Dilution and Transformation Processes within a Diesel Car Exhaust Plume. Measurements and Simulations of On-Road Conditions.

U. Uhrner, S. von Löwis, B. Wehner, H. Siebert, T. Tuch, F. Stratmann, A. Wiedensohler; Institute for Tropospheric Research, Leipzig, Germany

Introduction:

In this project, the dilution and transformation processes within a passenger car exhaust plume are studied for typical atmospheric and on-road conditions. The motivation is to understand the differing size distributions, resulting from measurements taken at an engine test station and measurements taken in an urban street channel. Maximum number concentrations were recorded in a range of 40 to 60 nm for different vehicle classes at an engine test station, whereas for urban street channel measurements the maximum was shifted to 10 to 20 nm during rush hour conditions (Wehner, 2002).

Approach:

SMPS (3-400 nm), CO_2, NO, NO_x, humidity, temperature and velocity measurements are taken within the exhaust plume during on-road conditions. Details of the measurement devices used in this project are shown in Table 1. The measurement equipment is placed inside the car and the inlet system is fixed on a rear mounted bike rack. The adjustable inlet position design facilitates measurements at different distances from the exhaust pipe. The system can be used on public roads.

Device	Range	Resolution	Parameter
SMPS	7-400nm	1s, 50s per scan	dN/dD_p
Emission analyzer	0-1000ppm 0-250ppm 0-1(5)vol%	5s 5s 10s	NO_x NO CO_2
Vaisala sensor	0-100% -40-180°C	5s 5s	RH T
Lyman-α hygrometer	0-14g/m^3	10ms	ρ_w (abs. humidity)
Thermocouple	-25-550°C	10ms	T
Prandtl Pitot tube	0-40m/s	10ms	p_{tot}, p_{stat}

Table 1: Measurement devices used in this project.

Accompanying to the measurements a complementary model set-up is developed to account for the flow characteristics of the car as well as dilution and aerosol dynamics of H_2SO_4-H_2O-soot aerosol. The exhaust plume of a moving car is modelled using computational fluid dynamics software FLUENT 6 (www.fluent.com) together with the add-on model FPM (Fine Particle Model, www.particle-dynamics.de). The focus of measurements and simulations is the characterization of mixing and dilution processes important for particle formation in the exhaust plume. The exhaust concentrations are predicted from fuel composition, consumption and operating conditions. The exhaust sulphuric acid concentrations are determined based on an approach by Baumgard and Johnson (1996). The impact of varying ambient conditions such as temperature, humidity, and the speed of the car on dilution and new particle formation will be analysed. Due to computational limits the focus of the modelling efforts is placed on the exhaust region whereas the body of the car is simplified.

First Results:

First measurements were carried out for approximately constant car velocities with different rpm due to different gears used. The inlet system was mounted at 0.41 / 0.48 m distance on the centre line of the exhaust pipe. The test drives were carried out on a less frequented motorway with a common European estate car with a 90 KW Diesel engine.

For car velocities larger than 90 km/h the size distribution showed a second mode at around 100 nm. For lower speeds the distribution consisted of one mode with maximum number concentrations of 40-60 nm. For same speed and higher rpm the size distribution shifted towards smaller particle sizes and higher particle number concentrations. Significantly increased particle number concentrations (up to $7 \cdot 10^7$ cm^{-3}) in the range of 7-15 nm were recorded at constant car velocities higher than 140 km/h and 3800-4000 rpm (4th gear). For strong acceleration cycles i.e. from 50 km/h to 140 km/h similar results were found.

First model results show a good agreement for flow velocity, temperature and humidity, as well as temperature and humidity gradients within the exhaust plume. Simulations with prescribed exhaust particle flux based on the measurements accounting dispersion and coagulation have been carried out for soot particles. Further measurements at various distances will be made to validate these results.

Outlook:

The measured data and further measurements will be analysed with regard to formation of nuclei particles upon cooling of exhaust by rapid turbulent dilution. Conditions and parameters that foster or suppress nucleation using on road conditions will be evaluated.

Supplementary software (UDF's) is being developed to account for H_2SO_4-H_2O nucleation and condensation. Model calculations with FLUENT/FPM are carried out based on experimental boundary conditions such as speed, fuel consumption, air mass flow, moisture, T, CO_2, and SO_2.

References:

Baumgard, K. J., and Johnson, J. H. (1996). The Effect of Fuel and Engine Design on Diesel Exhaust Particle Size Distributions. Society of Automobile Engineers, SAE 960131, 37-50.

Wehner, B., Birmili, W., Gnauk, T., Wiedensohler, A., Particle number size distributions in a street canyon and their transformation into the urban-air background: measurements and a simple model study, Atmos. Environ. 36, 2215-2223, 2002.

Dilution and Transformation Processes within a Diesel Car Exhaust Plume. Measurements and Simulations of On-Road Conditions.

U. Uhrner, S. von Löwis, B. Wehner, H. Siebert, T. Tuch, F. Stratmann, A. Wiedensohler; Institute for Tropospheric Research, Leipzig, Germany

Introduction:

In this project, the dilution and transformation processes within a passenger car exhaust plume are studied for typical atmospheric and on-road conditions. The motivation is to understand the differing size distributions, resulting from measurements taken at an engine test station and measurements taken in an urban street channel. Maximum number concentrations were recorded in a range of 40 to 60 nm for different vehicle classes at an engine test station, whereas for urban street channel measurements the maximum was shifted to 10 to 20 nm during rush hour conditions (Wehner, 2002).

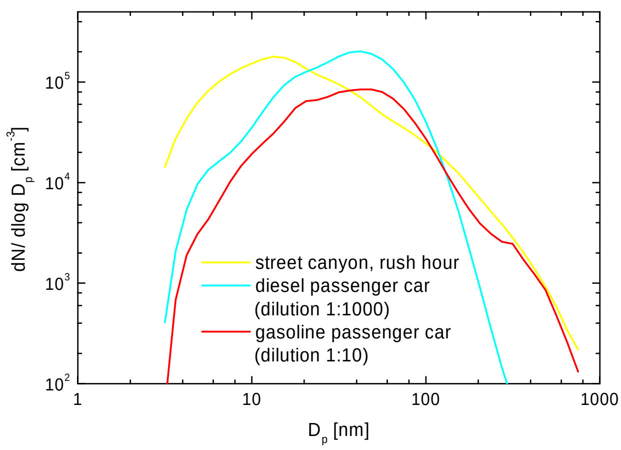

Fig. 1: Measured size distributions at engine test stations and in an urban street canyon (Wehner, 2002).

Approach:

SMPS (3-400 nm), CO_2, NO, NO_x, humidity, temperature and velocity measurements are taken within the exhaust plume during on-road conditions. Details of the measurement devices used in this project are shown in Table 1. The measurement equipment is placed inside the car and the inlet system is fixed on a rear mounted bike rack. The adjustable inlet position design facilitates measurements at different distances from the exhaust pipe. The system can be used on public roads.

Accompanying to the measurements a complementary model set-up is developed to account for the flow characteristics of the car as well as dilution and aerosol dynamics of H_2SO_4-H_2O-soot aerosol. The exhaust plume of a moving car is modelled using computational fluid dynamics software FLUENT 6 (www.fluent.com) together with the add-on model FPM (Fine Particle Model, www.particle-dynamics.de). The focus of measurements and simulations is the characterization of mixing and dilution processes important for particle formation in the exhaust plume. The exhaust concentrations are predicted from fuel composition, consumption and operating conditions. The exhaust sulphuric acid concentrations are determined based on an approach by Baumgard and Johnson (1996). The impact of varying ambient conditions such as temperature, humidity, and the speed of the car on dilution and new particle formation will be analysed. Due to computational limits the focus of the modelling efforts is placed on the exhaust region whereas the body of the car is simplified.

Device	Range	Resolution	Parameter
SMPS	7-400nm	1s, 50s per scan	dN/dD_p
Emission analyzer	0-1000ppm 0-250ppm 0-1(5)vol%	5s 5s 10s	NO_x NO CO_2
Vaisala sensor	0-100% -40-180°C	5s 5s	RH T
Lyman-α hygrometer	0-14g/m^3	10ms	ρ_w (abs. humidity)
Thermocouple	-25-550°C	10ms	T
Prandtl Pitot tube	0-40m/s	10ms	p_{tot}, p_{stat}

Table 1: Measurement devices used in this project.

First Results:

First measurements were carried out for approximately constant car velocities with different rpm due to different gears used. The inlet system was mounted at 0.41 / 0.48 m distance on the centre line of the exhaust pipe. The test drives were carried out on a less frequented motorway with a common European estate car with a 90 KW Diesel engine.

For car velocities larger than 90 km/h the size distribution showed a second mode at around 100 nm (see Fig. 2). For lower speeds the distribution consisted of one mode with maximum number concentrations of 40-60 nm. For same speed and higher rpm the size distribution shifted towards smaller particle sizes and higher particle number concentrations (see Fig. 3). Significantly increased particle number concentrations (up to $7 \cdot 10^7$ cm^{-3}) in the range of 7-15 nm were recorded at constant car velocities higher than 140 km/h and 3800-4000 rpm (4th gear), see Fig. 4. For strong acceleration cycles i.e. from 50 km/h to 140 km/h similar results were found.

First model results show a good agreement for flow velocity, temperature and humidity, as well as temperature and humidity gradients within the exhaust plume. Simulations with prescribed exhaust particle flux based on the measurements accounting dispersion and coagulation have been carried out for soot particles (see Fig. 5 and 6). Further measurements at various distances will be made to validate these results.

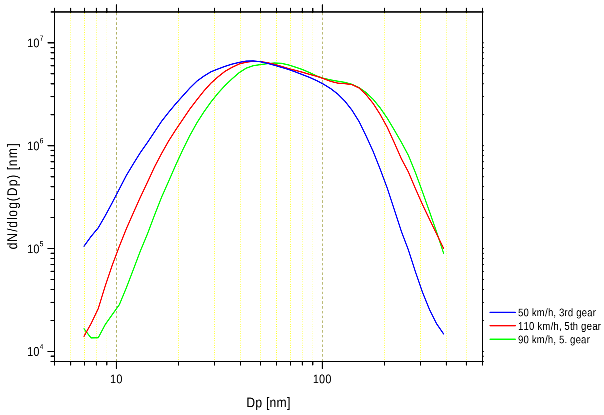

Figure 2: Averaged size distributions (3-4 complete up and down scans).

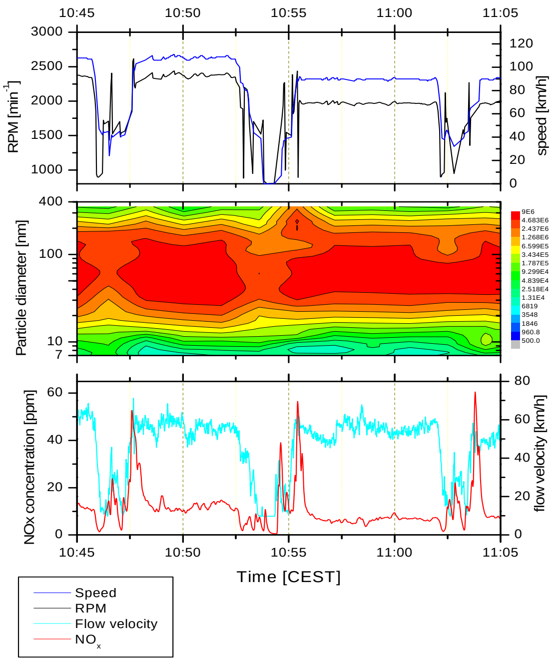

Figure 3: Time series of car velocity and revolutions per minute (rpm) (top), particle size distribution (middle), flow velocity and NO_x (bottom) at 0.48m distance from the exhaust pipe.

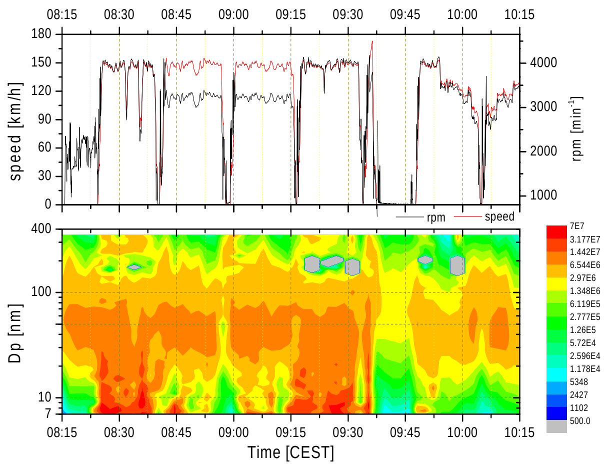

Figure 4: Time series of car velocity, rpm, and particle size distribution.

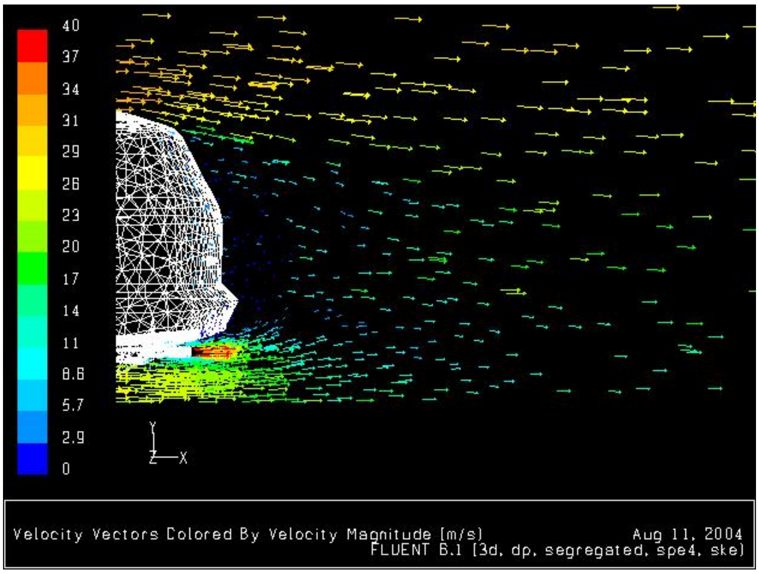

Figure 5: Cross section of simulated flow field in the exhaust pipe plane.