BC AFTER DIESEL PARTICULATE FILTERS

6th ICCT Workshop on Marine Black Carbon Emissions
17th of September 2019
Helsinki, Finland
Dr. Daniel Peitz
<table>
<thead>
<tr>
<th><strong>KEY FACTS</strong></th>
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<tbody>
<tr>
<td><strong>hugengineering</strong></td>
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<tr>
<td><strong>A FAURECIA COMPANY</strong></td>
</tr>
<tr>
<td><strong>Turnover</strong></td>
</tr>
<tr>
<td><strong>Employees</strong></td>
</tr>
<tr>
<td><strong>Headquarters</strong></td>
</tr>
<tr>
<td><strong>Subsidiaries</strong></td>
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<tr>
<td><strong>Certification</strong></td>
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*2018

| **faurecia** |
| **inspiring mobility** |
| **Turnover** | € 17.5 billion* |
| **Employees** | 122,000 |
| **Headquarters** | Nanterre, France |

More than 300 sites including 35 R&D centers in 37 countries

*2018
INNOVATION FOR YOU
BASED ON EXPERIENCE

1988
Urea-operated DeNOx System, Schaffhausen

1992
SCR Marine System

1993
CODiNOx System, Zuurbier

2003
Serial order DPF, SBB locomotive

2005
DPF installation Megayacht, MY White Rose of Drachs

2014
1st ultra-low NOx powerplant

2015
IMO Tier III certification nauticlean™

1983
Foundation Company

2018
Acquisition by Faurecia S.A.

2011
Acquisition by ElringKlinger Group

2016
Acquisition of CODiNOx Beheer Group, Netherlands
# PRODUCT PORTFOLIO - OVERVIEW

<table>
<thead>
<tr>
<th>Stationary</th>
<th>Power plants</th>
<th>Cogeneration plants</th>
<th>Emergency power</th>
<th>Power range</th>
<th>Installed units</th>
<th>Installed power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>200 – 40,000 kW</td>
<td>2,100</td>
<td>9.5 GW</td>
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<tr>
<td>Mobile</td>
<td>CO₂-fertilizing in greenhouses</td>
<td></td>
<td></td>
<td>200 – 6,000 kW</td>
<td>1,800</td>
<td>3.2 GW</td>
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<tr>
<td></td>
<td>On- and offshore vessels</td>
<td>Cruise liners</td>
<td>Freight vessels</td>
<td>500 – 40,000 kW</td>
<td>550</td>
<td>1.5 GW</td>
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<tr>
<td></td>
<td>Yachts</td>
<td>Inland water vessels</td>
<td>Ships</td>
<td>200 – 9,000 kW</td>
<td>850</td>
<td>600 MW</td>
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<tr>
<td></td>
<td>Locomotives</td>
<td>Track construction machines</td>
<td>Railcars</td>
<td>200 – 5,000 kW</td>
<td>1,100</td>
<td>1,200 MW</td>
</tr>
<tr>
<td></td>
<td>Construction machines</td>
<td>Commercial machines</td>
<td>Trucks &amp; buses</td>
<td>15 – 5,000 kW</td>
<td>More than 37,000</td>
<td>n.m.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Agricultural &amp; forest machines</td>
<td></td>
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DIESEL PARTICULATE FILTER (DPF)

• Extensive experience for high speed engines on ULSD/MGO
• First projects for small (< 3 MW) medium speed engines on MGO/MDO
• Under development for large (> 3 MW) medium speed engines on MGO/MDO
• Medium speed engines on HFO under testing, but so far not promising
• Low speed 2-stroke engines so far out of discussion (commercial & technical reasons)
diesel burner for regeneration (burner pipe or chamber)
reactor housing with filter cassettes (various aspect ratios)
→ modular setup for flexible arrangement
Yacht/inland water vessel DPF+SCR

nauticlean™
Exhaust Gas Purification System
Diesel Particulate Filter with Active Regeneration and Selective Catalytic Reduction

-80% NOx
-97% BC
MARINE DPF EXPERIENCE
MOTIVATION

Clean decks and upholstery «no visible black carbon»
PN (particle number) limit of 250’000 #/cm³ for all NRMM VERT certificate accepted (DPF with >97% PN reduction)

→ wall-flow DPF for locomotives, construction machinery, vessels, …
EXPERIENCE IN SWITZERLAND

Field conditions:
High speed diesel engines up to few MW
EN 590 diesel fuel required (max. 10 ppm sulfur)

Only clean exhaust is measured by CPC (condensation particle counter),
all particles above 23 nm are counted, independent of particle composition

accredited measurement devices are typ. inappropriate for raw exhaust
⇒ only approximations for relative PN abatement in the field (but >97%)
⇒ no monitoring of black carbon emissions or abatement efficiency
Annual check with additional raw gas measurement:

1’500 kW high speed diesel engine with active regeneration DPF

30% engine load: 8’300’000 #/cm³ (raw gas)

36’700 #/cm³ (clean gas)

⇒ 99.6% PN (particle number) abatement based on CPC measurement
LUXURY YACHT WITH DPF

SCR spot checks, additionally Hug-conducted DPF evaluation

270 & 200 kW high speed diesel engine gensets with active regeneration DPF
Engine operation on ISO 8217 DMA («MGO») with 1000 ppm sulfur (ECA 0.1%)

Measurement with AVL MSS (PAS measurement principle)

<table>
<thead>
<tr>
<th>Engine</th>
<th>Load</th>
<th>Raw (mg/kWh)</th>
<th>Clean (mg/kWh)</th>
<th>Abatement</th>
</tr>
</thead>
<tbody>
<tr>
<td>270 kW</td>
<td>50%</td>
<td>42</td>
<td>0.30</td>
<td>99.3%</td>
</tr>
<tr>
<td></td>
<td>75%</td>
<td>47</td>
<td>0.26</td>
<td>99.4%</td>
</tr>
<tr>
<td>200 kW</td>
<td>50%</td>
<td>70</td>
<td>0.13</td>
<td>99.8%</td>
</tr>
</tbody>
</table>

➤ >97% black carbon abatement based on PAS measurement
LAB TESTING OF DPF

Filtration efficiency assessment by different analytics

Cambustion Diesel Particle Generator (DPG) test setup
(controlled hot air flow with EN 590 diesel burner-generated soot)

Measurement analytics:
PN – condensation particle counter (CPC)
PM (soot) – AVL micro soot sensor (MSS)
PM (soot) – AVL smoke meter (FSN)

Filter cassette taken from a luxury yacht after 6’000 h field operation
Soot filter cake was burnt via a regeneration before start of test
RESULTS

>97% abatement based on all measurements after <200 s
FIELD MONITORING

100’s of marine DPF installations available, but no PM, PN or BC regulation → no scientific monitoring of emissions or abatement efficiency

Equipment logistics, space requirements for installation, sampling possibilities on site, operational restrictions, timetables and expenses associated with field measurements challenging as solely voluntary data acquisition

→ Invitation for collaboration partners to confirm field performance
NEXT STEPS

Besides luxury yacht and NRMM exposed applications new market drivers:

- Customers asking for «getting the job done, but green»
- Passengers caring about health and environment
- Classification notations such as «ultra low emission vessel – ULEV»

➔ DPF spreading to medium speed diesel engine applications

DPF integration requires rethinking of engine operation, e.g. fuel & lube*

* K. Christianen, Y. Loulidi, D. Peitz, L. Mattheeuws, T. Berckmoes
Integration and Matching of Diesel Particulate Filters for ABC Medium-Speed Engines, CIMAC Congress 2019, paper no. 361.
NEXT STEPS

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Horizon 2020 project «LeanShips»

Target was a cruise ship DPF for HFO with automatic ash removal

However, ash removal later limited to ISO 8217 DMA (MGO) and DMB (MDO) due to field trial results

Prototype in operation at Hug, but limited commercial interest due to exclusion of HFO operation
Thank you for your attention.