Detailed characterization of nanoparticles emitted by spark ignition direct injection engines

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Introduction

In the context of strong evolution of European emissions standards for motored vehicles, the introduction of a regulation concerning the number of particles emitted by vehicles leads to new challenges related to the understanding of their formation process. The present work focuses on the detailed characterization of particles emitted by spark ignition direct injection (SIDI) engines as a lot of studies have shown that this type of vehicle emits a number of particles which could be higher than the future Euro 6b standards [1-5].

Vehicle tests

A Euro 5 passenger car equipped with a 1.6L stoechiometric SIDI engine has been tested on a vehicle chassis dynamometer for multiple operating conditions including several types of driving cycle (NEDC, WLTC, Artemis...). As reported on figure 1, the particle number measured for each cycle following the PMP procedure confirms that the vehicle do not comply with the Euro 6b limit which will be effective in 2017. Moreover, the comparison of driving cycles enables to highlight the strong influence of cold start, engine warm-up and transient phases on particle emissions (an example is given on figure 2 for the ARTEMIS cycle).

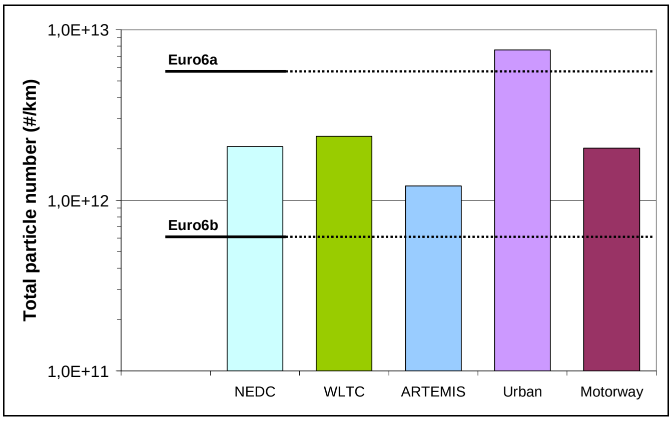


Fig.1 : Particle number measured following PMP procedure

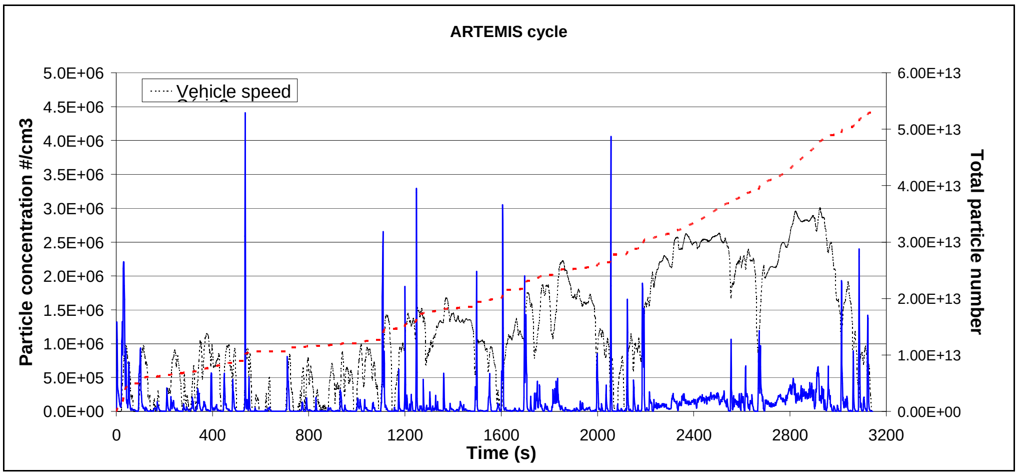


Fig.2 : Instantaneous and cumulative particle number emitted during the ARTEMIS cycle

An assessment of individual phases of the ARTEMIS cycle has been performed and shows that urban driving conditions which are characterized by transient conditions at low load and low speed, lead to a high number of particles emitted per kilometer, compared to motorway conditions (figure 1).

Additional measurements have been performed in order to characterize the size distribution (using the DMS500), directly at the exhaust pipe of the vehicle, confirming that urban driving conditions generate high concentrations of particles, specially in accumulation mode (figure 3).

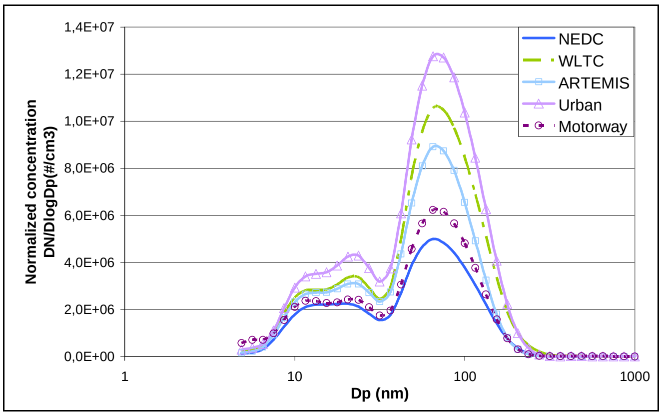


Fig.3 : Influence of driving cycle on particle size and number concentration

Morphology and chemical composition

The morphology and the chemical composition of particles have been compared for the NEDC and the Urban phase of the ARTEMIS cycle. The microscopy analysis, based on scanning electron microscopy (SEM) and transmission electronic microscopy (TEM), did not highlight noticeable differences of structure of soot aggregates or primary particles related to driving conditions (figure 4).

NEDC URBAN

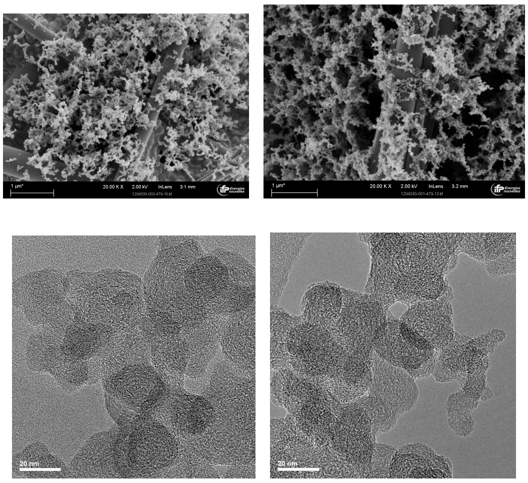


Fig.4 : Microscopy analysis

Chemical analysis of the soluble organic fraction has been performed using High Performance Liquid Chromatography (HPLC), what enabled to identify and compare the concentration of 15 polycyclic aromatic hydrocarbons (PAH) specified by the Environment Protection Agency (EPA) as priority pollutants.
The chemical composition of SOF is quite similar in terms of PAH. However, some slight differences could be observed on the relative content of fluoranthene and pyrene (figure 5).

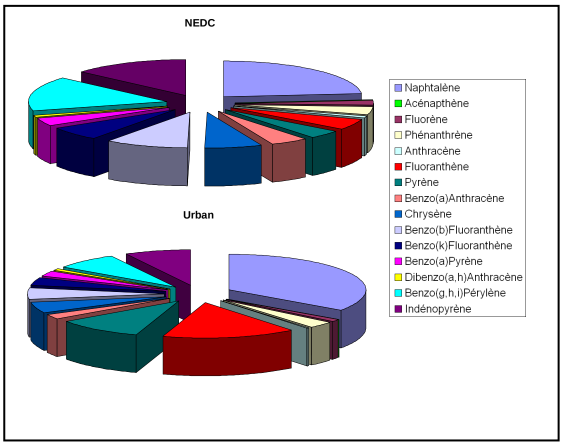


Fig.5 : PAH composition of the soluble organic fraction

Influence of engine settings and fuel properties

Simultaneously, in order to identify technical ways of reduction of particle formation in SIDI engines, further investigation has been performed on an engine test bench using the same type of SIDI engine. This engine was equipped with an opened engine control unit (ECU) which enabled to modify the engine operating settings. Particle emissions have been measured with the DMS500 for multiple variations of selected settings, showing the strong effect related to injection parameters (timing, pressure) and to warm-up calibration on particle concentrations (figure 6).

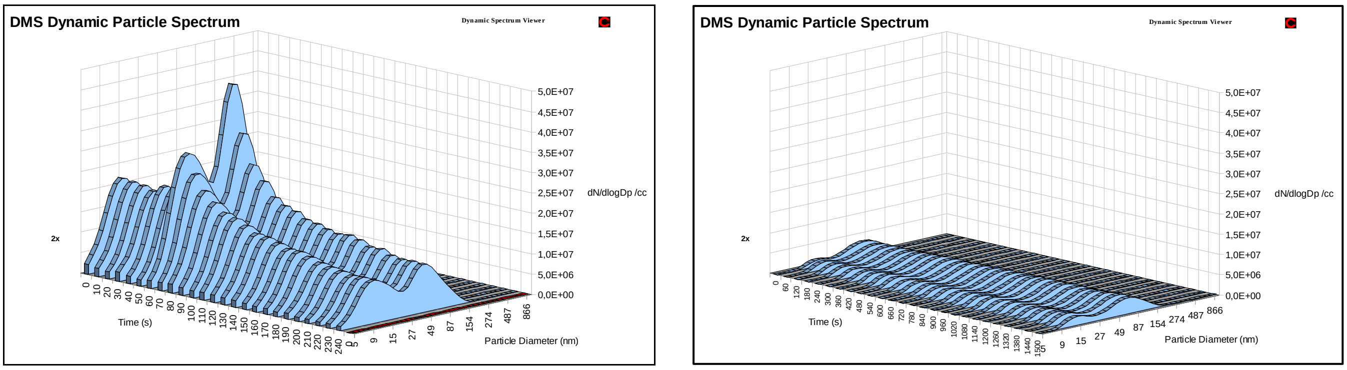


Fig.6 : Comparison of particle concentration during cold start (left) and hot conditions (right) – 1500rpm / IMEP=3bar

This parametric study has been completed by an evaluation of the effect of fuel properties on particle emissions. A reference ethanol-free gasoline (E0) has been compared to an E10 fuel (containing 10% ethanol) and to an alkylate synthetic fuel mainly containing paraffinic compounds (figure 7). The results show that the alkylate fuel leads to a strong reduction of particle concentration and to the diminution of the particle mean diameter compared to E0 and E10 (figure 8). Cold start tests confirmed that such a type of paraffinic fuel has a high potential to decrease raw particle emissions, even during the critical phases of engine starting and catalyst heating (figure 9).

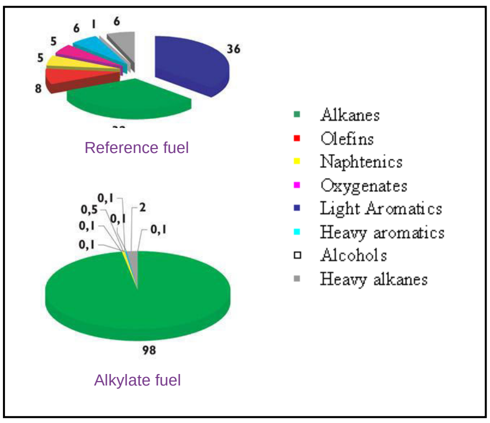


Fig.7 : Alkylate fuel composition

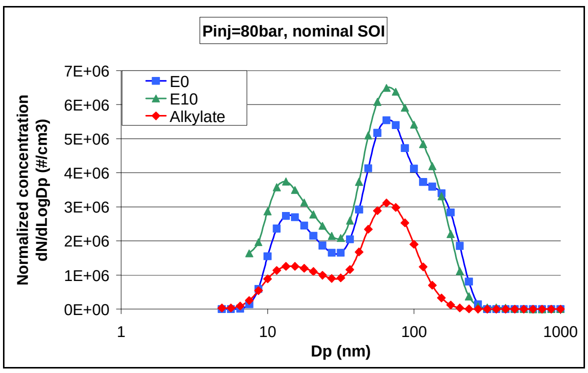
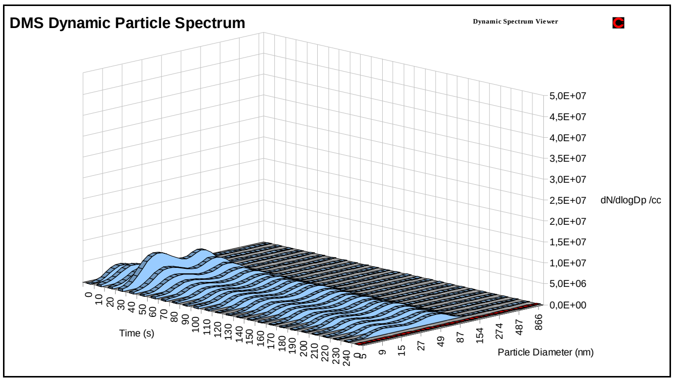


Fig.8 : Comparison of particle concentration 1500rpm / IMEP=10bar (hot conditions)



Alkylate fuel

Fig.9 : Evolution of particle concentration during cold start using an alkylate fuel - 1500rpm / IMEP=3bar

Conclusion

Particles emitted by vehicles equipped with SIDI engines have been characterized, showing the effects of urban driving conditions and engine calibration during cold start on emissions. Concentrations of particles could be strongly modified depending on driving conditions, whereas morphology and chemical composition of particles remain quite similar.

Substantial reduction of particles emitted can be obtained by optimizing engine parameters (injection phasing, injection pressure...), or by using alternative fuels with low aromatic content.

Future work will focus on the following topics :

- Chemical characterization of ultrafine particles < 30 nm
- Optimization of fuel formulation using ethanol-alkylate blends
- Global evaluation and comparison of particle emissions for different vehicle technologies (SIDI, Diesel with DPF, SCR...)

References

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Background

The introduction of a regulation concerning the number of particles emitted by vehicles leads to new challenges related to the identification of the main parameters of influence and to the knowledge of their physicochemical nature. The present work focuses on the detailed characterization of particles emitted by spark ignition direct injection (SIDI) engines and on the effects of engine settings and fuel properties on particle emissions.

Vehicle tests

A Euro 5 passenger vehicle equipped with a 1.6L stoechiometric SIDI engine has been tested for multiple operating conditions including several types of driving cycle (NEDC, WLTC, Artemis...).

This vehicle does not comply with the future Euro 6b limit for particle number following the PMP measurement procedure, and the comparison of driving cycles showed that urban driving conditions lead to high number of particles emitted per kilometer (fig.1)

The size distribution, directly measured at the exhaust pipe (using the DMS500), confirms that urban driving conditions generate high concentrations of particles specially in accumulation mode (fig.2).

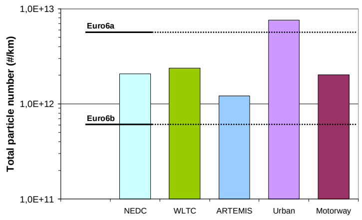

Fig.1 : Total Particle number (PMP)

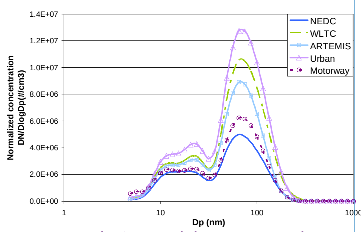

Fig.2 : Particle concentration

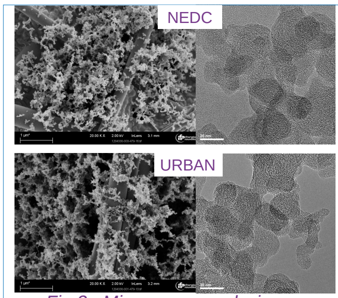

Fig.3 : Microscopy analysis

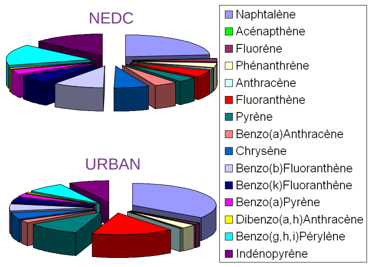

Fig.4 : PAH composition of the SOF

Morphology and chemical composition

Microscopy analysis did not highlight noticeable differences of structure of soot aggregates or primary particles related to driving conditions (fig.3).

Chemical analysis of the soluble organic fraction has been performed using High Performance Liquid Chromatography (HPLC) and enabled to identify and compare the concentration of 15 polycyclic aromatic hydrocarbons (PAH) specified by the Environment Protection Agency (EPA) as priority pollutants.

The chemical composition of SOF is quite similar in terms of PAH. However, some slight differences could be observed on the relative content of fluoranthene and pyrene (fig.4)

Engine settings and fuel effects

A parametric study has been performed on an engine test bench using the same type of SIDI engine equipped with an opened ECU which enabled to modify the engine operating settings.

Particle emissions have been measured with the DMS500 for multiple variations of selected settings, showing a strong effect due to injection parameters (timing, pressure) and to warm-up calibration (catalyst heating) on particle concentrations (fig.5).

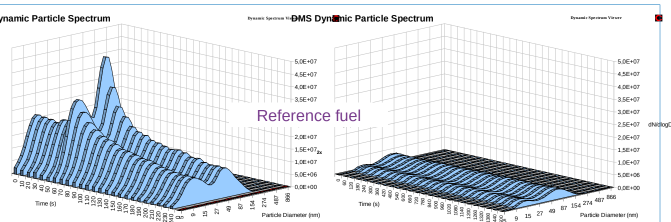

Fig.5 : Comparison of particle concentration during cold start (left) and hot conditions (right) – 1500rpm / IMEP=3bar

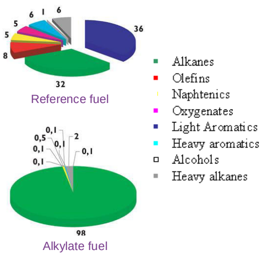

Fig.6 : Fuel composition

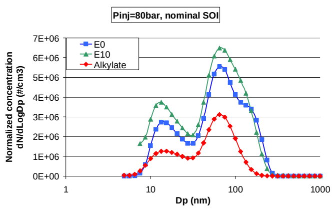

Fig.7 : Comparison of particle concentration 1500rpm / IMEP=10bar (hot conditions)

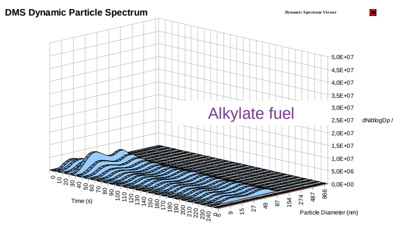

Fig.8 : Evolution of particle concentration during cold start using an alkylate fuel

The reference ethanol-free gasoline has been compared to an E10 fuel (containing 10 % ethanol) and to an alkylate synthetic fuel mainly blended from paraffinic compounds (fig.6).

The results show that the alkylate fuel leads to a strong reduction of particle concentrations and to the diminution of the particle mean diameter compared to E0 and E10 (fig.7).

Cold start tests confirmed that such a type of paraffinic fuel have a high potential to decrease raw particle emissions, even during critical phases of engine start and catalyst heating (fig.8).

Future work

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Future work will focus on the following topics :

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