SUREAL-23 Project: Measurement of sub-23 nm particles on Gasoline Direct Injection Engine under various conditions

Authors: Stéphane ZINOLA (IFPEN), Mickaël LEBLANC (IFPEN), Leonidas CHASAPIDIS (CERTH/APTL), Daniil DELOGLOU (CERTH/APTL), Penelope BALTZOPOULOU (CERTH/APTL), Anastasios MELAS (CERTH/APTL), Athanasios G. KONSTANDOPOULOS (CERTH/APTL), Tobias RÜGGEBERG (FHNW), Martin FIERZ (FHNW), Heinz BURTSCHER (FHNW), Alberto TEJERO (SEADM), Mario AMO (SEADM), Daoíz ZAMORA (SEADM)

23rd ETH-Conference on Combustion Generated Nanoparticles, Zürich, June 19th, 2019

This project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 724136.
**CONTEXT**

- **Current Euro regulation:**
  - PN limit at $6.10^{+11}$ part/km, fuel neutral, cycle WLTC + RDE limit with a CF = 1.5
- **PMP Protocol (chassis dyno):**
  - Hot dilution + Evaporation Tube + Cold dilution
  - Particle Number Counter with a 50% cut-off diameter at 23 nm to avoid condensation / re-nucleation artefacts

![Diagram of PMP system](https://example.com/pmp-diagram.png)

Red: Semivolatile particles
Black: Solid (mostly soot) particles

Courtesy William Robertson, CARB

Bukowiecki et al., 2002
CONTEXT

- Limitations of the current PMP protocol:
  - 50% cut-off diameter at 23 nm
  - Solid particle only
  - Initially developed for Diesel engines

A significant part of PN emissions is missed (solid and/or semi-volatile), especially for non-Diesel applications.

How to measure below 23 nm with high reliability/reproducibility?

B. Giechaskiel et al. (2017)
SUREAL-23 PROJECT

● Focus:
  ○ Exhaust particles, smaller than regulation cut-off of 23 nm, Light Duty engines (Diesel and gasoline).

● Objectives:
  ○ Complement and extend existing instrumentation for particles below 23 nm.
  ○ Further understand the nature of the particulate emissions below 23 nm.
  ○ Support future emissions regulations, including the recent RDE one.

● Partnership:
Objective:

- Evaluation of the new instrumentation for particles below 23 nm on GDI engine
- Comparison with state-of-the-art apparatus
- Determination of the < 23 nm / > 23 nm ratio

Dual-stage diluter
- Variable dilution ratio: 30 → 120
- CS with Sulfur Trap
- CS conv. eff > 99.9% @ 20 l/min
- Penetration 75% @ 10 nm

ICAD
- Induced Charge Aerosol Detector
- 50% cut-off diameter at ~ 10 nm
- Max operating temperature ~ 150°C
- dilution can be reduced
- Max. PN conc. ~ 1.10^7 part/cm^3

HM-DMA
- High resolution Particle Size Distribution in the range 4 – 30 nm
- Max operating temperature ~ 200°C
- Fast electrometer: response time ~100 ms

Comparison with state-of-the-art apparatus

CPC 3775
CPC 3776
AE33
DMS500
EXPERIMENTAL SETUP

Engine
- Gasoline Direct Injection Engine w/Turbocharger
- Volume displacement 1.3 L
- Engine Power = 120 kW

Dekati diluter

Prototype dual-stage diluter APTL

Sampling tube

Prototype instrument

Reference instrument

Exhaust line

Vent

DR meas.

CO2

CPC 3775
CPC 3776
AE-33

I-CAD

Reference instruments

Prototype instrument

Prototype instrument

HM-DMA

SEADM

DMS-500

EXPERIMENTAL SETUP IN THE TEST CELL
RESULTS: ICAD AND APTL DILUTER VALIDATION

- PN measurement on WLTC cycle from ambient temperature (~ 23 °C) (tailpipe):
  - Cycle representative of the EU regulation

- The APTL diluter, with a Catalytic Stripper, is relevant to measure PN with various diameters cut-offs
- The ICAD device exhibits consistent results compared to the reference devices
RESULTS: EFFECT OF DRIVING CYCLE AND START TEMPERATURE

- PN measurement on various cycles and start temperatures

| Sub-23 nm ratio decreases with total PN increase | True for RTS95 ambient cycle
| False for WLTC hot cycle |
| Sub-23 nm ratio increases with driving aggressiveness | True for hot conditions |
| High PN emissions is preponderant for ambient conditions |
| Sub-23 nm ratio increases at lower temperature start | True for WLTC cycle |
| High PN emissions is preponderant for ambient conditions |

Several parameters can affect the sub-23 nm ratio – not only one parameter
RESULTS: EFFECT OF THE CATALYZED GPF

- PN measurement on WLTC cycle from ambient temperature (~ 23 °C) (tailpipe, w/ cGPF):

- PN down to the Euro 6d-Temp limit, whatever the measurement device and so the diameter cut-off.
- The conversion efficiency is about 90% regarding the number and 80% regarding the mass.
- Apparent inconsistency: the lowering of the diameter cut-off threshold does not lead to an increase of the PN.

### Device Cut-off diam (nm) GPF Eff.\
<table>
<thead>
<tr>
<th>Device</th>
<th>Cut-off diam (nm)</th>
<th>GPF Eff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICAD</td>
<td>10</td>
<td>90.8%</td>
</tr>
<tr>
<td>DMS500 &gt; 5 nm</td>
<td>5</td>
<td>94%</td>
</tr>
<tr>
<td>DMS500 &gt; 23 nm</td>
<td>23</td>
<td>93.6%</td>
</tr>
<tr>
<td>CPC3775</td>
<td>4</td>
<td>91.7%</td>
</tr>
<tr>
<td>CPC3776</td>
<td>2.5</td>
<td>88.8%</td>
</tr>
<tr>
<td>AE33 (mg/km)</td>
<td>-</td>
<td>79%</td>
</tr>
</tbody>
</table>
RESULTS: EFFECT OF THE CATALYZED GPF

- PN concentration in the range 5 – 23 nm is very low downstream of the cGPF
- Possible trapping and/or oxidation of the smallest particles by the cGPF
RESULTS: EFFECT OF THE CATALYZED GPF

Confirmation with the HM-DMA measurement (range 5 – 28 nm) on RTS95 cycle from ambient
The hybridization effect was evaluated by simulating the operation of an hybrid vehicle at the engine test bench. The Simcenter Amesim™ software was used, with the IFP-Drive library.

- Building of 2 Simcenter Amesim simulators: 1 conventional vehicle + 1 hybrid vehicle
- Generation of engine speed + load profiles
- Test bench monitoring with Morphée 2 supervisor
- PN exhaust measurement

Model of Parallel hybrid vehicle

Compact MPV vehicle 1430 kg

Battery capacity 1.55 kW.h
Electric Motor 40 kW
T-GDI engine 1.3L, 120 kw
6-speed manual gearbox
RESULTS: HYBRIDIZATION EFFECT

- Significant increase of PN emissions with hybridization (from x2.5 to x4 depending on the measurement device)
- Lower sub-23 nm fraction in hybrid mode

<table>
<thead>
<tr>
<th>Device</th>
<th>Cut-off diam (nm)</th>
<th>Conv. Mode</th>
<th>Hybrid Mode</th>
<th>% overPN hybride</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICAD</td>
<td>10</td>
<td>1.13E+12</td>
<td>3.53E+12</td>
<td>212%</td>
</tr>
<tr>
<td>DMS500 &gt; 5 nm</td>
<td>5</td>
<td>2.03E+12</td>
<td>5.93E+12</td>
<td>192%</td>
</tr>
<tr>
<td>DMS500 &gt; 23 nm</td>
<td>23</td>
<td>1.18E+12</td>
<td>4.62E+12</td>
<td>293%</td>
</tr>
<tr>
<td>CPC3775</td>
<td>4</td>
<td>4.77E+12</td>
<td>1.21E+13</td>
<td>153%</td>
</tr>
<tr>
<td>Sub-23 ratio</td>
<td>-</td>
<td>52%</td>
<td>28%</td>
<td>-</td>
</tr>
</tbody>
</table>
**RESULTS: HYBRIDIZATION EFFECT**

- Substantial PN peaks during the thermal engine restart phases:
CONCLUSIONS

- Lowering the cut-off diameter from 23 nm to 10 nm leads to an increase of the total PN at the tailpipe
  - This increase is limited to around 10% - 20% because of the use of a Catalytic Stripper that efficiently convert the volatile fraction
  - This increase is not observed downstream of a catalyzed particulate filter (cGPF)

- Hybridization
  - The total PN increases from a factor x2.5 to x4 - Reduction of the sub-23 nm fraction
  - Efforts are required to optimize hybrid management not only regarding FC / CO₂ but also regarding PN emissions
ACKNOWLEDGEMENTS

Horizon 2020 research and innovation program for funding the SUREAL-23 project

The partners of the project

... and thank you for your attention. Questions?

Find us on:

🌐 www.ifpenergiesnouvelles.com
🐦 @IFPENinnovation