India Off-Road After-treatment Technologies for Bharat TREM V: Emission Legislation, Challenges and Opportunities

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Abstract

The Bharat TREM-V emission legislation for Off-Road applications will be implemented in India expected from April 2024. The change from Bharat TREM IV to TREM V opportunities and challenges are being covered in this paper. The current system of Bharat TREM IV satisfies legal standards using only the Diesel Oxidation Catalyst (DOC), but Bharat TREM V has stringent PN Particulate Number $1x10^{12}$ and PM particulate mass 0.015g/kWh. To control PN and PM the need for coated DPF is being used widely to achieve an efficiency of >90%. Nevertheless, the accumulated PM in the pores of the DPF creates soot cake layers, which then impede the flow of exhaust gas. This block causes an increase in back pressure in the exhaust, which is unfavorable for engine performance, and drops in fuel economy. The accumulated particulate mass must periodically/continuously need to be removed from the DPF by a process called regeneration. For less than 56kW power rating which is leading the market a DOC+CSF=CCRT® [Continuous Catalytic Regeneration Trap] system is required and for > 56 kW Engine power rating, a DOC+CSF+SCR/ASC=SCRT® system is required to control NOx, a regulation pollutant. The Indian NRMM (Non-Road Mobile Machinery) market is extremely competitive, and OEMs wish majorly to employ a passive system Pt only with JM technology CCRT® for power levels up to 56kW to improve fuel penalty and simplify passive regeneration with the help of engine out temperature and continuous NO_2 with help of CSF.

Introduction

Currently, India is the largest Tractor manufacturer (by volume) in the world. The non-road equipment market has grown in India along with high tailpipe emissions. Agriculture and construction equipment constitute about 90% of the non-road market [1]. It is predicted that India's agricultural machinery market size will grow at a CAGR of 8.5% during the 2023-2028 period (15.42 billion USD-2023 to 23.18 billion USD-2028) [2]. It is expected to have enormous growth in the agriculture machinery sector. This can be related to high population and economic dependence on the agriculture sector. The agriculture machinery is used in farming or any other agriculture use. In India, this agriculture machinery market is classified into tractors (<50 HP, 50-75 HP, 76-100 HP, 101-150 HP, >150 HP), equipment (rotovators and cultivators, harrows, plows, seed, and fertilizer drills), harvesting machine (forage and combine harvesters) and irrigation machine (drip irrigation and sprinkler machine).

Table 1. Bharat TREM emission standards for Diesel Off-road [4,5].

Year	Standard	Engine Power, kW	CO g/kWh	HC g/kWh	HC+NOx g/kWh	NOx g/kWh	PM g/kWh	PN #/kWh
1999	Bharat TREM I	All	14	3.5	-	18	-	-
2003	Bharat TREM II	All	9.0	-	15.0	-	1.0	-
2005	Bharat TREM III	All	5.5	-	9.5	-	0.80	-
2010	Bharat TREM III-A	P<8	5.5	-	8.5	-	0.80	-
2010		8≤P≤19	5.5	-	8.5		0.80	-
2010		19≤P≤37	5.5	-	7.5		0.60	-
2011		37≤P≤75	5.0	-	4.7		0.40	-
2011		75≤P≤130	5.0	-	4.0		0.30	-
2011		130≤P≤560	5.0	-	4.0	-	0.20	-

Based on the data, around 9.55 lakh units of tractors were sold in the current year 2023 in India. Also, the consumption of total diesel is about an average of 7.5% by Indian tractors. In this way, almost 300 kilotons of nitrogen dioxides (NOx) and 25 kilotons of particulate matter (PM) are emitted into the air. To control harmful emission pollutants, the Indian government adopted the Bharat TREM I as the first standard for off-road in the year 1999 and it was the basic emission norm for off-road systems in India [3,4]. This was taken from the United States of America standards for off-road vehicles. In this TREM, hydrocarbons (HCs), carbon monoxide (CO), and NOx pollutants were regulated. Bharat TREM II standard came in the year 2003 after a gap of 4 years in India and focused on controlling CO, HC+NOx, and PM. The PM was first time regulated in Bharat TREM II. In 2005, Bharat TREM III was implemented in a fast manner which can be considered a proactive approach from the Indian government towards the environment as the pollutants limits of CO, HC+NOx, and PM were made tighter than Bharat TREM II. After this, Bharat TREM III-A came into existence in April 2010 which went up to 2011. This was an extended version of Bharat TREM III. This version of the standard was aimed at emissions based on the power output of the tractor. Table 1 shows the Bharat TREM emission standards (I to III-A) for off-road engines and vehicles.

Bharat TREM V

Bharat TREM IV

		CO	HC	NOx	PM	PN	Test Cycle
Category, kW	Category, HP	g/kWh				#/kWh	
P<8	<10	8.0	7.5 (HC+NOx)		0.4	-	NRSC
8≤P<19	10 – 25	6.6	7.5 (HC+NOx)		0.4	-	
19≤P<37	25 - 50	5.0	4.7 (HC+NOx)		0.015	$1x10^{12}$	
37≤P<56	50 – 75	5.0	4.7 (HC+NOx)		0.025-IV*; 0.015-V#	$1x10^{12}$	NRSC & NRTC
56≤P<130	75 - 175	5.0	0.19	0.4	0.025-IV*; 0.015-V#	$1x10^{12}$	
130≤P<560	175 – 750	3.5	0.19	0.4	0.025-IV*; 0.015-V#	$1x10^{12}$	
P≥560	>750	3.5	0.19	3.5	0.045	-	NRSC

Figure 1. Bharat TREM emission standards (IV and V) for Indian agriculture tractors (*Bharat TREM-IV & #Bharat TREM-V).

To avoid confusion, the agricultural machinery (TREM) and construction equipment vehicles (CEV) were separated in 2020. On 1st Oct 2020, Bharat TREM IV was implemented after several delays by the Indian government and applies to off-road systems ≥50HP [6,7,8]. These are the latest emission norms in India and are based on the European Union (EU) TREM IV. This standard is focusing on CO, HCs, NOx, PM, and PN pollutants. There is a requirement for advanced technologies such as EGR (exhaust gas recirculation), SCR (selective catalytic reduction and DPF (diesel particulate filter) in this standard. This is the reason for the sudden hike in prices of current tractors because of meeting the TREM IV norms. Figure 1 shows the Bharat TREM V emission standards (IV to V) for Indian agricultural tractors. The Bharat TREM V is expected to be implemented in April 2024. This will include P<8; 8≤P≤19; 19≤P≤37; 37≤P≤56; 56≤P≤130; 130≤P≤560 and P>560. As compared to current TREM IV, PM is going to decrease from 0.025 to 0.015 g/kWh for category 37≤P≤56; 56≤P≤130; 130≤P≤560, and other pollutants will remain the same.

The DPF capability is limited only to hold the particles [9,10]. Therefore, a regeneration strategy is employed to burn the captured particles via active and passive regeneration. The active regeneration includes raising the temperatures by fuel injection consumption [11]. Different researchers have used different strategies to increase engine exhaust temperatures. Lee et al. [12] explained the use of electrically heated catalysts (EHC) to manage exhaust gas temperatures in non-road 110PS engines and measured engine emissions in non-road transient cycles. Similarly, Zhang et al [13] used a microwave-assisted regeneration strategy. The passive regeneration strategy depends on the availability of NO_2 to oxidize the soot particles at engine exhaust temperatures. Since the amount of NO_2 is low in the engine, DOC can increase the amount of NO_2 by oxidizing NO. The continuous regenerating technology CRT® of JM oxidizes soot at lower temperatures in the presence of NO_2. This CRT® system reduces CO, HC, and PM by 90% or more [14,15]. The Pt-based catalyst is put into the substrate which will generate a good amount of NO_2 to catalyze the soot. This catalyst also does CO and HC oxidation.

This paper covers in detail Synthetic Gas testing, Engine testing & advantages, and limitations in terms of strategies to meet upcoming Bharat TREM V legislation.

Challenges associated with Bharat TREM V

Indian OEMs have already started working on Bharat TREM V. Most OEMs prefer passive systems, but few OEMs are keeping active DOC and bare filter systems for Bharat TREM V. TREM V systems with <75hp engines mostly are naturally aspirated, and considering the duty cycle, there is sufficient temperature and a good amount of NO_2/NOx for DPF regeneration, that's why most of the Indian OEMs opt for passive systems. Also, one more reason could be the low cost of passive systems. Some OEMs are thinking in terms of the use of adulterant fuel in tractors by the farmers which may require frequent active regeneration strategy.

After-treatment technology for Bharat TREM V

25HP – 75HP	DOC Pt-Pd active zoned	CSF Pt-Pd Cordierite/SiC		
>75HP	DOC Acive: Pt-Pd zoned Passive: Pt only	CSF Pt-Pd Cordierite/SiC	SCR Cu-SCR: 400/600 cell V SCR: Coated/ Extruded	ASC Zoned with SCR or Stand alone

Figure 2. After treatment technologies for <75HP and >75HP.

Figure 2 shows the after-treatment technologies for <75HP and >75HP for Bharat TREM V. In <75HP system, JM has both active (Pt-Pd zoned) and passive (Pt-only) technology for DOC. Additionally, for CSF, both Pt-Pd (Pt-rich) and Pt-only technologies are present in JM's product portfolio. In >75HP system, due to the requirement of reduction of NOx, SCR and ASC system is needed.

For the vehicle to work effectively, soot that builds up in the filter must be removed since it will cause an unfavorable increase in backpressure. This removal must occur during normal vehicle operation. Figure 3 shows the O_2-active regeneration and the NO_2-passive regeneration. Methods of soot removal (i.e., Regeneration) Passive regeneration – this happens during normal vehicle operation; Active regeneration – exotherm generated over DOC by burning additional fuel, triggered by the system control unit. It is very important to clean carbon soot particles from diesel particulate filters otherwise it will get blocked, and its performance will be adversely affected. These particles are burnt off by the oxidation process during the regeneration phase. During passive regeneration, the carbon soot particles are burnt off continuously without affecting the engine's working system. The position of the filter is designed in a way too close to the engine to have exhaust temperatures of 350-500°C (example on motorway). The NO_2 will convert the carbon soot into CO_2. This process works continuously and slowly with platinum coating. The nitrogen oxides convert to nitrogen dioxide using a platinum catalyst (equation 1).

$$NOx + O_2 \rightarrow NO_2 + x/2\, O_2 \quad (1)$$

The nitrogen dioxide in reaction with carbon soot changes to carbon monoxide and nitric oxide (equation 2).

$$NO_2 + C \rightarrow CO + NO \quad (2)$$

The carbon monoxide and nitric oxide react with oxygen and form nitrogen dioxide and CO_2 (equation 3).

$$CO + NO + O_2 \rightarrow NO_2 + CO_2 \qquad (3)$$

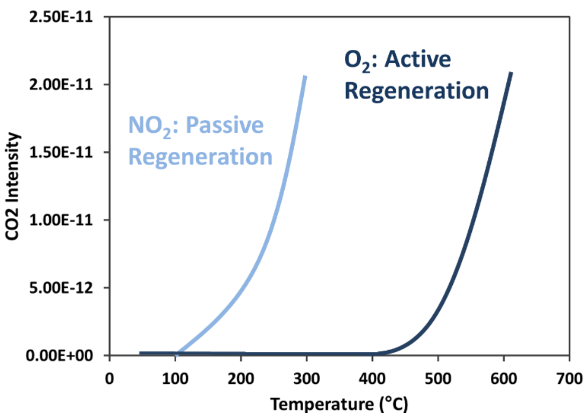

Figure 3. Active Vs Passive Regeneration.

The soot particles are burnt by increasing the exhaust gas temperatures without affecting the engine's working system in the active regeneration process. The engine exhaust temperature is too low in urban traffic with low loads. The build-up of carbon soot particles stored on the filter in the case of low temperatures. These soot particles cannot be broken on their own. In this situation, the engine management system initiated active regeneration. During this phase, the build-up of soot particles quickly burns off and oxidizes to CO_2 in the presence of oxygen.

In the Continous Regeneration Trap (CRT®) system (DOC+bare DPF), there is no re-use of NO_2 to oxidize soot to CO_2 and H_2O (figure 4). The Catalyzed Continous Regeneration Trap (CCRT®) is a combination of DOC and CSF (figure 5). A wash coat is introduced onto a DPF to enhance passive regeneration which when we use re-use of NO_2 will help have continuous soot oxidation based on temperature. CSF development focuses on a thermally stable system, high filtration & regeneration efficiency, low backpressure, maintaining NO_2/NOx ratio to get optimum system performance, and clean-up function for HC slip during active regeneration.

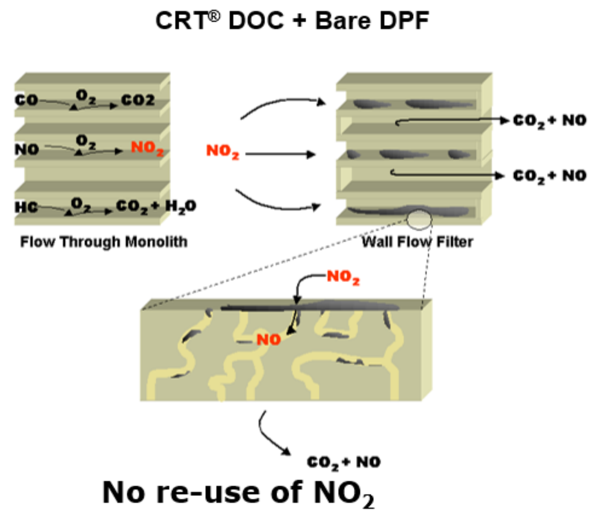

Figure 4. NO_2 regeneration CRT® (DOC + Bare DPF) system.

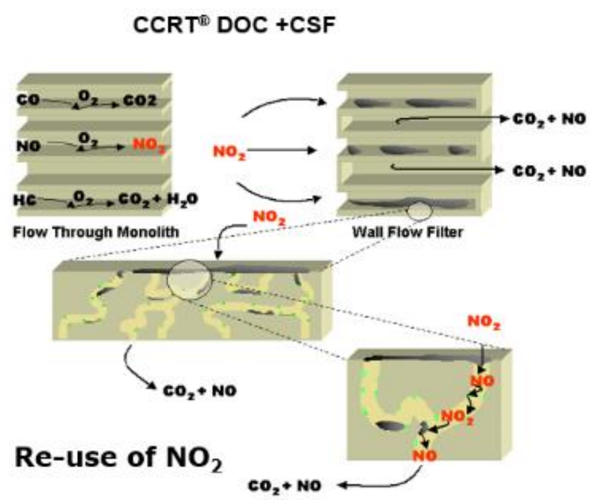

Figure 5. NO_2 regeneration CCRT® (DOC + CSF) system.

This CCRT® system can remove more than 90% of particles and convert more than 60% of HC and CO [16]. Zhang et al. [17] found that the CCRT® system converts more than 73% HC and 81% CO as compared to CDPF alone. Zhong et al. [18, 19] tested the DPF, CDPF, CRT®, and CCRT® systems and found that CCRT® performance was best among these four systems. Similarly, the regeneration performance of CCRT® was better than CRT® or single CDPF when checked using simulation [19, 20]. Furthermore, a comparative study has been performed for the regeneration of soot with NO_2 as shown in Figure 6. It is observed that CCRT® (DOC+CSF) results in better pressure drop during regeneration as compared to CRT® (DOC+DPF).

Adequate performance of CCRT® has also been observed by Tan et al. [21].

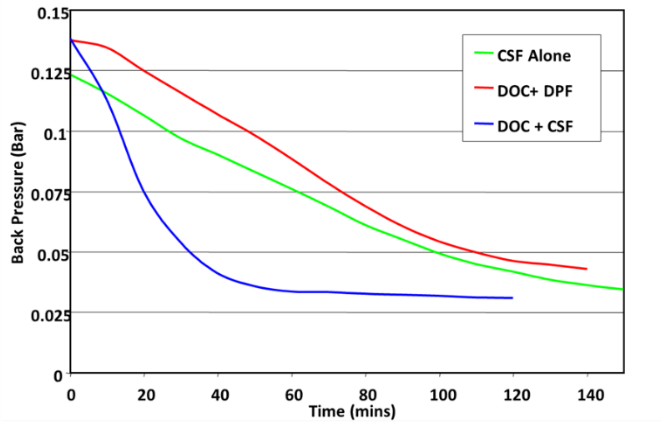

Figure 6. Back Pressure during regeneration of soot with NO_2 at 350°C.

Moreover, an engine test for the NRTC cycle has been performed to study the effect of Pt and Pt-Pd systems on PN control. Variation of PN with the number of NRTC cycles has been shown in Figure 7. It shows that PN formation is significantly low with the Pt-only system as compared to the Pt-Pd system.

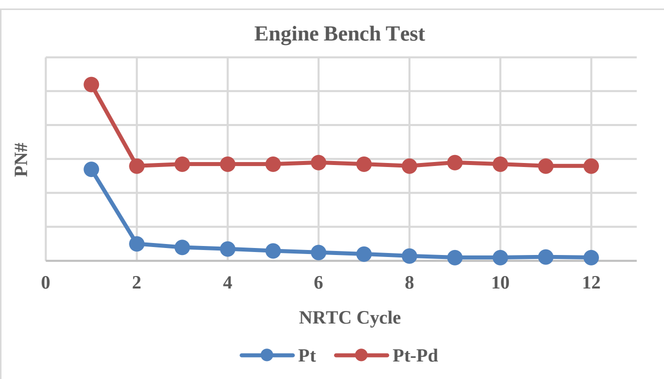

Figure 7. Engine bench data of Pt and Pt-Pd.

The NO oxidation-based experiments were performed on the SCAT (Synthetic Catalytic Reactor Testing) reactor with Pt only and Pt-Pd CSF. Figure 8 shows the DOC NO oxidation data with Pt-Pd and Pt-only CSF. The Pt-only system shows higher NO oxidation than Pt-Pd. Additionally, degreened data shows better NO oxidation than the aged system.

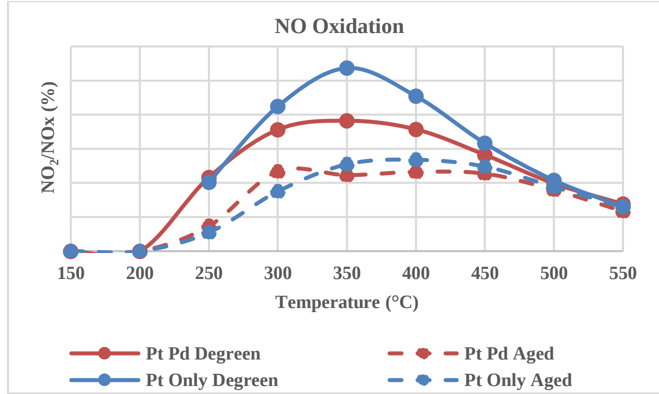

Figure 8. NO oxidation over Pt Pd CSF and Pt Only CSF.

Figure 9 shows the backpressure data of bare filter, CSF, CRT®, and CCRT®. Among all systems, the CCRT® system showed the lowest backpressure.

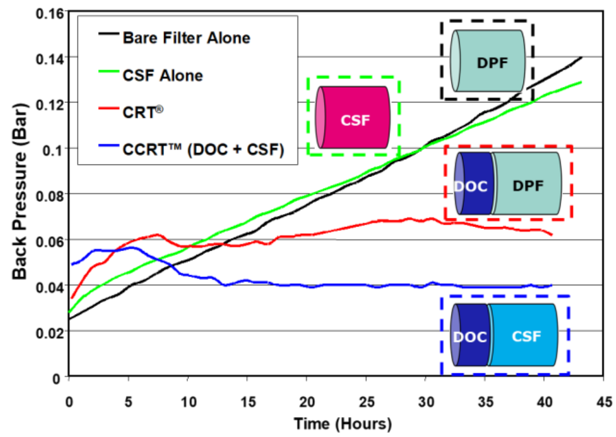

Figure 9. Back Pressure of Bare Filter, CSF, CRT®, and CCRT® on Engine Bench.

Summary

The passive system Pt only with JM CCRT® is preferred by the Indian OEMs for power levels up to 56kW to improve fuel penalty and simplify passive regeneration with the help of engine out temperature and continuous NO_2 with the help of CSF. The exhaust gas of modern heavy-duty engines frequently operates in low-temperature regions. Passive regeneration occurs at significantly lower temperatures and typically occurs during normal engine operation. The back pressure is one of the main parameters for DPF performance. The accumulation of soot particles on the filter resulted in channel block and finally, the backpressure tends to increase which will consume extra fuel and even destroy the engine in some cases. Hence, it is important to keep the filter clean by using regeneration technology. The CCRT® system has the advantages owing to its better performance than CRT® and single

CSF system. Also, the CCRT® system shows lower backpressure than CRT® and CSF alone. The order of performance is as follows.

CCRT® (DOC + CSF) > CRT® (DOC + Bare DOC) > CSF

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Definitions/Abbreviations

ASC	Ammonia Slip Catalyst
BS	Bharat Stage
CO	Carbon Monoxide
CSF	Catalyst Soot Filters
CRT®	Continuous Regeneration Trap
CCRT®	Catalytic Continuous Regeneration Trap
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
HC	Hydrocarbons
NOx	Nitrogen Oxides
NRTC	Non-Road Transient Cycle
NRSC	Non-Road Steady State Cycle
PGM	Precious Group Metal
SCR	Selective Catalyst Reduction
SCAT	Synthetic Catalytic Activity Testing