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Comparison of measured and model-calculated real-world traffic emissions

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Abstract

The quality of an emission calculation model based on emission factors measured on roller test stands and statistical traffic data was evaluated using source strengths and emission factors calculated from real-world exhaust gas concentration differences measured upwind and downwind of a motorway in southwest Germany. Gaseous and particulate emissions were taken into account. Detailed traffic census data were taken during the measurements. The results were compared with findings of similar studies.

The main conclusion is the underestimation of CO and NO_x source strengths by the model. On the average, it amounts to 23% in case of CO and 17% for NO_x. The latter underestimation results from an undervaluation by 22% of NO_x emission factors of heavy-duty vehicles (HDVs). There are significant differences between source strengths on working days and weekends because of the different traffic split between light-duty vehicles (LDVs) and HDVs. The mean emission factors of all vehicles from measurements are $1.08\,g\,km^{-1}\,veh^{-1}$ for NO_x and $2.62\,g\,km^{-1}\,veh^{-1}$ for CO. The model calculations give $0.92\,g\,km^{-1}\,veh^{-1}$ for NO_x and $2.14\,g\,km^{-1}\,veh^{-1}$ for CO.

The source strengths of 21 non-methane hydrocarbon (NMHC) compounds quantified are underestimated by the model. The ratio between the measured and model-calculated emissions ranges from 1.3 to 2.1 for BTX and up to 21 for 16 other NMHCs. The reason for the differences is the insufficient knowledge of NMHC emissions of road traffic.

Particulate matter emissions are dominated by ultra-fine particles in the 10–40 nm range. As far as aerosols larger than 29 nm are concerned, 1.80×10^{14} particles $km^{-1}\,veh^{-1}$ are determined for all vehicles, 1.22×10^{14} particles $km^{-1}\,veh^{-1}$ and an aerosol volume of $0.03\,cm^3\,km^{-1}\,veh^{-1}$ are measured for LDVs, and for HDVs

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7.79×10^{14} particles $km^{-1} veh^{-1}$ and $0.41 cm^3 km^{-1} veh^{-1}$ are calculated. Traffic-induced turbulence has been identified to have a decisive influence on exhaust gas dispersion near the source.

Keywords: Real-world emissions; Emission model; Traffic census; Emission measurements; Gaseous emissions; Particulate matter emissions

1. Introduction

1.1. Scope of the paper

To ensure the efficiency of strategies to reduce air pollutants caused by road traffic, it is essential to evaluate the emission data to be used in emission calculation models (Kühlwein and Friedrich, 2000). Under the BAB II project (**B**undes**A**uto**B**ahn—federal highway), this was done by simultaneous measurements of concentrations of gaseous and particulate emissions in ambient air on the upwind and downwind side perpendicular to a motorway under real-world conditions. From the differences of the measured fluxes, the emissions caused by traffic on the motorway can be calculated. Measurements of high horizontal and vertical resolution of CO, NO, NO_x, 21 non-methane hydrocarbon (NMHC) compounds, and particulates were made on both sides of the motorway.

The scope of this final paper within the special issue on the results of the BAB II project is (i) to summarise the main results, (ii) to compare the measured and model-calculated source strengths of emissions, released by traffic on the motorway section under investigation and finally to evaluate the quality of the emission calculation model updated by the results of the traffic census made simultaneously. Although emission factors for a ‘‘mean vehicle’’ depending on the fleet composition passing the measurement site are given, the main objective is the improvement of the emission model by reliable traffic data and not by updated emission factors. These can not be estimated by the method used in BAB II, because the model needs emission factors of individual vehicle types (motors) as input data rather than emission factors valid for a fleet of vehicles passing the site randomly distributed. The remaining differences between measured and model-calculated source strengths is therefore mainly attributed to imprecise or even missing emission factors for gases, NMHC compounds and particulates from roller test stands.

1.2. State of the art

Former emission measurements of gaseous and particulate compounds and subsequent emission factor calculations were often restricted to tunnel studies (Pierson et al., 1996; Weingartner et al., 1997; John et al., 1999; Schmid et al., 2001; Gomes et al., 2004). The advantage of the tunnel studies is that they are dealing with well-defined volumes of air. However, a major problem of all one-way tunnels is the airflow of up to $30 km h^{-1}$ in the tunnel tube. Consequently, the driving resistance of the passenger cars changes and, thus, the emission behaviour no longer corresponds to that of vehicles operated in free air.

Zhang et al. (1995) used a remote sensing technique to determine the relative CO and VOC emissions of about 1 million cars at 22 different locations all over the world. The study shows that a small percentage of cars caused 50% of the total emissions of CO (‘‘high emitters’’). De Vlieger (1997) measured the tailpipe emissions of 7 cars under different driving cycles using an on-board measuring system. Major findings were the importance of the cold-start emissions and differences between emissions measured in chassis dynamometer tests and real traffic situations. The advantage of on-board measurements is that errors due to the necessary flux measurements in the tunnel and in free air studies are avoided. An alternative to the on-board measurements are emission measurements made on dynamic roller test stands. Although such emission factors estimated for typical driving cycles are valuable emission model input data, they are available for a very limited number of motors and driving cycles only.

The efficiency of a controlled 3-way catalytic converter in a passenger car and cold-start emissions with respect to benzene, toluene and xylene (BTX) emissions in particular was investigated by Heeb et al. (2000, 2003). Free air measurements were made by Leisen et al. (1992) on a motorway in Germany and by Kittelson et al. (2004) in the US. In the former BAB 656 study by Vogel et al. (2000), model-calculated emissions using real-world concentration differences between the lee and the windward side of the motorway were evaluated. The deficiencies of BAB 656 consisted in the estimation of the CO and NO_x plume height using O_3 as indicator and in comparing measured and calculated emissions for three 1-h intervals only. As there are indications of traffic-induced turbulence being important to the dispersion of emissions close to the source (Eskridge and Rao, 1983; Rao et al., 2002), additionally horizontal and vertical profiles of turbulence were measured in BAB II.