Evolution of Particle Number and Size Distribution in a Diesel Engine at Different Operating Conditions

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1. INTRODUCTION and OBJECTIVES

The recent technological development of different instruments to measure nanoparticle number and size distribution has provided a better understanding of nanoparticle emission from combustion engines (Domínguez-Sáez, 2011).

Concern about the adverse effects of particles (Rissle et al, 2012) has led to characterize these emissions with the aim of promoting improvements in attempt to reduce the particle emission. The main objective of this study is to evaluate continuously nanoparticle emission of a Euro 4 diesel engine (engine bench) running at 25% of maximum engine load with different engine speed conditions and to establish the relation between nanoparticle emission and engine operating parameters.

2. MATERIAL and METHODOLOGY

The experiments were carried out on an engine test bench dynamometer (Schenck W150) equipped with 2.0 TDI 140 HP diesel engine. The engine speed and torque are electronically controlled and measured with a Sparc. To establish a correct relation between nanoparticle emissions and engine operating parameters the engine is fully sensorized to measure the mediator variables such as intake air temperature, exhaust gas recirculation, fuel temperature, boost pressure, Fuel/Air ratio, engine speed, torque, catalyst temperature at the inlet and outlet, exhaust gases flow, etc.

Table 1- Experimental conditions

Engine Speed (rpm)	Torque (N*m)
Cold Start	0
Idle	0
1250	36.5
1500	48
1750	62.2
1500	48
1750	62.2
2000	79
2250	90.6
Idle	0

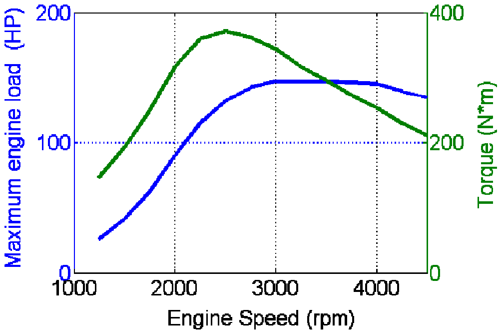

Figure 1- Torque curve of the 2.0 TDI 140 HP diesel engine

The measurement was performed using a EEPS 3090 and a dilutor MD 19-2E, with a first dilution in hot conditions (150º and 1:1695 dilution factor) and a second dilution in cold (1:2 dilution factor) (Barrios et al, 2011), the thermodynamic control of the sampling line prevents nucleation of volatile particles (Rubio et al, 2009). In order to measure the concentration of exhaust gases (CO, CO_2, THC and NOx), an OBS 2200 was used.

To ensure 25% of maximum load on each engine speed condition, the torque was adjusted according to Figure 1. The steps of engine speed followed were: idle in cold start (coolant temperature < 90º), idle, 1250, 1500, 1750, 1500, 1750, 2000, 2250 rpm and idle. The time for each experimental condition was the time required for the stabilization of temperature of the catalyst. The final experimental design is shown in Table 1.

3. RESULTS

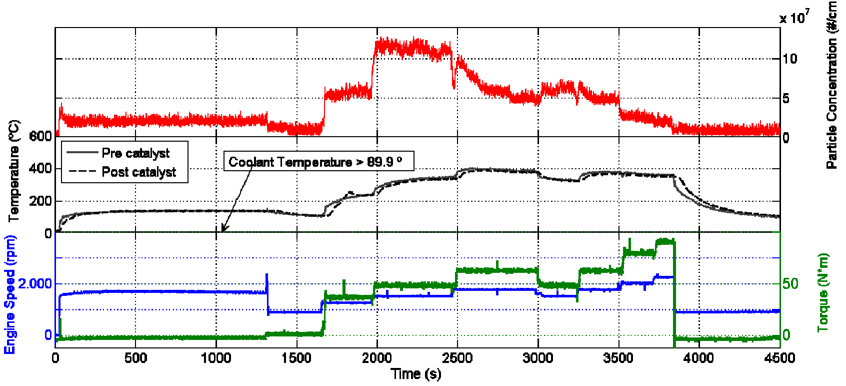

Figure 2- Catalyst temperature, total particle concentration, speed and torque

Some of the most relevant results show that when the coolant temperature reaches 90° (1600 to 850 rpm) the nanoparticle concentration decreases of 2.03E7 to 1.07E7 #/cc, and particles in nucleation mode increase from 3E6 to 4E6 #/cc (Figure 2), idle with hot engine has the highest nucleation mode nanoparticle emission. In this engine, the catalyst starts its operation at 210-220° with a significant decrease in THC and CO (Figure 3), but without significant reduction in the total particle concentration. If the turbo compressor is running slower the total nanoparticle number increases with engine speed, also increasing the geometric mean diameter (Figure 4) of the particle size distribution (enrichment of the fuel/air ratio). When the engine reaches an engine speed greater than 2000 rpm, the turbo compressor increases the boost pressure in 16%, increasing the air mass flow and decreasing the fuel/air ratio, which leads to an abrupt decrease of the total concentration of nanoparticles (from 1.12E8 to 2.6E6 #/cc). In these experiments, we do not observe a significant influence of the external recirculation because the values are relatively stable (between 32% and 41%).

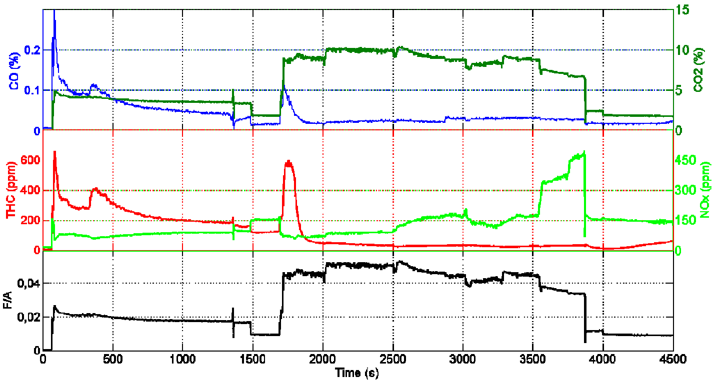

Figure 3- CO, CO2, THC and NOx concentration and Fuel/Air ratio

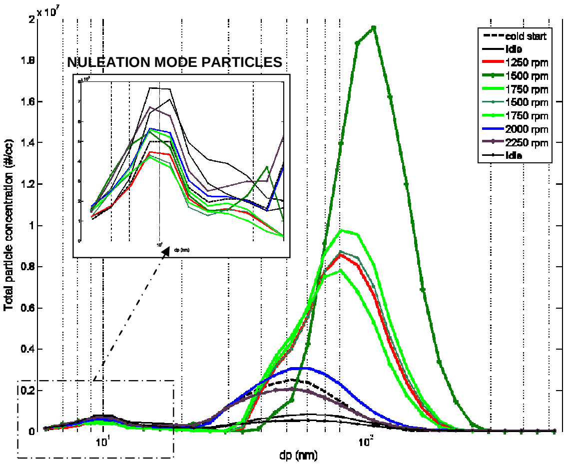

Figure 4- Particle size distribution in the considered conditions

4. DISCUSSION and CONCLUSIONS

Most of mediator variables have influence on the emission of nanoparticles and/or gaseous pollutants. The emission of nanoparticles in number and size distribution is highly dependent on variations in air fuel ratio and all the variables acting on this ratio. Influence of the temperature of the catalyst, or the external recirculation on the emission of nanoparticles has not been observed in this work. It is necessary to extend the study with variations in the percentage of maximun engine load and with engines with different technologies to ensure this.

Following the experimental torque curve, it can be observed that in the first stage there is an increase in the total concentration of particles, but from 1500 rpm, approaching the optimum operation of the experimental curve, the total concentration of particles decreases.

The greater number of nucleation mode particles are produced at idle, so as stop-start technologies are good solutions to reduce the emission of particles smaller than 30 nm.

Knowing the relationship between engine operating parameters and nanoparticles emitted makes possible the characterization of minimum emission allowing manufacturers to propose alternatives for reducing their emissions.

REFERENCES

Barrios, C. C.; Domínguez-Sáez, A.; Rubio, J.R.; Pujadas, M. (2011) *Aerosol Sci. Technol.* **45**(5), 570-580.

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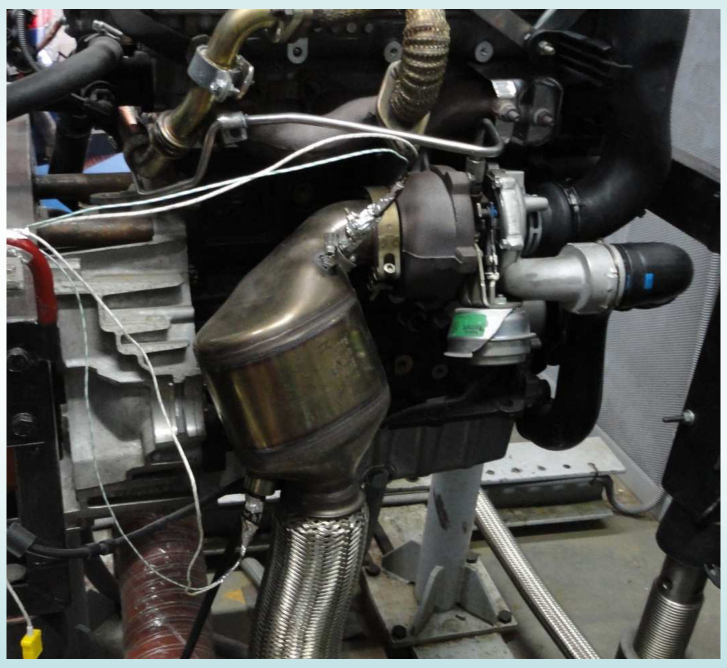
MATERIALS and METHODOLOGY

VARIABLE SELECTION

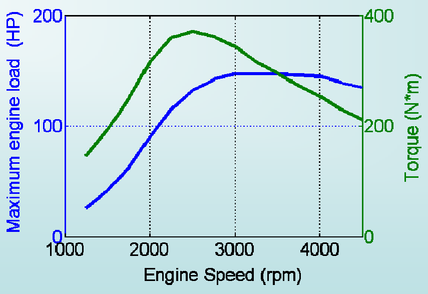
	Independent Variables	Mediator Variables	Dependent Variables
WHAT?	- Torque - Engine Speed	-Intake air, fuel and catalyst temperature - EGR, F/A ratio - Boost Pressure - Exhaust gas flow - …	- Particle number and size distribution (5.6 to 560 nm) - CO, CO_2, THC, and NOx concentrations
and			
HOW?	An dynamometer (Schenck W150) and Sparc were used to measure and control the engine speed (rev/min) and torque (N*m)	Different devices were used for the acquisition of these variables such as vehicle diagnostic interface, temperature sensors, pitot flowmeter, etc..	Particle measurement was measured (Barrios et al, 2011) using an EEPS 3090 and a dilutor MD 19-2E, with a first dilution in hot conditions (150º and 1:1695 dilution factor) and a second dilution in cold (1:2 dilution factor) (Rubio et al, 2009). In order to measure exhaust gas emission, an OBS 2200 was used.

ENGINE BENCH



SPARC

TORQUE CURVE



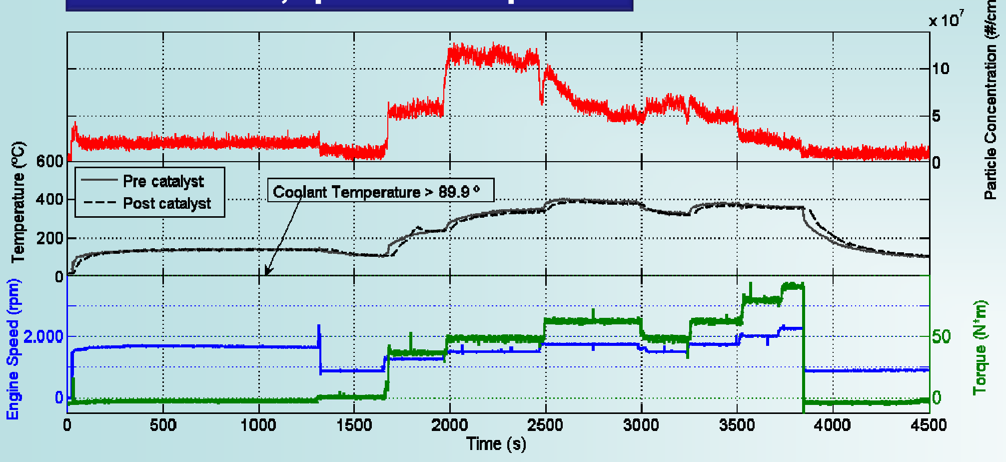
EXPERIMENTAL DESIGN

Engine Speed (rpm)	Torque (N*m)
Cold Start	0
Idle	0
1250	36.5
1500	48
1750	62.2
1500	48
1750	62.2
2000	79
2250	90.6
Idle	0

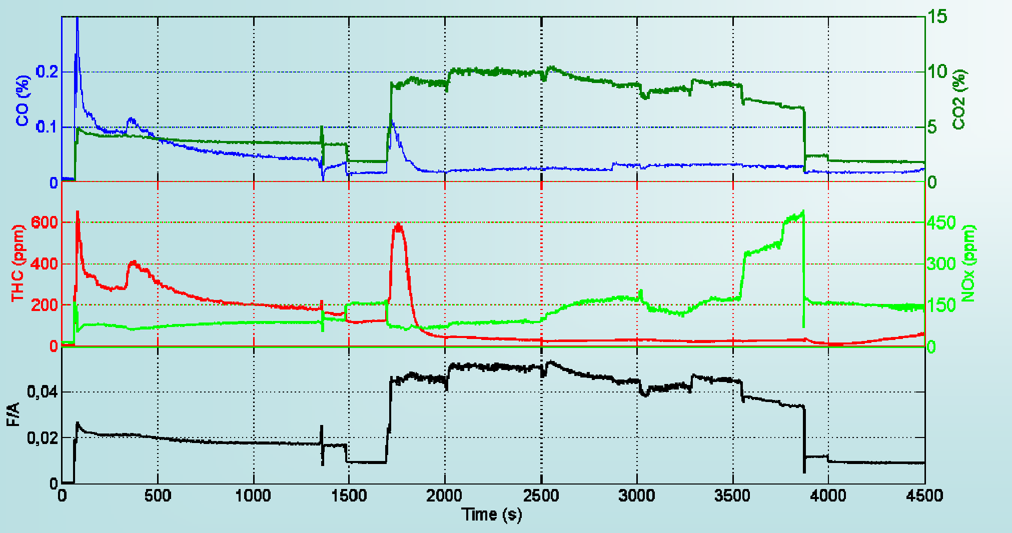
Engine running continuously. The time of each experimental condition was the necessary to ensure stabilizing the temperature of the catalyst.

RESULTS

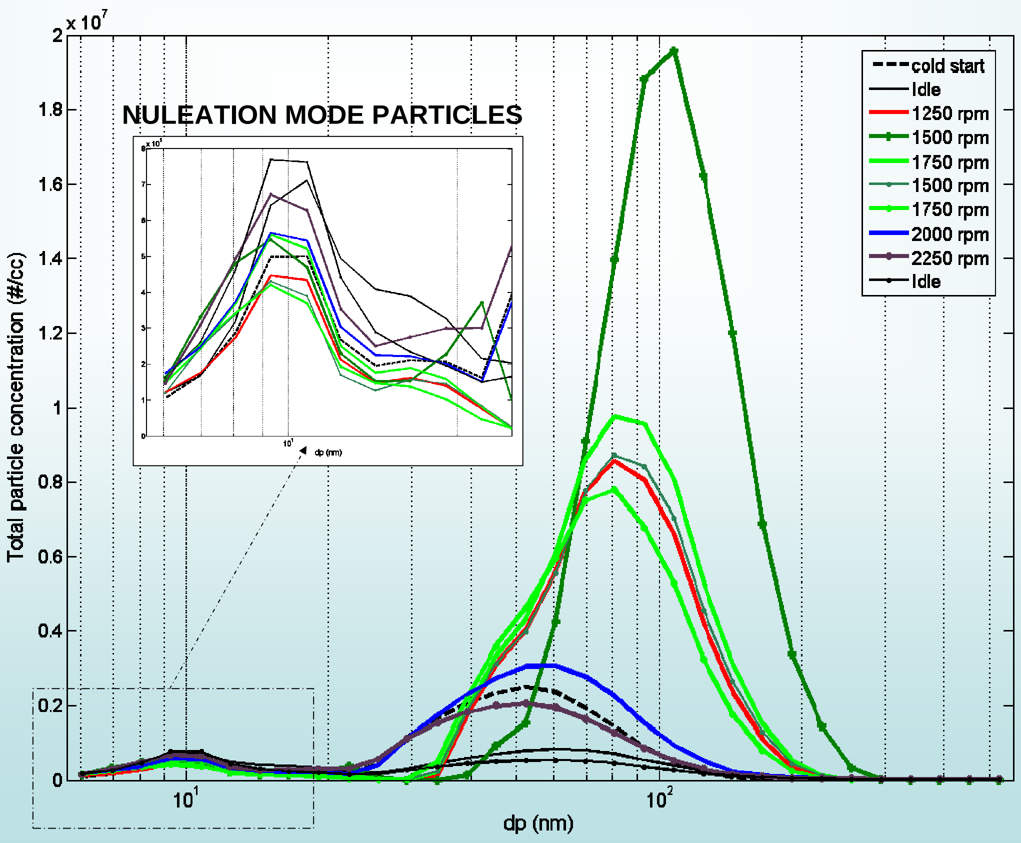
Catalyst temperature, total particle concentration, speed and torque



CO, CO_2, THC and NOx concentration and Fuel/Air ratio



Engine Speed (rpm)	Nnucleation	Ntotal	%Nucleation mode	GMD accumulation	GSD accumulation
Cold Start	2,60E+06	2,03E+07	12,82	53,08	1,49
Idle	3,80E+06	1,07E+07	35,44	61,65	1,61
1250	2,19E+06	5,59E+07	3,92	80,21	1,42
1500	3,11E+06	1,12E+08	2,79	104,38	1,38
1750	2,69E+06	6,51E+07	4,14	82,07	1,43
1500	2,47E+06	6,11E+07	4,04	83,74	1,42
1750	2,46E+06	5,19E+07	4,73	75,21	1,44
2000	3,01E+06	2,60E+07	11,55	57,52	1,52
2250	3,72E+06	1,98E+07	18,85	53,94	1,56
Idle	4,03E+06	8,88E+06	45,36	62,28	1,71



Coolant temperature > 90º ⟶ N ↓ Nn ↑

Idle (hot engine) ⟶ Nn ↑↑

Catalyst temperature > 210º ⟶ THC↓ CO↓ N ≈

n > 2000 rev/min
⬇
nearest the optimum running point
⬇
N↓↓

Surely more than one mediator variable is involved

Boost Pressure ↑
⬇
A ↑ ⟶ F/A ↓

If the turbocompressor is running slower

n ↑ ⟶ N ↑ GMD ↑
⬇
n=1500
N&GMD (condition 1) >> N&GMD (condition 2)

Under these conditions, the external recirculation has no significant influence on the emission of nanoparticles

DISCUSSION and CONCLUSIONS

- **Most of all mediator variables have influence on the emission of nanoparticles and/or gaseous pollutants.**
- **The emission of nanoparticles in number and size distribution is highly dependent on variations in air fuel ratio and all the variables acting on this ratio.**
- **In this work has not been observed influence of the temperature of the catalyst, or the external recirculation on the emission of nanoparticles. It is necessary to extend the study with variations in the percentage of maximun engine load and with engines with different technologies to ensure this.**
- **Following the experimental torque curve: in the first stage there is an increase in the total concentration of particles, but from 1500 rpm, approaching the optimum operation of the experimental curve, the total concentration of particles decreases.**
- **The greater number of nucleation mode particles are produced at idle, so as start-stop technologies are good solutions to reduce the emission of particles smaller than 30 nm.**
- **Knowing the relationship between engine operating parameters and nanoparticles emitted makes possible the characterization of minimum emission allowing manufacturers to propose alternatives for reducing their emissions.**

REFERENCES

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