22nd & 23rd October ECT 2024

ECOCAT INDIA PVT. LTD.

VIKAS GROUP

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Technologies for Clean Environment

Challenges and Solutions in EATS to meet Emission Legislation Required for Off-road and Stationary Segments

Vishnuvarthan Muthusamy, Manash Bhadra, Rajan Bosco, Shashank Sahai & Alok Trigunayat

Contents

- Ecocat Innovative Emission Control Technologies
- Emission Legislation Norms in Off-road and Stationary Category
- Challenges & Solutions in Off-road (TREM V & CEV V) & Stationary Segments
- Summary & Conclusion

Contents

COMPLETE SYSTEM DESIGN & DEVELOPMENT

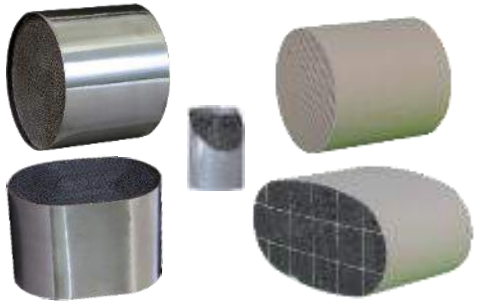
ECOCAT INDIA PVT. LTD.
VIKAS GROUP
VICAT
Technologies for Clean Environment

TOTAL Exhaust Solution | Complete System Responsibility | Shorter Lead Time | Cost Effective

OUR MISSION

Clean the Environment for the World by providing innovative technological solutions to reduce pollution

SUBSTRATE TECHNOLOGY



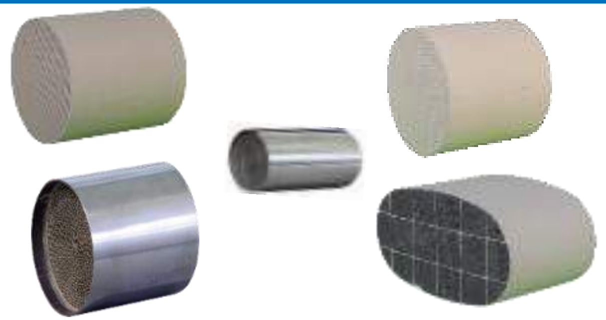
Metallic Substrate

- Brazed Substrates
- VIKPIC®-D (DOC)
- VIKPIC®-F (POC)

Ceramic Substrate

- Flow through
- PFF
- DPF

CATALTST/COATING TECHNOLOGY



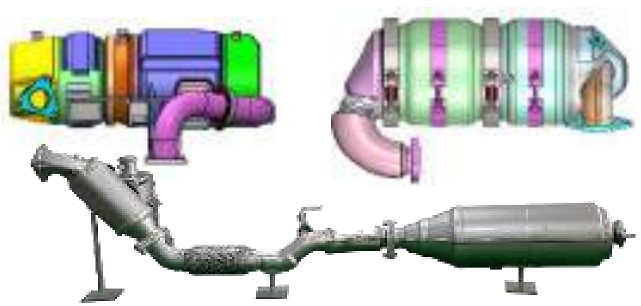
DIESEL

- Diesel Oxidation Catalyst
- Coated Diesel Particulate Filter
- SCR (Vanadia/Cu Zeolite)
- Ammonia Slip
- LNT (Lean NOx Trap)

GASOLINE/CNG/BIFUEL

- Three Way Catalyst (Gasoline)
- Three Way Catalyst (CNG/HCNG)
- Three Way Catalyst (Bi fuel)
- Hydrogen Oxidation catalyst

AFTER TREATMENT SYSTEM



HOT END

- TWC (Gasoline & CNG) ASSY
- DOC ASSY
- DOC + cDPF ASSY
- DOC + cDPF + SCR ASSY

COLD END

- MUFFLERS
- COMPLETE EXHAUST SYSTEM

Ecocat Innovative Emission Control Technologies

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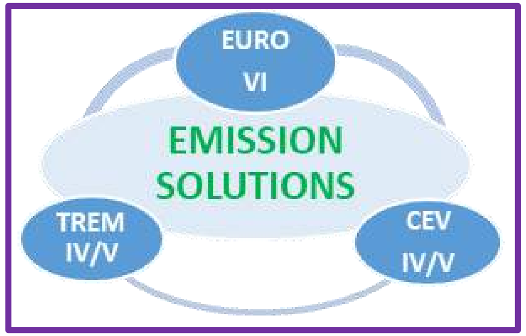
Ecocat Innovations



- New Metallic Structured Substrates
- Advanced Chemistries/ Washcoats for Gasoline/ Diesel/ CNG (BSVI/TREM V)
- Complete ATS to meet BS-VI, TREM-V, CEV-V, CPCB IV+ norms

Our R&D

- R&D Mechanical
- R&D Testing
- R&D Chemical

Mechanical R&D

- CAD
- CAE

Testing R&D

- EURO VI / TREM V Emission Testing
- Chassis
- Transient
- Eddy Current

Chemical R&D

- Efficient PGM usage
- Washcoat design, development & coating processes
- State of the Art Characterization Techniques
- Simulated Gas Test Bench Apparatus

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- **Emission Legislation Norms in Off-road and Stationary Category**
- Challenges & Solutions in Off-road (TREM V & CEV V) & Stationary Segments
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Emission Legislation Norms in Off-road Category

Category	TREM V & CEV V						TREM IV & CEV IV					NRSC/NRTC Test Cycle
	CO	HC	NOx	HC+NOx	PM	PN	CO	HC	NOx	HC+NOx	PM	
kW	g/kWh				mg/kWh	#kWh	g/kWh				mg/kWh	
P < 8	8.0			**7.5**	**400**		5.5			**8.5**	**800**	**CEV-V** 1st Jan 2025 **TREM-V** 1st April 2026
8 ≤ P < 19	6.6			**7.5**	**400**		5.5			**8.5**	**800**	
19 ≤ P < 37	5.0			**4.7**	**15**	$1X10^{12}$	5.5			**7.5**	**600**	
37 ≤ P < 56	5.0			4.7	**15**	$1X10^{12}$	5.0			4.7	**25**	**CEV-IV** 1st April 2021 **TREM-IV** 1st April 2023
56 ≤ P < 130	5.0	0.19	0.4	**0.6**	**15**	$1X10^{12}$	5.0	0.19	0.4	0.6	**25**	
130 ≤ P < 560	3.5	0.19	0.4	**0.6**	**15**	$1X10^{12}$	3.5	0.19	0.4	0.6	**25**	
P ≥ 560	3.5	0.19	3.5	3.7	**45**	-						

ATS with SCR

NH_3 Emission Control

25 ppm for engine category < 56 KW

&

10 ppm for engine category ≥ 56 KW

- **Introduced new power category of ≥560kW.**
- **Stringent control on PM emissions & also on THC+NOx emissions.**
- **PM reduction requirement: Ranges from 40% to 97.5%.**
- **THC+NOx reduction requirement: Ranges from 12% to 37% (<37 kW).**
- **Both reduction in THC+NOx & PM emission - observed for 19 to 37 kW.**

Emission Legislation Norms in Stationary Category

Category	CPCB IV						CPCB III					
	CO	HC*	NOx	HC*+NOx	PM	Smoke	CO	HC*	NOx	HC*+NOx	PM	Smoke
kW	g/kWh				**mg**/kWh	1/m	g/kWh				**mg**/kWh	1/m
P < 8	3.5	-		7.5	300	0.7	3.5	-		7.5	300	0.7
8 ≤ P < 19	3.5			4.7	300	0.7	3.5			4.7	300	0.7
19 ≤ P < 56	3.5			4.7	**30**	0.7	3.5			4.7	**300**	0.7
56 ≤ P < 75	3.5	0.19	0.4	**0.6**	**20**	0.7	3.5			**4.7**	**300**	0.7
75 ≤ P < 560	3.5	0.19	0.4	**0.6**	**20**	0.7	3.5			**4.0**	**200**	0.7
560 ≤ P ≤ 800	3.5	0.19	0.67	**0.9**	**30**	0.7	3.5			**4.0**	**200**	0.7

5-Mode
ISO 8178 D2
Test Cycle

CPCB IV
1st July 2023

CPCB III
1st April 2014

ATS with SCR

NH_3 Emission Control

25 ppm for engine category < 56 KW
&
10 ppm for engine category ≥ 56 KW

- **No change in norms for genset lower than 19 kW power.**
- **Stringent control on PM emissions & also on THC+NOx emissions.**
- **PM reduction requirement: Ranges from 85% to 93%.**
- **THC+NOx reduction requirement: Ranges from 79% to 87%.**

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The Challenges

- **Stricter NOx limits**: TREM V requires a significant reduction in NOx emissions, making it challenging to achieve with existing technologies.
- **Particulate Matter (PM) reduction**: TREM V mandates a substantial decrease in PM emissions, demanding advanced filtration systems and engine optimization.
- **Regeneration Strategies**: Manufacturers must design systems for primary DPF regeneration strategis between active & passive.
- **Increased complexity**: Meeting TREM V standards will require more sophisticated engine management systems, aftertreatment technologies, and control strategies.
- **Technological innovation**: Meeting TREM V standards will drive the need for innovative solutions, such as advanced catalysts, new materials, and alternative technologies.
- **Cost and affordability**: Implementing TREM V-compliant solutions may increase production costs, potentially affecting market competitiveness and customer affordability.
- **Fuel quality and availability**: TREM V's stricter standards may necessitate the use of cleaner fuels, which might not be widely available or compatible with existing infrastructure.

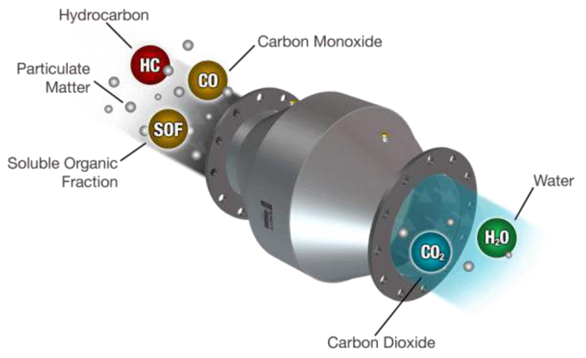
Solutions

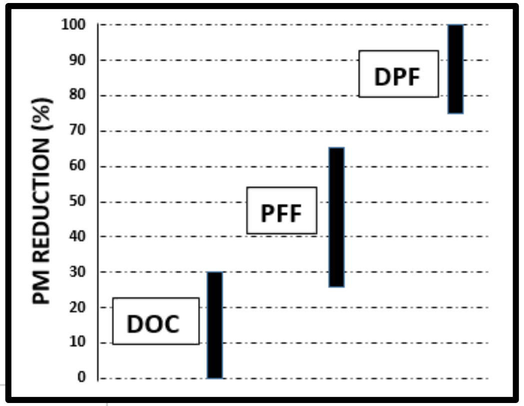
- **Compact & Integrated aftertreatment system design** : Designing smaller, more efficient systems. Optimizing system design to minimize cost and complexity while meeting emission standards.
- **Particulate filters**: Implementing filters to capture particulate matter.
- **Advanced catalysts**:
  - Developing high-performance Diesel Oxidation Catalysts for Exotherm generation (Active regeneration)
  - Developing high-performance Diesel Oxidation Catalysts for NO2 formation (Passive regeneration)
- **Thermal management**: Using techniques like insulation, heat exchangers, or electric heating to maintain optimal temperatures.
- **Alternative technologies**: Exploring alternative technologies like electric or hybrid propulsion.

Strategies

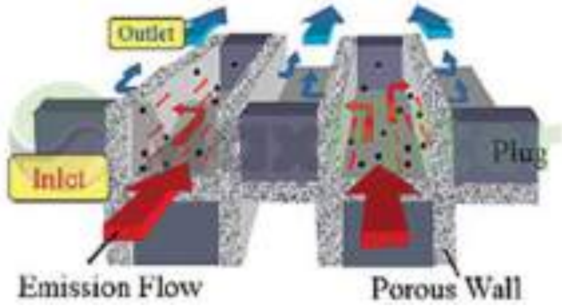
Catalytic System	DOC	cDPF/PFF or POC	SCR	ASC
Pollutant Control	CO, THC, & SOF part of PM Removal & NO_2 Formation	PM Removal & NO_2 Formation	NOx Removal	NH_3 Removal

- DOC Coating/Washcoating Technologies
  - For Active Regeneration
  - For Passive Regeneration
- NO_2 formation in DOC/cDPF
- Washcoat Technologies in cDPF
  - For Active Regeneration
  - For Passive Regeneration





$2CO + O_2 = 2CO_2$
Hydrocarbons + O_2 = $CO_2 + H_2O$
SOF + O_2 = $CO_2 + H_2O$



Strategies

Active Regeneration	Passive Regeneration
Active regeneration is a process in which extra fuel is sent to the exhaust, via in-cylinder post injection, or in-exhaust injection, so that its temperature can be raised in order to burn off the excess soot which is starting to block your DPF	**Passive regeneration** is an approach used to oxidise particulate matter (PM) in the diesel particulate filter (DPF) by using normal exhaust temperatures and nitrogen dioxide (NO_2) made by a DOC, as the reactant to oxidise PM in the DPF
• $C(S) + 0.5\ O_2 \rightarrow CO$ • $C(S) + O_2 \rightarrow CO_2$ • $CO + 0.5O_2 \rightarrow CO_2$	• $C(S) + 2NO_2 \rightarrow CO_2 + 2NO$ • $C(S) + NO_2 \rightarrow CO + 2NO$ • $C(S) + NO_2 \rightarrow CO_2 + 0.5N_2$
A pre-DPF temperature of > 600°C is required to oxidize PM in the DPF	DOC temperatures of 280 – 420°C are required to generate nitrogen dioxide (NO_2) which then can oxidize the PM in the DPF
The high pre-DPF temperature is attained by injecting fuel upstream of a DOC. This fuel undergoes catalytic oxidation in the DOC. The exotherm generated during this reaction provides the required high pre-DPF temperature	Regeneration happens at normal pre-DPF temperatures, & additional fuel injection is not required
In-cylinder post injection requires additional ECU programming. In-exhaust injection requires additional hardware, making it expensive	No special hardware required to induce DPF passive regeneration, except for suitably formulated DOC

DOC Washcoat Technologies for DPF Regeneration

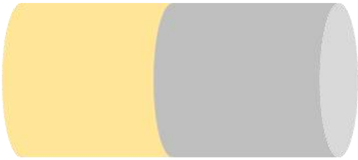
For Passive Regeneration

- Pt-only washcoat technology.
- Enhanced generation of NO_2 in the temperature range of 270°C to 450°C.

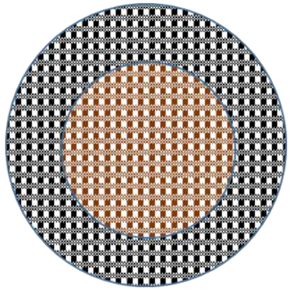
For Active Regeneration

- Pt-Pd based washcoat technology.
- Enhanced in-situ oxidation of injected diesel fuel within the DOC, when its inlet temperature < 240°C, generating an exotherm of 600°C, at its outlet.
- Minimum HC slip (> 1000 ppm).

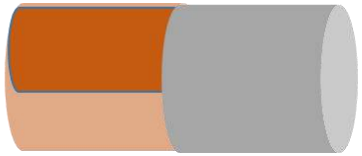
DOC Coating Technologies



Axial Zone coating

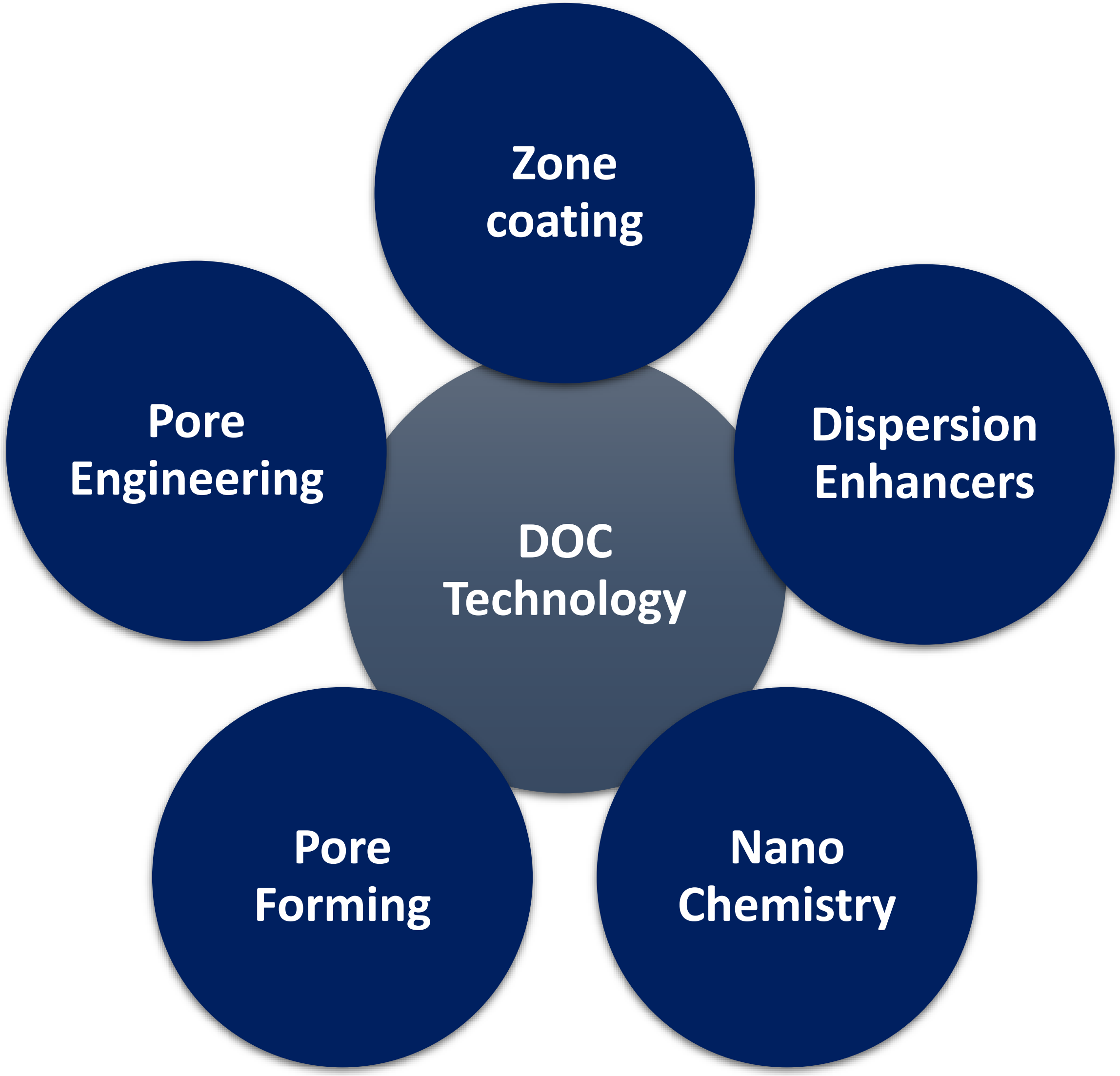


Radial Zone coating



Combination of Zone and layer coating

Zone coating in a catalytic converter refers to applying different types or amounts of catalyst coating to specific regions of the substrate.

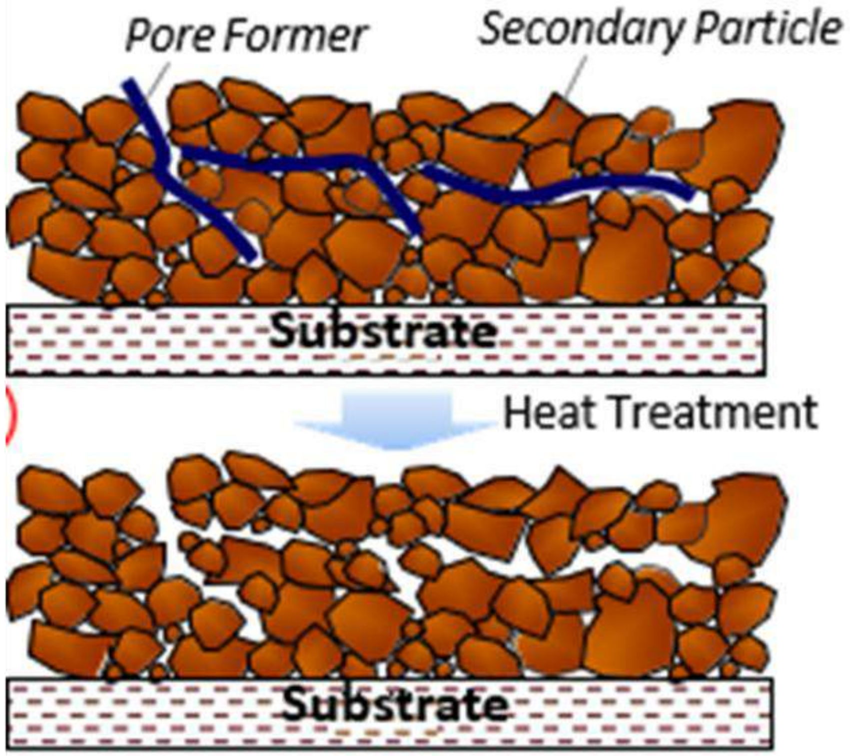


Customised Coatings for fast light-off & high temp durability

DOC Coating Technologies: Pore Forming

Pore Forming refers to the creation of small opening or channels in washcoat which allows diffusion of gas molecules to react with active sites deep within.

- **Creates new intra-particle channels in the washcoat.**
- **Enhances interaction of gas with active metals embedded deep into the washcoat.**
- **Provides a larger area to adsorb gas molecules.**
- **Enables access to active sites deep within the washcoat.**

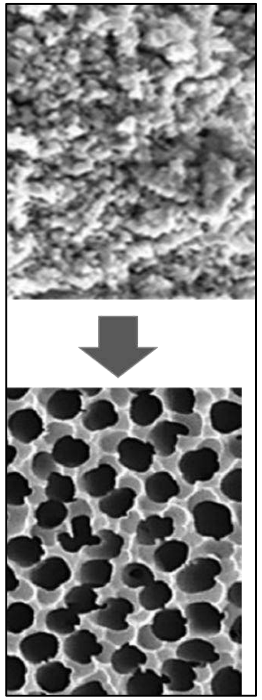


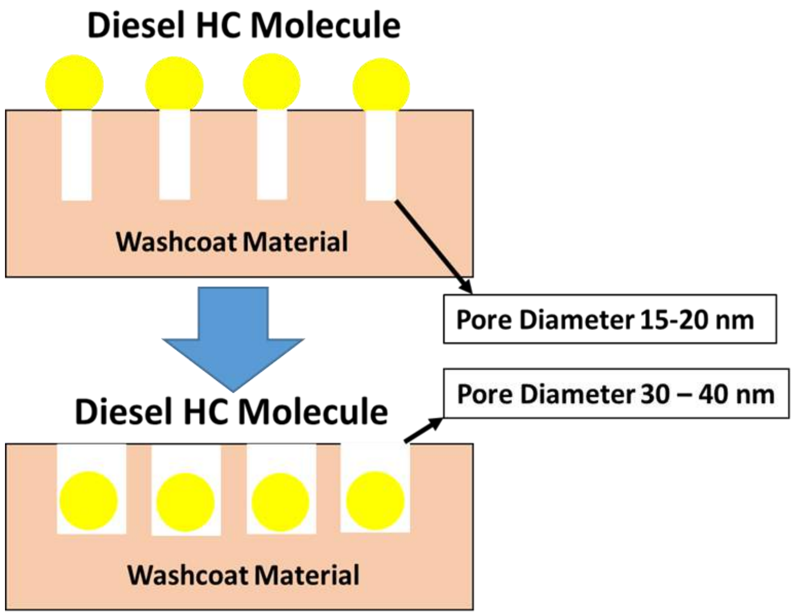
Securing Reaction Efficiency by Adding Pore Former for better diffusivity

DOC Coating Technologies: Pore Engineering

Pore Engineering is tailoring or redesign of existing pores of the washcoat to achieve specific functions.

- **Allows preparation of DOC washcoat with tailor made porosity.**
- **Bulky hydrocarbon molecules, trapped deep within the washcoat and oxidized efficiently to generate exotherms.**
- **Application: In ceramic DOC where DPF demands active regeneration.**

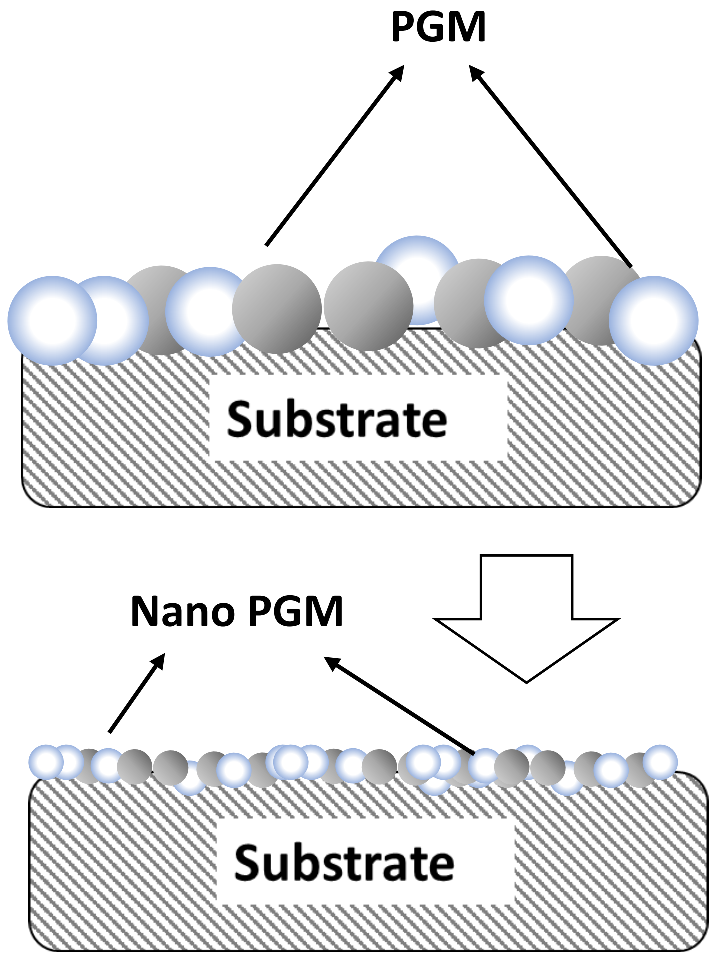




DOC Coating Technologies: Nano washcoats

Nano washcoating technology deals with designing and synthesis of washcoat chemistry at of nano scale.

- **In-situ activation of PGM by a proprietary chemical makes nano sized PGM particles.**
- **PGM metal surface area increases.**
- **Enhancing performance – Faster light off & enhanced durability**



DOC Coating Technologies: PGM Dispersion Enhancers

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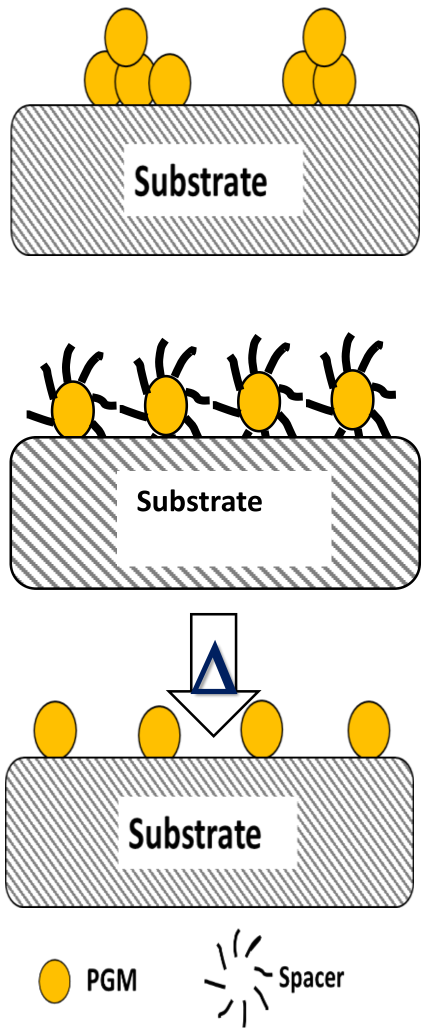
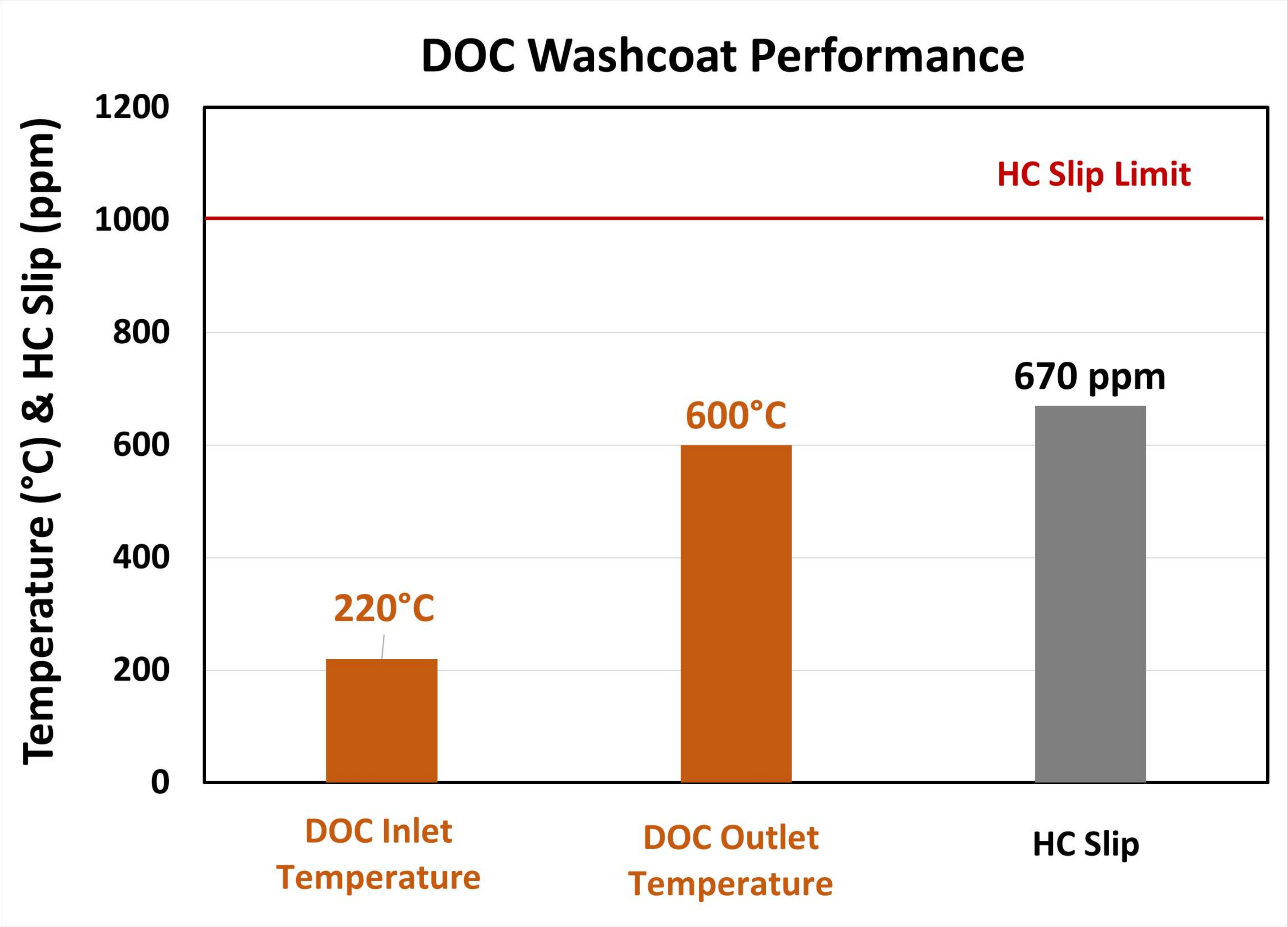
- A proprietary spacer is introduced during washcoat preparation.
- They align themselves between the PGM atoms in such a way that these atoms are evenly dispersed throughout the washcoat matrix.
- After thermal treatment, they burn off but the PGM is fixed
- Reduce sintering effect and durability enhancement



Technology Advantages - Coating

- Effective Use of PGM by targeted positioning.
- Tailored Catalyst design giving optimized Catalytic Activity
- Reduced Cold Start Emissions
- Enhanced fuel exotherm at lower temperatures during Post injection
- Efficient passive regeneration at lower temperatures
- Reduced PGM use - lowering costs

Active Regeneration Strategy (Pt-Pd Technology)



Our Active Regen. DOC washcoat is resilient to thermal aging due to the synergetic effect of Pt-Pd.

Passive Regeneration Strategy (Pt Only Technology)

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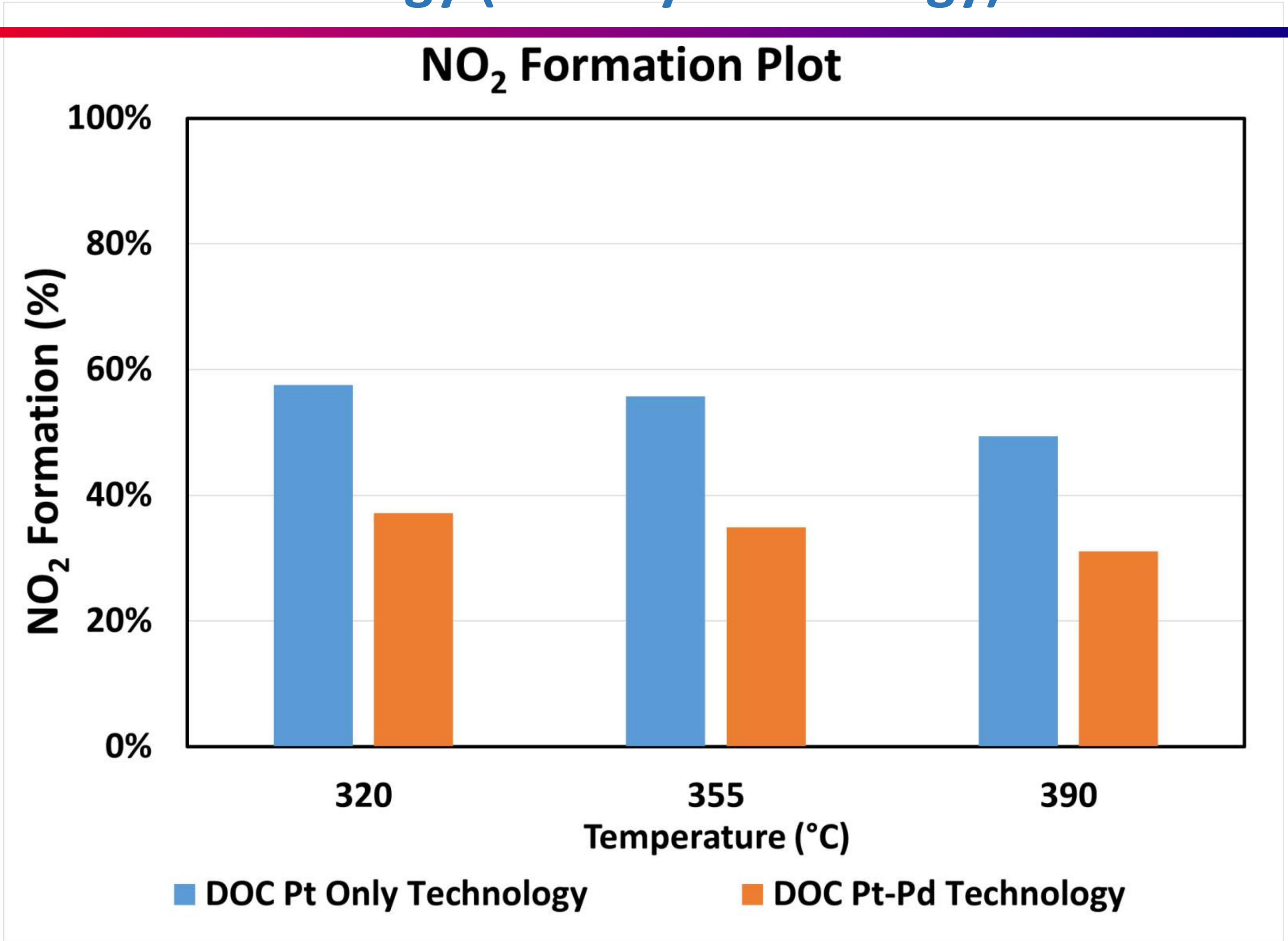
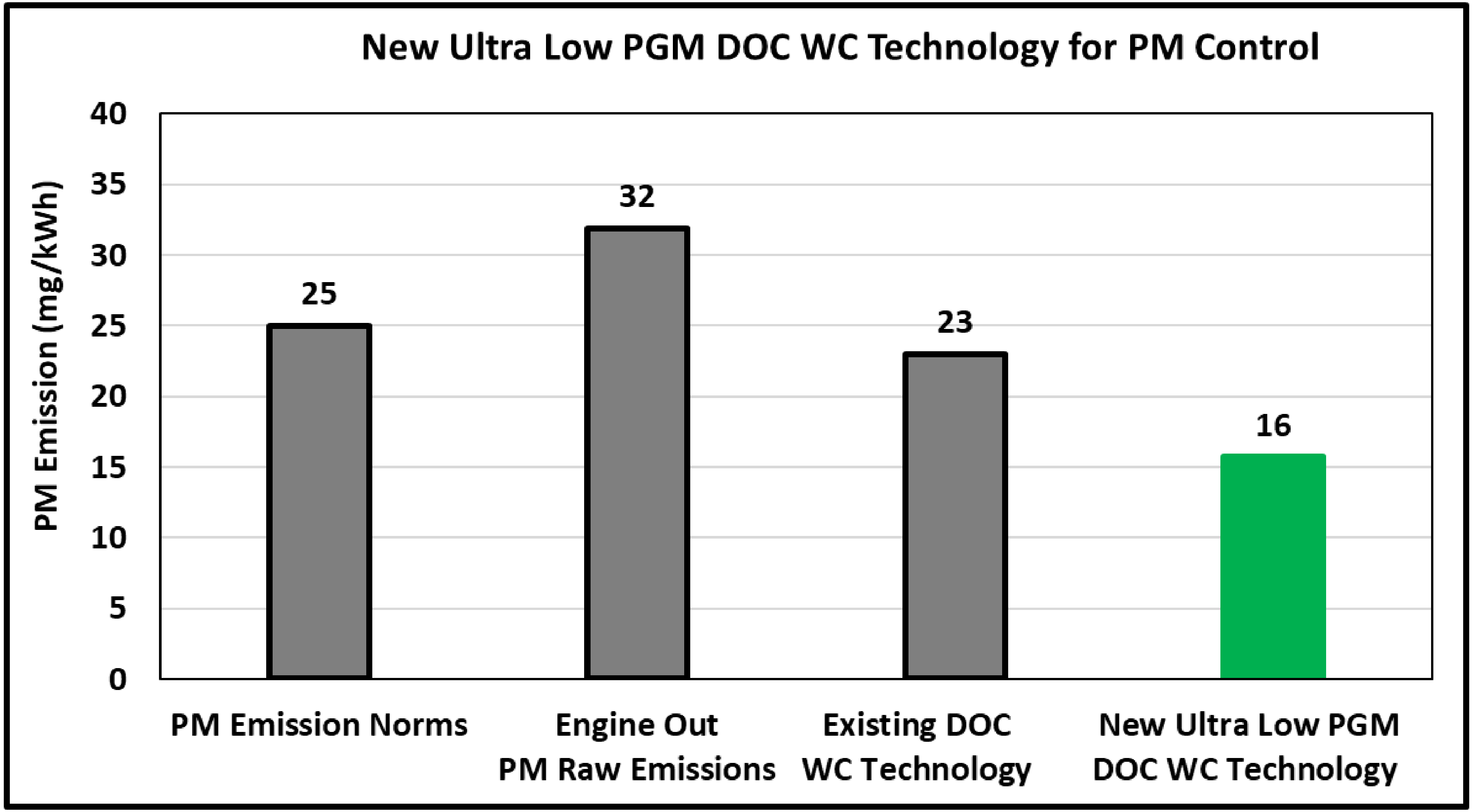


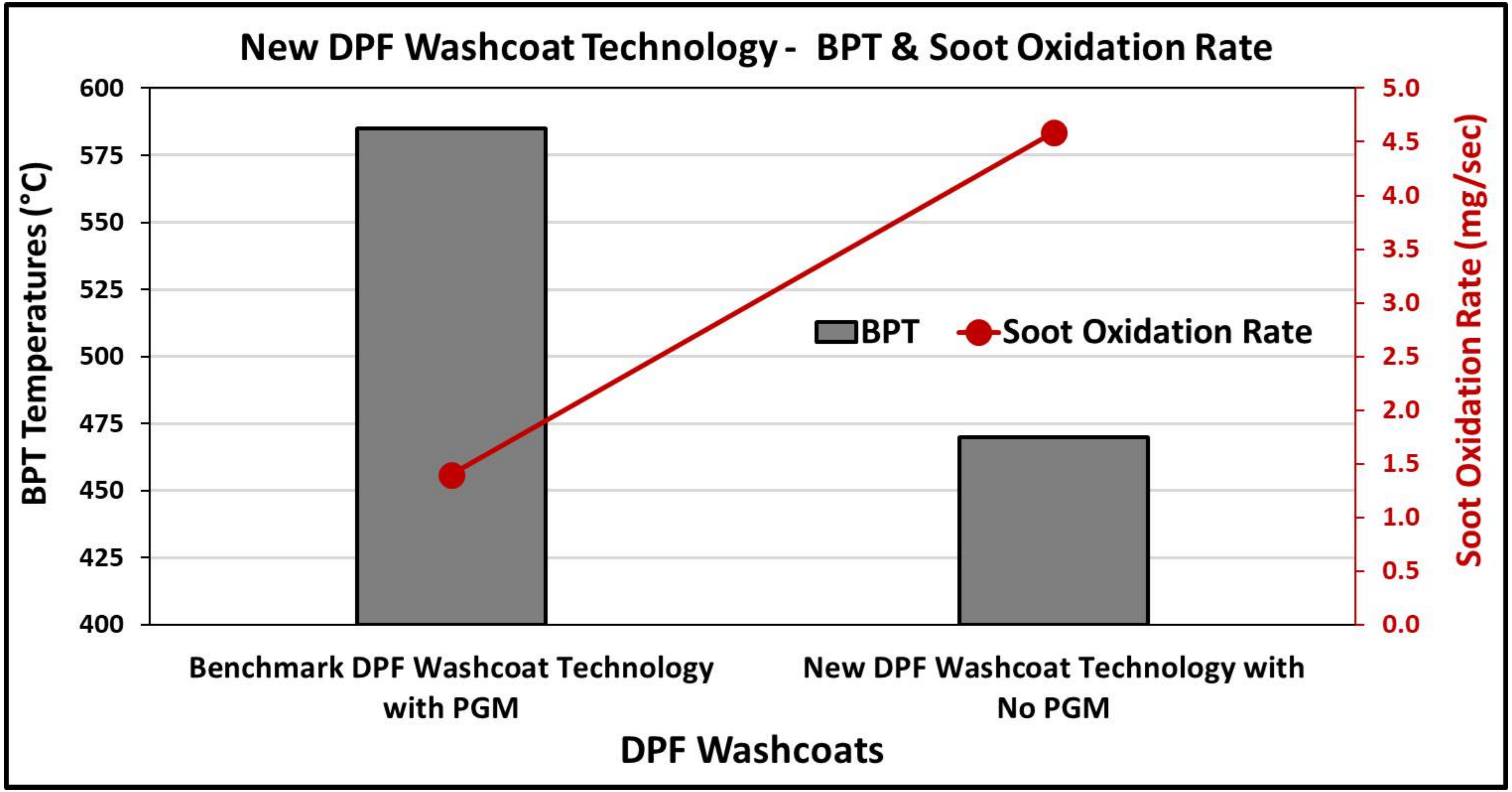
- Space Velocity: 60,000/h. Pt-only DOC forms higher NO_2 than DOC with Pt-Pd.
- Pt is better than Pt-Pd for NO_2 formation

Ultra Low PGM DOC Washcoat - Off-road and Stationary



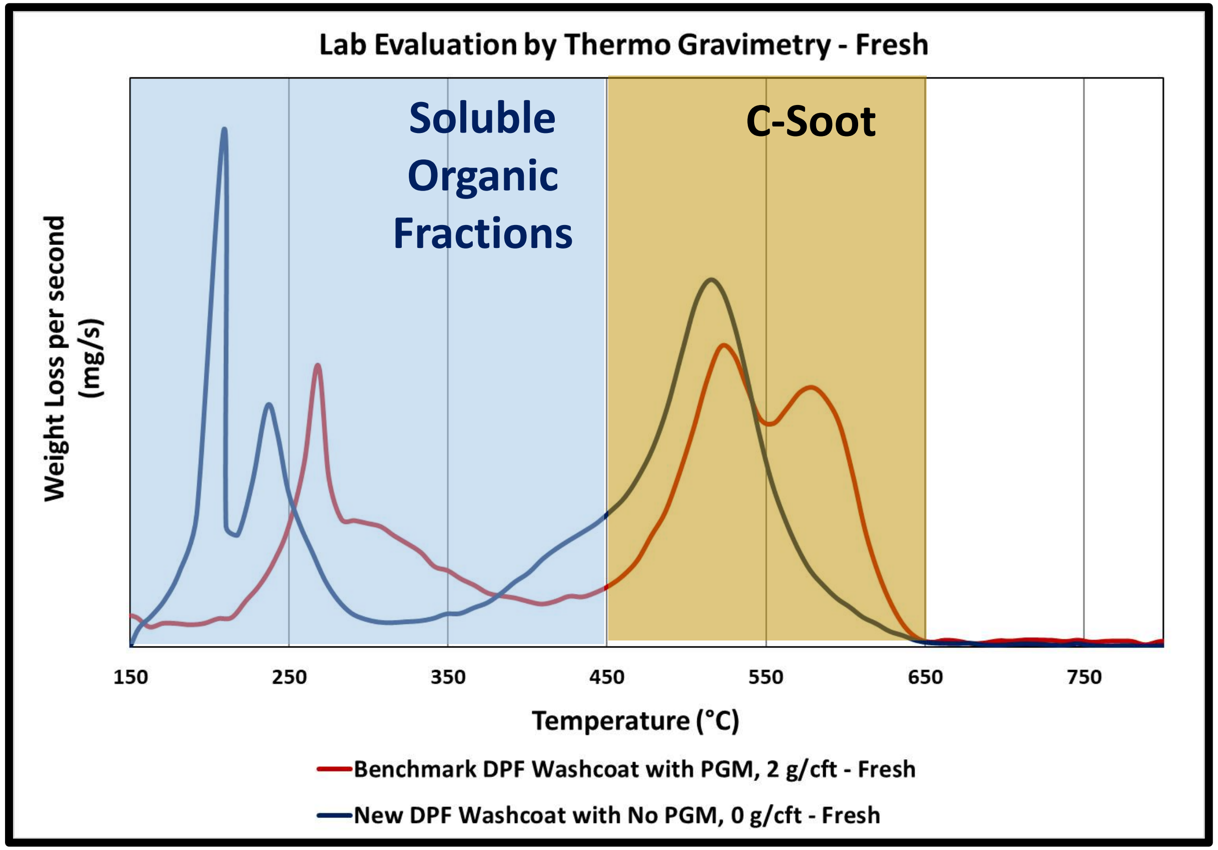
Our Low PGM DOC washcoat is highly efficient in converting PM to meet stringent emission norms .

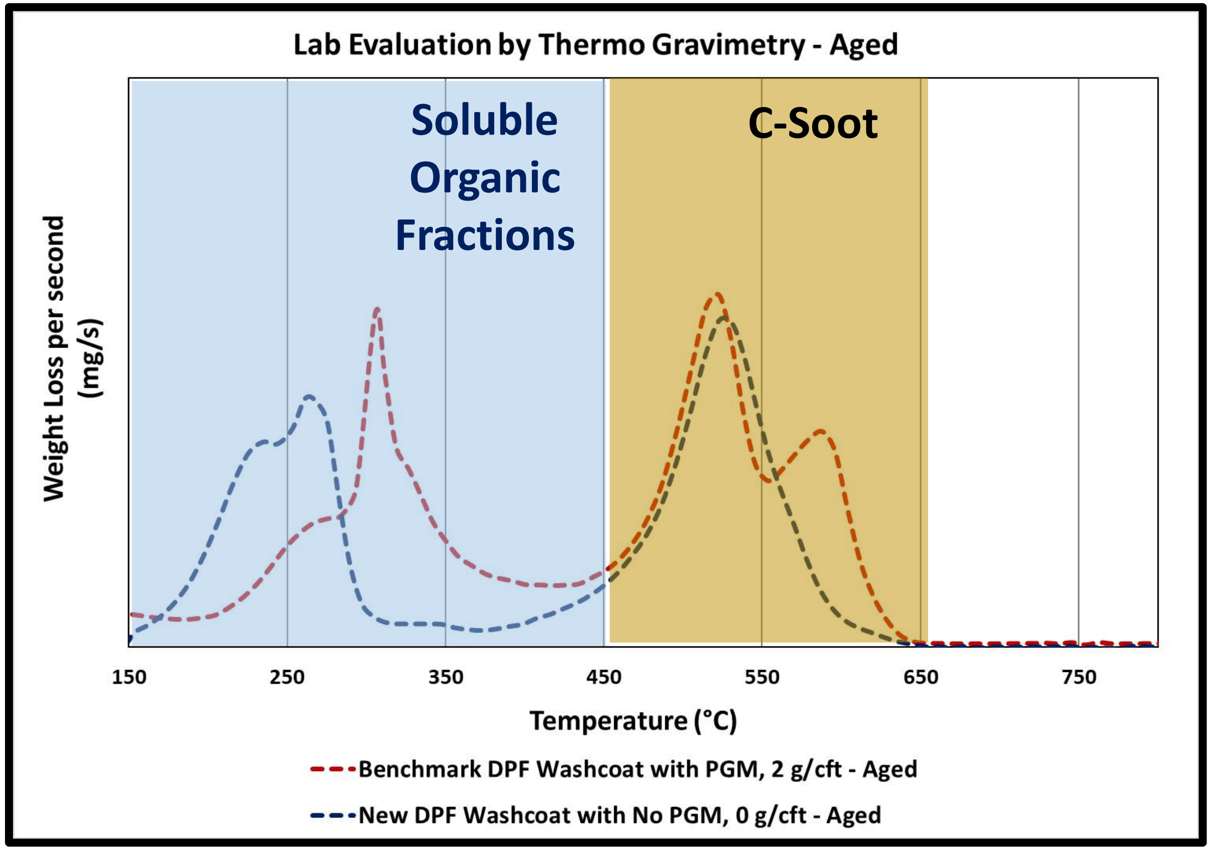
NO_2 Formation on DPF – Regeneration Functions



DPF washcoats shows higher soot oxidation rate and lower balance point temperature in PM removal.

PGM Free DPF Washcoat Technology – Regeneration Functions





The SOF & C-soot oxidation on our PGM-free DPF washcoat occurs at relatively lower temperatures when compared to a DPF washcoat with Pt loading of 2 g/cft.

SCR Washcoat Technology – Low Temperature NOx conversion

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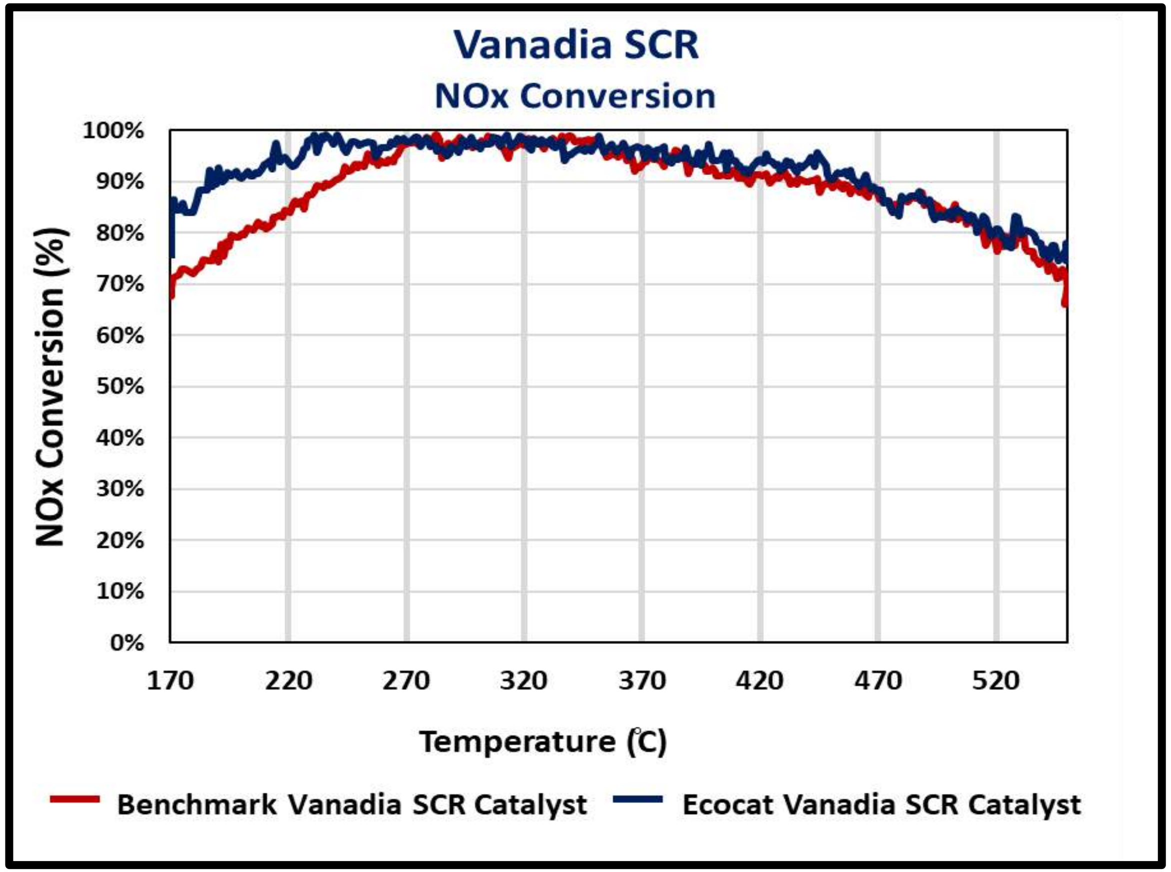
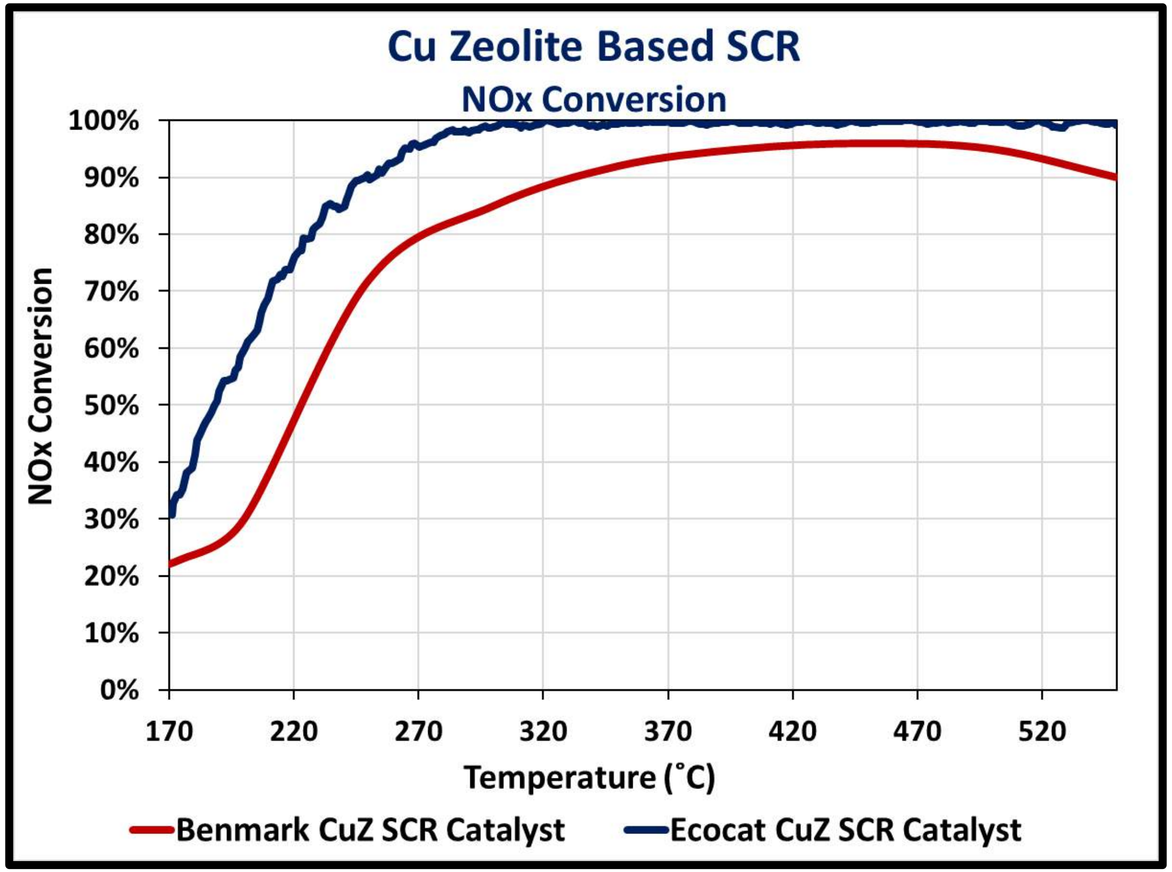
Low & Medium Temperature Technology

Vanadia SCR



Wider Temperature Technology

Cu-Zeolite SCR

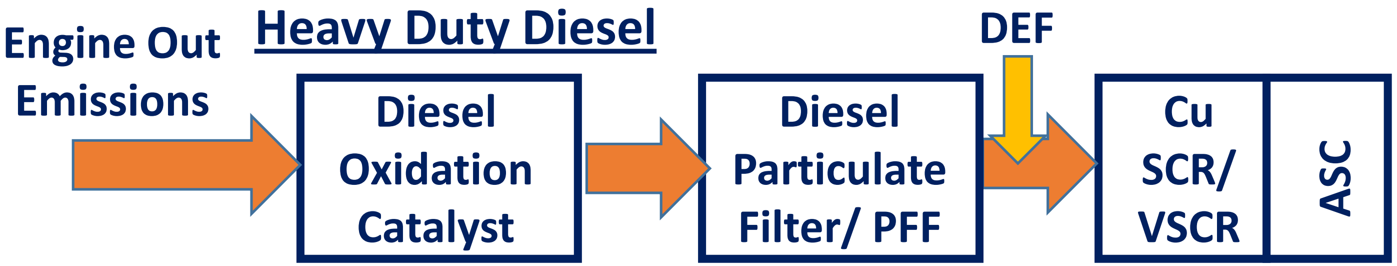


SCR washcoat technology shows efficient NOx conversion at wider temperature range with lower LOT.

ATS Solutions – From TREM IIIA to TREM V

<table>
<tr><th>Category</th><th>TREM IIIA</th><th>TREM IV</th><th>TREM V</th></tr>
<tr><td>< 37 kW</td><td rowspan="5">DOC only (optional, mostly no ATS required)</td><td>• DOC only</td><td>• DOC + DPF</td></tr>
<tr><td>37 to < 56 kW</td><td>• DOC only
• DOC + PFF</td><td>• DOC + DPF
• DOC + DPF + SCR + ASC</td></tr>
<tr><td>56 to < 130</td><td rowspan="3">• DOC + SCR + ASC
• DOC + PFF</td><td rowspan="2">• DOC + DPF + SCR + ASC</td></tr>
<tr><td>130 to < 560</td></tr>
<tr><td>560 & above</td><td>• DOC + DPF
• DOC + DPF + SCR + ASC</td></tr>
</table>

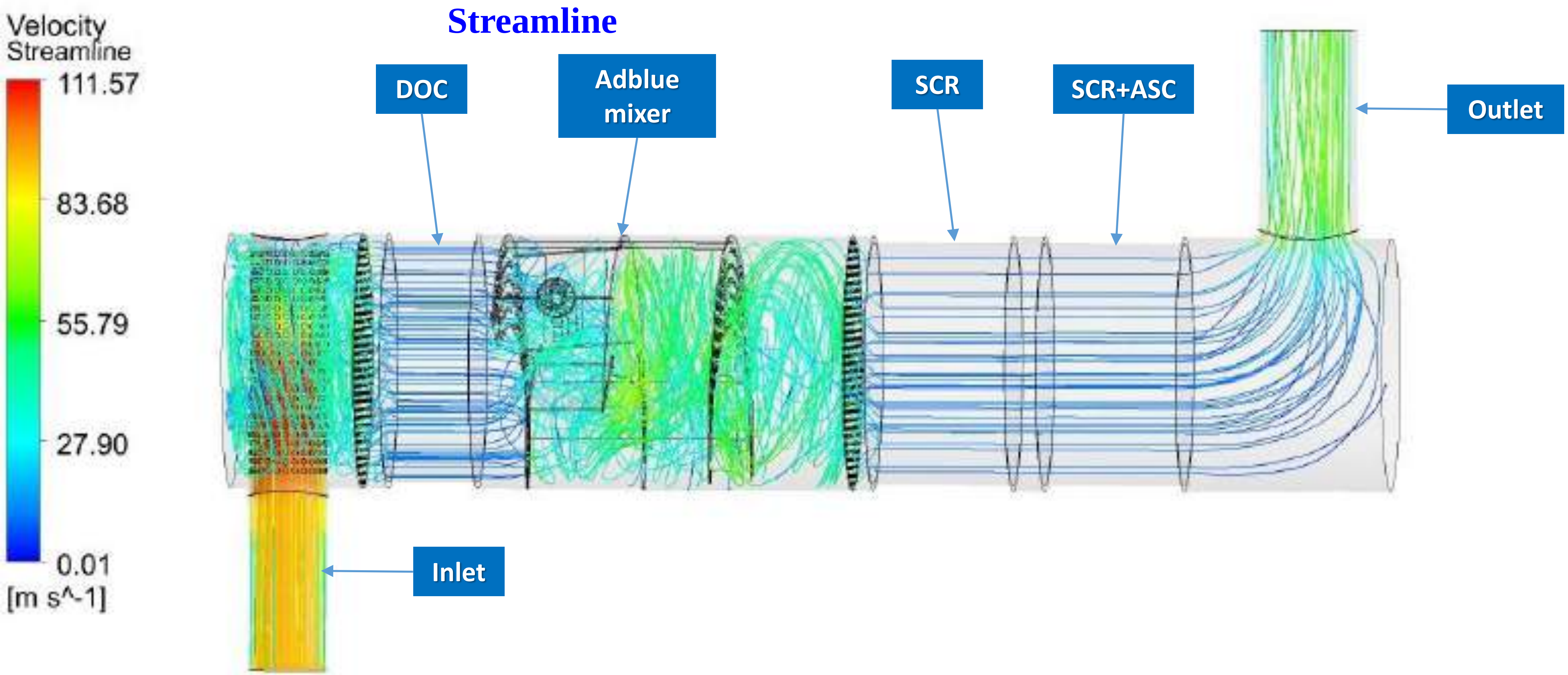
- *These are typical catalytic converter combinations. In actual use, these might change depending on the specific engine emissions*



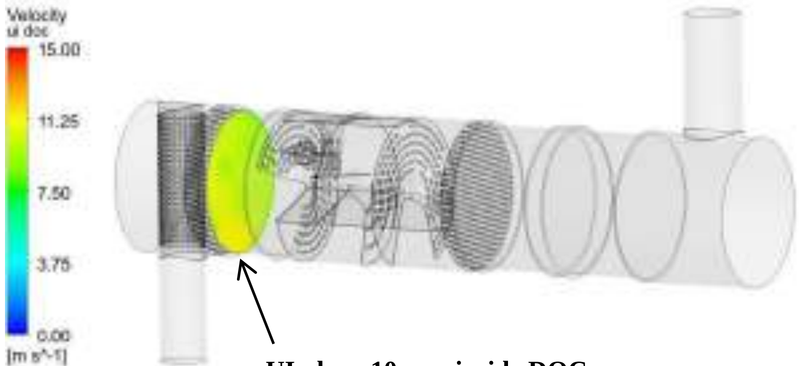
Category	TREM V					
		CO	THC	NOx	THC + NOx	PM
kW		g/kWh				mg/kWh
37 ≤ P < 56	Norm	5	-	-	4.7	15
	NRSC	0.09	0.010	2.620	2.6	5
	NRTC	0.13	0.027	2.606	2.6	6

Category	CPCB IV				
		CO	THC	NOx	PM
kW		g/kWh			mg/kWh
56 ≤ P < 560	Norm	3.5	0.19	0.670	30
	5-Mode	0.01	0.003	0.652	17

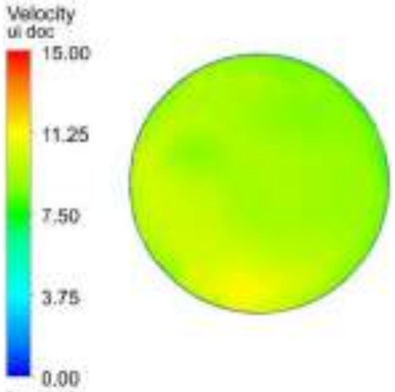
ATS Solutions – CPCB IV+ Norms



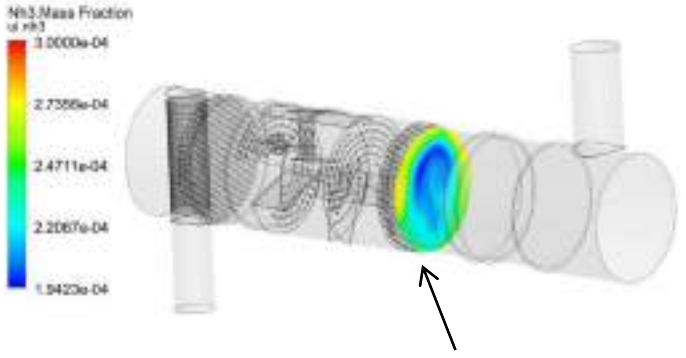
ATS Solutions – CPCB IV+ Norms



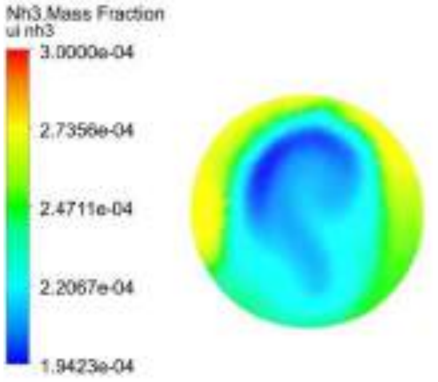
UI plane 10 mm inside DOC



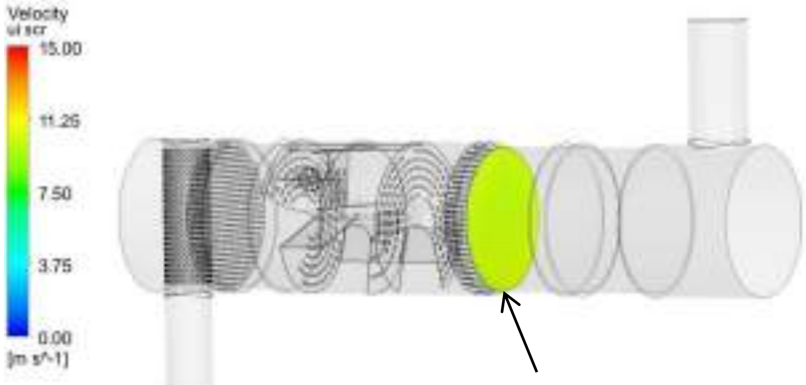
UI_DOC = 0.97



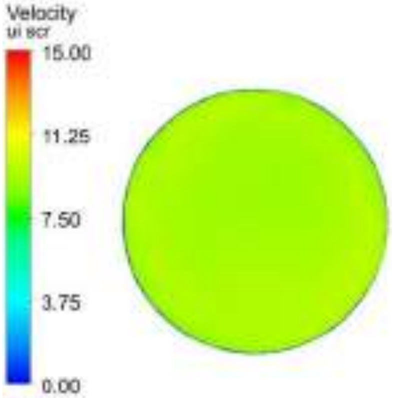
UI plane 10 mm inside SCR



UI_NH3 = 0.96



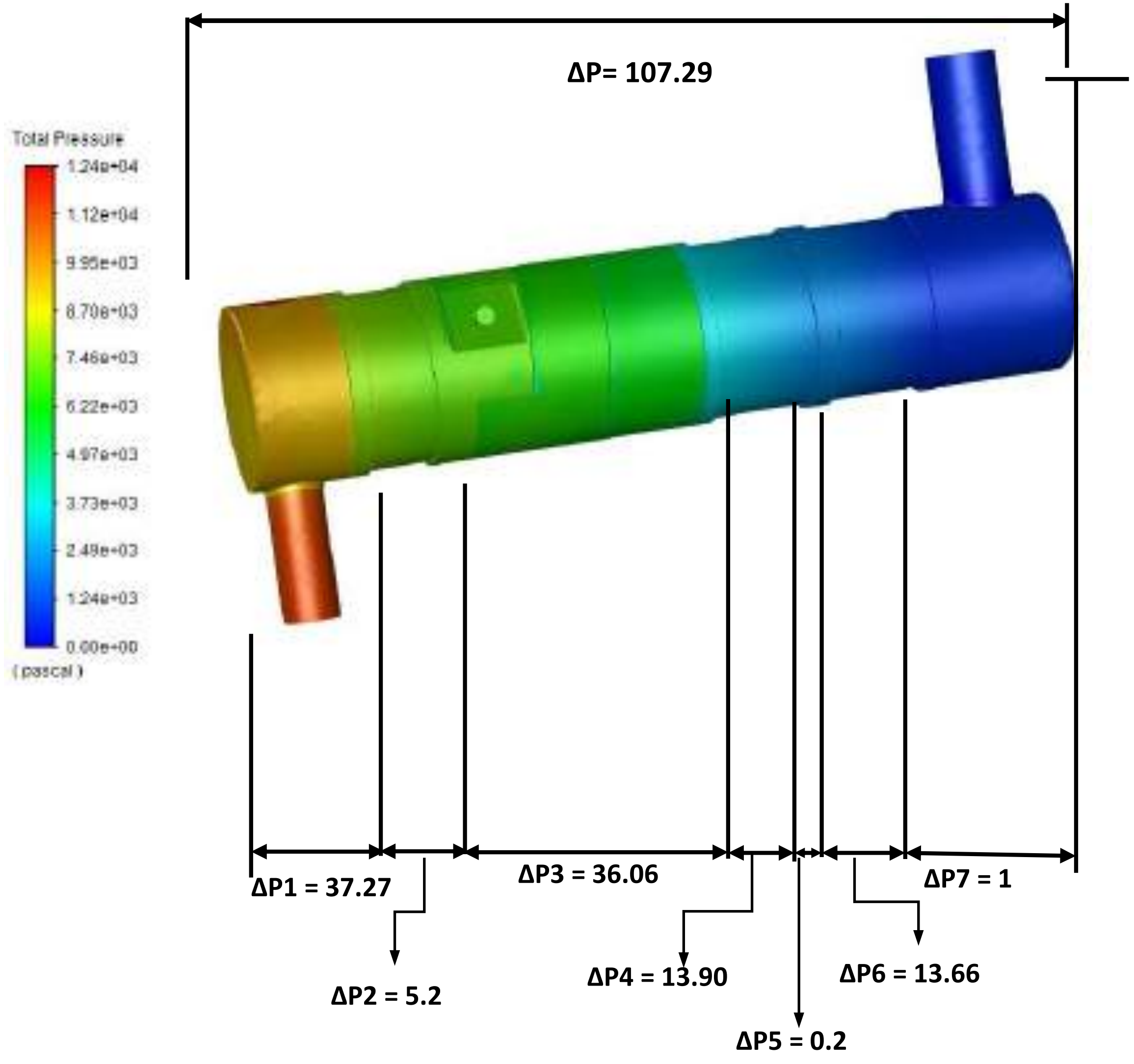
UI plane 10 mm inside SCR



UI_SCR = 0.99

Maximum Mass Flow	Simulated Values
SDPF Velocity UI	0.99
V_{max} / V_{mean}	1.08
V_{min} / V_{mean}	0.86
Nh_3 Mass Fraction UI	0.96
C_{max} / C_{mean}	1.15
C_{min} / C_{mean}	0.81

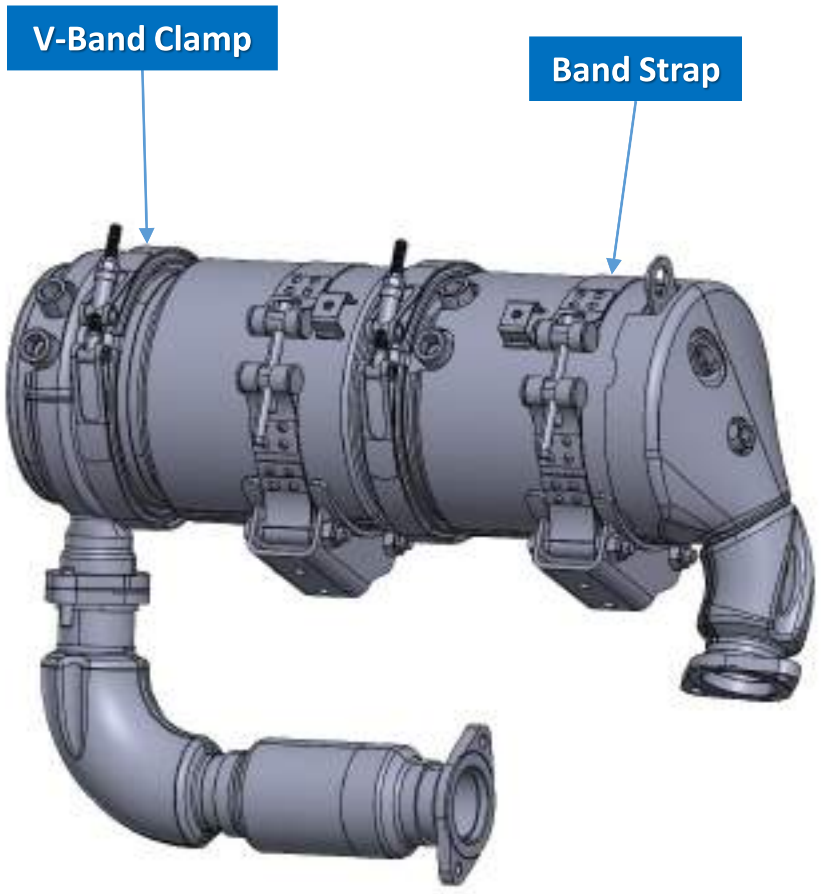
ATS Solutions – CPCB IV+ Norms

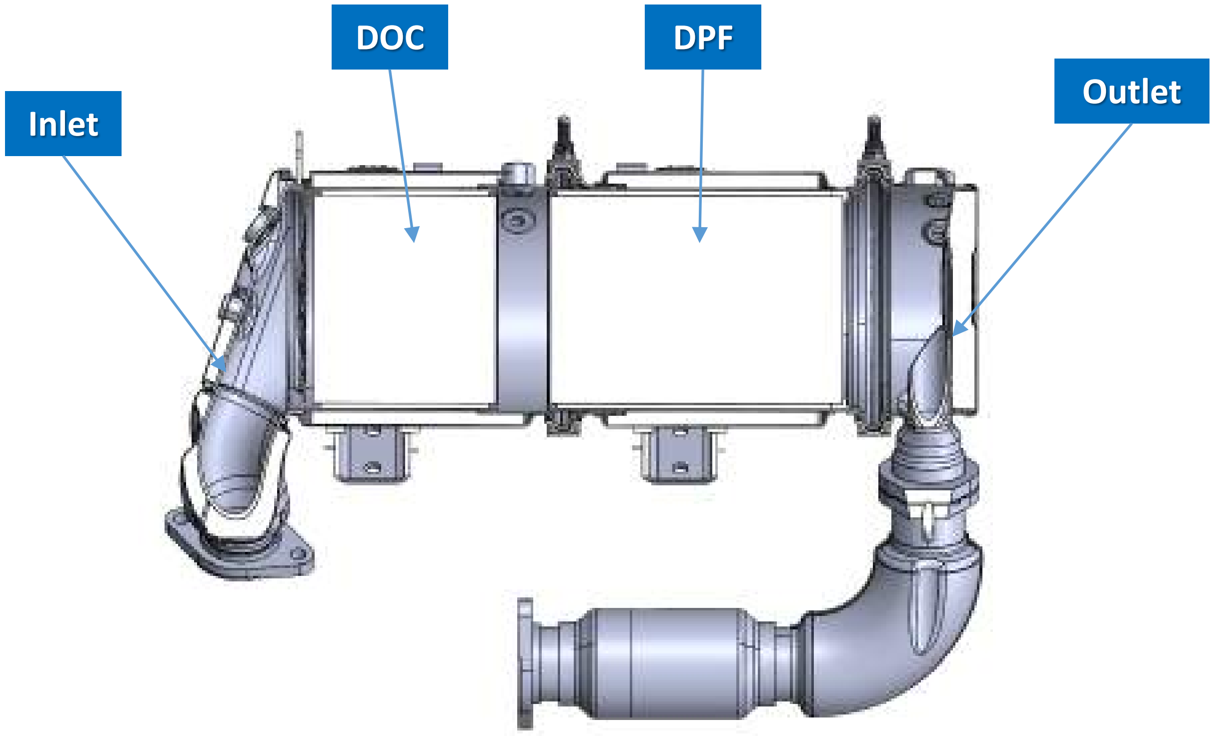


Pressure drop values (in mbar)

Inlet Cone , **ΔP1**	37.27
DOC , **ΔP2**	5.2
Mixer Region, **ΔP3**	36.06
SCR , **ΔP4**	13.90
Space, **ΔP5**	0.2
SCR /ASC, **ΔP6**	13.66
Outlet Cone , **ΔP7**	1
Pressure, **ΔP**	107.29

ATS Solutions – TREM V Norms





ATS Solutions – TREM V Norms

ECOCAT INDIA PVT. LTD. VICAT Technologies for Clean Environment VIKAS GROUP

Parameters	Value					
DPF material	Cordierite					
Soot mass loading (g/L)	3 and 4					
Mass flow rate, (kg/h)	225					
Temperature (°C)	590					
Lube oil consumption (g/hr)	6					
Ash content in oil	1%					
Ash finding factor	0.6					
Proposal	Option-1	Option-2	Option-3	Option-4	Option-5	Option-6
Diameter, mm	197x102.2(Oval)	197x102.2(Oval)	143.8(Round)	143.8(Round)	143.8(Round)	207x160(Oval)
Length, mm	203.2 (8″)	254(10″)	203.2(8″)	254(10″)	241.3(9.5″)	150.5
CPSI/mil	300/9	300/9	300/9	300/9	300/9	300/9
Volume, L	3.452	4.314	3.295	4.123	3.917	3.926

ATS Solutions – TREM V Norms

Following parameters are the assumed DPF BP calculations:

Parameter	Value	Unit
Plug Length	7.5	mm
Pore Diameter of PF	10	micron
Porosity of PF	51	%
Ratio of Channel diameters	1.31	-
Ash packing Density	217	kg/m^3
Ash Permeability	5.56E-13	m^2
Wall Permeability of PF	4.00E-12	m^2
Soot cake packing density	110	kg/m^3
Soot cake permeability	3.21E-14	m^2
Ash layer/plug distribution factor	0.18	-

*PF= Particulate filter

ATS Solutions – TREM V Norms

ECOCAT INDIA PVT. LTD. VICAT Technologies for Clean Environment VIKAS GROUP

Ash cleaning interval calculation

			Time Interval [hrs] at SML 3 g/L								
Option	DPF description	Clean	0	1000	2000	3000	4000	5000	6000	7000	8000
1	Oval (197x102.2) x 203.2	31.0178	54.832	62.6474	71.7844	83.1479	98.1505	119.188	151.886	210.476	336.038
2	Oval (197x102.2) x 254	35.1547	56.9272	63.3502	70.3071	78.1883	87.3692	98.5217	112.808	132.267	160.751
3	Round 143.8 x 203.2	32.8049	57.6664	66.6974	77.6014	91.5558	110.89	140.178	191.116	300.422	-
4	Round 143.8 x 254	37.1161	59.8426	67.2383	75.4428	84.8539	96.1507	112.516	129.888	158.421	206.85
5	Round 143.8 x 241.3	36.0445	59.142	66.8301	75.4979	85.6563	98.1803	114.638	138	174.616	242.814
6	Oval (207.6x160) x 150.5	15.7999	35.0499	40.0908	46.2547	54.0881	64.5042	79.0535	100.858	136.943	204.915

			Time Interval [hrs] at SML 4 g/L								
Option	DPF description	Clean	0	1000	2000	3000	4000	5000	6000	7000	8000
1	Oval (197x102.2) x 203.2	31.0178	62.3644	71.4984	82.5464	96.578	115.382	142.321	184.797	261.467	428.997
2	Oval (197x102.2) x 254	35.1547	63.2818	70.4502	78.4771	87.7251	98.7569	112.523	130.428	155.238	192.371
3	Round 143.8 x 203.2	32.8049	65.5264	76.1424	89.3083	106.647	131.052	168.853	235.313	379.188	-
4	Round 143.8 x 254	37.1161	66.4804	74.7867	84.2215	95.3248	109.039	126.815	151.343	188.358	251.573
5	Round 143.8 x 241.3	36.0445	66.015	74.7387	84.8221	96.9552	112.374	132.965	162.748	210.394	300.225
6	Oval (207.6x160) x 150.5	15.7999	41.7797	48.0374	55.8185	65.8488	79.3044	98.377	127.194	174.632	264.767

Summary & Comments

- Ecocat India provide one stop solution to OEM with shorter lead time and cost effective ATS solution. Also, continuously investing significant resources to meet current and upcoming emission norms such as TREM V / CEV V / CPCB IV^+ /BS VI as well as to be ready in providing solutions related to future emission norms.

- DOC washcoats shows significant NO_2 formation and exotherm generation for regeneration at lower temperatures in passive and active DPF regeneration applications.
- Specific innovative DOC washcoat technologies for active and passive regeneration approaches.
- DPF washcoats also shows higher soot oxidation rate and lower balance point temperature in PM removal. SCR washcoats covers wide range of temperatures for NOx conversion.

- Ecocat India catalyst chemistry & ATS design supporting efficient emission control with innovative washcoat technological solutions in diesel ATS such as DOC, cDPF, V-SCR / Cu-SCR and ASC to meet stringent norms. Also, giving advanced ATS solution to Gasoline / CNG segments.

Thanks !