Impact of catalytic stripper (CS) on the characteristics of particle number (PN) emissions from a GDI vehicle over the world-harmonized light-duty vehicle test cycle (WLTC)

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Introduction

1. GDI leads to increased particle number (PN) due to partially fuel-rich zones, incomplete combustion, and wall wetting to piston.

2. From September 2017, PN emissions of gasoline vehicles should be lower than 6.0 x10^{11} N/km over WLTC and PN emissions have to be lower than 9.0 x10^{11} N/km (conformity factor = 1.5) during real driving emissions (RDE) test.

3. Owing to particle losses in sampling systems and high uncertainty of measuring nucleation mode particles, Catalytic stripper (CS) emerged as a key apparatus in the PN measuring systems.

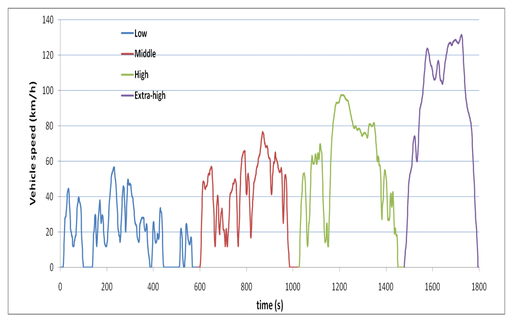
Focused on PN Emission Characteristics of a GDI vehicle over WLTC at the cold start / hot start with and without CS.

Experimental Apparatus and Condition

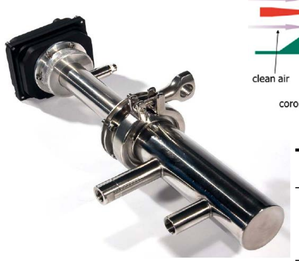
Test vehicle specification

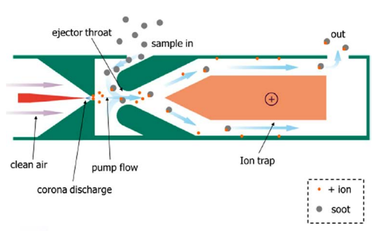
Engine Type	In-line, stoichiometric direct injection
Engine Displacement	2359 cc
Bore x stroke (mm)	88 x 97
Compression ratio	11.3:1
Fuel system	Camshaft-driven high pressure pump Side mounted injector Split injection during cold start
Exhaust system	Under-floor catalytic converter
Transmission	6 speed automatic transmission

Vehicle test mode - WLTC



PPS





Particle size range	~ 2.5 μm
Concentration range	1 μg/m^3 ~ 250 mg/m^3
Response time	10 ms
Sample flow	9.75 L/min (vacuum driven)

Catalytic stripper

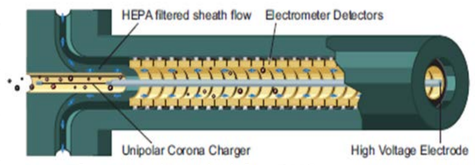
Solid particle loss	<40% at 100 nm
Oxidation efficiency	>99% of propane
Operating gas temperature	350°C
Outlet temperature	ambient +10°C

➢ **The working principle – CS**

→ Combined diffuser and sample preheater spreads the airflow and heats the sample flow (300°C)
→ Evaporation of semivolatiles
→ removes gaseous hydrocarbons

DMS-500

Particle size range	5 ~ 1000 nm
Size classification	Electrical Mobility
Dilution factor range	1 ~ 3000
Maximum primary dilution / Heated line temperature	150 °C
Sample flow rate	8 L/min (at 0°C, 100kPa)
Number of electrometers	22

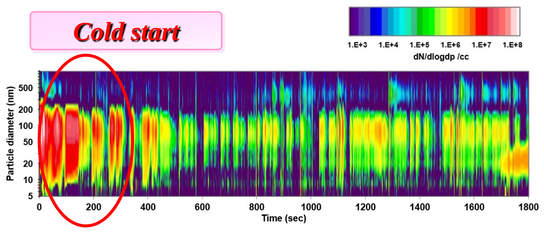


➢ **The measuring principle – DMS**

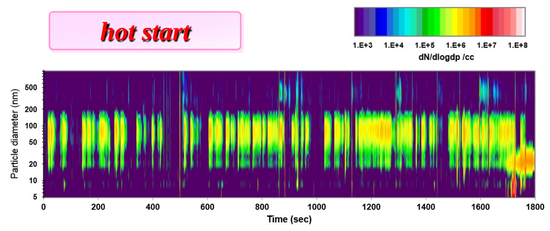
Inhalation by vacuum pump
→ Cyclone separator removes particles 〉 1㎛
→ Two stages dilution → Flow into the aerosol charger
→ Corona discharge charger → classifier column
→ The charged particles flow within sheath flow
→ Electrode rings (charge and aerodynamic drag)

Results

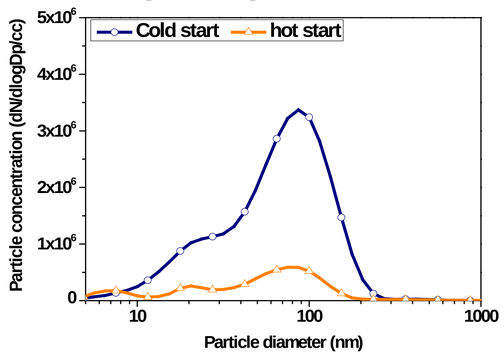
PN size distribution at the cold start / hot start



Total particle size spectra at the cold start



Total particle size spectra at the hot start



Total particle number size distribution at the cold start / hot start

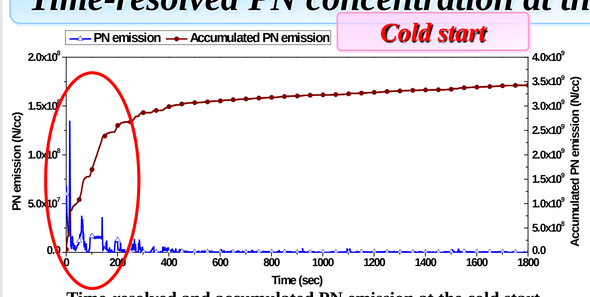
➢ *Particle number emission increased in the warm-up phase due to fuel-rich mixture, incomplete combustion and cylinder being cold.*

➢ *Before TWC reached the Light-off temperature, nucleation Mode particles and accumulation mode particles emitted a lot compared with PN at hot start.*

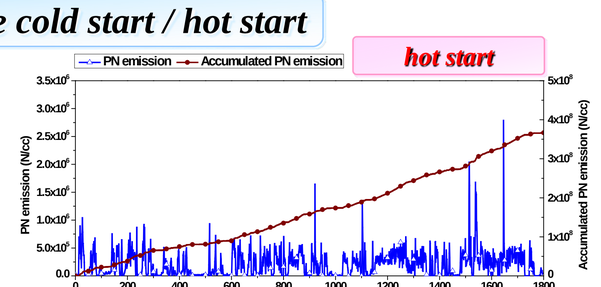
➢ *Accumulation mode particles dominated the cold start PN size distribution because GDI leads to fuel impingement on combustion chamber surfaces and pistons.*

➢ *Droplets accumulate on the surfaces to form soot at the warm-up phase.*

Time-resolved PN concentration at the cold start / hot start



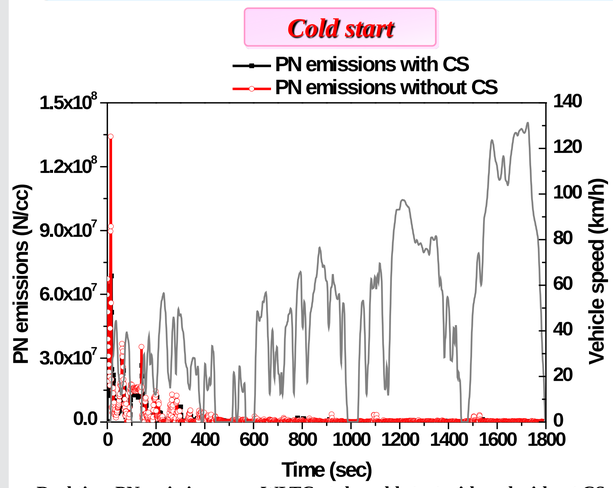
Time-resolved and accumulated PN emission at the cold start



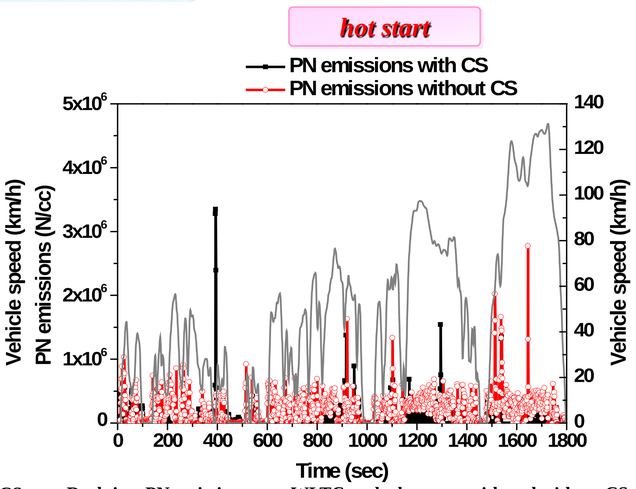
Time-resolved and accumulated PN emission at the hot start

➢ *Most of PN emission at cold start emitted in the warm-up phase (~200s).*
➢ *There is no significant difference on PN emissions between cold start after warm-up phase and hot start.*
➢ *PN emission are mainly affected by the cold / hot start condition and TWC temperature.*
➢ *Total PN emissions at the hot start (1.49E+11) decreased up to 90 - 97 % compared to them at the cold start (1.5E+12).*

The effect of Catalytic stripper on PN emission



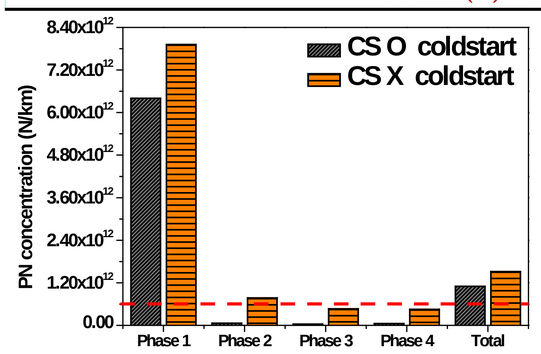
Real time PN emissions over WLTC at the cold start with and without CS

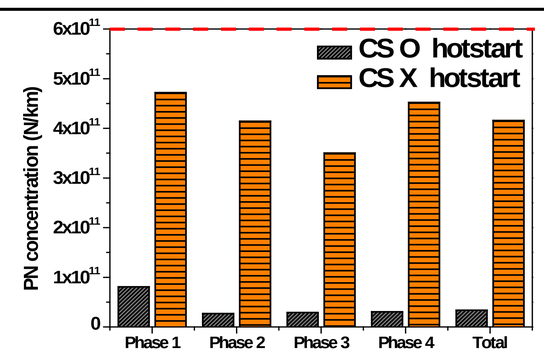


Real time PN emissions over WLTC at the hot start with and without CS

The result of PN emission on WLTC with and without CS

Cold start / hot start	Catalytic stripper	PN emission	Phase 1	Phase 2	Phase 3	Phase 4	Total
Cold start	X	PN (N/km)	7.9181E+12	7.71E+11	4.67E+11	4.49E+11	1.52E+12
	O	PN (N/km)	6.402E+12	6.15E+10	3.7E+10	5E+10	1.1E+12
		CS effect (%)	19.1463161	92.02336	92.07674	88.87777	27.48133
Hot start	X	PN (N/km)	4.7171E+11	4.14E+11	3.5E+11	4.52E+11	4.16E+11
	O	PN (N/km)	8.0661E+10	2.68E+10	2.9E+10	3.03E+10	3.35E+10
		CS effect (%)	82.9002114	93.53086	91.71527	93.29329	91.94661





➢ *Except PN emission on phase 1 of cold start, there are similar trends on the effect of CS (90 %).*
➢ *The total PN emissions were 1.10 x10^{12} N/km with CS and 1.50 x10^{12} N/km without CS.*
➢ *The 27 % of PN emissions at the cold start were volatile particles which were removed by the CS.*
➢ *The 92 % of PN emissions at the hot start were volatile particles which were removed by the CS.*
➢ *Solid particles composed a large portion of total particles in the warm-up phase because accumulation mode particles are highly formed at the cold start.*
➢ *Volatile particles consisted of about 90 % of the total particles at the cold start after warm-up phase and hot start.*

Conclusion

The effect of cold start / hot start

➢ **Particles were primarily formed in the warm-up phase due to fuel-rich mixture, incomplete combustion and Cylinder being cold.**
➢ **Accumulation mode particles dominated the cold start PN size distribution because GDI causes fuel impingement on combustion chamber surfaces and pistons.**

The effect of catalytic stripper

➢ **Solid particles composed a large portion of total particles in the warm-up phase because accumulation mode particles were extremely formed before TWC reached the LOT.**
➢ **Volatile particles consisted of about 90 % of the total particles at the cold start condition after warm-up phase and hot start condition.**

➢ **This research will offer some insight into the characteristics of PN emissions for forthcoming emission regulation depending on start condition and usage of CS.**

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