DETERMINATION OF A PRECONDITIONING PROTOCOL TO STABILIZE NOx AND PN EMISSIONS FOR EURO 6 ENGINE CERTIFICATION

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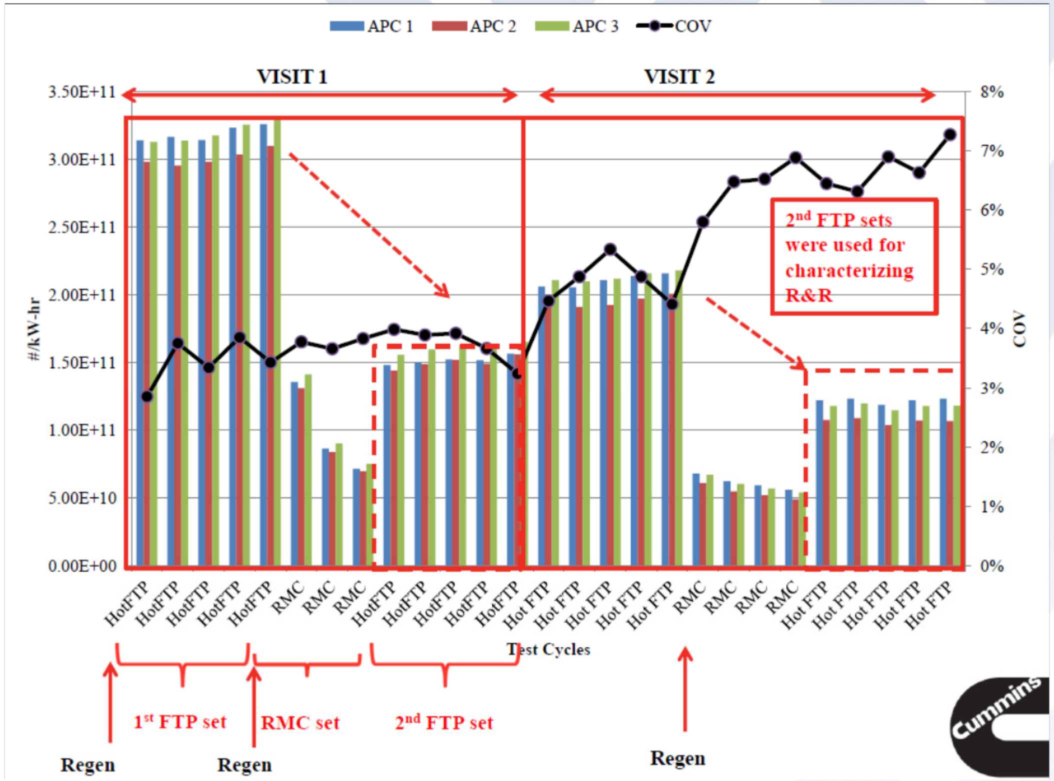
Motivation

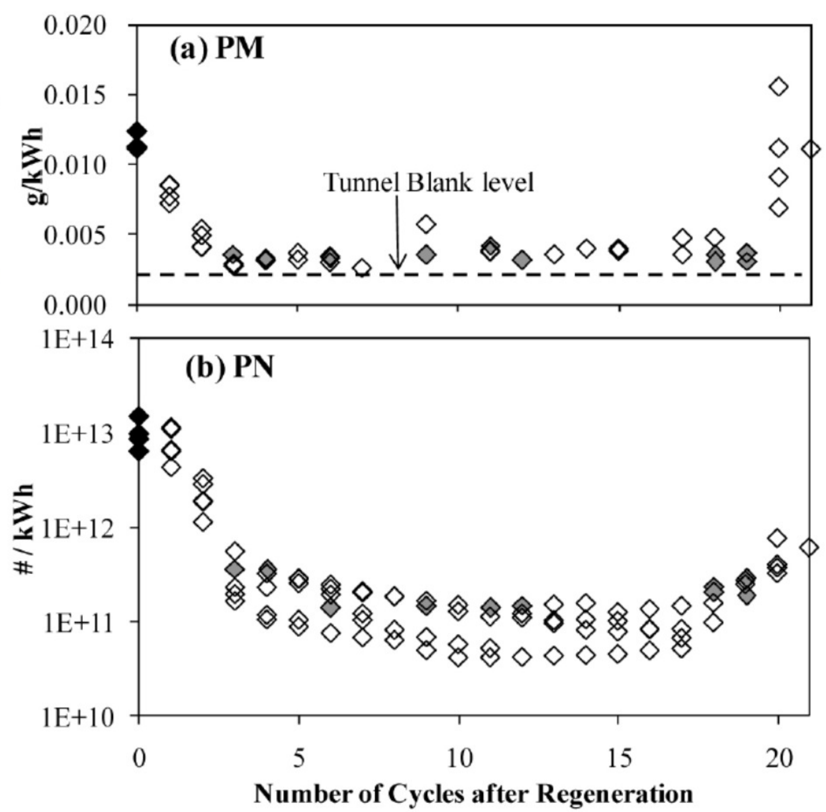
- With Euro-VI (Euro 6) emissions limits being phased in by 2016, more and more engines are being certified under these standards at different Cummins facilities around the world.
- Previous studies performed at Cummins technical center (CTC) showed significant variation in PN measurement from one run to the other



24th CRC RWE Workshop presentation by Yusuf Khan et.al

Background

- The state of the DOC-DPF-SCR aftertreatment status primarily governed the trends in variation of PN emissions. In specific, DPF soot load and exhaust temperatures were the primary factors that was found to drive the level of PN emissions and their stability from these modern engines and aftertreatment systems.



PM (a) and PN (b) emissions from SCR engine as a function of the number of cycles after regeneration. Symbol filled with gray are cold starts and ones filled with black are cycle with regeneration [1]

1. PN emissions from Heavy-Duty Diesel Engine with Periodic Regenerating DPF; Hiroyuki Yamada, NTSEL; SAE international, 2013-1-1564.

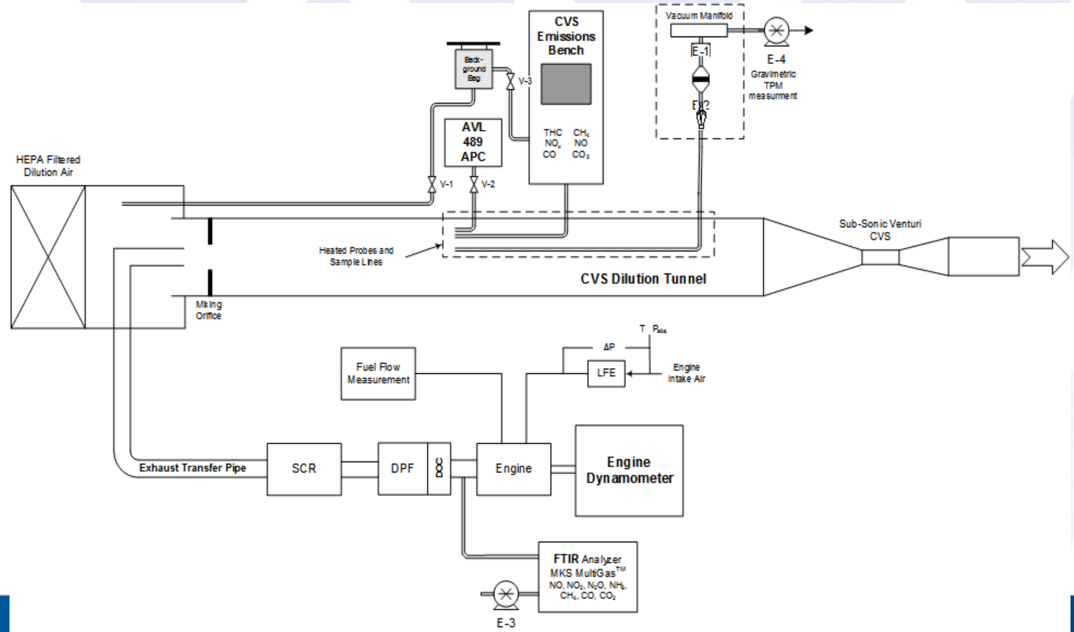
Objective

- To investigate the effect of soot loading and engine out exhaust temperatures on PN emissions and to develop a preconditioning protocol in order to obtain stabilized NOx and PN emissions from these engines.
- To understand the effect of different technology pathways on the stability of PN and NOx emissions and preconditioning process.

Experimental Setup

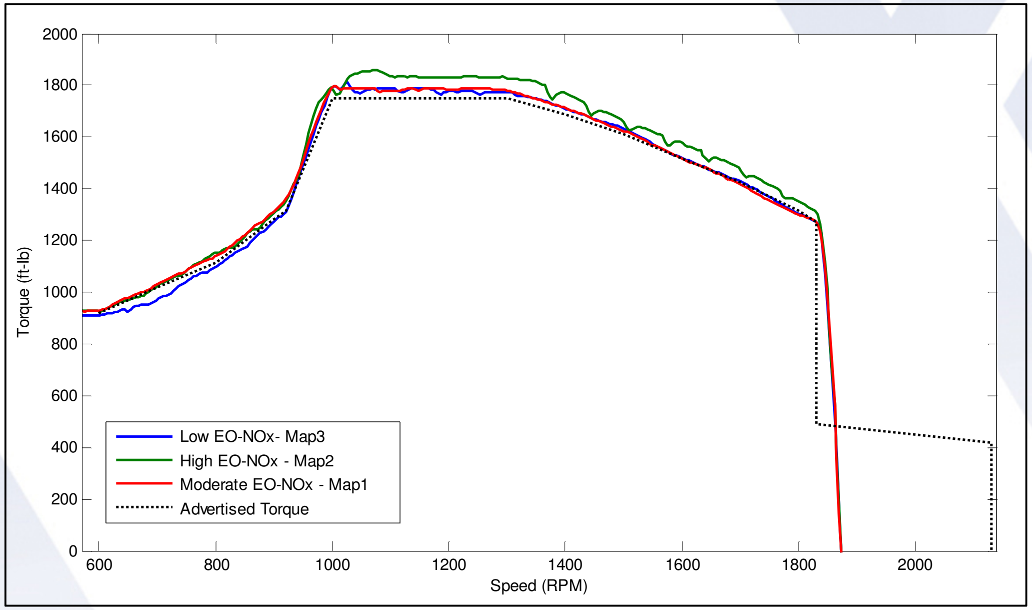
- The study was carried out in CVS test cell at Cummins Technical Center.
- FTIR analyzer was setup to measure engine out gaseous emissions, in order to quantify engine-out NOx emissions during the three different operating modes.
- AVL 489 APC was used to measure PN emissions from the CVS dilution tunnel along with gravimetric filter method to quantify TPM emissions.
- A 15L MY2016 Cummins ISX15 450 engine was used for this part study.

Engine Model	ISX15 450
Model Year	2016
Rated Power	450 hp @ 1800 rpm
Peak Torque	1750 lb-ft @1000 rpm
AT system	DOC-DPC-SCR



Test Methodology

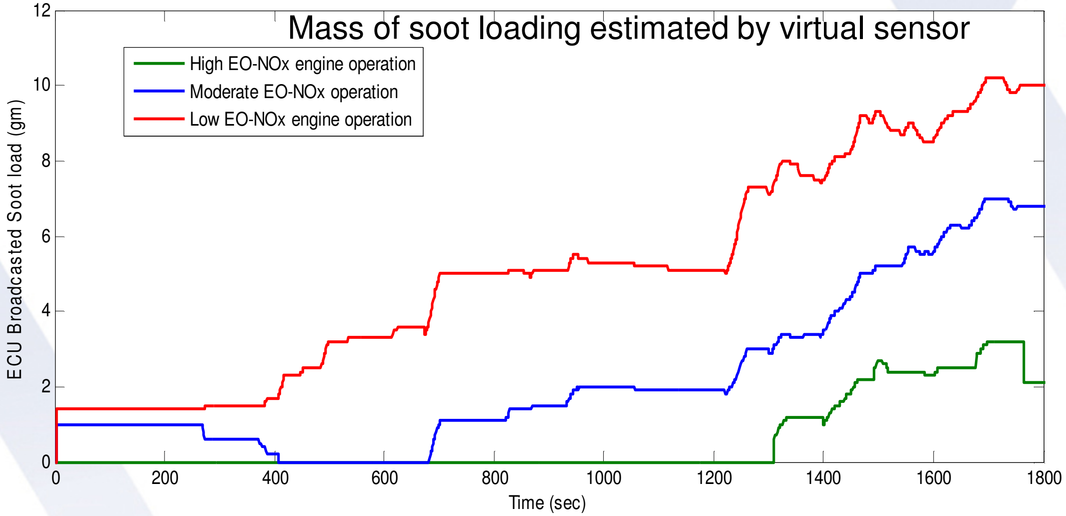
- The test sequence was designed in such a way that the first cycle in each sequence would represent cold start emissions from a clean de-greened DPF.
- The engine was exercised over 10 WHTC cycles followed by 3 WHSC cycles with 20 minute soak periods in between tests.
- Three engine operating modes were simulated with varying engine out NOx levels (EO-NOx). This was done by running the engine in three different engine calibrations.

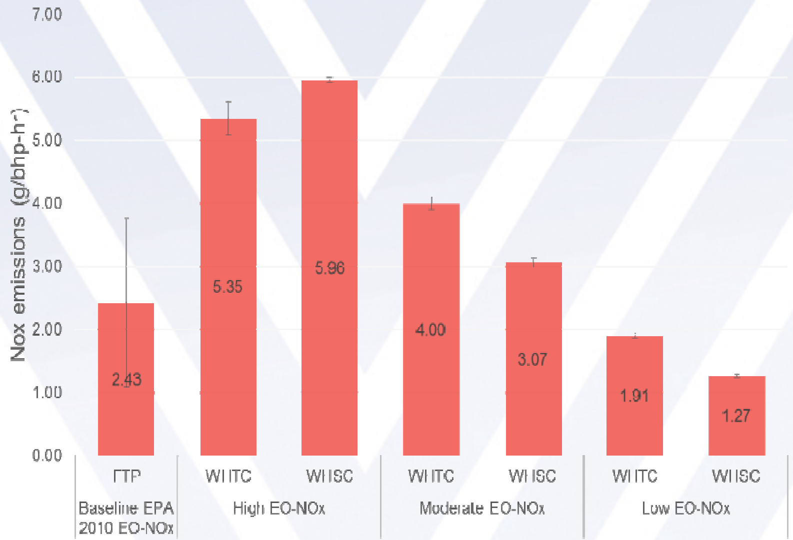


Torque curves for each EO-NOx engine operation that was used to generate the reference test cycles

Test Methodology (continued.)

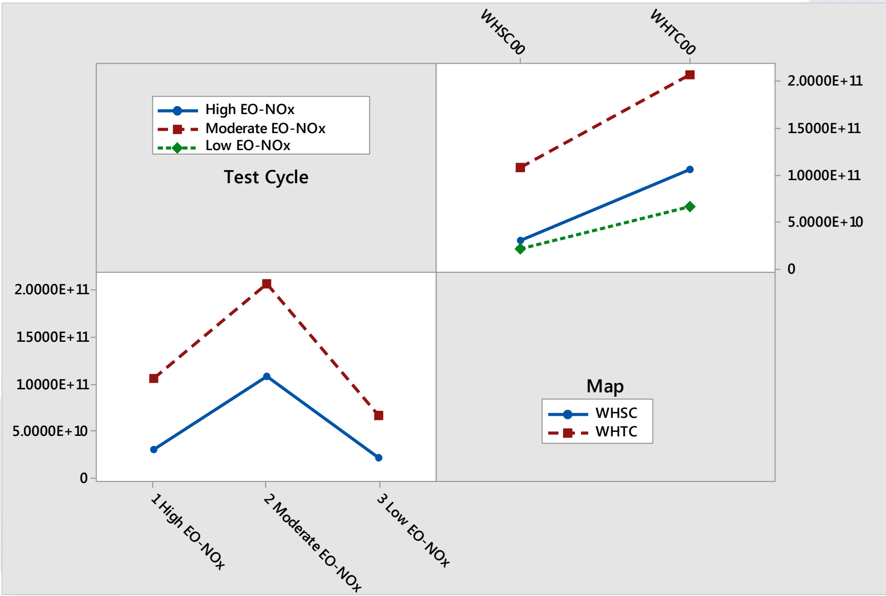
- The NOx-PM trade off also resulted in varying levels of soot loading. Thus resulting in high EO-NOx engine operation with the lowest and low EO-NOx having the highest rate of soot loading.
- Varying levels of EO-NOx were used to understand the effect of varying size and porosity of DPFs, engine calibration strategies and also account for different technology pathways on the preconditioning procedure required for stabilizing particle number emissions.

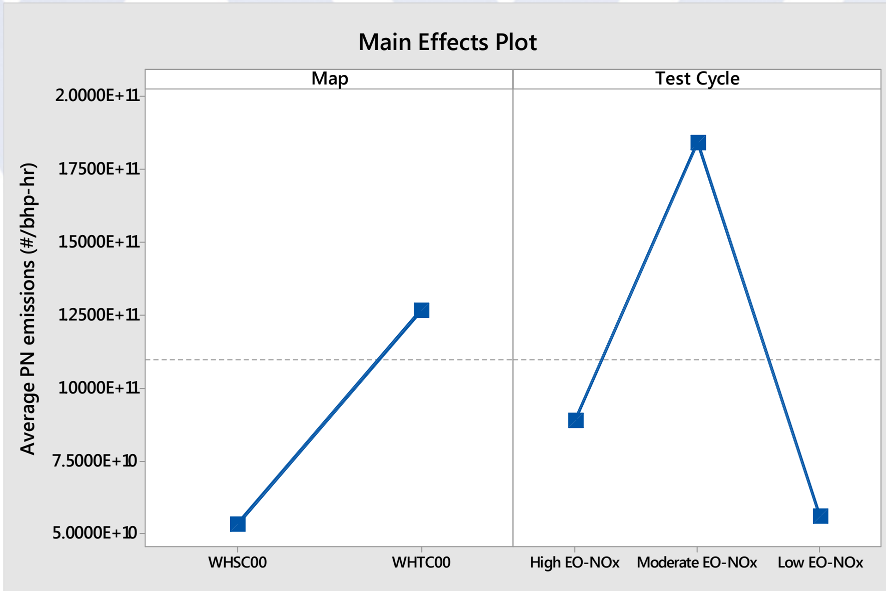




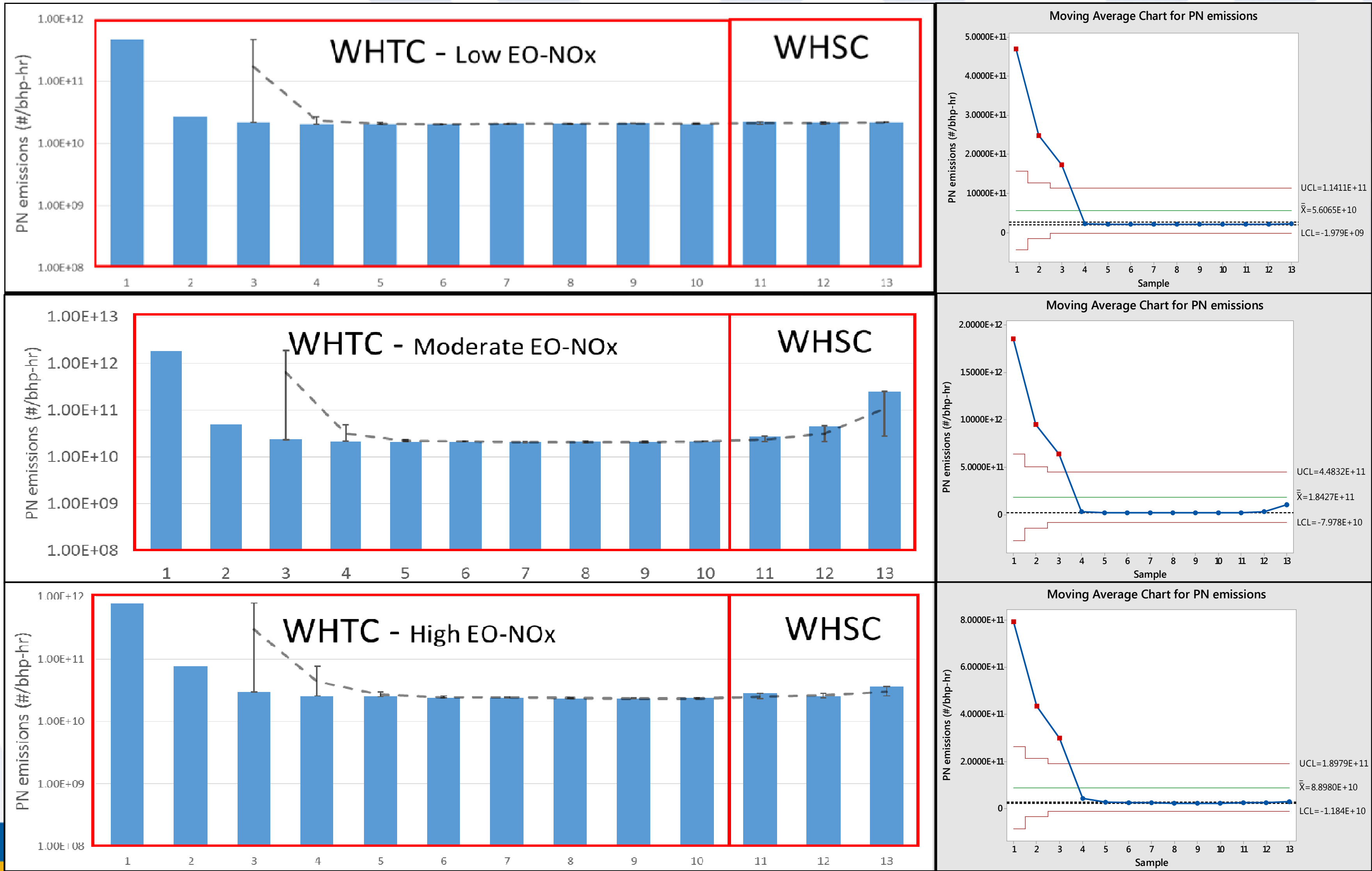
Results

- Average brake specific bsPN emissions during moderate EO-NOx engine operation resulted in the highest level of PN emissions as compared to the others engine operating modes.
- Higher level of bsPN emissions could be attributed to significant level of soot loading as well as turbine-out exhaust temperatures leading to more frequent catalytic oxidation of soot over the cycle as compared to the other two modes which can be characterized either by high soot and low exhaust temperatures or low soot and high exhaust temperatures.



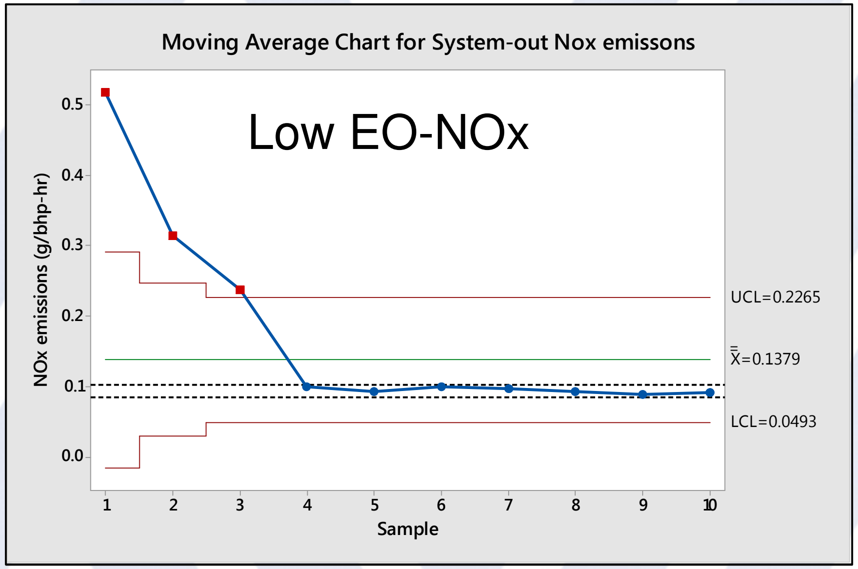


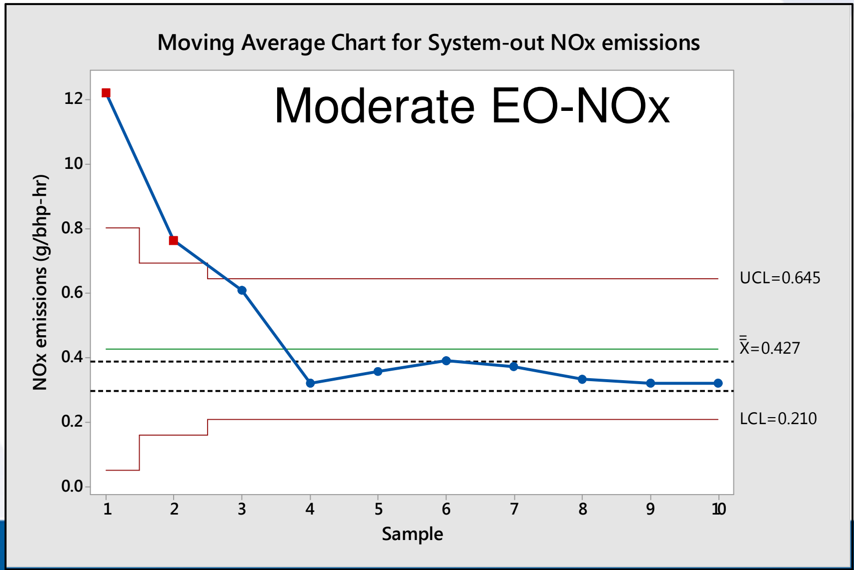
Effect of preconditioning cycles on PN emissions

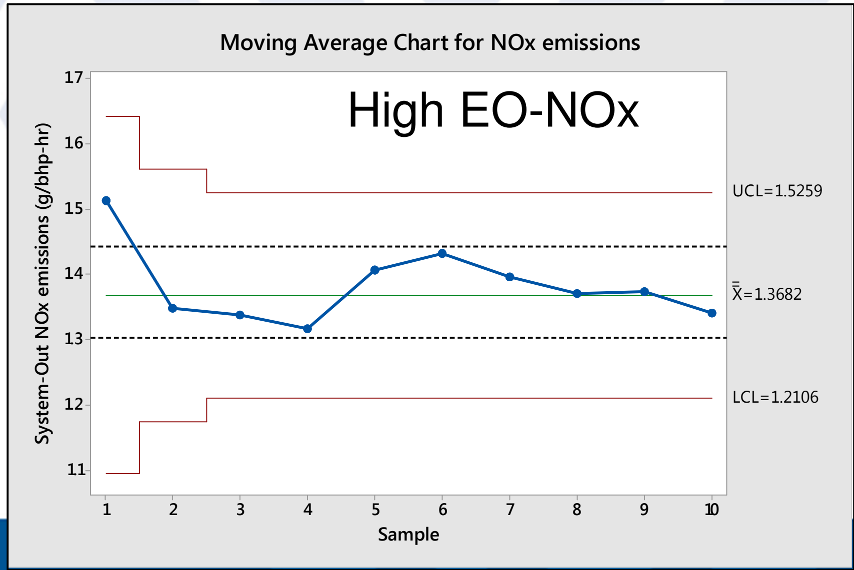


Effect of preconditioning cycles on NOx emissions

- 3 preconditioning cycles are need to stabilize both particle number emissions as well as NOx emissions from the engine.
- NOx emissions varied over three calibration even though the aftertreatment urea dosing controller was performing optimally.

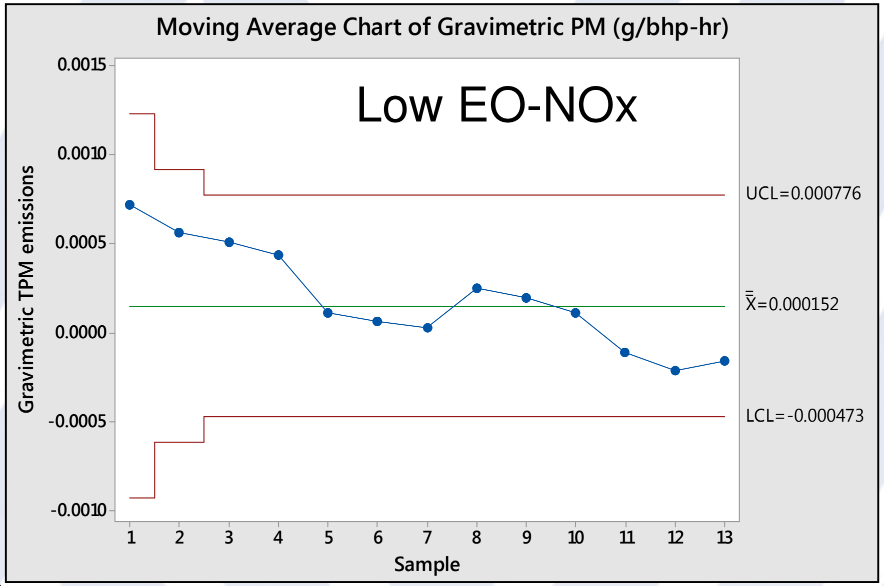


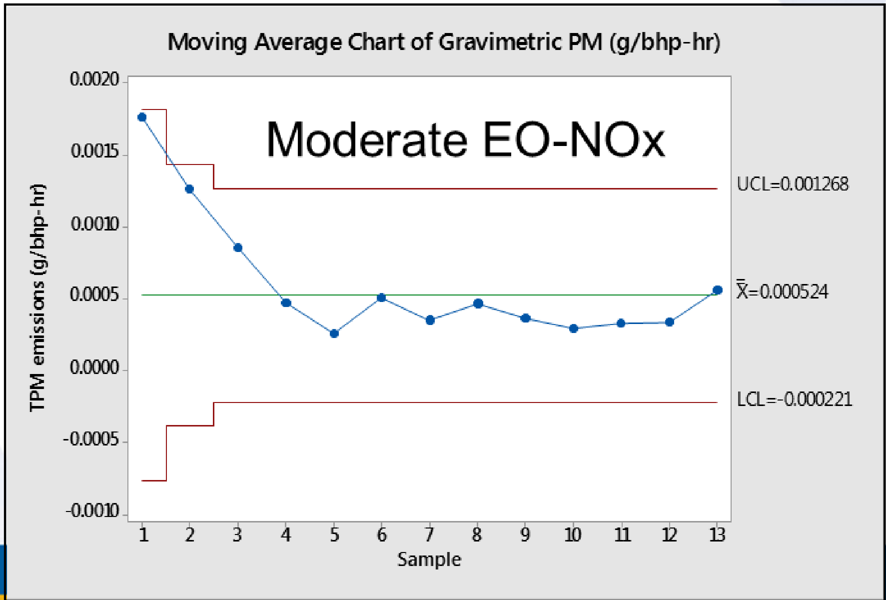


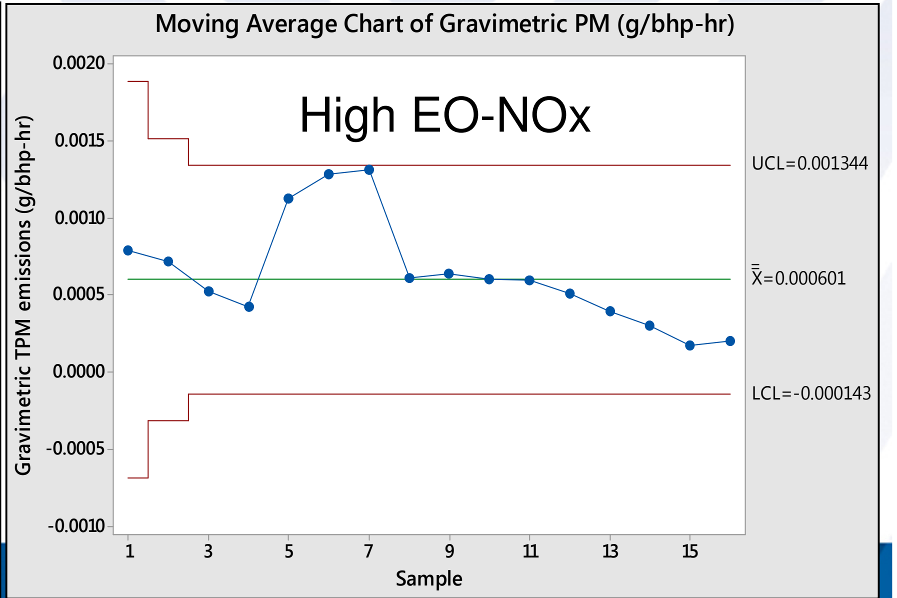


Effect of preconditioning cycles on TPM emissions

- There was little to no effect on TPM brake specific emissions for the three engine operations.
- Control charts show that TPM emissions where within the noise level of the measurement process.

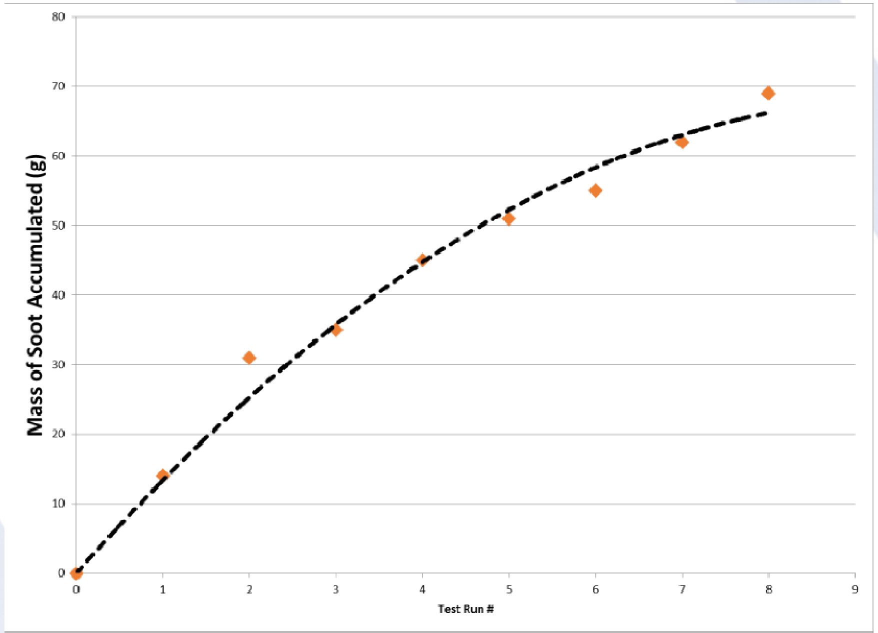




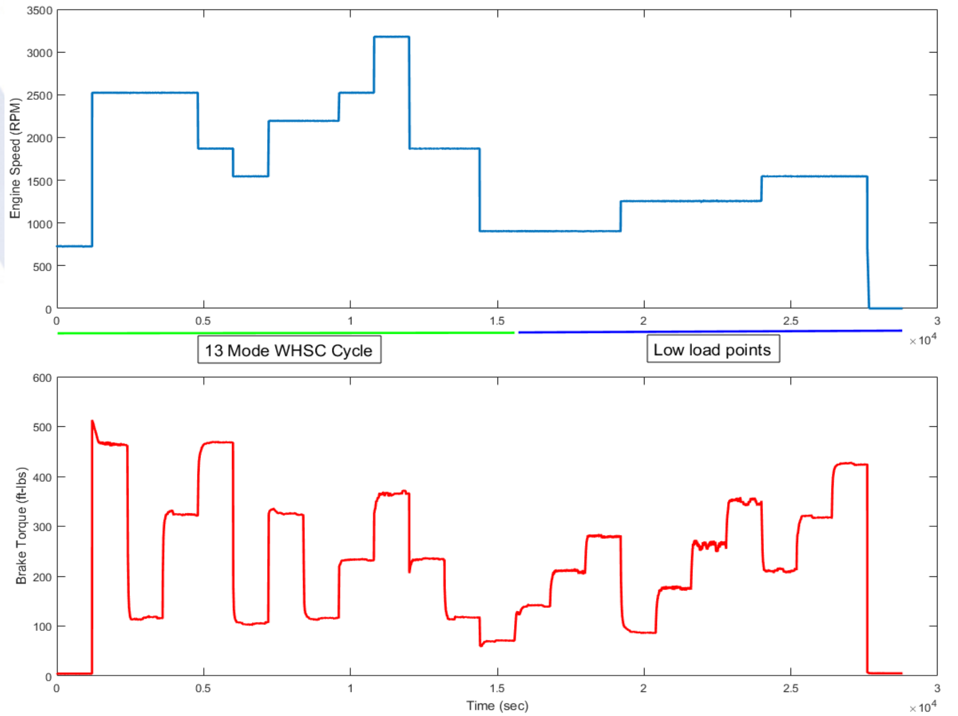


WVU work on PN stabilization

- MY2008 medium-duty diesel engine equipped with DOC+DPF aftertreatment system was tested on an engine dynamometer.
- Customized 24 mode pseudo transient steady state cycle was created for accelerated soot loading of the DPF

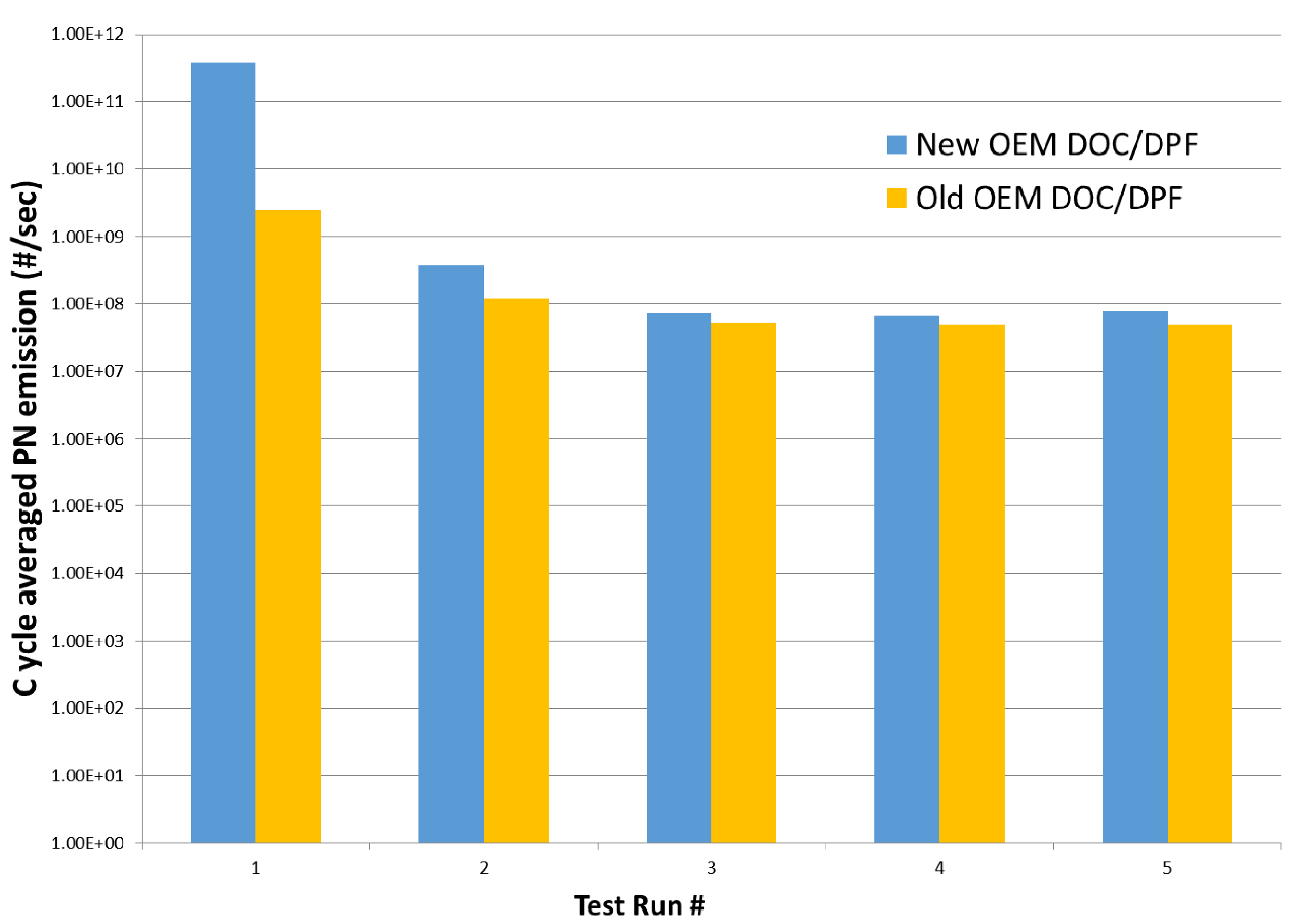


Soot mass accumulation profile for the new DOC+DPF Aftertreatment System



Accelerated Engine Dynamometer Soot-Loading cycle

Comparison between older and newer Aftertreatment systems



Conclusion

- The highest bsPN emissions was observed with the moderate EO-NOx engine operation. This could be attributed to the following reasons:
  - Significant soot loading on the DPF and exhaust temperatures causing catalytic oxidation of soot during the cycles. As compared to the other two engine operating levels which either had high soot loading and low exhaust temperature or low soot loading high exhaust temperature causing their bsPN emissions to be lower.
  - Moderate EO-NOx engine operation was able to move between different calibration maps.
- Results show that 3 preconditioning cycles are needed to stabilize both particle number emissions as well as NOx emissions from this engine.
- Exhaust temperatures, rate of soot loading and EO-NOx levels do not have a significant effect on the number of preconditioning cycles that are required to stabilize the particle number and NOx emissions.
- TPM emissions were within the noise level of the measurement method and engine calibration had little to no effect of level TPM emissions
- Work done at WVU showed that although there is significant difference in the magnitude of emissions between older and newer and aftertreatment system, they both follow the same general trend for PN stabilization.

Future Work

- Investigate stability of bsPN emissions from engines with different engine sizes and aftertreatment packages including after market systems.
- Development of a robust preconditioning cycle using methods such as genetic algorithms to get faster stability of PN emissions in place of the current 3 cycle method.

Thank You

QUESTIONS?