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# Size-resolved Nano-particle Filtration Characteristics with Metal foam Gasoline Particulate Filter (GPF) for a modern GDI vehicle


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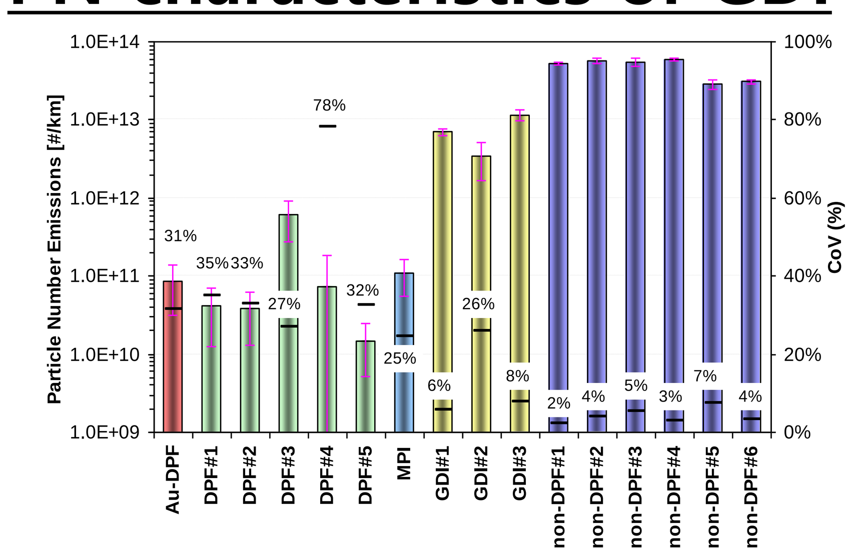
## Introduction

### Main issue about modern GDI vehicle ; PN

- Locally rich A/F mixture
- Wall-wetting phenomena
  - Cylinder wall
  - Piston crown

### PN characteristics of GDI



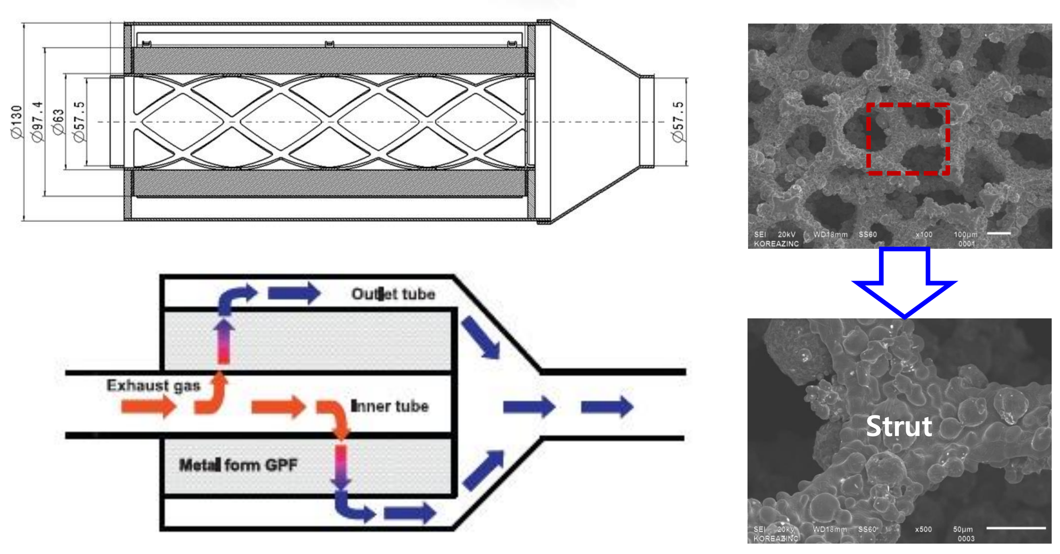

### Necessity of GPF for future PN regulation

## Experiment Method

### Metal foam filter (GPF)

Alloy Foam

- Super alloy porous media with opened pore structure
- Characteristics
  - High-temperature sintered super alloy : Ni, Cr, Al, Fe
  - Uniformly opened pore structure
  - large surface area by alloy powder method
  - Various pore sized alloy form
  - Light weight : 300~650 kg/m³



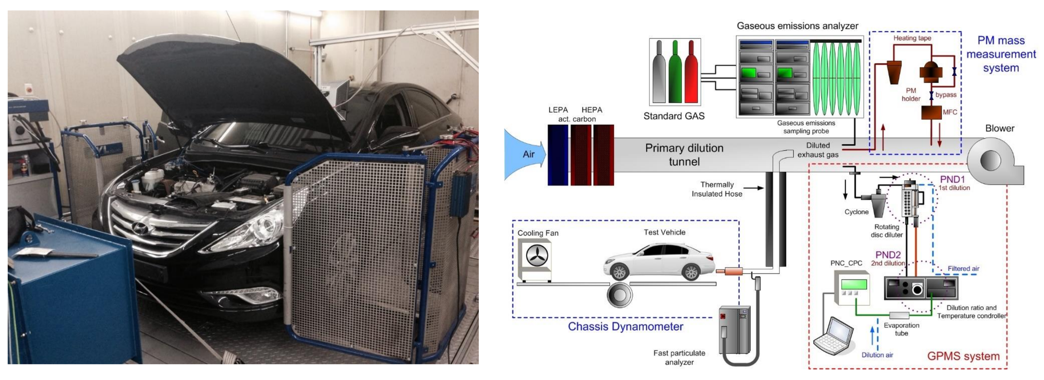

### EU certificate mode – NEDC (New European Driving Cycle)

## Experimental Apparatus

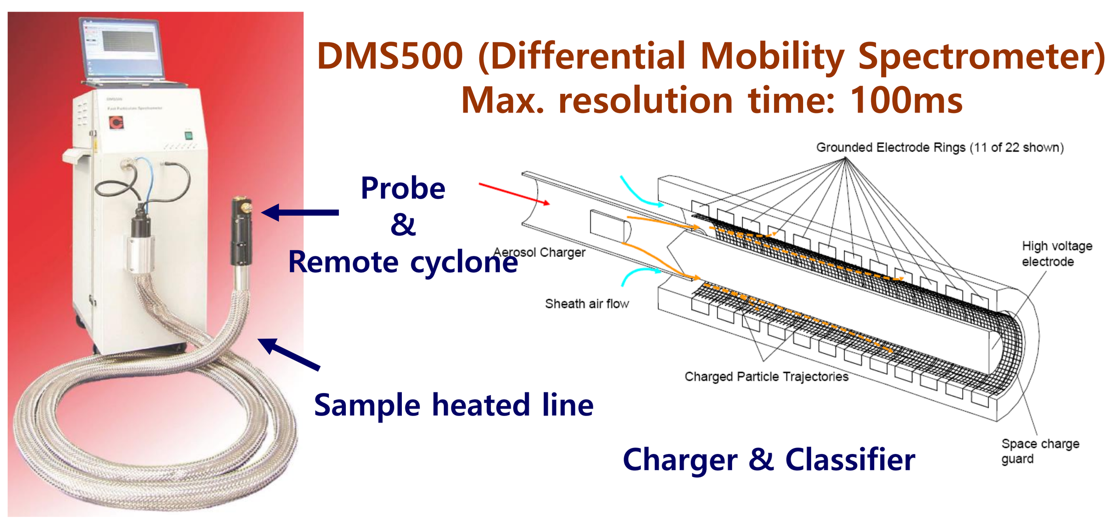
### Test vehicle specifications

| | |
|---|---|
| Engine Type | 2.4L I4 Stoichiometric Direct Injection |
| Displacement | 2,359 cc |
| Compression ratio | 11.3 : 1 |
| Fuel system | Camshaft-driven high pressure pump |
| Exhaust system | Under-floor catalytic converter |
| Max. power | 201hp |
| Max. torque | 25.5kg.m |
| Transmission | 6-speed A/T |

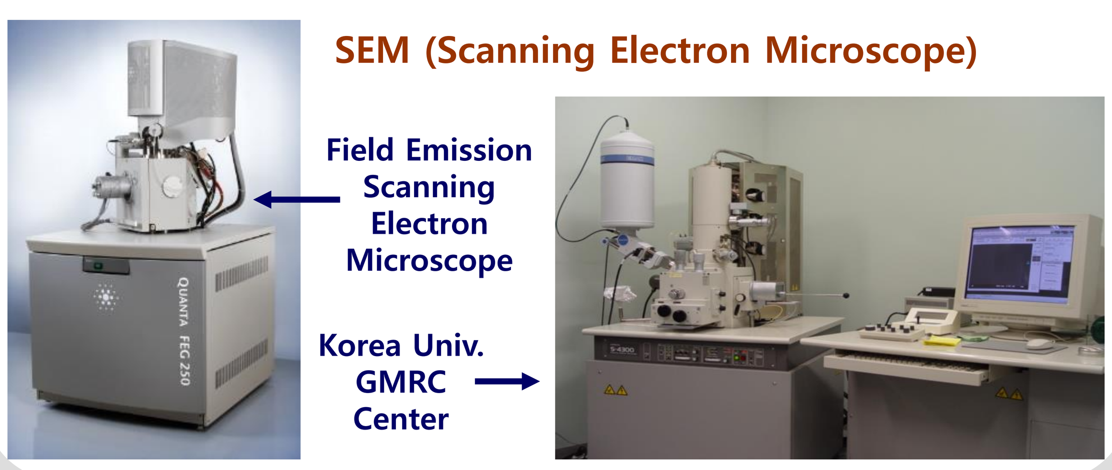
### Vehicle test schematic diagram



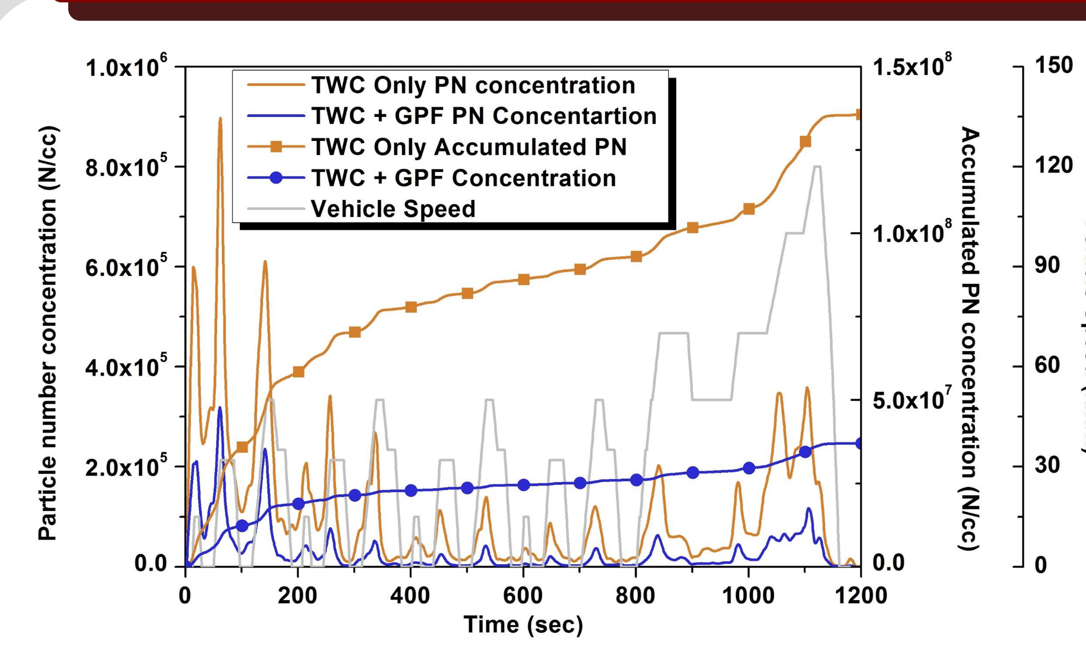
### Size-resolved nano-particle measurement system



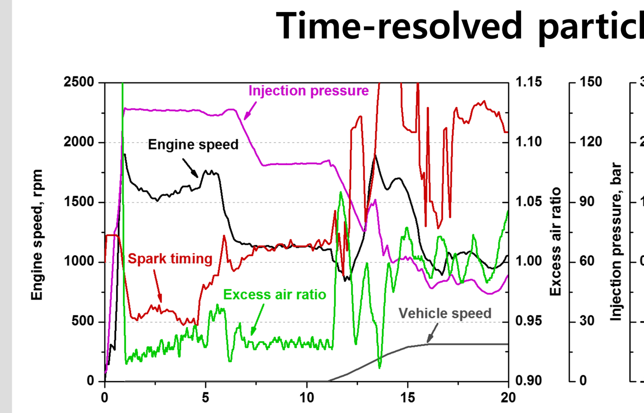

### Nano-particle morphology analysis equipment



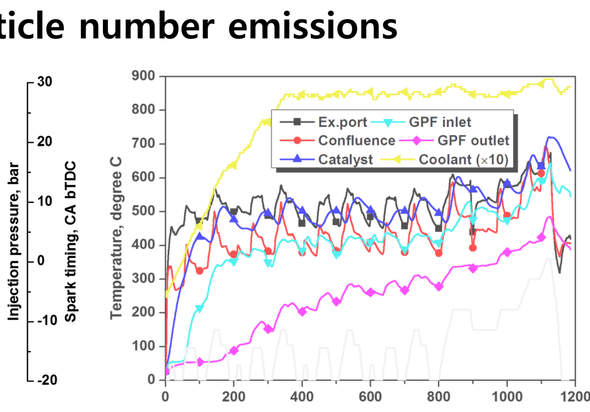

## Nano-particle emissions



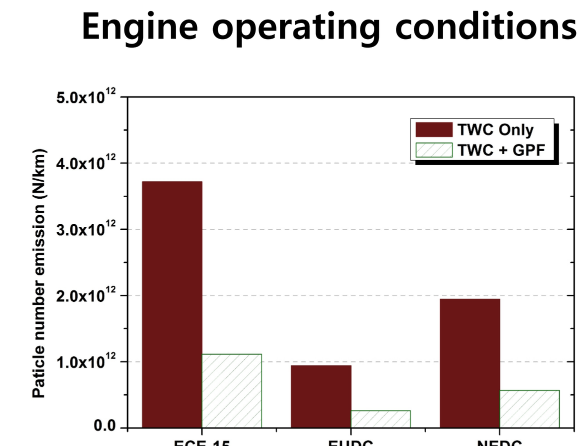

Time-resolved particle number emissions



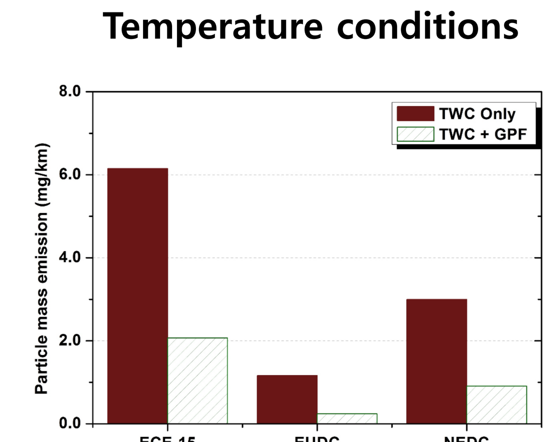

Engine operating conditions



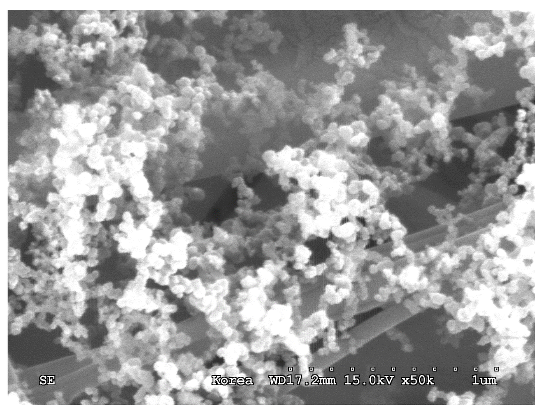
Temperature conditions



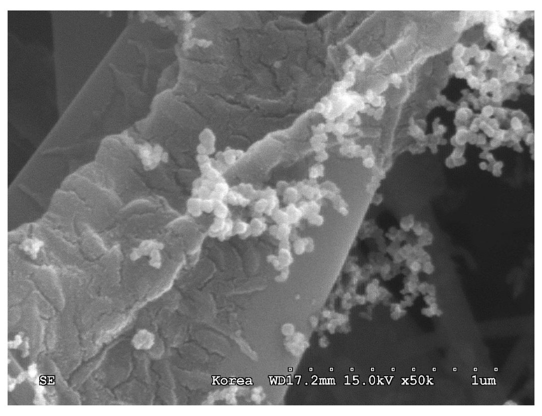

Comparison of particle number




Comparison of particle mass



TWC-only FE-SEM image

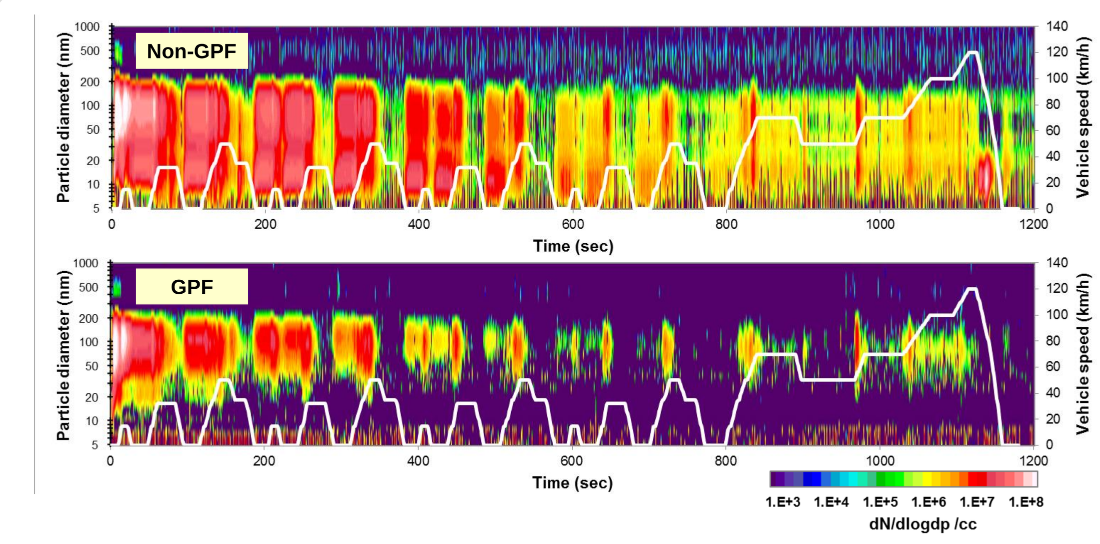


TWC+GPF FE-SEM image

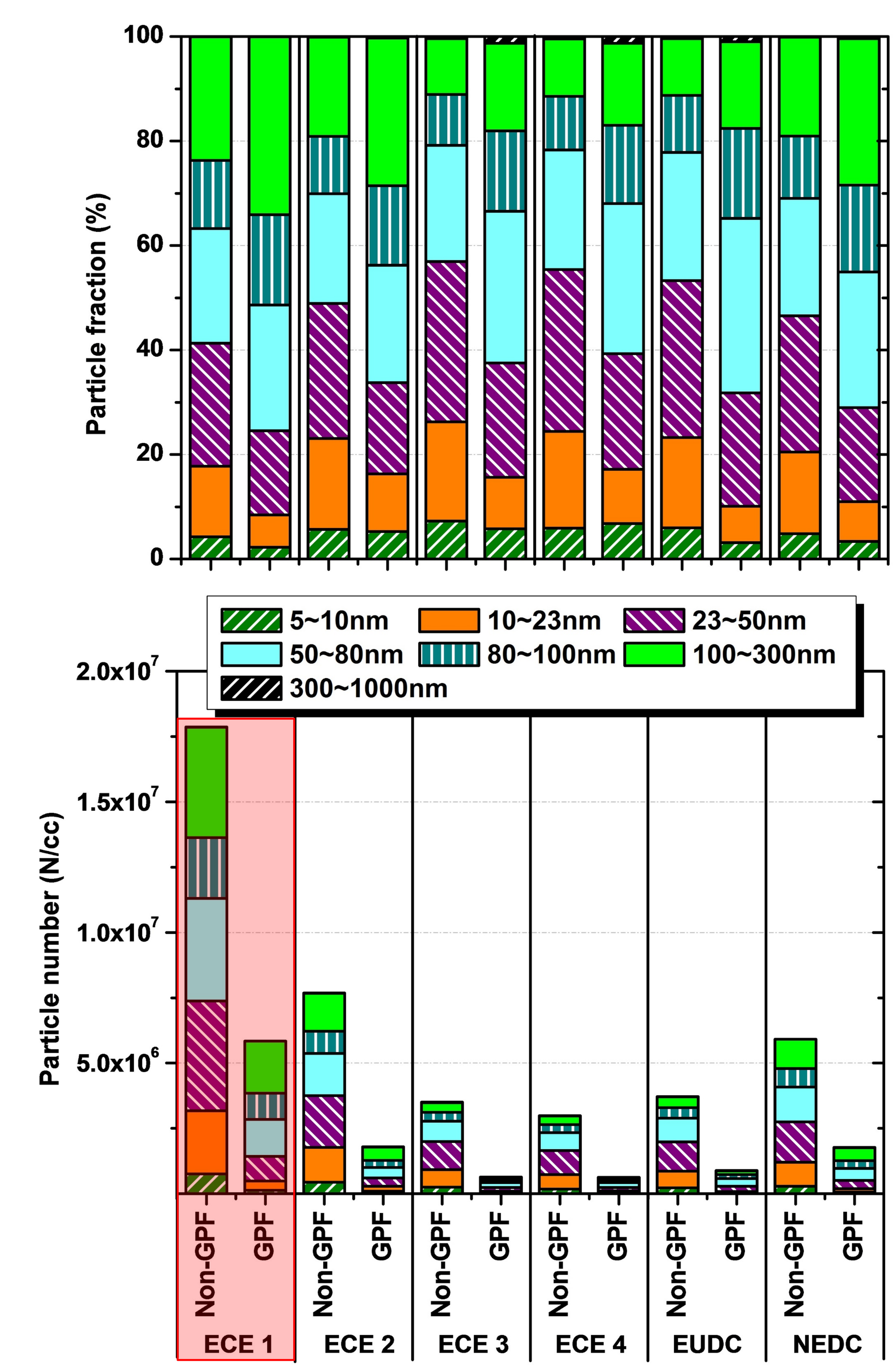
Nano-particle emission evaluation

| | TWC-only | | TWC+GPF | | Filtration Eff. | |
|---|---|---|---|---|---|---|
| | PN [#/km] | PM [mg/km] | PN [#/km] | PM [mg/km] | PN [%] | PM [%] |
| ECE-15 | 3.72E+12 | - | 1.12E+12 | - | 70 | - |
| EUDC | 9.41E+11 | - | 2.60E+11 | - | 72 | - |
| NEDC | 1.95E+12 | 3.030 | 5.68E+11 | 0.909 | 71 | 70 |

## Size-resolved characteristics




Time/Size-resolved PN emissions




Size-resolved particle number/fraction

- TWC-only GDI vehicle emits 57% of PN under ECE-1 phase
- With GPF, filtration efficiency under ECE-1 mode was 68%
- GPF is more efficient for small size nano-particle reduction

## Conclusion

### Nano-particle emission evaluation

- Modern GDI vehicle was inspected to evaluate PN/PM emission filtration efficiencies.
- Particle number/mass emissions were reduced up to 71% and 70% under NEDC mode, respectively
- With FE-SEM image, it was clearly verified that GPF system could drastically reduce nano-particles

### Size-resolved characteristics

- There was no critical difference of size distribution between TWC-only and TWC+GPF system.
- TWC only vehicle emits 1.95E+1 #/km of nano-particles, which excesses EURO 6-c regulation.
- The key of the solution of drastic reduction of PN is decreasing PN emissions under cold start phase.
- GPF system could reduce these PN emissions up to 68% (with respect to NEDC first ECE-15 mode).
- Totally, with GPF system, modern GDI vehicle could satisfy future stringent nano-particle regulation.

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## 1. INTRODUCTION

- Modern Gasoline Direct Injection (GDI) vehicle would be suffering from satisfying Particle Number (PN) regulation, especially in Europe.
- There were several researches including Particle Measurement Program (PMP) inter-laboratory correlation test, which indicated the excessive PN emissions of GDI vehicle comparable even with non-DPF diesel vehicle.
- Nowadays, few OEM decided - and the others might be doing so - to adopt Gasoline Particulate Filter (GPF) system to comply with forthcoming legislation because of its performance per price.

## 2. EXPERIMENTAL APPARATUS

- Thus, we focused on PN characteristics from modern GDI vehicle (HYUNDI-KIA MOTORS) with respect to particle size depending on whether or not equipped with GPF (ALANTUM Co.) or not.
- We used GDI vehicle which has displacement of 2.4 L and compression ratio of 11.3 to 1. Also, the vehicle has 6-speed auto transmission system and under-floor three-way catalytic converter.
- The key experimental setup was DMS500 (CAMBUSTION Co.) which could facilitate investigation of size-resolved nanoparticle characteristics. Working principle of DMS is that a balance of inertia force and electric-mobility cause difference streamline by the size of particle in a detector.
- Furthermore, we took FE-SEM (field emission scanning electron microscope, KOREA UNIVERSITY) image of sampled filter frame to identify filtration efficiency qualitatively.

## 3. EXPERIMENT METHOD

- The GPF system is composed of Ni-Cr-Al-Fe alloy substrate which has various pore sized foam structure. Axial flow goes through the 1st substrate area (inner tube) and filtered exhaust gas is disposed through 2nd substrate area (outlet tube).
- Total outer diameter of GPF system is 130 mm and inlet diameter is 57.5 mm respectively. Non-filtered weight of the after treatment system is 300 kg/$m^3$ and filtered weight of it is up to 650 kg/$m^3$.
- The GDI vehicle was investigated under EU certification test mode, NEDC (New European Driving Cycle).

## 4. NANOPATICLE EMISSIONS

- In the first figure (Time-resolved particle number emissions), dark yellow lines show PN emissions from TWC-only GDI vehicle, blue lines show that of TWC+GPF vehicle, respectively, and grey line shows vehicle speed. Simple line means real-time PN concentration while dotted line indicates accumulated PN emissions.
- As you see, from cold start phase to end of the test mode, GPF system caused drastic decrease of PN emissions around 70% in accumulated concentration wise.
- Overall engine operation parameter and temperature conditions were given here. For earlier warm-up of after treatment system, slightly rich air-fuel ratio condition was maintained for 11 seconds and spark timing was delayed for 5 seconds. Temperatures near the engine were increased with a start of the test mode, reaching LOT (light-off temperature) in about 90 seconds (350 Celsius degrees for TWC, 200 Celsius degrees for GPF, respectively).
- Following the PN & PM (particle mass) summary graphs and table, averagely 70% of particles filtered with GPF system. And the same results are shown in SEM image below. Morphologically, the shape of particles is a wide-spread aggregate of lots of small spherical particulates inconsistent with that of diesel particulates.

## 5. SIZE-RESOLVED CHARACTERISTICS

- From the top, time & size-resolved PN emissions are given like this. The color of the graph shows particle number concentrations. From purple to red/white color, it indicates increasing of PN emissions. X axis indicates time and particle size is shown in Y axis.
- As you can see again, TWC+GPF system shows great filtration efficiency not only acceleration timing, but also during not only cold start phase which is one of the main conditions of an excessive PN emissions from GDI vehicle, where especially small size of particulates decreased more efficiently.
- Modern GDI vehicle emits about 57% of PN emissions during the first quarter of ECE 15 mode (designated as ECE-1; 1$^{st}$ and 2$^{nd}$ hill of NEDC mode) and, simultaneously, filtration efficiency of GPF was 68% in this period.
- In the same perspective, following these two graphs which shows PN concentration and fraction with each single mode, metal foam GPF system has strength for reducing small size nanoparticles.

## 6. CONCLUSION

- Modern GDI vehicle was evaluated with respect to PN /PM filtration efficiency under NEDC mode.
- PN/PM filtration efficiency was 71%/70%, respectively and SEM images convinced of the same results again.
- There was no big difference of size distribution between TWC-only/TWC+GPF system, but there was evident effect of GPF system on small particulates.
- GPF system could reduce PN emissions under not only acceleration terms, but also cold start period up to 68%.
- In performance per price wise, GPF system is definitely robust solution to meet future stringent nanoparticle control including regulation on sub-23 nm particulates.