Determination of the “non exhaust pipe” PM_{10} emissions of roads for practical traffic air pollution modelling

A.J. Gámez[1], R. Berkowicz[2], M. Ketzel[2], A. Lohmeyer[1] and W. Reichenbächer[3]
[1]Lohmeyer Consulting Engineers, Mohrenstraße 14, D-01445, Radebeul, Germany
[2]National Environmental Research Inst., Frederiksborgvej 399, DK-4000, Roskilde, Denmark
[3]Senatsverwaltung für Stadtentwicklung, Brückenstraße 6, D-10173 Berlin, Germany

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1 Introduction

The first daughter directive of the EC air quality guideline (EC, 1999) sets an upper limit for the concentration of PM_{10} in the ambient air. The ”stage I” objective of the 24-hour limit value is 50 µg/m³, not to be exceeded more than 35 times a calendar year (approximately the 90-percentile), with an annual limit value of 40 µg/m³, both to be achieved by 1 January 2005. Field measurements show an exceedance of these values in the vicinity of roads (Abraham et al., 2001), thus the problem has to be addressed and the reasons for the exceedances found out. However, PM_{10} pollution modelling in the vicinity of a paved road is deficient because the determination of the PM_{10} emissions is 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 PM_{10} emission resulting from abrasion of vehicle components and especially from the road surface is not satisfactorily solved. A survey (Düring et al., 2001) shows that the US-EPA model (EPA, 1997) seems to be the only easily available operational model but it does not seem to be suitable for predicting PM_{10} emissions as there are large deviations between calculated and observed emissions (Venkatram, 2000). So that, better tools have to be developed for determining and predicting PM_{10} emission from paved roads. This paper shows measurements that have been made recently on several urban paved roads of Germany: Frankfurter Allee (Rauterberg-Wulff, 2000) and Schildhornstraße (Düring et al., 2001) in Berlin and several roads in Brandenburg (LUA Brandenburg, 2000). Using these data, the procedures and results of PM_{10} emission calculations are shown using backward dispersion modelling and alternatively NO_x as a tracer. Additionally, comparisons with results of the EPA formula are shown. The problem of the emission during rainy days is addressed and a first idea of what a better model might contain is enumerated.

2 Calculating and predicting PM_{10} emission from a paved road

Several authors have stated that the EPA model is not physically acceptable for paved roads (Venkatram, 2000; Gámez et al., 2001). Instead of the EPA model, we propose the following: to calculate the PM_{10} emission as the sum of all the emission incomes from all the primary PM_{10} sources as exhaust pipe, vehicle components (tyre, brake, clutch) wear, road abrasion and emission resulting from material entering the road via external sources (for example, dirt inputs, sanding processes…):

$$e = e_{exhaust\ pipe} + e_{vehicle\text{-}components\ \ wear} + e_{road\ abrasion} + e_{external}$$

This formula claims that the dust re-suspension mechanism subjacent in the EPA formula is unimportant on a paved road as the deposition speed of PM_{10} particles is much lower than the traffic-produced turbulent wind speed and the meteorological wind speed. Fragmentation of the larger particles into finer ones is not considered relevant, as the tyre-affected area is small compared to the turbulent-wake-affected area. The silt load then is not used. We presume that the traffic-induced turbulence has enough energy to dilute all the PM_{10} particles, so the PM_{10} part of the silt load is negligible compared to the emitted part. Therefore, the PM_{10} emitted is not directly related with the silt load. Several measurements show that the traffic-affected part of the lane has much less material than the part near the curb (Düring et al., 2001). That is why we suggest that the bigger particles are moved to the sides of the road where they are deposited, but not the smaller ones, which are removed by the wind because their low deposition speed, as stated before.

The knowledge of the emission factor of pollutants is basic to calculate concentrations in road canyons and also to predict them in order to make Environmental Impact Studies. Also, it is very important to have models for the emission of the pollutant, as they are essential to provide us with a better knowledge of the real emission process. For PM_{10} emission, the exhaust pipe contribution can be directly determined by measuring the flow rate and the concentration in the pipe. Nevertheless, this cannot be done for the important "non exhaust pipe part" of PM_{10} as it does not come from a confined source and the emission process cannot be easily simulated in the laboratory. Thus, different methods are needed for the determination of the non exhaust pipe part of PM_{10} emission. The methods used by the authors are described below.

3 Procedures used for determining the PM_{10} emission from field measurements

For determining the PM_{10} emission of a paved road, three alternative procedures are used here: backward dispersion modelling (sometimes also called inverse dispersion modelling), concentration scaling with NO_x as tracer and the EPA emission formula for paved roads.

3.1 Backward dispersion modelling

The widely used backward dispersion modelling can be applied if there are measurements of

- the background and roadside concentration of PM_{10} and
- the meteorological (wind) conditions.

Different dispersion models can be applied to calculate the emission of the street canyons studied here. IMMIS-Luft (see http://www.immis.de for information) was used for Frankfurter Allee in Berlin. For all other streets MISKAM (Eichhorn, 1995) was applied. It needs to be said that dispersion modelling cannot predict concentrations if emissions and meteorological data are not known.

3.2 Concentration scaling with NO_x as tracer

The less used concentration scaling with NO_x as tracer can be applied for calculating the PM_{10} emission provided there are measurements of

- the background and roadside concentrations of PM_{10}
- the background and roadside concentrations of NO_x and
- the traffic volume and the driving patterns (to determine the NO_x emission factors) on the road.

In this case the comparatively well-known NO_x emission of the road is determined from the traffic volume and the driving pattern and, for the period of time under consideration (from the whole monitoring period down to single hours) one simply states:

$$\text{emission}(PM_{10}) = \text{emission}(NO_x) \times \frac{\text{concentration }(PM_{10})}{\text{concentration }(NO_x)}$$

where concentration means additional road concentration, i.e. roadside minus background concentration. As the driving patterns of a road can only be determined with certain subjectivity, sometimes two reasonable driving patterns were used to estimate the NO_x emission. To use NO_x as a tracer, the meteorological conditions and the building configurations at the side of the road are not needed and that is a big advantage. For most German monitoring stations the NO_x concentrations are available. Thus from the operational point of view, the use of NO_x as a tracer is less time consuming than the backward dispersion calculations with MISKAM, as the flow field modelling in the built up areas on the basis of a digital building model did not need to be done.

3.3 The EPA model

As it was previously mentioned, the emission formula for paved roads developed from the Environmental Protection Agency of the United States is used for comparison in the following version:

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

where sL is the silt load in g/m^2, W is the average weight fleet in tons and e is the PM_{10} emission in g/VKT for days without rain, where VKT means Vehicle Kilometre Travelled.

3.4 Comments to the procedures

As the deposition speed of the particles is small and only the additional concentrations of the PM_{10} concentrations measured in the vicinity of roads are used, for our operational purposes the assumption that the behaviour of PM_{10} particles is similar to that of a gas may be allowed. Additionally, it is stated that the differences in the release mechanisms of particles and NO_x are not significant for the roadside concentration. We expect them to be reduced by the mixing mechanism of traffic-produced turbulence. Then, we assume that differences between the dispersion of PM_{10} and NO_x are negligible, thus the dilution between road and monitoring station for both pollutant is considered the same.
First and second procedures do not take rain into account. They give the PM_{10} emission of the road as it was in the time under consideration. Rain can introduce errors from two sources. First, the emission may be different because the tyre wear and the road abrasion can be affected by the existence of water in the tyre-road interface. Second, some particles may disappear from the PM_{10} range because of coagulation, making the calculated emission lower than the real one. But for operational purposes, we presently seem to have much larger problems with rain, as can be seen below.

4 Results

Below, results for the silt load, influence of rain and emission factors are given.

4.1 Silt loads for three roads in Germany

Table 1 displays the results of silt load measurements during a time limited monitoring phase done on three street canyons with heavy traffic in Germany. On the traffic lane, mean values between ca. 0,1 and 0,2 g/m^2 are found, the highest values on an old, patched up asphalt road with many cracks. The values might be considered to be random samples, accumulation effects as discussed in Sieker et al. (1988) are not respected in detail and nothing is known about the applicability of these values for other roads but, to the authors knowledge, these are the only recent measurements that deal with the problem of PM_{10} emission from German roads.

Table 1 Silt load (PM_{75}), found on three street canyons with heavy traffic in Germany. Due to the limited number of measurements, they may be not representative for the whole year. For more parameters, as composition of the silt load, average daily traffic (ADT) etc see the reports.

Name of road	**Silt load [g/m²]**				
	at curb	**on traffic lane**	**weighted mean**	**material road surface**	**state road surface**
Frankfurter Allee, Berlin (Rauterberg-Wulff, 2000)	0,42±0,17 *	0,16±0,09	0,2±0,07	asphalt	medium
Lützner Straße, Leipzig (Düring et al., 2001)	1,8±1 #	0,2±0,1	0,38±0,21	asphalt	old, patched, cracked
Schildhornstraße, Berlin (Düring et al., 2001)	2±1,3 #	0,09±0,05	0,16±0,09	asphalt	good

* on outer lane, used as parking lane during night   # at 0 - 25 cm distance from kerbstone

4.2 Influence of rain in calculated emissions

The definition of a rainy day, for example, via a minimum amount of precipitation per unit time is not clear. Nevertheless, several points can be addressed about the practical application for PM_{10} emission calculation: the EPA considers that emission is zero during rainy days (Kuykendal, 2000, private communication); Rauterberg-Wulff (2000) deducts, from a three-months monitoring phase at Frankfurter Allee in Berlin, that the emission is reduced to one half during rainy days; Düring et al. (2001) find, for a four-week monitoring phase in Schildhornstraße in Berlin, no reduction of PM_{10} emission on days with rain. The authors conclude then that further measurements are needed as a basis for an understanding of the physical processes while rain appears.

4.3 PM_{10} emission factors for several roads in Germany

The PM_{10} emission factors for the German roads under study are displayed in **Table 2**. The variation is large, ranging from 0,02 to 1 g/VKT for the non exhaust pipe part. The emission factors found with the EPA formula differ by a factor of ca. two when compared to the other two methods. Moreover, it does not predict the large variations in the emission factors between Lützner Straße and the other roads.

Table 2: Results for PM_{10} emission factors in (g/VKT) for roads in street canyons with heavy traffic in Germany. Due to the limited number of measurements, they may be not representative for the whole year. For more parameters as driving patterns, average daily traffic (ADT), truck content etc… see the reports.

Name of road	Backward Disp. Modelling		NO_x as tracer		EPA formula
	total	non exhaust	total*	non exhaust	total*
Frankfurter Allee (Rauterberg-Wulff, 2000)	ca. ½ of values of EPA formula	-	0,06 to 0,14#	0,02 to 0,10#	0,15 to 0,24
9 roads in Brandenburg (3 for NO_x) (LUA, 2000)&	0,14 to 0,23	0,11 to 0,17	0,12 to 0,16	0,08 to 0,11	silt load unknown
Lützner Straße (Düring et al., 2001)	0,49§ to 1,1§	0,45§ to 1§	NO_x-conc. unknown	NO_x-conc. unknown	0,29 to 0,60
Schildhornstraße (Düring et al., 2001)	0,089 to 0,094	0,044 to 0,059	0,079 to 0,095	0,034 to 0,060	0,17 to 0,23

§not representative because of short monitoring period #deducted from values in the report &reduced quality because of weak information about background concentration

5 Conclusions

The survey of the available models for determination of PM_{10} emission factors show that there is a great variation depending on the method used. Our idea is to develop a model not dependant on the silt load, as this parameter does not seem to be reasonable. At this moment, although we do not have enough data, we propose to discuss a model with the following input parameters:

- Composition of the road surface (as, for example, asphalt has a larger abrasion than concrete)
- State of the road (new, old, porous, smooth, rough, patched, cracked, weather beaten etc)
- Driving pattern, vehicle speed, ADT, truck content, etc
- Amount of dirt deposited from outside sources
- Local conditions of rain and humidity

More theoretical work is needed as well as communication input from road maintaining civil engineers. More experiments have to be designed to determine the relevance of the above-mentioned parameters and also to find new possible parameters governing PM_{10} emission.

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