

ECT-2023

Session 4

Off-Road Applications 01

2nd November 2023



Technology of Diesel Particulate Filter for Tighter Non-Road regulation in India

**T. Aoki, K. Tanaka, T. Ogata, H. Ota
NGK Insulators, Ltd.**

**N. Hibi, S. Muraoka, N. Gautam, T. Matsuda
NGK Technologies India Pvt. Ltd.**

Background

Experimental Setup

Test Condition and Result

1. PN Filtration
2. Passive Regeneration
3. Active Regeneration
4. Drop To Idle

Conclusion

Background





Experimental Setup

Test Condition and Result

1. PN Filtration
2. Passive Regeneration
3. Active Regeneration
4. Drop To Idle

Conclusion

Non-Road Regulation

	2021	2022	2023	2024	2025	2026	2027	2028~
	Stage V							Stage VI?
	<p>PN 1.0×10^{12} #/kWh (NRTC/NRSC), NTE with CF=2.0 for <560kW</p>							PEMS?
	Tier4 Final							Tier5?
	<p>No PN, PM 0.02 g/kWh, NTE with CF=1.5 for <560kW</p>							PM 5mg/kWh
	China Stage III			China Stage IV			China Stage V?	
				<p>PN 5.0×10^{12} #/kWh (NRTC, NRSC)</p>			<p>PN 1.0×10^{12} #/kWh (NRTC, NRSC)</p>	
	TREM III	TREM IV		TREM V				
	CEV IV			CEV V				
	<p>No PN, PM 0.025 g/kWh</p>			<p><u>PN $1E+12$#/kWh</u> (NRTC/NRSC)</p>				

Requirements for DPF

High Filtration Performance

Low Heat Mass

Low Pressure Drop
(with soot and ash)

Solutions

Smaller Pore Size

Cordierite Material

Thin wall
Asymmetric cell

Required DPF for Non-Road in Indian market:

Cordierite material + thin wall + Asymmetric cell

DPF with different materials, with and without precious metal coating are compared with presented as viable options.

Background

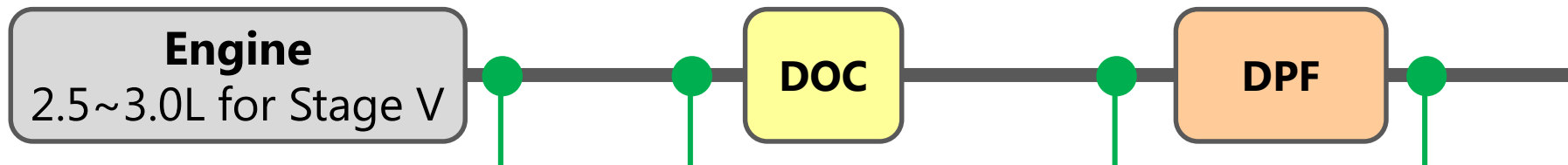
Experimental Setup

Test Condition and Result

1. PN Filtration
2. Passive Regeneration
3. Active Regeneration
4. Drop To Idle

Conclusion

1. Testing Equipment



Measurement	Engine Out	DOC Inlet	DPF Inlet	DPF Outlet
Pressure	✓	✓	✓	✓
Temperature	✓	✓	✓	✓
PN Counter				✓

2. Sample List

	DOC	DPF		
Sample ID:	-	A (Cd-Coated)	B (Cd-Bare)	C (SiC-Coated)
Material:	Cordierite	Cordierite	Cordierite	<u>Silicon carbide</u>
Catalyst	with catalyst	with catalyst	<u>without</u> catalyst	with catalyst
Porosity / MPS:	-	Base	← Same	Low / Same
Cell Structure:	400cps	8mil / 300cps Asymmetric	← Same	10mil / 300cps Asymmetric
Size:	Φ6.77" x 3"L	Φ6.77" x 5"L		

Test Item	Measurement Item	Purpose
1. PN Filtration	PN [# / kWh]	Demonstrate TREM V compliance
2. Passive Regeneration	Soot Amount [g/L] Pressure Drop [kPa]	Support for regeneration interval consideration
3. Active Regeneration	Regeneration Efficiency [%]	Compare fuel consumption during the regeneration
4. Drop To Idle	Max Temperature as per soot amount [deg.C]	Compare soot mass limit

Background

Experimental Setup

Test Condition and Result

1. PN Filtration
2. Passive Regeneration
3. Active Regeneration
4. Drop To Idle

Conclusion

1. Result of PN Filtration

*PN for NRTC = Weighted PN Cold x 0.1 + Hot x 0.9

*Error bar in RMC: plotted 1st and 2nd measurement



1. Test Conditions

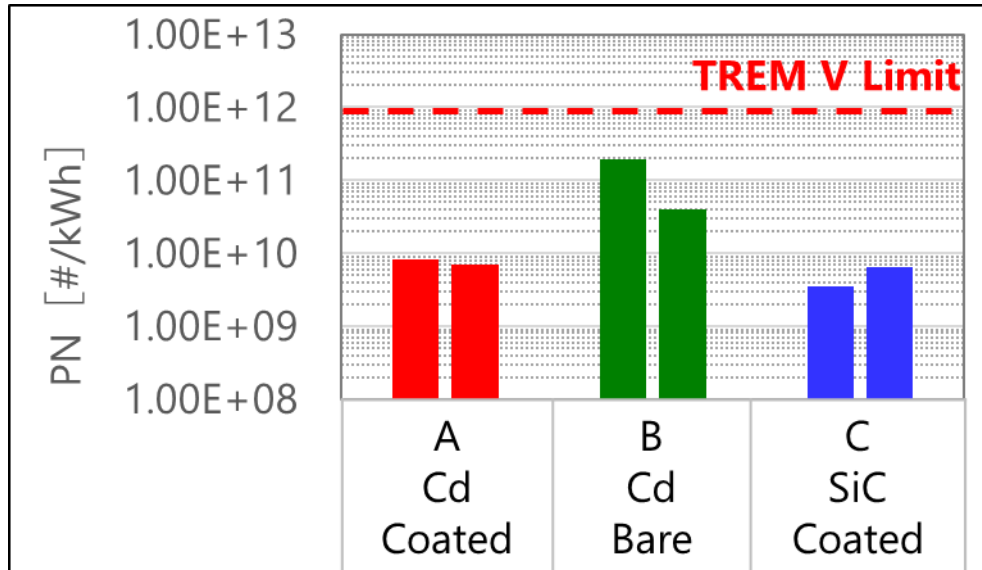
Preconditioning: (Hot NRTC: 30 min) x 4times → Soaking:6hrs

NRTC Test (Cold NRTC: 30min) x 1time → Soaking: 20min → (Hot NRTC: 30min) x 3times → PN measurement

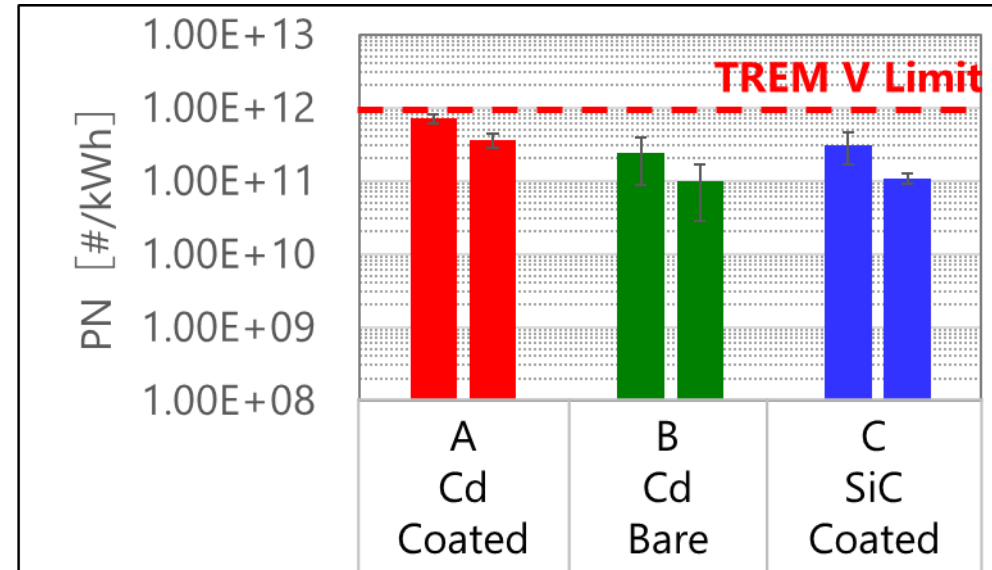
RMC test (Rated Speed and Torque by 50%): 30min → (Soaking: 20min and RMC) → PN measurement (1st)
→ (Soaking: 20min and RMC) → PN measurement (2nd)

2. Test Results

NRTC Cycle (N=2)



RMC cycle (N=2)



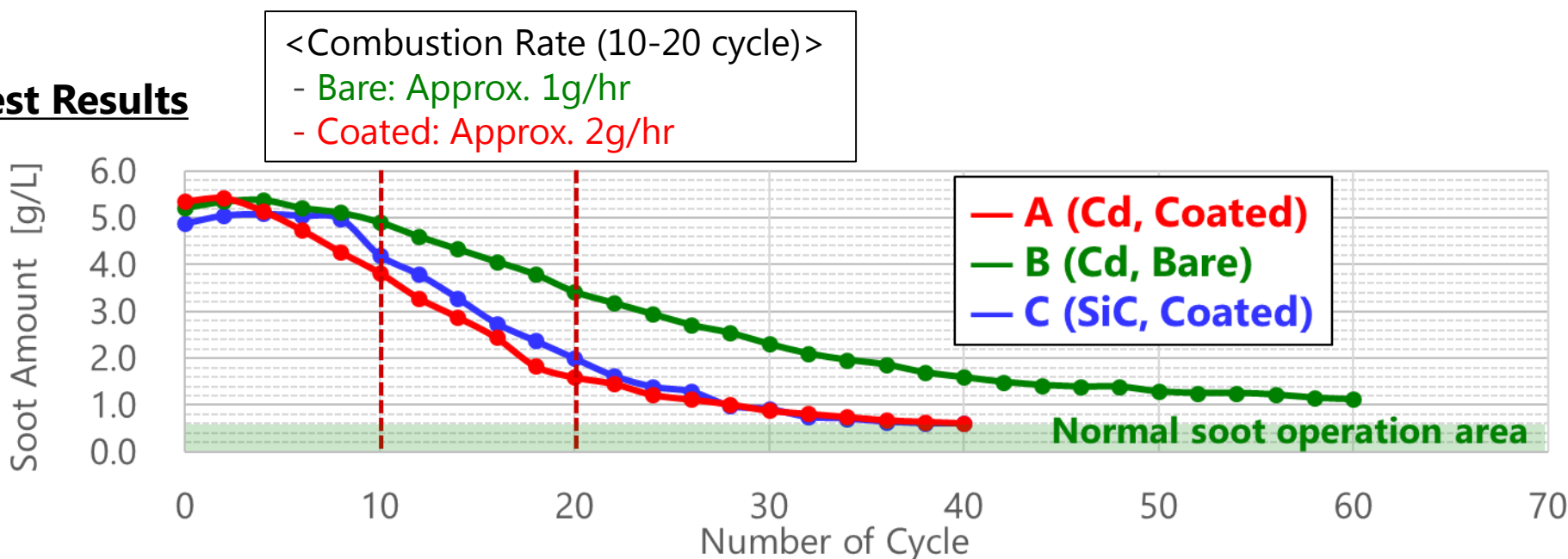
PN emission with NRTC and RMC meet TREM V regulation limit.
Coated Cd-DPF and coated SiC-DPF showed better PN filtration in NRTC.

2-1. Result of Passive Regeneration (Soot Amount)

1. Test Conditions

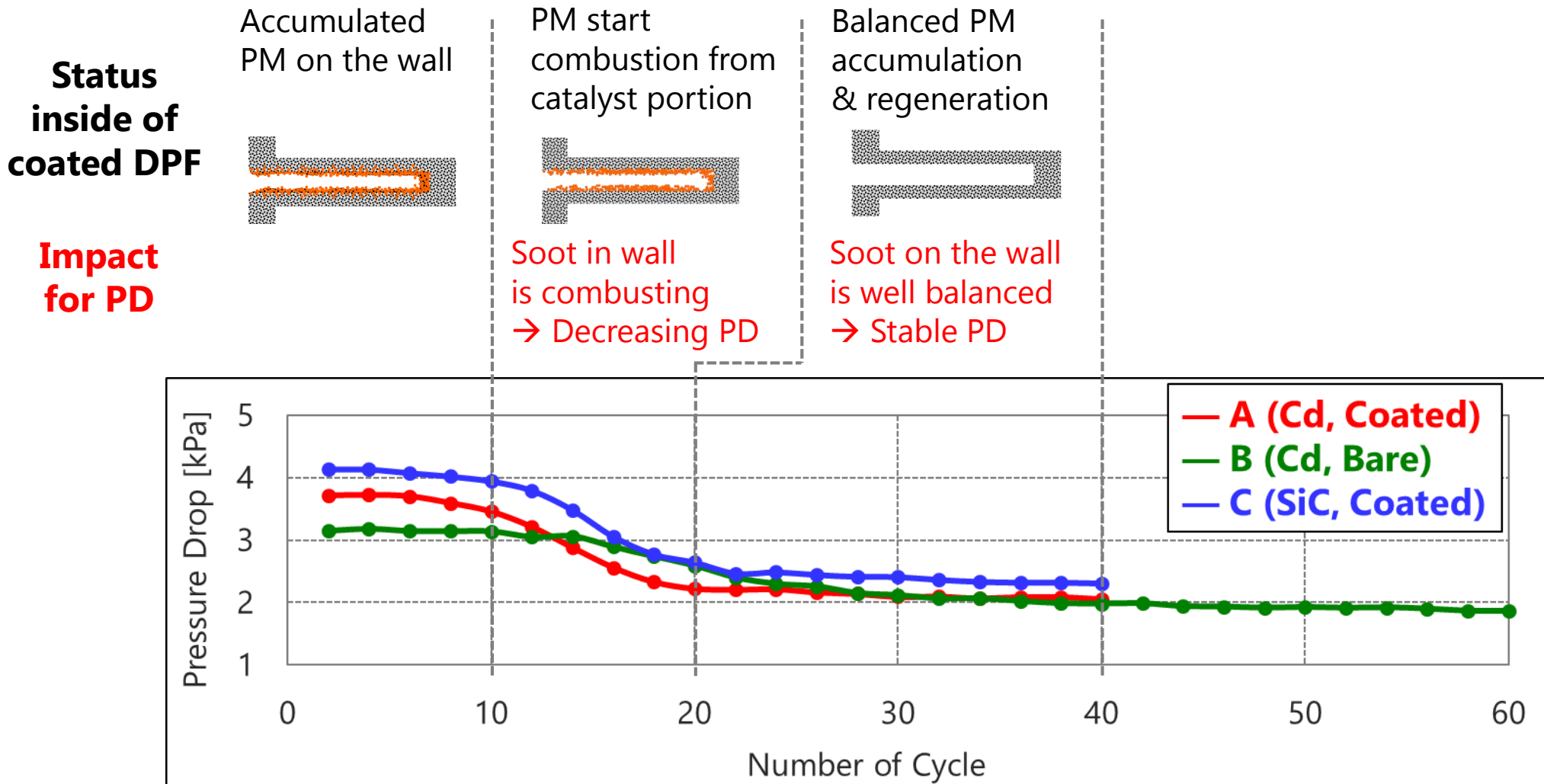
Initial Soot loading:	5g/L
Measurement of Soot Amount:	2 NRTC running and weighing after stabilization
Total number of cycles:	40 NRTC

2. Test Results



- Soot was combusted until soot amount to around 0.5g/L (“Normal soot operation area”).
- These coated DPF samples showed similar combustion speed. Moreover, Cd material can reduce soot amount faster than SiC-DPF due to low heat mass.
- Bare DPF sample went to around 1.0g/L with less combustion speed.

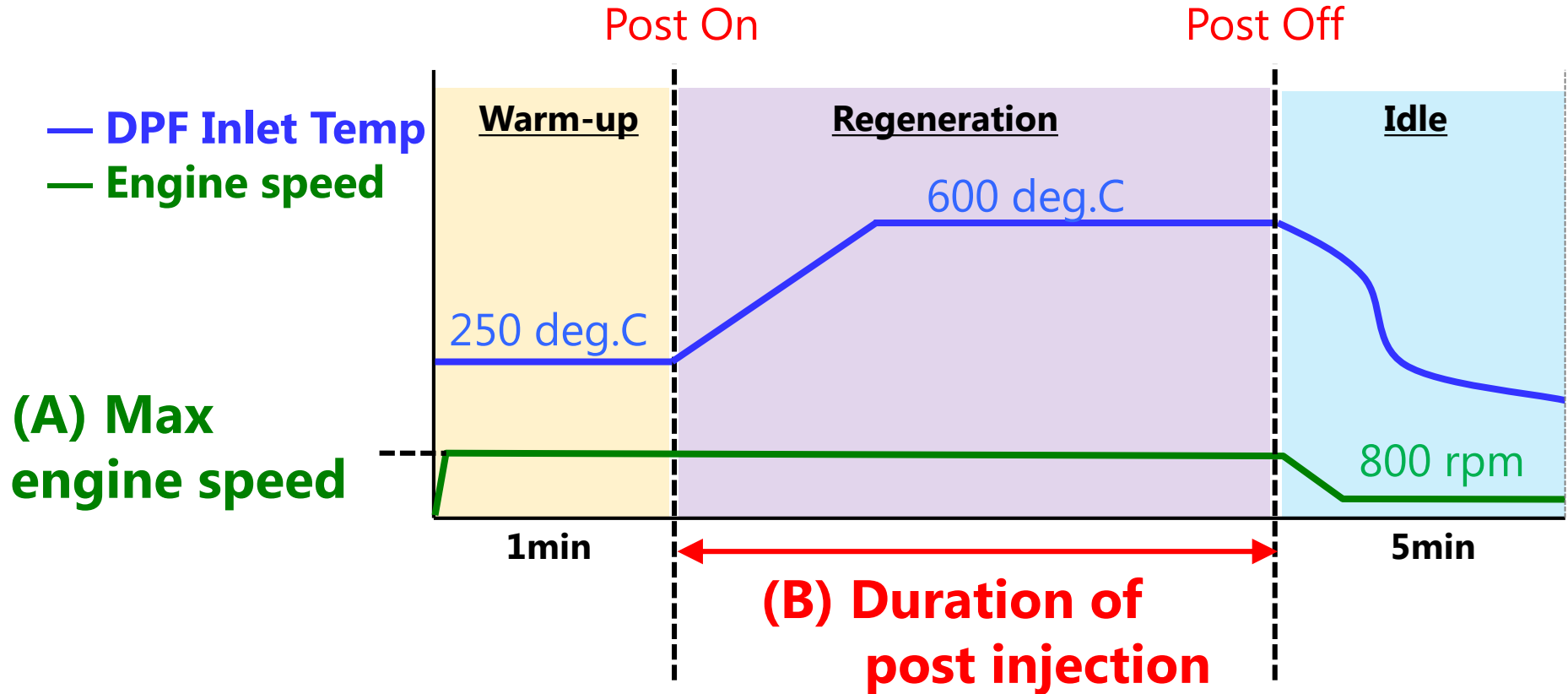
2-2. Result of Passive Regeneration (PD: Pressure Drop)



- Cordierite(Cd) DPF is lower pressure drop level than Silicon carbide(SiC) DPF.
- Pressure drop behavior of coated DPF is almost same with soot behavior.
- Initially, Bare DPF showed less Pressure Drop due to none of coating PD increasing impact.

3-1. Conditions of Active Regeneration

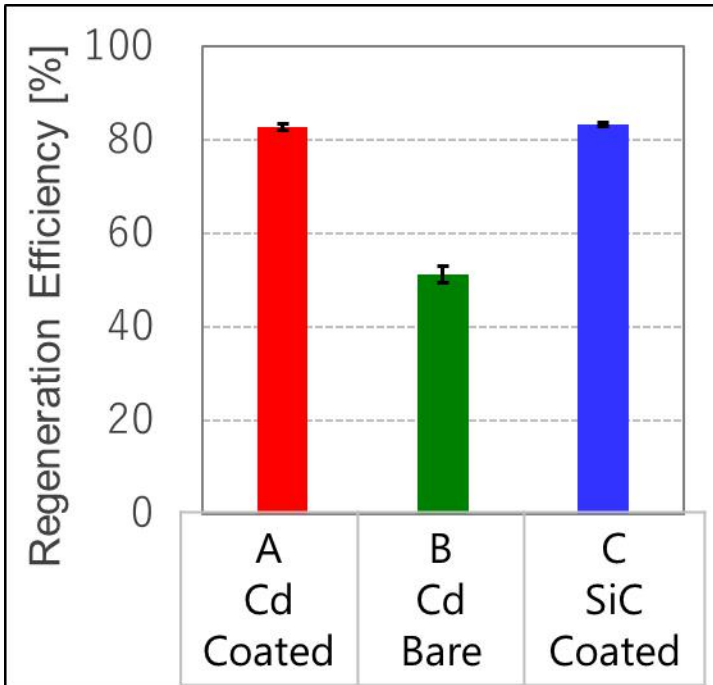
Conditions	(A) Max engine speed	(B) Duration of post injection
1. Regular	2000 rpm	10 min
2. Low Flow	<u>1400 rpm</u>	10 min
3. Shorten post injection	2000 rpm	<u>5 min</u>



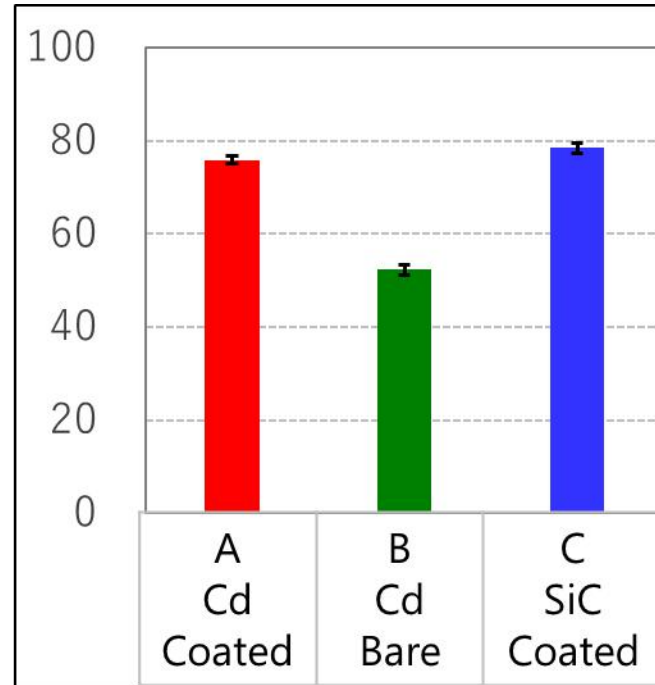
3-2. Result of Active Regeneration (RE: Regeneration efficiency)



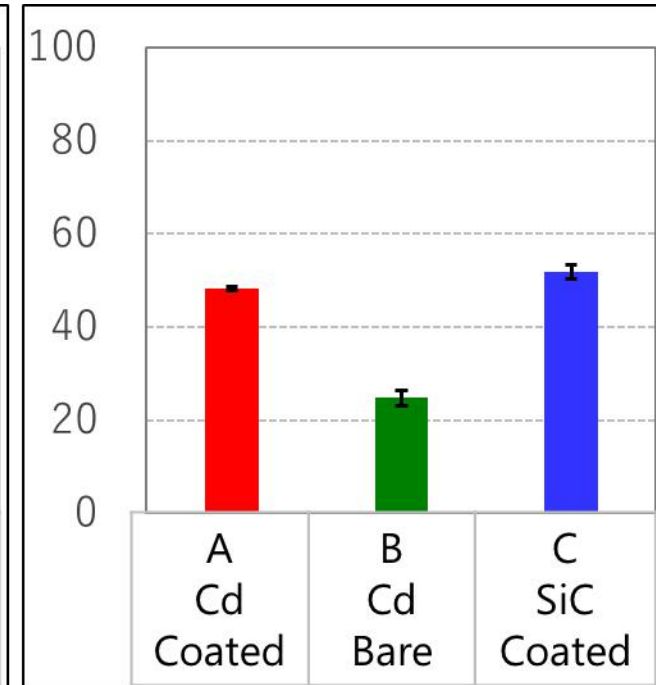
1. Regular Duration (10min / 2000rpm)



2. Low Flow (10min / 1400rpm)



3. Shorten post injection (5min / 2000rpm)



<Coated DPF>

1. RE of coated DPF achieved around 80%.
2. RE drops slightly with reduced gas flow rate. Still coated DPF achieved around 80%.
3. RE showed more sensitive to duration compared to gas flow rate and around 50%.

< Bare DPF>

RE showed approx. half or less compared with coated DPF.

4. Result of Drop To Idle (DTI)

1. Test Conditions

Engine Speed:	2000rpm to 800rpm (IDLE)
Target Temperature :	600deg.C before DTI at inlet DPF
DTI Timing :	Worst

2. Test Results

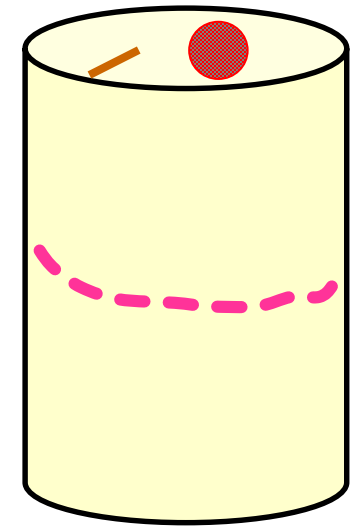
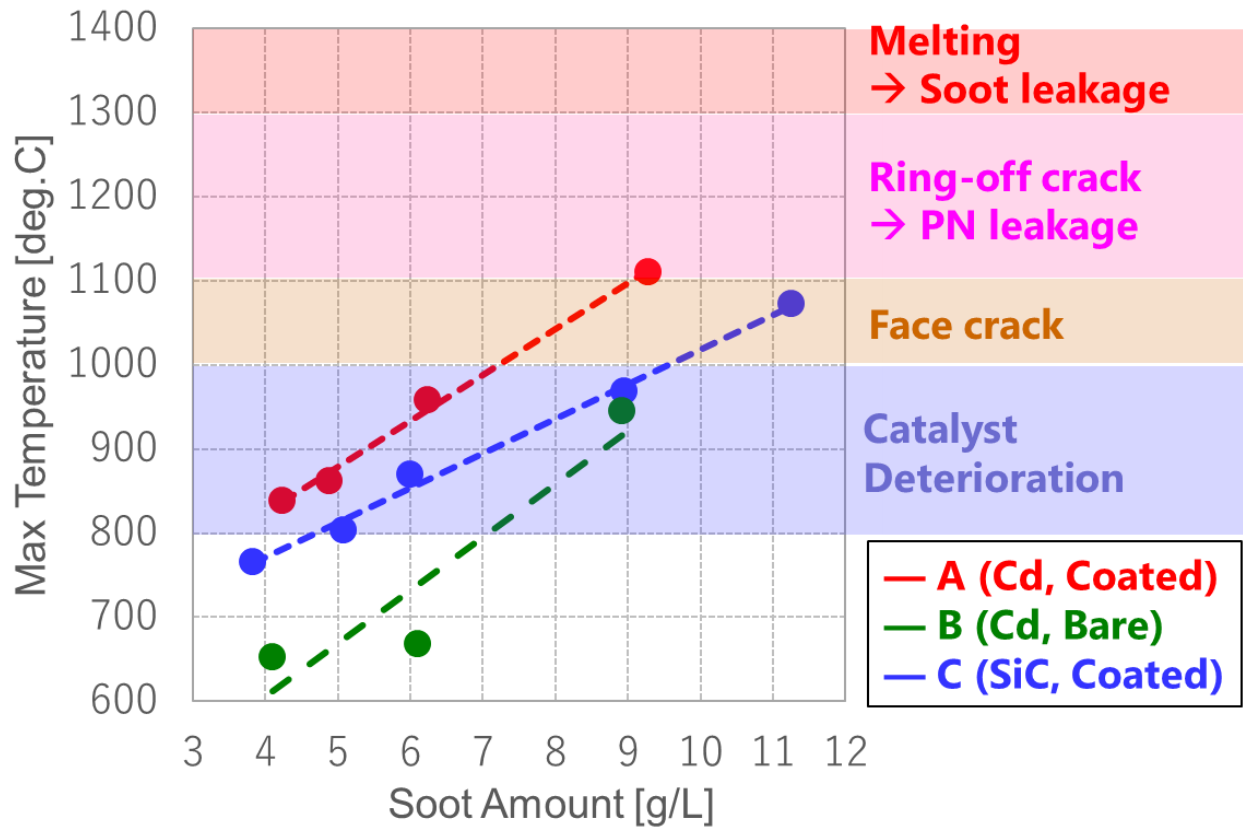


Image of failure mode

Note)
Failure temperatures of SiC-DPF and Cd-DPF are similar level.

Safe SML of Cd-DPF is less than SiC-DPF around 1100deg.C of DPF Max temperature. Bare DPF didn't reach 1100deg.C, safe SML could be similar with Coated SiC-DPF.

Background

Experimental Setup

Test Condition and Result

1. PN Filtration
2. Passive Regeneration
3. Active Regeneration
4. Drop To Idle

Conclusion

Conclusion

+ Positive
- Negative



Test Items		A Cordierite-DPF Coated	B Cordierite-DPF Bare	C Silicon carbide-DPF Coated
PN	NRTC	Base	-	Same
	RMC	Base	+	+
Passive Regeneration (Soot Combustion)		Base	-	Same (Slight lower)
Passive Regeneration (Pressure Drop)		Base	+	-
Active Regeneration (Regeneration efficiency)		Base	-	Same
Soot Mass Limit		Base	+	+
Total expectation		Balanced	PN/PD oriented	PN/SML oriented

Coated Cordierite-DPF has balanced performance as TREM V.
Bare Cordierite-DPF or Coated SiC-DPF could be an alternative candidate depending on required performance.

A large, light blue graphic of an open hand, palm facing up, with fingers spread. The hand is centered on the slide.

Thank you

NGK