GasOMeP

Gasoline Vehicle Emission Control for Organic, Metallic and Particulate Non-Legislative Pollutants

Scope of project

In 2020 it is expected that >50 million gasoline direct injection (GDI) vehicles will operate on European roads. The majority of these vehicles will not be equipped with filter technologies and will release substantial numbers of inhalable, soot-like nanoparticles smaller than 100 nm. In the GASOMEP project we studied seven GDI vehicles under transient and steady driving conditions with varying converter technologies and fuels. Due to the well appreciated support from our industrial partners, four prototype gasoline particle filters (GPFs) could be studied. Our focus was on emissions of toxic and environmentally relevant pollutants. Particle characterization included size, number distribution and metal content. Emissions of genotoxic compounds included polycyclic aromatic hydrocarbons (PAHs) and their alkylated and nitrated forms which were studied in detail to assess the genotoxic potential of GDI vehicle exhausts and the effects filters and fuels have on these critical compounds. In addition, secondary organic aerosol (SOA) formation potentials of GDI exhausts were investigated in smog chamber and flow reactor experiments to assess their impact on secondary ambient particle formation.

Status of project

Within three years five sampling campaigns have been organized, each lasting 3–4 weeks, which were performed at the chassis dynamometer of the University of Applied Sciences Bern. Overall, four teams (from PSI, FHNW, BFH-TI and Empa) met in Nidau to investigate emissions of regulated pollutants, nanoparticles (BFH-TI, FHNW), non-regulated pollutants, metals (Empa) and secondary organic aerosols (PSI, FHNW). The project is now in its last phase which includes data evaluation, reporting, publishing and dissemination of the many results.

Main scientific results of workgroups

Experimental set-up

The vehicle fleet studied consisted of seven GDI vehicles representing technology of the Euro-3, Euro-4, Euro-5 and Euro-6 legislation. The fleet included a Euro-3 Mitsubishi Carisma (1.8 L), the first GDI vehicle released. Furthermore, an Euro-5 flex-fuel vehicle (Volvo V60, T4I, 1.6 L) was used to compare emissions when operating the vehicle with gasoline (E0), two (bio) ethanol/gasoline blends (E10, E85) and n-butanol/gasoline (B15). For comparison, a Euro-5 diesel vehicle (Peugeot, 4008, 1.6 L) equipped with diesel particle filter was also studied.

Our industrial partners contributed four prototype gasoline particle filters, two non-coated and two coated filters. The world harmonized light vehicle test cycle (WLTC) was applied under cold start and hot conditions. The WLTC will be the next legislative cycle representing transient driving in urban, extra-urban, highway and motorway conditions. The particle characteristics were also studied in a steady state cycle (SSC) with constant vehicle operation at 94, 61, 45, 26 km/h and idle.

Large numbers of inhalable 10–100 nm particles released by all GDI vehicles

Figure 1 displays the particle number size distribution of an Euro-5 GDI vehicle (Volvo V60) exhaust at 95 km/h. A bimodal distribution with maxima at 20 and 70 nm (nucleation and accumulation modes) was observed. Particle number concentrations of 10e6 to 10e7 particles/cm^3 were found. Nano-SMPS and SMPS data are in good agreement in the overlapping size range.

The time-velocity diagram of the WLTC and its four phases are indicated in figure 2 together with time-resolved CO (red) and particle (black) data. Particles and CO are released together throughout the entire cycle. They are well correlated and increase 2–3 orders of magnitude while accelerating the vehicle. In other words,

List of abbreviations

DPF	Diesel Particle Filter
GDI	Gasoline Direct Injection
GPF	Gasoline Particle Filter
nSMPS	Nano Scanning Mobility Particle Sizer
SMPS	Scanning Mobility Particle Sizer
SOA	Secondary Organic Aerosol
SSC	Steady State Cycle
PAH	Polycyclic Aromatic Hydrocarbons
PN	Particle Number
WLTC	World Harmonized Light Vehicle Test Cycle

Major partners in the ETH domain

- Empa – Laboratory for Advanced Analytical Technologies
- Empa – Laboratory for Air Pollution/Environmental Technology
- PSI – Laboratory for Atmospheric Chemistry

Main Investigator

Norbert Heeb, Empa

Project Partners

BAFU
Empa
Industry
PSI
BFH-TI
FHNW

Time frame of Project

2013–2017

Thematic Relationship to SCCER

Mobility

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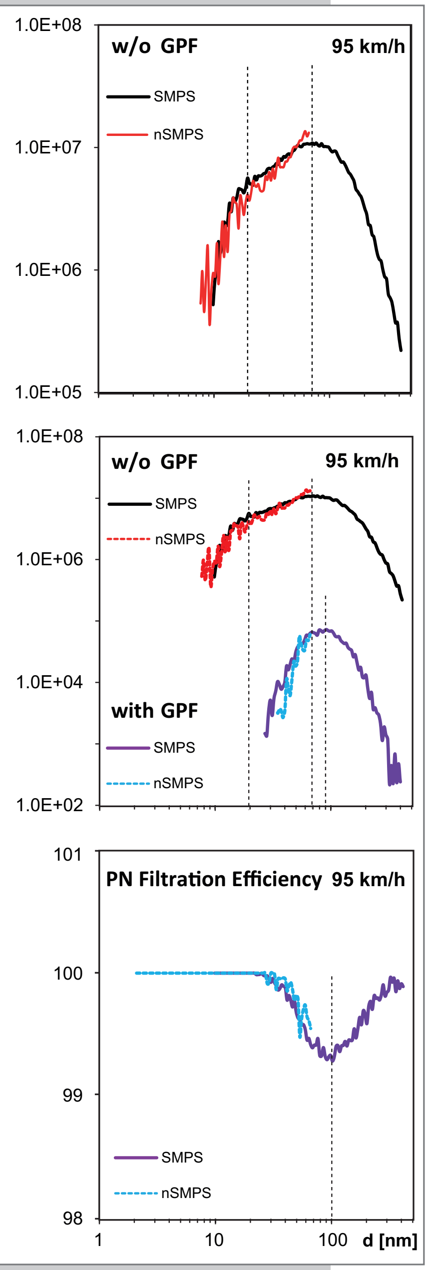

Figure 1 :
Particle size distributions (#/ccm) of Euro-5 GDI vehicle (Volvo V60, 1.6 L) exhausts without (top) and with particle filter (middle) at 95 km/h. SMPS and nanoSMPS data are in good agreement.
Particle filtration efficiency (bottom) is above 99 % for all particle sizes.

highest particle and CO emissions occur under fuel-rich conditions with sub-stoichiometric oxygen levels. Such events are frequent in real world driving. On the contrary, hydrocarbon emissions of GDI vehicles are highest in the first 200 seconds of driving before catalyst light-off and are hence released mainly at vehicle start. We conclude that current GDI vehicles, not equipped with filters, release substantial numbers of particles, wherever they are used, in urban, extra-urban and highway conditions.

GDI vehicles release up to 3 orders of magnitude more particles than current diesel vehicles

The GDI vehicles studied, released nanoparticles in the range of 7x10e11 to 2x10e13 particles/km, exceeding the particle limit for Euro-5/6 diesel passenger cars of 6x10e11 particles/km. Comparing these values with those of the Euro-5 diesel vehicle (Peugeot 4008, 1.6 L), which were 3x10e9 to 4x10e10 particles/km, revealed that current GDI vehicles release 20–4000 times more particles than the comparable diesel vehicles, equipped with particle filters. Diesel particle filters are robust and efficient technologies already introduced in the market in 2000 by Peugeot.

Genotoxic PAH emissions of GDI-vehicles exceeded those of the diesel vehicle

Figure 3 displays toxicity-weighted emission factors (ng TEQ/m^3) of 8 genotoxic PAHs of Euro-5 GDI (Volvo V60 1.6 L) and diesel (Peugeot 4008, 1.6 L) vehicles. Genotoxic PAH emissions of the GDI vehicle were 390 and 410 ng-TEQ/m^3 in the cold and hot WLTC; those of the diesel vehicle equipped with a filter were 45 and 150 ng-TEQ/m^3. In other words, the genotoxic potential of the GDI-vehicle exhausts was 3- to 9-fold higher than the one of the diesel vehicle. Non-filtered diesel exhausts, containing large numbers of nanoparticles and comparable amounts of genotoxic PAHs, are considered as class 1 carcinogen inducing lung cancer in humans.

In conclusion, GDI vehicle exhausts not only contain billions of inhalable soot-like nanoparticles, they also include relevant amounts of genotoxic PAHs and with this, strongly resemble non-filtered diesel exhausts. Such mixtures are potentially dangerous. Due to the fast implementation of GDI vehicles in Europe, we conclude that such exhausts will substantially contribute to the overall burdens of nanoparticles and genotoxic compounds in ambient air representing a serious health threat for people exposed to traffic.

Gasoline particle filters lower genotoxic PAH and nanoparticle emissions

Figure 1 also displays the particle number distribution after a gasoline particle filter (middle) and shows the size-resolved conversion efficiency (bottom). Particle emissions dropped by two orders of magnitude for 80 nm particles and even more for 20 nm particles,

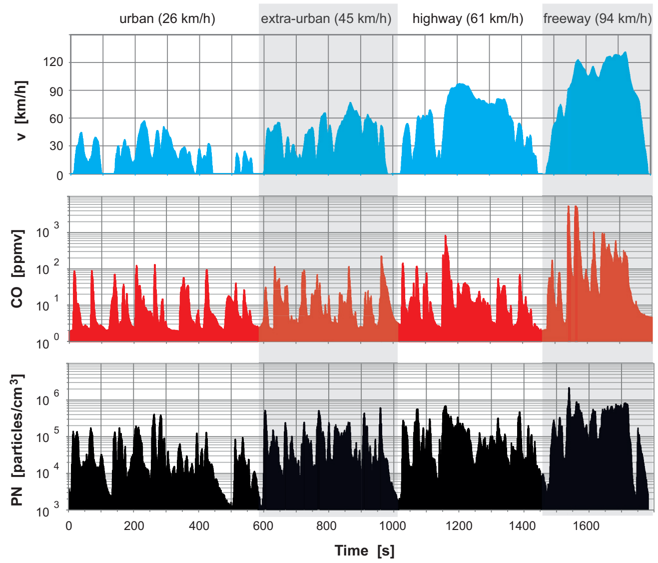

Figure 2 :
Time-resolved CO (red) and particle (black) emissions (logarithmic scales) during a hot transient cycle of a Euro-5 GDI vehicle (Volvo V60, 1.6 L). The velocity-time diagram (blue) and the four phases of the WLTC are also shown.

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which couldn’t be detected anymore after the filter. Respective filtration efficiencies exceed 99 % in the entire size range, indicating that particle emissions can be lowered substantially with well-designed filters. It is also evident that smallest particles are even removed better than larger ones.

Figure 3 also includes genotoxicity-weighted PAH emissions of a GDI vehicle (Volvo V60, 1.6 L) equipped with four prototype GPFs. Three filters lowered the genotoxic potential by 40–70 % and 65–80 % in the cold and hot WLTC. Filter 4 was not active in the cold WLTC and released 2 times more genotoxic PAHs in the hot WLTC. Filter 4 also had the lowest performance for solid particles. Filter 4 was inactive and did not convert genotoxic PAHs, but was storing them in the cold and releasing them again under hot conditions.

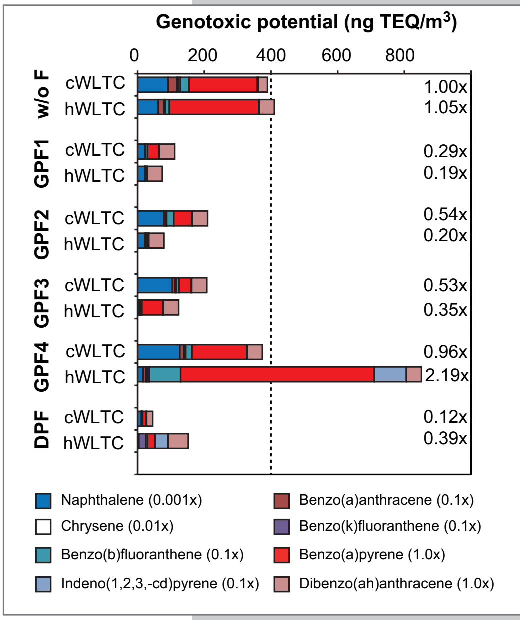
In conclusion, well designed and catalytically-active filters can remove nanoparticles and genotoxic PAHs and with it substantially detoxify GDI-vehicle exhausts. However, filters with poor efficiency and without catalytic activity will not be able to remove genotoxic PAHs to the extent that is needed. Such filters intrinsically can store PAHs in the cold and release them again in high concentrations when exhaust temperatures rise.

Time-resolved secondary organic aerosol formation potential

The secondary organic aerosol (SOA) forming potentials were investigated with smog chamber experiments and two independent flow reactor approaches. One of the reactors, the Micro Smog Chamber (MSC), exposes gaseous (filtered) vehicle emissions to high intensity UV light to achieve photochemical aging of the gaseous compounds within 10 seconds. The advantage of the flow reactor approach, and in particular of the MSC, is that time-resolved SOA data can be obtained and paired with real-time vehicle emission data to establish specific SOA emission factors.

Figure 4 displays that for most of the WLTC, the secondary aerosol production remained below 1 mg SOA/lt-fuel, but intervals with emissions close to 300 mg SOA/lt-fuel were observed during cold start operation. After integration of time-resolved data, average SOA emission factors of 0.68 and 0.33 mg/km were observed for the Euro 5 vehicle (Volvo V60) during the cold and warm WLTC, respectively.

Figure 3: Genotoxic potential of non-filtered and filtered GDI- and diesel-vehicle exhausts. Eight genotoxic PAHs, weighted with their toxicity equivalence factors (ng TEQ/m³), of an Euro-5 vehicle (Volvo, V60, 1.6 L) operated without filter (top) and with four prototype GPFs in cold- and hot-started WLTCs are compared with the benchmark Euro-5 diesel vehicle (Peugeot 4008, 1.6 L) which included a DPF (bottom).



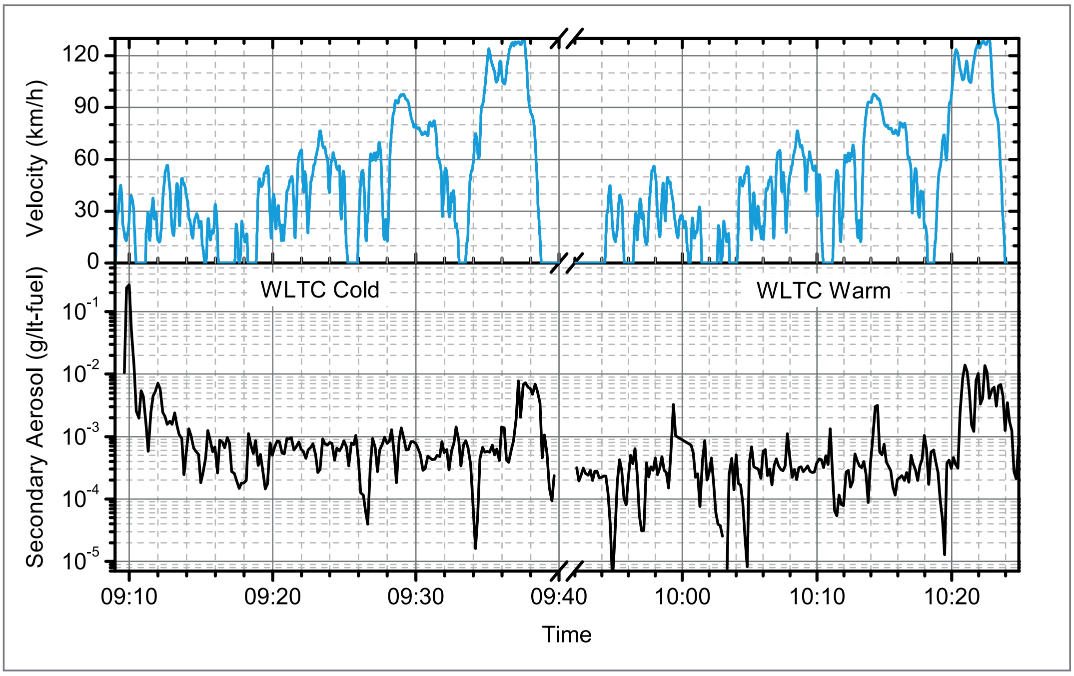


Figure 4 : Time-resolved SOA potential (logarithmic scale), obtained using the micro-smog chamber, during cold and hot WLTC for an Euro-5 vehicle (Volvo, V60, 1.6 L). The mass concentration was derived from the observed number concentration, average mass distributions from the SSC, and a particle density ρ = 2000 kg/m³.