Evaluation of non-volatile nucleation particles in a HSDI engine over transient operating condition

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Extended Summary

Currently, diesel particle emissions regulations are based on emitted particle mass and particle number concentration for particles between 23nm and 2.5µm; however the particle size distributions are also important factors in air quality and necessary to development efficient after-treatment system. This study investigates the particle size distributions in the exhaust aerosol focusing in measured and evaluated the non-volatile nucleation particles emitted for a light-duty diesel engine over transient operations conditions.

In order to measure the particle size distributions the exhaust sample was diluted in a dilution system with two stages, a porous tube (PTD) was used to obtained hot dilutions at 320ºC to avoid the generation of nucleation particles in the dilution system, after the first stage dilution, the sample passes through an evaporating tube at 350ºC used like a residence chamber (RC) to stabilize the particle transformation process, finally a ejector diluter (ED) was used like second dilution stage, in this stage the dilution air temperature was 40ºC. The particle size distribution was measured in the diluted gases with a TSI® Engine exhaust particle sizer; a data rate of 10 Hz was used in this study for the particle measurement, while for the engine measurement the data rate was 100 Hz.

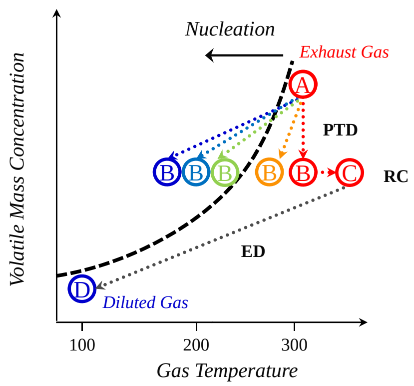

Figure 1: *Theoretical phase diagram of the aerosol in their different stages in the dilution system*

Figure 1 show a theoretical phase diagram of the volatile compounds plotted against temperature. In fresh engine exhaust in the tailpipe, temperature and concentration of the volatile are high (denoted by point A). During first isothermal dilution in the porous tube, concentration of the volatile compounds was reduced (path by point B), posteriorly was maintained in the residence chamber (denoted by point C) and finally was reduced by cold dilution performed in the ejector diluter (point D); both temperature and concentration of the volatile are decreased preventing the nano-droplet formation.

For New European Driving Cycle (NEDC) measurements, engine was warmed up beforehand in order to avoid the effect of cold starts and to perform several tests a day. With these conditions the particle size distributions for the four repetitions of the Urban Cycle (ECE-15) do not present significant changes between them. At the beginning of the NEDC (ECE-15 cycle), the driving speed and the load of engine are low, with a large drop in load in several zones, which leave the torque near zero. These changes produce the disappearance of the accumulation mode and the shift of the particle size distribution to the nucleation mode zone. However in the EUDC cycle as the loads on the engines increased, the particle size distribution is dominated by the accumulation mode.The nucleation mode particle concentration in the NEDC represents 38% of the total particle concentration.

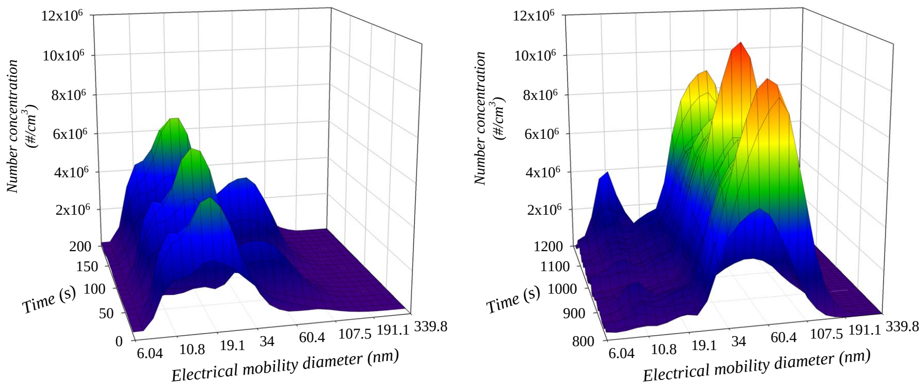

Figure 2: *Particle size distributions for the New European Driving Cycle. ECE-15 Cycle (Left) and EUDC (Right)*

In Artemis cycle the load and the speed in the engine are high, but both fluctuate rapidly, resulting particle size distribution dominated by the nucleation mode due to the quickly change in the combustion conditions. The contribution of nucleation mode particle into the total particle concentration in the Artemis cycle was 54% in the Urban cycle, 65% in the Rural cycle and 68% in the Motorway cycle.

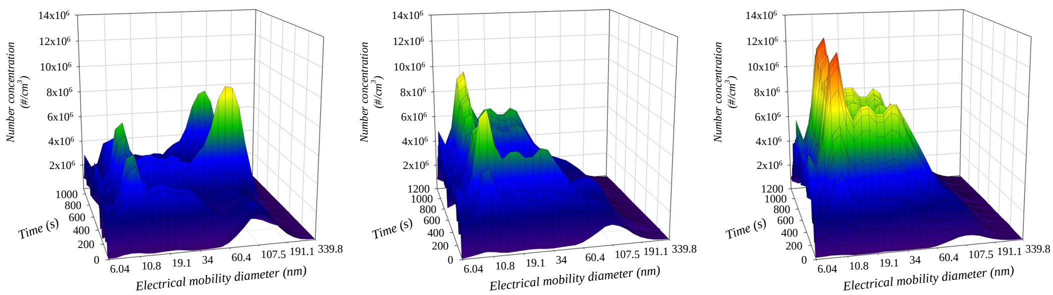

Figure 3: *Particle size distributions for the Artemis Cycle. Urban (Left), Rural (Centre) and Motorway (Right)*

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Introduction

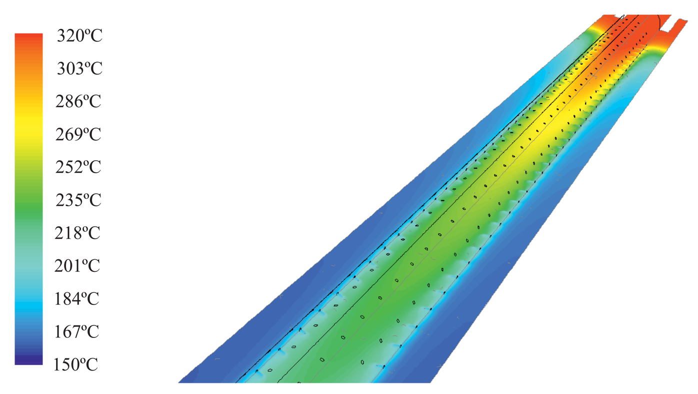
Currently, diesel particle emissions regulations are based on emitted particle mass and particle number concentration for particles larger than 23 nm, assuming that the contribution of solid particles with diameters less than 23nm are insignificant. Nevertheless; the existence of nonvolatile particles <23 nm, can rise concentrations higher than the accumulation mode particles, concerns raises about the robustness of the protocol. This study investigates the particle size distribution in the exhaust aerosol, focusing on measurement and evaluation of the non-volatile nucleation particles emitted for a light-duty diesel engine over transient operations conditions

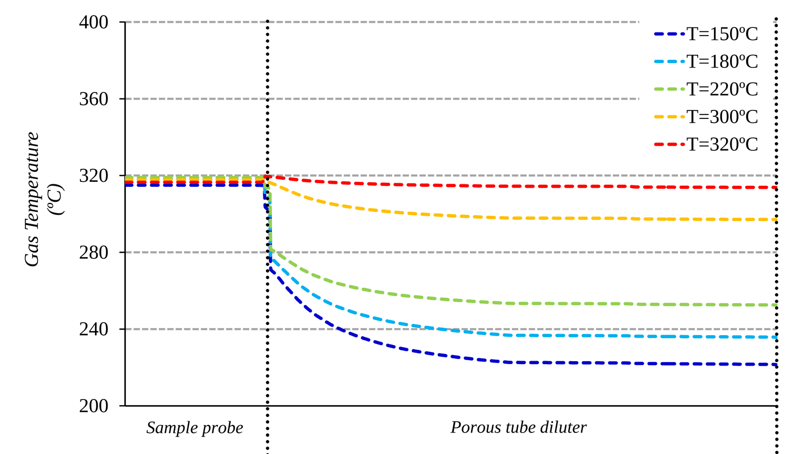
Objectives

The main aim of this work is to evaluate and measure the particle size distributions in a light duty diesel engine during the official New European Driving Cycle (NEDC cycle), and over real-world driving conditions (Artemis cycle) due to the limited comparability of the NEDC with real driving conditions. A secondary objective of this study is developing a methodology to prevent the nano-droplet formation in the dilution system avoiding the use a volatile particle removal, in order to measure the nucleation mode particles formed by the pressure and temperature gradient at the exhaust valve.

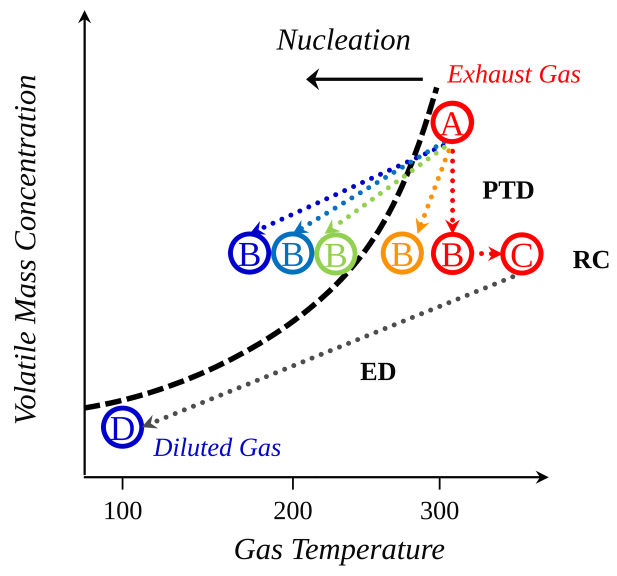
Methodology

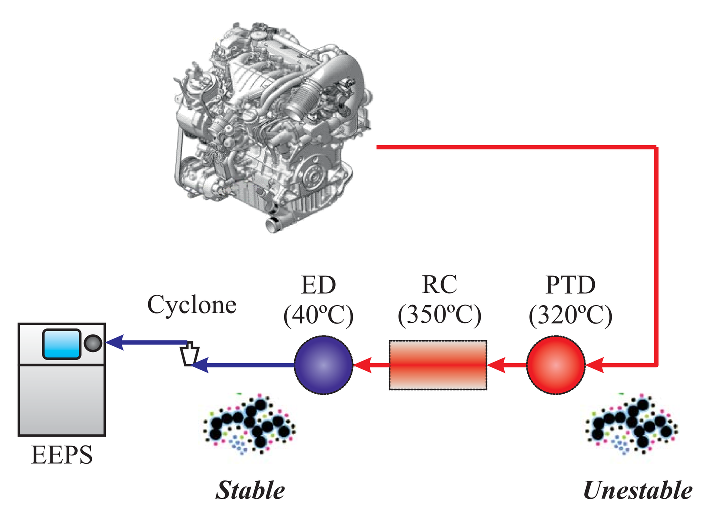
The development of the measure methodology includes modeling the dilution system using commercial software (Ansys Fluent), to determine the optimum dilution conditions and possible cold zones inside the dilution system, in which the volatile compounds can be able to nucleate. To validate the theoretical result, experimental measurements of particle size distributions in the real dilution system were also carried out.



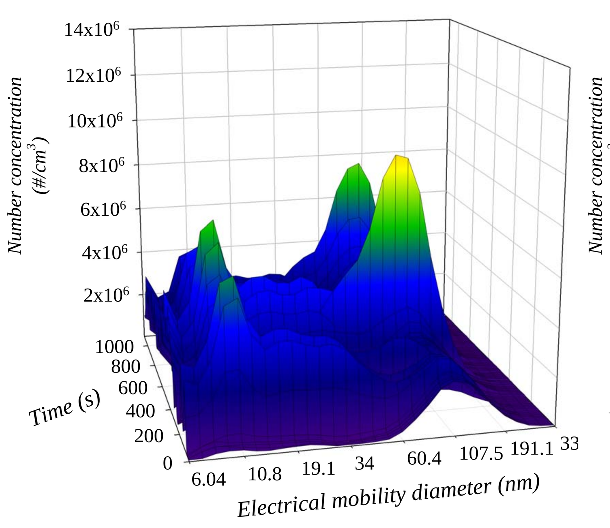


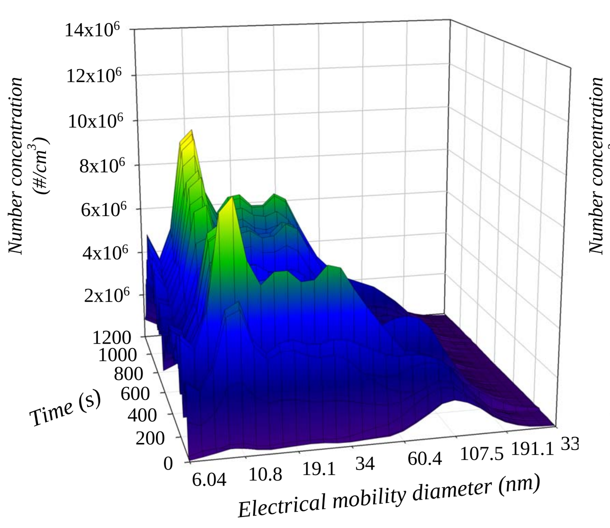
The combination of modeling and experimental results, showed independence of the particle number concentration and the geometric mean diameter when the exhaust gases are diluted in a dilution system with two stages, first a hot dilution in a porous tube (PTD) at 320 °C, after the first dilution, the sample passes through a evaporating tube at 350°C used like a residence chamber (RC) to stabilize the particle transformation process, and finally a ejector diluter (ED) used like second dilution stage.

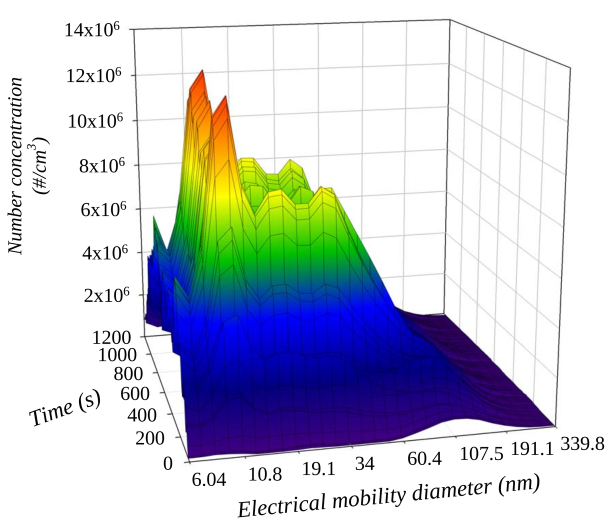




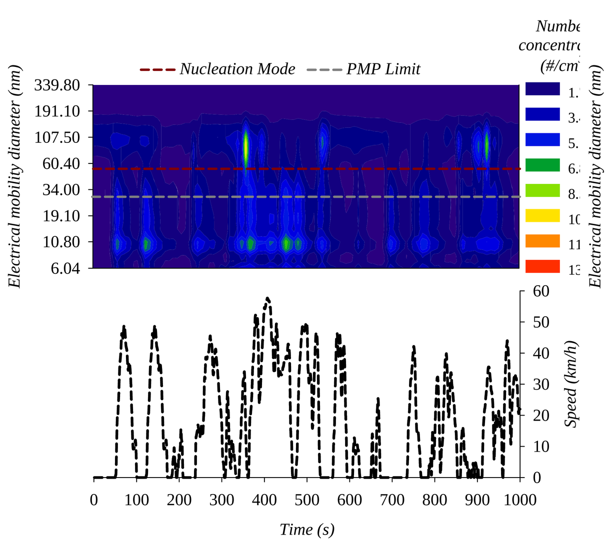
Artemis Cycle

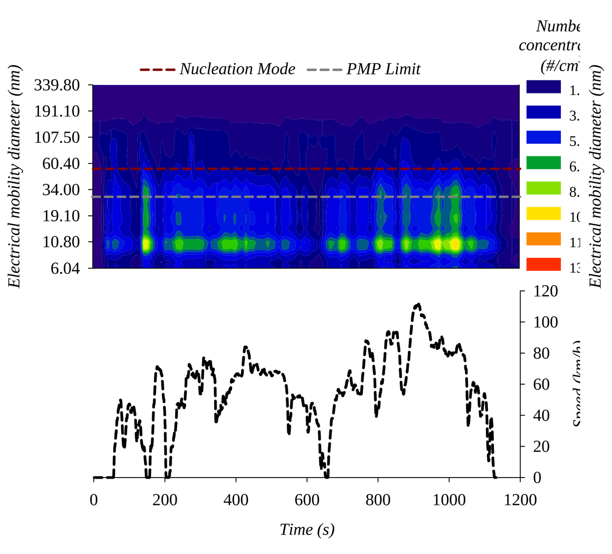


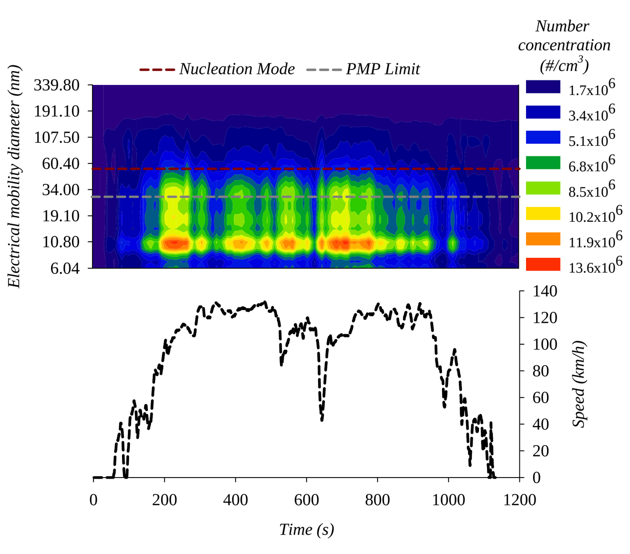




The Artemis project established a harmonized emission model for all transport levels, to provide consistent emission estimations for national, international and regional usage. This project proposes three transient cycles (Urban cycle, Rural-road cycle and Motorway Cycle) with a total of twelve classes of driving conditions [1]. Figures show time resolved particle size distribution for each cycle.

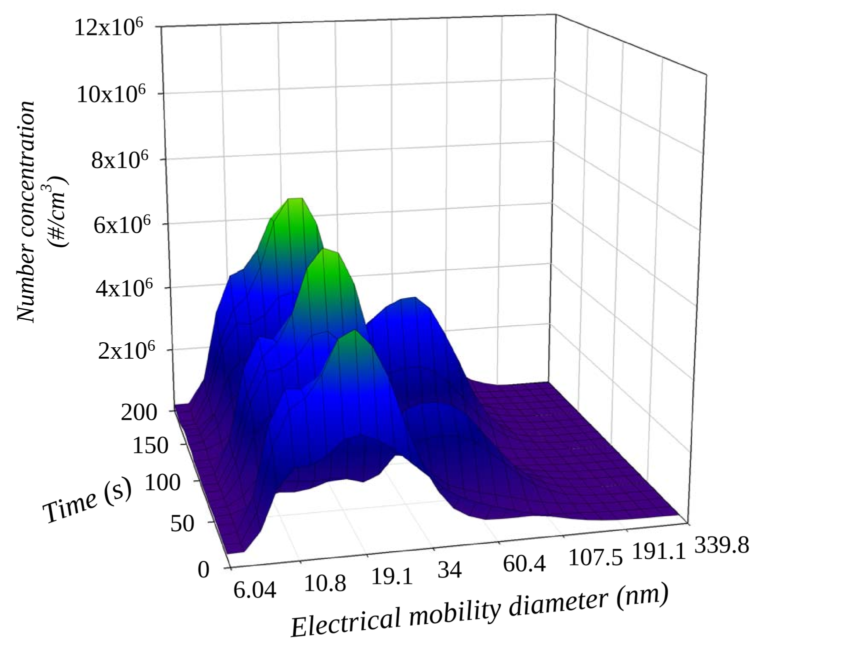


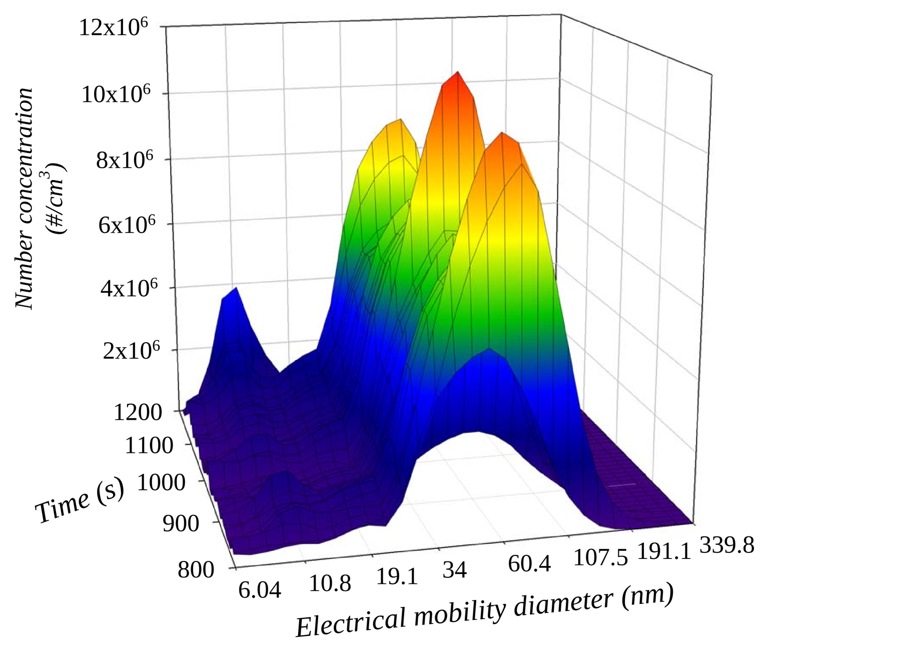




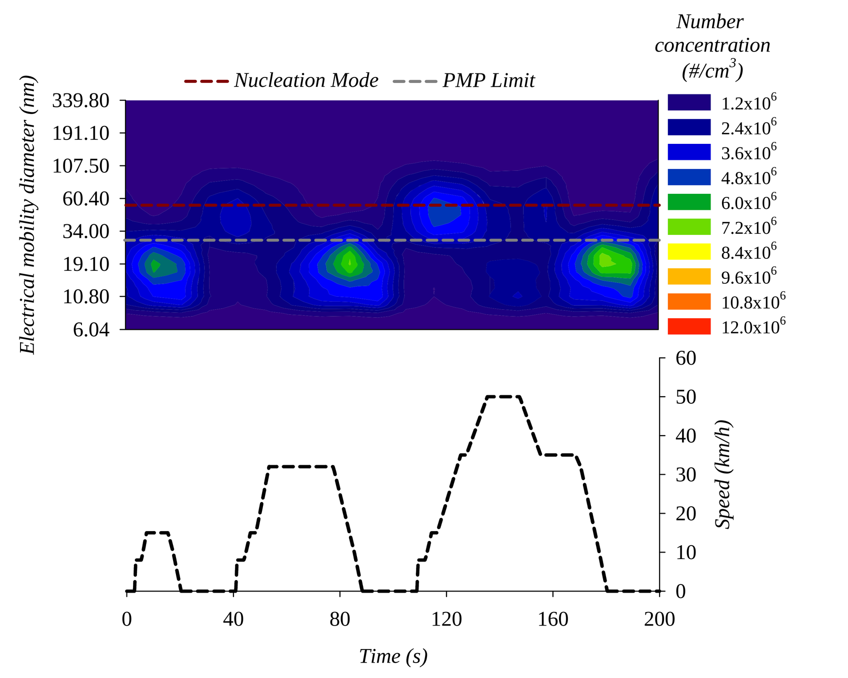
In Artemis cycle the load and the speed in the engine are high, but both fluctuate rapidly, resulting particle size distribution dominated by the nucleation mode due to the quickly change in the combustion conditions.

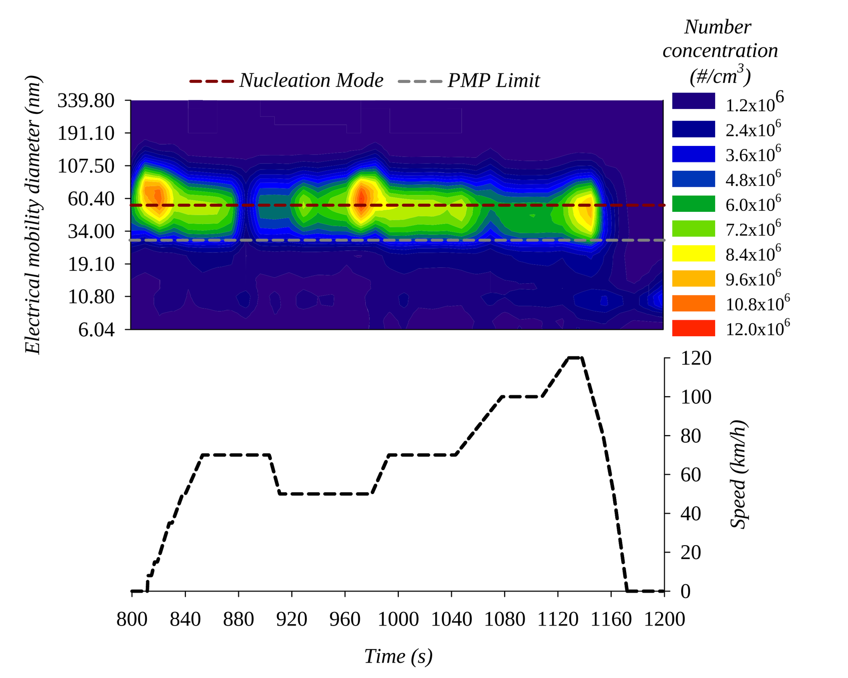
New European Driving Cycle





For New European Driving Cycle (NEDC) measurements, engine was warmed up beforehand in order to avoid the effect of cold starts and to perform several tests a day [2]. With these conditions the particle size distributions for the four repetitions of the Urban Cycle (ECE-15) do not present significant changes between them. First figure shows the mean of the four repetitions of particle size distribution for the ECE-15 cycle, while second shows the particle size distribution in the Extra Urban Cycle (EUDC) of the NEDC.





At the beginning of the NEDC (ECE-15 cycle), the driving speed and the load of engine are low, with a large drop in load in several zones, which leave the torque near zero. These changes produce the disappearance of the accumulation mode and the shift of the particle size distribution to the nucleation mode zone. However in the EUDC cycle as the loads on the engines increased, the particle size distribution is dominated by the accumulation mode.

Conclusion

- A methodology for measure particle size distributions over transient operating condition was established with modeling and experimental tests.
- Low combustion temperature in the ECE-15 cycle, increases the nano-particle emission, while in the EUDC the particle size distributions moves to larger particle diameters.
- The nucleation mode particle concentration in the NEDC represents 38 % of the total particle concentration.
- Swift changes of load in the Artemis cycle vary the combustion process producing a large number of nano-particles.
- In the Artemis cycle the contribution of nucleation mode particle into the total particle concentration was 54 % in the Urban cycle, 65 % in the Rural cycle and 68 % in the Motorway cycle.

References

[1] Andre, M., (2004). The ARTEMIS European driving cycles for measuring car pollutant emissions. Sci Total Environ., 334-335, 73-84.

[2] Arregle, J., Bermudez, V., Serrano, J R., Fuentes, E., (2006). Procedure for engine transient cycle emissions testing in real time. Exp Therm Fluid Sci., 30, 485-496