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Laboratory Evaluation of Diesel Oxidation Catalysts for NO_2 Formation

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Work Performed for CAMIRO (Canadian Mining Industry Research Organization)

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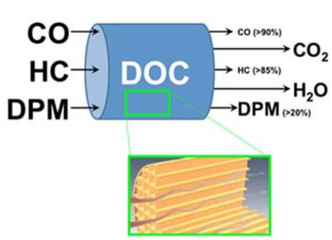
Introduction

- Diesel oxidation catalysts (DOCs) have been used successfully in the mining industry for a long time to control CO and HC emissions.
- Some older catalyst formulations are known to increase NO_2 which is detrimental to mine air quality.
- Some newer catalyst formulations claim to reduce NO_2 or be NO_2 neutral.
- Most mines do not have a purchasing strategy specific to DOCs so there are large numbers in service without much supporting documentation or performance data.
- A review of DOC technologies is recommended.

Diesel Oxidation Catalysts (DOC)

- DOCs operate by using the excess oxygen in diesel exhaust to oxidize CO and HC.
- Some catalysts can also oxidize NO to NO_2.



Desired Reactions

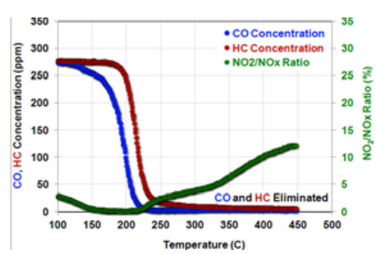
$CO + O_2 \rightarrow CO_2$

$HC + O_2 \rightarrow H_2O + CO_2$

$DPM + O_2 \rightarrow H_2O + CO_2$

Undesired Reactions

$NO + O_2 \rightarrow NO_2$



Courtesy: AirFlow Catalyst

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Underground mining applications

- Large numbers of DOCs in service underground in many applications:

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Project Objectives

- Earlier laboratory studies have identified the NO_2 conversion of certain catalyst formulations.
- Unclear how those studies translate into real world, highly transient mining vehicle applications.
- What is the NO_2 formation potential of the different types of DOCs in known vehicle applications?
- Are there certain types that have a higher potential than others?
- Can an evaluation process to deal with the DOCs be developed as a guide to improving air quality?

DOC Selection

- Consortium partner mines removed a selection of DOCs from in-use vehicles underground.
- 32 DOCs sent to CanmetMINING for evaluation.
- 16 were selected as suitable for testing based on type, vehicle application, duty cycle, etc.
- 5 brand new DOCs with advanced NO_2 suppression catalysts were also tested.

DOCs Selected for Testing

CAMIRO - DOCs selected for Laboratory Testing

DOC #	Vehicle Unit #	Vehicle Description	Service	DOC Make	DOC Model	Engine Make	Engine Model	Engine kW (HP)	Hours on unit	Vehicle Supplier	Test cycle	Group Type
Vale-Sudbury												
C2	37-099	T1400 Scooptram	Heavy	ECS	A20-0072	Detroit	6063EK32	242 (325)	20000+	Sandvik	LHD	2
C5	27-014	Scissor truck	Light	NETT	SP2918	Mercedes	OM 904	112 (150	2700	Maclean	Utility	1
C8	10-340	LT-350 3.5yd	Heavy	DCL	3205MD-1R07-21	Deutz	BF4M1013C	86 (115)	4850	MTI	LHD	2
C3	17-630	1700G Scooptram	Heavy	DCL	CE3125	Cat	C11 ACERT	241 (323)	3300	Toromont	LHD	1
C6	23-1106	Mancarrier (Jeep)	Light	ECS	A20-0718	Toyota	1HZ6	100 (134)	3400	Mobile	Pickup	1
C12	37-6067	Tractor	Light	CEP	IFIC06349	Iveco	N45MNS	74 (99)	110	Industrial Fabrication	Tractor	1
Glencore-Sudbury												
C16	U11	Marcotte U-11	Moderate	CEP	6SX	Deutz	F6L912W	60 (80)	7825	Marcotte	Utility	1
C17	GR002	Cat Grader	Moderate	DCL	DQ8R	Mercedes	904	130 (174)	6985	WajaX	Utility	3
C18	MB024	Bolter	Light	Englehard	1470	Deutz	BF4M1013C	113 (152)	707	Maclean	Utility	2
C19	LH859	1700G	Heavy	DCL	CAT OEM	CAT	C11ACRT	241 (323)	10132	Toromont	LHD	2
Glencore-Timmins												
C13	33843	Waldon Forklift		ECS	5DM	Deutz	F3L912W	40 (53)			Utility	3
C14	33940	Waldon Forklift		DCL	2000-DOQ-1R05-21	Deutz	F3L912W	40 (53)			Utility	2
C15	33683	LH514	Heavy	Finnkatalyt	FK26	Detroit	6063MK32	242 (325)	13393	Sandvik	LHD	2
C20	33673	Toro 1400	Heavy	Finnkatalyt	FK23	Detroit	6063MK32	242 (325)	7,604	Sandvik	LHD	2
C21	AM	Truck "Jeep" crew cab		CEP	5SX	Toyota	1HZ	100 (134)	7,324	Access Industrial	Pickup	1
Vale Creighton												
C22	20	Cubex D6200 Drill		Exhaust Co	PZ05C25	Deutz	F4L912W	40 (54)	1000	Sandvik	Utility	2

New Advanced DOCs

- Several manufacturers were asked to supply a new, advanced formula DOC properly sized for the laboratory engine and designed for an underground LHD cycle.

CAMIRO - New DOCs for Laboratory Testing

DOC #	DOC Make	DOC Model	DOC SN.	Test cycle	Group Type
C31	Catalytic Exhaust Products Limited	12SC-5.0" F	88586	LHD	3
C32	Nett Technologies Inc.	DH522W-5.0" D series		LHD	3
C33	CDTi	Y13-0002	B184602	LHD	3
C34	DCL International Inc.	RD2L-01-1X14-22	662204	LHD	1
C35	Airflow Catalyst Systems Inc.	MinNoDoc-S12000MM16P4P4	46"x19"x23"-10561	LHD	3

Engine testing

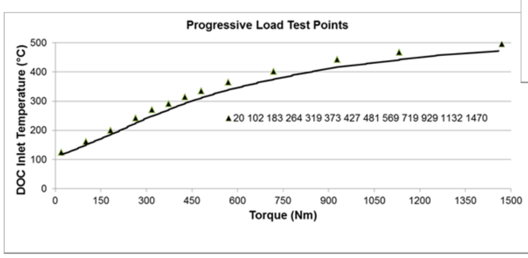
- All DOCs tested at CanmetMINING with a laboratory reference engine. (Detroit Diesel Series 60 – 325hp)
- Ten (10) DOCs were from applications with a similar engine rating as the reference engine so they could be tested at full exhaust flow.
- The remaining eleven (11) DOCs came from lower power applications so they were tested at a lower exhaust flow by proportionally bypassing some of the engine exhaust.

Test Cycles

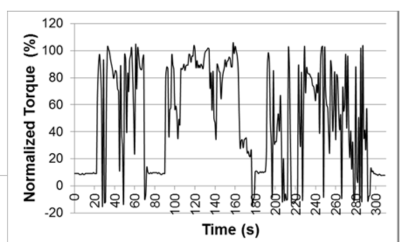
- Two emissions tests required per DOC
  - Progressive Load Test (PLT)
  - Vehicle Transient Test (VTT)
- Progressive Load Test
  - Standardized test for catalyst performance over a fixed exhaust temperature range.
- Vehicle Transient Test
  - Simulated mining vehicle duty cycles to provide exhaust temperature distribution.
- Combing the two tests allows us to identify potential applications where NO_2 formation is a risk.

Test Cycles

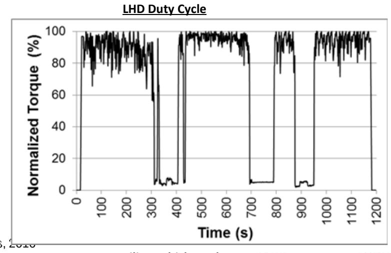
- Progressive Load Test
  - Constant speed.
  - Increased load and exhaust temperature.



- Vehicle Transient Test
  - Simulated mine vehicle
  - Temperature distribution



LHD Duty Cycle



Utility Vehicle Cycle

Results

- Vehicle Cycle Tests
  - Each DOC cycle tested according to the vehicle it came from originally.
  - New DOCs were tested on the LHD cycle.
  - Percent change in baseline specific emissions were calculated for each DOC over its representative cycle.

DOC Number	Mine Engine Rated Power kW	Transient Vehicle Cycle	Percent Change in Exhaust Specific Emission (g/kWh)		
			CO	THC	NO_2
In-use DOCs tested with full exhaust flow					
C2	242	LHD	-60	-45	-18
C3	241	LHD	-70	-59	32
C15	242	LHD	-49	-51	-5
C19	241	LHD	-58	-49	-2
C20	242	LHD	-53	-51	-17
New DOCs tested with full exhaust flow					
C31	N/A	LHD	-67	-62	-71
C32	N/A	LHD	-61	-62	-81
C33	N/A	LHD	-6	-72	-47
C34	N/A	LHD	-99	-68	184
C35	N/A	LHD	-98	-72	-94
In-use DOCs tested with partial exhaust flow					
C17	130	Utility	-34	-27	-37
C18	113	Utility	-70	-49	-2
C5	112	Utility	-99	-74	154
C6	100	Pickup	-81	-54	102
C21	100	Pickup	-84	-59	179
C8	86	LHD	-55	-43	-24
C12	74	Tractor	-66	-50	18
C16	60	Utility	-91	-71	446
C22	40	Utility	-58	-38	8
C13	40	Utility	-46	-41	-47
C14	40	Utility	-64	-48	9

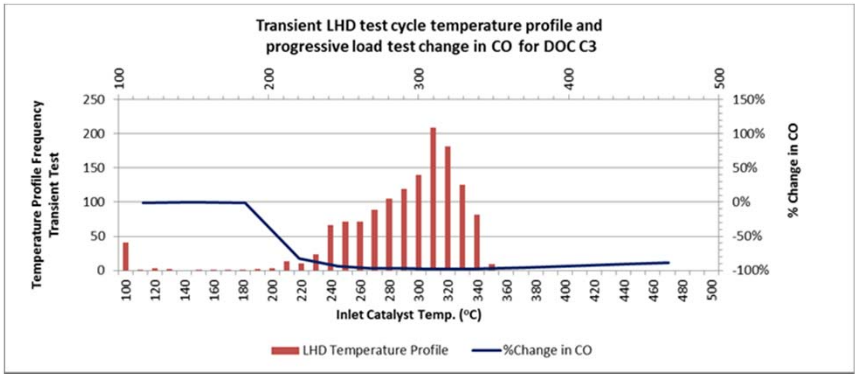
DOC Classification

- DOC's were classified into three distinct groups based on NO_2 formation.
- Group 1: "Active" DOCs greatly increase NO_2
- Group 2: "Neutral" DOCs may slightly increase or slightly decrease NO_2 or be NO_2 neutral.
- Group 3: "Advanced" DOCs significantly reduce NO_2.

Group Type	DOC Number	Transient Vehicle Cycle	Critical NO_2 Temperature (°C)	% change in NO_2 (g/kWh)
1	C16	Utility	215	446
	C21	Pickup	220	179
	C5	Utility	230	154
	C34	LHD	235	184
	C6	Pickup	240	102
	C3	LHD	245	32
	C12	Tractor	245	18
2	C18	Utility	255	-2
	C15	LHD	280	-5
	C8	LHD	285	-24
	C2	LHD	290	-18
	C22	Utility	295	8
	C20	LHD	300	-17
	C14	Utility	300	9
	C19	LHD	320	-2
3	C33	LHD	325	-47
	C17	Utility	330	-37
	C31	LHD	335	-71
	C32	LHD	365	-81
	C35	LHD	370	-94
	C13	Utility	415	-47

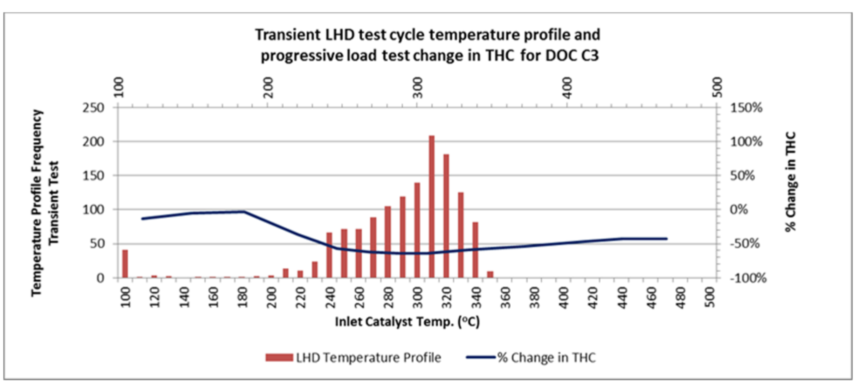
In-Use Cycle Emissions – C3

- Combining catalyst performance with duty cycle exhaust temperature. CO emissions.



In-Use Cycle Emissions – C3

- Hydrocarbons



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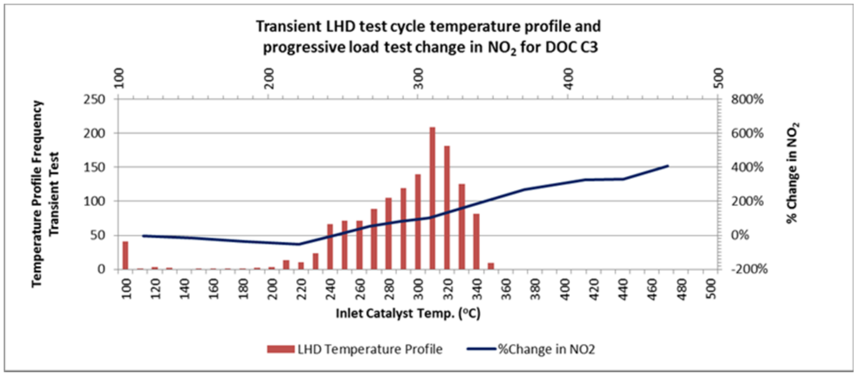
In-Use Cycle Emissions - C3

- NO_2 emissions

Group 1 "Active" DOC increases NO_2 over the engine operating range.



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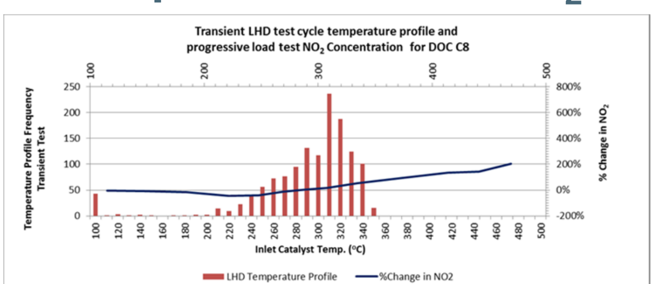
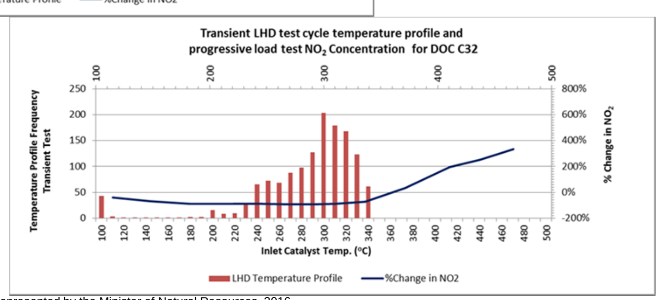
Group 2 and 3 DOC NO_2 formation



Group 2 "Neutral" DOC either slightly reduces NO_2, slightly increases NO_2 or remains NO_2 neutral over the vehicle operating range.

Group 3 "Advanced" DOC reduces NO_2 over the entire engine operating range.



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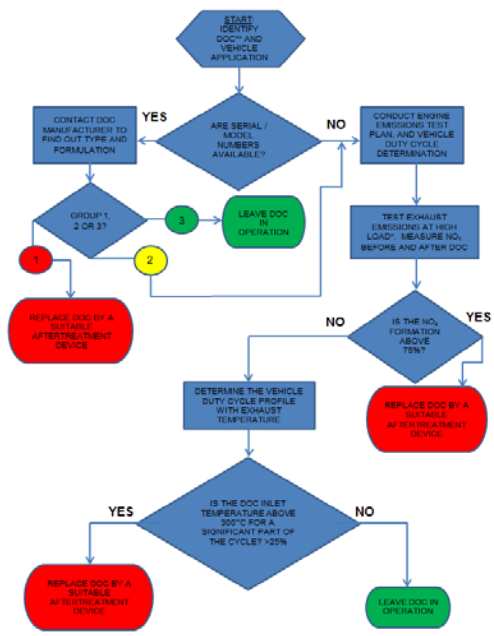
Discussions

- DOCs are readily classified into three major groups based on NO_2 conversion.
  - Group 1 – "Active" (generally platinum catalyst coatings)
  - Group 2 – "Neutral" (generally base metal catalyst coatings)
  - Group 3 – "Advanced" (catalyst coatings not generally known)

- NO_2 conversion is also affected by engine exhaust temperature.
- In use vehicle exhaust temperature is based on the engine loading during the vehicle duty cycle.
- Thus in-use NO_2 formation potential is a combination of DOC group and vehicle duty cycle.
- Can we design an evaluation process to deal with the risk of NO_2 formation from in-use DOCs?

DOC Evaluation

- The chart can be used as a basic guide to evaluating the risk of NO_2 formation and developing a plan to deal with DOCs in service.
- Group 1 DOCs should be removed as they pose the highest risk and better emissions control devices are available.
- Group 3 DOCs should remain as they are a benefit.
- Group 2 DOCs need to be evaluated more thoroughly to determine the NO_2 risk.



* The engine emissions test must be performed at high load to ensure the DOC is in its normal operating temperature range. The transmission stall or hydraulic stall tests as mandated by the Ontario MOL are acceptable.
** This chart is derived from limited laboratory testing of selected DOCs.

Recommendations

- The DOC evaluation flow chart can be used by mines to develop a plan for risk assessment of in-service vehicle/DOC applications.
- DOCs can be removed from high risk applications and replaced with new, advanced DOCs or other aftertreatment technologies.
- Mines can revise purchasing plans to only buy the most advanced, NO_2 suppression DOCs.
- These steps will help reduce the underground NO_2 burden and improve mine air quality.

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Questions?

- Thank you!
- Please also see "*Effect of In-Use DOCs on NO_2 Emission in the Underground Operation*" Joe Stachulak, Vale; Mahe Gangal, CanmetMINING, MDEC 2013.

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