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Emissions reductions performance with retrofit integrated SCR/DPF system: Preliminary results

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Introduction

- The Canadian underground mining fleet is beginning to see penetration of clean diesel engines equipped with OEM combined diesel particulate filter (DPF) and selective catalytic reduction (SCR).
- DPFs can reduce the total particulate from the engine including elemental black carbon which is a health hazard and a greenhouse gas with a high CO_2 equivalency.
- SCR systems can reduce oxides of nitrogen (NOx) which are also a human health hazard.
- Together with carbon monoxide and hydrocarbon reduction, these clean diesel technologies can reduce emissions by 90% and ventilation rates by 50%.

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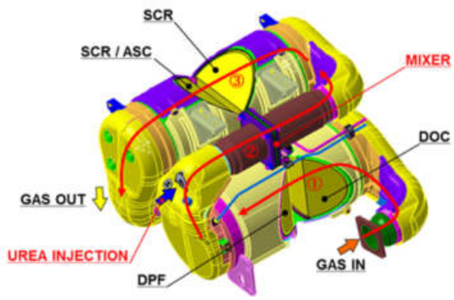
Combined SCR/DPF Systems

- Most commercial OEM systems have separate modules for SCR and DPF operation often with additional modules for CO and HC control as well as NO/NO_2 ratio adjustment and ammonia slip oxidation.
- This can result in large, complex emissions control hardware assemblies.



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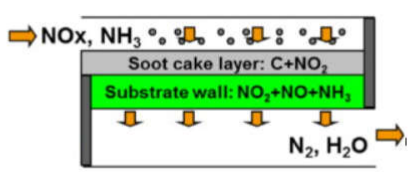
Integrated Prototype CDPF

- CanmetENERGY has developed an integrated SCR/DPF catalyst formulation that may be applied to a single monolithic substrate that can perform many of the functions of a modular system.
- The integrated CDPF system can be more compact, easier to manufacture and more suitable for retrofit applications.
- CanmetMINING collaborated with CanmetENERGY to test a prototype integrated CDPF system retrofitted to a Tier 2 mining diesel engine to determine the emissions reduction potential of the system.



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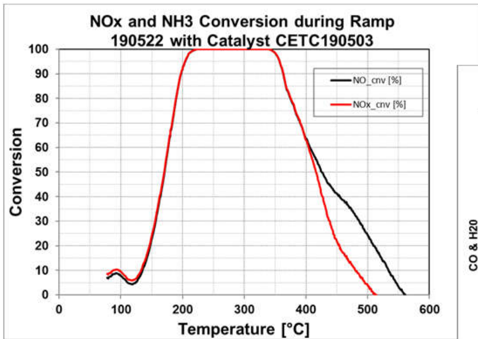
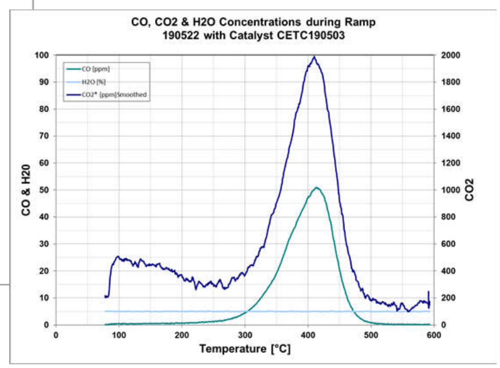
Catalyst Reactor Tests

- Before constructing a full-scale prototype for engine testing the new CanmetENERGY SCR catalyst formulation was tested in a bench reactor for C and NOx conversion.





Engine Emissions Testing

- Emissions testing was performed with a Tier 2 Deutz F6L914 engine to evaluate retrofit potential of the scaled prototype.

Table 1 – Engine Specification Data

Make	Deutz
Model	Deutz F6L914 T2
Serial number	87299570
Displacement	6.5 Liter
Rated power	71.5 kW @ 2300 rpm
Fuel rate at rated power	17.1 kg/hr
Peak torque	350 N.m @1500 rpm
Aspiration	Naturally aspirated
Fuel system	Mechanical
Max air intake restriction-clean air filter	3 kPa
Max exhaust backpressure	7.5. kPa
Low idle speed	650 rpm
High idle speed	2480 rpm

Test Results

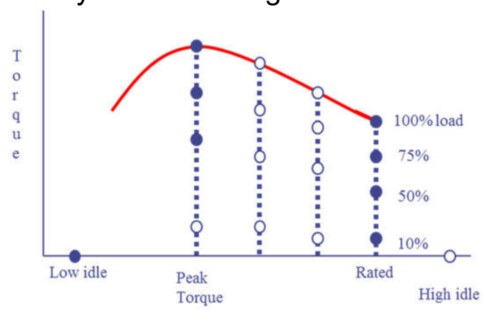
Parameter	Method		
Carbon	ASTM D5291 modified	86.1	wt%
Hydrogen	ASTM D5291 modified	13.9	wt%
Nitrogen	ASTM D5291 modified	<0.15	wt%

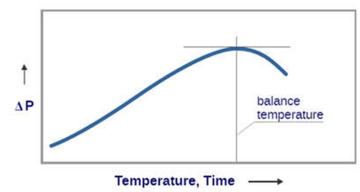
Test Results

Parameter	Method		
Density @ 15°C	ASTM D4052	814.9	kg/m3
Flash Point, Pensky-Marten Closed Cu	ASTM D93	49.5	°C
Specific Gravity 60/60F	ASTM D4052	0.8156	GRAV
Sulphur	ASTM D7039	6.9	mg/kg

Evaluation Protocols

- Traditionally, separate protocols are used to evaluate PM reduction, DPF regeneration effectiveness and NOx control.
- Integrated PM and gaseous emissions reduction were evaluated with the ISO8178 test.
- DPF regeneration was evaluated with a balance point test.
- System was de-greened over a loading/regen cycle for 30hrs.





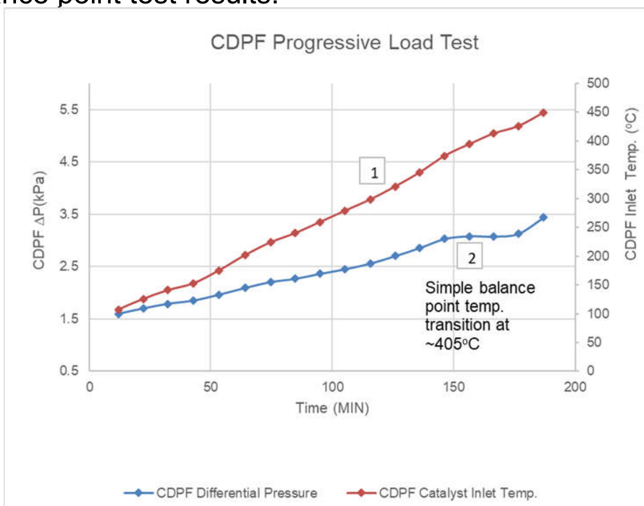
ISO8178 Test Results

- Integrated ISO8178 test results:

Parameters		Catalyst Inlet	Catalyst Outlet	
Test Points->	Units	Integrated	Integrated	% Change
Specific emissions				
CO	g/hr	152	136	-7%
NO_2	g/hr	17	3	84%
NO	g/hr	164	145	11%
NOx	g/hr	180	148	18%
DPM	g/hr	3.86	0.46	88%

Balance Point Test Results

- Balance point test results:



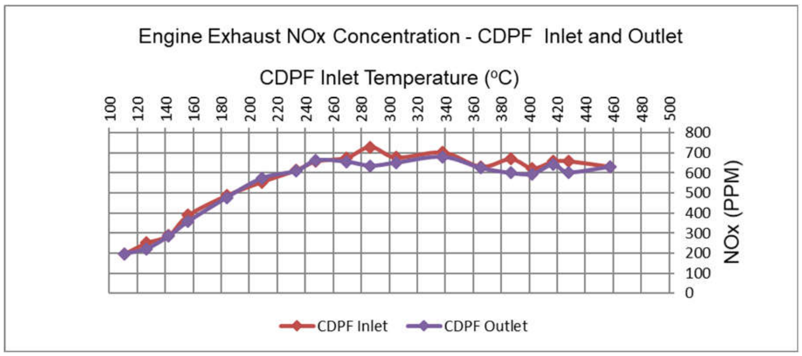
Analysis Test Results

- Total PM mass reduction is good at 88%.
- DPF regeneration temperature around 405ºC.
- Small CO increase.
- NOx reduction only 18%!

- We were expecting 80-90% NOx reduction to be in line with commercial SCR systems. Reactor tests showed 100% conversion was possible.
- NO_2 reduction was 84% which seems good.
- So what's going on here?

NOx Conversion Engine Test

- The NOx emissions at the inlet and outlet of the CDPF were essentially unchanged even with full ammonia dosing for SCR operation.



Factors for low NOx conversion

- Factors affecting NOx conversion in integrated SCR/DPF systems:
  - High soot loading can block catalyst pores. (Ref: Oladipo et al., DEER Conference, 2008)
  - Multiple DPF regenerations can significantly degrade performance due to deactivation of SCR catalyst. (Ref: Lee et al., SAE Paper 2008-01-0072)
  - Lower soot loadings need to be maintained in order to prevent deactivation during regeneration. (Ref. Dobson et al., CLEERS Conference, 2009)
  - Resistance to mass transfer with wall-flow monolith instead of flow-through monolith. (Ref. Devarakonda DOE-CLEERS 2009)
  - Hydrocarbon (HC) poisoning as high concentrations of HC occur in the DPF during regeneration. (Ref. Devarakonda DOE-CLEERS 2009)

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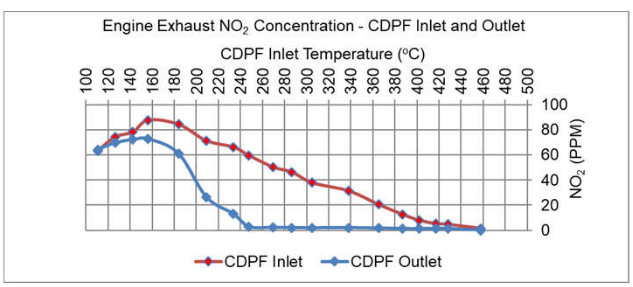
Possible SCR catalyst deactivation

- Multiple regenerations were part of the de-greening process for this study. The CDPF was loaded and regenerated fifteen (15) times over five days. High substrate temperatures during regen may have damaged the SCR catalyst.
- The Deutz test engine was at a Tier 2 emissions level thus CDPF PM mass loadings were high.
- The first balance point test was started at a loading of approximately 10g(PM)/L(substrate volume). This is a very high loading. Loadings of 2.5 – 5.0g/L are expected to deteriorate SCR performance.
- High DPM loadings may have blocked catalyst sites and reduced conversion.

NO_2 Reduction/consumption

- NO_2 oxidation of PM is a well-known mechanism for DPF regeneration. PM oxidation by NO_2 can occur at a lower temperature than PM oxidation by O_2, generally starting at 225-320°C.



- The CanmetENERGY CDPF formulation shows NO_2 reduction at 160°C

NO_2 + C reaction in DPFs

- Catalysts (such as Pt) can catalyze the NO + O_2 reaction to NO_2. However, it is unclear if the presence of a catalyst improves the NO_2 + C reaction or only catalyzes the formation of additional NO_2 through the NO + O_2 reaction, thus indirectly affecting the carbon reactivity. (*Ref. Williams, Surface Intermediates, Mechanism and Reactivity of Soot Oxidation. University of Toronto, PhD Thesis 2008*)

- The high PM loading that occurred would make enough C available to consume all of the NO_2 in the system.
- SCR catalyst deactivation may not be critical.
- The CanmetENERGY CDPF appears to be able to support the NO_2 + C reaction at low temperatures.

Conclusions

- Integrated SCR/DPF technology is attractive but challenging.
- Great potential for compact design and retrofit.
- But DPF loading and regeneration strategies must be managed effectively to assure good system performance.
- Its possible to easily damage the system and lower NOx conversion.
- Sensitivity to loading may mean high PM emitting engines will require a different system or a modular system.

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Recommendations / Future Work

- Important to determine the critical PM loading limits to reduce blocking of catalyst sites and prevent high temperature excursions during regen to prevent deactivation.
- Low-temperature NO_2 + C reaction is not well understood.

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Thank you for your attention!