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DEVELOPMENT OF ENGINE FOR BSIV NORMS WITH DIFFERENT AFTERTREATMENT AND DOE APPROACH

Vishal P.Chavan[#], Prof. Vivek S. Shinde[#]and Prof. Sachin V. Mutalikdesai

Mechanical Engineering Department, Savitribai Phule Pune University, TCOER, Pune-411048
‡Assistant Professor Mechanical Engineering Department, Savitribai Phule Pune University, TCOER, Pune-411048
aAssistant Professor Mechanical Engineering Department, Savitribai Phule Pune University, TCOER,Pune-411048

Abstract

The demand for reduced pollutant emissions has motivated various technological advances in commercial diesel engines. The challenge for the direct injection diesel engines today is to reduce harmful emissions of diesel engines, such as Particulate Matter (PM) and Nitrogen oxides (NOx) and enhance the fuel efficiency and power.

Since BSV Emission norms has been skipped and BSVI Emission norms implementation is not yet clear, it has given a breathing time for all OEM's in India. This presents an opportunity to all OEM's to sale BSIV Vehicles for 4 more years. This large volume of sales calls for value engineering in existing BSIV Vehicles.

It was decided to develop a new variant of engine from Existing BSIV Engine (with DOC and POC) to an Engine without POC and reduced DOC loading. This have proven to be a cost effective solution.For this various Project strategies were adopted to go with the following variables:

1) *DOE Approach*
2) *DOC variants with low loading*
3) *Change in Injector hole size*
4) *Change in EGR %*
5) *Increase the number of injections from 1 Pilot to 2 Pilots and from 1 post to 3 post injections*
6) *Changing Injection Timing, Quantity, Separation.*
7) *Inclusion of alternate cost effective after treatment solution (example PPF) if required*

With the combination of above variables a systematic test plan was prepared and implemented.

Keywords:*Diesel Oxidation Catalyst (DOC), Design of Experiments (DOE), Exhaust gas recirculation (EGR)*

1. Introduction

The main objective of this project was to achieve BSIV norms by using DEO approach which will help in reducing engine out emissions. In DEO approach along with injection strategies, we have also studied the effect of other combustion parameters like maximum rail pressure, EGR rate, Injection timing, Injection Quantity, Injection Separation and finalise the best possible combination with DEO approach.

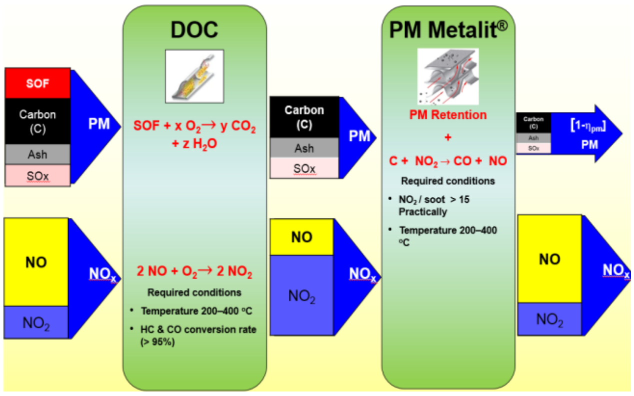
After Finalisation of Engine out emissions the second step was to try different options of after treatment available with different working principle like DOC, PPF with different loadings and different companies. By this systematic approach of DOE, Combustion variants and After treatment variables we have selected best possible combination.

Diesel fuel injection system is one of the most important part of the direct-injection diesel engine and in recent years. It has become one of the critical technologies for emission control with the help of electronically controlled fuel injection system.Many studies and applications have reported the advantagesof common rail system to meet the stringent emissionregulation and to improve engine performance for dieselengines. DEO approach is the key to utilise this unique feature of thecommon rail system towards further reduction in exhaustemissions and improvement in performance. High injectionpressure, pilot and post injection are some of the majorparameters in electronic governed engine. This paper dealswith effective use of multiple injections across all the partand full load condition in improving fuel consumption andemission. Injections parameters are mainly used for emission and secondly for fuel efficiency, Particulate matter and NOx productionalong with engine noise highly depend on the combustionprocess. Precise control over the fuel injection andspray formation is thus necessary in forcombustionand performance optimisation. To improve the performance andto reduce the NOx – particulate formation without sacrificingthe fuel consumption, it is important to understand therelationships between various injection parameters and howthey affect the Emission process. We can achieve reduction in PM without increase in NOx emission by using multiple injections.

Optimizing the injectionpressure and number of has proven to be an effective wayto reduce particulate emissions and consequently improvesthe engine performance along with BSFC improvement.

The influence of some injection parameters are very prominent (main injection timing, pilot injectiontiming, pilotinjection duration) on combustion, on noise and performance.By optimizing injectiontimings and quantity maintaining and dwell between mainand pilot injections simultaneous reduction of NOx and PMwas obtained in diesel engine.

After treatment approach DOC+PFF (if required)



COST MATRIX

Existing	New
DOC + POC	DOC or DOC + PFF
INR. 35000 /-	INR. 18000 /-

TARGET EMISSION VALUES:

ESC (European Stationary Cycle)

Pollutant	Unit	BSIV Limits
CO	g/kWhr	1.50
HC		0.46
NOx		3.50
PM		0.02

ETC (European Transient Cycle)

Pollutant	Unit	Limits
CO	g/kWhr	4.00
HC		0.55
NOx		3.50
PM		0.03

Emission results with Existing engine configuration (with DOC+POC):

Pollutant	BSIV Limits	Engine out Emission	Emission with DOC+POC
CO	1.5	0.82	0.01
HC	0.46	0.10	0.01
NOx	3.5	3.25	3.17
PM	0.02	0.04	0.016

2. EXPERIMENTAL SET UP AND TEST CONDITION

The layout for adaptation of temperature and pressure sensorsalong with EMS related sensors mounted across the engine during the test cell is shown in Fig. 1

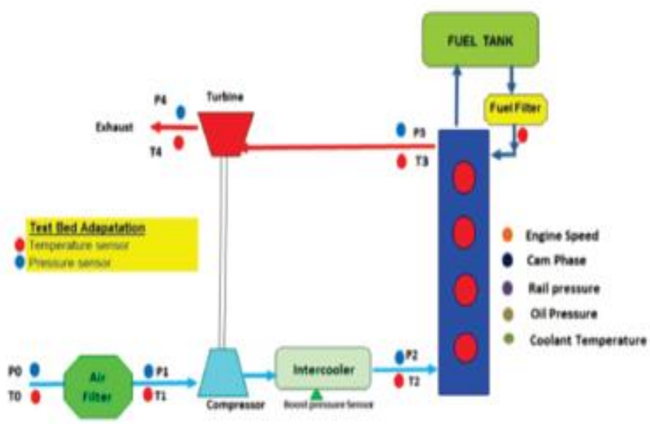


Figure 1. Test Bed Adaptation of Temperature and Pressure Sensors.

The engine specification is mentioned in Table 1.

Table 1. Test Engine Specification.

Engine Capacity	4.8L
Max Power	120kW

No of Cylinder	4

The experimental layout for the test cell is shown below in Fig. 2. The details of equipment used in the test cell is also mentioned in Table 2.

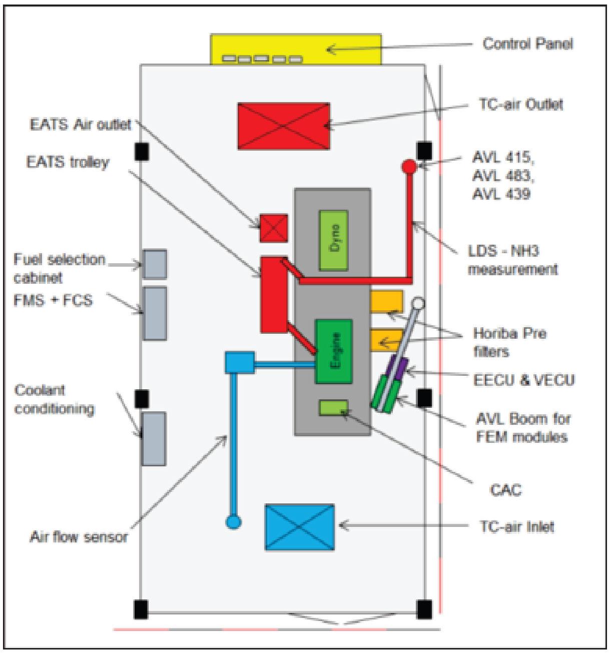


Figure 2. Experimental Layout of Test Cell.

Table 2. Basic Instrumentation for Pollutant Emissions Measurements.

Unit Instrumentation	Type	Operating principal
Dynamometer	AVL	Eddy Current
Fuel mass flow meter	AVL – 735 (Measurement)	Coriolis effect
Air mass flow meter	AVL CACS 2400 with fast response	Hot film anemometer
Smoke meter	AVL – 415 SE	Hartridge, optical
NOx	HORIBA MEXA - 7100	Chemiluminescence detector
HC	HORIBA MEXA - 7100	Flame ionization detector

During the experimental tests, the following data were recorded:

1. Engine torque
2. Engine speed
3. Fuel consumption
4. Exhaust emissions: Soot, NOx and HC
5. Exhaust Smoke
6. In-cylinder pressure
7. Injection pressure

3. DESIGN OF EXPERIMENT (DOE)

DOE was carried out to investigate the capability of multiple injections for performance, emission and fuel consumption.
The summary of the DOE variables are mentioned below:
1. Engine Speed
2. Pilot Quantity
3. Pilot Separation
4. Post Quantity
5. Post Separation
6. Rail Pressure
7. Main Injection Quantity
8. Number of injection

Using this DOE method, a series of screening experiments were undertaken on the engine to understand the sensitivenessof all the variables on key responses such as fuel consumption, emission and combustion stability. The engine speed was verified between 700 rpm to 2600 rpm and the number offuel injections between 1 to 4. The total injection durationwas varied from 3 - 8 mg for pilot and post injection. Theseparation time also varied from 700 μs- 2000 μs for bothpilot and post injections.

METHODOLGY

Experimental results were optimized using DOE technique, toevaluate the influence of the injection parameters. CAMEOsoftware has been used for preparing the engine model andanalysing to optimize the best combination of combustionparameters with multiple injection parameters at full loadand part load engine performance. The results were carriedto optimize emission and BSFC. The weightage of pilotinjection, pilot separation and pilot quantity were evaluated
using the design of method (DOE) technique.

DOE OPTIMIZATION PROCEDURE

The DOE was made with S-Optimal design method to get theoverall behaviour of engine related variables and combustionbehaviour. Then engine model has been created in the softwareusing free polynomial method. The model was run with thedifferent variation of parameters like rail pressure, boostpressure, and air flow to optimize the injection quantity andseparation for pilot and post to evaluate BSFC, emissionand performance. The optimizing constraint were defined forthe test are T3, PCP, EOI and smoke to run the cycle havebeen considered. After that model optimization was run withgeneric algorithm method to get the best possible combinationof injection parameters with mentioned constraint (Fig. 3)

4. TEST CONDITION

After optimizing the best injection strategy output from DOE, the test has been carried out in the test cell to check the accuracy of DOE with the actual test results

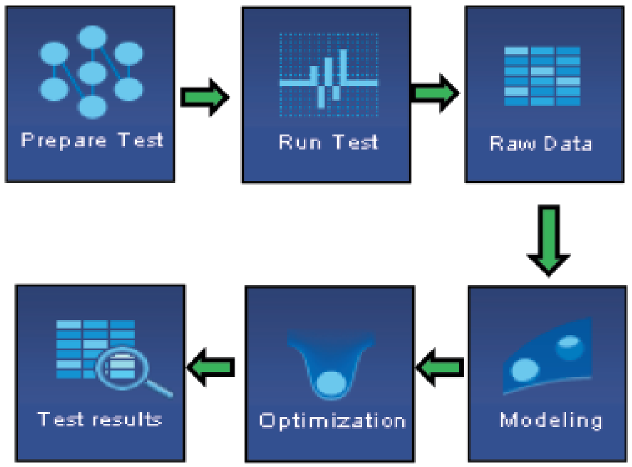


Figure 3. DOE Layout Procedure.

Engine testing was done at A, B and C point to optimize the emission and BSFC. The other engine zones are tested to get the best possible combination of injection parametersto get optimum BSFC and performance. The engine testedconditions are mentioned in Table 3.

Table 3. Test Condition.

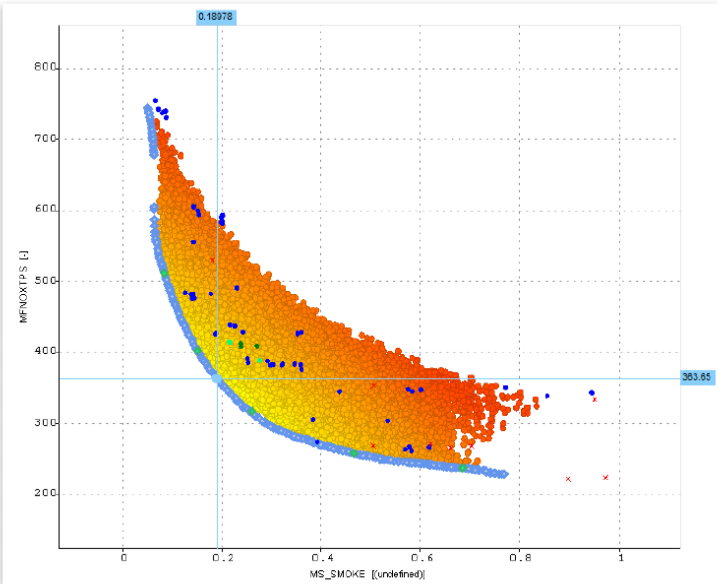
Item	Unit	Target
Air Pressure Intake	kPa	100
Exhaust Pressure	kPa	10
Ambient temperature	°C	25±2
Intake Manifold Temperature	°C	50±2
Coolant Temperature Out	°C	80±2
Fuel Temperature Flow Meter In	°C	38±2

The boundary conditions for testing were considered as shown inTable 4. The emission values are limited in the A, B and Czones whereas other limitations are kept for the other partof region.

Table 4. Test Condition.

Item	Unit	Limit
Compressor Air Temperature Out	°C	200
Turbine Mean Temperature	°C	720
Turbo Speed	*1000 rpm	250
Peak Cylinder Pressure	MPa	18
EOI	degree (°)	~15° aTDC
NOx	g/kWh	5.0
PM	g/kWh	0.1
Soot	g/kWh	-
CO	g/kWh	2.1
HC	g/kWh	0.66
Smoke for ELR	m^{-1}	0.8

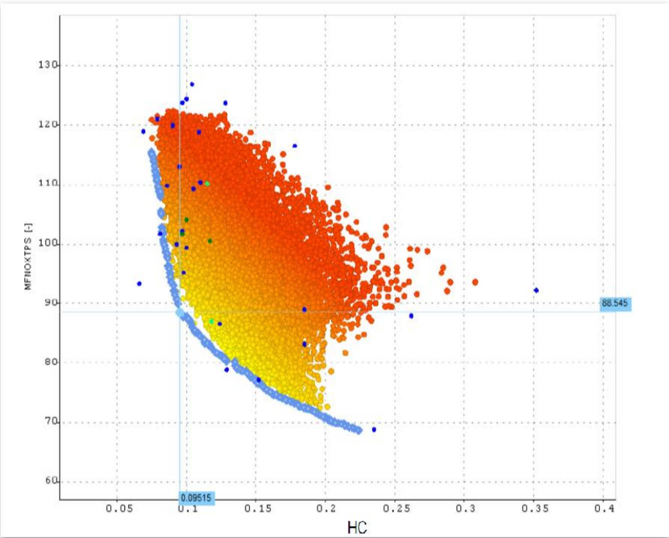
Typical Optimisation profile in CAMEO



Variations	
Sr. No	**Calibration parameters**
1	Main timing
2	Rail pressure
3	EGR rate
4	Pilot timing
5	Pilot quantity
6	After injection timing
7	After injection quantity
8	Post#1 injection timing
9	Post#1 injection quantity
	Hardware parameters
10	NTP
11	Injectors

5. RESULTS:

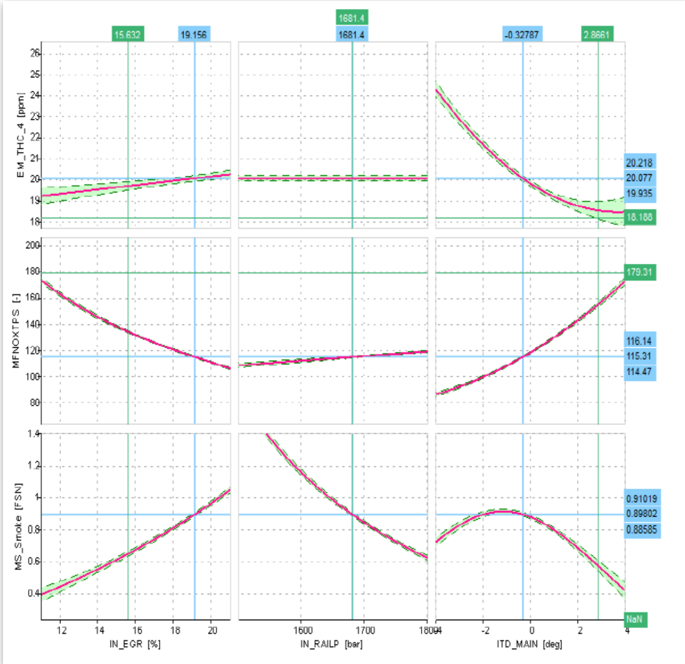
A. Lower Load Optimization:



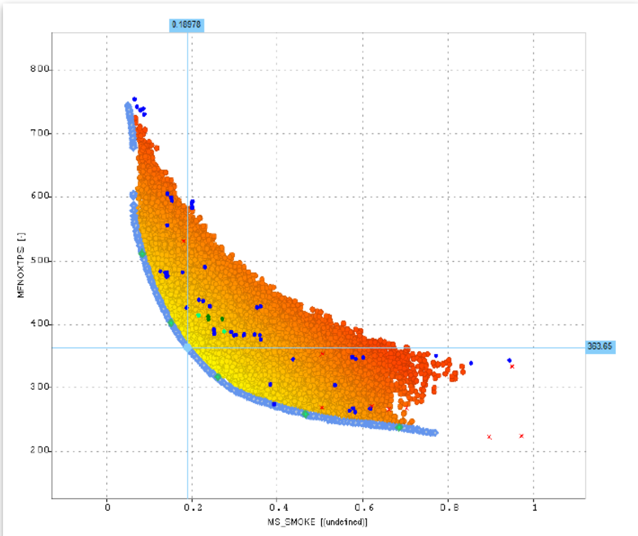
Observation:

- NOx VS HC Trade off was done to see the effect of HC on PM
- At Lower Speeds reduction in HC has contributed to reduction in PM with increase in Soot

Variation effects in Emission:



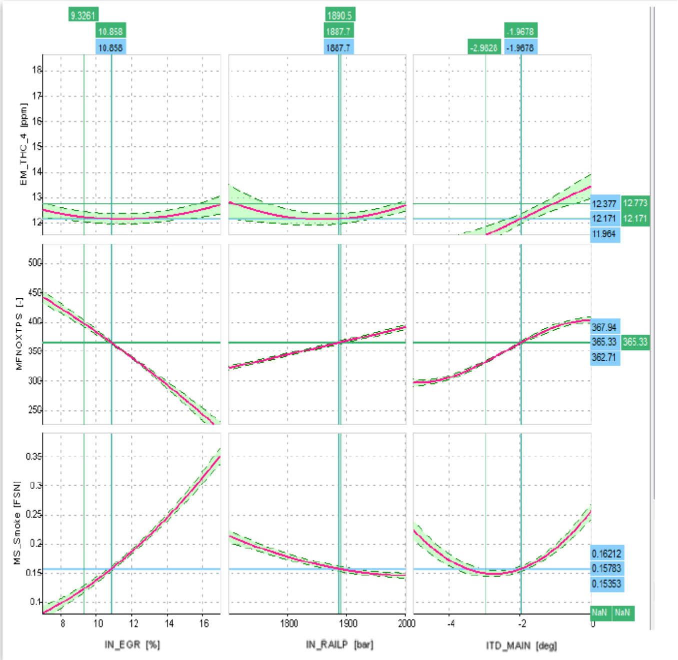
B. Higher load optimization:



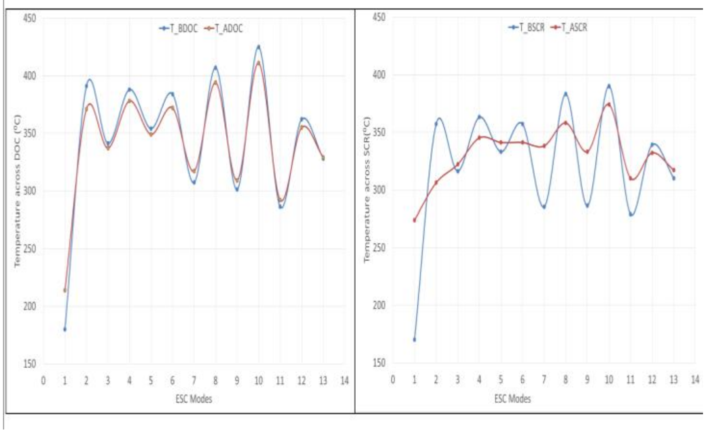
Observation:

- At higher loads NOx VS Soot tradeoff has shown better results compared to NOx VS HC trade off in PM reduction.

Variation effects in Emission:

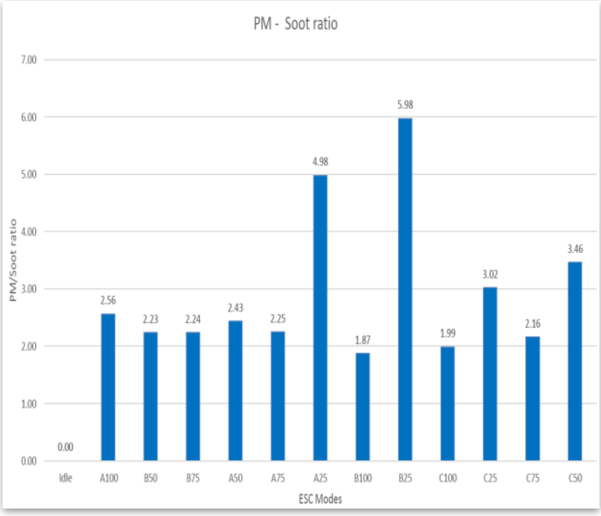


C. ESC Temperature profile



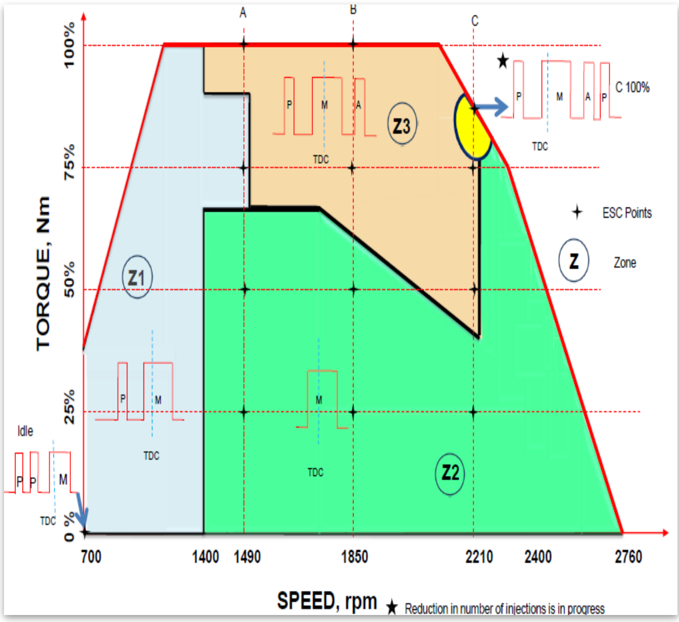
- ESC temperature profile for all 13 modes is shown in graphs
- It is observed that there is significant difference in temperature pattern across SCR compared to DOC which would be helping in better oxidation to reduce total PM.
- Especially at modes 1, 7, 9 and 11 T_ASCR is greater than T_BSCR.
- This indicates the oxidation process is more rapid in these points

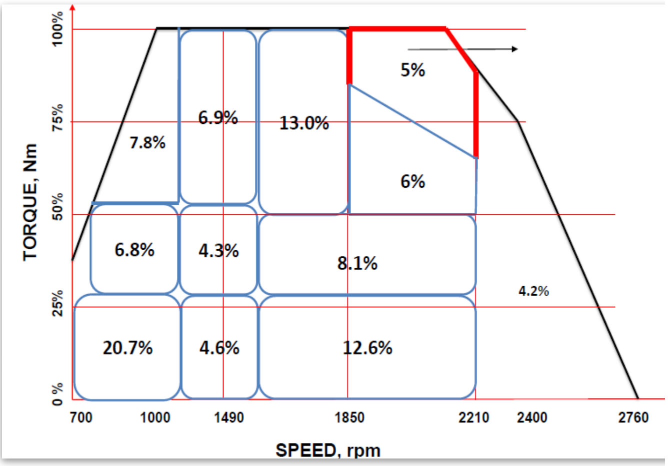
D. PM to Soot ratio



- After optimization of ESC points by using CAMEO, the PM to Soot ratio study was conducted
- At low load points like A25 and B25 the PM to Soot ratio is high.

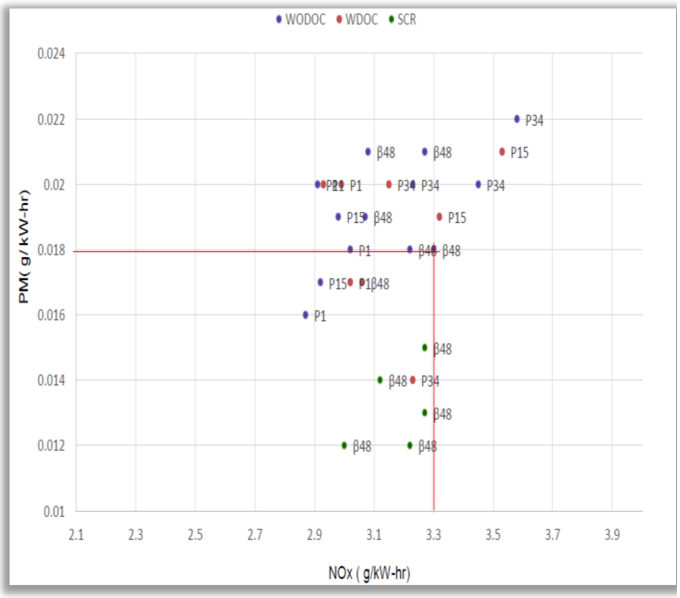
E. INJECTION STRATEGY FINALISATION





- B100, C100 and C75 emission points are optimized with 2000 bar rail pressure.
- With this optimization 5% of Total vehicle run time is between 1800 to 2000bar

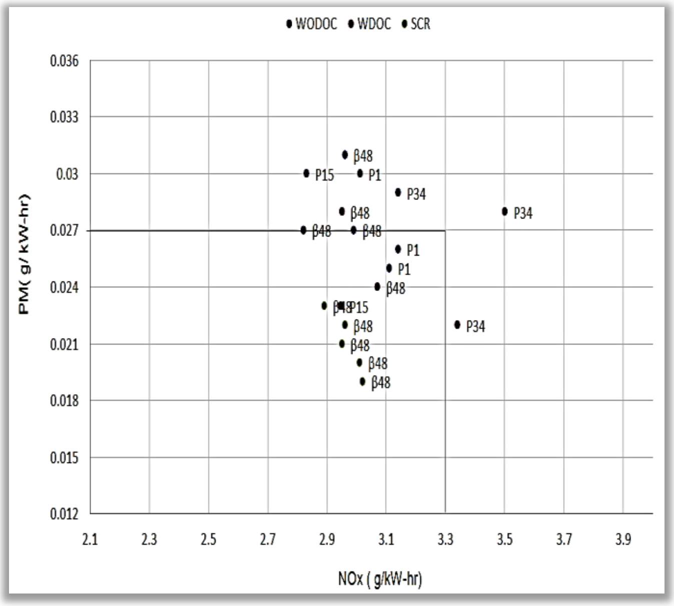
F. ESC RESULTS:



- Test was conducted with DOC, without DOC and with SCR Catalyst
- It is observed that low loading of DOC it is not causing significant effect in ESC results

- For repeatability it was checked on 4 engine with 2 different levels of releases. The trend repeats

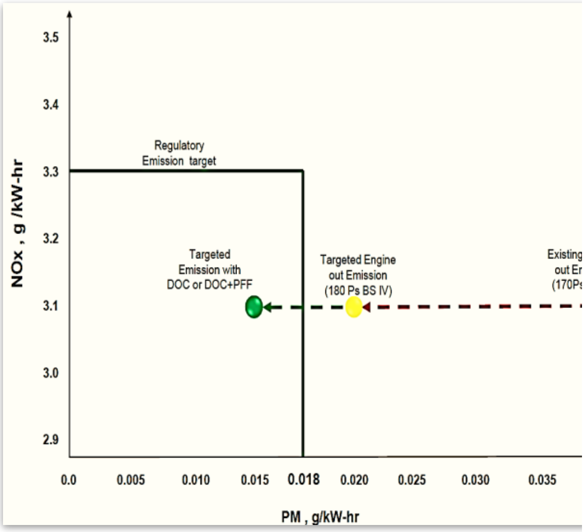
G. ETC RESULTS:



- The same engines were tested for ETC with DOC , without DOC and with SCR catalyst
- Repeatability in trend was observed.

Final results after optimization With and without DOC

Pollutant	BSIV Limits	Engine out Emission after optimization	Emission with DOC
CO	1.5	0.52	0.00
HC	0.46	0.06	0.00
NOx	3.5	3.20	3.12
PM	0.02	0.020	0.015



6. CONCLUSION AND WAY FORWARD:

- Engine out Emission optimization was successfully completed with DOE Approach
- With reduction in DOC loading there is no significant change in the ESC cycle emission observed. Hence we could go with DOC with less loading
- Tests are performed on different engines and with different DOC samples, similar effect was observed.
- SCR catalyst showed prominent effect on PM reduction in both ESC and ETC emission cycles.
- DOC + PFF combination will have significant effect of reduction in emission. We can use this combination in future for further Emission reduction and in turn achieve BEFC improvement
- With this combination of Reduced loading of DOC and elimination of POC we can save 50% cost of After treatment.

7. AKNOWLEDGEMENT

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