Recalibration of the parSYNC® Particulate Calculation Matrix and Investigations Into PN and PM Reported From Different Emissions Measurement Systems During Chassis Dynamometer Testing of a GDI Vehicle

Authors: Daisy Thomas and Gurdas S. Sandhu

Introduction

Accurate measurement of particulate emissions from vehicles is important. Particulate matter is a physically and chemically heterogeneous substance. The properties of particulate matter are not constant, and depend on many different factors. After their creation, they can be easily affected by external factors and will not maintain the same form; the measured properties of particulate matter are highly dependent upon the sampling methodology.

Time-resolved PM equipment has been developed for research testing. CVS measurements are required for most regulatory testing, but research testing can often use alternative methods, such as direct tailpipe sampling. Additionally, different sampling conditioning systems such as volatile particle removers and hot diluters can be used. There are known to be differences in the reported values when using different methodologies and equipment.

In this poster, the effects of different sample conditioning methods on reported PN and PM values are investigated. The differences in PN and PM values reported from CVS sampling are compared to those from tailpipe sampling, to study different particulate quantification methods. The correlation between PM and PN, and PM and soot are also investigated, to infer the comparability and interchangeability of particulate quantification metrics.

The 3DATX parSYNC offers a particulates sensor for dual PN and PM readout using a combination of three sensors: Scattering, Ionization and Opacity. Each of these sensors is more sensitive to a different type of particulate, so the calculation matrices for PN and PM should be adjusted based on the expected particulate composition. This work outlines the first steps in recalibration of the PN/PM calculation matrix for gasoline direct injection (GDI) vehicles.

Methodology

Experiments were conducted at Ford Motor Company's Vehicle Emissions Research Laboratory (VERL) – a chassis dynamometer test facility. A gasoline direct injection (GDI) test vehicle equipped with three-way catalyst (TWC) but no gasoline particulate filter (GPF) completed a range of test cycles including FTP75, US06 and LA92.

Particulate measurement equipment included:

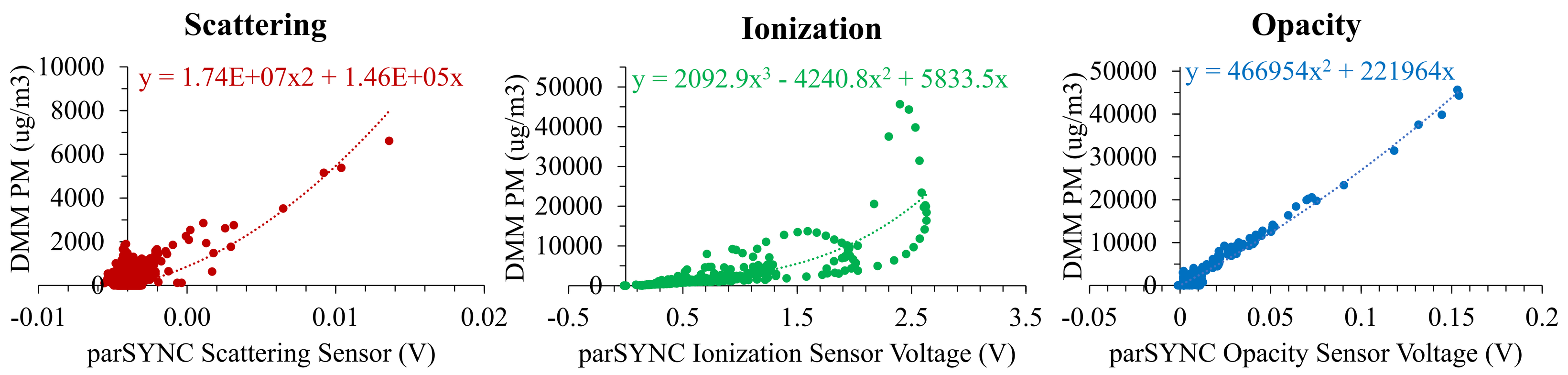
- TSI Engine Exhaust Particle Sizer – EEPS 3090 – for particle number and size distribution (both total PN (>6nm) and 23nm cut-off PN is presented),
- AVL Particle Counter – APC 489 – for particle number,
- Dekati Mass Monitor – DMM-230A – for particle mass,
- AVL Micro Soot Sensor – MSS 483 – for soot mass,
- 3DATX – parSYNC – for particle number and mass.

Additional sample conditioning included:

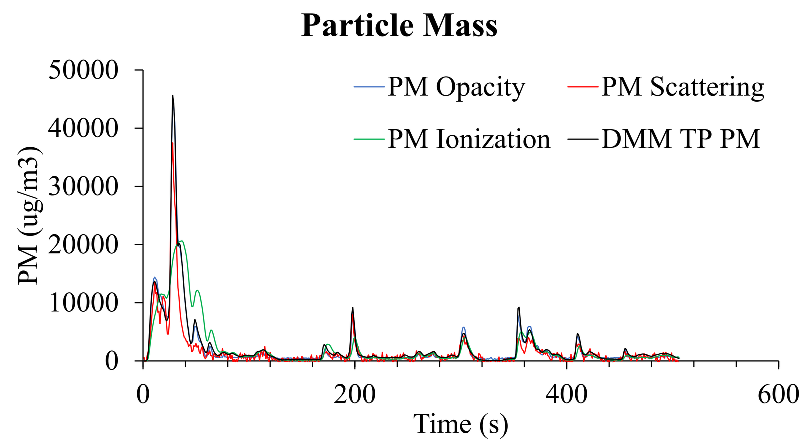
- When sampling at the Tailpipe, the EEPS and DMM were used with a Dekati Engine Exhaust Diluter (DEED) for hot dilution of sample (some VPR effect),
- When sampling from the CVS, no additional conditioning was used,
- The APC was always used with a VPR as per the PMP (note: EEPS is not PMP-compliant).

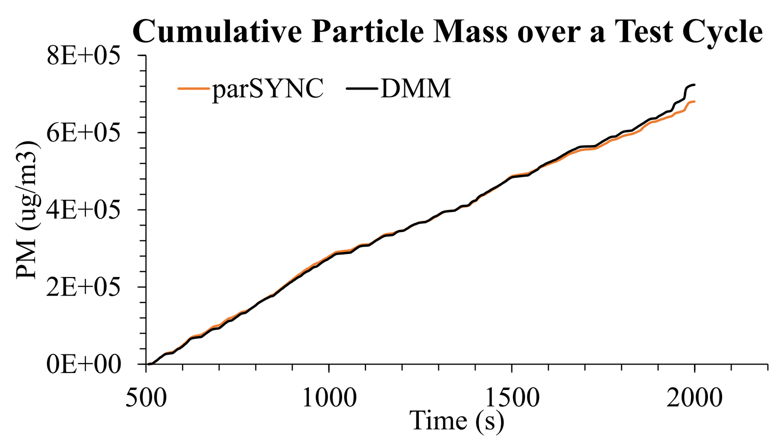
Method to recalibrate the parSYNC PN/PM calculation matrix

To recalibrate the PN/PM calculation matrix, the time-aligned transient tailpipe DMM and EEPS data from a test was individually correlated with each of the three sensor voltage outputs on the parSYNC: Scattering, Ionization and Opacity. E.g.



The coefficients of correlation from the line of best fit were then used as the coefficients for each sensor in the new calculation matrix. The weighting coefficients of each of the three sensors for the overall PN/PM calculation were chosen to maximise the agreement between cumulative cycle values of the new calculated PN/PM and EEPS/DMM respectively, over the test cycle. E.g.

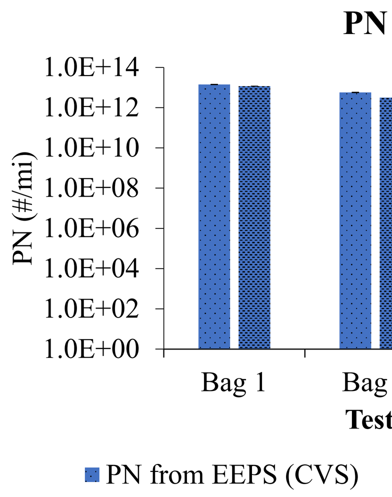


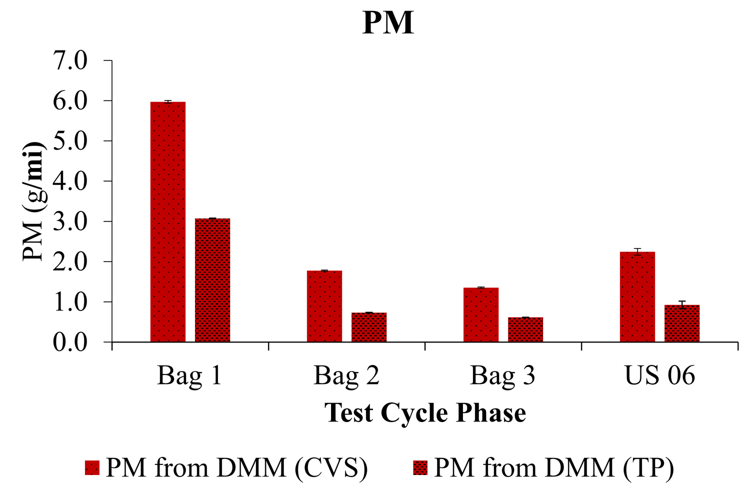


The resulting new matrix was then tested against a different test cycle, to check that it gave reliable results.

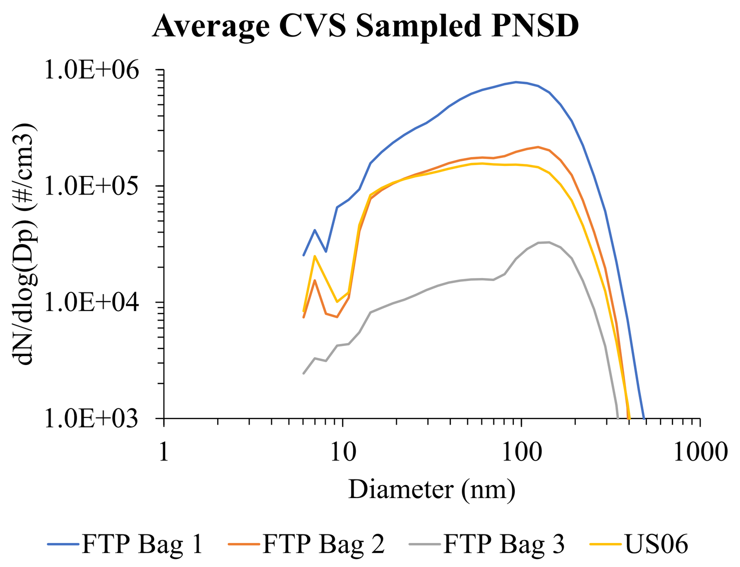
Results – Investigation of Sampling Techniques

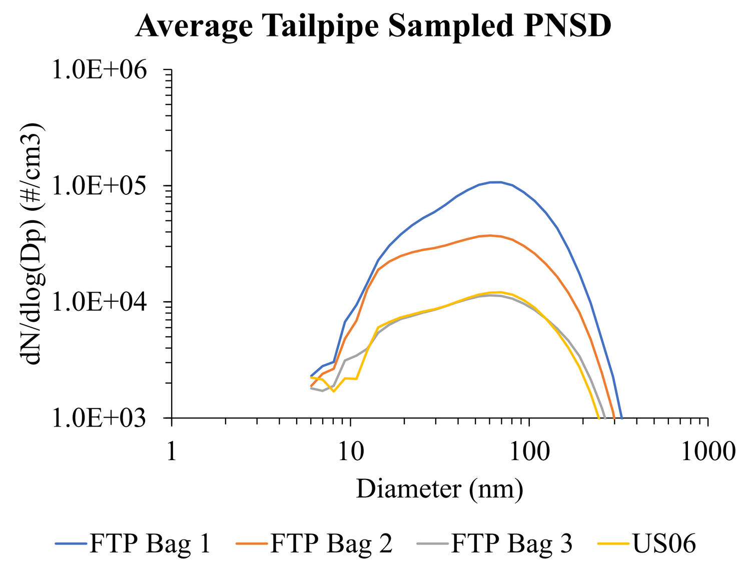
Higher PN and PM concentrations are reported when sampling from the CVS system as opposed to the tailpipe. The DEED diluter at the tailpipe sampling point suppresses nucleation and condensation effects, leading to lower PN and PM values from tailpipe sampling.



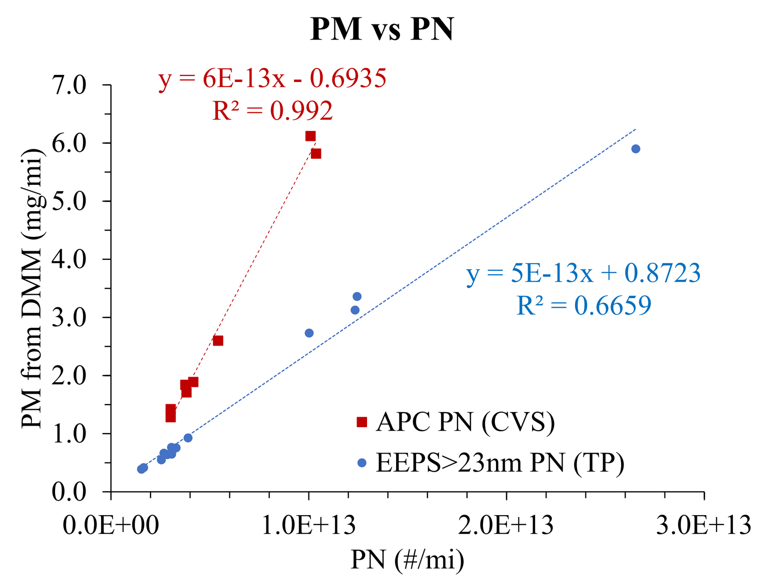


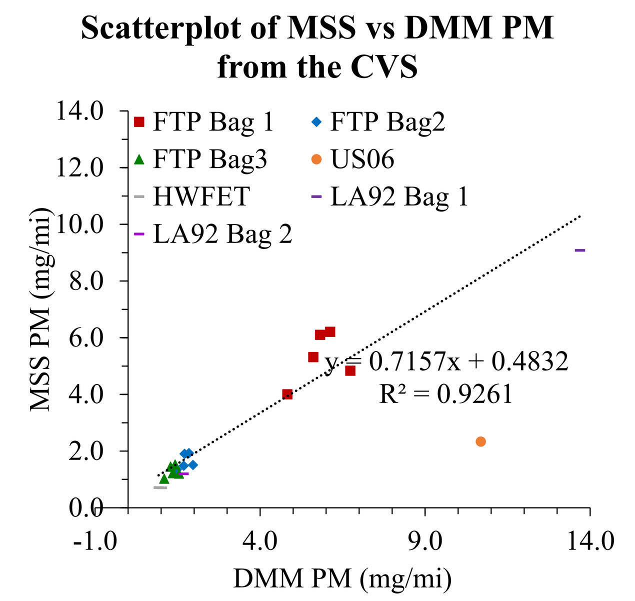
Investigation of the particle number size distribution (PNSD) shows a broader particle diameter range with higher maximum seen from the CVS sampling than tailpipe sampling, likely due to a lack of volatiles removal and additional particle interactions allowed from the CVS tests.





Strong correlations between PM and PN are seen from both tailpipe and CVS sampling methods, indicating good comparability and interchangeability. PM and soot measurements also have strong correlations between individual test cycles, indicating that soot can also be a good predictor of GDI PM under moderate test cycles.

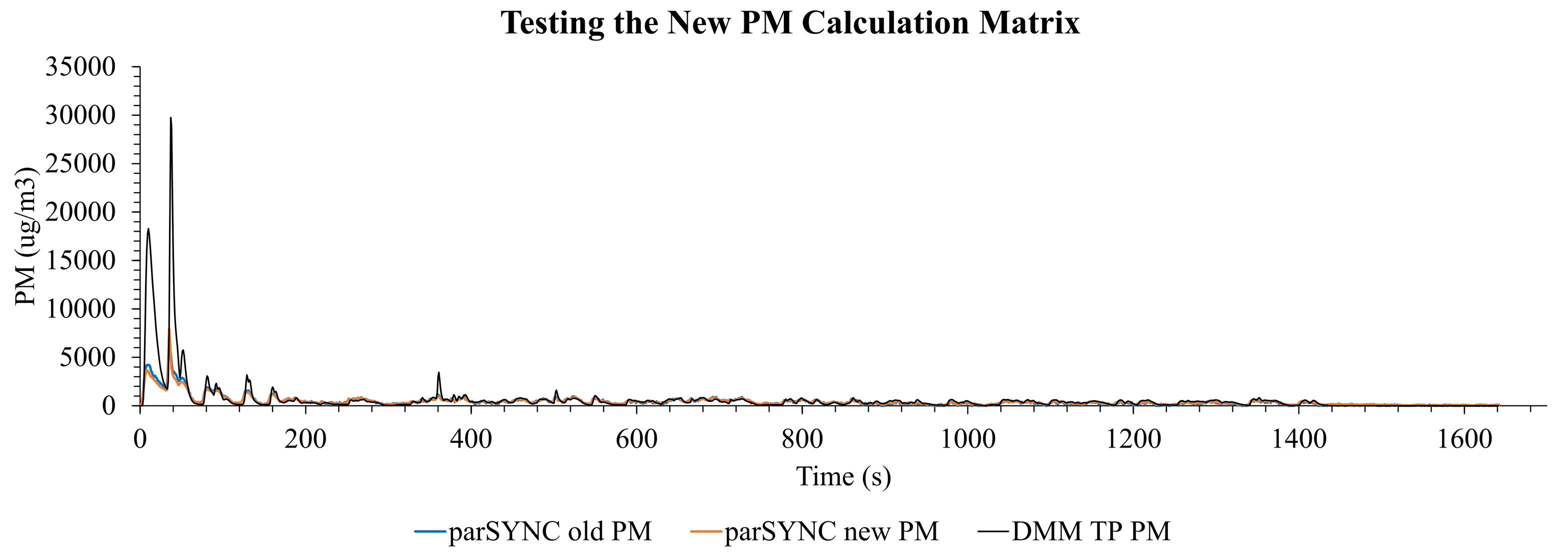




As the parSYNC uses tailpipe sampling, these results highlight the importance of using similar test data for the recalibration of the PN/PM calculation matrix. The following sections will outline the recalibration results for PM.

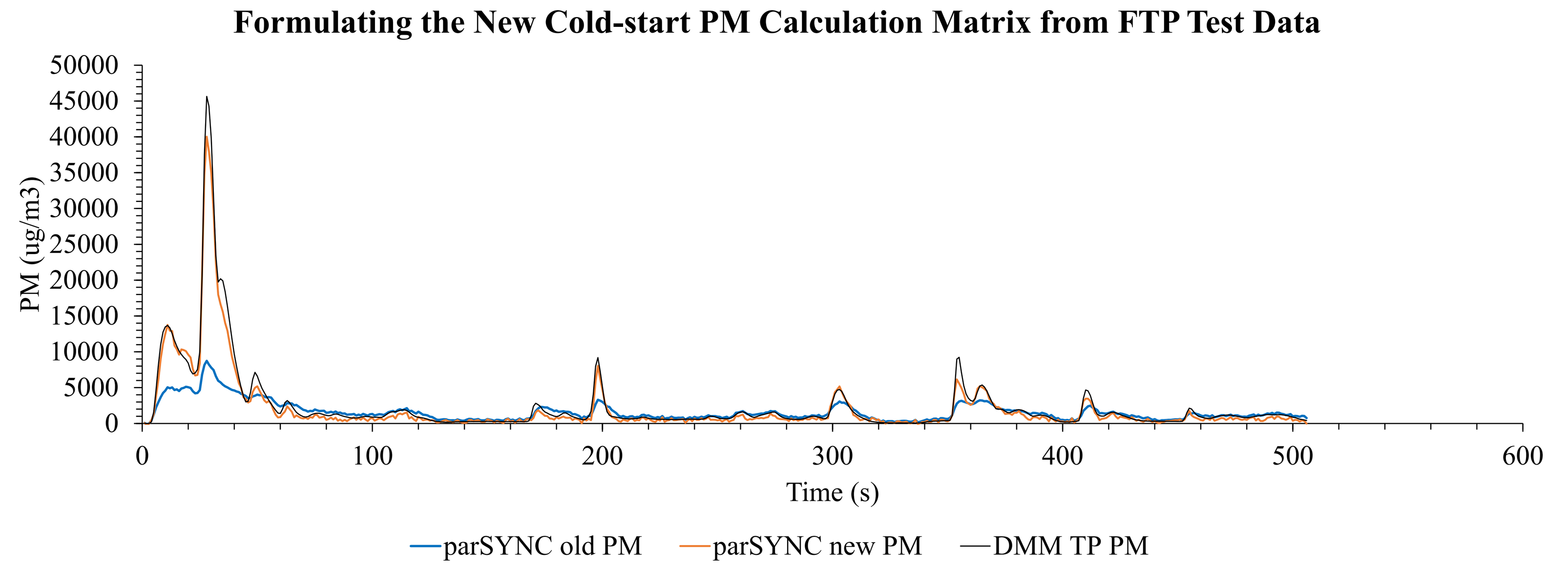
Results – Recalibration of the parSYNC PN/PM matrix

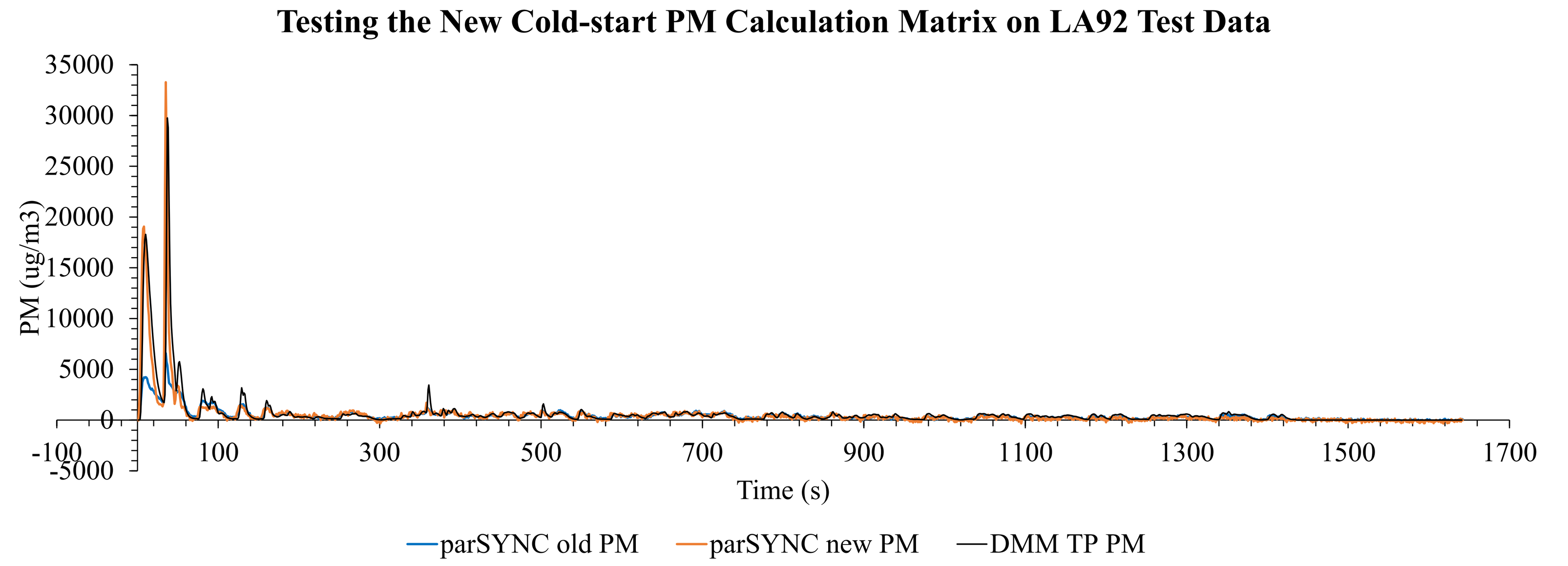
A new matrix calibration based off the data from a cold start FTP75 cycle followed by a US06 cycle did not improve the agreement during cold start drive cycle sections where the greatest difference between parSYNC and tailpipe DMM PM was seen. See example below, where the calculation matrix calibrated from an FTP-US06 test cycle combination was applied to an LA92 test. A different set of cold start calculation matrices were required.



Results: Formulation of a Cold-Start parSYNC PN/PM Matrix

The new cold-start PN/PM calculation matrix improved the agreement between lab equipment and parSYNC tailpipe PM during cold start. See example below, where the calculation matrix formulated from the first section of an FTP test was applied to an LA92 test. More test data is required to further improve the GDI calculation matrix.





Conclusions

1. The reported PN and PM values, as well as PNSD seen, between tailpipe and CVS sampling methods vary over testing, with reported values from CVS sampling methods being higher than those of tailpipe sampling methods.
   - ➢ Particulate matter characteristics are affected by transportation and sampling methods. Care must be taken to consider these methods when analyzing test data
2. Comparison of PN equipment and with PM equipment suggests that the PM/PN ratio is fairly constant between test cycles.
   - ➢ There is good comparability between these two metrics for most test cycles.
3. PM and soot measurements give a fairly constant ratio for most cycles.
   - ➢ Soot can be a good predictor of GDI PM under moderate test cycles.

Points 2 and 3 indicate that one can employ surrogates for PN measurement when the use of PMP solid particle counters is impractical: We can still attain reasonable measurement capabilities with alternative equipment.

4. The calculation matrix for PN and PM from the parSYNC under GDI vehicle testing has been formulated and tested using tailpipe-sampled emission test cycle data. As cold start was the type of driving with greatest divergence from lab equipment, the process used a test section with a large portion of cold start conditions.

The new calculation matrix improves the parSYNC's ability to quantify the particulate emissions from a GDI vehicle. More test data is needed to fully characterize this vehicle type and finalize the PN/PM calculation matrix coefficients.

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