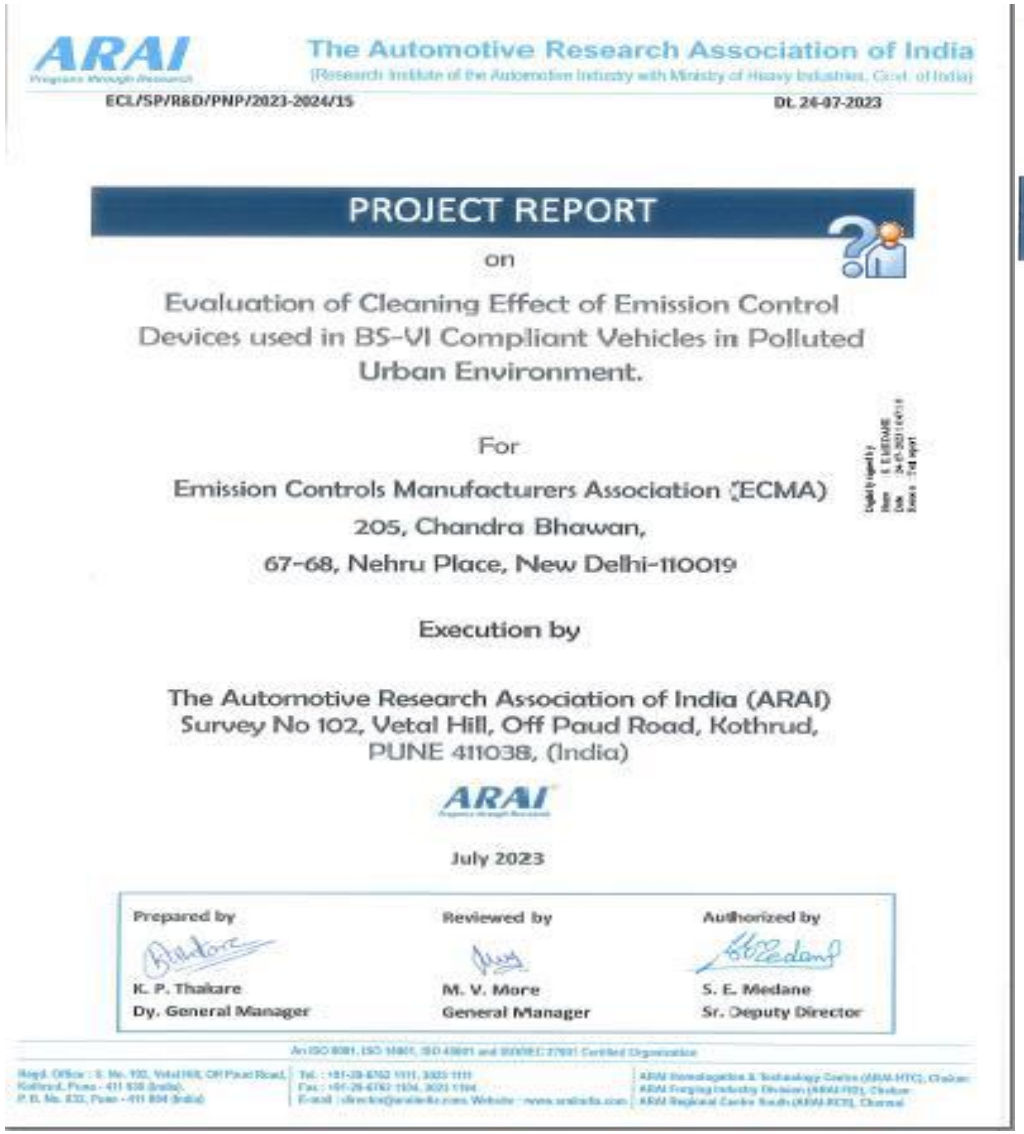
Evaluation Of Cleaning Effect of Diesel Particulate Filter Used In BSVI Compliant Vehicle in Polluted Urban Environment w.r.t Particulate Mass And Particulate Number

By ECMA And ARAI



ARAI
The Automotive Research Association of India
(Research Institute of the Automotive Industry with Ministry of Heavy Industries, Govt. of India)

ECL/SP/R&D/PNP/2023-2024/15 Dt. 24-07-2023

PROJECT REPORT

on

Evaluation of Cleaning Effect of Emission Control Devices used in BS-VI Compliant Vehicles in Polluted Urban Environment.

For

Emission Controls Manufacturers Association (ECMA)
205, Chandra Bhawan,
67-68, Nehru Place, New Delhi-110019

Execution by

The Automotive Research Association of India (ARAI)
Survey No 102, Vetal Hill, Off Paud Road, Kothrud,
PUNE 411038, (India)

ARAI

July 2023

Prepared by	Reviewed by	Authorized by
K. P. Thakare	M. V. More	S. E. Medane
Dy. General Manager	General Manager	Sr. Deputy Director

ECL/SP/R&D/PNP/2023-2024/15 Dt. 24-07-2023

PROJECT REPORT

This Presentation is based on the Test Report on Particulate Filter Tests done on a vehicle by ARAI for ECMA

DISCLAIMER: *ARAI has made this report on the vehicle actually tested at ARAI at the presented condition with as fitted Emission Control Devices and is not applicable to general production. This test report does not indicate any measure of approval, certification, supervision, control of quality surveillance by ARAI of the vehicle/ Emission Control Devices. No extract, abridgement or abstraction from the test report shall be published or used to advertise the product without the written consent of the Director of ARAI, who reserves the absolute right to agree or reject all or any of the details of any items of publicity for which consent may be sought. The appropriate local courts at Pune shall have the jurisdiction in respect of any dispute, claim or liability out of this report.*

Table of Content

Preamble

Major reasons leading to air pollutant emissions and poor air quality :

- Rising urbanization
- Growing industrialization at a high pace
- Associated anthropogenic activities influenced by human business

CPCB has set NAAQS (National Ambient Air Quality Standard) for assessing the air quality through the status of following 12 pollutants

- Particulate Matter 10 (PM10)
- Particulate Matter 2.5 (PM2.5)
- Nitrogen Dioxide (NO2)
- Sulphur Dioxide (SO2)
- Carbon Monoxide (CO)
- Ozone (O3)
- Ammonia (NH3)
- Lead (Pb)
- Benzene
- Benzopyrene
- Arsenic
- Nickel

- **Out of these, particulate matter is found to be a major contributor to deteriorating air quality in India, especially PM 2.5**
- **The level of PM pollutant is reported to have exceeded the recommended national and international standards in many Indian cities, causing severe impact on public health**

Purpose/objectives of the Project

About ECMA and the Objective of this Project

- ECMA represents seventeen member companies engaged with development of equipment for control and reduction of vehicle tail-pipe emissions to ultra-low levels, thus assisting to achieve clean Air Quality to the public and supporting green environment committed by the government at global level

- PM being the major concern for poor air quality and human health, ECMA recognized the utility of the Particulate Filters fitted on BS 6 vehicles, in filtering out PM and providing particulate free air at the exhaust regardless of the high particulates in polluted ambient air with excessive AQI.

- The need was felt to test and demonstrate this cleaning potential through testing at a reputed Test Agency such as ARAI.

- To meet the focus of the proposed study, it was necessary to develop a test methodology, which can effectively demonstrate the real-field situations and create a confidence in the test results.

- Accordingly, ARAI was chosen as a Partner to develop this demonstration test for efficacy of Particulate Filter in cleaning polluted atmospheric air

Air Quality Standard

National Ambient Air Quality Standard

Pollutant	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural, and Other Areas	Ecologically Sensitive Area (notified by Central Government)
Sulphur dioxide (SO_2), $\mu g/m^3$	Annual 24 hours	50 80	20 80
Nitrogen dioxide (NO_2), $\mu g/m^3$	Annual 24 hours	40 80	30 80
Particulate matter (< 10 µm) or PM_{10}, $\mu g/m^3$	Annual 24 hours	60 100	60 100
Particulate matter (< 2.5 µm) or $PM_{2.5}$, $\mu g/m^3$	Annual 24 hours	40 60	40 60
Ozone (O_3), $\mu g/m^3$	8 hours 1 hour	100 180	100 180
Lead (Pb), $\mu g/m^3$	Annual 24 hours	0.50 1.0	0.50 1.0
Carbon monoxide (CO), mg/m^3	8 hours 1 hour	02 04	02 04
Ammonia (NH_3), $\mu g/m^3$	Annual 24 hours	100 400	100 400
Benzene (C_6H_6), $\mu g/m^3$	Annual	05	05
Benzo(α)Pyrene (BaP) – particulate phase only, ng/m^3	Annual	01	01
Arsenic (As), ng/m^3	Annual	06	06
Nickel (Ni), ng/m^3	Annual	20	20

- The first ambient air quality standards were developed in 1982 pursuant to the Air Act. Later, in 1994 and 1998, these standards were revised. The latest revision to the NAAQS was done in 2009 and this is the latest version being followed.
- National Ambient Air Quality Standards (NAAQS) are standards for air quality comprise 12 pollutants.
- The NAAQS was more technical in nature and was not easy for the common man to comprehend
- The compliance of the NAAQS is monitored under the National Air Quality Monitoring Programme (NAMP). NAMP is implemented by the CPCB.

Air Quality Standard

Air Quality Index or simply AQI

- The National Air Quality Index (AQI) was launched in 2014 to measure the air quality and rate it in six categories. The AQI includes all the NAAQS pollutants except benzene, benzopyrene, arsenic and nickel.
- Air Quality Index is a tool for effective communication of air quality status to people in terms, which are easy to understand. It transforms complex air quality data of various pollutants into a single number (index value), nomenclature and colour.
- The AQI was launched keeping in mind the idea of 'One Number-One Colour-One Description'.
- The Sub-indices for individual pollutants at a monitoring location are calculated using its 24-hourly average concentration value (8-hourly in case of CO and O3). The worst sub-index is the AQI for that location.
- All the eight pollutants may not be monitored at all the locations. Overall AQI is calculated only if data are available for minimum three pollutants out of which one should necessarily be either PM2.5 or PM10.

AQI Index and its effects as per CPCB

AQI (Air Quality Index)			
Good (0–50)	Minimal Impact	Poor (201–300)	Breathing discomfort to people on prolonged exposure
Satisfactory (51–100)	Minor breathing discomfort to sensitive people	Very Poor (301–400)	Respiratory illness to the people on prolonged exposure
Moderate (101–200)	Breathing discomfort to the people with lung, heart disease, children and older adults	Severe (>401)	Respiratory effects even on healthy people

Laboratory test set-up for AQI Generation and Vehicle Testing

The following test methodology was followed during the execution of project

Test On Chassis Dynamometer	On road test using 2 PEMS system
Chassis dynamometer tests (2 each) on test vehicle on MIDC cycle with following intake air PM2.5 AQI subindex • ~50-100 (test cell ambient air) • ~200-300 • ~350-450 • >700.	1) City tests: Inside city portion of Pune during minimum ambient AQI during the day and maximum ambient AQI during the day) 2) RDE tests on certification route consist of Urban, Rural and Motorway trip share.

Test Vehicle Details-Diesel Passenger Car BS-VI (OBD-I Compliant)

Model	XXXXX (M1 category BS-VI OBD Stage-I Compliant)
Fuel Type	Diesel
Engine Displacement (cc)	~1500
No. of cylinder	4
Max Power (Bhp@rpm)	~115bhp@~3700rpm
Max Torque (Nm@rpm)	~260Nm@1500-2700rpm
Seating Capacity	5
Transmission Type	Manual
Emission Control Devices	EGR +DPF and LNT

- The test vehicle is identified and approved by ECMA
- The vehicle was subjected to running-in on road for 1500 kms for stabilization of aftertreatment system of vehicle.
- After 1500 kms the vehicle was serviced at authorized service center as per the vehicle OEM recommendation prior to test.

Laboratory test set-up for AQI Generation and Vehicle Testing

Assumptions:-

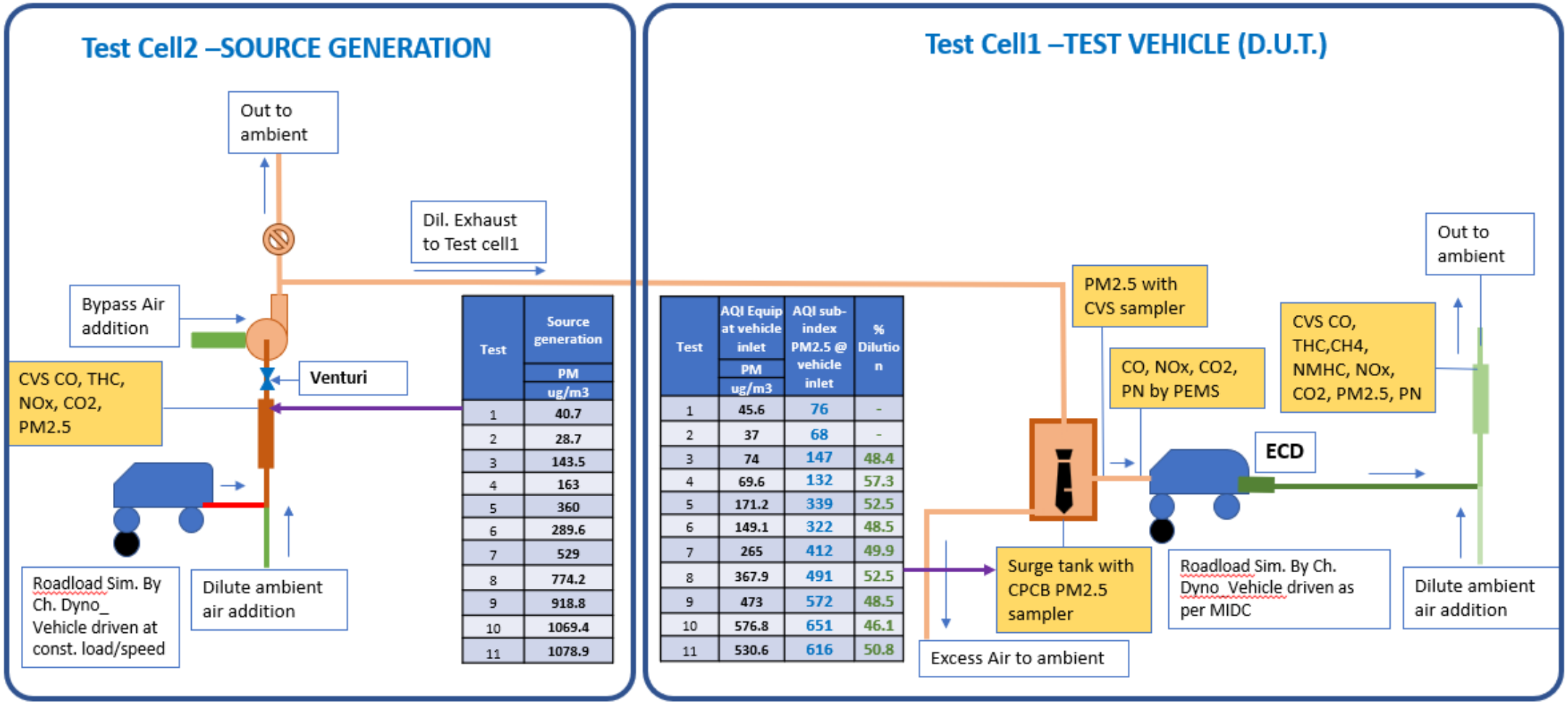
1. As per NAAQS, the PM2.5 is measured on 24 hr sampling and the gross value is reported.
   - This is basically to account for the variation of air quality during the day and then report average representative value for any given day
   - In our case, on chassis dyno emission generation, we will running the vehicle @ constant speed and load, so emission of PM will be constant for the entire test duration(~20 mins). So the calculation and correctness of the procedure proposed is ok.

2. During test, PM2.5 Sub-index is always considered as worst sub-index to calculate AQI irrespective of CO and NO_2 value at test vehicle inlet.

3. The AQI generated using Vehicle Exhaust and Dilution air may have different chemical composition compared to normal AQI consist of air pollution from different sources.

4. The below two aspects are not in the scope of present study
   - There may be a change in Periodic regeneration interval of vehicle running in polluted air as defined above
   - There might be an impact on Fuel economy and maintenance interval of vehicle

Laboratory test set-up for AQI Generation and Vehicle Testing



- A butterfly valve in the CVS blower out line of source generation vehicle helps to provide adequate flow to project vehicle inlet. Excess flow is sent out to the ambient.
- Source generation vehicle is run at different steady speeds and loads and controlled flow of Dilution air is fed at the exhaust of source-generation vehicle to provide different sets of PM2.5 AQI index at the inlet of test vehicle.
- Emissions are measured both at inlet and exhaust of test vehicle using PEMS system and CVS sampler.

Laboratory test set-up for AQI Generation and Vehicle Testing

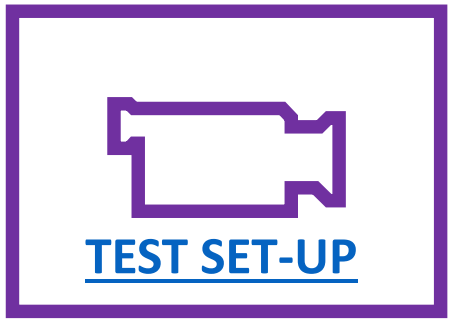
Test cell 2 (VTC2) CVS-Blower outlet connection to Test cell1 (VTC1) Vehicle air filter inlet




AQI PM2.5 Sampler Installation in the flow path near vehicle inlet

Laboratory test set-up for AQI Generation and Vehicle Testing

Video Clip



On Road Emission Test Set-up and Testing

On road testing

- PEMS (portable emissions measurement system) is a useful tool for on road real world emissions because they provide emissions under a wide range of operating conditions, including those that would otherwise be difficult to replicate in the laboratory

- To understand the performance Emission Control Device of vehicle, it was decided to drive the vehicle on road by driving in different traffic pattern like only urban and a combination of urban / rural/ motorway.

- For on-road tests, emissions of PN were measured as no reliable technique to measure PM2.5 existed at the time of testing.

- **Two on roads tests each were performed on identified route**
  - **City test:**
    - Inside city portion of Pune with minimum ambient AQI during the day
    - Inside city portion of Pune with maximum ambient AQI during the day
  - **RDE test on certification route.**

On Road Emission Test Set-up and Testing

Lab Validation

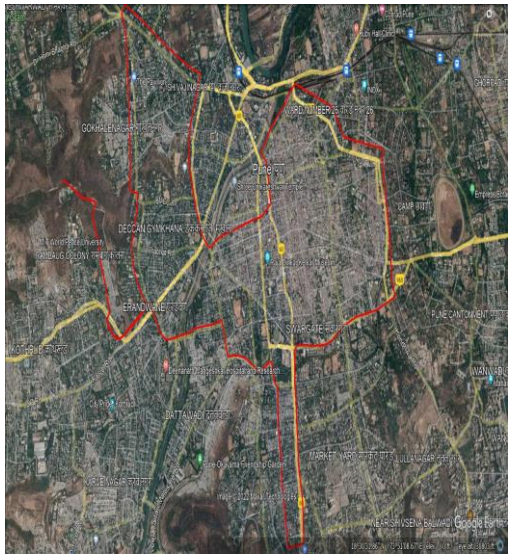
PEMS at Vehicle Inlet

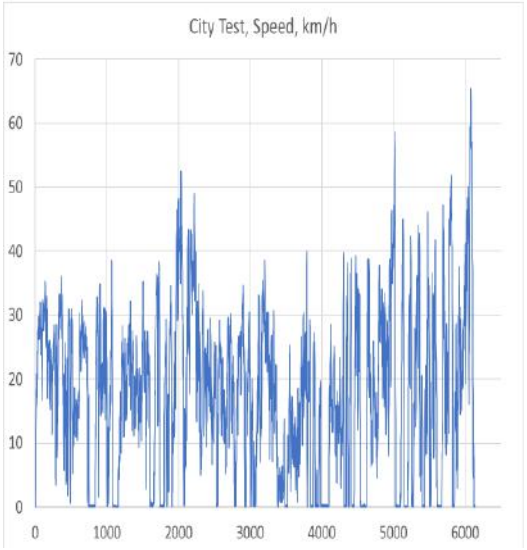
PEMS at Vehicle Tail pipe

- Two Portable Emission Measurement Systems (PEMS) were mounted on the BS 6 LDV test Vehicle for simultaneous measurement of PN emission, one at the inlet of the vehicle and other at outlet of the vehicle exhaust
- Lab validation tests were conducted to confirm the installation of PEMS system at vehicle inlet and tailpipe
- RDE emission test results are generated over **complete cycle** (in # /km)

On Road Emission Test Set-up and Testing

CITY ROUTE

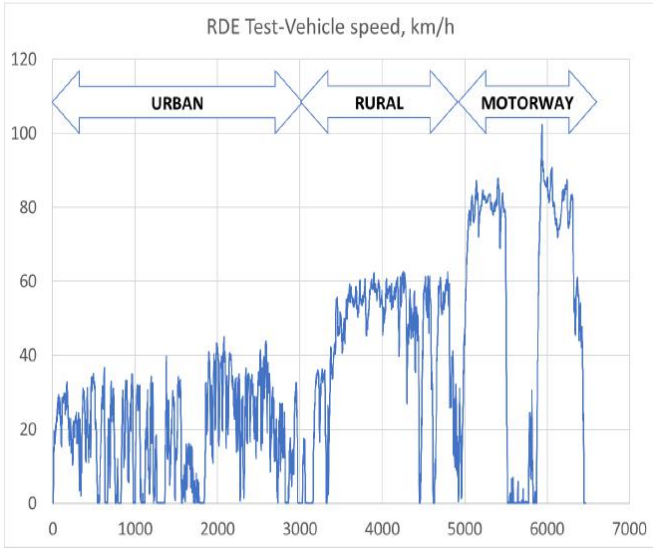




ARAI-Nal Stop-Mhatre bridge- Swargate-sahakar nagar-swargate- Seven Loves Chowk- East street- Kumbhar Wada- Laxmi road- Garware chowk- Shivaji nagar- E-square-Chaturshringi- Law College road- Paud Phata- ARAI

	Start time	Duration	km	Temp C	Altitude m
Test 1	14:00:00	1:49:07	30.8	34.5	578.3
Test 2	07:37:00	1:35:45	30.2	19.3	577.8

RDE CERTIFICATION ROUTE

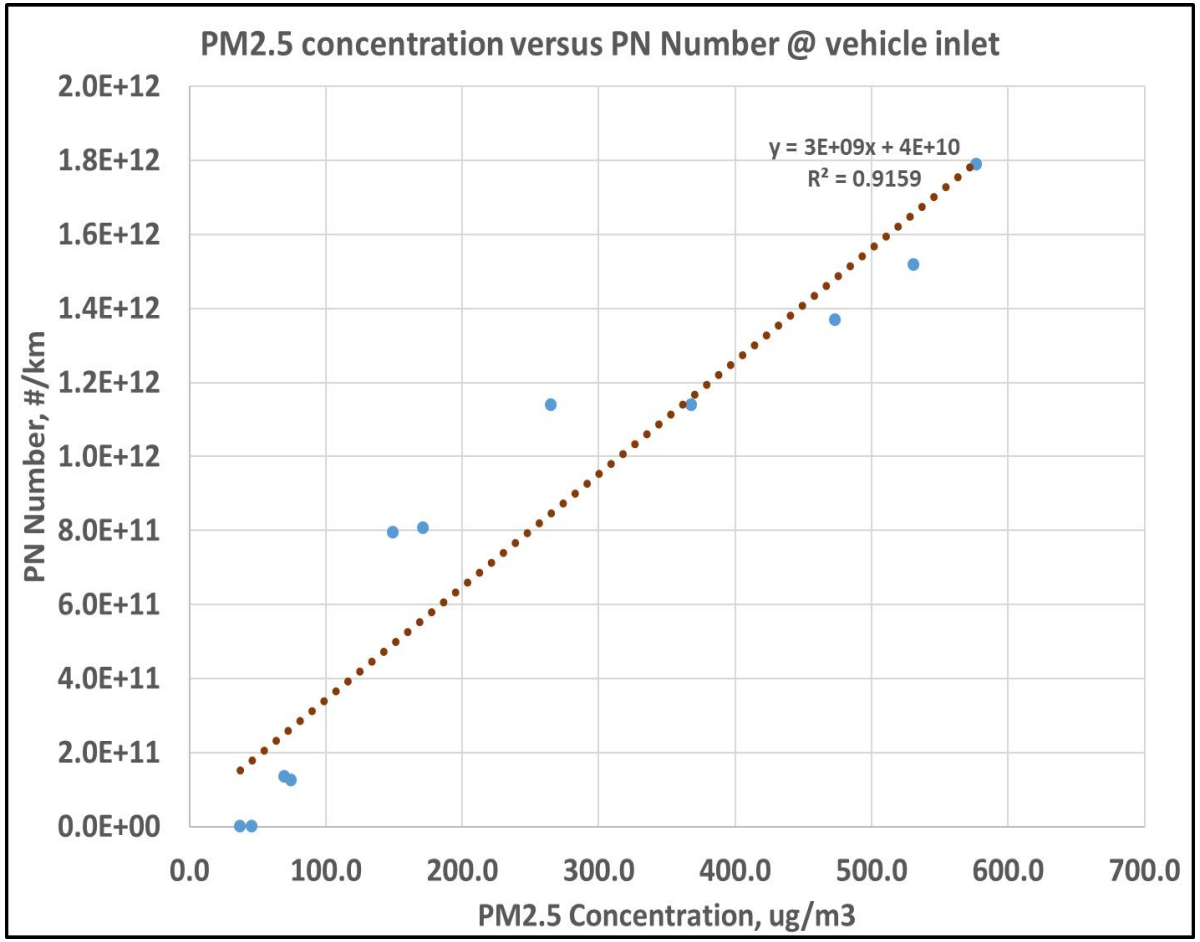


URBAN: ARAI – Nal stop- law college road- university road- Aundh- Baner- Balewadi Phata-
RURAL: Pune Mumbai old highway- Dehu road- Somatne Toll gate- U-turn- Mukai Chowk-
MOTORWAY: Express way- Talegaon-U-turn-Mukai Chowk- Test end.

	Start time	Duration	km	Temp C	Altitude m
Test 1	14:13:11	1:47:45	61.4	29.2	581.6
Test 2	10:09:22	1:41:30	61.3	28.9	579.1

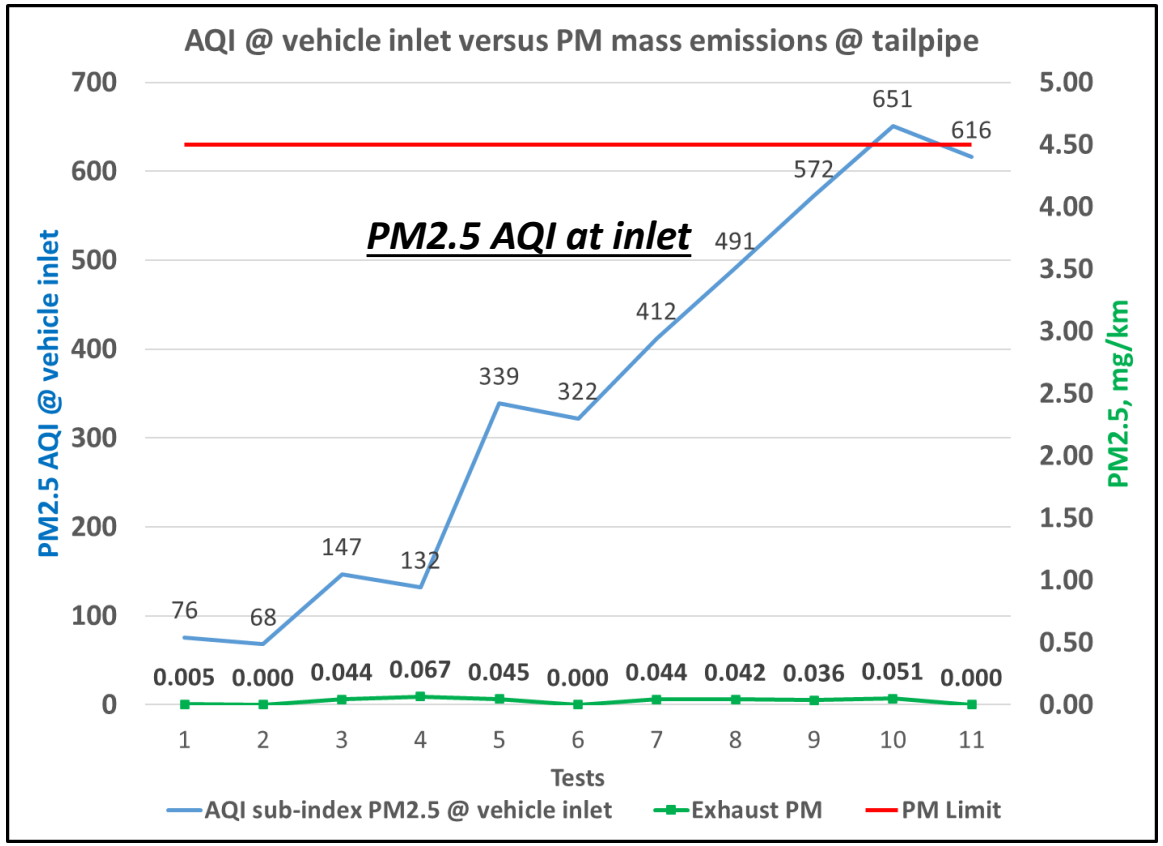
Laboratory test results and Trend

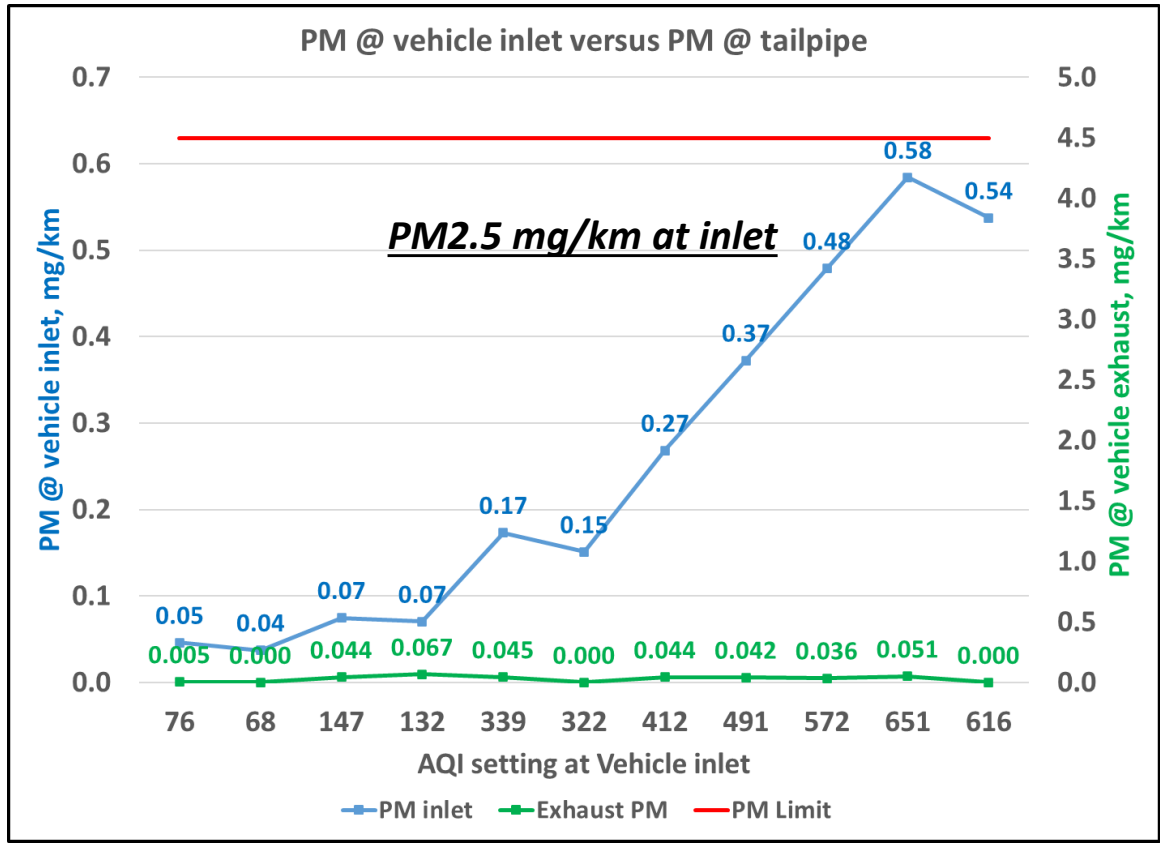
Date	Test condition of vehicle in source generation test cell	AQI sub-index PM2.5 @ vehicle inlet	Vehicle tail pipe Emission										
			CO	THC (C_1)	CH4	NMHC	NOX	CO2	HC+Nox	FE	PM	PN	PN @ Vehicle inlet
			mg/km	mg/km	mg/km	mg/km	mg/km	g/km	mg/km	km/ltr	mg/km	#/km	#/km
	BS-VI Limits	-	500	-	-	-	80	-	170	-	4.5	6.00E+11	-
01-Mar-23	Test set up Baseline-2	76	225.6	70.0	30.0	41.9	42.8	133.5	112.9	19.6	0.005	5.00E+08	1.510E+09
14-Mar-23	Test set up Baseline-1	68	211.5	72.0	32.5	41.5	31.4	132.7	103.3	19.4	0.000	5.37E+08	9.15E+08
02-Mar-23	setting-1	147	205.1	77.6	33.0	46.7	34.5	130.3	112.1	20.1	0.044	6.963E+08	1.27E+11
03-Mar-23	setting-1	132	180.2	70.4	32.4	40.1	29.8	133.5	100.3	19.7	0.067	7.75E+08	1.37E+11
04-Mar-23	setting 2	339	178.4	68.4	31.8	38.6	28.1	135.5	96.5	19.0	0.045	7.12E+08	8.08E+11
06-Mar-23	setting 2	322	239.4	80.5	33.4	49.2	36.3	135.7	116.7	19.0	0.000	1.06E+09	7.95E+11
08-Mar-23	setting 3	412	185.2	66.2	32.2	36.1	26.3	137.1	92.5	18.8	0.044	1.39E+09	1.14E+12
10-Mar-23	setting 4	491	188.3	72.4	34.4	40.2	22.6	138.6	95.0	18.6	0.042	5.76E+08	1.14E+12
15-Mar-23	setting 5	572	222.3	75.8	36.6	41.6	18.0	145.1	93.8	17.8	0.036	4.48E+08	1.37E+12
07-Mar-23	setting 6	651	181.5	70.1	33.1	39.1	25.7	135.8	95.8	19.0	0.051	3.74E+08	1.79E+12
09-Mar-23	setting 7	616	182.6	67.2	33.1	36.2	24.5	141.6	91.7	18.5	0.000	4.89E+08	1.52E+12



- A good correlation is seen between PM2.5 and PN of the inlet atmosphere created by the source generation vehicle.
- These PN numbers may be different then a real-field atmosphere since other sources like dust, ash, etc is missing in the source generated flow.

Laboratory test results and Trend

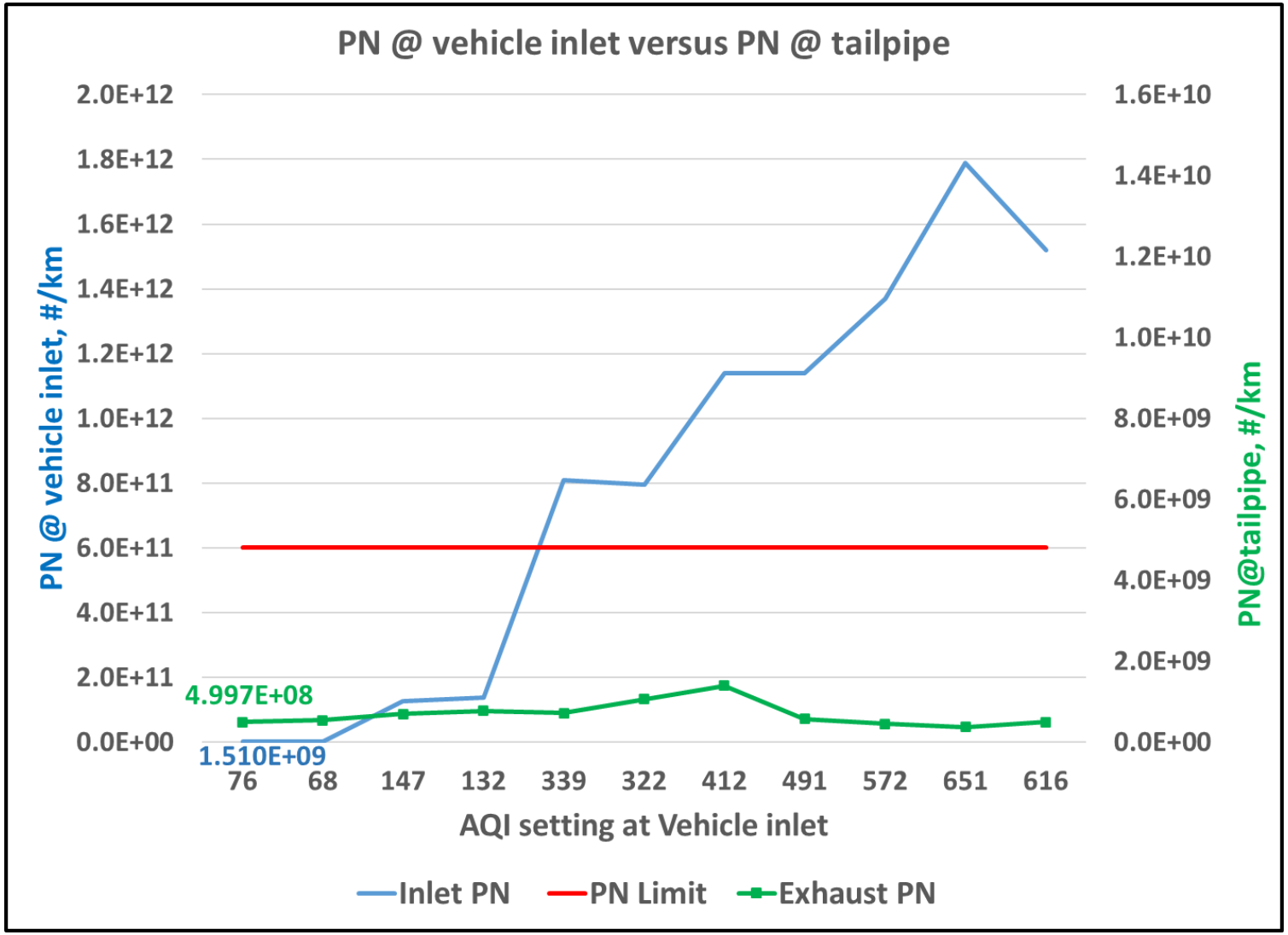




- Tail pipe PM emission of project vehicle are more or less constant with increasing number of PM2.5 AQI at project vehicle inlet.
- Tail pipe PM emissions are well below certification limit

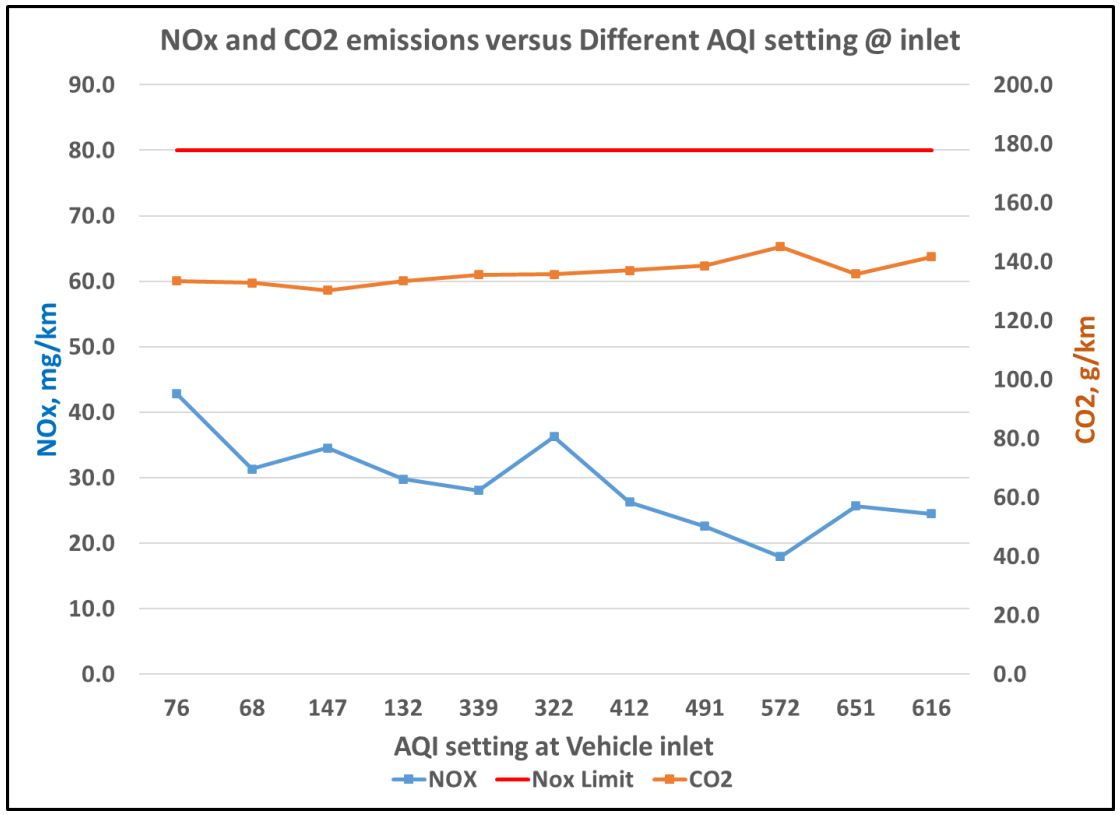
- PM 2.5 mass emission (mg/km) at inlet increases with the increase in PM2.5 AQI at the inlet.
- However, Tail pipe PM emission (mg/km) of project vehicle are almost constant

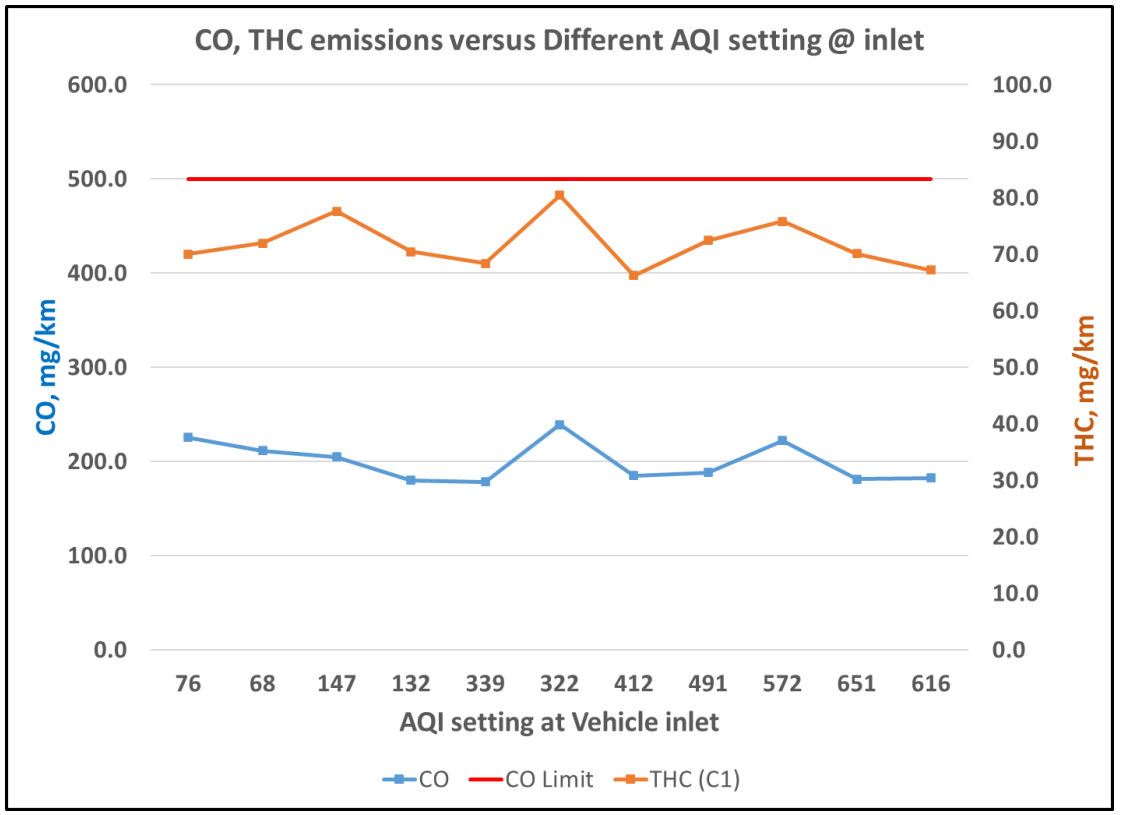
Laboratory test results and Trend



- PN increases in the inlet with increasing PM2.5 AQI.
- However, PN in the exhaust is more or less constant.
- PN in the exhaust is well below certification limit.

Laboratory test results and Trend





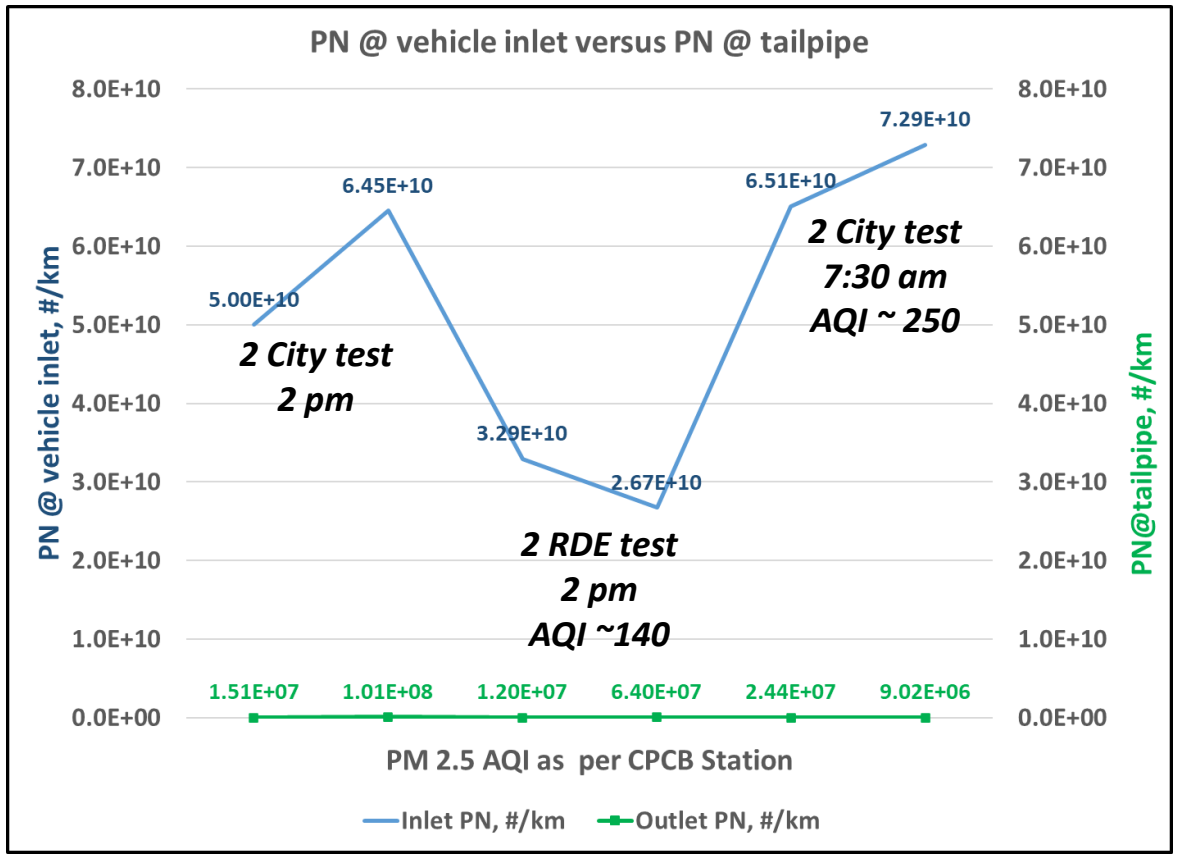
- With the increasing PM2.5 AQI at vehicle inlet, results at vehicle exhaust show that –
  - there is a slight increase in CO2 emission
  - there is a marginal decrease in NOx emission. It could be due to EGR effect owing to rising CO2
  - NOx emissions are well within NOx limits

- With the increasing PM2.5 AQI at vehicle inlet, there is practically no change in CO and THC emissions at the vehicle exhaust.
- CO emissions are well within CO limits

On-road test results and Trend

	position	CO2, g/km	PN, #/km	% eff of PN reduction	Purple Air Inst. PM2.5 ug/m3	PM2.5ug/m^3 CPCB Station (Shivaji Nagar)	Ambient AQI at CPCB Site
TEST1 18.01.2023, 14.00, On-road, Cold	inlet	2.102	5.00E+10	99.97%	Min: 29.2 Avg: 45.7 Max: 152.1		
	outlet	259.8	1.51E+7				
Test2 19.01.23 14.00, On-road, Cold	inlet	2.210	6.45E+10	99.84%	Min 24.4 Avg 38.8 Max 74.2		
	outlet	254.3	1.01E+8				
Test3 20.01.23 14.00, RDE, Cold	inlet	1.283	3.29E+10	99.96%	Min 17.9 Avg 67.1 Max 127	83.35	177
	outlet	161	1.20E+7			72.60	142
Test4 30.01.23 14.00, RDE, Cold	inlet	1.242	2.67E+10	99.76%	Min 27.5 Avg 49.9 Max 119.5	91.67	206
	outlet	173.9	6.40E+7				
Test5 23.01.23 7.30, On-Road, Cold	inlet	1.824	6.51E+10	99.96%	Min 35.8 Avg 69.9 Max 145	116.52	287
	outlet	196	2.44E+7			102	240
Test6 24.01.23 7.30, On-Road, Cold	inlet	2.08	7.29E+10	99.99%	Min 60.4 Avg 87.2 Max 118.2	128.61	306
	outlet	194.4	9.02E+6			107	257

Avg. 24 Hr. Values Avg. Values during test duration



- Regardless of PN at the vehicle inlet –
  - PN in the vehicle exhaust remained more or less constant, although driving conditions, day and time of the driving differs
  - PN in vehicle exhaust is lower than PN in vehicle inlet. PN reduction is more than 99%
  - As observed in Chassis dyno tests (lab test), PN emission is less in vehicle exhaust as compared to vehicle inlet.

Summary

- It is evident from the both tests, in the laboratory and on the road, that aftertreatment devices as fitted in a production BS 6 light duty vehicle are performing as per requirement.

- This elaborate set up made it possible to accurately measure and compare varying AQI levels at vehicle inlet with the test vehicle exhaust emissions.

- Cleaning effect on PM 2.5 with the use of Particulate Filter is demonstrated in both laboratory and on-road tests cleaning the ambient air of any AQI quality.

- The results clearly demonstrate that appropriate exhaust aftertreatment devices, in particular Particulate Filters has the capability of reducing PM 2.5 pollutants to very low level and this, quite consistently irrespective of the Air Quality Index the vehicle is exposed to.

- Similar trends are expected with other types of fuel (gasoline, CNG Bio-fuels) in passenger car and heavy-duty vehicles too. However, this needs to be evaluated.

Thank You