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

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Introduction

With Euro-VI (Euro 6) emissions limits being phased in by 2016, more and more engines are being certified under these standards at different facilities around the world. The emissions limits defined in Euro 6 regulations are comparable US-EPA 2010 emissions standards with introduction of particle number (PN) emissions limits to the regulations. This adds complexity to the engine testing and certification process. Table 1 below, shows the comparison below the 2010 US-EPA emissions limits along with Euro 6 emissions limits.

Table 1: Emissions limits for Heavy-Duty on road engines.

Regulations	Test Cycle	CO	NMHC	HC	NOx	TPM	PN
		g /bhp-hr*					#/kw-hr
2010 US EPA	FTP	15.500	0.140	-	0.200	0.010	-
	SET	15.500	0.140	-	0.200	0.010	-
EURO VI	WHTC	2.983	0.550	0.119	0.373	0.007	6.0×10^{11}
	WHSC	1.119	-	0.097	0.298	0.007	8.0×10^{11}

Euro 6 limits have been converted to g/bhp-hr units.

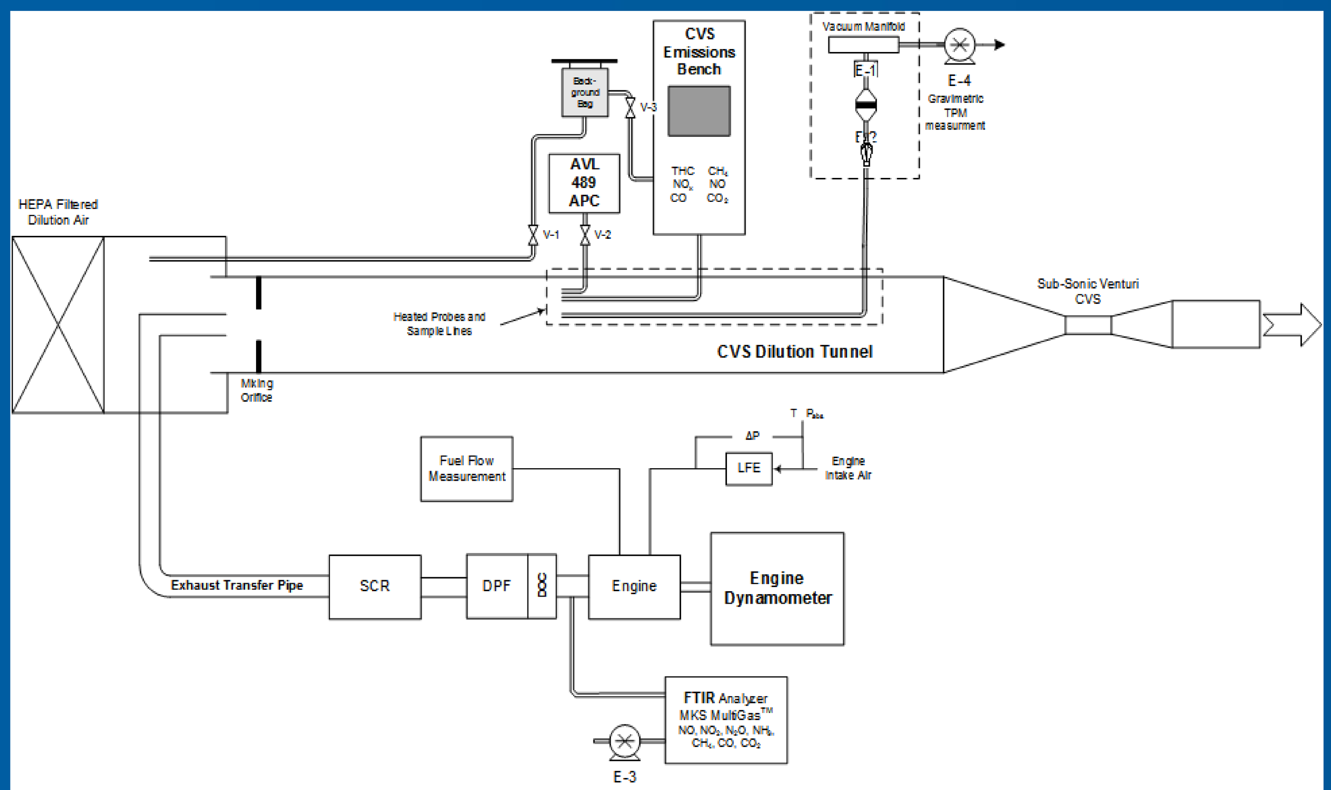
Previous studies performed at Cummins technical center (CTC) using three AVL 489 APCs for PN measurement showed significant variation in PN emissions from one test run to the other [1]. The results from this study also showed that the trends in variation of PN emissions from an engine equipped with DOC-DPF-SCR after treatment systems depended greatly on the amount of soot loading on the DPF at the beginning of the test cycle. With this in mind, this study was aimed 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 for certification of modern HD diesel engine.

Objective

The global objective of the study was to develop a generic preconditioning protocol for engine dynamometer testing in order to obtain repeatable NOx and PN emissions. The objective of the study was further included:

1. Investigating the effects 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. (Phase I)
2. To understand the effect of different technology pathways on the stability of PN and NOx emissions as well as the preconditioning process. (Phase II)

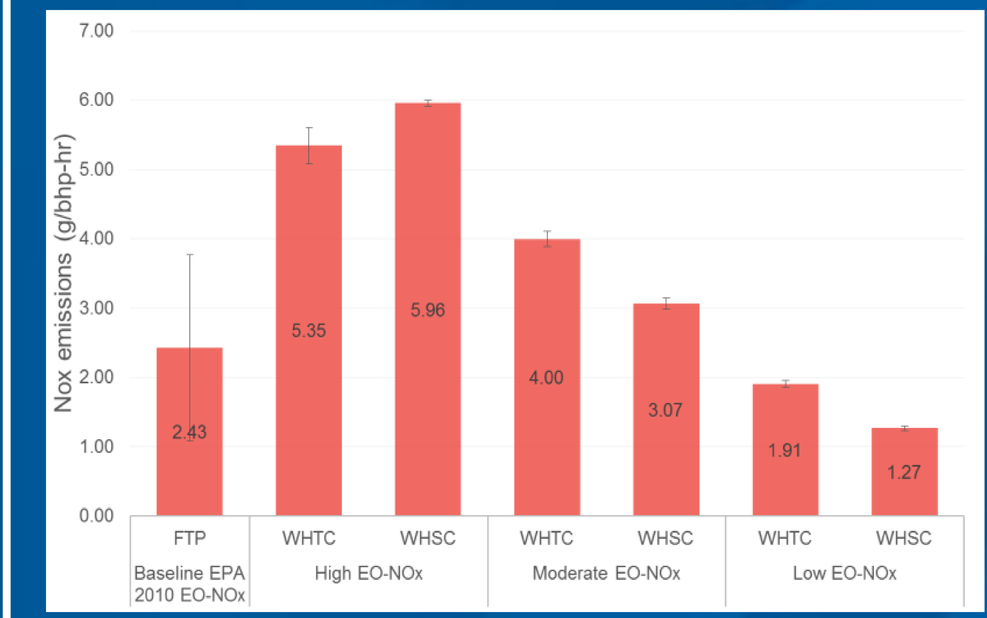
Experimental Setup



The first phase of study was carried out at Cummins Technical Center on an MY' 2016 15L ISX-450 heavy-duty diesel engine. The engine was equipped with an DOC-DPF-SCR aftertreatment system and was compliant with 2010 US-EPA standards. The Second phase of the study was conducted at WVU EERL engine dynamometer test facility . This part of the study made use of a MY' 2008 medium-duty diesel engine equipped with DOC-DPF aftertreatment only. It was done so in order to understand the effects of different aftertreatment packages and preconditioning cycles on engine stabilizing brake specific emissions.

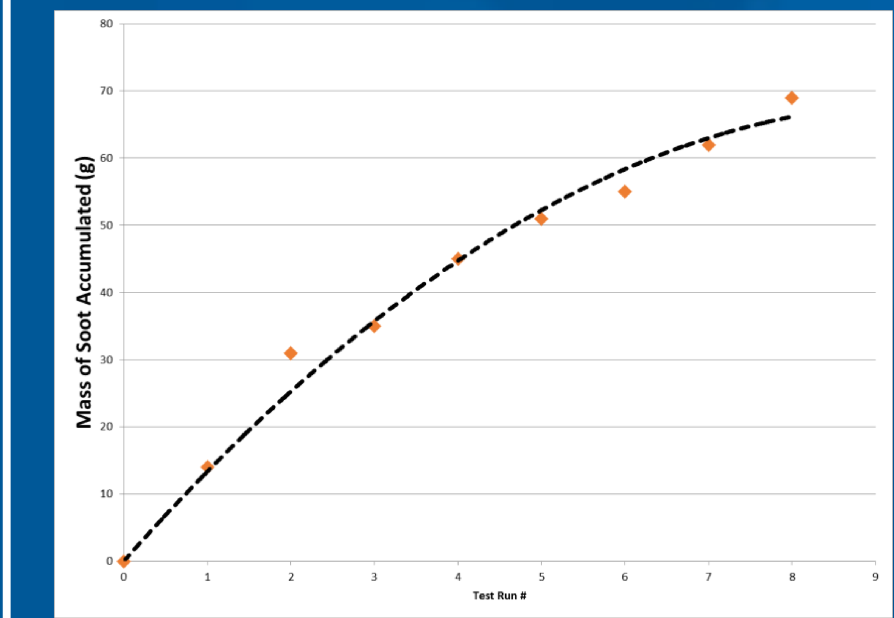
1. 24th CRC RWE Workshop presentation by Yusuf Khan et.al, Titled " CHARACTERIZATION OF REPEATABILITY AND REPRODUCIBILITY OF BSPN MEASUREMENTS FROM AVL PARTICLE COUNTERS"

Test Methodology

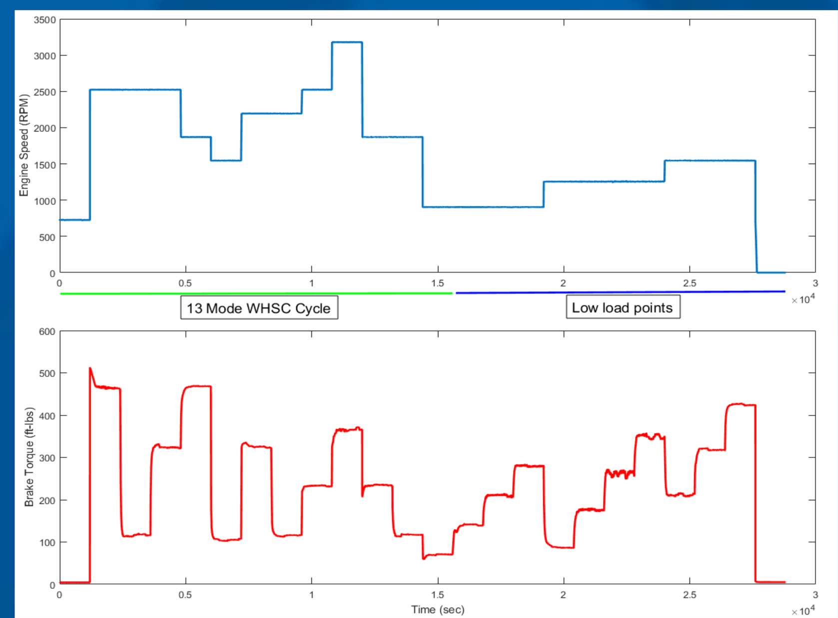


Phase I: Three unique engine calibrations with varying levels of Engine-Out NOx (EO-NOx) were developed. The Moderate EO-NOx level was the baseline US-EPA 2010 calibrations. The engine was exercised over 10 WHTC cycles and finally followed by 3 WHSC cycles with 20min soak times in between, for each EO-NOx engine calibrations. Each test started with an active regeneration for 40min followed by a 50min motoring to force cool the aftertreatment to 80°F.

Phase II: This phase of the project was to primarily understand the effects of aftertreatment age on PN and NOx emissions as well as understand how an aftertreatment package without an SCR system affects PN and NOx emissions and their repeatability. The engine was exercised over a customized 24 mode soot loading cycle. The first 13 modes of the cycle consisted of the ESC 13 mode test followed by low speed low load points specifically designed for soot loading. The test was repeated 5 times with 10min soak times in between tests.

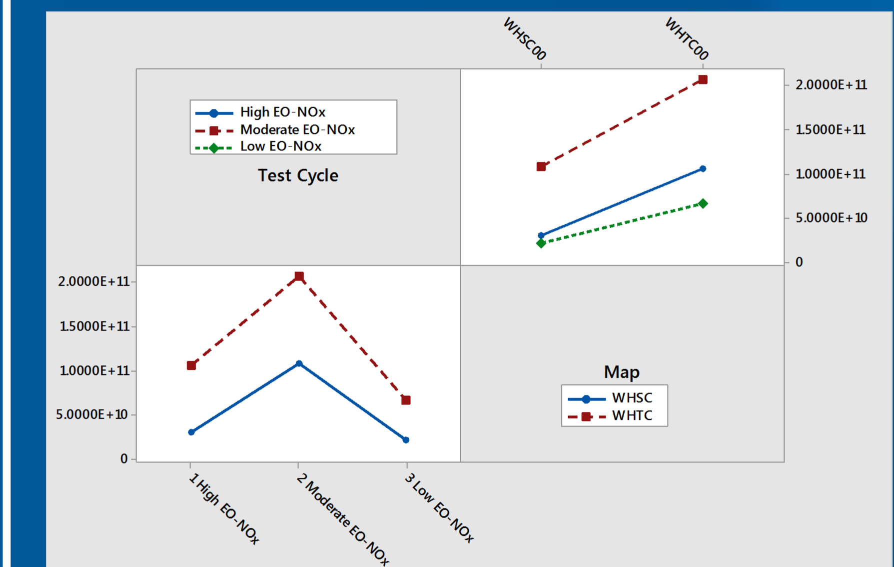


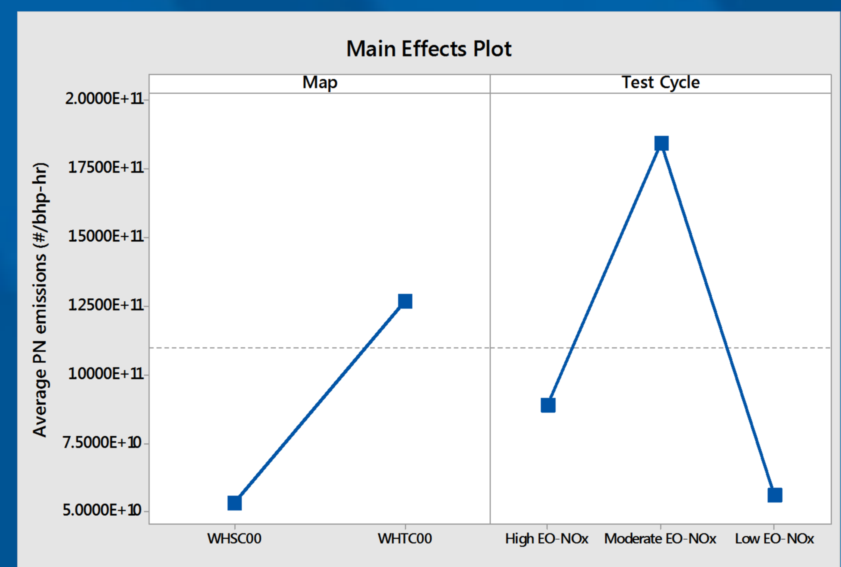
Soot mass accumulation profile for the new DOC+DPF Aftertreatment System over the custom 24 mode pseudo transient steady state cycle



24 Mode Engine Dynamometer Steady State Test Cycle

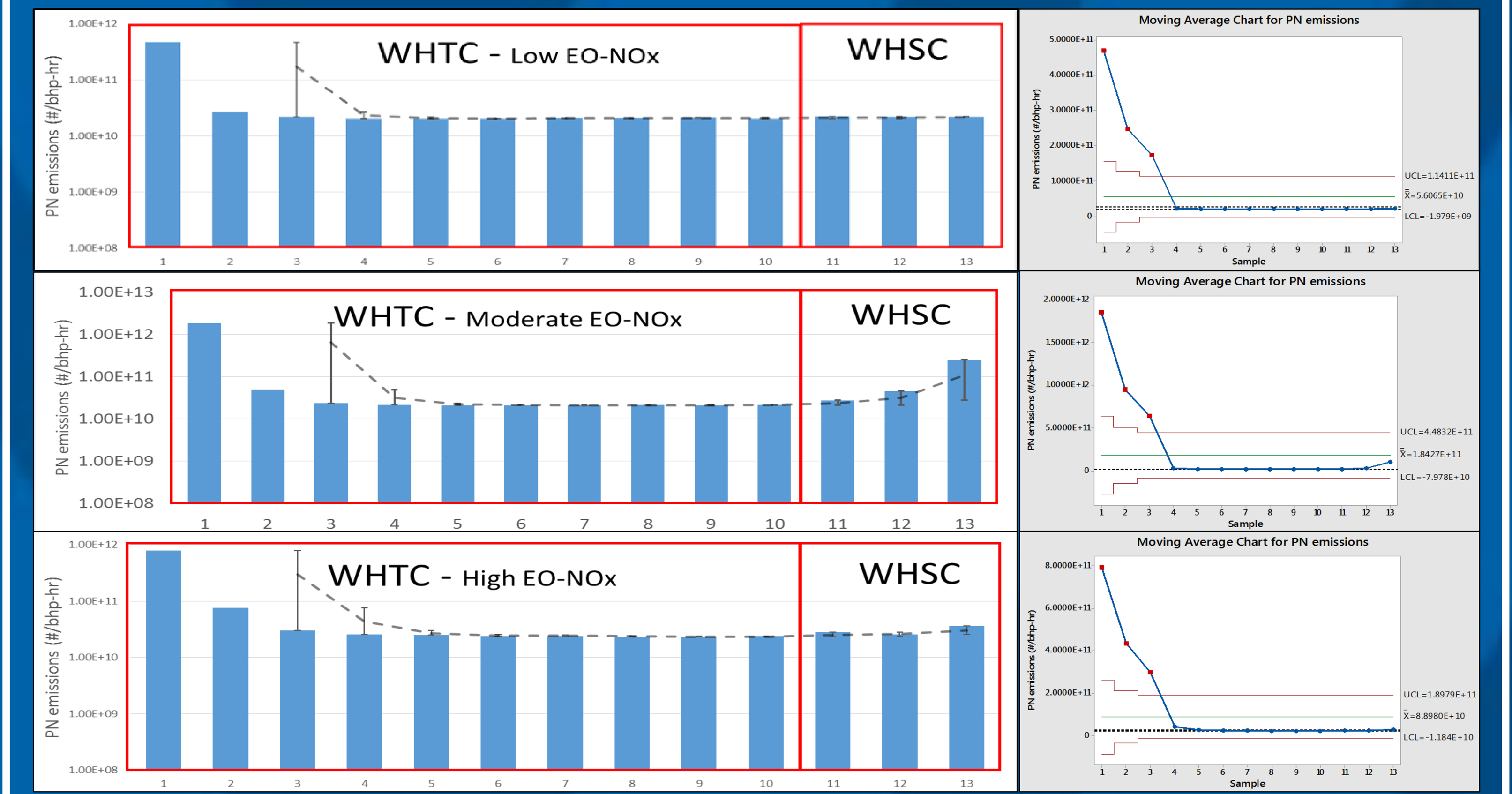
Effect of Engine Calibration Strategies on Brake Specific PN Emissions





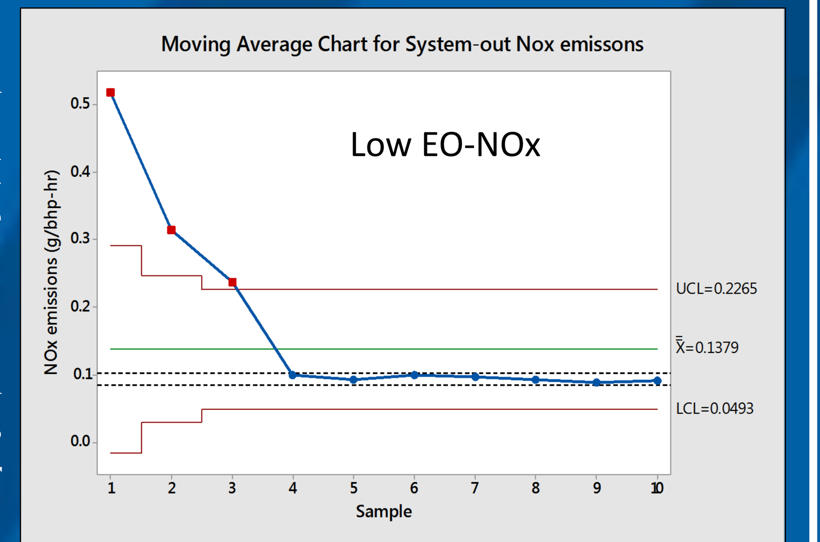
- Average brake specific bsPN emissions during moderate EO-NOx engine operation resulted in the highest level of PN emissions as compared to the others engine operating modes.
- Higher level of bsPN emissions could be attributed towards the combination of significant level of soot loading as well as turbine-out exhaust temperatures which may lead 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



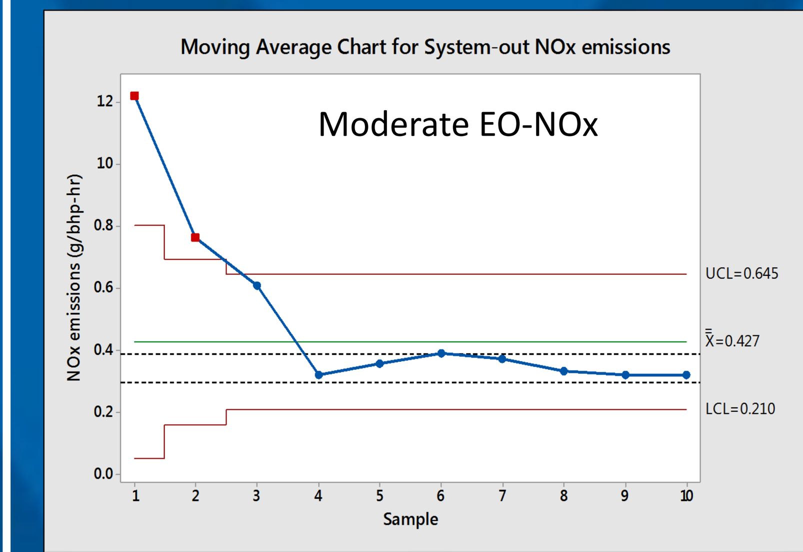
PN and PM Emissions:

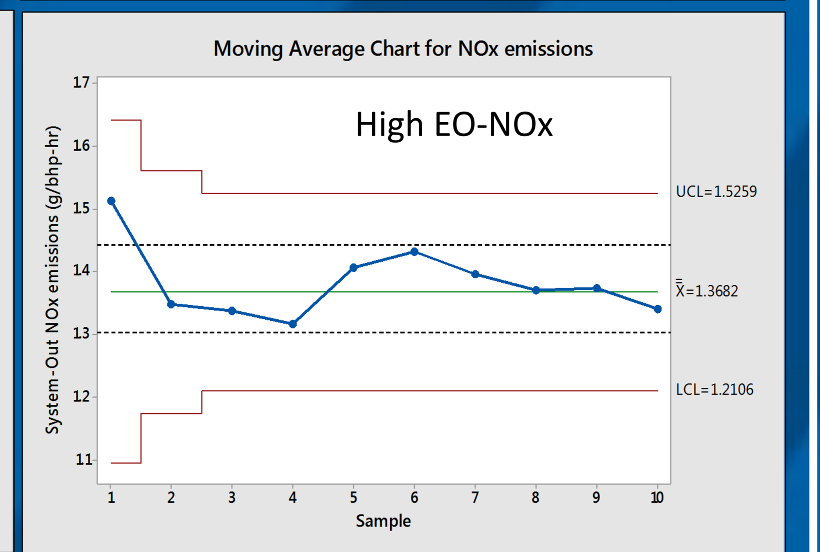
Control charts of the three test sequences showed that the bsPN emissions stabilized after 3 WHTC cycles. However, it was also observed that TPM emissions remained to be stable within the noise level of the process.



NOx Emissions:

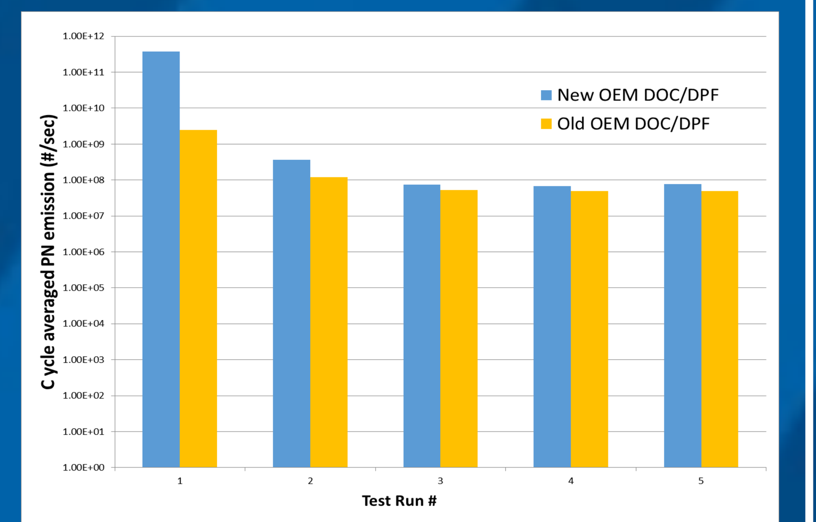
Although tailpipe NOx emissions levels varied over the three engine calibrations, it was observed that the NOx emissions stabilized after 3 WHTC cycles.





Aftertreatment Age:

Significant difference in the magnitude of emissions between older and newer aftertreatment systems was observed, but the PN emissions was observed to be stable after 3 engine test cycles.



Conclusion

- Results show that 3 preconditioning cycles are needed to stabilize both brake specific, PN emissions as well as NOx emissions.
- The test cycle used for the precondition the engine had insignificant effect on the number of cycles needed to stabilize brake specific NOx, PN and TPM emissions.

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