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Impact of PGM Loading in DOC for Off Road Engine to Meet CEVIV Norms

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ABSTRACT

Experimental study was done for evaluation of different type of PGM loading in Diesel oxidation catalyst (DOC) for off road vehicle. The main purpose of DOC is to reduce the hydrocarbon and carbon monoxide from exhaust line and increasing the DOC outlet temperature, which used in soot oxidation in DPF and increased conversion efficiency of SCR. It is very challenging to meet the emission norm with minimum loading of DOC for low cost and durable approach for non-auto application. Test results highlights impact on emission with different PGM loading in DOC.

This paper focused on the calibration of DOC model with different loading and observed that behaviour on THC and CO in exhaust system. Minimum Temperature constraint was come in NRTC rather than NRSC. With low, exhaust gas temperature white smoke observed, when unburned HCs was adsorbed on DOC. Data taken to understand thermal effect on DOC with different loading in aged condition. It observed that maximum DOC loading, conversion efficiency went up to 98% in THC after heating up. DOC loading is also responsible for conversion of NO to NO_2, which is used in conversion of SCR efficiency. Detailed comparison and analysis was done to understand the impact of PGM loading in DOC for NO_2 formation, exotherm, HC & CO light off temperature behaviour.

KEYWORDS: Diesel oxidation catalyst (DOC); Off road vehicle; CEVIV Norms; emission; NO2/NOx, PGMGM.

Introduction

Diesel Oxidation Catalyst (DOC) plays very important role to reduce CO and HC from the exhaust line of diesel engines. It contributes for exotherm during active regeneration and produces NO_2 used by downstream components for better SCR conversion efficiency. It helps to improve the NO_2/NO_X ration, to impact SCR efficiency. The function of DOC is to be oxidised nitric oxide (NO) to nitrogen oxide (NO2). Hydrocarbon are oxidised to form carbon dioxide and water vapour. Moreover, carbon dioxide.

$$HC + O_2 = CO_2 + H_2O$$

$$2CO + O_2 = 2CO_2$$

The oxidation of NO to NO_2 is important for the operation of selective reduction catalyst in diesel engine emission. Increased DOC loading which is used in SCR conversion efficiency improves NO_2/NOx ratio. Designing of DOC is function of many parameters like catalyst size, substrate type (cell density, wall thickness, material, etc.), Platinum Group Metal (PGM) loading and catalyst positioning relative to the Engine[1]. DOC is auxiliary catalyst supporting the performance of other types of catalysts—downstream on oxidation Catalyst[2].

$$2NO + O_2 = 2NO_2$$

Light off temperature is defined in which catalyst reaction initiate and starts its conversion efficiency. Light-off temperature the chemical reaction rate passes 50%, which is considered the temperature at which catalyst starts function[3]. The experimental study reflects light-off temperature increases with thermal aging of catalyst[4]. Effect of DOC loading were observed that at low temperature conversion efficiency of HC and CO has been reduced and its impact on shifting light –off temperature of DOC due to increasing the soot and emission at low temperature which is critical stage at diesel engine[5].

High sulphur content in fuel will contribute to this increase in light-off temperature. Light off temperature increases because of during combustion process, sulphur in the fuel is converted in SO_2 and above 600deg to SO_3. SO_2 and SO_3 will be adsorbed at the active on Pt and Pd. This will lead to deactivation and overall efficiency of DOC.

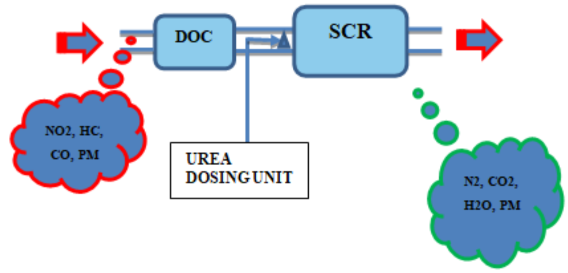

Fig. 1. Exhaust After Treatment System & Emission.

ABBREVIATIONS: SCR – Selective Catalytic Reduction; NOx – Nitrogen Oxides; NO_2-Nitrogen Dioxide; CO – Carbon Monoxide; THC – Total Hydrocarbon; NRSC –Non-Road Stationary Cycle; NRTC- Non-Road Transient Cycle; DOC – Diesel Oxidation Catalyst; Pt-Platinum Pd-Palladium; SO_2 -Sulphur dioxide; SO_3- Sulphur tri-oxide.

Emission legislation limit is difficult to maintain with minimum DOC loading. HC and CO Conversion efficiency were reduced with minimise the DOC loading. Its benefit to conversion of Ratio NO/NO_2 and increased efficiency of Selective Catalyst Reduction[6]. Like many other catalysts, DOC deactivates as the usage increases. The common deactivation form is thermal aging which reduces effective surface area of catalyst and in turn reduces ability for oxidation, especially the oxidation of NO due to catalyst selectivity.

Impact of PGM loading in DOC with Pt only and Pt: Pd Content

Pd is very high resistant of sulphur poisoning and high cost and low thermal durability. Sintering observed with only Pt used in DOC in high Temperature. Pt: Pd ratio depends on maximum temperature[7]. NH_3 is oxidised into NO_X with lower Pt layer and Higher SCR layer NO_x reduces with NH_3 stored. Pt: Pd loading is directly impact on SCR efficiency.

Pt: Pd has improved the performance of catalyst and light off Temperature, HC and CO conversion was maintained at aged condition of DOC and reduces the sintering. Pt: Pd ratio depends on heat up mode and NO_2 requirement. Light-off temperature and thermal durability stable improved with both Pt: Pd combined in catalyst as compare Only Pt or Only Pd.

Effect of Exhaust Temperature with DOC Out in Normal Mode

NO_2/NOx ration emission downstream cDPF were 38% during exhaust temperate range 238 deg C to 400 deg C in NRTC cycle taken in test bed. Decrease of exhaust temperature below 198 deg C and higher than 400 deg, NO_2/NOx remained at low level. The reaction of NO to NO_2 in DOC is controlled by thermodynamic. Pt is used in DOC catalyst, maximum NO_2 generated at the temperature range 295 deg to 345deg. Engine out temperature is an important role playing for NO_2/NOx ratio influence. Below graph highlights DOC inlet temperature trend in NRTC cycle at Figure No. 2

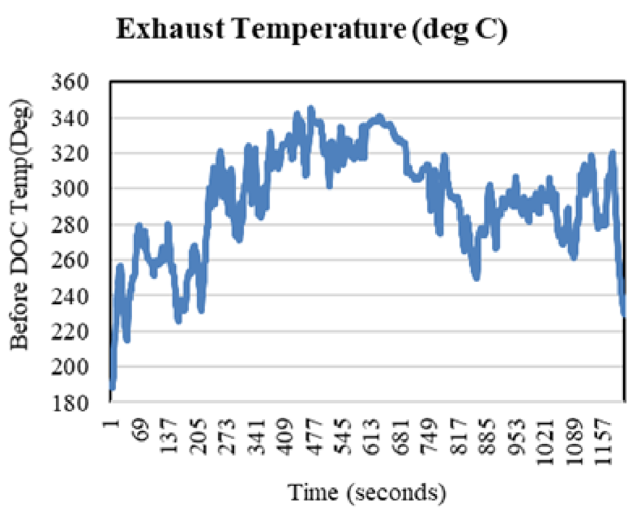

Fig. 2. Exhaust Temperature in NRTC Emission cycle.

DOC Heat up Test Data

It was observed that in low exhaust temperature, HC was not oxidised so its impact came on soot. Soot increased at low temperature and it had deposited on DPF, due to DPF chocked issue observed. So DOC is very critical for passive regeneration to avoid soot clogging in DPF. Fig 3 shows pre and Post Hydrocarbon effect w.r.t. DOC inlet temperature to understand trend of HC slip reduction with DOC out.

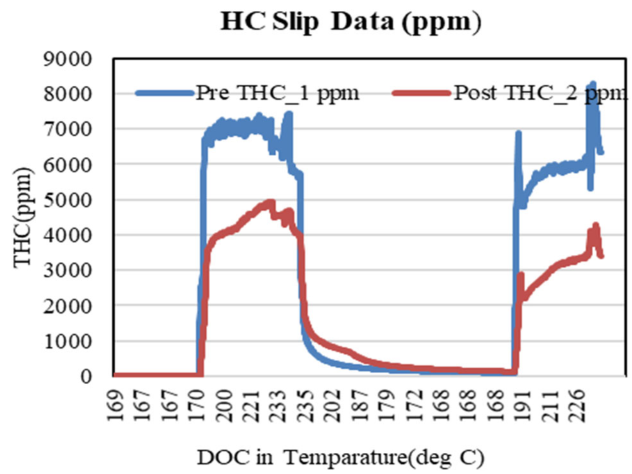

Fig. 3. DOC Heat up (THC Slip).

Effect of Selective Catalyst Reduction with DOC

Selective Catalytic Reduction (SCR) different type of technology used for active regeneration and passive regeneration. CuZe is used for active regeneration for NOx reduction[3]. CuZe can easily reach to target with 35% of NO_2/NOX ratio. And its exclude because of its limited sulphur resistance. For passive regeneration with extrude V-SCR required below 545Deg. V-SCR required ~40% more volume than CuZe –SCR.V-SCR is exclude because of or its limited thermal resistance. V-SCR can reached the target with 40% of NO2/NOX Ratio[3].

Below graph in figure no. 4 showing that NO_X conversion trend in NRTC cycle.

Engine Out & System Out -NOx (ppm)

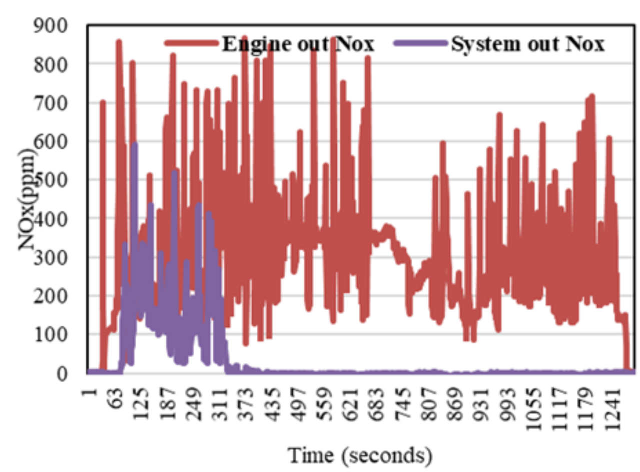

Fig. 4. SCR Efficiency in NRTC Emission cycle.

Experimental Set up & Test Condition

Experimental layout for engine set up in test cell is shown in Figure [8].

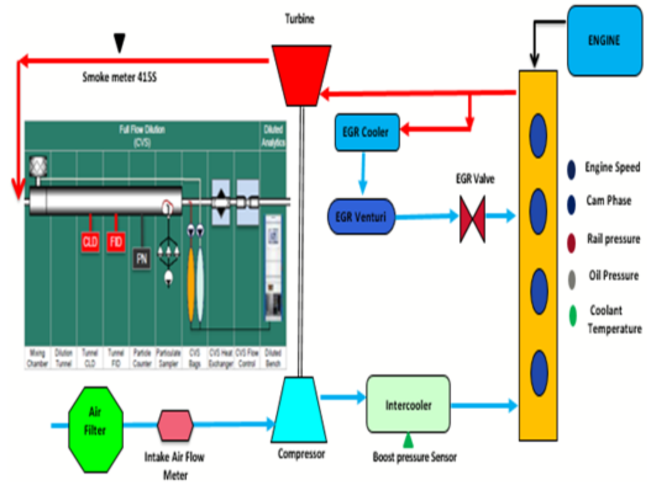

Fig. 5. Experimental Setup in test cell.

This chapter explains the experimental setup including the equipment such as engine, Intercooler, Turbocharger and Smoke meter equipment. Hardware plays a very important role in engine performance and emission. As it enables experiments as well as accurate data results. Which makes.

Dynamometer provides demanded speed and torque load to engine and monitor pressure and temperature. The exhaust gas flow through exhaust pipe and downstream to go through instrumented DOC. During part load conditions, the EGR valve is opened, and emission analysers are installed Pre and Post streamline. Diesel Oxidation Catalyst, which uses remaining oxygen in the exhaust system to be oxidized HC, CO and NO. However, there is no quick way to oxidize the fine particulate (soot). The SCR system was installed to meet the tighter emission regulations on Nitrogen Oxides Of a typical diesel engine after treatment system. DOC have been mentioned wherever after treatment systems have been mentioned. Therefore, the turbocharger, direct injection and intercooler has been used in engine development and monitoring the PUMA system for all pressure, temperature and after treatment system.

TABLE 1

Test Engine Specifications.

Engine	4Cyl
Bore	100mm
Stroke	120mm
Engine Volume	3.76Ltrs
Combustion System	Electronic Direct Injection System
Compression Ratio	17:5
Injector	Solenoid operated injector
Turbocharger Type	Waste gate
Maximum Rail Pressure	1800 bar

Results and Discussion

THC Conversion efficiency-DOC (PGM- 10 gm/cft³)

In below graph (Figure 6). THC conversion 58% efficiency at inlet DOC Temperature (T4) minimum 170 deg. Engine run at part load condition during trials.

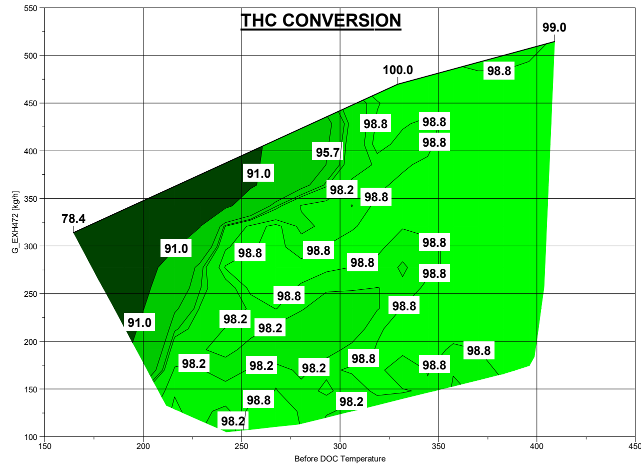

Fig. 6. THC conversion efficiency (PGM- 10 gm/cft3)

CO Conversion efficiency-DOC (PGM- 10 gm/cft³)

CO conversion efficiency 46% at inlet DOC temperature (T4) minimum 172 deg as shown in Figure 7 in engine part load.

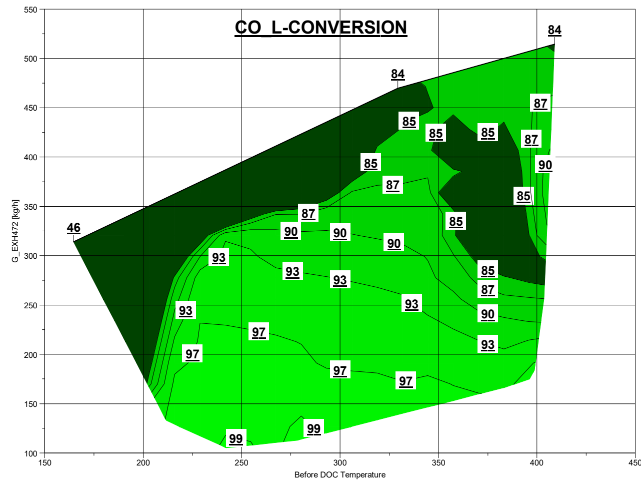

Fig. 7. CO conversion efficiency (PGM- 10 gm/cft³).

THC Conversion efficiency-DOC (PGM- 6 gm/cft³)

PGM loading is reduced in DOC from 10 g/cft3 to 6 g/cft3. Below graph shown impact of reduced DOC loading in THC conversion efficiency. This is clearly shown that reduction of PGM loading reduced ~2% at minimum inlet DOC temperature with reduced the DOC loading. Impact will be more severe after aging in DOC.

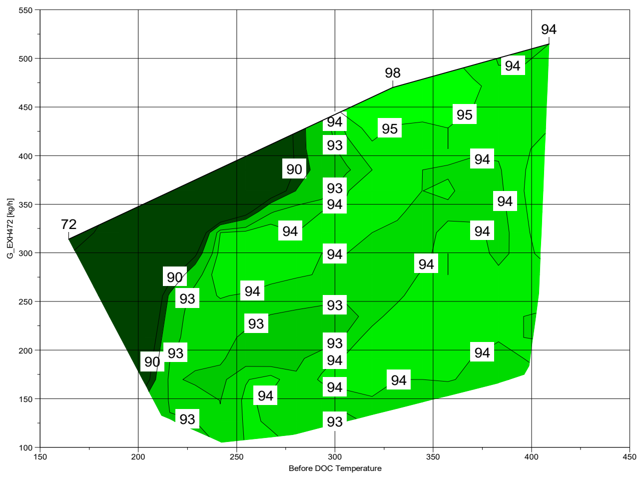

Fig. 8. THC conversion efficiency (PGM- 6 gm/cft3).

CO Conversion efficiency-DOC (PGM-6 gm/cft^3)

In higher light-off temperature also CO and HC conversion does not reach to 100% with DOC (PGM-6 gm/cft3). Overall assessment highlights that reduction of PGM loading from 10 to 6 g/cft3 loading reduced both CO and HC oxidisation rate. Selection of PGM loading is most critical parameter for HC & CO conversion along with SCR conversion.

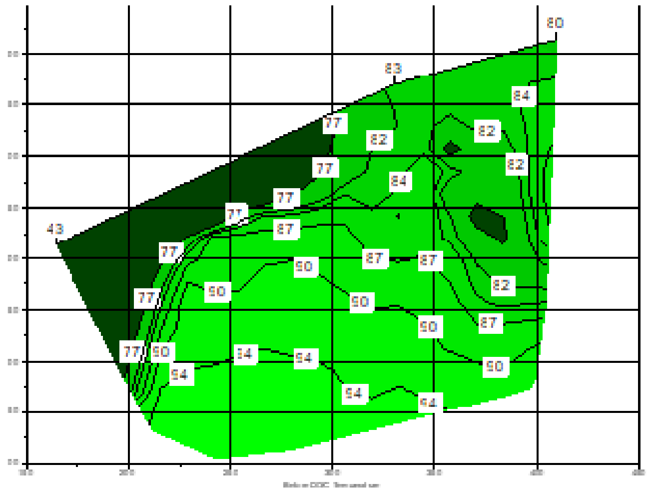

Fig. 9. CO conversion efficiency (PGM- gm/cft^3).

NO2/NOx Formation with DOC (PGM-10 gm/cft^3)

Engine mapping was done with DOC loading of PGM with 10 gm/cft^{3}loading to understand NO2/NOx ration as this will impact on SCR conversion efficiency and passive regeneration of soot from DPF if applicable. SCR efficiency is better in NO2/NOx ratio and range was 25-50% zone with Copper Zeolite SCR. The ratio is an important factor in determining the performance of the catalysts downstream of the DOC.

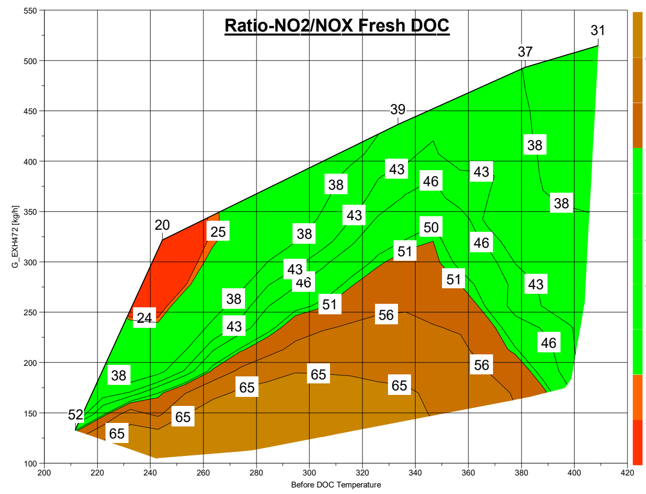

Fig. 10. NO2/NOx Formation with DOC (PGM-10 gm/cft^3)

NO2/NOx Formation with DOC (PGM-6 gm/cft^3)

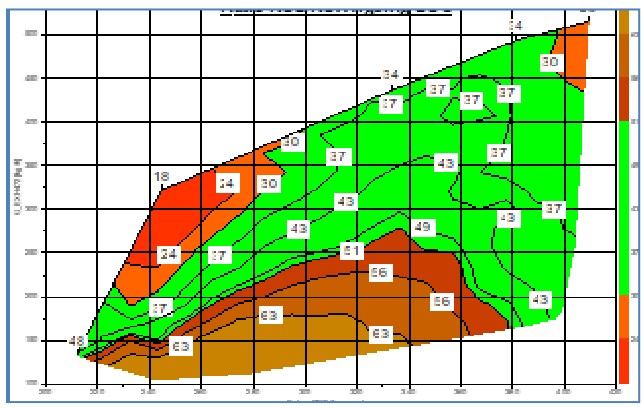

Fig. 11. NO2/NOx Formation with DOC (PGM-6 gm/cft^3).

Figure.11, PGM loading reduction in DOC also leads to low NO2 formation further NO2/NOx ratio also reduced by ~5% with DOC PGM loading of 6 gm/cft^3. Light-off temperature also reduced, and it shifted up to 18 deg C with same DOC PGM loading. This will further impact SCR conversion efficiency due to reduction of NO2/NOx ratio.

Inlet Temperature in 10 gm/cft3 loading DOC

DOC inlet temperature was kept same with both DOC of PGM loading (10 gm/cft^3 and 6 gm/cft^3). This was kept same to understand impact of DOC with both PGM loading. Engine out emission and exotherm is kept same in testing with both DOC PGM loading configuration.

Integration of NO_2-NO-NO_x Emission in NRTC cycle

Integrated NO_2-NO-NO_x trends with both PGM loading is compared in NRTC cycle. Figure represent x axis as integral of NO_2-NO-NO_x in NRTC cycle with respect to time (sec).

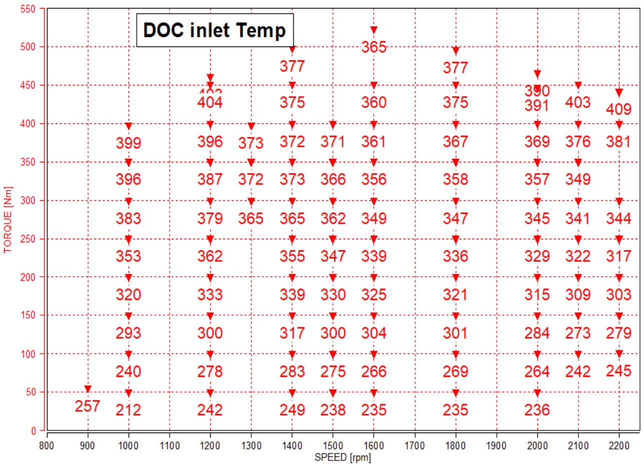

Fig. 12. DOC Inlet Temperature.

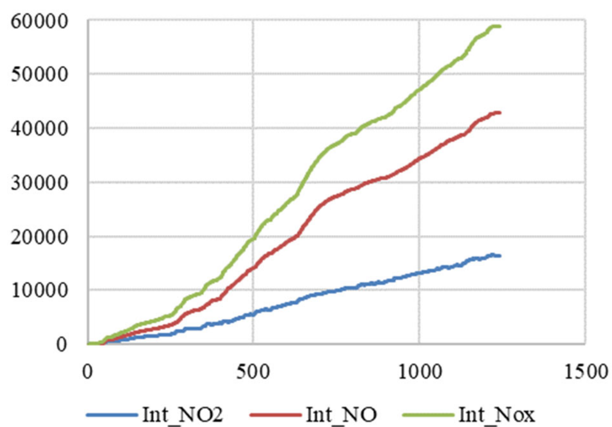

Fig. 13. Integrated NO, NO2 and NOx in NRTC cycle with DOC (PGM-10 gm/cft3).

Integrated NO, NO_2 and NOx is on lower side with DOC PGM loading of 6g/cft3 in comparison to PGM loading of 10g/cft3 as observed in NRTC cycle. Due to increased light off temperatures and it was directly effect on emission thus, low NO_2/NOx ratio and SCR efficiency was decreased.

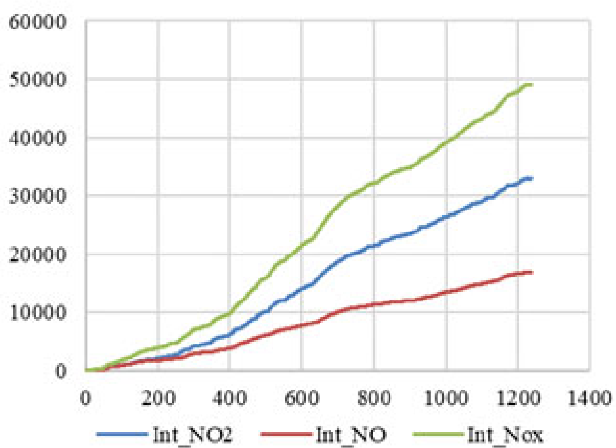

Fig. 14. Integrated NO, NO2 and NOx in NRTC cycle with DOC (PGM-6 gm/cft3).

DOC and SCR inlet temperature was low in cold phase as compare to hot phase. It was very challenging to increased DOC inlet and SCR inlet temaparuere in cold phase and HOT phase in initials condition due to DOC conversion efficiency was affected. Moreover, effect on NO_2/NOx ratio and SCR efficiency was low with DOC of PGM loading 6g/cft3.

Conclusion

Emission and Exotherm temperatures compete detailed study was done with two different PGM loading configuration of DOC. Evaluation was done on NRSC & NRTC cycle to understand NO and NO2 characteristics for SCR efficiency.

Increase of PGM loading in DOC impacts of light off temperature characteristic for HC & CO. The temperature shifts on lower side with decrease of PGM loading in DOC. Transient and Stationary experiments were carried out on engine out to understand behaviour of NO and NO_2 with DOC loading of 6 gm/cft^3 and 10 gm/cft^3.

1. DOC selection is very critical in EATS system as PGM loading impact in THC and CO conversion efficiency as well as increased the NO_2/NO_x ratio, which help to SCR efficiency.
2. PGM loading reduction show 3% with minimum Temperature Reduction in CO conversion
3. PGM loading reduction show 2% with minimum Temperature Reduction in THC conversion
4. PGM loading reduction in DOC to low NO2 formation further NO2/NOx ratio also reduced by 5%.

References

[1] Chang H. Kim, The Effect of Pt-Pd Ratio on Oxidation Catalysts under Simulated Diesel Exhaust, 2011-01-1164; Published 04/12/2011

[2] Irani, K., Epling, W., and Blint, R., "Effect of Hydrocarbon Species on NO Oxidation over Diesel Oxidation Catalysts," Applied Catalysis B Environment- **92(6-4)**: 422-428, 2009.

[3] Kim, C., Qi, G., Dahlberg, K., and Li, W"Strontium Doped Perovskites Rival Platinum Catalysts for trea-Ting. NOx in Simulated Diesel Exhaust Science, 624-1627, 2010.

[4] Després, J., Elsener, M., Koebel, M., Kröcher Schnyder, B. and Wokaun, A. "Catalytic Oxidation of Nitrogen Monoxide Over Pt/SiO2," Applied Catalysis B Environmental **50(2)**: 76-82, 2004

[5] Allansson R., Blakeman P., Cooper B., Hess H., Silcock P., and Walker A., "Optimizing the Low Temperature Performance and Regeneration Efficiency of the Continuously Regenerating Diesel Particulate Filter (CR-DPF) System" SAE 2002-01-0428

[6] Katare, Santhoji R., Joseph E. Patterson, and Paul M. Laing. "Diesel aftertreatment modeling: A systems approach to NO x control."Industrial & engineering chemistry research 46.8 (2007): 244-245.

[7] Kim, C., Schmid, M., Schmieg, S., Tan, J. et al. "The Effect of Pt-Pd Ratio on Oxidation Catalysts Under Simulated Diesel Exhaust," SAE Technical Paper 2011-01-1134.

[8] Gambhir, H., Barman, J., and Patchappalam, K., Experimental Investigation on the Effect of Pilot and post Injection on Engine Performance and Emissions SAE Technical Paper 2018-28-0015, 2018.

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