Mr Gerhard Rickert, BASF Catalyst
AECC NRMM & REC sub-group

AECC Test Program
Small Hand-held Equipment
Results

Brussels – 27 November 2012
Erratum note
(regarding PM measurements on small hand held machinery carried out by order of Association for Emissions Control by Catalyst AISBL in the period from Oct. 16th 2012 to Nov. 15th 2012)

The calculation of the absolutely emitted particulate mass based on the mass adherent to the filter plates shows a basic error. To be able to calculate the entire particulate mass, the overall volume through the dilution tunnel, as well as the partial flow over the filter plate is required.

The used CVS system records both volumes separately. The record of the overall volume being collected throughout an entire test is stopped after bag sampling time is over and is then automatically transferred to the data logging system.

To achieve sufficient deposits on the filter plates, the particulate mass sampling time had to be increased from 3 minutes (standard bag sampling time) to 10 minutes.

The automatic transfer of volume information derived from the bag sampling process (instead of the information from the particulate mass sampling process) led to a wrong dilution ratio which was used for the calculation of the overall particulate mass.

Since this calculation error is systematic and was not detected during the test campaign, all the results of particulate mass per volume, and kWh respectively, are incorrect. The effective PM values are by the factor 3.333 (10/3) higher than the previously published data. The relative relations between the different test carriers are not affected by this error.

Sincerely,

Ass.Prof. Dr. R. Kirchberger
Association for Emissions Control by Catalyst (AECC) AISBL

AECC members: European emissions control companies

Technology for exhaust emissions control on all new cars (OEM and Aftermarket) and an increasing number of buses & commercial vehicles, non-road applications and motorcycles.
Content

- Introduction
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Introduction

- Small hand-held equipment are regulated through the NRMM Directive 97/68/EC (chainsaws, leaf blowers, etc.)
- Contribution to air pollution inventory may not be predominant but occupational health is of primary concern with hand-held Non-Road Mobile Machinery.
- Objective of test program was to demonstrate emission levels of small hand-held state-of-the art equipment available in Europe, including low-cost import from Asia.
## Test Plan and Selection of Engines

- Evaluate state-of-the-art engines used in SHH applications.
- Regulated pollutant (HC, CO, NOx) according to Directive 97/68/EC.
- PM mass and number according to LD-PMP protocol.
- PM size distribution by SMPS on engines N°2 and 3.

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>Specifications</th>
<th>rpm</th>
<th>rpm certification</th>
<th>Mixture preparation</th>
<th>Oil/Fuel mixture ratio</th>
<th>Catalyst</th>
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</thead>
<tbody>
<tr>
<td>4 stroke dry sump lubricated without catalyst</td>
<td>Engine displ. [cm³]</td>
<td>25.0</td>
<td>max 11000</td>
<td>7000</td>
<td>carburetor</td>
<td>separated lubrication 10W30</td>
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<td>Power rating [kW]</td>
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<td></td>
<td></td>
<td></td>
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<td>2 stroke fuel/oil mixture lubricated fuel injection system without catalyst</td>
<td>Engine displ. [cm³]</td>
<td>72.2</td>
<td>max 10100</td>
<td>9500</td>
<td>fuel injection</td>
<td>synthetic oil 1:50</td>
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</tbody>
</table>
4. TYPE-APPROVALS STAGE II

Member States shall refuse to grant type-approval for an engine type or engine family and to issue the documents as described in Annex VII, and shall refuse to grant any other type-approval for non-road mobile machinery in which an engine is installed:

after 1 August 2004 for engine classes SN:1 and SN:2

after 1 August 2006 for engine class SN:4

after 1 August 2007 for engine classes SH:1, SH:2 and SN:3

after 1 August 2008 for engine class SH:3,

if the engine fails to meet the requirements specified in this Directive and where the emissions of gaseous pollutants from the engine do not comply with the technical and performance requirements of this Directive.

Notwithstanding the first subparagraph, an extension of the derogation period is granted until 31 July 2013, within the category of top handle machines, for professional use, multi-positional, hand-held hedge trimmers and top handle tree service chainsaws in which engines of classes SH:2 and SH:3 are installed.

### Cycle G3

<table>
<thead>
<tr>
<th>Mode number</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine speed</td>
<td>Rate speed</td>
<td>Intermediate Speed</td>
</tr>
<tr>
<td>Load %</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Weighting factor</td>
<td>0.85 (*)</td>
<td>0.15 (*)</td>
</tr>
</tbody>
</table>

The NOx emissions for all engine classes must not exceed 10 g/kWh.
Engine Power at Rated Speed

![Graph showing engine power vs. engine speed with annotations for different types of engines.]

- Engine power [kW] vs. engine speed [rpm]
- Idle speed indicated on the graph

Legend:

1. 4 stroke dry sump lubricated without catalyst
2. 4 stroke fuel/oil mixture lubricated without catalyst
3. 2 stroke fuel/oil mixture lubricated with catalyst
4. 2 stroke fuel/oil mixture lubricated with catalyst
5. 2 stroke fuel/oil mixture lubricated stratified scavenging without catalyst
6. 2 stroke fuel/oil mixture lubricated fuel injection system without catalyst

AECC — Association for Emissions Control by Catalyst RISBL
Open **Constant Volume Sampling**

![Diagram of open constant volume sampling](image)
Open **Constant Volume Sampling**
Open **Constant Volume** Sampling

- Evaporation tube temperature increased to 500°C to remove most volatiles.
Evaporation Tube Temperature Impact

- Because of high quantity of volatiles adsorbed to PM, the PM number was measured in 2 configurations of the evaporation tube: 350°C (LD-PMP procedure) and 500°C.
- Gas temperature was 220°C and 300°C respectively.

- No impact on PM number measured.
Measurement Procedure adapted for PM Sampling (3 repeats)

- Engine start
- Warm-up
- IDLE
- WOT

**Engin Speed [rpm]**
- 0
- 1000
- 2000
- 3000
- 4000
- 5000
- 6000
- 7000
- 8000
- 9000
- 10000

**Exhaust Gas Temperature [°C]**
- 0
- 50
- 100
- 150
- 200
- 250
- 300
- 350
- 400
- 450
- 500
- 550
- 600
- 650
- 700

**Spark Plug Seat Temperature [°C]**
- 0
- 50
- 100
- 150
- 200
- 250
- 300
- 350
- 400
- 450
- 500
- 550
- 600
- 650
- 700

**Time [s]**
- 0
- 100
- 200
- 300
- 400
- 500
- 600
- 700
- 800
- 900
- 1000
- 1100
- 1200
- 1300
- 1400
- 1500
- 1600
- 1700
- 1800
- 1900
- 2000
- 2100
- 2200

- PM sampled for 10 minutes
- PM sampling
Tests Results: Fuel Consumption

- **1** 4 stroke dry sump lubricated without catalyst
- **2** 4 stroke fuel/oil mixture lubricated without catalyst
- **3** 2 stroke fuel/oil mixture lubricated with catalyst
- **4** 2 stroke fuel/oil mixture lubricated with catalyst
- **5** 2 stroke fuel/oil mixture lubricated stratified scavenging without catalyst
- **6** 2 stroke fuel/oil mixture lubricated fuel injection system without catalyst

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- **g/kWh**

- **Fuel consumption [g/kWh]**

- **g/h**
Tests Results: calculated Air-Fuel Ratio

- All engines run rich, between 0.7 and 0.9.
- A/F ratio of the low-cost engine is the richer and the less controlled (larger error bar).
Tests Results: Exhaust Gas Temperature

idle

WOT

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4 stroke dry sump lubricated without catalyst</td>
</tr>
<tr>
<td>2</td>
<td>4 stroke fuel/oil mixture lubricated without catalyst</td>
</tr>
<tr>
<td>3</td>
<td>2 stroke fuel/oil mixture lubricated with catalyst</td>
</tr>
<tr>
<td>4</td>
<td>2 stroke fuel/oil mixture lubricated with catalyst</td>
</tr>
<tr>
<td>5</td>
<td>2 stroke fuel/oil mixture lubricated stratified scavenging without catalyst</td>
</tr>
<tr>
<td>6</td>
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</tr>
</tbody>
</table>
Tests Results: CO Emissions

- CO emissions are of similarly high level for most engines.
- The low-cost engine emitted the highest CO emissions.
- 2S fuel injection showed reduced CO emissions
Tests Results: HC Emissions

- HC emissions are lower for 4S engines than for 2S.
- The catalyst reduced HC emissions on 2S engine.
• NOx emissions are lower for 2S engines than for 4S.
• NOx emissions contribute relatively little to regulated HC+NOx (from 1 to 30%)
Tests Results: Emissions vs. Stage II Limits

- All engines met Stage II emissions limits but the low-cost model (N°4) is at the limit.
Tests Results: CO₂ Emissions

- CO₂ emissions of engine N°3 are higher because of CO conversion by catalyst
Tests Results: PM Mass Emissions

- PM mass results are repeatable.
- PM mass level depends on engine working principle.
- PM vary from 18 to 410mg/kWh.
- Presence of catalyst on 2S engine reduces PM mass.

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4 stroke dry sump lubricated without catalyst</td>
</tr>
<tr>
<td>2</td>
<td>4 stroke fuel/oil mixture lubricated without catalyst</td>
</tr>
<tr>
<td>3</td>
<td>2 stroke fuel/oil mixture lubricated with catalyst</td>
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<tr>
<td>4</td>
<td>2 stroke fuel/oil mixture lubricated with catalyst</td>
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<tr>
<td>5</td>
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<tr>
<td>6</td>
<td>2 stroke fuel/oil mixture lubricated fuel injection system without catalyst</td>
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</tbody>
</table>

Association for Emissions Control by Catalyst RISBL
Tests Results: PM Number Emissions

- PN vary from $2 \times 10^{12}$ to $5 \times 10^{14}$/kWh.
- PN emissions level depends on engine working principle.
- PN levels are of the order of magnitude of non-DPF equipped diesel engines.
- Presence of catalyst on 2S engine reduces PN.

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</tr>
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<tbody>
<tr>
<td>1</td>
<td>4 stroke dry sump lubricated</td>
</tr>
<tr>
<td></td>
<td>without catalyst</td>
</tr>
<tr>
<td>2</td>
<td>4 stroke fuel/oil mixture lubricated</td>
</tr>
<tr>
<td></td>
<td>without catalyst</td>
</tr>
<tr>
<td>3</td>
<td>2 stroke fuel/oil mixture lubricated</td>
</tr>
<tr>
<td></td>
<td>with catalyst</td>
</tr>
<tr>
<td>4</td>
<td>2 stroke fuel/oil mixture lubricated</td>
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<td>with catalyst</td>
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<td>5</td>
<td>2 stroke fuel/oil mixture lubricated</td>
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<td></td>
<td>stratified scavenging</td>
</tr>
<tr>
<td></td>
<td>without catalyst</td>
</tr>
<tr>
<td>6</td>
<td>2 stroke fuel/oil mixture lubricated</td>
</tr>
<tr>
<td></td>
<td>fuel injection system</td>
</tr>
<tr>
<td></td>
<td>without catalyst</td>
</tr>
</tbody>
</table>
PM Size Distribution

- Size distribution of PM emissions from engines N°2 and 3 were evaluated with an SMPS. PM were sampled directly from the CVS.
PM Size Distribution

- Particles emitted at idle are smaller than those emitted at full load.
- There is no clear evidence if the difference in mean particle size is based on the different combustion process or on the oxidation of SOF by the catalyst.

| 2 | 4 stroke
fuel/oil mixture lubricated
without catalyst |
|---|-------------------------------------------------|
| 3 | 2 stroke
fuel/oil mixture lubricated
with catalyst |

![Graph showing PM size distribution with labels for IDLE and WOT]
Effect of Oil on PM/PN Emissions

- The low-cost 2S engine was tested also with mineral oil (OEM recommendation).
- Compared to synthetic oil, PM mass doubled but PM number was stable when mineral oil was used.
Conclusions I

- 6 state-of-the-art engines of Small Hand-Held equipment available in EU have been evaluated.
- All engines met the Stage II emissions limits with some margin except for the low-cost product that was borderline after 3h of degreening.
- Regulated emissions do not directly relate to engine technology and combustion principle (2-stroke vs. 4-stroke).
- Stage II emissions levels can be reached without catalyst. Catalysts can help reduce further HC and CO emissions.
Conclusions II

• Adapted emissions measurement method provided repeatable results also for PM mass and number.
• EC/OC analysis of sampled PM still underway.
• PM and PN emissions depend on working principle and on lubrication method and oil quality.
• The use of catalyst can help reducing PM and PN emissions.
• PM mass and number were high due to the rich operation of the engines. Results were equivalent or higher than for typical diesel engines without DPF.
Thank you... OE manufacturer, TU Graz and the AECC Members ...and you for your attention