) and emission of dust arrived on the street from outside the street and may be crushed by the tires

$$e_{\text{re-suspension}} = e_{\text{street abrasion}} + e_{\text{vehicle component abrasion}} + e_{\text{crushed outside material}}.$$

The exhaust pipe contribution is taken from the German Exhaust Pipe Emission Factor Handbook (INFRAS, 1999). Thus it is depending on the year under consideration, in contrary to the contribution by re-suspension.

The re-suspension contribution is considered as in the EPA-model to be depending on the silt load, the average weight of the vehicle fleet and the number of rainy days (according to Rauterberg-Wulff (2000), emission reduced to 50 % compared to dry days). The proposal of the formula is (Gamez et al., 2001):

$$e_{\text{re-suspension}} = a \cdot k \cdot (sL)^{0.52} \cdot W^{2.14} \left[\frac{1}{0.85} \quad (1 - 0.5 \cdot r) \right] - e_{\text{exhaust pipe}}(2000) \qquad (1)$$

as the measurements to fit the parameters in the above formula were made in the year 2000, i.e. the PM10 emission of a street is

$e = e_{\text{re-suspension}} + e_{\text{exhaust pipe}}$(year under consideration) with

$$e_{\text{exhaust pipe}}(2000) = \begin{array}{l} 0.016\ g/km\ \textit{for passenger cars (incl. light utility vehicles) and} \\ 0.492\ g/km\ \textit{for trucks} \end{array}$$

with:

e= emission factor [g/VKT]

a = correction factor for application in Germany [-]

k = basic emission factor of US EPA = 0.18 g/km

sL = PM75 fraction of the silt load of the street [g/m^2]

W = mean weight of a vehicle of the fleet [t]

r = share of rainy days (precipitation > 0.1 mm per day) during the year, for example r = 0.3 [-] for 122 days of rain per year.

Basing on the EPA formula (EPA, 1997), the above formula may as the EPA formula only be used inserting the mean weight of a vehicle of the fleet, it might not be used separately for cars or trucks. Free parameters have to be set distinguishing between

a) Streets inside cities
b) Streets outside cities and motorways
c) Tunnels, where we find lower emissions by dust re-suspension than outside tunnels

For all details see Lohmeyer et al. 2001.

As the model is mostly based on the EPA model, it still contains its problems (Venkatram, 2000). Only the annual mean value may be determined in the proposed way, values for single hours might contain even higher errors.

INFLUENCE OF PRECIPITATION

On the basis of the results of the 3 Berlin roadside monitoring stations Stadtautobahn, Schildhornstraße and Frankfurter Allee for the period 01.06.1999 until 31.12.2000 the daily mean values of the monitored PM10 concentrations were examined upon the influence of precipitation. On the average over the period, a reduction of 20% was detected for days with precipitation larger than 0.1 mm. Already a precipitation as small as 0.1 mm reduced the concentrations significantly. But no conclusions can be drawn from that information for the PM10 emission modelling, as the monitored concentration contains the additional street concentration as well as the background concentration and there additionally might be correlations between wind speed, wind direction and precipitation leading to a systematically different concentration during rainy days.

Therefore high frequency monitoring data for Schildhornstrasse for the period 13.11. until 15.12.2000 and for Frankfurter Allee for 26.07 until 19.10.1999 were used to estimate the hourly PM10 emission factors of these streets and the influence of precipitation. This was done using hourly values of the monitored additional street concentrations (monitored street concentration minus background concentration) and the NO_x emissions, calculated from the monitored traffic parameters. The evaluation was done on an hourly basis for the hours between 7AM and 9PM and for working days, as the emissions were too low for the nighttime hours, for weekends the data basis was not sufficient.

It has to be noted, that the period und consideration is not long enough for reliable conclusions and that there should be examined more than just 2 streets, but our findings from these data are nevertheless interesting (Schulze, 2002):

a) The average reduction of the emission factors during the hours of rain is 15 to 20 %, the maximum observed reduction was 50% in Frankfurter Allee, which shows larger reductions than Schildhornstrasse.
b) The reductions already occur during hours with a precipitation of 0.1 mm.
c) The reductions during hours with precipitation go on for 1 to 2 hours (up to a maximum of 7 hours) after the hour with precipitation
d) For Berlin we have an average duration of a rain event of 2 hours. That means a reduction of 15 to 20% takes place during the 2 hours of rain plus 2 hours afterwards, leading to a reduction of the daily emission during a day with rain of approximately 3%. That means the influence of rain in eq.(1) might be overestimated, and also the proposal of the EPA for the modification of their formula might be too optimistic.

But as mentioned before: more work needs to be done in this field as the data basis for these conclusions about the influence of rain is not sufficient.

OPEN TASKS AND MORE PROMISING IDEA FOR LONGTIME SOLUTION

At this moment, although we do not yet have enough data, instead of the model according to eq.(1) we propose to discuss a model for heavily trafficked paved streets including the following input parameters:

- Materials of the street surface (asphalt, for example, has a larger abrasion than concrete) instead of the silt load,
- State of the street (new, old, porous, smooth, rough, patched, cracked, weather beaten etc.) instead of the silt load,
- Driving pattern, vehicle speed, ADT, (weight of vehicles as it is already done), etc.,
- Local conditions of rain and humidity, but the above mentioned study seems to indicate, that this influence is comparatively small.

More work is needed as well as communication input from street maintaining civil engineers. More experiments have to be designed to determine the relevance of the above mentioned parameters and also to may be find new possible parameters governing PM10 emission. There is especially a lack of measurements at open country motorways with high speed driving patterns.

REFERENCES

APEG (1999): Source appointment of airborne particulate matter in the United Kingdom. Report of the Airborne Particles Expert Group, prepared on behalf of the Dept. of the Environment, Transport and the Regions, the Welsh Office, The Scottish Office and the Dept of the Environment (Northern Ireland).

Bringfelt, B., Backström, H., Kindell, S., Omstedt, G., Persson, C., Ullerstig, A. (1997): Calculations of PM10 concentrations in Swedish cities - Modelling of inhalable particles.

Swedish Meteorol. and Hydrological Inst., Norrköping, Sweden (Rep. number RMK No. 76).

Gámez, A.J., Berkowicz, R., Ketzel, M., Lohmeyer, A. and Reichenbächer, W. (2001): Determination of the non exhaust pipe PM10 emissions of streets for practical traffic air pollution modelling. Paper, presented at the 7th Intl. Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Belgirate, May 28-31, 2001.

INFRAS (1999): INFRAS im Auftrag des Umweltbundesamtes, Berlin: "Handbuch Emissionsfaktoren des Straßenverkehrs", Version 1.2, Januar 1999.

Lenschow, P, H.J. Abraham, K. Kutzner, M. Lutz, J.-D. Preuß and W. Reichenbächer (2001): Some Ideas about the Sources of PM10. Atmospheric Environment, 35, Supplement No. 1 (2001) S23 – S33.

Lohmeyer, A, and Düring, I. (2001): Validierung von PM10-Immissionsberechnungen im Nahbereich von Straßen und Quantifizierung der Feinstaubbildung von Straßen. Bericht des Ingenieurbüros Lohmeyer, Radebeul für Senatsverwaltung für Stadtentwicklung, Berlin und Sächsisches Landesamt für Umwelt und Geologie. Downloadable from www.Lohmeyer.de/Literatur/zusammenfassung_06_01.pdf.

LUA (2000): Vorgehensweise bei der Schwebstaubimmissionsberechnung nach Richtlinie 1999/30/EG. Entwurf des Referats I3 vom 21.12.2000, Landesumweltamt Brandenburg.

Rauterberg-Wulff, A. (2000): Untersuchung über die Bedeutung der Staubaufwirbelung für die PM10-Immission an einer Hauptverkehrsstraße. Bericht der Techn. Univ. Berlin, Fachgebiet Luftreinhaltung (Januar 2000).

Schulze, E.(2002): Räumliche und zeitliche Analyse kontinuierlicher Luftschadstoffmessungen in Berlin: Einfluss von Regen und Luftfeuchtigkeit auf die PM10-Emission und –Immission. Diplomarbeit am Inst. Für Geographie, Lehrst. Landschafts- und Geoökologie, TU Dresden. See also www.Lohmeyer.de/literatur.htm.

US-EPA (1997): AP-42, 5. Edition, Volume 1, Chapter 13, Section 13.2.1. Miscellaneous sources.

US-EPA (2001): www.epa.gov/ttn/chief/ap42/ch13/draft/d13s02-1memo_oct2001.pdf

Venkatram, A. (2000): A critique of empirical emission factor models: a case study of the AP-42 model for estimating PM10 emissions from paved roads. Atmosph. Envir. 34, 1-11.

Hueglin, Ch. (2000): Anteil des Straßenverkehrs an den PM10- und PM2.5-Immissionen - Chemische Zusammensetzung des Feinstaubes und Quellenzuordnung mit einem Rezeptormodell. NFP41/C4, Bericht Nr. 801.683.d

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