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Comparison of PN filtering efficiency with GPF from a GDI vehicle over laboratory and real-world driving condition

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Introduction

Emission regulations has strengthened continuously to meet the demands of improvement of air quality

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As the fact that there has been a huge gap between the results measured through a pre-existing certification test and the real-world driving conditions has revealed, WLTC was adopted as an emission regulation test from September 2017

To satisfying emission regulations, which have been reinforced recently, the propagating trend of a GDI engine has been magnified

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By spraying a fuel into each cylinder directly, the flame quenching phenomenon occurs more frequently in GDI engine

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GDI engine generally exhibits a higher particle number (PN) and particulate mass (PM) emissions than PFI engine

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The C.F of RDE PN is set as **1.5** including cold-start at the moment

This study has focused on the **PN emissions** from a gasoline direct injection vehicle over WLTC with or without GPF

Experiment Apparatus and Conditions

2.4 ℓ GDI Engine

Engine Type	Wall-guided Stoichiometric Direct Injection
Engine Displacement	2,359 cc
Compression Ratio	11.3 : 1
Max. Power	201 ps / 6,300 rpm
Max. Torque	25.5 kg·m / 4,250 rpm
Transmission	6-Speed A/T
Exhaust System	Three-way catalytic converter
Regulation Category	ULEV2, PZEV

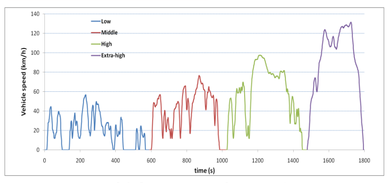
PPS

Particle size range	~ 2.5 μm
Concentration range	1 μg/m³ ~ 250 mg/m³
Response time	10 ms
Sample flow	9.75 L/min (vacuum driven)

DMS

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

Test Route



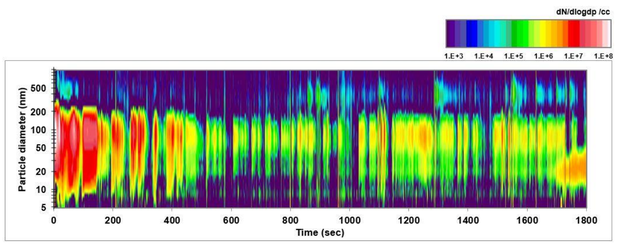
Vehicle test mode-WLTC

RDE Route

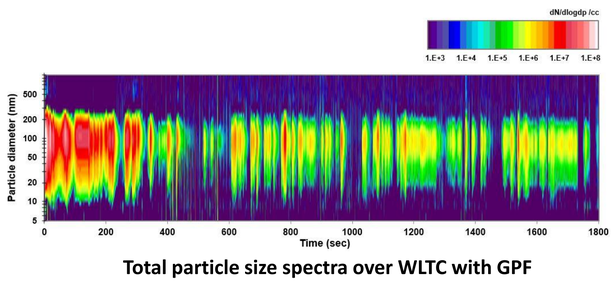
Route	Urban	Rural	Motorway	Total
Distance (km)	23	23	23	69
Route Possession (%)	33.3	33.3	33.3	100
Average Duration (s)	3831	1312	923	6066

Results

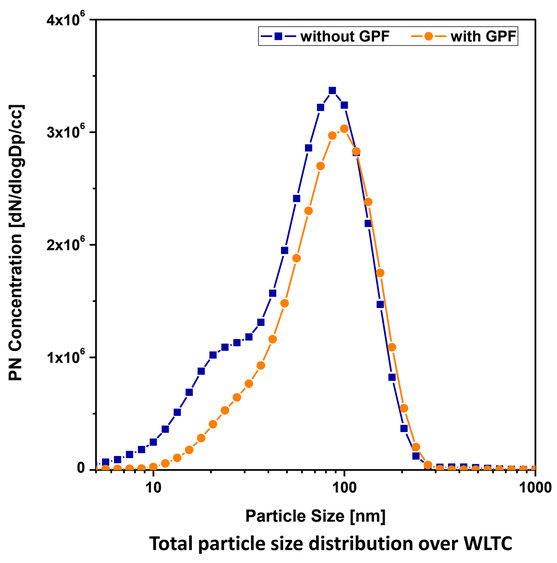
PN size distribution on WLTC with and without GPF



Total particle size spectra over WLTC without GPF



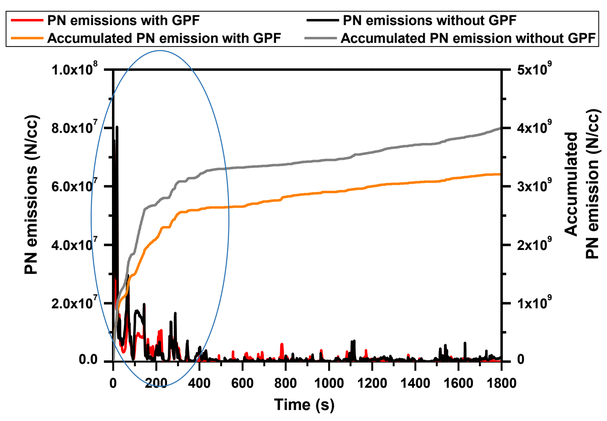
Total particle size spectra over WLTC with GPF



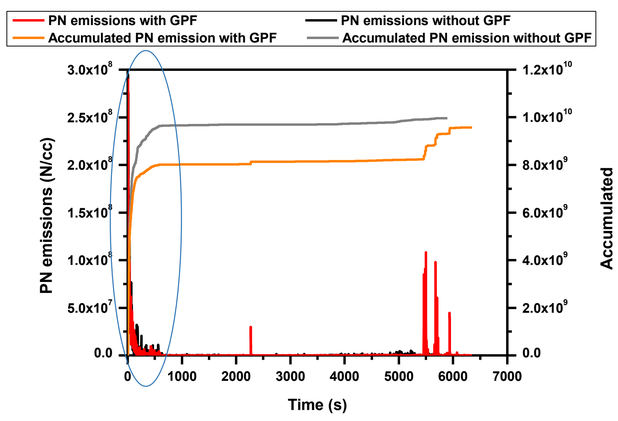
Total particle size distribution over WLTC

- **Particle emissions exhibit a high concentration at the initial period of the start-up**
  - → Particle filtration efficiency is very low until TWC reach the *Light-off temperature*.
  - → Cylinder wall has not warmed yet, there exist high probability of incomplete combustion.
  - → While heating function is working on, more fuel is supplying to have a rich air to fuel ratio ($\lambda \leq 14.7$).
- **Accumulation mode particles are seem to be overwhelming as fuel impingement occurs on the cylinder and piston wall after the engine warmed up.**
- **GPF is better filter out accumulation mode particles (relatively large) than nucleation mode particles.**
  - → Inhomogeneous porosity and pore size distribution of GPF are important factors on filtration performance.

Comparison of Time-resolved PN concentration with and without GPF



Real time PN emission over WLTC with and without GPF



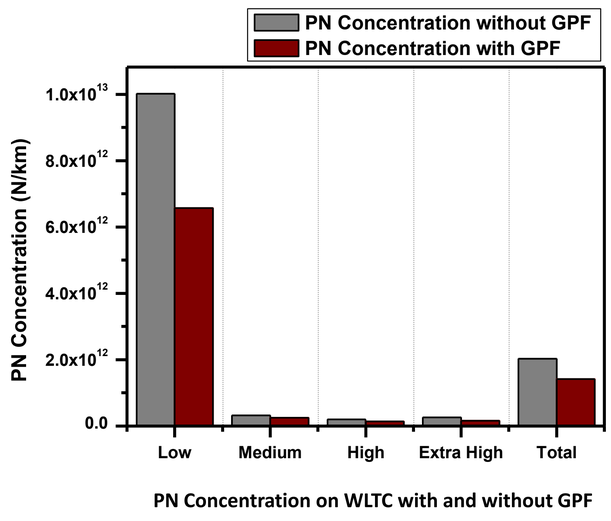
Real time PN emission over RDE with and without GPF

- **Most of PN emission** were emitted in the warm-up phase (~300s).
- Whether GPF is installed or not, there is **no significant difference on PN emissions** after warm-up phase.
- **The tendency of PN regeneration** occurs at the motorway when vehicle speed as well as exhaust gas temperature increase.
- Total PN emission over **WLTC** indicates **30 %** of reduction after the GPF have been installed.
- Total PN emission over **RDE** indicates **12.4 %** of reduction after the GPF have been installed.

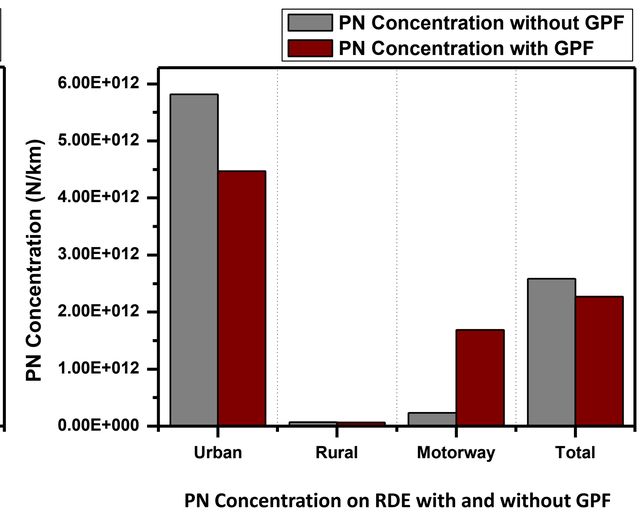
The result of PN emission over WLTC/RDE with and without GPF

	GPF	PN emission	Phase 1	Phase 2	Phase 3	Phase 4	Total
WLTC	Without GPF	PN (N/km)	1.00×10^{13}	3.19×10^{11}	2.05×10^{11}	2.56×10^{11}	2.03×10^{12}
	with GPF	PN (N/km)	6.57×10^{12}	2.50×10^{11}	1.37×10^{11}	1.65×10^{11}	1.42×10^{12}
		GPF effect (%)	*- 34.3*	*- 21.6*	*- 33.2*	*- 35.5*	*- 30.0*

	GPF	PN emission	Urban	Rural	Motorway	Total
RDE	Without GPF	PN (N/km)	5.82×10^{12}	6.98×10^{10}	2.35×10^{11}	2.59×10^{12}
	with GPF	PN (N/km)	4.47×10^{12}	6.22×10^{10}	1.69×10^{12}	2.27×10^{12}
		GPF effect (%)	*- 23.2*	*- 10.9*	*+ 619.1*	*- 12.4*



PN Concentration on WLTC with and without GPF



PN Concentration on RDE with and without GPF

- *Except in the case of motorway in RDE test*, there exist **26.5%** of reduction on average after GPF have been installed.
- The total PN emissions over WLTC were 1.42×10^{12} with GPF and 2.03×10^{12} without GPF.
- The total PN emissions over RDE were 2.27×10^{12} with GPF and 2.59×10^{12} without GPF.
- As vehicle speed as well as exhaust gas temperature increase at the motorway phase, the tendency of PN regeneration occurred and abnormal levels of PN were emitted.

Conclusion

- **Most particles were primarily emitted in the warm-up phase** due to fuel-rich mixture, incomplete combustion and cylinder being cold.
- To meet the recent regulation of **a particle number (PN) limit of 6×10^{11} N/km** for all GDI vehicles, *application of GPF is expected to necessitate.*
- Since there exist lots of variations on real world which have a influence on driving pattern, it seems to be that the **GPF is more effective over Chassis dynamometer test** than RDE.
- Considering a various conditions occur in the RDE test, it may be necessary to develop better GPF control logic with low PN emissions.

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

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