Precious metals have been used for many years in diesel oxidation (DOC). A DOC is designed to reduce the level of carbon monoxide (CO) and hydrocarbon (HC) emissions but will also reduce particulate matter (PM) mass emissions by reducing the mass of adsorbed volatile material. However the DOC makes no significant difference to the number of particles emitted. The DOC also has negligible effect on the total oxides of nitrogen (NOX) emitted. The effect of the DOC on nitrogen dioxide (NO2) varies with temperature. At light duties and hence lower temperatures the DOC reduces the NO2 emissions, however at high duty the DOC significantly increases NO2 emissions such that overall the NO2 emissions are increased. Data to support this was presented at the 7th International ETH Conference.

Work on a London Taxi Cab with a SiC wall flow diesel particulate filter (DPF) using an iron based fuel borne catalyst (FBC) not only gave 99% reduction of particulate number emissions but it has the added benefit of reducing emissions of NOX and in particular NO2. However it had little effect on the HC emissions. The use of a precious metal coating on such a filter has been proposed as an alternative regeneration method. However the work on the London Taxi Cab showed that this significantly increased NO2 emissions, but did significantly reduce hydrocarbon and carbon monoxide emissions. Slide 4 shows the NO2 data from the Taxi Cab with the alternative filter systems. Using the DPF/FBC system the total NO2 emissions were reduced by 30% with the majority of this reduction occurring during the EUDC part of the test cycle. However when the catalysed DPF was used the total NO2 emissions increased by 79%, again the majority of the difference occurred during the EUDC phase of the test cycle. The use of the DPF/FBC system produced similar results when applied to a >3.5 t truck. Slide 5 shows that the DPF/FBC system reduced NO2 emissions by 23%.

However by using a non-precious metal coating on the DPF, to facilitate the reduction of hydrocarbons and carbon monoxide, a system was developed that reduced all the hazardous emissions. The FBC was used to facilitate regeneration of the system. This type of system was been demonstrated on a Euro I specification single deck bus as shown in slide 8, with the installation shown in slide 9. Engine details are given in slide 10. The bus was tested to the FIGE cycle as shown in slide 11. The CO emissions were reduced by 78% whilst the HC and PM emissions were reduced by 94% and 87% respectively. The NOX emissions were also reduced by 11%, this is shown in slide 12. Besides being measured according to the regulated procedure NOX emissions were also speciated using FTIR. The total NOX emissions throughout the cycle are shown in slide 13 with the cumulative NOX emissions shown in slide 14. The instantaneous NO2 emissions are shown in slide 15 with the cumulative NO2 emissions shown in slide 16. This shows that the NO2 emissions were reduced by 89%. Following on from these promising early results further testing was undertaken with the base metal catalysed DPF with the FBC to ensure regeneration. Steady state testing was performed as part of the VERT Filter Test, Phase 1 using a Liebherr D914T engine. Testing was conducted according to the ISO 8178/4 procedure. Particle number measurements were performed using the SMPS instrument. The results at the 1400 rev/min, full load and 297 Nm test conditions are shown as
slides 18 and 19 respectively. This shows that the DPF is reducing particle numbers by over two orders of magnitude.

Secondary emissions measurements were also conducted by EMPA. The overall results of the regulated gaseous emissions measurements are shown in slide 20. This shows a reduction of total HC and CO emissions of 65%. The total NOX emissions were also reduced by 7%. The secondary emissions testing investigated the effect of the DPF/FBC system on PAH and nitro-PAH emissions. This is shown in slide 21 and shows that the overall PAH emissions were reduced by 99% with the DPF/FBC system and that the overall N-PAH emissions were reduced by 92%. Previous work with heavy metal FBCs has demonstrated that the DPF can act as a high temperature reactor and promote the production of dioxins and furans. However it has also been previously demonstrated that a base metal FBC and an uncatalysed DPF do not generate dioxins or furans even when the fuel is doped with additional chlorine. The base metal catalysed DPF in conjunction with the FBC was also tested to ensure that it did not produce dioxins or furans. The results of this testing showed clear reductions in the level of PCCD/F when using the DPF/FBC system with conventional diesel fuel. This is shown in slide 22. When the fuel was doped with additional chlorine there was again a small reduction of measured PCCD/F with the DPF/FBC system as shown in slide 23. The conclusion was thus drawn that the base metal catalysed DPF in conjunction with the base metal FBC gave “PCCD/F emissions factors comparable to those of the reference”.

Further vehicle testing was performed using a double deck bus that was to be used for city sightseeing tours. The bus is shown in slide 24 along with details of the DPF. Engine details are given in slide 25. This bus was tested according to the Millbrook London Bus Test (MLBT) cycle which is shown in slide 26. Again NOX was speciated using the FTIR analyser. The instantaneous NO2 emissions are shown in slide 27 with the cumulative NO2 shown in slide 28. This shows that the overall NO2 emissions were reduced by 92%.

The conclusions drawn are;

- A DPF/FBC system will reduce the number of emitted particles by over two orders of magnitude, including the ultra-fine particles and will slightly reduce NOX emissions but has little effect on HC or CO.
- A catalysed DPF with high Pt loading will reduce HC, CO and PM emissions but can significantly increase NO2 emissions.
- A base metal catalysed DPF/FBC system not only reduced CO, HC and PM emissions it also reduced NOX emissions and produced a significant reduction in NO2 emissions
- The base metal catalysed DPF/FBC system will also reduce the number of emitted particles by over two orders of magnitude, including the ultra-fine particles
- A base metal catalysed DPF/FBC system has also been shown to significantly reduce PAH and N-PAH emissions
- The base metal catalysed DPF/FBC system does not increase PCCD/F emissions even when the fuel is doped with chlorine
DPF/FBC Systems to reduce both PM and NO$_2$

P Richards  
J Chadderton

Associated Octel  
Adastra
Presentation outline

- Introduction
- Preliminary field application
- Additional bench testing
- Further field application
- Conclusions
Introduction

- A DOC will reduce PM emissions
  - this is as a result of removal of the VOF
  - a DOC will not significantly effect the number of particles emitted
- A DPF will significantly reduce the number of particles emitted
  - this includes a significant reduction in ultrafine particulate emissions
- A high Pt loading on the DPF (CDPF) will reduce HC, CO and PM emissions along with reducing the number of particles emitted
  - However this may increase NO₂ and sulphate emissions
- A DPF/FBC system does not exhibit these problems
Introduction - Cumulative NO$_2$ data from taxi cab

- CDPF system: total NO$_2$ = 2.64 g
- OE system: total NO$_2$ = 1.48 g
- DPF/FBC system: total NO$_2$ = 1.04 g
Introduction - Cumulative NO₂ on truck > 3.5 t
Introduction

- A low precious metal loading on a DOC will effectively reduce HC and PM mass emissions but has little effect on particulate numbers and can promote NO\textsubscript{2} formation at high engine duty.

- The high precious metal loading required to produce a CDPF will also reduce HC emissions but has been shown to promote high levels of NO\textsubscript{2} formation.

- A base metal FBC in conjunction with a DPF has been shown to significantly reduce PM mass, particulate numbers and also to reduce NO\textsubscript{2} emissions but has little effect on HC emissions.
Introduction - Effect of Base Metal Catalysed DPF

However -

by combining a Base Metal Catalyst coating on the DPF with a base metal FBC to create a BMCDPF/FBC system all of the regulated emissions can be reduced with a significant reduction in $\text{NO}_2$ emissions
Preliminary field application - DPF installation

DPF element

- Liqtech SiC honeycomb
- 22.9 cm diameter
- 25.4 cm length
- 10.4 litre volume
- Base metal catalytic coating from Haldor Topsøe A/S
Preliminary field application - Dennis Dart bus engine

<table>
<thead>
<tr>
<th>Type</th>
<th>Cummins 6BTA-130</th>
</tr>
</thead>
<tbody>
<tr>
<td>No cylinders</td>
<td>6 in-line</td>
</tr>
<tr>
<td>Swept Volume</td>
<td>5883 cm³</td>
</tr>
<tr>
<td>Bore / Stroke</td>
<td>102 mm / 120 mm</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>17.6 : 1</td>
</tr>
<tr>
<td>Power</td>
<td>97 kW @ 2500 rev/min</td>
</tr>
<tr>
<td>Torque</td>
<td>470 Nm @ 1500 rev/min</td>
</tr>
</tbody>
</table>
Preliminary field application - FIGE Test cycle
## Preliminary field application - Regulated emissions

<table>
<thead>
<tr>
<th>Emission</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td>94 %</td>
</tr>
<tr>
<td>CO</td>
<td>78 %</td>
</tr>
<tr>
<td>NO\textsubscript{X}</td>
<td>11 %</td>
</tr>
<tr>
<td>PM</td>
<td>87 %</td>
</tr>
</tbody>
</table>
Preliminary field application - $\text{NO}_x$ emissions
Preliminary field application - Cumulative $\text{NO}_x$
Preliminary field application - NO₂ emissions

Nitrogen Dioxide Concentration (ppm)

Vehicle Speed (km/h)

Time (s)

OE System

DPF System

Speed
Preliminary field application - Cumulative NO$_2$
Additional bench testing

- Testing was conducted for VERT Filter Test, Phase 1
- Secondary emissions testing at EMPA
- Testing conducted to ISO 8178/4
- Liebherr D914T engine
  - 6.11ltr
  - rated at 110 kW @ 2000 rev/min
Additional bench testing - 1400 rev/min, full load
Additional bench testing - 1400 rev/min, 297 Nm
**Additional bench testing - Regulated emissions**

<table>
<thead>
<tr>
<th>Emissions Factor (g/kWh)</th>
<th>Without DPF</th>
<th>With DPF/FBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>THC</td>
<td>65% reduction in T.HC</td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>65% reduction in CO</td>
<td></td>
</tr>
<tr>
<td>NOx/10</td>
<td>7% reduction in NOx</td>
<td></td>
</tr>
</tbody>
</table>
Additional bench testing - PAH, N-PAH emissions

- 99% reduction in PAH
- 92% reduction in N-PAH
Additional bench testing - PCDD/F emissions
Additional bench testing - PCDD/F emissions

“When fitting the DPF/FBC system, the PCDD/F emissions factors are comparable to those of the reference.”

with Cl doped fuel
Further field application - City Sightseeing bus

**DPF element**
- Liqtech SiC honeycomb
- 25.4cm diameter
- 25.4 cm length
- 12.9 litre volume
- Base metal catalytic coating from Haldor Topsøe A/S
Further field application - MCW Metrobus engine

<table>
<thead>
<tr>
<th>Type</th>
<th>Gardner 6LXB</th>
</tr>
</thead>
<tbody>
<tr>
<td>No cylinders</td>
<td>6 in-line</td>
</tr>
<tr>
<td>Swept Volume</td>
<td>10450 cm³</td>
</tr>
<tr>
<td>Bore / Stroke</td>
<td>121 mm / 152 mm</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>15:1</td>
</tr>
<tr>
<td>Power</td>
<td>134 kW @ 1850 rev/min</td>
</tr>
<tr>
<td>Torque</td>
<td>727 Nm @ 1000 - 1100 rev/min</td>
</tr>
</tbody>
</table>
Further field application - MLBT cycle
Further field application - NO$_2$ emissions
Further field application - Cumulative NO$_2$ emissions
Conclusions

• A DPF/FBC system will reduce the number of emitted particles by over two orders of magnitude, including the ultra-fine particles, will slightly reduce NO$_X$ emissions but has little effect on HC or CO.

• A CDPF with high Pt loading will reduce HC, CO and PM emissions but can significantly increase NO$_2$ emissions.

• A BMCDPF/FBC system not only reduced CO, HC and PM emissions it also reduced NO$_X$ emissions and produced a significant reduction in NO$_2$ emissions.
Conclusions

- The BMCDPF/FBC system will also reduce the number of emitted particles by over two orders of magnitude, including the ultra-fine particles.

- A BMCDPF/FBC system has also been shown to significantly reduce PAH and N-PAH emissions.

- The BMCDPF/FBC system does not increase PCCD/F emissions even when the fuel is doped with Cl.
This Bus is Green

Birkenhead Priory, Birkenhead Tramway, Wirral Museum, Williamson Art Gallery, Shore Road Pumping Station.

WIRRAL MUSEUMS

RM 4111 Built in 1932 for London Transport.