VERY LOW PM MEASUREMENTS FOR LIGHT-DUTY VEHICLES (E-99)

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Abstract

Present motor vehicle particulate matter (PM) emissions measurement regulations (Code of Federal Regulations [CFR] 40 Parts 1065 and 1066) require gravimetric determination of PM collected onto filter media from diluted exhaust. There have been discussions about whether current sampling and measurement practices are sufficiently accurate in quantifying PM at the proposed 3 mg/mi standards, and even more so at the 1 mg/mi PM emissions standards for LEV III light-duty vehicles.

The objective of this research program is to examine modifications to gravimetric PM measurement that preserve the integrity of the method and increase the robustness of the PM measurements, while decreasing the testing variability. For this program, a Lower PM Source vehicle with an emissions rate of <1 mg/mi and a Higher PM Source with an emission rate just below 2 mg/mi were evaluated over a series of tests designed to characterize PM mass emissions for 3-bag Federal Test Procedure (FTP) tests, 4-bag FTP tests, and the US06 test. The tests evaluated cumulative vs. individual bag filter PM collection, different sampling flow rates/filter face velocities (FFVs), and changes in dilution factor (DF) with a partial flow sampling system (PFSS).

Comparisons between different methods did not show statistically significant differences in the PM mass emission rates for most of the conditions, i.e., increased FFV, reduced DF, or combining/cumulative filters. However, it was found that greater mass could be collected on the filter over the course of testing, increasing the signal-to-noise ratio of the method. Additionally it was estimated that the measurement uncertainty (based on a propagation of error analyses) could be reduced by a factor of four between the traditional one filter per phase, FFV=100 and a DF=7, in comparison to a composite 4-bag FTP test, FFV=150 and a DF=5.

The E-99 project revealed several confounding influences for the quantification of PM emissions from vehicles that invite further investigation. These include understanding test-to-test variability, which can exceed 100% (0.1 to 0.5 mg/mi for the Lower PM Source and 1.2 to 2.0 mg/mi for the Higher PM Source) between tests conducted over a 12 month time period, PFSS to CVS comparison where 5-10% absolute bias was reported, characterizing the PFSS dilution factor to identify possibly sources of bias between the CVS and the PFSS, and understanding sample contamination between tests where excessive exhaust temperatures may contribute to PM emissions variability.

Acronyms and Abbreviations

σ…… .....standard deviation
ASTM……American Society for Testing and Materials
ANOVA……Analysis of Variance
API……American Petroleum Institute
APM.....Aerosol Particle Mass analyzer
CARB.....California Air Resources Board
CAST .....Combustion Aerosol STandard
CE-CERT.....College of Engineering-Center for Environmental Research and Technology (University of California, Riverside)
CFO.....critical flow orifice
CFR.....Code of Federal Regulations
CGA .....Compressed Gas Association
cm/s.....centimeters per second
CO .....carbon monoxide
COV .....coefficient of variation
CO_2 .....carbon dioxide
CPC.....condensation particle counter
CVS.....constant volume sampling
DMA .....differential mobility analyzer
DMM.....Dekati Mass Monitor
DOC .....diesel oxidation catalyst
DPF .....diesel particulate filter
DF .....dilution factor
EC .....elemental carbon as defined by NIOSH methods
ECM.....engine control module
EFM .....exhaust flow meter
efuel.....ECM fuel consumption rate
ELPI .....Electrical Low Pressure Impactor PM instrument
EPA.....United States Environmental Protection Agency
EEPS .....Engine Exhaust Particle Sizer
E10 .....10% ethanol in gasoline blend by weight
FFV .....filter face velocity
FID .....flame ionization detector
FTP.....Federal Test Procedure
g/mi .....grams per mile
GDI .....gasoline direct injection
GFM.....gravimetric filter module
i.d. .....inner diameter
inHg.....inches of mercury
IPSD.....integrated particle size distribution
ISO .....International Organization for Standardization
kPa.....kilo Pascal
LDVS .....light duty vehicles
LEV.....Low-Emission Vehicle
lpm .....liters per minute
ms.....milliseconds
MDL.....minimum detection limit

MEL .....Mobile Emissions Laboratory
MFC .....mass flow controller
MSS.....Micro Soot Sensor
NIOSH .....National Institutes of Safety and Health method
NIST.....National Institute for Standards and Technology
NMHC.....non-methane hydrocarbons
NO_x .....nitrogen oxides
OBDII .....On-Board Diagnostics version 2
OC .....organic carbon
o.d.....outer diameter
OEM.....original equipment manufacturer
PDP-CVS .....positive displacement pump - constant volume sampling
PEMS .....Portable Emissions Measurement Systems
PFI.....port fuel injection
PFSS.....partial flow sampling system
PM.....particulate matter
$PM_{2.5}$ .....final particles less than 2.5 µm (50% cut diameter)
PN .....particle number
PS .....particle surface area
PSA .....Pressure Swing Adsorption
PSD .....particle size distribution
PTFE .....polytetrafluoroethylene
QC .....quality control
RPM .....revolutions per minute
SAO.....smooth approach venturi
scfm.....standard cubic feet per minute
SEE .....standard error estimate
SIDI.....spark-ignited direct-injection
TB .....tunnel blank
THC.....total hydrocarbons
TWC.....three way catalyst
UCR .....University of California at Riverside
ULSD .....ultralow sulfur diesel
US06 .....US06 test cycle
VERL .....vehicle emissions research laboratory

Executive Summary

Present motor vehicle particulate matter (PM) emissions measurement regulations (Code of Federal Regulations [CFR] 40 Parts 1065 and 1066) require gravimetric determination of PM collected onto filter media. There have been discussions about whether current sampling and measurement practices are sufficiently accurate in quantifying PM at the upcoming 3 mg/mi standards, and even more so at the 1 mg/mi PM emissions standards for low-emission vehicle (LEV) III light-duty vehicles. Although the PM mass measurement methodologies were improved considerably with the application of 40 CFR Part 1065 to the 2007 PM standards for heavy-duty engines, there is a need to improve understanding of and confidence in mass measurements for light-duty vehicles given the potential of significant impacts on the automotive industry.

CRC's E-99 project was launched to investigate long-standing questions about the measurement of the particulate matter ($PM_{2.5}$) emissions from motor vehicle exhaust at very low levels. The complexity of the effects of multiple parameters on PM mass measurements were such that even basic questions about the accuracy near the lower detection limit, the robustness or stability of the current federal test procedures and the sensitivity of the various measurement parameters have remained unanswered. E-99 was designed as a systematic investigation of key procedures in the current federal method. This included questions about a number of key measurement parameters, such as the following:

1. Does increasing filter face velocity (FFV) decrease variability and improve signal-to-noise while not appreciably altering the measured PM emissions?
2. Does decreasing dilution factor (DF) decrease variability and improve signal-to-noise while not appreciably altering the measured PM emissions?
3. Does collecting cumulative filters over the entire Federal Test Procedure (FTP) or performing and extended 4-bag (as opposed to 3-bag) FTP decrease variability and improve signal-to-noise while not appreciably altering the measured PM emissions?
4. How do practices and measurement accuracies vary over a wide range of laboratories weighing PM filters for low level PM mass measurements of vehicle exhaust?
5. Would partial flow sampling systems (PFSSs) provide advantages in measuring low level PM mass in light duty emissions applications?

Throughout the E-99 project, the focus was better understanding of the sensitivity of the measured $PM_{2.5}$ mass to various procedural changes rather than suggesting modification to current federal methods. Although PM emission rates are presented, this study represents the testing of only two vehicles and was not designed as an emissions study. Any reference to the emission factors should be considered in light of the few vehicles studied.

Program Scope and Experimental Procedures

For this program, a Lower PM Source vehicle (a port fuel injected (PFI) vehicle) with an emissions rate of <1 mg/mi and a Higher PM Source (a gasoline direct injected (GDI) vehicle) with an emission rate just below 2 mg/mi were evaluated over a series of tests utilizing the 3-bag FTP test, 4-bag FTP test, and the US06 cycle. These vehicles were targeted to be representative of the PM emissions levels that could be found for vehicles meeting the upcoming 3 mg/mi and 1 mg/mi standards. The vehicles are not meant to represent the vehicle technology that would be prevalent when these standards are implemented in the future. Testing was conducted in two phases: a screening test phase and a confirmation testing phase. The screening tests were designed around varying several parameters, such as FFV and DF, over different extremes, and using cumulative filters, with the goal of recommending a combination that provides the most PM mass gain, while

providing stable repeatable emissions. The confirmation testing used the conditions deemed optimal based on the screening tests.

The changes in key parameters evaluated in the testing included the following:

- FFV was varied from 100 to 175 cm/sec, including FFVs of 100, 125, 150, and 175 cm/sec.
- Comparisons were made between probes in the constant volume sampler (CVS) where PM was collected cumulatively over the full FTP vs. a probe where PM was collected individually for each FTP bag.
- Comparisons were made between 3-bag and 4-bag FTP tests.
- Three DFs were evaluated: 3, 5, and 7. The changes in DFs were evaluated using a PFSS while the DF in the main CVS tunnel was maintained at 7.

Recommendations that were implemented for the confirmation testing:

- A 3-bag FTP test can provide sufficient filter masses for vehicles with PM emissions level near those of the Higher PM Source (~2 mg/mi).
- A 4-bag FTP test can increase the amount of mass on the vehicle filters closer to those for the Lower PM Source (~0.25 mg/mi).
- It is suggested to limit the FFV to 150 cm/sec.
- It is suggested that the minimum DF should be 5.
- It is suggested that a sufficiently robust and consistent preconditioning procedure be used for the US06 tests.

Results and Conclusions – Emissions Testing

A summary of the results and conclusions of this study are provided as follows. Note that the results primarily focus on the results of the confirmation testing, where the most extensive testing was conducted under conditions considered to be most advantageous for PM mass measurement. In some cases the screening data was also used to help explain observations. This will be noted when used; otherwise, the main observations were from the confirmation testing phase.

General Confirmation Testing Observations

This section discusses the general observations relating to PM emission rates and filter masses. A summary of these results is provided in Figure ES-1. These observations are primarily derived from the confirmation portion of the testing, which represented the most robust data set for consistent evaluations.

The following observations were made regarding PM mass emissions (mg/mi):

- The confirmation PM emissions agreed closely for the Higher PM Source FTP tests; the average of six tests ranged between 1.9 mg/mi to 2.0 mg/mi (with individual tests ranging from 1.7 to 2.1 mg/mi) for the various PM probes. The US06 tests were more varied; the average ranged from 2.0 mg/mi to 2.4 mg/mi (with individual tests ranging from 1.9 g/mi to 2.6 g/mi) for the different probes (Figure ES-1 caption defines probe as five different PM sampling arrangements).
- The confirmation PM emissions for the Lower PM Source had a much lower overall PM emission levels, as well as higher relative errors between the different probes. The Lower PM Source's emission rate averaged from 0.09 to 0.11 mg/mi (with individual tests ranging from 0.04 to 0.24 mg/mi) for the FTP test and 0.19 to 0.24 mg/mi (with individual tests ranging from 0.10 to 0.30 mg/mi) for the US06 test. The averaged difference between each probes was 0.02 mg/mi for the FTP tests, but the variability between tests was much larger and ranged from 0.04 to 0.24 mg/mi. The low mean average difference suggests the Lower PM

Source FTP results were on average repeatable and the mean differences were small, but the individual tests demonstrated much higher variability.

- The statistically different mean shown by the PFSS during FTP testing compared to the CVS for the Higher PM Source may be due to differences in measurement approach and not differences in lower DF and higher FFV (p-values less than 0.005 for all but probe D100i at 95% confidence).

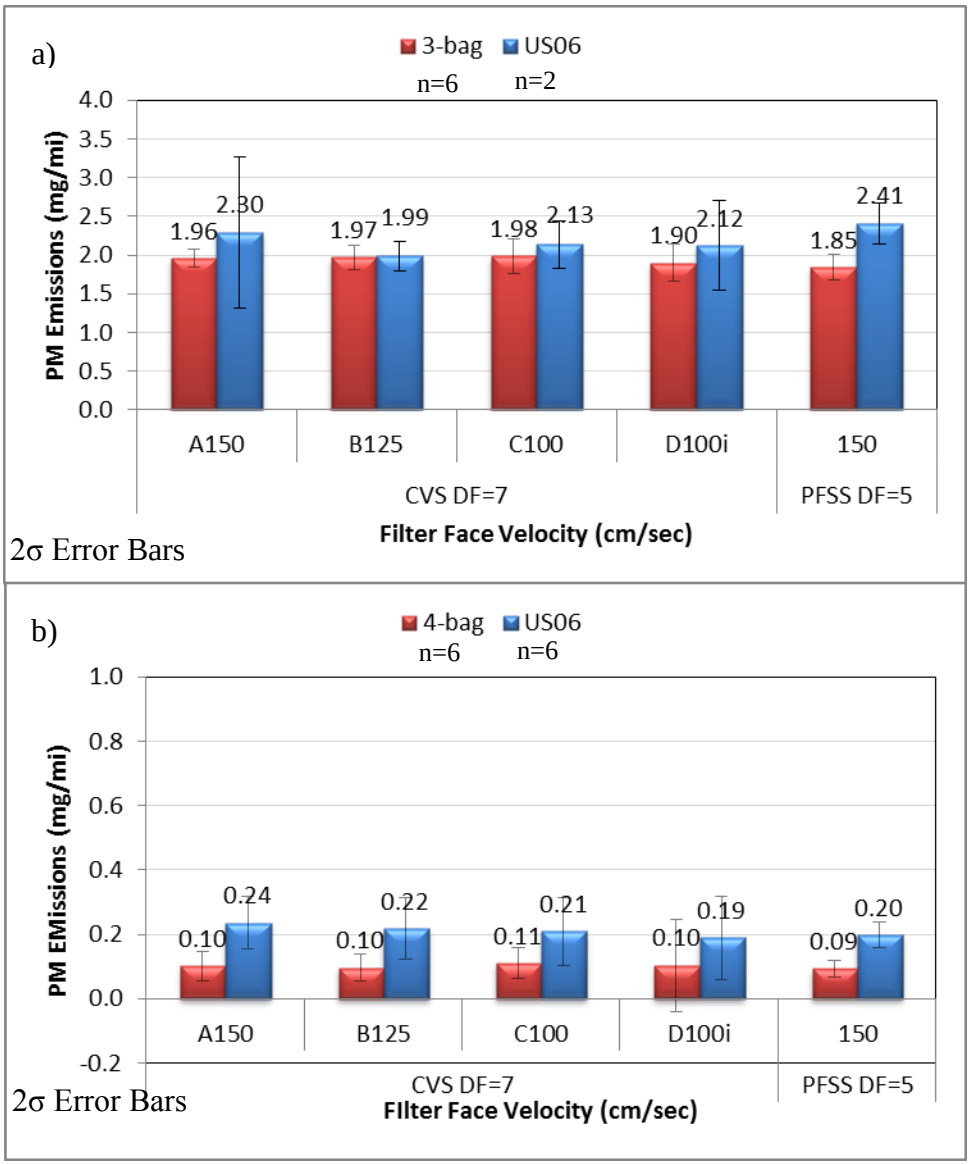

Figure ES-1. PM emission rates for the CVS and PFSS probes (a) High, (b) Lower PM Source

[1] Sample size is n=6 for the FTP tests and 7 for the lower PM Source US06 and 3 for the higher PM Source US06 tests. Data are corrected for background PM. Error bars represent two standard deviation (2σ). The labels A150, B125, C100, and D100i, denote different sampling probes (i.e., A, B, C, and D) along with the associated FFV (i.e., 100, 125, and 150). The D100i represents the probe D system with individual filters per phase. The others represent combined filters. The Higher PM Source GDI vehicle was unable to maintain the US06 trace, thus the sample size was reduced to n=2 and the data variability may be higher due to the operational difficulties. The higher PM Source US06 tests do show good comparison data between PM samplers.

The following observations were made regarding filter weights (µg/filter):

- The filter weights increased in proportion with increased FFVs and lower DFs for all test cycles and both vehicles. Thus, the signal-to-noise ratio improved at higher FFVs and lower

DFs. This would lower measurement uncertainty that depends on the PM method's lower detection limits.

- The Higher PM Source filter weights were well above the tunnel blank (TB) levels and varied from 205 μg for the PFSS and to 417 μg for the cumulative filter samples.
- The Lower PM Source filter weights varied from 26 μg for the PFSS to 39 μg for the cumulative filter samples. They were close to the CVS TB average of 5±4 μg and the PFSS TB average of 1±1 μg measured during the confirmation testing.
- The US06 test cycle showed lower filter weights than the FTP test cycle partly due to the absence of the cold start, shorter length cycle, and because it has fewer transients than the FTP test.

The following overall observations were made in terms of the physical properties of the PM:

- The impacts of the modified PM sampling conditions were evaluated where PM composition and particle size distribution (PSD) varied between the test vehicles and cycles.
- During confirmation testing, the PM composition for both vehicles were mostly soot for the FTP test cycle and about 50% soot for the US06 tests cycles.
- The cycle averaged PSD for the US06 test cycles showed two orders of higher number concentration peak at 10 nm particle diameter compared to the FTP cycle. The Higher PM Source showed a shift in the peak mass averaged concentration from a diameter of 105 nm (FTP cycle) to 80 nm (US06 cycle) and from 105 nm (FTP) to 10 nm (US06) for the Lower PM Source. The change in peak diameters for the mass average PSD would change the theoretical filtration efficiency as FFV varies.
- The PM composition and PSD varied over the course of testing. These variances show the robustness of the study to consider real impacts of modifying sampling conditions while the PM physical properties are varied.

It should be noted that the results of this study are designed to represent optimal conditions for PM mass measurement, including the use of dedicated vehicles, the same fuel (E10), a single test site at one facility, the use of one driver, ideal low dilution factors of 7:1, dedicated PM probe hardware, the same environmental conditions, no intermittent contamination from high emitter vehicle testing (contamination), the same PM filter weigh room / filter handling procedures, etc. The variability of PM measurements in the real world would inevitably be higher than the variabilities found in this study, where multiple facilities, different vehicle architectures, different drivers, different PM probe suppliers, sites exposed to different fuels (gas, diesel, CNG, E85, etc.), carry over from higher emitting vehicles, higher DF's up to 20 or more (hybrids), different environments, varying blank test (or background PM) corrections, etc. would be encountered.

The Impact of Filter Face Velocity, Dilution Factor, the Partial Flow Sampling System, and Combining or Collecting Cumulative Filters, and 3-bag vs. 4-bag FTPs

This section discusses the findings related to varying the sampling conditions in terms of FFV, DF, PFSS, cumulative vs. individual filters, and 3-bag vs. 4-bag FTPs. Note that the comparisons are primarily derived from the confirmation testing portion of the program. The confirmation data represented the most robust data set for comparisons, except as noted.

Findings regarding filter face velocity include:

- The results showed that comparisons between mean differences for flows varying from 100 to 175 cm/s were not statistically significant for most cases. These results generally suggest that increasing the FFV from 100 to 175 does not have a significant impact on the mean mass emission rates for the Higher and Lower PM Sources.

- The PM net filter weights increased for higher FFV compared to lower FFV, which increases the signal (i.e., filter mass). The corresponding overall signal-to-noise ratio was affected, although the f-test did not support a statistical improvement in the variance.
- At a FFV of 175 cm/sec. in the screening tests, some tests of the higher emitter showed evidence that FFV filter overloading could occur.

Findings regarding dilution factor and the PFSS include:

- Comparisons were made between DF=5 and DF=7, where a PFSS was used for the DF=5 and CVS measurements were used for the DF=7.
- For the Lower PM Source tests, in general, there were no differences that were statistically significant at a greater than 95% confidence level for the 4-bag FTP or US06 tests.
- The Higher PM Source showed more mixed results with the FTP tests; they showed a statistically significant difference in means at a 95% confidence level for the different DFs and the US06 tests showed no statistical differences for the different DFs. The US06 testing had larger variability and fewer samples (n=2) due to testing complications.
- The Higher PM Source mean emissions showed a low relative error rate of between -2.7% and -5.9% between the PFSS (DF=5 FFV=150) and the CVS system. A relative error of 5% is a reasonable and relatively small error considering the 20% variation in PM measurements between different laboratories reported by others during PM mass and number cross lab correlations.
- It should be noted that although statistically significant differences in means were found, the differences were relatively small and could be attributed to errors in the exhaust flow, proportionality, and other PFSS details. These possible sources of bias between the CVS and PFSS sampler, and the low mean in relative errors suggest that the lower DF may not be altering the measurement methods.
- The f-test p-values for most of the comparison cases were greater than 0.05, suggesting that the PFSS does not have a statistically lower variability compared to the flow-weighted CVS probes with a FFV from 150 to 100, or compared to the individually collected filters.
- The TB (i.e. TB = sampling on a filter over the course of an FTP with the engine off) results for the PFSS were lower than the CVS TB system (1 µg vs 5 µg) where the f-test suggests there is no difference in the variability between the CVS and the PFSS for any of the flow conditions and DFs evaluated. This suggests the impact of the PFSS's lower TB was not a significant influence on the PFSS performance over the CVS method.
- Tests were also conducted at a DF=3 during the screening portion of the study, but results indicated that at this DF, filter overloading could occur under different sampling conditions with the vehicles selected.

Findings regarding combining filters include:

- For the combined filters, the main comparisons were between CVS probes where PM was collected cumulatively over the full FTP vs. a probe where PM was collected individually for each FTP bag.
- Combined filters have the advantage of collecting more PM mass on a single filter, but have the disadvantage of reduced flow rate for some bags in order to flow-weight the accumulated PM mass as needed for the proper emission calculations.
- The FTP Lower and Higher PM Source tests did not show a statistical difference in means for cumulative filters compared to the filters collected individually by bag.
- The signal-to-noise ratio (as represented by the filter mass) did not necessarily improve for the combined filters. Typically, the filter mass collected for the cumulative filters was

reduced by the flow-weighting conditions for the single phase filter when compared to the filter masses for all of the individual FTP bags added together.

- Although the signal did not increase, the variability in the single filter method is statistically lower than for the multiple filter measurement for the Lower PM Source on the 4-bag FTP. This was confirmed for both the screening and confirmation testing portions of the project. This does suggest the signal-to-noise ratio could be improved by reducing the noise part of the ratio.

Findings regarding zero level uncertainty and method improvements:

- *Theoretical uncertainty calculation*: If the combined conditions of composite filters, 150 FFV, and lower DF=5 are utilized with a 4-bag FTP, the improvement in filter weighing / sampling uncertainty could be reduced by a factor of 4.5 compared to the traditional individual filter 3-bag FTP (1 filter per phase), FFV=100, and a minimum DF=7. The extent to which this is realized in the total PM uncertainty depends on whether the total is dominated by filter weighing / sampling or by other factors, such as driver, vehicle, or environmental variability.

PM Filter Survey

A filter survey was performed to evaluate laboratories' ability to weigh a Teflon™ filter, estimate its uncertainty, and to consider practices that may lower uncertainty in the weighing process. Thirteen laboratories across North America, representing industry, agencies, research institutes, and academic institutes, responded to the survey, and eleven laboratories providing filter data. The survey included raw data on quality control checks performed by each laboratory, as well as, information relating to elements that might influence the weighing process, such as environment (moisture, temperature control, etc.), equipment (micro balance, etc.), methods and procedures (human vs. robot, direct read vs. double substitution, etc.), and quality control and assurance (reference checks, etc.). Selected results from the filter survey include:

Summary of observations include are presented below for the Teflon™ filter:

- The *reference* filter variability (one standard deviation), within a given day over periods as short as one hour, ranged from 0.61 µg to 5.0 µg for the 5th and 95th percentiles and 2.0 µg for the 50th percentile (n>40,000 weights and 317 reference objects).
- *Reference* filters were found to gain weight on the order of 0.17 to 0.56 µg per day (50th percentile) and 0.8 to 1.8 µg per day (95th percentile). Metal reference objects didn't gain weight. This suggests some type of gaseous phase adsorption artifact occurring within the micro balance area.
- Robotically weighed *reference* filters showed lower variability (0.8±0.3 µg) compared to filters manually weighed.
- Robotically weighed *reference* filters also showed a much lower mass gain per touch at 0.01 µg/event.
- *Tunnel blank* mean biases (n=615) were much higher than the reference filter mean bias, ranging from 1.1, 2.8, and 13.0 µg, for the 5th, 50th, and 95th percentile.
- Robotically weighted *tunnel blanks* also had high mean biases similar to manually weighted filters. Thus, the advantages of robotically weighed filters were lost for all but one laboratory that was able to maintain a TB mean bias and single standard deviation of 1.0±0.2 µg (n=80).
- The higher TB compared to the reference blank suggests that the sample collection system is a relatively significant contamination source for Teflon™ gravimetric filters.
- Robotic filter weighing appears to be one element that can reduce filter weighing variability, as shown by the reference filter, this may needs to be combined with other 'best filter

measurement practices', such as proper filter handling before, during, and after emissions testing, storage filter media, etc. in order to achieve consistently low TB contamination also.

- Previous research at University of California Riverside (UCR) has shown hot TBs (200°C) in a diesel tunnel have higher and more variable PM artifact contribution compared to cold TB tests. Thus, the cold TB values presented may be conservative in comparison to the hot conditions of the sample systems during PM emissions testing.
- The cold TB uncertainty (a function of the single standard deviation) at the 50th percentile was 2.8 µg and on average was 3.6 µg for all the laboratories pooled together. The single standard deviation is the basis for characterizing filter sampling uncertainty where either 2σ or 3σ sigma are utilized.

General Screening and Confirmation Testing Observations

The screening results were used primarily for selection and recommendations of the confirmation FFV and DF conditions, but unique observations were found. This summary lists the highlighted observations for the full testing program.

- The Lower PM Source emissions variability was noticeably large (from 0.01 to 0.5 mg/mi) between the screening and confirmation testing. This may be due to environmental conditions, but the gaseous emissions did not show the same level of variability.
- The lower PM Source showed a relatively constant soot emissions rate of about 0.1 mg/mi for both the screening and confirmation testing where the volatile organics varied from test to test. The EC composition fraction varied from 0.22 to 0.97 with an average of 0.67 for the FTP test cycle. The PM emission rate at the 0.22 fraction of EC was the highest emission rate reported at 0.5 mg/mi. This suggests the contribution of test-to-test variability may be a result of volatile organic PM for the Lower PM Source.
- The Higher PM Source also showed a relatively large variability (~2 times from 1.2 to 2.1 mg/mi); most of this variability appeared to be vehicle related but it could be due to environmental conditions as well.
- The PM emissions appear to drift during the screening phase; however, t-tests do not indicate this drift to be outside the scope of natural variability. During the confirmation testing upon which the major study conclusions are based, the vehicles demonstrated more stabilized PM emissions.

Future work

The E-99 project revealed several confounding influences for the quantification of vehicle PM emissions that suggest areas for further investigation. These include understanding test-to-test variability, which could exceed 100% between tests conducted over a 12 month time period, PFSS to CVS comparison where 5-10% absolute bias was reported, characterizing PFSS dilution factors to identify possible sources of bias between CVS and PFSS, and understanding sample contamination between tests where excessive exhaust temperatures may contribute to PM emissions variability. To address these issues future tests should evaluate differences between different PFSS, noise sources, PFSS and CVS tunnel conditioning, sensitivity to exhaust flow measurement, sample proportionality issues, sample proportionality modeling, PFSS advantages and disadvantages, overall improvements recommended for both CVS and PFSS.

1 Introduction

Present motor vehicle particulate matter (PM) mass emissions measurement regulations (Code of Federal Regulations [CFR] 40 Parts 1065 and 1066) require gravimetric determination of PM collected onto filter media from diluted exhaust. These regulations were initially put in place to address issues of making PM measurements for the 2007 PM standards for heavy-duty engines (HDEs), at which point diesel particulate filters (DPFs) were implemented. For the 2007 HDE PM standards, artifact and blank levels represented only about 10% of the standard when changes to the gravimetric method were implemented in 40 CFR Part 1065, however. A previous study, E-66, [1, 2, 3] conducted a comprehensive investigation of PM measurement at these low mass emission levels, but the focus at that time was on heavy-duty applications.

Reductions to PM emissions standards are now also being implemented for light-duty vehicles (LDVs). The PM emission standards for LDVs will be lowered to 3 mg/mi for the United States Environmental Protection Agency (EPA) Tier 3 and the California Lower Emission Vehicle (LEV) III standard by 2017 (3 mg/mile), with an additional reduction to 1 mg/mi expected in 2025 as part of the California LEV III requirements. While the 2007 changes to the PM measurement methodology considerably improved measurement practices, there is a remaining need to improve the understanding and confidence in mass measurements for LDVs, given the implementation of these new standards. Currently, the protocol for the light-duty Part 1066 refers to the heavy-duty Part 1065 for most PM measurement parameters, even though equipment in light-duty laboratories are not necessarily the same as in a heavy duty laboratory. For example, most heavy-duty laboratories have secondary dilution tunnels to manage dilution factor (DF), filter face temperature, and condensation. These tunnels are not traditionally used for LDV testing. In addition, the higher water content of gasoline vehicles' exhaust makes condensation a bigger consideration in terms of exhaust dilution and dilution temperatures. There have also been discussions about whether current sampling and measurement practices are sufficiently accurate in quantifying PM at the proposed 3 mg/mi standards, and even more so at the 1 mg/mi PM emissions standards for LEV III LDVs. Additionally, there is interest in understanding how blank and artifact levels may contribute to the actual PM measurements at such low levels.

A number of strategies have been suggested that could further improve the measurement of PM mass at low levels. Increasing the filter face velocity (FFV) is one method for increasing PM mass levels. Currently, the filter face velocity based on 1065 is 100 centimeters per second (cm/s), which represents approximately 60 liters per minute (lpm). Increasing FFV has been shown to reduce filter efficiency based on prediction models at the University of Minnesota, but it is unknown what the real filter efficiency will be. When Swanson and Kittelson [4] examined the dependence of filter PM on face velocity using the vapor saturation ratio and the gas/particle ratio, they concluded that high face velocity minimizes adsorption artifacts (similar to the conclusions reached in the CRC E-66 study), but it can also increase semivolatile PM losses (desorption). Thus, the results from this project will be informative in helping understand adsorption and desorption for the PM Sources selected and FFV utilized.

Lowering the DF during sampling is another strategy to increase the mass collected on a filter. Although it is desirable to reduce DFs, this approach raises the possibility of increased water condensation and other artifacts. Also, DFs in a constant volume sampler (CVS) for LDVs tend to be higher than those for heavy-duty applications. DF is a particularly important parameter for phases with lighter loads/lower exhaust flows and lower PM emissions.

Combining filters is another method to increase the mass collected on the filter. A single combined filter approach was examined by Andersson et al. [5], but using different TX40 filter media. They found that a relatively low coefficient of variation (COV) of 15% could be obtained for exhaust PM levels of ~1 mg/mile using this combined filter method. Maricq et al. [6] also suggested that use of a single filter can reduce both the magnitude of the artifacts and uncertainty. Other strategies for improving PM mass emission measurements include using more advanced weighing strategies, trying to reduce or quantify the artifact contribution, and utilizing real-time or other measurement methods or methodologies. These topics are discussed in greater detail in Appendix A.

1.1 Objective

The objective of this program is to examine modifications to gravimetric PM measurement that preserve the integrity of the method (i.e., both solid and semivolatile PM), but could increase the robustness of PM measurements and decrease testing variability. The primary focus of this study is evaluation of current methods, along with potential improvements in sampling and other measurement parameters. This will provide information to characterize the fundamental limitations of the current gravimetric PM method and its application for LDV applications. Target questions for key measurement parameters include the following:

1. Does increasing FFV decrease variability and improve signal-to-noise ratio while not appreciably altering the measured PM emissions?
2. Does decreasing DF decrease variability and improve signal-to-noise ratio while not appreciably altering the measured PM emissions?
3. Does collecting cumulative filters over the entire FTP or performing an extended 4-bag (as opposed to 3-bag) FTP decrease variability and improve signal-to-noise ratio while not appreciably altering the measured PM emissions?
4. How do practices and measurement accuracies vary over a wide range of laboratories weighing PM filters for low level PM mass measurements of vehicle exhaust?
5. Would PFSSs provide advantages in measuring low level PM mass in light-duty emissions applications?

This program was designed in two different phases. The initial phase was a screening study that evaluated a wide range of FFVs, DFs, and combinations of filters. The second (main) phase of the study conducted more extensive testing under a set of recommended conditions that appeared to be the most promising as determined during the screening study. The changes in key parameters in the testing included the following:

- FFV was varied from 100 to 175 cm/sec, including FFVs of 100, 125, 150, and 175 cm/sec.
- Comparisons were made between probes in the CVS where PM was collected cumulatively over the full FTP vs. a probe where PM was collected individually for each FTP bag.
- Comparisons were made between 3-bag and 4-bag FTP tests.
- Three DFs were evaluated: 3, 5, and 7. The changes in DFs were evaluated using a PFSS while the DF in the main CVS tunnel was maintained at 7.

1.2 Report overview

Two vehicles were used in this study: a port fuel injected (PFI) gasoline vehicle with a PM emission rate below 1 mg/mi, which was termed the Lower PM Source, and a gasoline direct injection vehicle (GDI) with a PM emission rate around 2 mg/mi, which was termed the Higher PM Source. Additional measurements were also made for selected tests with several different real-time instruments to help characterize each vehicle's PM composition, size distribution, and other chemical/physical attributes unique. In addition, thirteen laboratories across North America were surveyed to evaluate their ability to weigh a filter, quantify its uncertainty, and to consider practices that may lower uncertainty in the weighing process. While this program will provide some evaluation of the methods utilized in 40 CFR 1065 and 1066, the goal of this program is not to suggest modification of these regulations, but rather to determine if changes in 1065 and 1066 might prove beneficial.

This report describes the experimental approach, presents the vehicle testing and filter survey results, and provides analyses of the data in the context of the fundamental limitations of the current gravimetric PM method and the ability to improve this method with different sampling conditions. The report is organized into sections as follows:

- *Experimental Approach* – This section describes the experimental procedures used in vehicle testing, including PM samplers, emissions measurements, and data analysis methodologies. This section also provides a more detailed discussion of the screening test results and what recommendations from the screening test were incorporated into the confirmation part of the E-99 project.
- *Results vehicle testing* – This section discusses the results of the main portion of the vehicle testing and includes analyses of those results. This section focuses primarily on the results from the confirmation testing portion of the program, which represented the most robust and consistent data set in evaluating the PM measurement methods and making comparisons between the different sampling methods.
- *Filter survey* – This section discusses the methodologies used in the filter weighing survey and the survey results regarding the variabilities in the fundamental filter weighing process and differences in weighing procedures between laboratories.
- *Summary and conclusions* – This section summarizes the results of the study and any conclusions about potential improvements/limitations in current PM measurement methods. A brief mention of future work to help understand PM emissions from light-duty vehicles is included as well.

2 Experimental approach

The vehicle testing included two main testing sections: 1) screening tests and 2) confirmation tests. The following experimental section covers the details of the approach, analysis, and conditions for both vehicle testing phases of this project. Some results are presented in the screening subsection of this section to support the recommendations of the confirmation testing.

2.1 Test vehicles

The test vehicles used for both phases of this program were targeted to be one near 3 mg/mi vehicle and one less than 1 mg/mi vehicle. Several GDI vehicles were tested but found to have emissions greater than 3 mg/mi and were thus not selected for this testing program. These vehicle results are in the appendix. The near 3 mg/mi PM Source selected was a Ford Escape, and the less than 1 mg/mi vehicle was a Honda Accord (see Table 2-1). The Higher PM Source (GDI vehicle) had a PM emission rate around 2 mg/mi and the Lower PM Source (PFI vehicle) had a PM emission rate around 0.25 mg/mi. These vehicles were selected based on results showing PM mass emissions that were relatively repeatable and around the emission level desired for this program. The Ford Escape had 25,678 accumulated miles at the time testing began and was equipped with a turbo charger. The Honda Accord had 31,144 miles accumulated at the time testing began and was naturally aspirated (see Table 2-1).

The test vehicles were obtained from a local rental agency and utilized commercial E10 gasoline fuel. Three test cycles were utilized: the 3-bag Federal Test Procedure (FTP), 4-bag FTP, and US06 test cycles (see Appendix B for details). Prior to performing these tests, a preparation cycle was performed to condition the vehicle for repeatable emissions. During testing it was observed that the US06 PM was significantly more variable than the FTP PM. It was suggested the cause was the US06 preparation cycle. A new preparation cycle was discussed with the E-99 stakeholders; that new prep cycle was utilized for the confirmation testing as discussed later in this section. The test vehicles were inspected to ensure that they were in sound mechanical and operational condition upon arrival, using a standard checklist.

The purpose of this study was not a vehicle/technology comparison, but an evaluation of different methodologies for measuring PM mass at a higher and a lower PM level. The GDI vehicle will be referred to as the Higher PM Source and the PFI vehicle as the Lower PM Source through the remainder of this report.

Table 2-1. Test vehicles used for the screening and confirmation testing

#	MY	OEM	Model	California Certification	Type	Engine Size	Mileage	Designation
1	2012	Honda [1]	Accord	PZEV II	PFI	2.4 L	31,144	Lower PM Source
2	2014	Ford [2]	Escape	SULEV II	GDI	1.6 L	25,678	Higher PM Source

GDI = Gasoline direct injection; PFI = port fuel injection.
[1] The Honda has a GVW of 4299 lb. and conformed to regulations EPA T2B2 LDV and included WV-TWC/TWC/A/F Sensor/HO2S/SFI aftertreatment. The engine family for this vehicle was CHNXV02.4MC3.
[2] The Ford Escape has a GVW of 4520 lb. and conformed to US EPA T2B5 LDT2 and included TWC/HO2S/AFS/CAC/TC/DFI aftertreatment. The engine family for this vehicle was EFMT01.62E9.

2.2 Emissions: PM sampling

Two unique PM samplers were utilized in this project: a multi-filter PM sampler in a CVS and a single partial flow sampling system (PFSS). Each sampler is a unique system. The CVS PM sampler was configured with four individual PM sampling systems that all sampled the same

dilute CVS exhaust. In contrast, the PFSS was an independent sampling system that sampled from the raw exhaust. The PFSS was subject to other factors such as proportionality, accuracy in the exhaust flow measurement, and DF that could affect the comparison between the CVS probes and the PFSS probe. As a result of these other modified conditions, there may be some additional biases between the CVS probes and the PFSS probes. This section describes the set up and operation of the PM samplers.

2.2.1 PM samplers: CVS

CE-CERT utilized a multi-filter sampler that simultaneously collected PM on four different gravimetric filter samplers from the dilute CVS to evaluate all parameter changes in parallel. This design maximized the number of parallel measurements to minimize the confounding factors of test-to-test vehicle/driver variability. This sampler utilized a single heated sample probe, a particle classifier, a heated control chamber for the various filter holders, a residence chamber designed to provide a residence time of 2.5 seconds for each of the FFVs, compliant filter holders with filter cassettes, solenoid bypass valves, and four National Institute of Standards (NIST) traceable mass flow controllers (MFCs). The system was controlled via LabVIEW and was integrated into CE-CERT's driver's aid system for automatic flow control, logging, and monitoring. Figure 2-1 shows a picture of the completed filter system.

The heated chamber contained four PM samplers designated Probe D, C, B, and A. Each probe was designed to facilitate the needs of varying FFV and flow-weighting, while maintaining similar residence times between the probes. These probes all collected from a standard a 1" o.d./0.87" i.d. tube that extended into the CVS, with no additional provisions utilized to maintain isokinetic sampling. The probe discussion below describes the design details of the PM samplers for the FTP specific tests.

Probe D – Probe D represents the traditional CVS filter sampling system. This probe was connected to a flow splitter with four sampling legs and a bypass leg that was automatically selected by solenoid valves. The flow rate was controlled with a single MFC. This probe collected the filters for the individual bags for either the 3-bag or 4-bag FTPs. The flow for this probe operated at a fixed FFV value of 100 cm/sec for both the screening and confirmation testing phases.

Probe C – Probe C was designed to collect a cumulative PM filter over the entire duration of a 3-bag or 4-bag FTP. Only one filter sampler and bypass control valve were setup for this probe system. The flow rate for Probe C utilized the same nominal flow as Probe D for the Bag 2 segment of the FTP and for the US06, but was varied to 43% and 57% of the nominal flow for Bags 1 and 3 of the FTP, respectively. The flow rate for Probe C for a 4-bag FTP was 75% of 100 cm/sec for Bags 1 and 2 and 100% of 100 cm/sec, for Bags 3 and 4. The flow rate was automatically set by software in the driver's aid system as it changed between bags of the FTP cycle. The nominal flow for Probe C was designed to operate with a FFV of 100 cm/sec for the screening and confirmation testing phases.

Probe B – Probe B was designed to collect a cumulative PM filter over the entire duration of a 3-bag or 4-bag FTP. This probe was designed to utilize a FFV that is higher than Probe C (up to 150 cm/sec) but lower than Probe A. Issues with maintaining flow have been identified with high flow PM samplers. As the flow rate across the filter increases, the pressure drop increases and the filter loading increases, which can further increase the pressure drop. If the filter pressure drop is too high, the MFC will be unable to maintain flow control; the flow will start decreasing until the

flow set point is reduced or the filter is replaced. To prevent the MFC flows from decreasing, Probe B had a larger capacity medium mass flow controller body compared to the MFCs used in Probes D and C. During testing, Probe B did not show any issues with flow control. Probe B utilized a flow-weighting similar to that of Probe C for the different FTP bags. The flow rate was automatically set by software in the driver's aid system as it changed between bags of the FTP cycle. The nominal flow for Probe B varied between the screening and confirmation testing phases (see Section 2.4 and Section 2.5 for details).

Figure 2-1 CVS multi-filter chamber and sampling system

Probe A – Probe A was designed to collect a cumulative PM filter over the entire duration of a 3-bag or 4-bag FTP at the highest flow rate possible. Probe A was designed to operate up to 175 cm/sec FFV with flow weighting controls similar to Probes B and C. As discussed with Probe B, pressure drop and proper flow control were considered in the design. The flow controller for Probe A was upgraded with the largest flow orifice available from the MFC manufacturer, and large body solenoid valves were utilized for bypass switching, and large 0.75 inch diameter sample lines were utilized. The system and MFCs were capable of 175 cm/sec of flow at a filter loading up to 400 µg. For the Higher PM Source 4-bag test, however, the filter mass was found to exceed 450 µg, and the flow was determined to be unstable (the pressure drop of the MFC was exceeded) at 175 cm/sec. The FFV was reduced for the Higher PM Source 4-bag testing as described in the screening and result sections below. The flow rate was automatically set by software in the driver's aid system as it changed between bags of the FTP cycle. The nominal

flow for Probe A varied between the screening and confirmation testing phases, as described in Section 2.4 and Section 2.5.

2.2.2 PM sampler: partial flow

Previous studies of PFSSs under the Coordinating Research Council's E-66 program [3] showed that the response time of commercially available PFSSs was better than 200 ms with excellent proportionality during exhaust flow rate changes for transient operation. Maricq et al. [7] pointed out that a PFSS can help reduce interference from artifacts by allowing lower DFs and avoiding the need for a long transfer hose for the full exhaust, which can cause storage/release effects. It is also relatively easy to provide a clean air system for a PFSS, as the requirement for the flow rate is smaller compared to a typical CVS for LDVs.

For this program, a PFSS was used to allow better understanding of the effects of a DF, which is more difficult to change with a full flow CVS system. The PFSS used for this study was a commercially available 1065 compliant system. The PFSS was configured with a similar residence time to the CVS of approximately 2.5 seconds. The flow proportionality was maintained by integrating the PFSS with a 4" exhaust flow meter (EFM) provided by SICK (Model FLOWSIC 150 Carflow). The EFM is an ultrasonic transit time difference measurement system designed for a range of flow from 0 to 1,800 m^3/h (1059 cfm). The EFM was provided to UCR in good working order and its calibration was not validated as part of this work. The EFM was connected in series with the raw exhaust to provide real-time exhaust flow measurements to the PFSS via an analog signal (the digital RS232 signal was not utilized). The PFSS sampled from the raw exhaust of the vehicle at a point just before it entered the CVS via a tube with a 0.25" o.d.

The PFSS was additionally configured to operate at various DFs from 7 down to a DF near, but slightly above 3, as calculated by 1066.610-2. These DFs were selected to test the extremes of the DF range, and to extend beyond the test conditions specified in 40 CFR part 1066. The DFs used for the testing with the PFSS were set in accordance with the 40 CFR Part 1066.610-3, which uses a ratio of the filter total diluted exhaust volume divided by the PFSS exhaust sample volume, as discussed in the next section.

2.2.3 Calculation of dilution factors

Different methodologies were utilized for the calculation of DFs for the PFSS and the CVS. The DF of the PFSS was determined by two methods, flow-based method (DF_Q) and Carbon balance method (DF_C). The flow-based method is the recommended method according to 40 CFR Part 1066.110(b)(2)(iii) for the PFSS and the carbon balance method is recommended for CVS systems. The carbon balance method can also be applied to the PFSS with the addition of gaseous sampling (CO_2, CO, THC) at an exhaust port of the PFSS.

(1) Flow-based method (DF_Q)

The flow-based method is the recommended method to determine DF over the test interval for a PFSS by 40 CFR 1066. The DF_Q was calculated using the following equation:

$$DF = \frac{V_{\mathrm{PMstd}}}{V_{\mathrm{exhstd}}} \quad \text{(40 CFR 1066.610-3)} \quad \text{(Eq. 2.2.3-1)}$$

Where V_{PMstd} is the total dilute exhaust volume sampled through the filter (denoted as G_{tot} from the PFSS) over the test interval at standard reference conditions (20˚C and 101.325 kPa), in

m^3/min. This flow volume is the accumulated volume sampled through the filter. V_{exhstd} is the total exhaust volume sampled (denoted as G_p from the PFSS as the probe flow) from the vehicle at standard reference conditions, in m^3/min. The exhaust volume sampled is the sample probe flow rate total volume that is in proportion to the exhaust flow. If we put DF_Q in terms of the PFSS measurements it becomes:

$$DF_Q = \frac{G_{tot}}{G_p} \qquad \text{(Eq. 2.2.3-2)}$$

where the G_{tot} and G_p are the total diluted exhaust flow (filter flow) and proportional sampled exhaust flow extracted from the raw exhaust. These measurements are directly measure from the PFSS and are independent of the CVS measurement system.

(2) Carbon balance based method (DF_C)

In this study, real-time dilute gaseous concentrations were measured downstream of the filter from a sampling port mounted on the PFSS utilizing UCR gaseous portable emission measurement system (PEMS). The DF_C over the given test interval was determined using the following equation (Eq. 1066.610-2) defined by 40 CFR 1065/1066.

$$DF = \frac{1}{\left(1+\frac{\alpha}{2}+3.76\cdot\left(1+\frac{\alpha}{4}-\frac{\beta}{2}\right)\right)\cdot(x_{CO2}+x_{NMHC}+x_{CH4}+x_{CO})} \qquad \text{(40 CFR 1066.610-2) (Eq. 2.2.3-3)}$$

where: x_{CO2}, x_{NMHC}, x_{CH4} and x_{CO} represent the averaged wet corrected concentration of CO_2, NMHC, CH_4 and CO measured in the sample over the test interval. Here, we set x_{CH4} to be zero because such measurements was not available with our PEMS device. The corresponding bias is negligible (<0.1%). α and β are the default values of the atomic hydrogen-to-carbon ratio and atomic oxygen-to-carbon ratio from Table 1 of 40 CFR 1065.655. In this study, α and β were set to be 1.92 and 0.03, respectively, because commercial E10 gasoline fuel was utilized.

The emissions measurements needed for the calculation of DF_C were made in a limited number of tests during the screening portion of the test program. The PFSS utilized for the E-99 project has a "CO_2 sample port" that allowed a gaseous sample of the PFSS diluted sample (proportional to the exhaust) to be analyzed by instruments such as a gaseous PEMS. The sample port is connected internally to the PFSS between the smooth approach venturi (SAO) G_{tot} measurement system and the vacuum pump venturi, as shown in Figure 2-2. This means the sample pressure inlet to the gaseous PEMS will be similar to the exit of the gravimetric filter. At high FFVs and nominal filter loadings, due to the accumulated PM from vehicle testing, a vacuum pressure > 5 inHg vacuum could be observed. These pressures are significantly higher than what a gaseous PEMS was designed for (positive pressures of +0.5 inHg to -1 inHg are typical), which may lead to errors due to the much lower vacuum on the PEMS system.

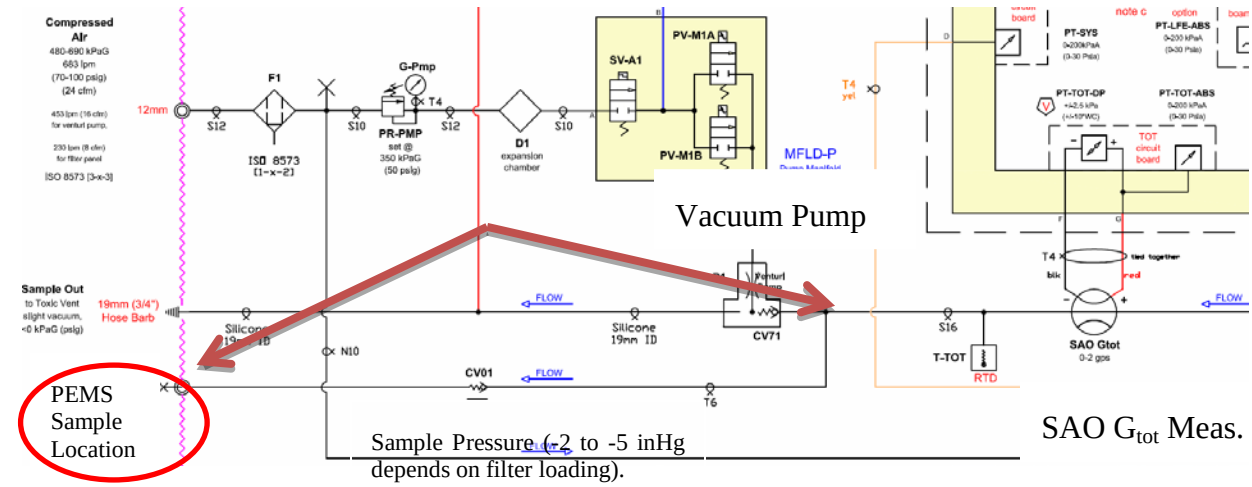

Figure 2-2 Partial flow CO_2 sample port between SAO outlet and the vacuum pump

Determinations of DFs for the CVS

For multi-phase tests, the CVS tunnel flow/dilution factor was set based on the DF found for the bag 1 cold start. The dilution factor for the CVS was defined by the carbon balance calculation.

Comparison of DFs of the PFSS

It is expected that PFSS DF_C and PFSS DF_Q should be in close agreement. Deviations between PFSS DF_C and the PFSS DF_Q would suggest a possible measurement difference between the PFSS and the CVS. In comparing the DFs for the two PFSS derived (DF_Q and DF_C) methods, a bias was found where the flow-based method was ~14% lower than that obtained with the carbon balance calculation.

The additional testing and evaluation necessary to determine the source of errors in the PFSS DFs is outside of the scope of this project. The PFSS was initially set up as another PM sampler; the evaluation of its performance was not part of this study. It is anticipated that the performance of PFSSs will be further evaluated in a future phase of this project. It is worth noting that the PFSS carbon balance method (DF_C) may be slightly less accurate since the carbon species were measured with UCR's PEMS. In particular, PEMS are not typically as accurate as laboratory analyzers, and the PEMS was calibrated on high concentration span gases typically used for raw exhaust sampling. Additionally the high inlet vacuum for the PEMS may have also affected its measurements.

2.2.4 Dilution factor configuration

The setup of the dilution factors for the CVS and the PFSS were performed separately. This section briefly describes how each of the PM samplers was configured. In general the CVS was maintained at a flow rate to achieve a dilution of 7 to 1, and the PFSS was configured for three different DFs (7, 5, and 3) for the screening phase and 5 for the confirmation phase.

CVS Setup: The CVS flow rate was set to target a dilution rate near 7 to 1 based on Bag 1 of the FTP test cycle. The CVS was controlled with a constant displacement pump system utilizing a heat exchanger prior to flow control. Typically the flow control is set by pre-configured targets designated by the manufacturer. Since a minimum phase DF = 7 was desired, the flow control was determined by selecting a rotational frequency of the CVS that produced the appropriate DF

as per the carbon balance method. The CVS was set to a frequency that produced a total flow rate of 133.7 ± 1.2 scfm for the lower PM Source and 144.1 ± 1.2 scfm for the Higher PM Source (see Table 2-2). The US06 utilized higher CVS flow rates: 242.2 ± 0.6 scfm for the Lower PM Source and 329.7 ± 1.3 scfm for the Higher PM Source. Propane recover tests performed at each CVS setting were found to be within specifications as described in Appendix C.

Table 2-2 CVS and PFSS dilution factor setup configuration

Test Cycle	Vehicle	CVS flow (scfm)		PFSS "r"at 100 FFV		
		ave	stdev	ph1	ph2	ph3
FTP	Low Source	133.7	1.2	0.00707	0.01636	0.00929
FTP	High Source	144.1	1.0	0.00547	0.01519	0.00863
US06	Low Source	224.2	0.6	-	0.00976	-
US06	High Source	329.7	1.3	-	0.00663	-

[1] CVS flow is based on measured values at standard temperature and pressure (1 atm 20°C) and not a flow setting mode such as "flow setting position "1, 2, 3 etc. as provided by the CVS manufacturer. The sample size was 6 for the signal standard deviation provided.
[2] PFSS results are based on a DF = 7 and a nominal FFV of 100. Higher FFV would produce higher "r" values and lower DF would produce higher "r" values. The flow-weighting for Phase 1, 2, and 3 were based on 1066 (0.43, 1.0, and 0.57).

PFSS Setup: The PFSS included a mode called CVS correlation. This mode was designed to mimic a CVS operation by inputting CVS total flow and the desired DF. The calculation was simply the G_{tot} divided by CVS flow rate in g/s. This mode was utilized for the duration of this testing program. For example at a CVS setting of 133.7 scfm one would set "r" to 0.007, 0.0163, and 0.00929 for Phases 1, 2, and 3 of the FTP assuming a FFV = 100 and DF = 7 (see Table 2-2). The value for "r" would increase with higher FFV and lower DFs. During cumulative filter loading, the G_{tot} and the sample ratio "r" were varied to maintain desired flow-weighted FFV. These details were managed with a modified script file provided by the PFSS manufacturer. It is expected that future versions of this PFSS will become more automated as PFSSs become more widely used and PM sampling methodologies become more complete.

2.2.5 Transfer Line

The transfer line between the vehicle's tailpipe and the dilution tunnel inlet was an important part of the overall sampling system, and was integral to both the CVS and PFSS sampling systems. A transfer line of approximately, but no more than, four meters was used for this project. The transfer line was insulated to minimize the temperature difference between the exhaust gas and the tubing wall over the course of the emission test. The total length of the sample line was four meters due to the inclusion of the selected EFM. The EFM incorporated heating which additionally pre-heated a portion of the transfer line prior to each test. The amount of flexible tubing used for the transfer line was limited to the extent practicable.

2.2.6 Background correction

According to Part 1066, the PM back ground used for emission correction should be based on best engineering practice, but not to exceed a maximum of 5 µg per filter. Correcting for background involves measurement of the tunnels background value via tunnel blank (TB) check. The TB for the CVS is the PM measured on a filter during a test with no exhaust. Similarly a TB for the PFSS is the PM collected on its filter during a test with no exhaust and no exhaust flow.

TBs were collected during both the screening and confirmation testing phases. Table 2-3 shows the average and 1σ standard deviation TB data for the screening and confirmation phases of this project. The average TB was slightly more than 5 µg (6.1 µg) for the screening phase and equal to 5 µg for the confirmation testing. The PFSS had a TB value that averaged 3 µg for the screening tests and 0.8 µg for the confirmation testing. The PFSS TBs were consistently lower with a smaller standard deviation than the TBs for the CVS system.

Since there was a significant time difference between screening and confirmation testing phases, including seasonal changes and some cleaning of the CVS PM sampler between phases, the TB data were averaged separately for each of the two testing phases. The TB correction values that were applied are listed in Table 2-4 for all corrected PM masses presented in the results section. Thus, the TB for the CVS sampler utilized a 5 µg background correction for both the confirmation and screening phases, and the PFSS used a background correction of 3 µg for the screening tests and 1 µg for the confirmation tests.

In some cases the background correction resulted in negative filter weights. According to 1066, negative filter weights (including those resulting from background corrections) should be zeroed out prior to emission factor calculations. Since the objectives of this project were to understand biases, variability, and mean differences, these negative filter weights (including the background correction) were allowed to be negative, and no truncation was performed. For example, a filter weight of 2 µg with a 5 µg background correction would be reported as -3 µg. In general, ~50% of the Phase 2, 3, and/or 4 (Probe D) background corrected filter weights were negative for the lower PM Source (see Appendix E for details).

Table 2-3 Tunnel blank results for the full testing program (µg)

	Screening			confirmation			total		
	Ave.	Stdev.	n	Ave.	Stdev.	n	Ave.	Stdev.	n
CVS Probe	6.1	4.3	18	5.0	4.0	20	5.5	4.1	38
PFSS	3.0	2.1	3	0.8	0.6	2	2.2	1.9	5

Table 2-4 PM Background values used in the calculations（µg)

Back Ground Correction	screening	confirmation
	Ave.	Ave.
CVS Probe	5.0	5.0
PFSS	3.0	1.0

2.3 Emissions: measurements

This section describes the emissions measurements performed. A diagram of the sampling configuration is provided in Figure 2-3.

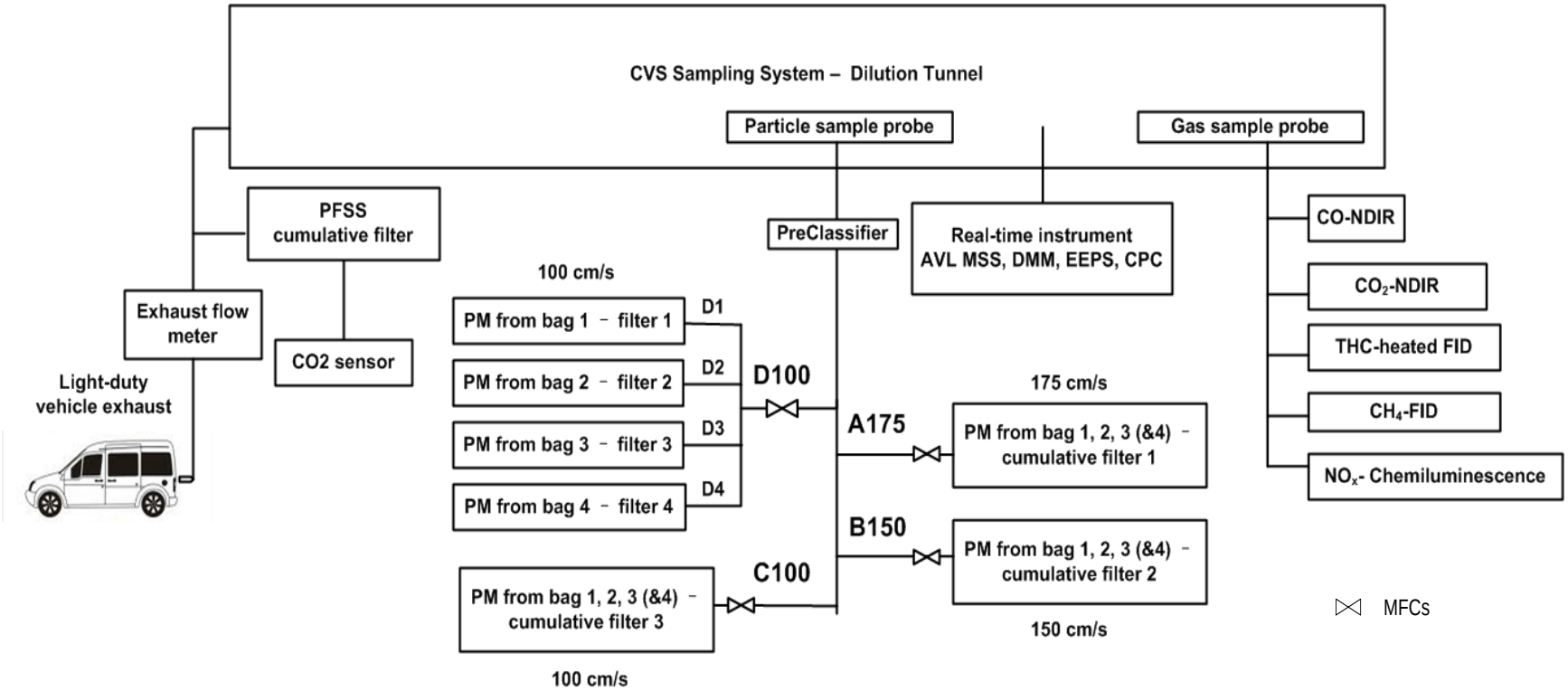

Figure 2-3 Schematic Diagram of Sampling Configuration for Emissions Measurements

[1] The CVS PM samplers (A, B, C, and D) are geometrically similar with slight differences in length to achieve 2.5 sec residence with varying FFV for each. Note the maximum FFV was set to 175 cm/s for the PFI vehicle, but was reduced to 150 cm/sec (Probe A = 150 and B = 125) during the course of the testing on the GDI vehicle. During confirmation testing, Probe A was set to 150 and Probe B to 125 cm/s for both vehicles. The PFSS PM sampler is connected to the raw exhaust; it sampled proportionally with an ultrasonic exhaust flow meter. Residence time was approximately 2.5 seconds. The DF was verified on selected tests with CO_2 measurement at the exhaust port of the PFSS. Real time PM instruments were connected to the CVS but not to the PFSS system.

2.3.1 Gaseous emissions

All tests were conducted in CE-CERT's Vehicle Emissions Research Laboratory (VERL) equipped with a Burke E. Porter 48-inch single-roll electric dynamometer. For these tests, standard bag measurements were obtained for total hydrocarbons (THC), non-methane hydrocarbons (NMHC), carbon monoxide (CO), nitrogen oxides (NO_x) and carbon dioxide (CO_2). NMHC was determined by combining results from the THC analyzer and a separate methane (CH_4) analyzer. Bag measurements were made with a Pierburg AMA-4000 bench. Exhaust emission rates were determined via calculations as put forth in 40 CFR 1066.605, along with provisions in associated CFR sections. CO_2, CO, and THC emissions were used to determine fuel economy. On-Board Diagnostic (OBDII) data was also collected for each of the vehicles.

2.3.2 PM mass emissions

PM mass samples from the CVS were collected by bag and cumulatively over each FTP. The PFSS was also used to collect cumulative PM samples proportionate to the raw exhaust. PM sampling was conducted following the procedures in 40 CFR 1066.110 and associated references in 40 CFR Part 1065 with the exception of changes to the protocol designed to test experimental extremes in variables, such as FFVs and lower DFs designed to extend beyond the standard CFR conditions. Cumulative PM samples were collected over each FTP with flow-weighting MFCs.

Total PM mass samples for both the CVS and PFSS were collected using Whatman 47 mm polytetrafluoroethylene (PTFE) filters. They were weighed with a 1065-compliant microbalance in a conditioned room meeting 1065 requirements. Investigators also performed buoyancy corrections for barometric pressure differences on PM filter weights as per 1065.

Six tunnel blanks from the CVS and six backgrounds from the PFSS were collected over the test period covering both test vehicles. PM background samples were collected as per 1066.110(b)(2)(i) over the duration of either a full 3-bag or a full 4-bag FTP. The background samples were collected at different times over the course of the testing, so that they are reasonably representative of the full time period of the testing.

2.4 Screening tests

The screening tests were designed to vary several parameters, such as FFV and DR, over different extremes using combined filters. The screening test goal was to evaluate several combinations to identify a combination that provided the most PM mass gain, while providing stable repeatable results. The test setup design maximized the number of parallel measurements to minimize the confounding factors of test-to-test vehicle/driver variability. Fewer repeat tests were conducted during the screening testing than during the confirmation testing.

2.4.1 FTP testing

Simultaneous gravimetric PM sampling was performed with a total of five PM samplers. Four PM samplers were connected to the CVS; one was connected to the raw exhaust using a PFSS. Table 2-5 shows the screening test matrix for both PM samplers. The test matrix was conducted for each of the vehicles, and nine FTPs were conducted on each vehicle. Each test in the matrix represents one individual test where some conditions were repeated, which allows "n" to be greater than one in some cases. This approach allowed testing of three different combinations of filter configurations for each vehicle. The first set of three tests on each vehicle were run over a 3-bag FTP, the second set of three tests were run over a 4-bag FTP, and the last set of three tests was run as a 3-bag FTP test but

with a different FFV for the PFSS compared to the first three tests. Note that two additional tests were run for Vehicle 1 under the initial 3-bag FTP conditions.

The CVS was configured for a constant DF of 7 for all nine tests while the PFSS was designed to operate at 7, 5 and 3, for both the 3-bag and the 4-bag tests (see PFSS configuration details in Section 2.2.2). Only the first test of each group of three tests had the same DF, FFV, and filter combining conditions between the CVS and the PFSS. The FFV was varied from 100 cm/sec to 175 cm/sec for the CVS PM samplers and from 100 cm/sec to 150 cm/sec for the PFSS PM sampler. The CVS probes were designed for varying the FFV. Probe D was configured for individual bag sampling at 100 cm/sec FFVs, Probe C was configured for cumulative sampling at the same 100 cm/sec nominal FFV, and Probes B and A were operated at higher FFVs with cumulative sampling. Probe B operated up to 150 cm/sec., and Probe A operated up to 175 cm/sec. See Section 2.2 for more details and a description of the probes and CVS PM sampler.

During the Higher PM Source 4-bag testing, excessive filter loading caused flow issues with the CVS Probe A sampler and the PFSS DF = 3 sample conditions. The CVS PM sampler flows were reduced from 175 to 150 for Probe A and 150 to 125 cm/sec for Probe B for the Higher PM Source 4-bag tests, as described in the footnotes of Table 2-5. The GDI PFSS PM data for test run #9 (DF = 3 and FFV = 150) was not valid due to flow stability issues and may represent the lower bound for the PFSS design for the selected vehicles. For the final three tests on each vehicle, it was decided to evaluate a higher FFV for the PFSS. This was done over a 3-bag test using the same CVS settings that were used in the initial three tests, but increasing the FFV for the PFSS to 150 cm/s. The DFs for the PFSS were 7, 5, and 3, similar to those used for the early 3-bag test.

The vehicles were preconditioned prior to running the initial FTP over an LA4 prep cycle (see Appendix B for details). In cases where the period between back-to-back tests exceeded 36 hours, such as over the weekend, an additional LA4 prep cycle was run on that vehicle prior to running the next FTP.

Table 2-5 FTP Test Matrix Design for Screening Tests with the Lower PM Source

Test #	FTP bags	CVS sample (DF=7)[1] FFV(cm/sec)		PFSS Sample[4] FFV(cm/sec)	
		1 Filt/Bag[2] "D"	1 Filt/FTP[3] "C", "B", "A"	1 Filt/FTP FFV	DF
1	3	100	100, 150, 175	100	7
2	3	100	100, 150, 175	100	7
3	3	100	100, 150, 175	100	5
4	3	100	100, 150, 175	100	5
5	3	100	100, 150, 175	100	3
6	4	100	100, 150, 175	100	7
7	4	100	100, 150, 175	100	5
8	4	100	100, 150, 175	100	3
9	3	100	100, 150, 175	150	7
10	3	100	100, 150, 175	150	5
11	3	100	100, 150, 175	150	3

[1] The CVS was set at a DF=7. The DF was based on Bag 1, so the weighted DF was higher since higher DFs are found in Bags 2 and 3.
[2] CVS Probe "D" is a complete sampler and configured for one filter per test.
[3] CVS Probes "C", "B", and "A" are three separate samplers. Each was configured for one filter per test. Flow-weighting was as per 1066.815(b)(4) [0.43, 1.0, 0.53] for a 3-bag FTP and (b)(5) [0.75, 0.75, 1.0, 1.0] for a 4-bag FTP.

[4] The PFSS was operated at three different DF's. Each DF was targeted based on the Bag 1 value. Only combined filter flow-weighted sampling (i.e., single filter usage) was performed with the PFSS.

Table 2-6 FTP Test Matrix Design for Screening Tests with the Higher PM Source

Test #	FTP bags [5]	CVS sample (DF=7) [1] FFV(cm/sec)		PFSS Sample [4] FFV(cm/sec)	
		1 Filt/Bag [2] "D"	1 Filt/FTP [3] "C", "B", "A"	1 Filt/FTP FFV	DF
1	3	100	100, 150, 175	100	7
2	3	100	100, 150, 175	100	5
3	3	100	100, 150, 175	100	3
4	4	100	100, 125, 150	100	7
5	4	100	100, 125, 150	100	5
6	4	100	100, 125, 150	100	3
7	3	100	100, 125, 150	150	7
8	3	100	100, 125, 150	150	5
9	3	100	100, 125, 150	150	3

[1] The CVS was set at a DF=7. The DF was based on Bag 1, so the weighted DF was higher since higher DFs are found in Bags 2 and 3.
[2] CVS Probe "D" is a complete sampler and configured for one filter per test
[3] CVS Probes "C", "B", and "A", are three separate samplers. Each was configured for one filter per bag. Flow weighting was as per 1066.815(b)(4) [0.43, 1.0, 0.53] for a 3-bag FTP and (b)(5) [0.75, 0.75, 1.0, 1.0] for a 4-bag FTP.
[4] The PFSS will operate at three different DF's. Each DF is targeted based on the Bag 1 value. Only combined filter flow-weighted sampling (i.e., single filter usage) was performed with the PFSS.
[5] The 4-bag Higher PM Source test showed flow issues for Probe A, so the FFVs for the 4-bag FTP tests were reduced from 175 cm/sec to 150 cm/sec for Probe A and from 150 to 125 cm/sec for Probe B.

2.4.2 US06 testing

Table 2-7 shows the test matrix for the US06 testing with the CVS and PFSS PM samplers. The CVS operated at a single DF of 7 and the PFSS DF varied from 7 to 3. Since the US06 is a single bag test, all probes for all the tests sampled onto a single filter. CVS Probe D was configured to sample at similar flow conditions as Probe C. CVS probes B and A were sampled at higher FFVs of 150 and 175 cm/sec respectively, as per Table 2-7. The partial flow system was operated at three DFs (7, 5, and 3) and two different FFVs (100 and 150 cm/sec).

The CVS and PFSS systems were configured to meet the cycle averaged DF as per 1066.610-2. Because the US06 is a more aggressive driving cycle than the FTP, the CVS and PFSS required higher dilution flows to yield average DF's similar to those used for the FTP cycle.

The US06 tests were preconditioned with either an FTP, US06, or an LA-4, as allowed by 1066.831. During the screening tests, it was noticed that the variability of the PM emissions for the US06 data was more than five times higher than the FTP tests. The E-99 committee recommended a more robust and consistent vehicle preconditioning warmup for the US06 tests. The revised US06 preparation for the confirmation testing was a FTP, followed by a US06 (prep) followed by a US06 (test) where the time between the US06 (prep) and US06 (test) was between one to two minutes. The next repeated US06 was performed on the following day, as described in Section 2.5 below. Thus, the preconditioning for the screening and confirmation tests were not the same; the approach for the confirmation testing represented best practices.

Table 2-7 US06 Test Matrix Design for Screening Tests

	Test #	Prep.	CVS Filter=1 "D","C","B","A"		PFSS	
			DF	FFV(cm/sec)	DF	FFV(cm/sec)
Ford Escape (GDI)	US06_1	Cold start US06 + 5.min soak	7	90, 100, 125, 150	7	100
	US06_2	Cold start US06 + 5 min soak	7	90, 100, 125, 150	5	100
	US06_3	Cold start US06 + 5 min soak	7	90, 100, 125, 150	3	100
	US06_4	After 3-bag FTP + 5 min soak	7	90, 100, 125, 150	5	150
	US06_5	After US06_4 + 5 min soak	7	90, 100, 125, 150	4	150
	US06_6	Cold start US06 + 5 min soak	7	90, 100, 125, 150	3	150
Honda Accord (PFI)	US06_1	70MPH for 10 min + 5 min soak	7	80, 100, 150, 175	7	100
	US06_2	After US06_1+70MPH for 10 min+ 5 min soak	7	80, 100, 150, 175	5	100
	US06_3	After US06_2+70MPH for 10 min+ 5 min soak	7	80, 100, 150, 175	3	100
	US06_4	Cold start US06 + 5 min soak	4	80, 100, 150, 175	n/a	n/a
	US06_5	After US06_4+ 5 min soak	4	80, 100, 150, 175	n/a	n/a
	US06_6	After US06_5+ 5 min soak	4	80, 100, 150, 175	n/a	n/a

2.4.3 Results

This subsection discusses the screening results that were the basis for the recommendations for the FFV and DF for the confirmation tests. The recommendations were based on trends with the mean emission rates, filter loadings, and variability. This subsection describes the PM emission rates, the filter PM masses, and the associated PM measurement variability. Due to the wider range of conditions evaluated and few repeats, the paired t-test analysis was limited to only special cases where parallel sampling was performed. As such, this section is mostly focused on a comparison of means, mass gains, and variability, with some mention of statistical paired t-tests where possible.

PM Emission rates: The main purposes of this research were to evaluate alternative sampling methodologies and characterize changes in mean PM emission rates between test conditions. Figure 2-4 shows the average PM emissions for the Higher (a) and Lower (b) PM Sources during the 3-bag FTP, 4-bag FTP, and US06 testing, with the error bars representing single standard deviations. The 4-bag data was not available for the Higher PM Source testing at 175 FFV due to filter overloading. The Higher PM Source 4-bag FFVs were reduced to 150 FFV for Probe A and 125 FFV for Probe B. The filters were also near the maximum for the 3-bag FTPs for the Higher PM Source, so the FFVs for Probes A and B were also reduced for the final three 3-bag FTP tests.

The mean emission rate for the Higher PM Source varied from 1.65 mg/mi to 1.29 mg/mi for the 3-bag FTP CVS probes; the differences in the mean were within the uncertainty of the 1σ error bars. The Lower PM Source varied from 0.31 to 0.25 mg/mi for the CVS probes; the differences in the mean were again within the uncertainty of the error bars. It is important to realize that the variability shown in Figure 2-4 is not representative of the difference between test cycles, bag tests, or methods, but appears to be mostly the result of test-to-test differences. For example, some readers may

interpret that the 4-bag FTP is less variable than the 3-bag FTP. During deeper analysis it was found that the 3-bag variability for tests 7, 8, and 9 were very similar to the 4-bag variability. Figure 2-4 shows all the 3-bag data (tests 1, 2, 3, 7, 8, and 9) lumped together, which may be misleading to the reader, but necessary for the objectives of the screening tests during the paired analysis. The test-to-test variability utilizing all the data will be discussed in more detail in Section 3.3.1. In general, these results suggest that any of the FFVs would be a reasonable choice for the CVS samplers, but a 150 FFV maximum as a reasonable limit to prevent filter overloading.

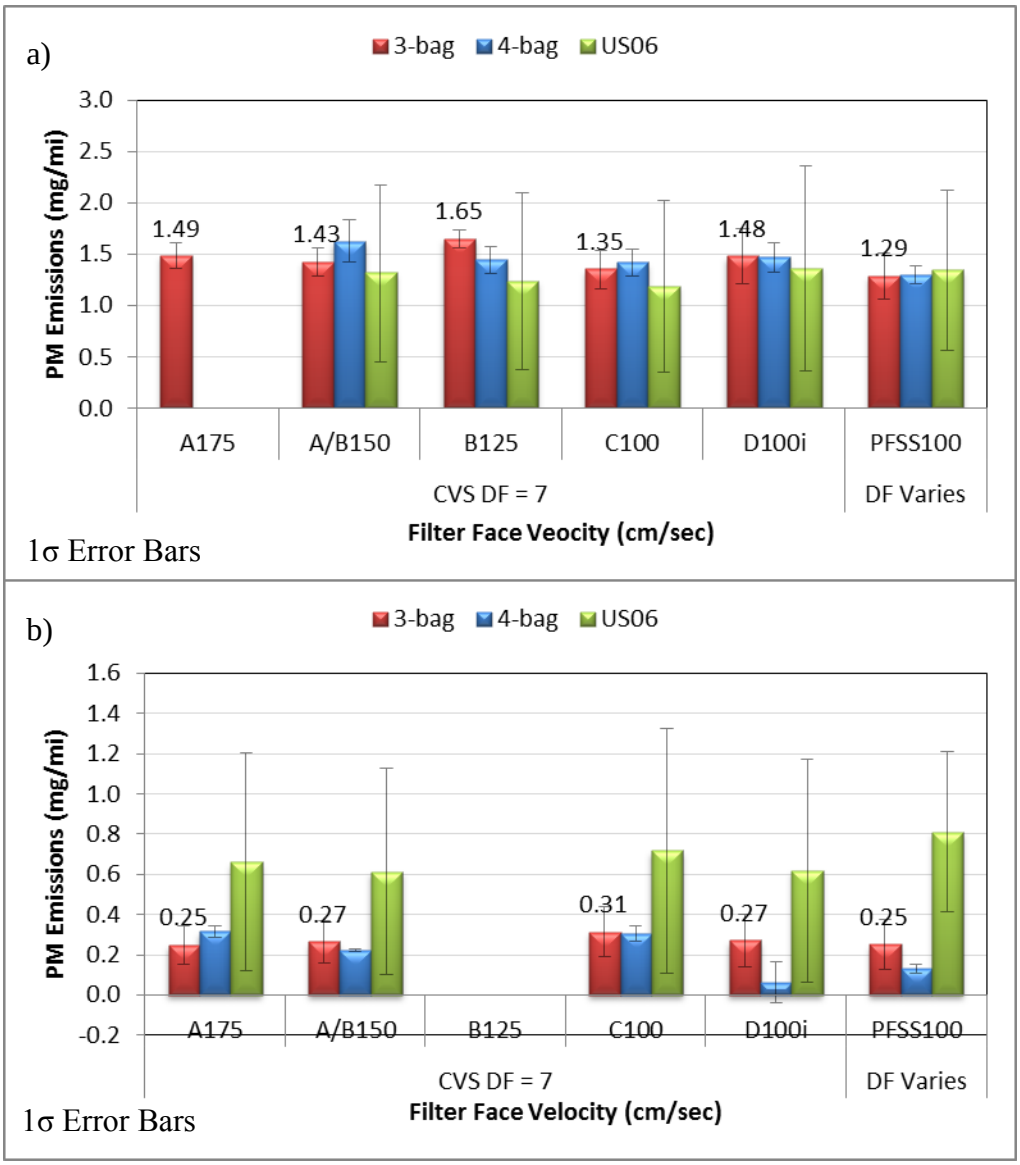

Figure 2-4 PM Emissions at various FFV for the Higher (a) and Lower (b) PM Sources

[1] CVS was operated with $DF_{phase\ 1}$ =7, while PFSS was operated with various $DF_{phase\ 1}$ from 7, 5 and 3 and a FFV = 100. The error bars represent one standard deviation (Probe A for the GDI vehicle operated at FFV = 175 for the 3-bag test and 150 for the 4-bag test due to filter overloading with the 4-bag test. Probe B operated at 150 and 125 FFV.
[2] The number of repeats varied from 10 to 3 and depended on the test conditions. See statistical support data in Appendix J for details.

Figure 2-5 provides further comparison between the CVS and PFSS samplers. Figure 2-5 shows the PM emissions for DF 7, 5, and 3 at 100 and 150 cm/sec FFVs during PFSS operation and for DF=7 and FFVs at 100 and 150 cm/sec for the CVS sampling for the Higher (A) and Lower (B) PM Source. The DF tests for the PFSS were single tests, so no error bars are plotted. The CVS probes

were the averages of the data represented by the single PFSS tests where the error bars are represented by single standard deviations. The filter for the PFSS overloaded at DF=3 and a FFV = 150 for the 4-bag test, so those data are not provided for the Higher PM Source. There is no noticeable difference in the mass emission rate between the CVS and the PFSS compared to the testing variability for the FTP tests, but there is a noticeable difference for the US06 results. Due to the high variability and the single test configuration for the PFSS, these differences are not significant, thus all FFVs and DFs are reasonable for the confirmation testing. These results suggest that all of the DFs and FFV would be reasonable for the PM samplers, but DF=5 as a suggested minimum for the PFSS is a reasonable limitation to prevent filter overloading.

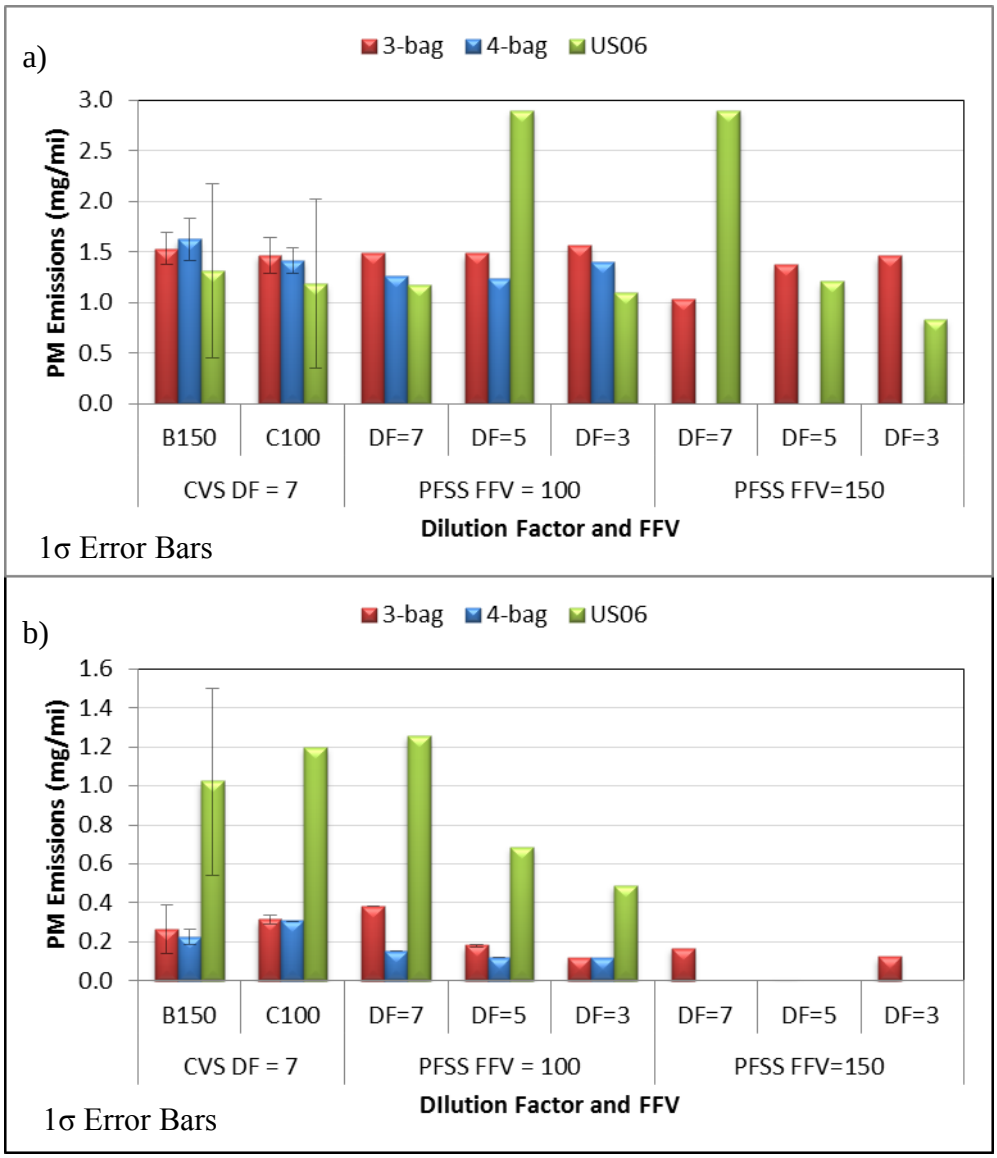

Figure 2-5 PM Emissions at various DFs and FFVs for the Higher (a) and Lower (b) PM Sources

[1] CVS was operated with $DF_{phase\ 1}$ =7, while PFSS was operated with $DF_{phase\ 1}$ varied with 7, 5 and 3. The error bars represent one standard deviation. Probe A for the GDI vehicle operated at FFV = 175 for the 3-bag test and 150 for the 4-bag test due to filter overloading with the 4-bag test. Probe B operated at 150 and 125 FFV.

[2] The number of repeats varied from 10 to 3 for the CVS and depended on test conditions. The number of repeats for the PFSS varied from 3 to 1. See statistical support data in Appendix J for more details.

Filter PM mass gain: A goal of modifying the sampling conditions was to increase the signal-to-noise ratio of the gravimetric method. The higher FFVs and lower DFs were utilized as methods to

increase the measurement signal by increasing the filter mass collected. Figure 2-6 shows the filter masses accumulated on the Teflon™ filter in mg for the Higher (A) and Lower (B) PM Sources for all the tests cycles. The filter weight for the Higher PM Source 3-bag FTP test increased from 141 μg to 271 μg with a corresponding increase if FFV from 100 cm/sec to 175 cm/sec for the flow-weighted probes. The Lower PM Source also showed similar trends, but at much lower overall filter weights (see Figure 2-6 (B)). The Lower PM filter weight increased from 61 μg to 112 μg at FFV = 100 and FFV = 175 for the 4-bag FTP respectively. The 3-bag FTP showed much lower filter weights compared to the 4-bag FTP for both PM Sources. The mass gain can be attributed to the fact that the 4-bag FTP included an additional bag, and also because the flow rates for Bag 1 were only 43% of the nominal for the 3-bag test compared to 75% of the nominal for the 4-bag test. The filter weight of the Higher PM Source at the 4-bag FTP FFV=175 exceeded the capacity of the CVS mass flow controllers, and thus is not shown in the figure. The invalid filter weight was in excess of 450 μg when the MFC exceeded its control capacity. Additionally, some of the 3-bag Higher PM Source filters were very close to the limits of the MFCs control capacity. To prevent sampling errors caused by operating the MFCs near their maximum capacity, the FFV for Probe A was reduced from 175 to 150 FFV.

Figure 2-7 shows the filter weight accumulation for the different DF conditions and combined FFVs as sampled by the PFSS probe system in comparison to the FFV 150 and 100 CVS probes. The Higher PM Source filter weights increased from 241 μg to 615 μg for DF = 7 and DF = 3, respectively. The DF=3 and FFV = 150 filter weights were overloaded, and thus not reported. The filter weight gain for the Lower PM Source showed slightly lower PM mass with lower DF. This is thought to be a result of the Lower PM mass and relatively high test-to-test variability. The final confirmation testing will help assess these influences where six repeats were utilized.

Variability: The final goal for modifying the gravimetric methods was to reduce overall variability in the measurement system. The sampling variability for the CVS probes could be compared since they were configured in parallel to maximize the number of paired measurements to minimize test-to-test vehicle/driver variability as a confounding factor. There was significant vehicle drift during the screening test which did not affect the paired analysis, but did affect comparisons between 3-bag, 4-bag, and US06 test cycles since they were not paired tests. The discussion on variability presented here is limited to FFV and combined filter discussions within a test specific cycle. The vehicle drift is discussed greater detail in section 3.4.1 and in Figure 3-31.

Figure 2-8 shows the PM emission rate variability (1σ standard deviation in mg/mi) for the CVS and PFSS probes for all test cycles and both PM Sources. The variability for the higher FFVs was mixed: in some cases the variability both increased and decreased (3-bag Higher PM Source Probes A, B, C, and D), but for others it decreased (3-bag and 4-bag Lower PM Source), and for others there was no real change (4-bag Higher PM Sources). The difference in these observations may be a result of a wider range of test conditions (the high flow conditions may have caused instability in the flow controllers), low repeats (varied from 3 to 10 for the CVS probes), and low filter weights. The Lower PM Source showed a filter weight around 50 μg, and the Higher PM Source had an average filter weight that was typically more than 200 μg each for this vehicle for all the probes. The 3-bag test appears to have more variability than the 4-bag test for the Lower PM Source, but deeper analysis shows this is a result of test-to-test variability and should not be used to say 3-bag testing has higher variability than 4-bag testing at low emissions levels.

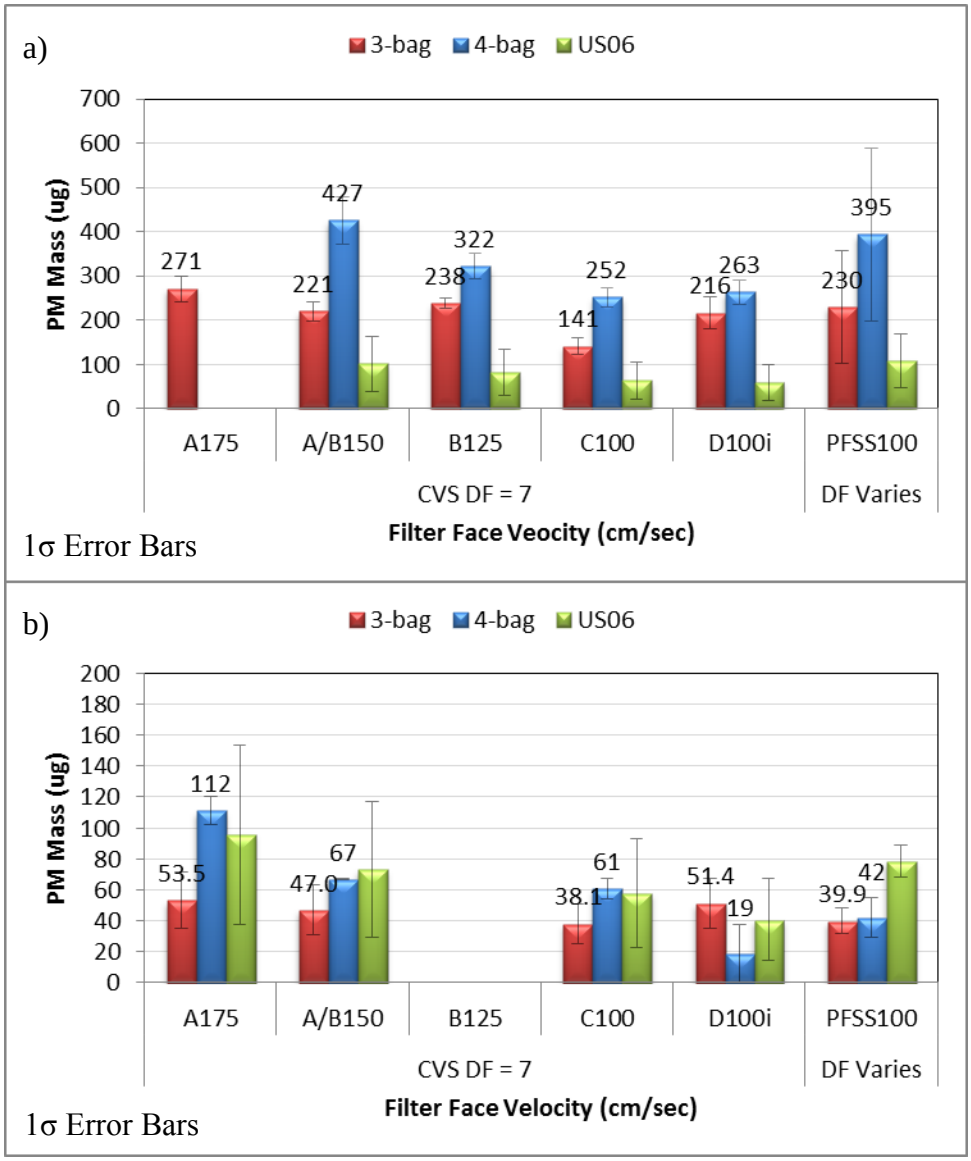

Figure 2-6 PM filter mass collected for all cycles (a) Higher and (b) Lower PM Source

[1] The error bars represent one standard deviation. Filter weights corrected for PFSS extraction ratio to make the PFSS and CVS filter weights comparable (0.5% to 3% flow affect). Filter weights not corrected for background conditions. PFSS was operated at DF = 3, 5, 7 and FFV = 100 and 150 cm/sec. The number of repeats varied from 10 to 3 and depended on test conditions. See statistical support data in Appendix J.

Another observation is the significantly higher variability with the US06 tests compared to the FTP tests. Although these tests are not paired tests and were performed at different times, they do show differences in magnitude between FTP and US06 testing. The variability for both vehicles is about two times higher for the US06 compared to the FTP for both vehicles. With deeper analysis, it was suggested that the preparation cycle for the US06 may be more critical for PM emissions than gaseous emissions, which led to the use of a more robust and consistent preconditioning protocol for the confirmation phase. The CFR allows many different options for the US06, several of which were used by UCR during the screening tests. Table 2-7 shows a list of the prep cycles utilized for the US06 cycle for both vehicles. During discussions with the CRC project panel, it was decided to utilize a single preparation cycle of a FTP, followed by a prep US06 2 minute soak, followed by a

US06 test for the confirmation testing. This improvement appears to have reduced the US06 PM emissions variability, as discussed in the final results section.

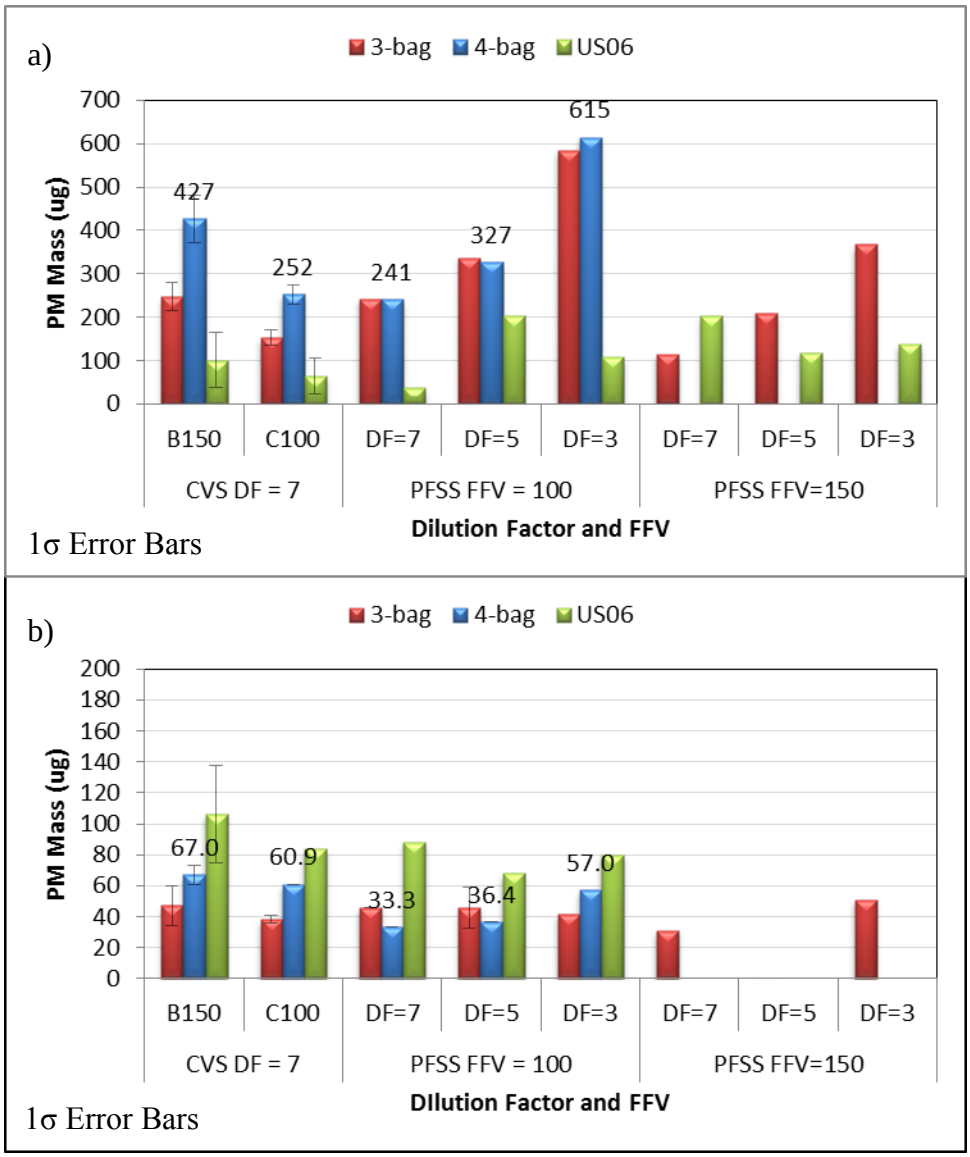

Figure 2-7 PM filter mass collected at varying DF and FFV (a) Higher and (b) Lower PM Source

[1] The error bars represent one standard deviation. The number of repeats varied from 10 to 3 and depended on the test conditions. See statistical support data in Appendix J.

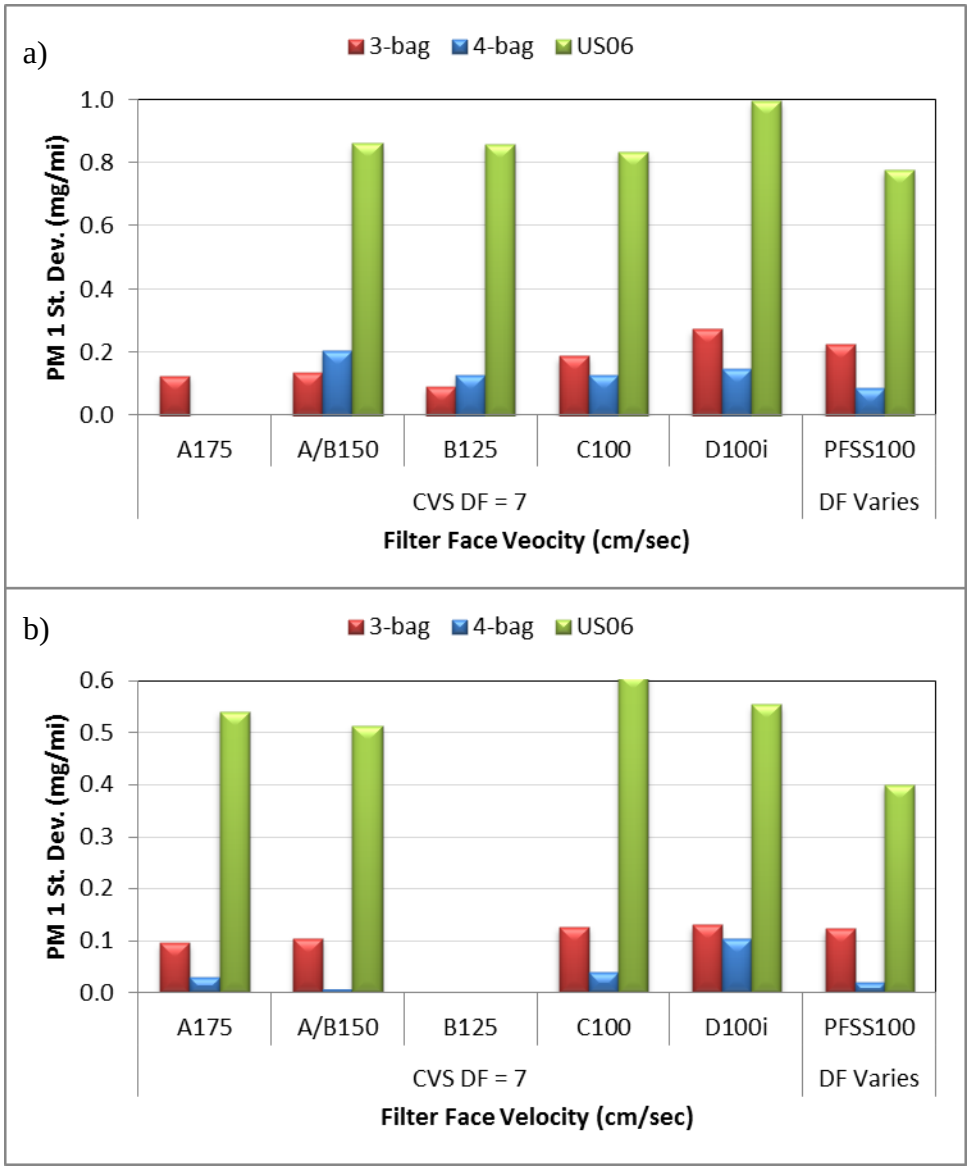

Figure 2-8 PM emission rate (mg/mi) variability for A) Higher and B) Lower PM Sources

[1]Variability plotted is represented by one standard deviation. PFSS represents variable DF and FFVs thus its variability may be a result of parameter changes in addition to test-to-test differences. The number of repeats varied from 10 to 3 and depended on the test conditions. See statistical support data in Appendix J for details.

Statistical t-tests: The paired t-tests analysis is limited to the 3-bag FTP because only three samples were collected for the 4-bag FTP. Up to six samples were collected for the 3-bag FTP, and the US06 testing had more variable results because of filter overloading at the higher FFVs. The comparison was to the traditional individual filter per phase PM sampler (Probe Di) as discussed previously. The p-value for all combinations but one showed a p-value greater than 0.05. This suggests there was no statistical difference in the means for the FFV from 175 cm/sec compared to the one filter per phase PM sampler. This suggests any of the higher FFV combinations would be suitable for the confirmation testing based on the t-test analysis.

Table 2-8 Screening paired two tail t-test for the evaluation of FFV: p-values (3-bag FTP mg/mi)

Source	n	Combined Filters p-value		
		A175/D100i	B150/D100i	C100/D100i
low	6	0.566	0.858	0.325
high	6	0.97 (n=3)	0.472	0.048

2.4.4 Recommendations for confirmation testing

In summary, the screening results did not show a significant mean difference between PM samplers at the various DF, FFV, and combined filters, allowing for a wide range of recommended combinations. Decisions for the confirmation testing were based on the reliability of the measurements. Based on the filter overloading issue discussed for high FFVs and low DFs, a maximum FFV of 150 cm/sec and a minimum DF of 5 were recommended. The 4-bag FTP had a larger PM mass signal compared to the 3-bag FTP; to improve the Lower PM Source's signal-to-noise ratio, use of the 4-bag FTP was recommended. Since the signal-to-noise ratio was not as big an issue for the Higher PM Source vehicle, the shorter 3-bag FTP was recommended. This test is less burdensome to perform on a large scale in the industry. Additionally, the US06 preparation cycle from the screening tests was modified to reduce test-to-test variability. The new US06 preparation cycle is a cold start FTP, US06 preparation, 1-2 minute soak, followed by a US06 test.

2.5 Confirmation test matrix

The confirmation tests were designed around a single condition to allow sufficient replicates to evaluate statistically the performance and repeatability of the new test conditions. These final tests, denoted as the confirmation tests, were based on the E-99 Panel's recommendations utilizing the screening results. This section presents those confirmation test protocols.

Table 2-9 lists the PFI and GDI test conditions for the FTP and US06 confirmation tests. The maximum FFV was limited to 150 cm/sec with a minimum dilution factor of 5 to 1. The committee also agreed that the FTP should be run as a 3-bag test for the Higher PM Source and as a 4-bag test for the Lower PM Source. Due to condensation issues, the CVS minimum dilution factor remained at 7 to 1 and only the PFSS system operated at the 5 to 1 DF. The FFV of the CVS and the PFSS both operated at a maximum of 150 cm/sec. Since the CVS system is configured with multiple probes, the other flow-weighted probes operated at FFVs of 125 and 100 cm/sec. Since the US06 is a single phase test, Probe D and Probe C both sampled a cumulative filter at the same conditions of 100 cm/sec FFV and a DF =7.

2.6 Data analysis

The main analysis for this research includes comparisons of means and standard deviations for each sampling method on a mg/mile and filter weight gain (µg/filter) basis. In order to evaluate if the difference in the means is statistically significant the 40 CFR 1066 t-test and f-test were also performed. The t-test was used to evaluate if the means were statistically different, and the f-test was used to evaluate changes in variance or variability. Since the data was collected by the various PM samplers in parallel, the analysis considers the paired t-test utilizing both tails of the student-t's distribution. If the resulting paired two tailed t-test p-value is greater than 0.05, this suggests the means are not statistically different at the 95% confidence interval. This represents a condition where the null hypothesis is true, or where there is not a probable difference due to the modification of a given parameter. If the p-value is less than 0.05, then the means are statistically different (i.e., the null hypothesis is not true), which suggests the modified parameters may be impacting the mean differences between the probes.

Table 2-9 Test matrix design for confirmation testing (n=6 except for GDI US06)

Vehicle	Cycle[1]	FTP bags[5]	Test	CVS sample (DF=7)[2] FFV(cm/sec)		PFSS Sample[5]	
				1 Filt/Bag[3] "D"	1 Filt/FTP[4] "C", "B", "A"	1 Filt/FTP FFV	DF
PFI	FTP	4	1-6	100	100, 125, 150	150	5
PFI	US06	n/a	1-6	100	100, 125, 150	150	5
GDI	FTP	3	1-6	100	100, 125, 150	150	5
GDI	US06	n/a	1-2	100	100, 125, 150	150	5

[1] FTP is performed as a cold start FTP with typical soak conditions as described in the test plan. The US06 is performed as a hot start test. The US06 preparation is a FTP, followed by a US06 (prep) followed by a US06 (test) where the time between the US06 (prep) and US06 (test) is between 1 to 2 minutes. Also the next repeat will be performed on the following day. The US06 test with the Higher PM Source was not able to maintain the speed trace due to possible cooling issues; thus only two tests were completely. [2] The CVS will remain at DF=7 where the DF is based on Phases.1 for the FTP. [3] CVS Probe "D" is a complete sampler and configured for one filter per phase. [4] CVS Probes "C", "B", and "A" are three separate samplers. Flow- weighting is as per 1066.815(b)(4) [0.43, 1.0, 0.53] and (b)(5) [0.75, 0.75, 1.0, 1.0]. [5] The PFSS will operate at DF = 5 where the DF is based on phs.1 for the FTP.

Paired statistical tests

The base method for comparison in this work is Probe D100, which represents the best practices for PM emissions measurements at the time of this project. Probe D represents a single PM sample flow rate (maximum of 100 cm/sec FFV) for individual filters (one filter per phase) sampled over each phase. Additionally, it should be noted that Probe D100 was utilized at a DF = 7 (as defined by the lowest phase of the multiphase test), which required a slightly lower CVS setting than would be used traditionally. Typically, a higher CVS setting would be used for measurements focused predominantly on gaseous emissions, where a Bag 1 DF of around 11 might be more commonplace. Thus, the proposed baseline condition represents a more ideal case than what is traditionally used for light-duty vehicle emissions testing. Therefore, any findings represent a reasonable comparison to a PM optimized CVS configured baseline.

3 Results vehicle testing

The goal of this research was to investigate PM sampling methodologies beyond the recommendations of 1066 and 1065. The objective of the study was to evaluate how differences in sampling methodology could improve accuracy, reduce variability, and increase the signal-to-noise ratio. The modifications investigated were limited to varying FFV, DF, and using combined or cumulative filters instead of filters for individual bags, as described previously in Section 2. The primary questions addressed in the result section are:

1. Does increasing FFV decrease variability and improve the signal-to-noise ratio while not appreciably altering the measured PM mass?
2. Does decreasing DF decrease variability and improve the signal-to-noise ratio while not appreciably altering the measured PM mass?
3. Does combining filters (3-bag & 4-bag) decrease variability and improve the signal-to-noise ratio while not appreciably altering the measured PM mass?
4. What impact do the FFV and DF changes have on US06 PM measurements, in terms of both accuracy and variability?
5. What lessons are learned about very low PM measurements by examining survey data from a wide variety of laboratories?

Secondary questions include:

6. What special issues/considerations are associated with US06 testing, e.g., vehicle preparation or tunnel preparation?
7. What is the preliminary assessment of partial flow diluter performance in light-duty emissions applications?

3.1 General observations: Confirmation results only

This section provides an overview of the PM characteristics of the Higher and Lower PM Sources tested, the PM emission level, composition, and size distributions, and the real-time PM trends. This helps to provide a basis for understanding possible differences between the PM Sources and a context for understanding the statistical comparisons for the modified FFVs, DFs, and combined filter.

3.1.1 PM mass emissions (mg/mi)

The PM emissions for both vehicles are shown in Figure 3-1 for the FTP and US06 test cycles. The PM emissions were in close agreement for the Higher PM Source and averaged between 1.85 mg/mi to 1.98 mg/mi for the various PM probes sampled over the FTP cycle and between 1.99 to 2.41 mg/mi for the US06 test cycle. The 3-bag FTP Higher PM Source mean emissions showed a low relative error of –5.9% between the PFSS (DF=5, FFV=150) and Probe A (DF=7, FFV=150) and only -2.7% between the PFSS and Probe D. A relative error of 5% is a reasonable and relatively small error considering the variabilities of up to 20% in PM measurements found in comparisons between different laboratories and in a number of cross lab correlations [8].

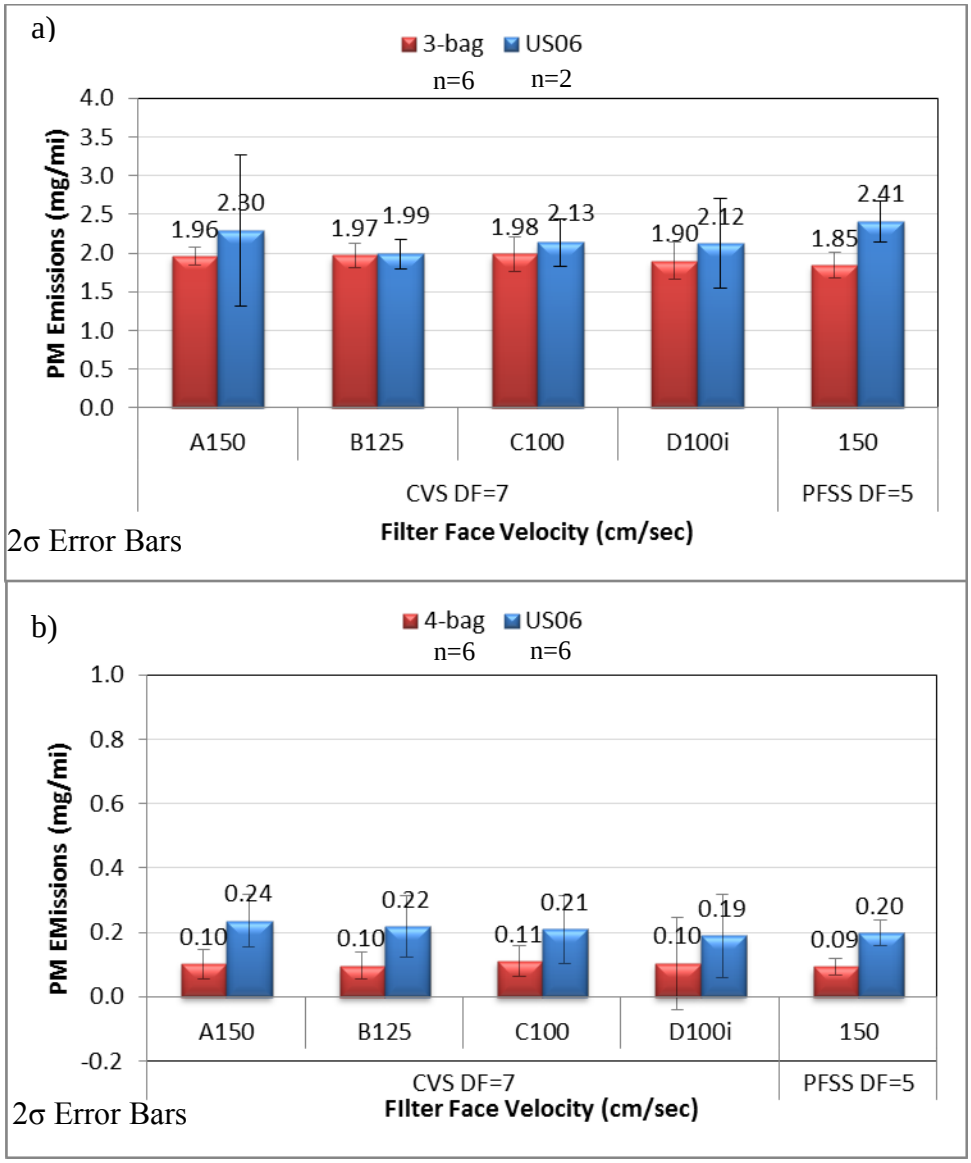

Figure 3-1 PM emission rates for the CVS and PFSS probes (a) High, (b) Lower PM Source

[1] Data are corrected for background PM. Error bars represent two standard deviations (2σ). The labels A150, B125, C100, and D100i, denote different sampling probes (i.e., A, B, C, and D) along with the associated FFV (i.e., 100, 125, and 150). The D100i represents the Probe D system with individual filters per phase; the others represent combined filters. The Higher PM Source GDI vehicle was unable to maintain the US06 trace, reducing the sample size to n=2, which means that the data variability may be higher due to the operational difficulties. See statistical support data in Appendix J for details.

The Lower PM Source had much lower overall PM emission levels. The Lower PM Source showed an emission rate that varied between 0.11 to 0.09 mg/mi for the FTP test and 0.19 to 0.24 mg/mi for the US06 test. The differences between each of the probes and the overall average for all the probes were only 0.02 mg/mi for the FTP. This suggests good consistency across the different sampling probes. The Lower PM Source US06 data also showed relatively small differences between the PM emissions measured for the different sampling probes.

3.1.2 PM filter weights (µg)

Figure 3-2 shows the accumulated PM filter weights for all the PM probes for both PM Sources and both cycles. The filter weights increased in proportion with increased FFVs and lower DFs for all test cycles and both vehicles. The Higher source filter weight varied from 205 µg to 417 µg for the

C100 samplers and PFSS, respectively. The US06 test cycle showed lower filter weights compared to the FTP test cycle for several reasons. The US06 is a shorter cycle, it does not include a cold start, and it has fewer transients than the FTP test. The Lower PM Source filter weights varied from 26 µg to 39 µg for the C100 and PFSS, respectively. The Lower PM Source filter weights are close to the CVS tunnel blank average of 5±4 µg and the PFSS tunnel blank of 1±1 µg measured during the confirmation testing. Thus, in general, the Higher PM Source vehicle showed filter weights well above the tunnel contamination levels, but the Lower PM Source weights were close to the CVS tunnel blank levels.

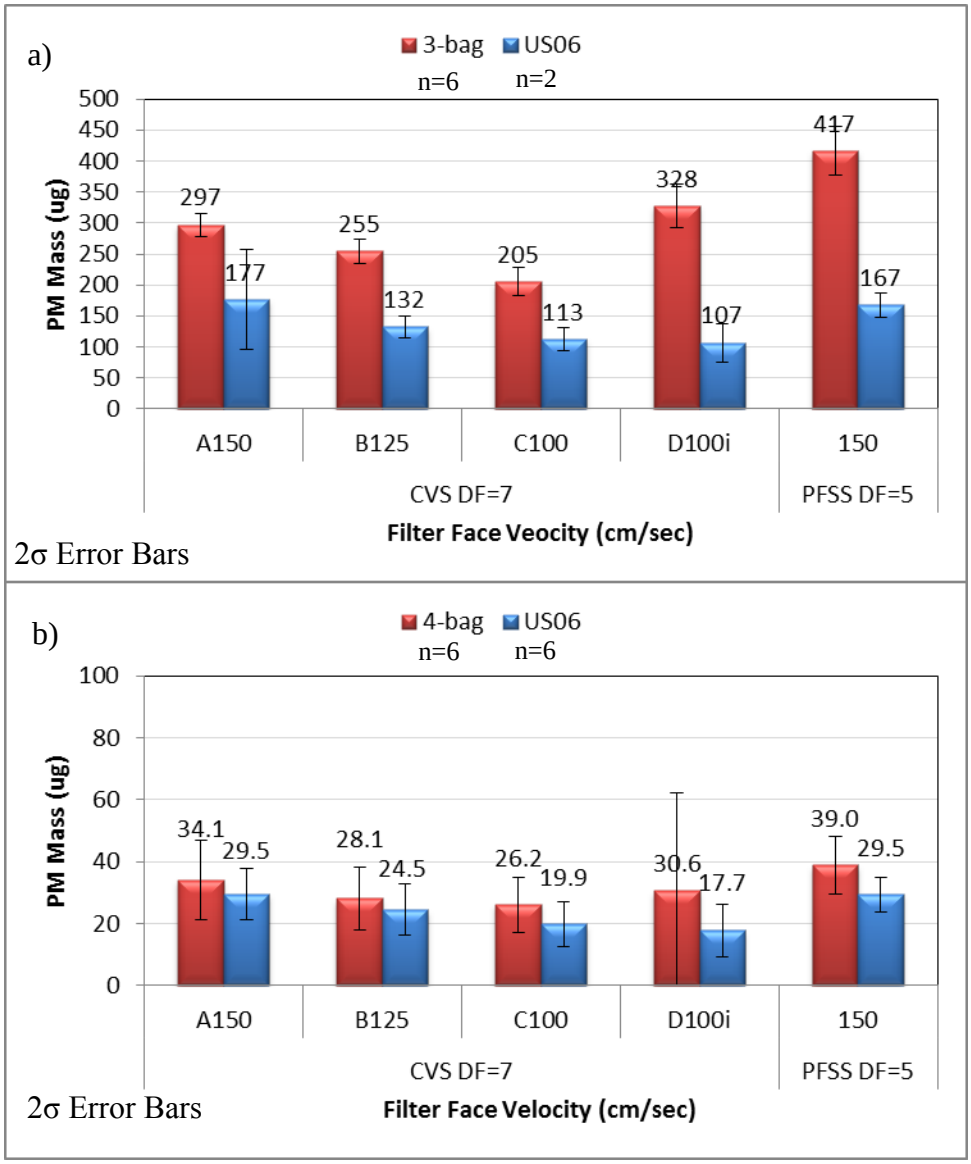

Figure 3-2 PM filter mass gain for the CVS and PFSS probes (a) High, (b) Lower PM Source

[1] Error bars represent two standard deviations (2σ). The labels A150, B125, C100, and D100i, denote different sampling probes (i.e., A, B, C, and D) along with the associated FFV (i.e., 100, 125, and 150). The D100i represents the probe D system with individual filters per phase; the others represent combined filters. The Higher PM Source was unable to maintain the US06 trace, which reduced the sample size to n=2, which means that the data variability may be higher due to operational difficulties.

3.1.3 PM composition (mg/mi)

Composition of the PM is important to understand differences in the analysis of higher FFV, lower DF, and flow-weighted combined filters. The PM from the Higher and Lower PM Sources are expected to have different compositions due to their combustion design differences. This section discusses the composition for both vehicles and provides a context for understanding the analysis and discussion provided in the later sections. During this program composition was measured with quartz filter media via the National Institute for Occupational Safety and Health (NIOSH) method and with the use of the micro soot sensor (MSS) measurement system. The NIOSH filter method was limited to the screening tests so the NIOSH results will be presented in a later section.

Figure 3-3 shows the correlation between PM mass (Probe C100) and the MSS soot particles for both PM Sources and for the FTP and US06 tests cycles during confirmation testing. Since the MSS predominantly measures soot particles, the larger the fraction of soot in the total PM the closer the correlation will be one-to-one. In contrast, a lower slope would suggest a lower fraction of soot in the PM and the greater likelihood for more organics. For the Higher PM Source, the results show that the soot measurements are biased low (slope = 0.98 forced through 0) compared to the total PM mass. The R^2 was low (~0.5) for this data set, but when the screening and confirmation data were grouped, the R^2 was greater than 0.95 (see Figure 3-19). For the US06, the slope was only 0.52, suggesting that soot was cut in half compared to the FTP. Only two data points were available for the confirmation testing, but when the screening data was also considered, a slope of 0.54 and an R^2 of 0.86 were reported (see Figure 3-19). In summary, the Higher PM Source showed a consistent ratio of soot to total PM. The ratio was 0.97 for the FTP cycle and 0.54 for the US06 cycle, thus suggesting there was more organic PM for the US06 test cycles compared to the FTP cycles.

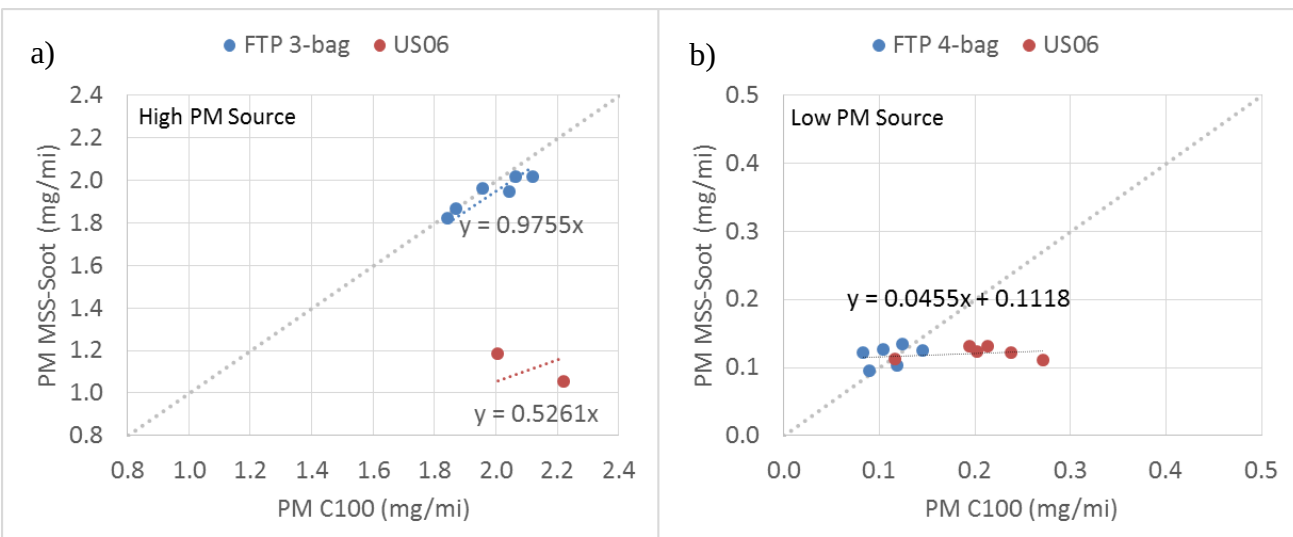

Figure 3-3 MSS and PM mass correlations for the (a) Higher and (b) Lower PM Sources

[1] MSS and PM emission determined by Probe C with (a) FTP tests with Higher PM Source, (b) FTP tests with Lower PM Source, and (c) US06 tests with the Lower PM Source.

For the PFI vehicle, on the other hand, the results show little correlation between soot particles and total PM mass. Figure 3-3 (b) shows that the slope for the FTP and US06 tests cycles was flat and similar (0.045 mg/mi) and had a constant offset of 0.11 mg/mi. It is interesting to note that the emission level range for the FTP was small and within 0.1 mg/mi, while the US06 was more variable from 0.15 to 0.24 mg/mi. For both cycles, as the PM emissions increased, the soot fraction seems to have remained relatively constant (at around 0.11 mg/mi) and only the organics have increased. If

the screening results are included, this trend was found for both the FTP and US06 tests. This suggests that the ratio of soot to total PM for the Lower PM Source vehicle varies with emissions level where the soot fraction is relatively constant at around 0.11 mg/mi.

Comparisons between the MSS soot measurement agreed well with the elemental carbon (EC) NIOSH measurement for both cycles and both vehicles from the screening tests (see Section 3.3.2 for details). Additionally the OC measurements were relatively consistent between tests. In general the overall results indicate that the soot fraction of the PM mass was higher for the Higher PM Source vehicle and lower for the Lower PM Source vehicle. Based on the low soot and EC measurements for the Lower PM Source vehicle, it can be assumed that organic aerosols represent a large fraction of the PM mass, which could have different characteristics as a function of varying FFVs, DFs and combining filters, as discussed in Appendix A.

Summary of observations for the composition results (from confirmation testing only):

- During confirmation testing, the FTP PM composition was mostly soot (EC) for the Lower and Higher PM Sources.
- The US06 tests showed less soot dominance for both vehicles. The Lower PM Source showed a range of soot to total PM between 40 to 95%, and the Higher PM Source was about 50% soot. The lower PM Source showed relatively constant soot (EC) emissions rate of about 0.1 mg/mi where the volatile organics varied from test-to-test.

3.1.4 Real-time PM emissions

The real-time PM results are presented here to show when the PM emissions are occurring in order to quantify possible deviations. Several real-time PM instruments were utilized in this program, as described in the experimental section. Real-time mass measurements are presented on a concentration basis in mg/m^3, as measured or calculated by the instrument on a percent of total accumulated mass basis. The percent of accumulated mass basis is the continuous mass sum of the mass emissions over time divided by the final mass. The accumulated mass percent basis shows a direct relationship between the test phases and when the PM is emitted. Note that the real-time PM measurements do not necessarily represent total PM mass emissions, as the measurement principles for some instruments, such as the MSS, differ in their effectiveness in measuring total PM for PM with different compositions.

Figure 3-4 through Figure 3-7 show real-time PM mass results for the Higher and Lower PM Sources tested for the FTP and US06 test cycles. Figure 3-4 and Figure 3-5 show the real-time and accumulated PM mass as measured by the MSS for the FTP for the Higher PM Source and Lower PM Source, respectively. Figure 3-6 and Figure 3-7 show the real-time and accumulated PM mass as measured by the MSS for the US06 for the Higher PM Source and Lower PM Source, respectively. In addition, Figure 3-5 shows accumulated PM mass from the integrated particle size distribution (IPSD) method based on EEPS measurements. See Section 2.3.2 and Appendix H for details on the IPSD real-time PM mass calculation method.

Figure 3-4 shows that 50% of the accumulation of soot PM for the Higher PM Source occurred during the first 100 seconds of Phase 1 of the FTP, but that PM emissions were more evenly distributed over the US06 test cycle. This is particularly important for the FTP, since the 3-bag FTP utilizes a 43% flow-weighting factor for Phase 1 of the 3-bag FTP and 75% flow-weighting factor for the 4-bag FTP. The fact that most of the mass occurs during Bag 1 of the FTP has a significant effect on the distribution of the PM mass that is collected on the accumulated filters between the 3-

bag and 4-bag tests. For the lower PM Source, as much as 80% of the soot is accumulated during the Phase 1 bag (see Figure 3-6).

The US06 test results show a different accumulation profile. The PM accumulation is more evenly distributed and appears to be accumulated during the several hard accelerations for both the higher and lower PM Sources. The US06 FFV and DF comparisons should be interesting since flow-weighted FFV reductions will not affect the overall flow rates as they do in the FTP testing.

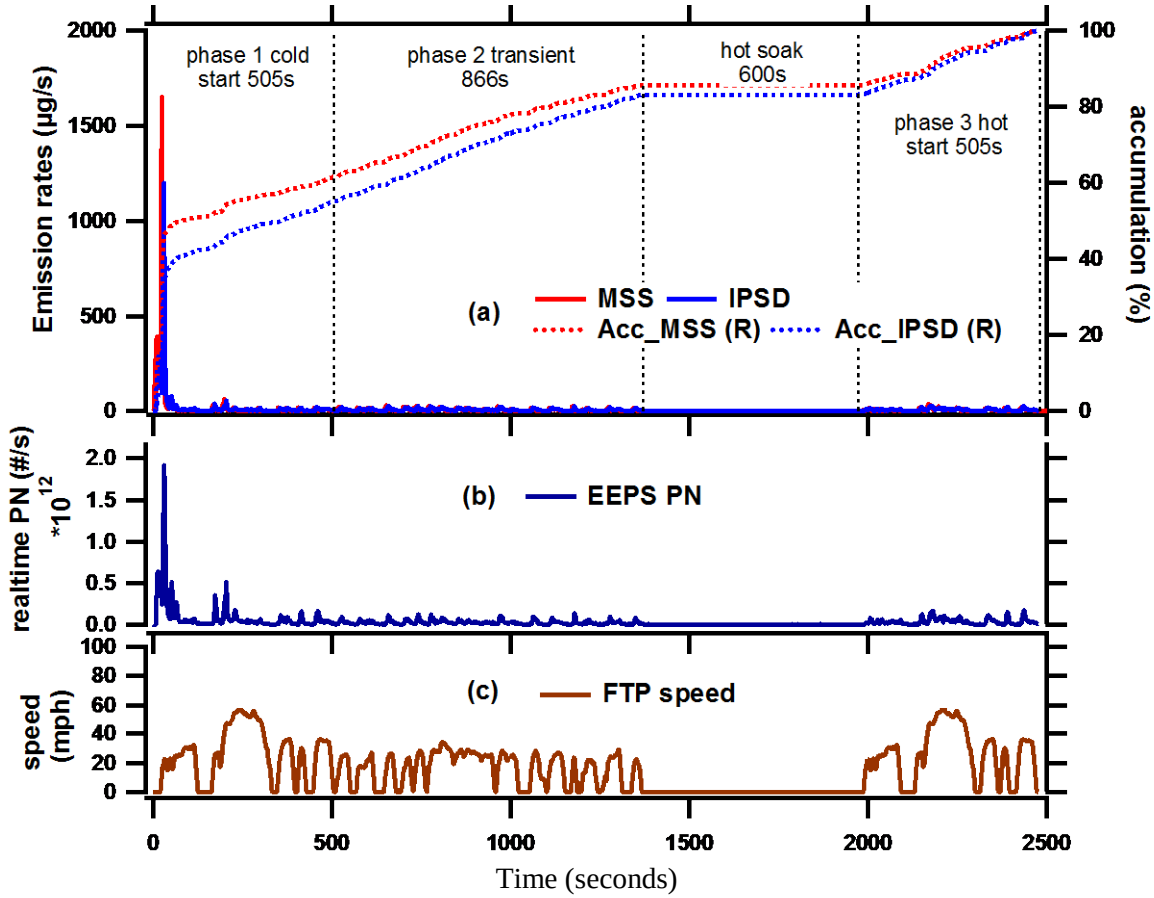

Figure 3-4 Real-time PM emissions for a 3-bag FTP test with the Higher PM Source.

[1] Note IPSD means Integrated Particle Size Distribution method to estimate PM mass. The IPSD derived value is measured by the EEPS instrument. (R) in figure (a) means the scale is on the right y-axis.

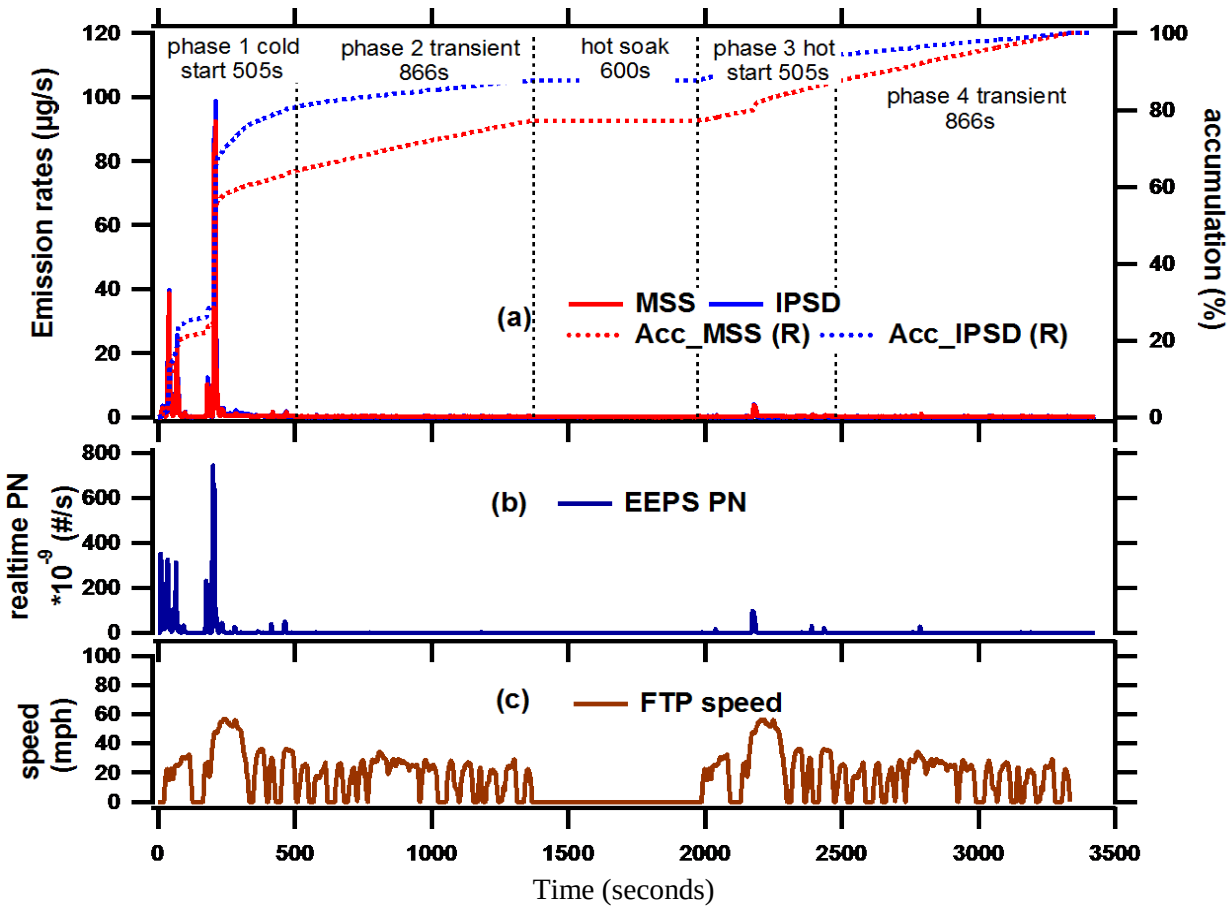

Figure 3-5 Real-time PM and PN emissions for the 4-bag FTP test with the Lower PM Source

[1] Note IPSD means Integrated Particle Size Distribution method to estimate PM mass. The IPSD derived value is measured by the EEPS instrument. (R) in figure (a) means the scale is on the right y-axis.

The Lower PM Source was composed of mostly organic species, which are not well-characterized by the MSS instrument. Organic species which condense on filters may not be captured by the MSS, EEPS, and DMM instruments. Particle number (PN) emissions also provide a measure of real-time PM emissions, including organic species. PN emissions are measured as #/cc; this was translated to #/s to better understand the transient emission rates. It should be noted that the condensation particle counter (CPC) (TSI, 3776) measurements were over-ranged (> $1.5*10^5$) for portions of the FTP test, in particular during the cold start. The CPC results are given primarily to show more qualitative trends in the emissions. Figure 3-8 shows the real-time measurements of PM and PN emissions during the FTP cycle for the Lower PM Source. The real-time instruments show consistent emission trends for both PM and PN emissions. The data show that the majority of particles are produced during the cold start and during vehicle accelerations on a mass and number basis. In addition, the mass emissions are mostly zero after Phase 1, but the PN emissions are still relatively transient. This suggests that the organics are formed throughout the test, but most of the soot is formed at the cold start. In general, the MSS provides higher mass emission rates than the IPSD method using the EEPS, especially during peaks in the particle concentration, and the CPCs show consistent number emissions for the full test cycle.

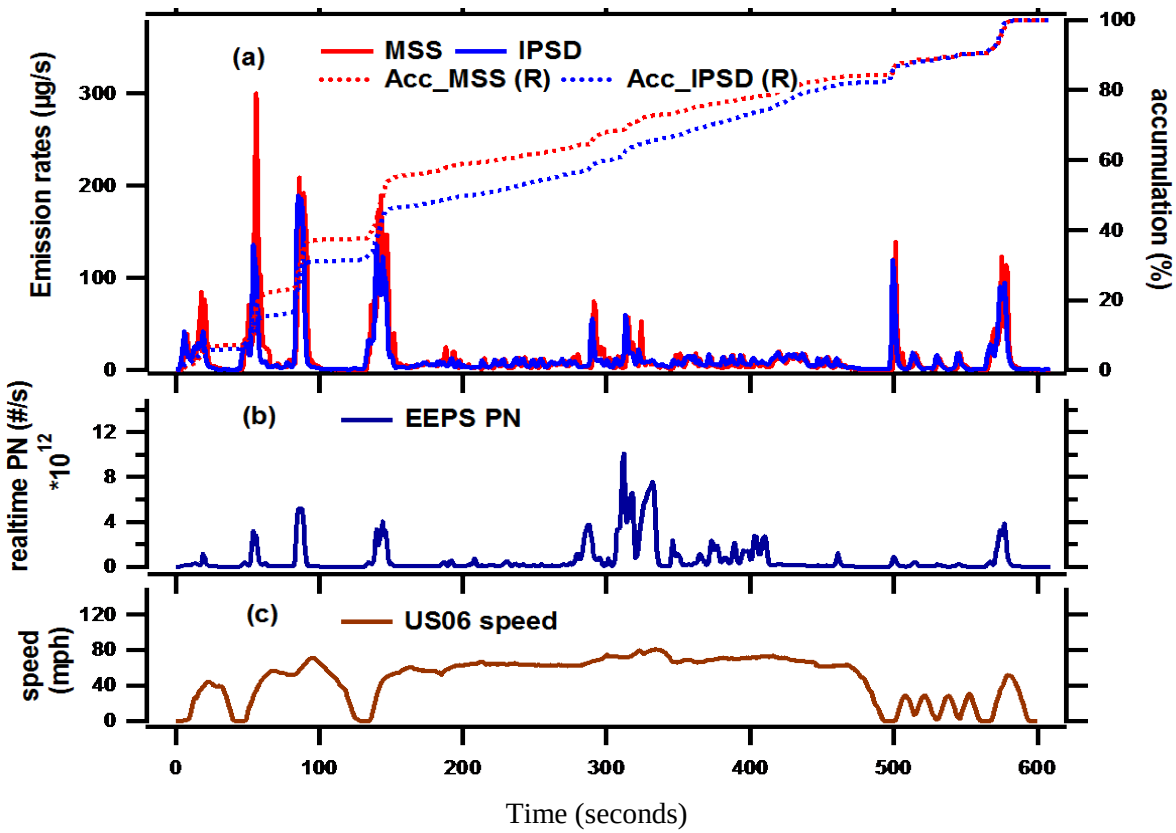

Figure 3-6 Real-time PM emissions for the US06 test with the Higher PM Source

[1] Note The IPSD derived value is measured by the EEPS instrument. (R) in means the scale is on the right y-axis.

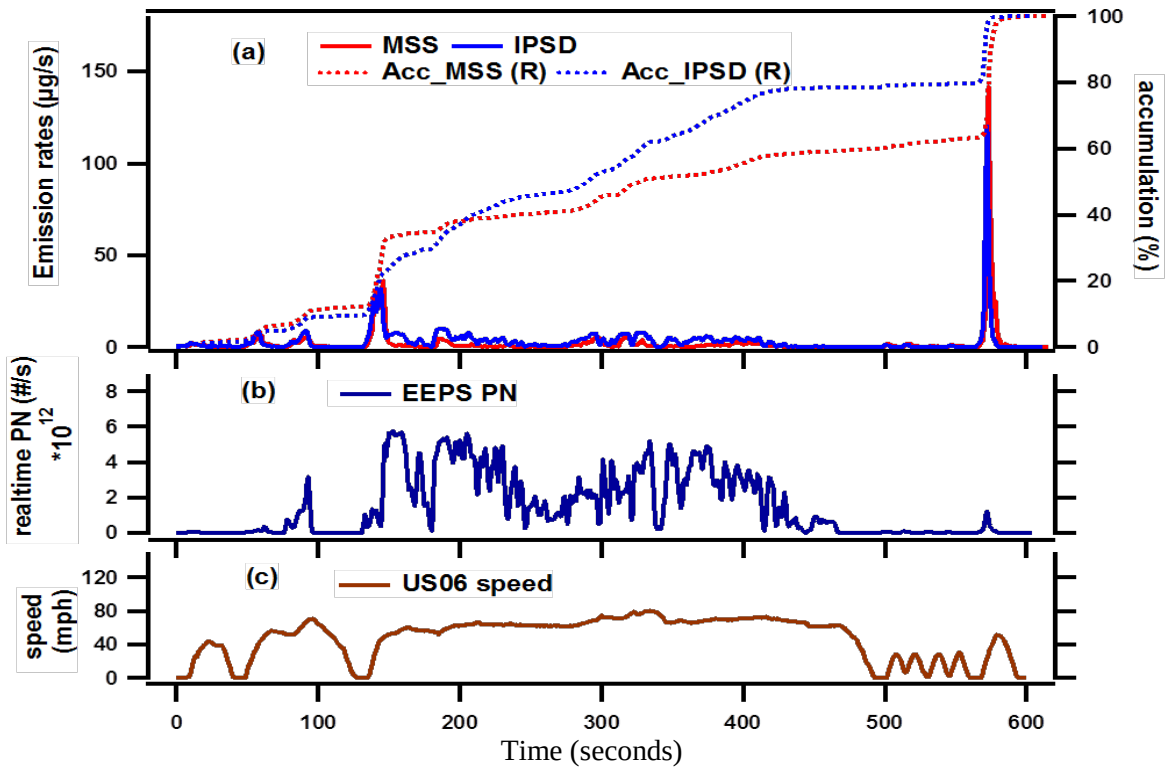

Figure 3-7 Real-time PM emissions during the US06 test with Lower PM Source

[1] Note that the IPSD derived value is measured by the EEPS instrument. (R) in means the scale is on the right y-axis.

Another characteristic important for evaluating the effects of FFV, DF, and combined filters is the particle size distribution. As discussed in Appendix A, Teflon™ filter penetration efficiency is a function of particle size and FFV, where the penetration efficiency increases for smaller size particles and higher FFVs. Thus, understanding the differences in particle size distributions between the two sources and the two test cycles is necessary for a thorough understanding of the method improvements considered. The particle size distributions (units of #/sec) for the Lower and Higher PM Source are shown in Figure 3-9 through Figure 3-12 for each of the test cycles. The test cycle speed trace is also shown in the figures by the yellow line in the background. Figure 3-9 and Figure 3-10 show results for the Higher PM Source for the FTP and US06 test, and Figure 3-11 and Figure 3-12 show results for the Lower PM Source for the FTP and US06 test cycle.

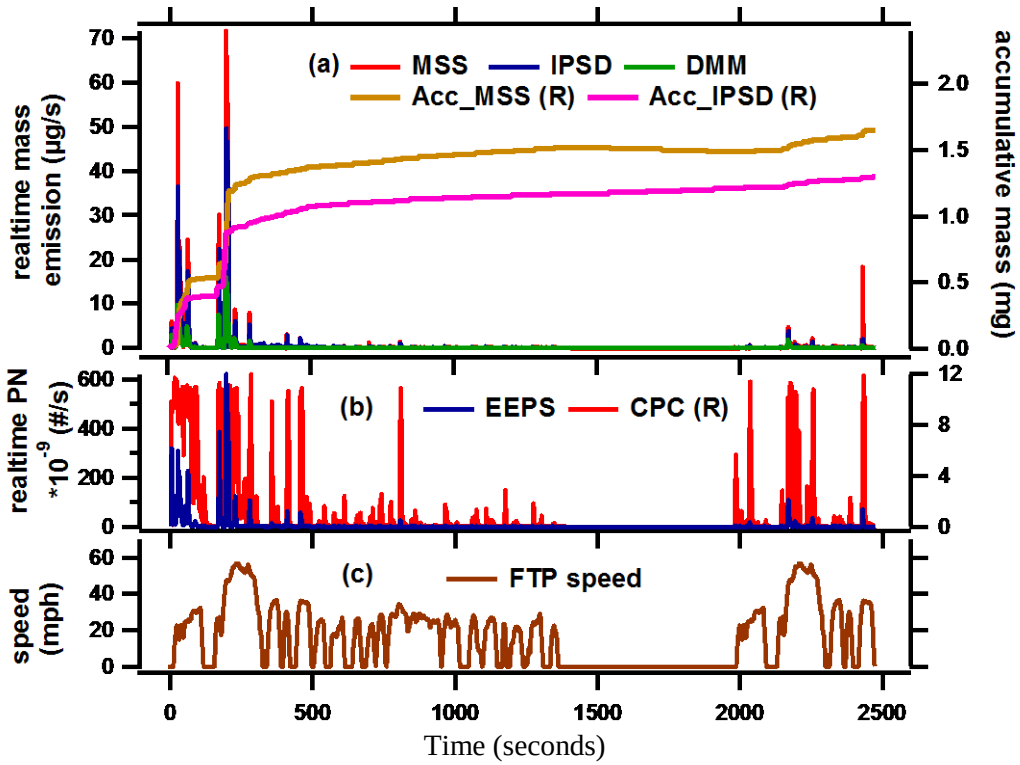

Figure 3-8 Real time PM and PN emissions during Lower PM Source FTP cycle.

[1] Note IPSD means Integrated Particle Size Distribution method to estimate PM mass. The IPSD derived value is measured by the EEPS instrument. (R) in figure (a) means the scale is on the right y-axis.
(a): Real-time and accumulated PM determined by the MSS, DMM and the IPSD method. (b): PN determined by EEPS and CPC. CPC seems to be saturated though the max reading (1.2E5) is far lower than the detect limit (3.E5) of the instrument; (c) FTP cycle speed.

For the Higher PM Source, the particle size distribution shows a concentration peak during the cold start. The high concentration required additional dilution for the Higher PM Source FTP test to prevent over ranging the EEPS. The large EEPS PSD concentration spike agreed with the MSS-soot measurement spike of ~1.5 mg/m3 (Figure 3-4) where ~60% of the total soot mass was accumulated. The distributions showed a predominant accumulation mode with peaks around 65-90 nm for both cycles, with bimodal size distributions seen under some conditions, but not others. In general, the Higher PM Source exhibited diesel-like size distributions over both cycles, with peaks at ~65-90 nm. This finding is consistent with previous studies conducted on GDI vehicles (Storey et al., 2010; Storey et al., 2012; He et al., 2012). For the Higher PM Source, the higher concentrations were seen for Bag 1 of the FTP and for the US06, although the shape of the size distributions is very similar.

Nucleation mode particles with peaks at ~15 nm and ~55 nm in the size distributions were also found for the Higher and Lower PM Sources.

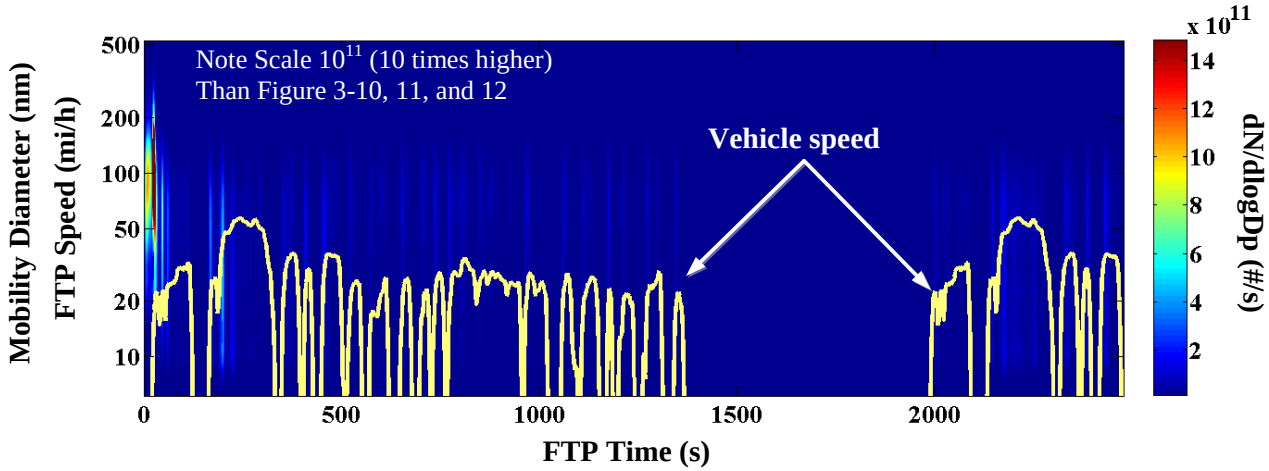

Figure 3-9 FTP particle size distributions (EEPS) for the Higher PM Source

[1] EEPS particle concentration was converted to tailpipe emission rate (in #/s) for better inter-comparison. Sampling was conducted from a secondary dilution tunnel connected to the CVS due to over ranging issues with the Higher PM Source (Additional dilution set at 10 to 1).

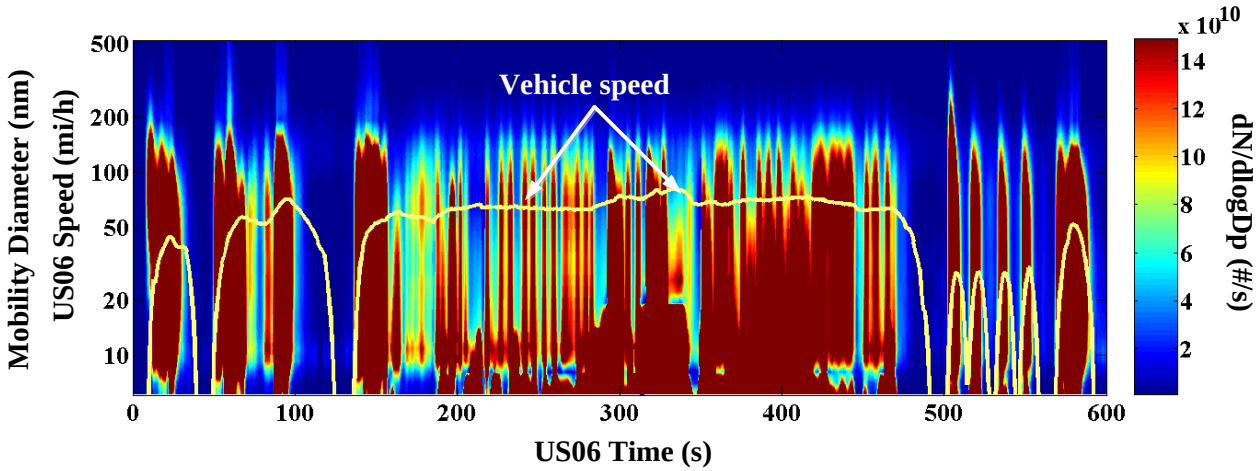

Figure 3-10 US06 particle size distributions (EEPS) for the Higher PM Source

[1] EEPS particle concentration was converted to tailpipe emission rate (in #/s) for better inter-comparison. Sampling was conducted from the CVS without secondary dilution.

The average particle size distributions for the EEPS are presented in Figure 3-13 on a number basis and in Figure 3-14 on a mass basis. The size distributions appear to have, on average, a larger presence of nucleation mode particles during the US06 test cycle compared to the FTP test cycle (see Figure 3-14). If one looks at these results on a mass basis, the Lower PM Source US06 test peak mass diameter agrees with the results from the FTP tests and is centered over 105 nm as assumed during the filter efficiency hypothesis testing presented in Appendix A5. The presence of a large nucleation mode peak for the Higher PM Source for the US06 test cycle contributed to the overall peak particle diameter for the PSD on a mass basis shifting from over 105 nm to 80 nm.

In general, the Lower PM Source for either of the cycles and the Higher PM Source for the FTP cycle do not show a significant nucleation mode mass contribution that could influence the effectiveness of the different methods. There is an indication of nucleation mode particles for the Higher PM Source for the US06 test cycle.

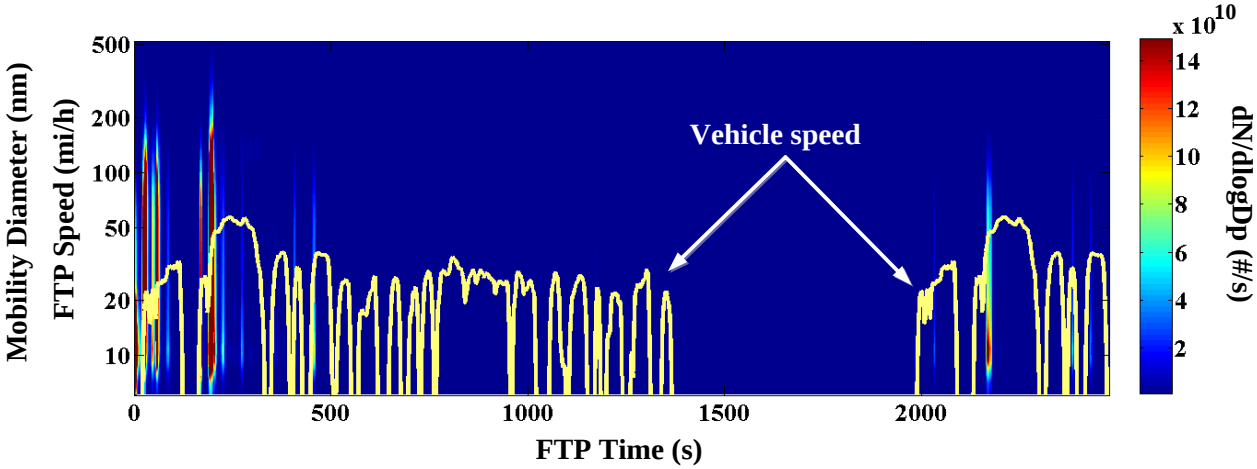

Figure 3-11 FTP particle size distributions (EEPS) for the Lower PM Source

[1] EEPS particle concentration was converted to tailpipe emission rate (in #/s) for better inter-comparison. Sampling was conducted from the CVS without secondary dilution.

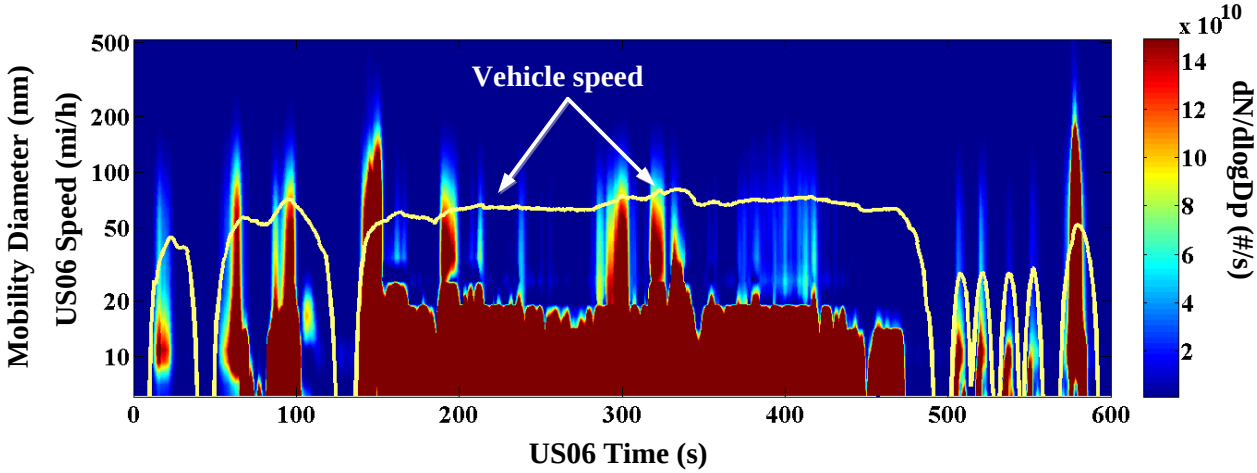

Figure 3-12 US06 particle size distributions (EEPS) for the Lower PM Source

[1] EEPS particle concentration was converted to tailpipe emission rate (in #/s) for better inter-comparison. Sampling was conducted from the CVS without secondary dilution.

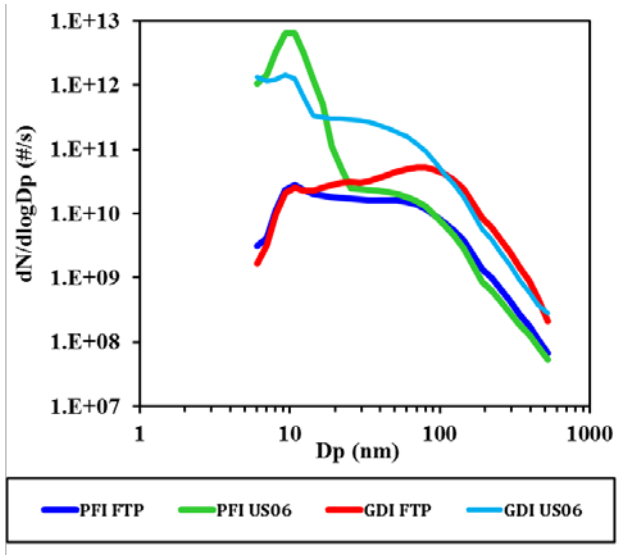

Figure 3-13 Averaged number-PSD for the Higher and Lower PM Sources

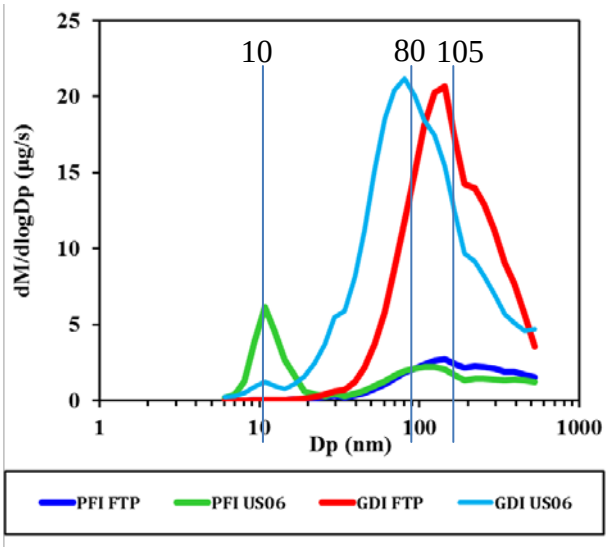

Figure 3-14 Averaged mass-PSD for the Higher and Lower PM Sources

Summary of observations for the PSD properties of the tested vehicles:

- The PM PSD showed a large nucleation mode (~10nm) for the US06 tests on both vehicles which were not present for the FTP tests. The event was more pronounced for the Higher PM Source vehicle. The nucleation event occurred during the steady state portion of the US06 where exhaust temperatures exceeded 200ºC in the exhaust and transfer tube systems. The nucleation event could be from the transfer line where sample line condition may be important.
- The Higher PM Source mass-based PSD decreased from the FTP to the US06 tests. The cause of this reduction was the large nucleation mode event that occurred during the stabilized portion of the test where temperatures exceeded 200ºC in the exhaust and transfer tube systems.
- The PSD was lower for the US06 test cycles compared to the FTP cycle and caused a shift in the mass median diameter from 105 to 80 nm for the Higher PM Source and 105 to 10 nm (with a secondary peak at 100 nm) for the Lower PM Source. This is significant because the lower PSD would change the theoretical filtration efficiency expected as FFV varies.
- The change in composition and PSD is significant as it demonstrates the robustness of this study to consider real impacts of modifying sampling conditions while the PM sources' physical properties are varying.

3.2 PM method assessment (mg/mi): Confirmation results only

This section provides a more detailed discussion of the effectiveness of the changes in FFV, DF, and combined filter to improve the effectiveness of gravimetric PM mass measurements. The results are predominantly based on the confirmation results, since this was the most robust and consistent portion of the testing, but in some cases, they also incorporate results from the screening tests, since some of the parameters were repeated in both portions of the study to increase the sample size.

3.2.1 Filter face velocity (FFV)

In this subsection, the results are provided to answer the question "Does increasing the FFV decrease variability and improve the signal-to-noise ratio, while not altering the measured PM mass?" An evaluation of CVS probes A, B, and C answers this question. These probes were all operated with the same DF and flow-weighting conditions and sampled from the same diluted exhaust system. This

represents the most direct evaluation of FFV, since only the FFV was varied; DF and combining of filters was common to all three probes. This comparison considers FFV changes between 150 and 125, 150 and 100, and 125 and 100 cm/sec. The comparison to Probe D, which collected an individual filter for each bag of the FTP, is considered in the combined filter subsection.

Overall, it was anticipated that the increase in FFV would provide higher filter masses, which could improve the signal-to-noise ratio for the PM mass measurement. In turn, there is a possibility that the collection of more mass could increase the pressure drop across a filter, which could promote volatilization that could lead to the loss of adsorbed mass. It has also been suggested that increased FFVs could lead to reduced PM filter efficiencies (see Appendix A for details). A reduction in the PM filter efficiency or a reduction in PM mass via volatilization would have a direct impact on reducing the PM emission rate on mg/mi basis, thus causing an alteration to the measurement method which would not be a desirable outcome.

The predicted PM filter efficiencies were very high: greater than 99.9% for changes in FFV from 20 up to 300 cm/sec for a nominal filter fiber specification and a nominal mass particle size distribution (see Table A-1 Appendix A). A slight change in the filter fiber details dropped the filter efficiency from 99.996 to 88% at a FFV of 200 cm/sec (see Table A-2). Additionally, if the mean mass particle size distribution shifts to smaller sizes, the filter efficiency could be reduced to between 48% to 89% efficiency, depending on the filter solidity and effective fiber diameter (see Figure A-3 and A-4, Appendix A). This suggests that filter media and PSD are critical for the evaluation of FFV. The impact of FFV on filter mass could also be affected by the composition of the PM due to adsorption and desorption issues, but these complex details would require detailed studies beyond the scope of this project. In general, the US06 tests for both vehicles showed up to 50% of the PM from semi-volatiles compared to the FTP tests, which suggests composition differences were incorporated in the FFV evaluation part of this study.

For this discussion, we investigate if the FFV method improvement altered the measured PM emission rate for the Higher PM Source near 3 mg/mi and the Lower PM Source less than 1 mg/mi. Next, we investigate if the higher FFVs improved the signal-to-noise ratio with an analysis of the mass gain on the filter weight. Finally, we evaluate whether the higher FFVs reduced the measurement variability.

Mean differences: Table 3-1 shows the paired two tailed t-test results for the selected FFVs evaluated from the CVS PM samplers for the Higher and Lower PM Sources for the FTP and US06 tests. Each column shows the p-values for a statistical comparison between two different probes operating at different FFVs. P-values below 0.05 are shown in red, showing that the differences between the probes are statistically significant at a confidence level of 95% or more. P-values greater than 0.05 but less than 0.1 are shown in blue, showing that the differences between the probes are statistically significant at confidence level greater than 90% but less than 95%. Out of the 12 combinations evaluated, only one of the p-values was blue at 0.068 (see Table 3-1). The high p-values for most of the combinations in Table 3-1 indicate that most of the mean differences are not statistically significant at the 95% confidence level. The low p-value for the 125/100 FFV combination for the 4-bag Lower PM Source tests suggests the means are statistically different at the 90% confidence level. These results in general suggest that increasing the FFV (from 100 to 150, flow-weighted, and at a DF=7) does not have a significant impact on the mean mass emission rates for Higher and Lower PM Sources. This suggests that higher FFVs did not alter the mean emission rates.

Table 3-1 Paired two tail t-test for the evaluation of FFV: p-values (mg/mi)

Cycle	Source	n	FFV Comparison p-value		
			A150/B125	A150/C100	B125/C100
4-bag	low	6	0.280	0.450	0.068
3-bag	high	6	0.614	0.339	0.553
US06	low	6	0.460	0.331	0.638
US06	high	2	0.473	0.615	0.187

[1] Note: The Higher PM Source US06 results include one screening test result to increase the sample size from two to three.

The statistically significant differences in the EC and OC fractions and particle size distributions between the Higher PM and Lower PM Source vehicles and the lack of statistically significant mean differences as discussed with the paired t-test analyses suggest that these physical PM differences did not have a significant impact when varying FFV from 100 to 150 cm/sec. This suggests adsorption and desorption concerns are not statistically significant for the 150 to 100 FFV flow-weighted comparisons. Additionally the mass-based PSD for the two PM Sources on the US06 tests cycle varied from 110 nm to 70 nm mass median diameter (see Figure 3-14). The filter efficiency derived in Appendix A was based on a mass median diameter around 110 nm, where, at lower mass median diameter, it is expected the filter efficiency may be reduced. One might expect the US06 tests to show a different trend between low and high FFVs. The fact that there was no statistically significant difference between the US06 mean tests suggests that the impact of the PSD is not significant for the vehicles tested under these conditions.

Signal-to-noise ratio: The net PM filter weights did increase for the higher FFV compared to lower FFV. Figure 3-2 shows the net filter weights in µg for the various probes for the Higher and Lower PM mass sources. An increase from 100 FFV (Probe C100) to 150 FFV (Probe A150) for the Higher PM Source produced an increase in net filter mass from 113 µg to 177 µg (n=2) for the US06 test and 205 µg to 297 µg for the 3-bag FTP test (n=6). The Lower PM Source also showed an increase in net filter mass for an increase in FFV from 100 to 150, where the net mass increased from 19.9 µg to 29.5 µg for the US06 (n=6) and 26 µg to 34 µg for the 4-bag FTP (n=6). These results show that for a given mass emission rate the signal (i.e., filter mass) was increased, thus the overall signal-to-noise ratio was affected. Although the f-test did not indicate a statistical improvement in the variance, as discussed next, the measurement signal was increased which would help minimize the influence of contamination.

Variability: Figure 3-15 shows the single standard deviation for selected confirmation tests for the Lower PM and Higher PM Sources. The variability for the Higher PM Source US06 exceeded 0.4 mg/mi for all the probes due to issues with the repeatability of the vehicle, which would mask any of the potential benefits of the evaluation; these data were not included in this analysis. The variability was lowest for the Lower PM Source 4-bag FTP and highest for the US06 tests. It appears that the variability decreased with higher FFV for the 3-bag Higher PM Source from FFV=100 to FFV=150, but as shown with the f-test in Table 3-2, these differences were not statistically significant at the 95% confidence level.

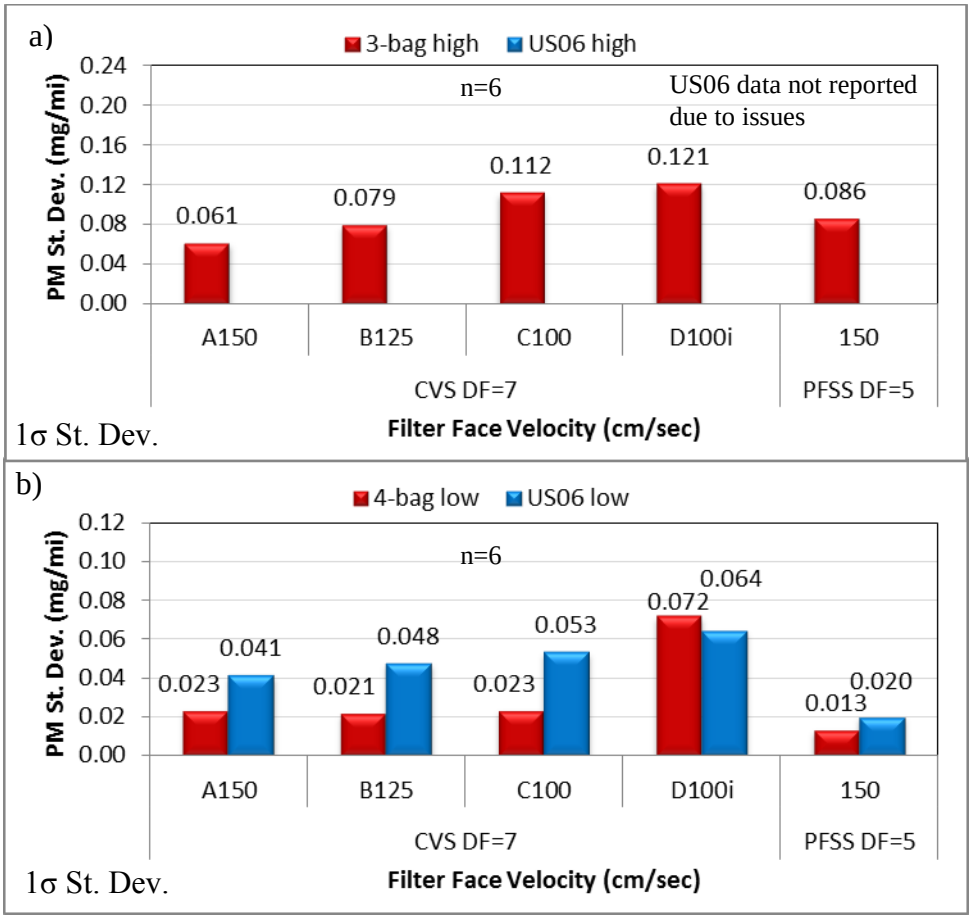

Figure 3-15 PM variability by FFV for the (a) Higher and (b) Lower sources, both cycles

[1] The Higher PM Source US06 test-to-test variability was very large (greater than 0.4 mg/mi) due to issues with the vehicle overheating. Therefore, these tests are not valid for a comparison on variability but are valid for mean differences and filter mass gain evaluations.

Variability was evaluated using an f-test to compare the variance among the different FFV cases utilized for Probes A, B, and C. Table 3-2 shows the f-test p-values for the Higher and Lower PM Sources for the FTP and US06 test. The p-values for all the tested combinations were greater than 0.05 except for the B125/C100 combination (p-value = 0.019), as shown in red in Table 3-2. The low p-value suggests the FFV of 125 compared to the FFV of 100 cm/sec for the 4-bag Lower PM Source showed a statistically significant difference in the variance at a 95% confidence level. The remaining f-test showed higher p-values than 0.05, suggesting that there were not significant differences in the variance for the different FFVs evaluated. In general, these results suggest the differences in the PM measurement variability were not statistically significant between the low FFV and high FFV for flow-weighted filters.

Table 3-2 F-test for the evaluation of FFV: p-values (mg/mi)

Cycle	Source	n	FFV Comparison p-value		
			A150/B125	A150/C100	B125/C100
4-bag	low	6	0.874	0.986	0.019
3-bag	high	6	0.582	0.211	0.377
US06	low	6	0.757	0.590	0.527
US06	high	2	0.242	0.389	0.398

[1] Note: The Higher PM Source US06 results include one screening test result to increase the sample size from two to three.

Summary: Findings regarding filter face velocity include:

- The results showed that comparisons between mean differences for flows varying from 100 to 150 cm/s were not statistically significant for most cases. These results generally suggest that increasing the FFV from 100 to 150 does not have a significant impact on the mean mass emission rates for the Higher and Lower PM Sources.
- The PM net filter weights did increase for the higher FFV compared to lower FFV, thus the signal (i.e., filter mass) was increased, and the corresponding overall signal-to-noise ratio was affected, although the f-test did not support a statistical improvement in the variance.
- Tests conducted at a FFV of 175 cm/sec (screening tests) suggested that at this FFV, filter overloading could occur under different sampling conditions.

3.2.2 Dilution factor (DF)

The dilution factor evaluation considers the differences between PFSS, which was set to a DF=5, and the CVS system, which was set to a DF=7. The DF=5 for the PFSS was the minimum average dilution factor recommended based on the screening testing. The DF comparisons could only be performed utilizing the PFSS due to the greater potential for condensation for the full flow CVS compared to the partial flow sampling process. The dilution factor for the CVS is defined by the carbon balance calculation, and the DF for the PFSS is defined by the flows of the PFSS system, as discussed Section 2.2.3. There were differences in the evaluation of the DF, as discussed in Section 2.2.3. Dilution factor also has an impact on particle formation, which is a complex process dependent on composition, humidity, residence time, temperature, vapor pressure, and PSD. The actual DF will oscillate above and below DF=5 during a transient test, but based on predictions, the relative humidity at the filter surface will never reach condensation at 47°C, as discussed in Appendix A. It is not well known what may happen to the PM collection method during short durations of very low dilution. This section investigates the impacts of low DF on PM emissions measurements as compared to the approved minimum DF=7 and various FFVs.

The DF=5 results for the PFSS (FFV=150) and the DF=7 results for CVS Probes A, B, and C (with flow-weighted FFVs of 150, 125, and 100 cm/sec, respectively) and CVS Probe D (the individual filter per phase FFV = 100 cm/sec denoted as PM Sampler D100i) were compared. The PFSS was set up for a single FFV (=150 cm/sec) based on the results of the screening tests. In comparing the CVS and PFSS, the most direct comparison was between the PFSS and Probe A for the CVS, as both samples were collected at an FFV = 150 cm/sec. Probe D100i represents the CFR 1066 best practices at the time of this research; this will represent a comparison to the initial best practices.

The differences between the CVS and PFSS PM samplers need to be considered when reviewing these results. The CVS probes collect their sample from the same diluted exhaust, dilution air treatment system, transfer lines, and heated systems. These probes will have similar contamination

artifacts, residence times, diluted PM concentration, and the same water concentrations. The main differences among these four unique CVS probes are the modified conditions and the calibration of the mass flow controllers (calibrated by the same outside laboratory). The PFSS is an independent measurement system compared to the CVS where the PFSS has a different dilution process, dilution air treatment, transfer line, flow meters, and calculation approach. Additionally, the PFSS relies on a proportional signal to the exhaust flow using an advanced exhaust flow meter where slight timing errors can accumulate to yield inaccurate comparisons to a full flow CVS. Thus, it is expected the CVS PM probes would have closer agreement than comparisons between the CVS and PFSS PM probes. A future research project to evaluate differences between the CVS method and various available PFSSs is recommended.

Mean differences: Table 3-3 shows the paired two tailed t-test for the comparison between the PFSS probe and the CVS probes for the Higher and Lower PM Source on both test cycles. P-values below 0.05 are shown in red. The 4-bag Lower PM Source tests had p-values greater than 0.05 for all the combinations tested and all but one of the US06 tests, suggesting the mean differences are not statistically significant at the 95% confidence level. Interestingly, the one US06 condition that did show a statistically significant p-value of less than 0.05 was the comparison between the PFSS and Probe A in the CVS tunnel, where both used a FFV=150 only differed by DF (7 vs 5 for the CVS vs PFSS probes, respectively), notwithstanding the differences between the PFSS and CVS itself. More statistically significant differences were found for the 3-bag Higher PM Source. For the Higher PM Source, statistically significant differences in means at a 95% confidence level were found for the combined filter CVS probes for FFV = 150, 125, and 100 (and DF=7) compared to the PFSS, but not for the individually sampled filter base conditions case (Probe D100i). The Higher PM Source showed no statistically significant means for the US06 testing.

Table 3-3 Paired two tail t-test for the evaluation of DF: p-values (mg/mi)

Cycle	Source	n	Dilution Factor p-value			
			A150/PFSS	B125/PFSS	C100/PFSS	D100i/PFSS
4-bag	low	6	0.166	0.616	0.133	0.736
3-bag	high	6	0.002	0.004	0.001	0.083
US06	low	6	0.053	0.405	0.616	0.729
US06	high	2	0.727	0.043	0.032	0.236

[1] The PFSS was operated at DF=5 and a flow-weighted FFV = 150 cm/sec, CVS (probes A, B, C, D) are DF=7. The Higher PM Source US06 results includes one screening test result to increase the sample size from two to three

In evaluating the results of the comparisons based on dilution factor, it is important to consider several factors. Although statistically significant, the differences in the means were relatively small. The mean difference for the PFSS compared to the CVS probes averaged -2.7% compared to Probe D100i and -5.9% compared to Probe A150, as discussed later. These differences could be attributed to a variety of factors, including errors in the exhaust flow, proportionality, flow measurements, and other proportional sampler details. When the DF was evaluated for the PFSS utilizing the carbon balance method, the PFSS DF was 14% higher than the DF of the CVS measurement. The DF bias may be affecting the mean differences suggested for the Higher PM Source. The basis for a DF difference is discussed in more detail in Section 2.2.3.

Signal-to-noise ratio: The DF=5 and FFV=150 for the PFSS PM sampler showed the largest net filter mass compared to all the other probes for all but the US06 Higher PM Source test (see Figure 3-2). The net filter mass for the 3-bag FTP Higher PM Source tests for the PFSS PM probe was 417 µg and for D100i was 328 µg combined (215, 70, 46 µg for phase 1, 2, and 3 respectively), thus the

lower DF and higher FFV for the PFSS for the 3-bag test provided more filter mass than the baseline system. For the rest of the flow-weighted probes, at the same DF in the CVS, the combined filter mass for D100i was more than the filter weights for Probes A150, B125, and C100 for FFV = 150 to 100 cm/sec for the Higher PM Source. This can be attributed to the differences in the flow weighting for probes used for the collection of the cumulative PM samples.

Variability: Table 3-4 shows the f-test evaluation of the PFSS probes with the CVS probes. The f-test only was less than 0.05 for the D100i base case. The remaining p-values were greater than 0.05, suggesting that the PFSS does not have a statistically lower variability compared to the flow-weighted CVS probes with a FFV from 150 to 100, or compared to the individually collected filters (D100i) in most cases. The tunnel blank results for the PFSS were lower than the CVS system (1 µg vs. 5 µg), where the f-test suggests no difference in the variability between the CVS and the PFSS for any of the flow conditions and DF evaluated. This suggests that the impact of the PFSS lower tunnel blank was not a significant influence on the PFSS performance over the CVS method.

Table 3-4 F-test for the evaluation of DF: p-values (mg/mi)

Cycle	Source	n	Dilution Factor p-value			
			A150/PFSS	B125/PFSS	C100/PFSS	D100i/PFSS
4-bag	low	6	0.223	0.284	0.217	0.002
3-bag	high	6	0.477	0.870	0.573	0.468
US06	low	6	0.135	0.077	0.050	0.022
US06	high	2	0.341	0.243	0.982	0.786

[1] The Higher PM Source US06 test-to-test variability was very large and nominally greater than 0.4 mg/mi due to issues with the vehicle overheating. The Higher PM Source US06 results include one screening test result to increase the sample size from two to three.

Summary: Findings regarding dilution factor and the PFSS include:

- Comparisons were made between DF=5 and DF=7, where a PFSS was used for the DF=5 and CVS measurements were used for the DF=7.
- For the Lower PM Source tests, in general, there were no statistically significant differences at greater than a 95% confidence level for the 4-bag FTP (all p-values > 0.05 an) and US06 (all but 1 p-value > 0.05) tests. Statistically significant differences were identified for one US06 test, but the mean differences were low (~10% at the 0.21 mg/mi emission level) thus, the significances is low.
- The Higher PM Source showed more mixed results. The FTP tests showed a statistically significant difference in means at a 95% confidence for the different DFs for all probes except the individual probe (D100i). The US06 tests showed no statistical difference in the means, but the sample size was small (n=2 due to difficulties).
- The Higher PM Source mean emissions showed a low relative error of between -2.7% and -5.9% between the PFSS (DF=5 FFV=150) the different CVS flows. A relative error of 5% is a reasonable and relatively small error considering PM measurement between different laboratories where a 20% variation between facilities has been reported during PM mass and number cross lab correlations.
- It should be noted that although statistically significant differences in means were found with the Higher PM Source for the FTP tests, the mean differences were relatively small and could be attributed to errors in the exhaust flow, proportionality, and other PFSS details. These possible sources of bias between the CVS and PFSS sampler and the low mean relative errors suggest the lower DF may not be altering the measurement methods.

- The f-test p-values for most of the comparison cases were greater than 0.05, suggesting the PFSS does not have a statistically lower variability compared to flow-weighted CVS probes with a FFV from 150 to 100, or compared to the individually collected filters in most cases.
- The tunnel blank results for the PFSS were lower than the CVS system (1 μg vs 5 μg) where the f-test suggests there is no difference in the variability between the CVS and the PFSS for any of the flow conditions and DF evaluated. This suggests the impact of the PFSS lower tunnel blank was not a significant influence on the PFSS performance over the CVS method.
- Tests were also conducted at a DF=3 (screening tests), but the results indicated that at this DF, filter overloading could occur under different sampling conditions with the vehicles selected.

3.2.3 Combined filters

Combined filters have the advantage of collecting more PM mass on a single filter, but have the disadvantage of a reduced flow rate for some bags in order to flow-weight the accumulated PM mass as needed for the proper emission calculations. More significant differences in flows are needed for the 3-bag test compared to the 4-bag test. Based on the real time PM results, 50% to 70% of the PM mass are emitted during Bag 1 of the FTP test for the Higher PM Source and Lower PM Source, respectively. This means that the reduced flow during Bag 1 of the FTP probably has the biggest impact on the filter mass collected. For the US06 cycle, flow-weighting is not needed because that test is a single phase test. Therefore only FTP results are presented in this section.

Composition and PSD are important for combined filter analysis, since there is concern that the some of the PM mass accumulated during Bag 1 may be desorbed in subsequent bags when the PM concentrations are lowered by the high sampling flows. This would not be experienced with the multi-filter approach used for Probe D100i where each filter collects PM under similar conditions. Again, these details of adsorption and desorption are beyond the scope of this project, but the results for the higher FFVs could provide some indication if these issues alter the vehicles' measured emission rates. The main comparison for this section is the CVS sampler probe D100i, which was operated at a FFV = 100 and a DF = 7. The most direct comparisons are between the CVS probes, since the only differences between these probes are the FFV and the combined filters. Probes D and C provide the most direct comparison, where the FFV is the same and the only difference was combining or not combining filters.

Mean differences: Table 3-5 shows the statistical results of the paired t-tests performed between the D100i probe and the other CVS probes for both PM Sources and both test cycles. The Lower and Higher PM Source FTP cycles showed no statistical differences at 95% confidence level in means from a FFV = 150 to 100 cm/sec as compared to the individually utilized D100i conditions. One of the Higher PM Source FTP tests showed a statistically different mean at 90% confidence level between the 100 FFV probes.

Signal-to-noise ratio: The signal-to-noise ratio did not necessarily improve for the combined filters, and typically the filter mass collected for the cumulative filters was reduced due to flow-weighting conditions for the cumulative filters when compared to the filter masses for all of the individual FTP bags added together for Probe D. The filter mass for the combined D100i filters was higher for the Higher PM and Lower PM Source FTP tests (see Figure 3-2). For the Higher PM Source, the combined D100i filters weights were 328 μg compared to A150 filter weight of 297 μg for the 3-bag FTP. For the Lower PM Source, the combined D100i filter weights were 34.8 μg compared to A150 filter weight of 46.5 μg for the 4-bag FTP. The higher filter mass for the individual bag filters (when

added together) shows the significance of the flow weighting and the higher amount of PM emitted during the phase 1 portion of the FTP.

Table 3-5 Paired two tail t-test for the evaluation of combined filters: p-values (mg/mi)

Cycle	Source	n	Combined Filters p-value		
			A150/D100i	B125/D100i	C100/D100i
4-bag	low	6	0.986	0.828	0.840
3-bag	high	6	0.161	0.145	0.085

Variability: Table 3-6 shows the statistical results of the f-tests performed on the D100i probes and the other CVS probes (A, B, and C) for both emission sources and test cycles. The low p-value for the 4-bag tests suggests that the means differences are statistically significant at the 95% confidence level for the Lower PM Source vehicle with p-values ranging from 0.026 to 0.019. None of the other comparisons tests supported a statistically significant difference in variance. Figure 3-16 shows the Lower PM Source single standard deviation results between the flow-weighted tests and the individual filter tests for the 3-bag and 4-bag FTP using combined data from both the screening and confirmation tests. The standard deviation for the flow-weighted CVS and PFSS probes averaged less than 0.04 mg/mi, while it ranged between 0.13 to 0.10 mg/mi for the individual filter by bag PM sampler. The variability for the Higher PM Source did not show statistically significant differences possibly due to the much higher filter weights. This difference in variability between the Lower PM Source and the Higher PM Source suggests the light filter weight for the lower PM Source is contributing to the variability possibly due to measurement uncertainty in the gravimetric method and/or due to measurement artifact at the conditions of the lower PM Source.

Table 3-6 F-test for the evaluation of combined filters: p-values (mg/mi)

Cycle	Source	n	Combined Filters p-value		
			A150/D100i	B125/D100i	C100/D100i
4-bag	low	6	0.026	0.019	0.027
3-bag	high	6	0.161	0.377	0.869

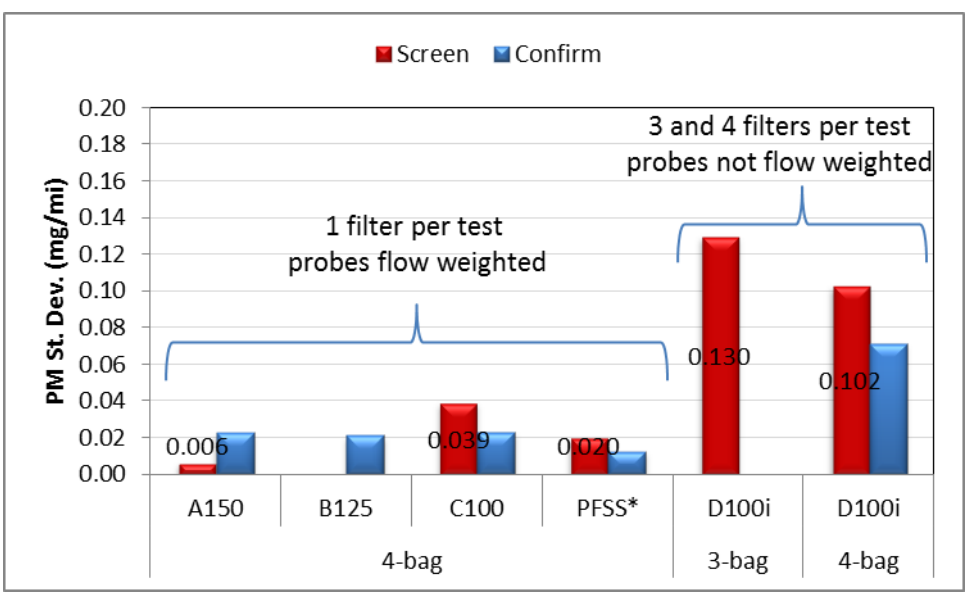

Figure 3-16 Variability between flow-weighted and individually loaded filters, Lower PM Source

Summary: Findings with respect to combining filters include:

- For the combined filters, the main comparisons were between CVS probes where PM was collected cumulatively over the full FTP vs. a probe where PM was collected individually for each FTP bag.
- Combined filters have the advantage of collecting more PM mass on a single filter, but have a disadvantage of a reduced flow rate for some bags in order to flow-weight the accumulated PM mass as needed for the proper emission calculations.
- The FTP Lower and Higher PM Source tests did not show a statistically significant difference in means for cumulative filters as compared to the filters collected individually by bag (all p-values were . 0.05).
- The signal-to-noise ratio (as represented by the filter mass) did not necessarily improve for the combined filters; the typical filter mass collected for the cumulative filters was reduced due to the flow-weighting conditions for the single phase filter when compared to the filter masses for all of the individual FTP bags added together.
- Although the signal did not increase, the variance was statistically significantly at the 95% confidence level for the Lower PM Source 4-bag FTP tests between all probes (p-values ranged from 0.026 to 0.019). This suggests the lower variance for the accumulated filter is statistically significant from the individually loaded filter for the lower PM Source 3-bag FTP test.
- The variability in the single filter method for the Higher PM Source was not statistically significant possibly due to the much higher filter weights. This was confirmed for both the screening and confirmation testing portions of the project.

3.3 Observations: Confirmation and screening data

This section explores some of the observations that were made during the vehicle emissions testing. These include data from the screening and confirmation testing.

3.3.1 PM variability (mg/mi)

PM emissions measurement variability is important to consider at these low emission levels where the range of emissions due to test-to-test differences can be more than the magnitude being measured. It is not clear whether the variability is due to the vehicle, sample system, or some systematic nature of the PM sampling method. This section presents the range of emission rates measured for the high and lower PM Sources as a function of time for the full E-99 testing program. The significance of these results is representative of five separate gravimetric PM samplers where two samplers are completely independent measurement systems (CVS vs PFSS) in addition to one real time PM sampling method (the MSS measurement). As such, these results are important for understanding the significance of the statistical confirmation tests performed at the various FFV, DF, and combined filter methods.

Figure 3-17 and Figure 3-18 show the PM emission rate for all tests during the E-99 testing program for the Lower and Higher PM Sources, respectively. The 12 month testing period shows a range of barometric pressures up to 0.55 inHg difference (2% absolute difference) for the Lower PM Source and 0.25 inHg for the Higher PM Source. The PM emission rate for the Lower PM Source ranged from 0.5 mg/mi to 0.1 mg/mi for all PM samplers, but the MSS showed a very low relative range

(0.14 to 0.08 mg/mi). For the Higher PM Source, all the PM samplers and the MSS shows a similar range of PM emissions from 1.2 mg/mi to 2.0 mg/mi.

Interestingly, the PM emissions trended very closely with ambient test cell barometric pressure for both vehicles. The trend is different for the two PM Sources. A correlation of all the PM samplers to Probe D suggested an R^2 of greater than 0.5 for both figures where the slope was negative for the Lower PM Source and positive for the Higher PM Source. It is not clear from these results if there is a statistically significant correlation between ambient pressure and PM emission rates, but it may clearly be a trend that is significant at these low PM emission rates. This high level of variability suggests a need for additional investigation to understand the impact at the 3 and 1 mg/mi certification standards and to isolate the cause of the variability (vehicle, ambient conditions, driver, measurement system, etc.…). Since the MSS soot measurement appears to follow the same trend for the Higher PM Source, this suggests the vehicle rather than measurement is causing the variability for the Higher PM Source. For the lower PM Source, the total PM shows greater variability than the MSS soot measurements, which could be due to the greater variability in the organic fraction of the PM, although the MSS measurements represent fairly low soot levels.

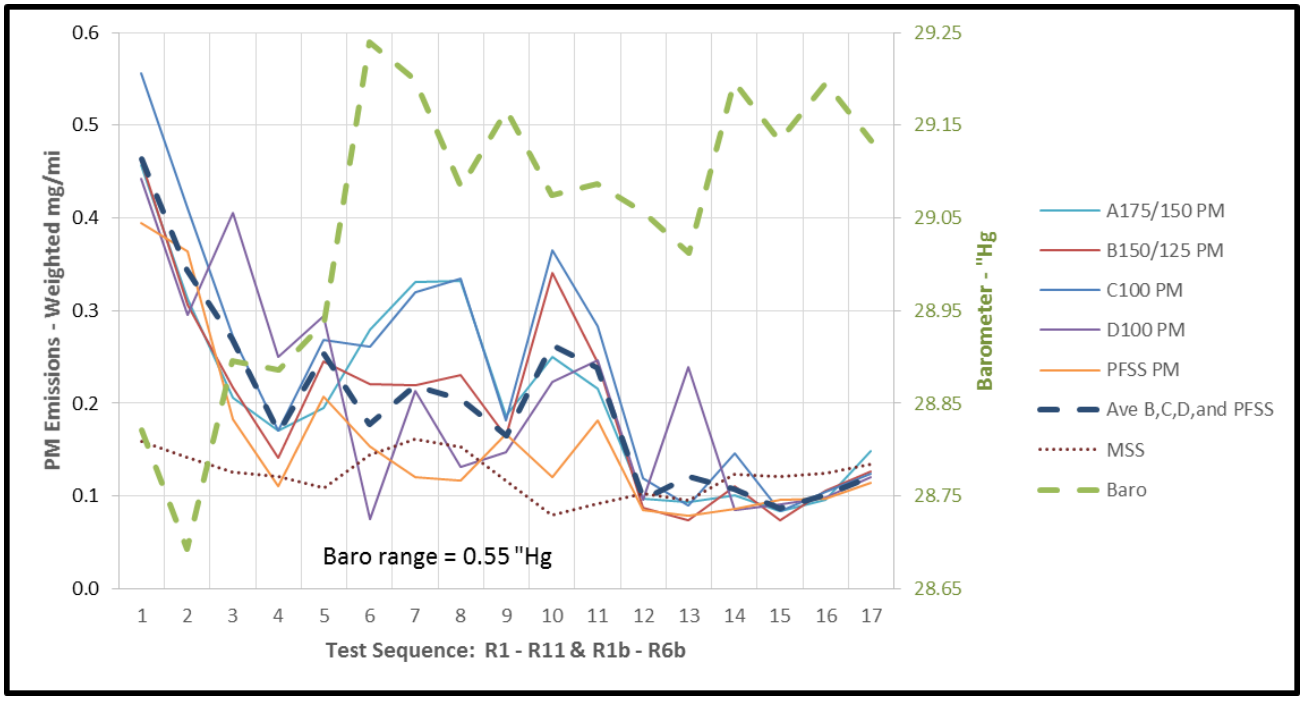

Figure 3-17 FTP time-sequenced plots for the Lower PM Source screening and confirmation tests

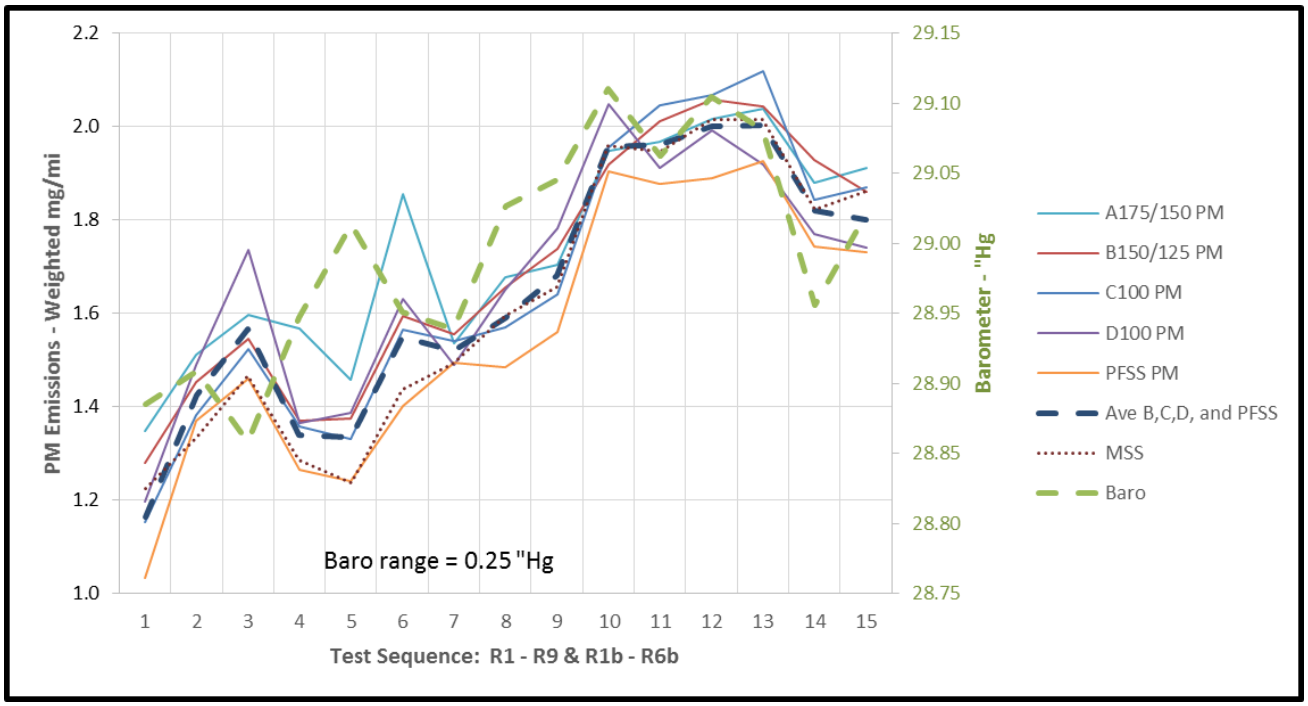

Figure 3-18 FTP time-sequenced plots for the Higher PM Source screening and confirmation tests

3.3.2 PM composition all data (mg/mi)

Table 3-7 shows the elemental carbon (EC), organic carbon (OC), EC/OC ratio, and EC/$PM_{2.5}$ ratio for a random subset of the total project tests. Figure 3-19 and Figure 3-20 show the correlation of the PM composition for all available tests in comparison to the total PM (as measured by Probe C100). Figure 3-19 shows the MSS and EC data and Figure 3-20 shows the EC and OC data in comparison to total PM.

The results show that the Higher PM Source had a higher fraction of EC or soot PM for both the US06 and FTP test cycles in comparison to the Lower PM Source. For the Higher PM Source, as the emission factor increases so does the soot by a constant slope for both cycles where the slope is 0.97 for the FTP and is 0.54 for the US06. By contract the Lower PM Source slope was relatively low at 0.07 for both tests and appears to be polynomial for the US06 tests. Only three data points are available at these high emission factors. Also those points correspond to a point when the vehicle was operating poorly due to issues with cooling fans in the test cell.

Table 3-7 EC, OC, and EC/OC ratio results for the FTP and US06 test cycles (mg/mi)

Cycle	Source	EC	OC	EC/OC	EC/$PM_{2.5}$
4-bag	low	0.10	0.19	0.51	0.43
3-bag	high	1.24	0.27	4.60	0.70
US06	low	0.13	0.19	0.69	0.20
US06	high	1.24	0.65	1.93	0.96

[1] EC/OC sampler tests were limited (confirmation and screening), so comparison to the average PM total mass emissions may not be relevant due to test-to-test variability and vehicle drift as discussed in a later section. (n =3).

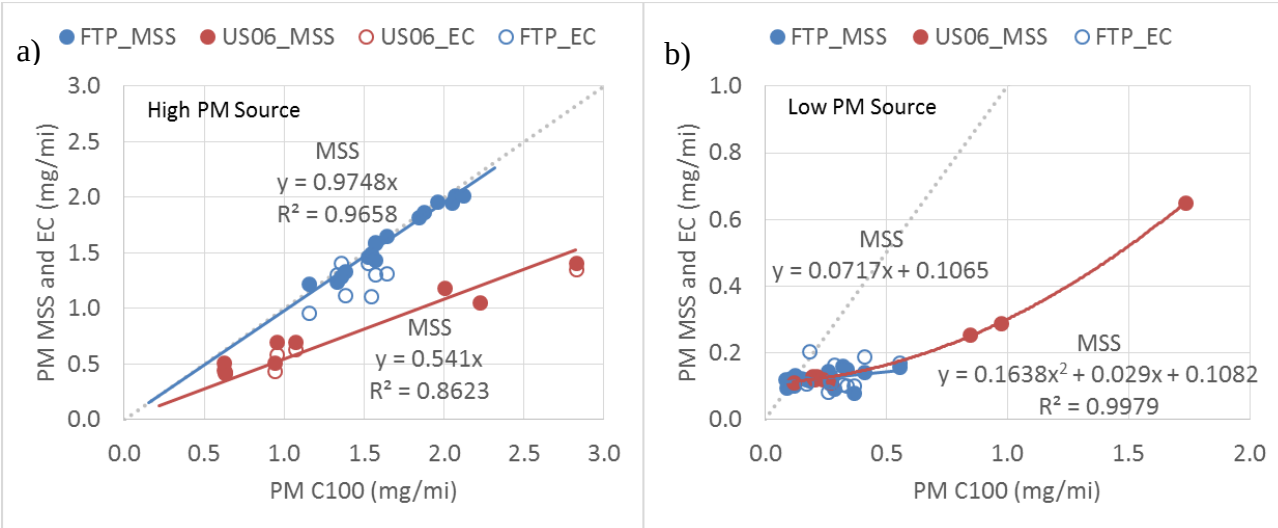

Figure 3-19 PM MSS-soot and EC-NIOSH method correlation to total PM (Probe C100): mg/mi
[1] Higher PM Source a) and Lower PM Source b).

The lower PM Source showed a relatively constant soot (EC) emissions rate of ~0.1 mg/mi for both the screening and confirmation testing where the volatile organics varied from test-to-test. The EC composition fraction varied from 0.22 to 0.97 with an average of 0.67 for the FTP test cycle. The PM emission rate at 0.22 fraction of EC was the highest emission rate reported at 0.5 mg/mi. This suggests the contribution of test-to-test variability may be a result of volatile organic PM for the Lower PM Source. In summary, the Lower PM Source PM was composed of higher fractions of organic PM (OC) did not show statistically significant differences in composition between the FTP and US06 test cycle due to the low number of filter samples collected. The Higher PM Source PM was mostly soot for the FTP and around 50% soot for the US06 tests.

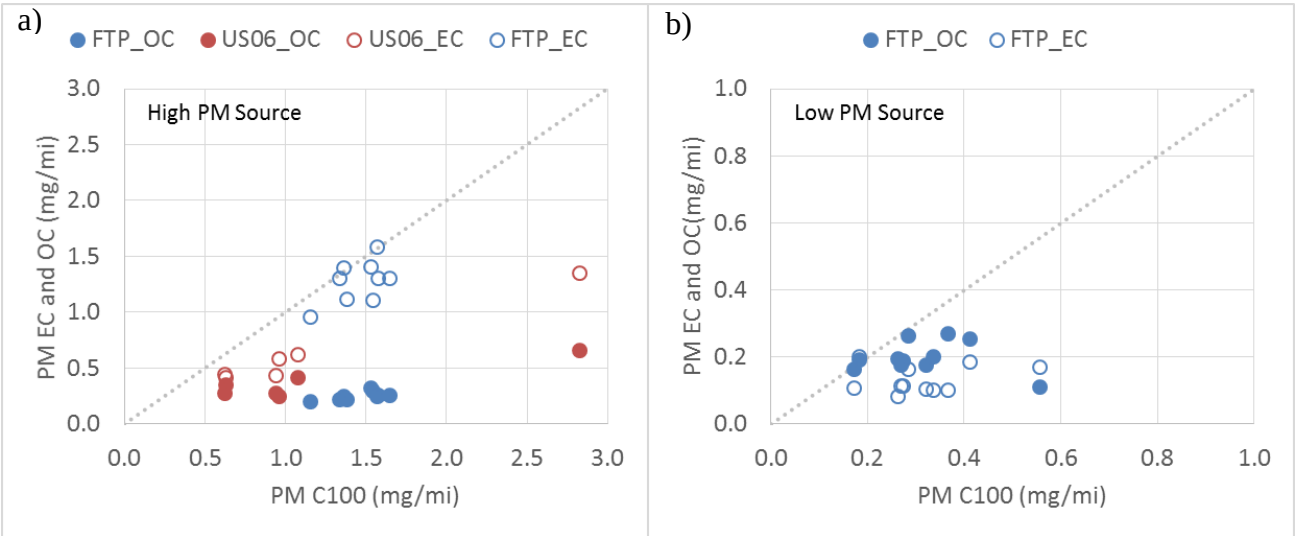

Figure 3-20 EC and OC-NIOSH method correlation to total PM (Probe C100): mg/mi
[1] Higher PM Source a) and Lower PM Source b).

3.3.3 Preparation cycle

It was quickly discovered during the screening testing that the PM emissions varied more for the US06 tests than the FTP tests. Further investigation showed that this difference appeared to be the

result of a few selected tests. It was suggested that differences in the preparation cycle could be the cause of these outliers, or that this might be test-to-test variability for any given vehicle. During Members of the E-99 panel recommended that a specific prep cycle for the US06, not detailed in 40 CFR 1066, be used. The updated preparation cycle (a cold start FTP, US06 prep, 2 min soak, US06 test) was implemented for the confirmation testing, but not for the screening tests. Figure 3-21 shows the single standard deviation for the US06 for the Lower PM Source vehicle during both the screening and confirmation testing. The figure shows that the average single standard deviation was reduced by about a factor of five or 0.040 mg/mi for each of the CVS and PFSS PM samplers. Table 3-8 shows an unpaired two tailed t-test between the confirmation and screening tests for selected CVS and PFSS probes. The resulting p-value shows that only the PFSS probe had a standard deviation that was statistically different at 95% confidence level, but Probe D and C were just above the p-value of 0.05 suggesting they were statistically different, but at a slightly lower confidence level. These results suggest that PM emission rates for aggressive cycles may depend more on the preparation cycle and the condition of the vehicle warmup. Additional testing is needed to confirm these conclusions.

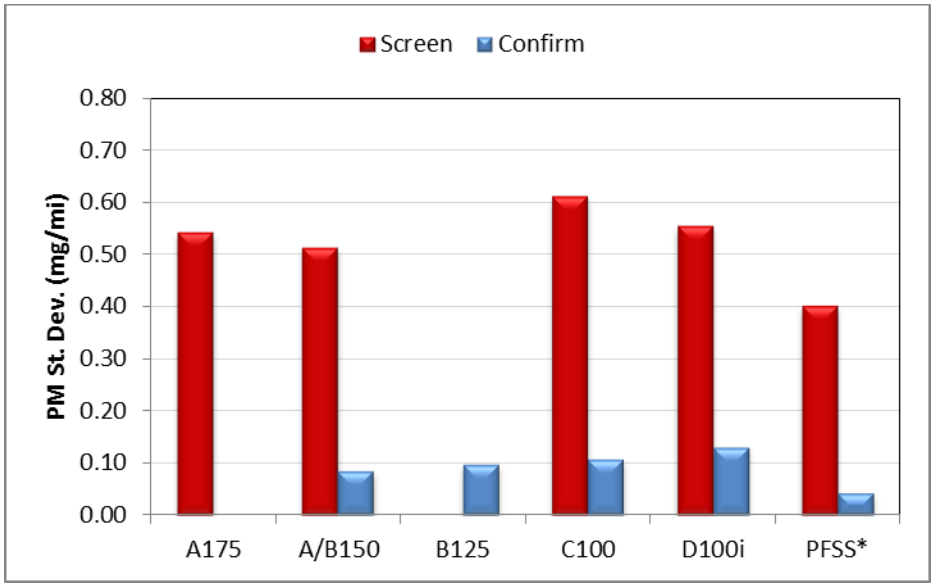

Figure 3-21 Single standard deviation for the US06 cycle for the Lower PM Source

[1] The Higher PM Source had operational issues and could not follow the US06 trace so only the Lower PM Source is available in this figure.

Table 3-8 Unpaired two tailed t-test p-values screening vs confirmation testing

Source	A/B150	C100	D100i	PFSS
Low	0.103	0.070	0.088	0.005
n	6	6	6	3

[1] Only the Lower PM Source for the US06 was evaluated. The FFV = 150 utilized probe B for the screening tests and probe A for the confirmation tests. "n" is the number of tests

3.3.4 PFSS accuracy

During the E-66 program, the comparison between the CVS and different PFSS showed percent differences on the order of 5% to 70% that depended greatly on the PFSS manufacturer, PM concentration, and conditions. One system showed a difference as high as 2.5 times the CVS value. This work shows the performance of one PFSS system in its current status.

Figure 3-22 shows the emission rate comparison for the FTP and US06 and for both the Higher and Lower PM Sources between Probe A150 and the PFSS. The Probe A150 conditions were the closest to the PFSS conditions, where the FFV was the same and only the DF varied (PFSS = 5 and Probe A = 7). The results show that the relative error at ~0.1 to ~0.2 mg/mi was -10% to -15% and at ~ 2 mg/mi it was between -5.9% and +5.0%. In comparison to the CRC E-66 study, these percent differences are much lower for both lower PM Sources and Higher PMPM Sources, over a range of filter weights between 34 and 297 µg, respectively, as shown in Figure 3-22. This suggests the current PFSS is operating very similarly to the CVS system, but it may still have some systematic bias that could be responsible for the statistically significant differences in means. The differences could be related to the measurement of flows (dilution, total, or exhaust flows) or the proportionality control systems needed for the PFSS to operate.

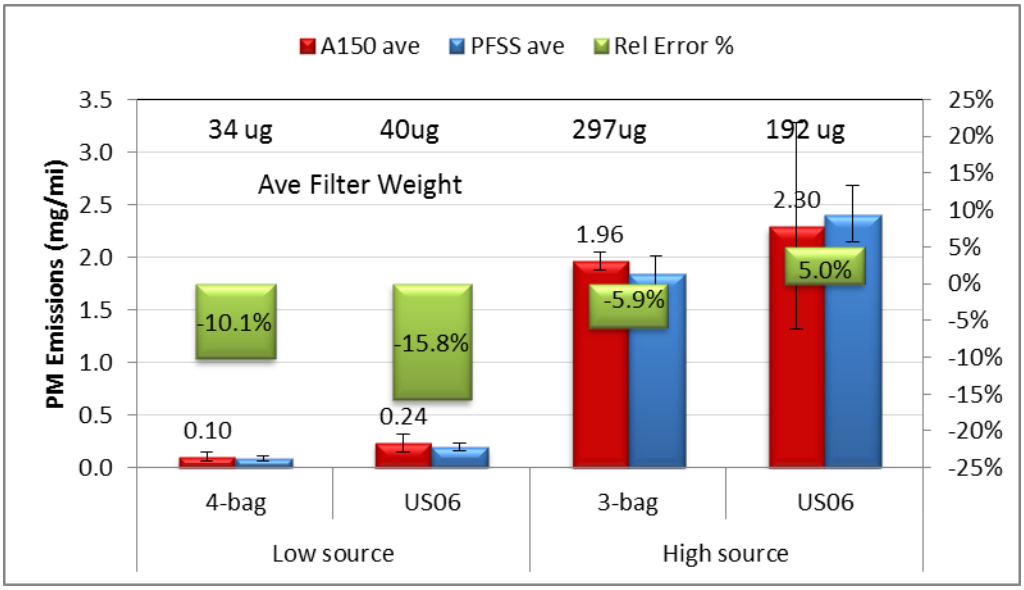

Figure 3-22 PFSS comparison to the CVS PM probe A150 at the same FFV = 150

[1] Dilution factor for the PFSS is 5 and the CVS is 7. The US06 test data was limited to 2 repeats and is represented by more variability.

3.3.5 PFSS proportionality

The ability to maintain proportionality – proportionality being the sample flow rate proportionally varying with the exhaust flow – depends on the PFSS control capability and accurate fast exhaust flow measurements. Figure 3-23 shows an example of the transient exhaust flow (Q_{exh}) and sample flow (Q_p) rates for a 3-phase FTP. Figure 3-24 shows the same details, but zoomed in so the comparison between the exhaust flow and sample flow can be more easily visualized. In both figures one can see how well the sample flow follows (is proportional) to the exhaust flow. Due to flow weighting for a single filter over a 3-phase FTP, the ratio of exhaust "r" varies at the different phases. The exhaust fraction changes from 0.66% (i.e., a percent of the total exhaust sample volume) for Bag 1 to 1.53% for Bag 2 and 0.87% for Bag 3. During the change from Bag 1 to Bag 2, there are apparent deviations in the sample flow and the exhaust flow. These apparent deviations are expected; they represent the change in sample fraction for the flow-weighted sample.

The recommended performance specifications for partial flow systems are defined in 40 CFR Part 1065 and ISO references. These specifications can be used to see how well the tested PFSS system compares to recommended practice. Figure 3-25 shows the correlation between the exhaust flow measurement and the sample flow for each phase of the 3-Bag FTP. The results show that the

correlation exceeds the $R^2 > 0.9$ specification: the reported R^2 was greater than 0.99 for all bags. Table 3-9 shows the calculated performance statistics for the proportionality analysis. The PFSS passed the standard error estimate (SEE) divided by the maximum exhaust specification of 5%: the SEEs for Bags 1, 2, and 3 were 0.9%, 1.7%, and 0.8%, respectively (see Table 3-9). The zero intercept also passed the zero intercept divided by maximum sample flow ($b/maxG_p$) < 2% specification where the $b/maxG_p$ was less than 0.05% for each the bags evaluated. The PFSS specifications were consistently better than the recommended specifications, which suggests this PFSS proportionality was operating well within the recommended practice. This suggests the mean bias errors reported earlier may be a result of other PFSS differences, like exhaust flow measurement accuracies.

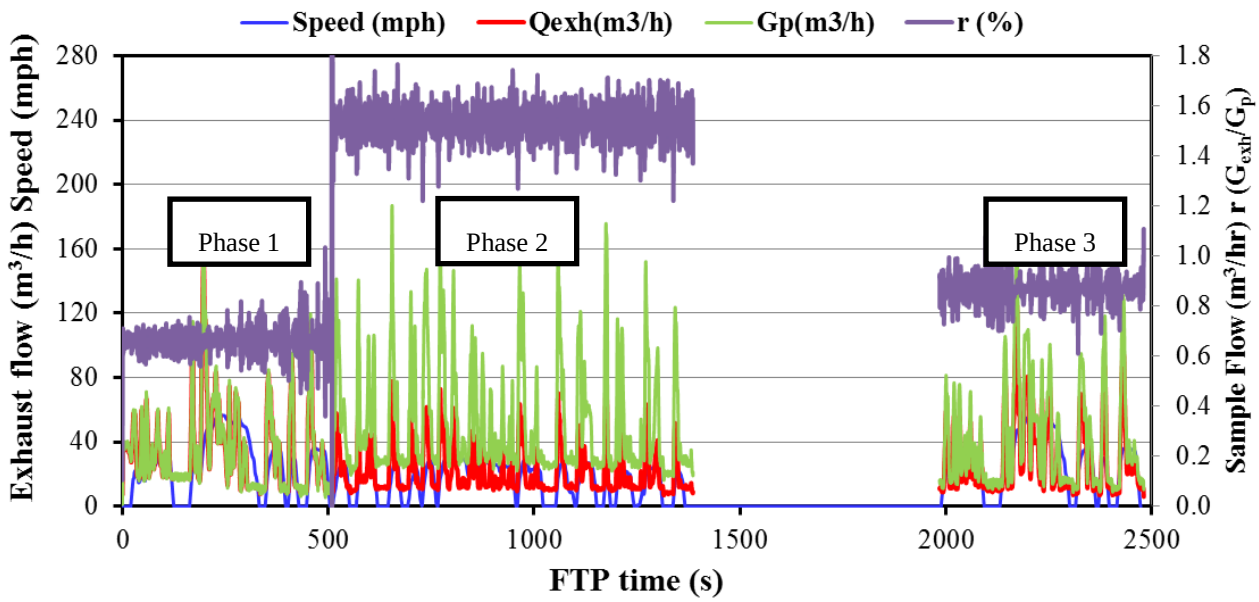

Figure 3-23 Exhaust flow and sample flow (G_p) for the PFSS for a selected test: full view

[1] Speed is the vehicle speed in mph, Q_{exh} is the exhaust flow rate in m3/h, G_p is the exhaust sample flow rate in m3/h, and r is the exhaust fraction G_p/G_{exh} removed from the raw exhaust stack in percent. These data are from a 3-phase FTP test for the flow-weighted setup of the PFSS. Phase 1 flow was 43% of Phase 2, and Phase 3 was 57% of Phase 2 flow as defined in 1066 for accumulative filter sampling.

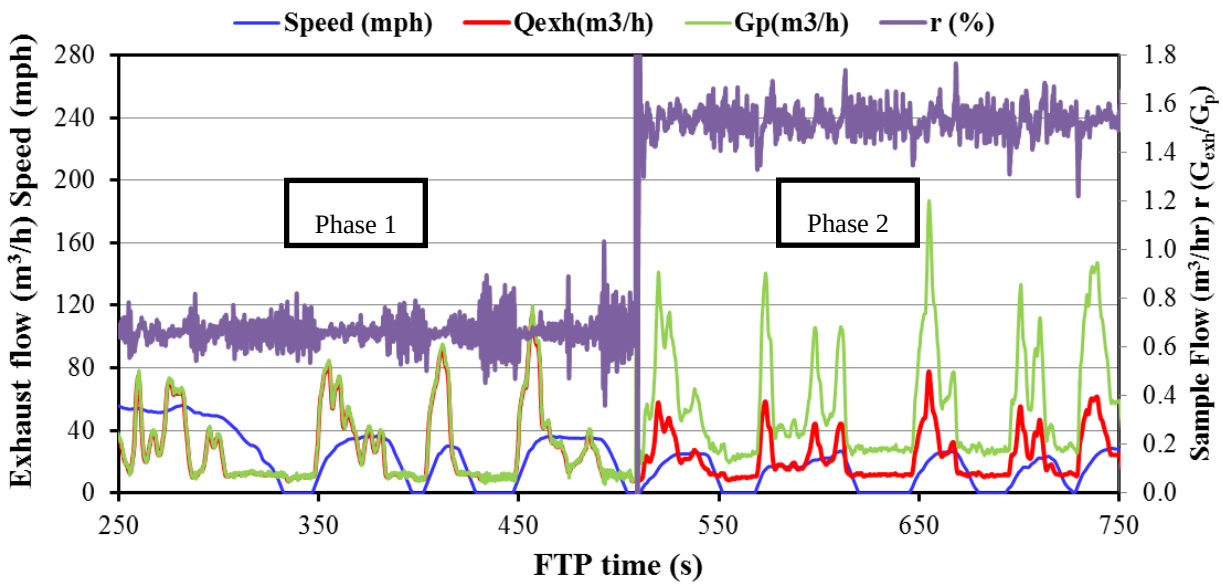

Figure 3-24 Exhaust flow and sample flow (G_p) for the PFSS for a selected test: zoom view

[1] Speed is the vehicle speed in mph, Q_{exh} is the exhaust flow rate in m3/h, G_p is the exhaust sample flow rate in m3/h, and r is the exhaust fraction G_p/G_{exh} removed from the raw exhaust stack in percent. These data are from a 3-phase FTP test for the flow-weighted setup of the PFSS. Phase 1 flow was 43% of Phase 2, and Phase 3 was 57% of Phase 2 flow as defined in 1066 for accumulative filter sampling.

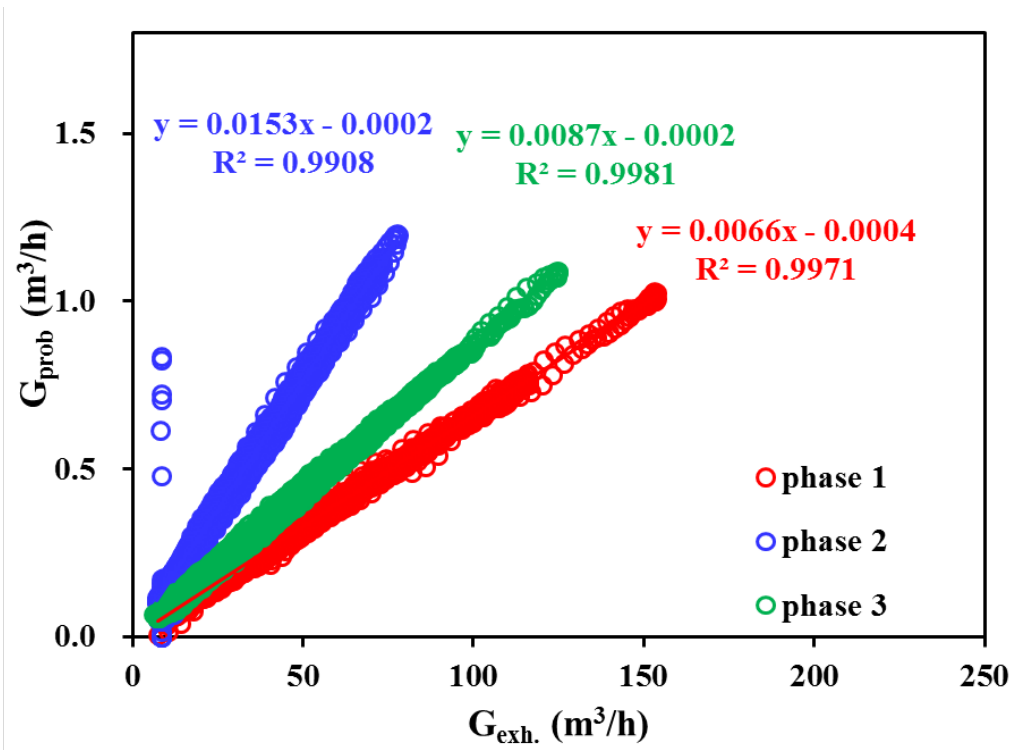

Figure 3-25 Proportionality for the PFSS by phase for a selected test

Table 3-9 PFSS proportionality performance for the selected 3-phase FTP test

Desc.	ph1	ph2	ph3
SEE (m^3/hr)	1.34	1.34	1.01
G_{exh}mean (m^3/hr)	34.2	21.5	29.5
G_{exh}max (m^3/hr)	153.6	77.8	124.9
$G_p$max(m3/hr)	1.0	1.2	1.1
SEE/G_{exh}mean	3.9%	6.2%	3.4%
SEE/G_{exh}max	0.9%	1.7%	0.8%
R^2	0.997	0.998	0.991
b (m^3/hr)	0.0004	0.0002	0.0002
b/$G_p$max	0.04%	0.02%	0.02%

[1] ISO and 1066 performance specifications for partial flow systems is 5% SEE/G_{exh}_max, R^2> 0.9, intercept "b" is less than ±2% of G_p max. All of the listed performance specifications were met.

3.3.6 PFSS dilution factor

Dilution factor (DF), an important parameter for a PM measurement system, it is determined as per 40 CFR Part 1066 for LDVs. DF can have two impacts on the PM comparison between two independent samplers: 1) slight differences in PM composition from targeted DF and 2) differences in calculating the DF and how they propagate through total PM calculations. Considering the first point, configuring the PFSS for a particular DF that is unintentionally slightly different (such as ± 20%) compared to a second independent sampler (such as a CVS system) would not necessarily create a bias in the final emission factor (since the DF would be accounted for in the mass calculations), but it could create a difference in the PM formation mechanism. The DF difference is expected to have a small mass impact on the overall results for typical LDVs (as was discovered in this study for the two PM Sources tested). Considering the second point, an error in calculating the targeted DF utilizing an independently measured DF may suggest there is a flow measurement error, e.g. exhaust flow, sample flow, or total flow. An evaluation of the measured DF can provide an independent comparison of the PFSS independent of the PM mass comparison. This section considers the second point and evaluates the comparison of the flow-based DF (DF_Q) and the carbon balance DF (DF_C). Even if there is a difference in measured DFs, this does not imply that the PM should be biased by the same amount. This is because most PM emissions are found during low DFs (acceleration and high loads) and little are formed during high DFs (idle, decelerations, and light loads) which confounds this discussion. The CVS DF is based on the carbon balance approach and is denoted here as DF-CVS_C. See Section 2.2.3 for a complete development of the calculations used for this discussion.

Real-time DFs from the CVS_C, PFSS_Q and PFSS_C methods for one FTP test are presented in Figure 3-26. The figure shows that all the DFs track well during accelerations and steady driving, while larger relative deviations were found during decelerations. The high DF at decelerations was expected as a result of the measurement differences between flow and carbon balance methods during fuel cutoff common during decelerations (40). More important for PM emissions are the DF differences during acceleration events and the steady state operation. The CVS_C shows a lower

bias compared to the PFSS_C and PFSS_Q under conditions where vehicle is under load (i.e., not decelerating or idling).

Figure 3-27 shows the correlations between DF_Q and DF_C for nine 3-phase FTP tests on the Lower PM Source vehicle. The results presented include different DF setup configurations and individual bags to look at a range of DF comparisons. The correlation shows the DF methods have a slope of 1.14 with an R^2 equal to 0.98 when the regression is forced through zero. The slope of 1.14 suggests there is a systematic bias where the DF_Q is approximately ~14% lower than DF_C. This suggests the flow-based DF_Q (G_{tot}/G_p) may be low which could be from a low G_{tot}, high G_p, or a high G_{exh} measurement (where G_p is proportional to G_{exh} so if G_{exh} is high G_p will be high). Propagating the DF bias through the calculations increased the mass PFSS PM mass measurement up to a factor of 1.14 times in comparison to the CVS measurements.

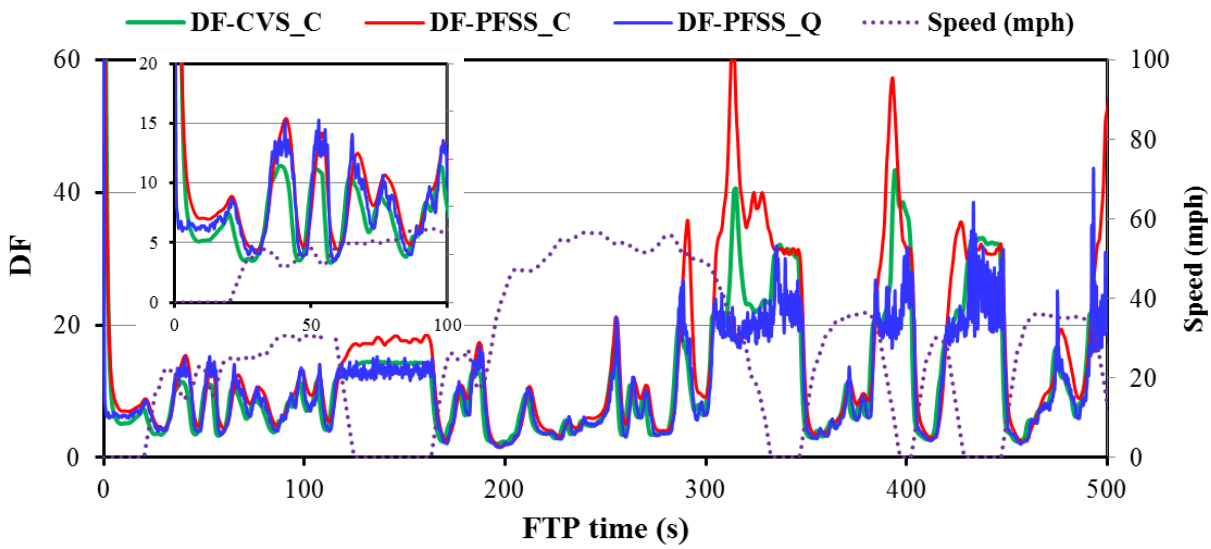

Figure 3-26 Dilution factor from the CVS_C and PFSS_C and PFSS_Q
[1] Carbon balance DF-CVS_C was based on the measurement of CO_2, NMHC, DF-PFSS_C was based on measurements of CO_2 and CO for the PFSS and DF-PFSS_Q was based on Gtot/Gp as described in Section 2.2.3.

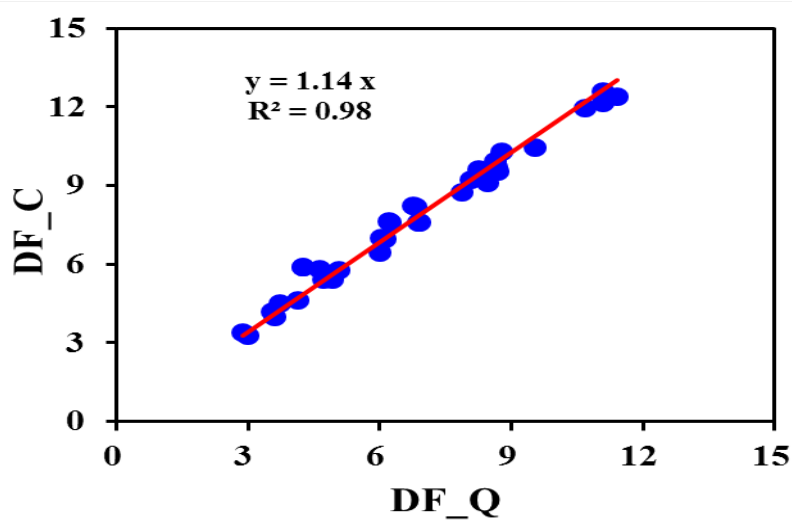

Figure 3-27 Correlation between two independent DF methods PFSS DF_C and PFSS DF_Q
[1] Carbon based method (DF_C) and flow-based method (DF_Q)

The DF bias does not affect the PM mass directly (a bias of 14% doesn't imply 14% higher PM), since there are situations of low PM concentration during high DF bias. Figure 3-28 shows the PFSS and CVS DF_C in the top figure with the real-time PM soot concentration in the lower figure for the Lower PM Source emission test. The PM contributing to the filter weight is primarily from acceleration events and conditions where the vehicle is under load in the test, not when the vehicle is decelerating or idling. As the bias is predominantly present under deceleration and idling conditions where little PM mass is emitted, the bias does not significantly impact the PM emission rates.

The -5.6% difference between the PFSS and the CVS Probe A150 could easily be explained within the uncertainties quantified by the DF bias. Additional analysis and testing would be needed to quantify this, but it does suggest the statistically significance differences may be due to factors other than differences in the methods. Additional testing is needed to quantify any DF differences utilizing a more direct measurement method such as real-time raw and dilute CO_2 measurements.

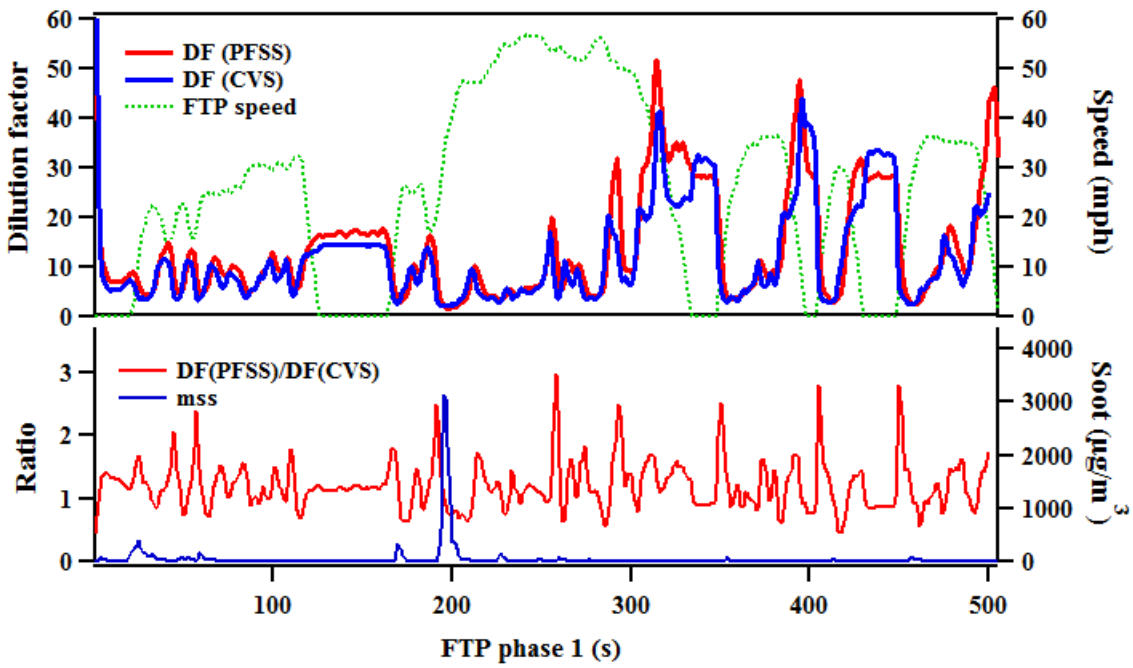

Figure 3-28 Example of the CVS and PFSS_C real time DF comparisons Lower PM Source FTP

3.3.7 Exhaust flow for PFSS

Exhaust flow was not measured during the E-66 partial flow study; it was calculated from measurements of intake air flow with assumptions for fuel flow [3]. These systems were later shown to have time alignment issues due to the difficulties of translating the signals through the engine to the exhaust sample location. Later analysis was used to improve exhaust flow estimation with better modeling terms for intake air flow and fuel flow transport dynamics [9]. The exhaust flow signal deviations may have caused proportionality errors during the E-66 study that resulted in relatively large PM biases, even though proportionality statistics were met.

A major improvement in this E-99 study was the use of state-of-the-art exhaust flow measurement (EFM) systems. These new EFMs are typically designed for a variety of ranges; E-99 testing used an ultrasonic flow meter. The EFM was set up for a range from 0-1059 cfm (0-1800 m^3/hr) and is expected to operate to less than 3 scfm (5.1 m^3/hr), which is less than 1% of the span value where the specified precision for the flow meter is about 5-10%. Others have reported 5-10% deviations in CO_2 comparisons for a proportional sampling bag mini diluter [10].

Figure 3-29 and Figure 3-30 show real-time exhaust flow measured signals in relationship to their 10% and 1% of scale reference lines. The exhaust flow meter utilized in this project was designed for a range of operation up to 1059 scfm (1800 m^3/hr). The percent of time the exhaust flow is below 10% of scale is 100% of time for the FTP tests and 96% for the US06 tests. The percent of time the exhaust flow is below 1% of span is 8.3% for the FTP and 5.3% for the US06. The mean FTP exhaust flow varied from 34.2, 21.5, and 29.5 m^3/hr for Bags 1, 2, and 3, respectively (see Table 3-9). The US06 showed a higher average exhaust flow of 59.3 m^3/hr. These low exhaust flows and high span values suggest the bias may be due to the exhaust flow meter. Additional testing and analysis are needed to quantify these differences.

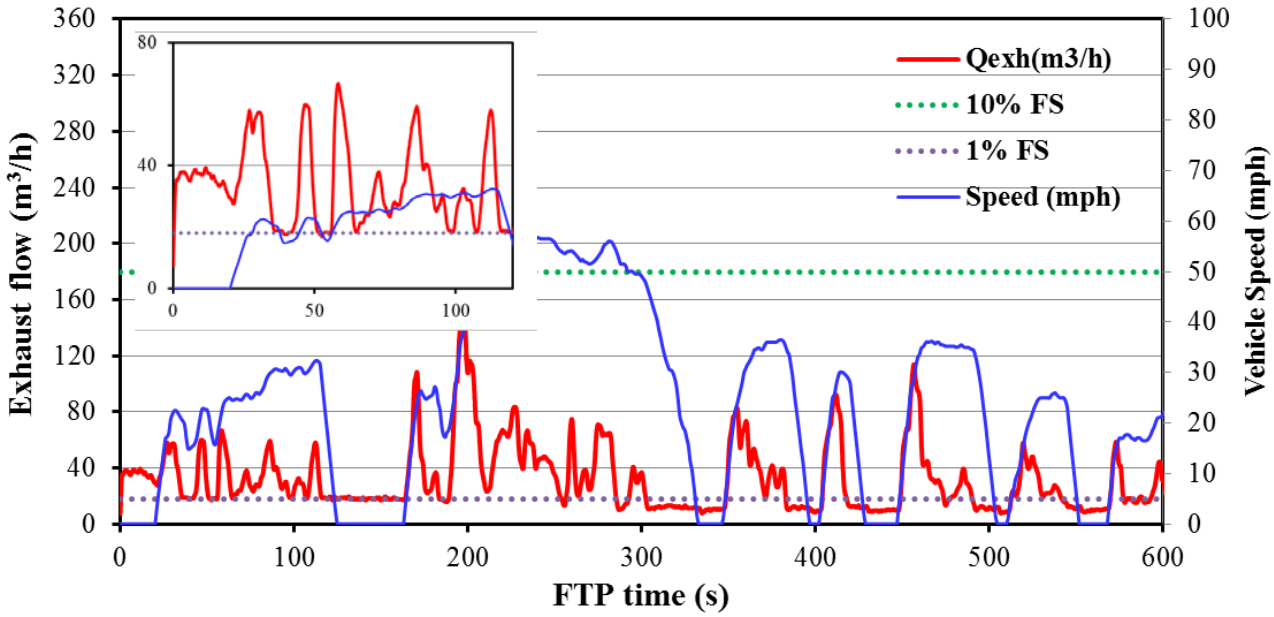

Figure 3-29 Real time exhaust flow for a selected FTP phase 1 test

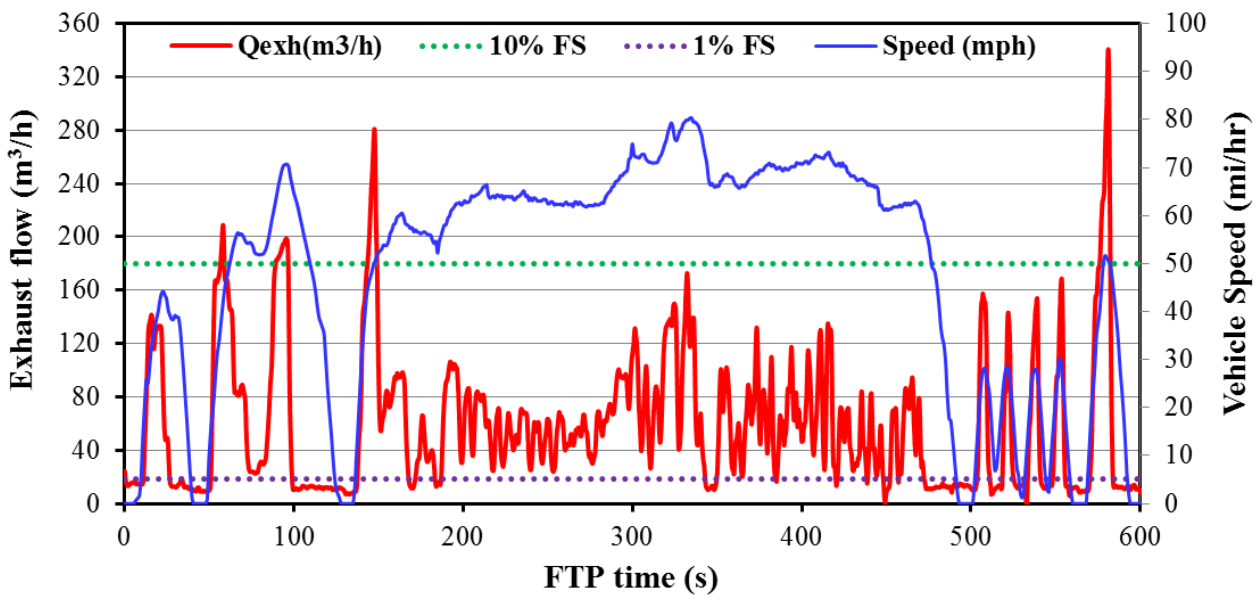

Figure 3-30 Real time exhaust flow for a selected US06 test

3.4 Uncertainty (mg/mi): Confirmation and screening data

This section of the report discusses the test-to-test variability with an investigation of soot vs total PM and then a theoretical analysis of uncertainty as it relates to FTP testing. The soot vs total PM discussion provides a view into the source of the variability and its magnitude for both vehicles tested using both the screening and confirmation data. The theoretical analysis section provides the user a predictive model and results for the proposed E-99 improvements (higher FFV, lower DF, and combined filters) as they compare to base conditions.

3.4.1 Variability: PM mass vs soot

It is important to separate the different components of testing variability to understand their physical sources (i.e., is the variability a result of the test article or the measurement method?). Testing variability includes contributions from vehicle emission, storage/release (including the tailpipe, transfer line, and CVS), and filter operation, flow fluctuation, etc. In this section, the chronological evaluation of soot and total PM emission measurements is investigated by investigating the emission rate for the single cumulative probe C (DF = 7, FFV = 100 flow weighted).

Figure 3-31 shows the test-to-test variability for (a) the Higher PM Source and (b) the Lower PM Source, respectively in the order they were tested (i.e., time sequenced). These graphs show emission rates measured by the cumulative probe (C) at 100 cm/s for each test. For comparison, the emission rate of soot particles estimated by the MSS is also presented. For the screening results of the Higher PM Source, the 3-bag test results show a wider range (1.20 to 1.70 mg/mi) in general compared to the 4-bag results (1.40-1.46 mg/mile) over the sequence of tests that were conducted, but the 3-bag confirmation testing was even higher than both screening groups. For the Lower PM Source screening data, the 3-bag test results show a wider range (0.17 to 0.54 mg/mi) in general compared to the 4-bag results over the sequence of tests that were conducted and the confirmation results were very low and stable comparatively. The results indicate that variability is contributed mostly by the hydrocarbon-related components of the particles. The hydrocarbons can be either organic particles or adsorbed gas phase hydrocarbon by the filters.

One interesting observation shown in Figure 3-31 is that the ratio of soot fraction to total PM increased with time (from 0.22 to 0.97 (soot/total PM), see Section 3.3.2. In reality the soot emission rate was relatively constant (Figure 3-31), but the total PM was decreasing. This suggests the semivolatile PM fraction was decreasing significantly over the course of testing. It is also interesting that the total PM for the two independent PM samplers (CVS four PM samplers and the PFSS sampler) showed relatively similar total PM results, suggesting the trend was observed not only in the CVS, but also from a sample drawn at the vehicle exhaust tailpipe. This suggests the observed reduction in semivolatile PM composition is occurring between the PFSS sample location and the vehicle. One speculation is that semi-volatile PM is a result of a surface release from previously accumulated PM from a transfer line or vehicle exhaust tubing. That seems unlikely given the frequent US06 testing where exhaust temperatures reached 500°C. Another suggestion might be some combustion-related phenomenon related to ambient conditions. Section 3.3.1 shows a slight correlation between PM emissions and barometric pressure. The root cause for the change is unknown, but it is obvious the impact is significant and can produce a PM emission rate five times higher between test R1 and test R6b (from 0.1 to 0.5 mg/mi).

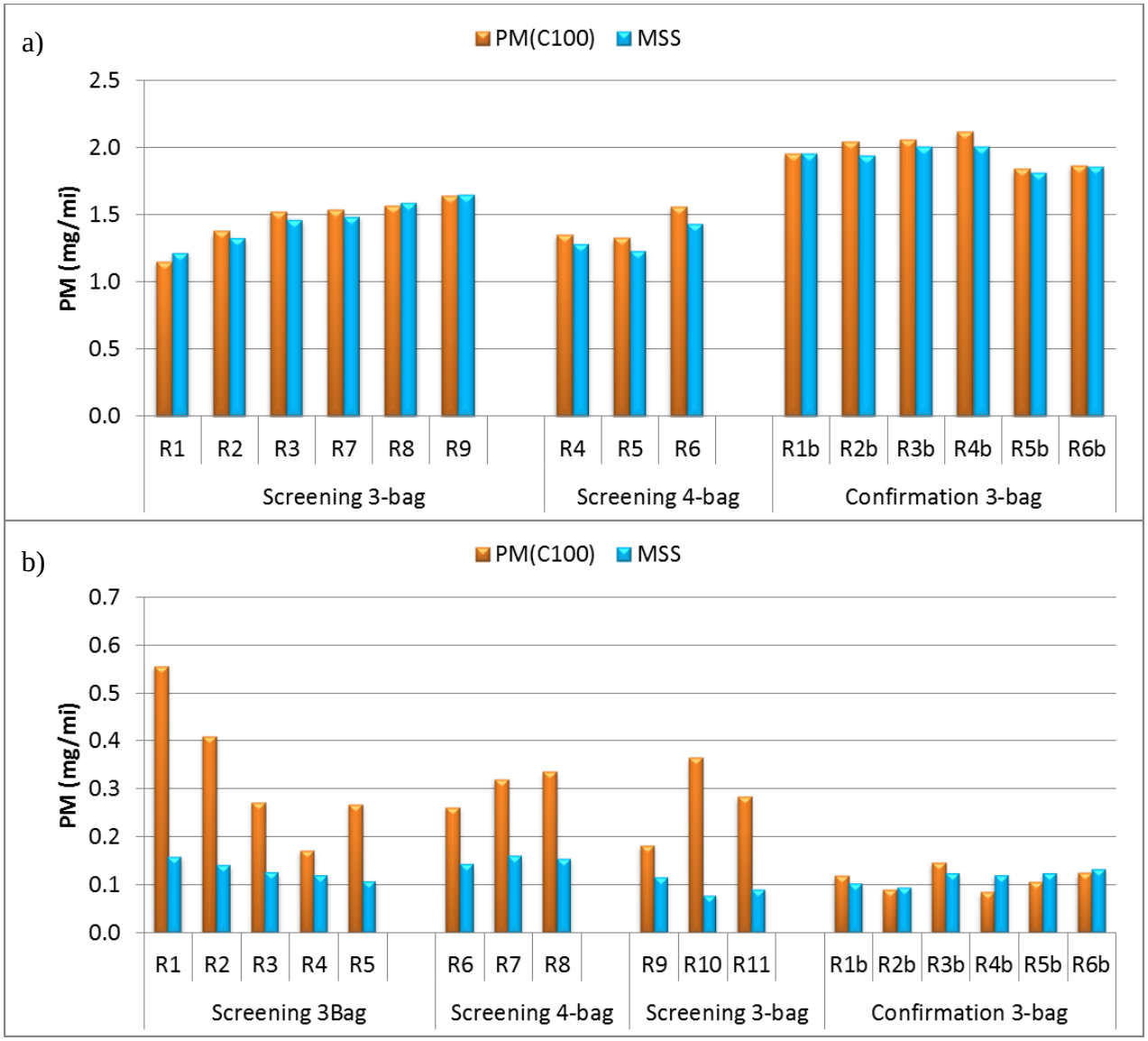

Figure 3-31 Individual PM mass and soot emissions for the a) Higher and b) Lower PM Source

[1] This figure includes Screening and Confirmation results for the Probe C100 (cumulative FFV = 100 DF=7) results in comparison to the MSS soot-PM results. The (a) figure is for the Higher PM Source for the 3-bag and 4-bag FTP. The (b) figure is for the Lower PM Source for the 3-bag and 4-bag FTP.

3.4.2 Theoretical calculation

To provide a better understanding of the potential uncertainty with different probes, the theoretical sensitivity of the measured PM emission rate as a function of change of PM mass (measurement uncertainty) on individual filter is discussed below. This is done by the propagation of error from the filter sampling / weighing process to its impact on the FTP average PM emissions. By EPA's definition, the FTP weighted average PM mass emissions is given by

$$PM_{wgt} = 0.43\left(\frac{M_1 + M_2}{d_1 + d_2}\right) + 0.57\left(\frac{M_3 + M_x}{d_3 + d_x}\right) \quad \text{(40 CFR 1066.820-1)} \quad \text{(Eq.3.4.2-1)}$$

Where the PM mass/phase is given by

$$M_i = \frac{V_{total,i}}{V_{filter,i}}\,(m_i - m_{bak}) = \frac{F_{total,i}}{F_{filter,i}}\,(m_i - m_{bak}) \qquad \text{(Eq.3.4.2-2)}$$

Here m_i is the filter mass gain and m_{back} is the facility average tunnel background correction, and x=2 for a 3-phase test and x=4 for a 4-phase test. The EPA's definition is in terms of the CVS and filter total volumes. But since volume = flowrate * time, this can also be written in terms of flow rates, where the latter more directly relate to DF and FFV; i.e., <DF = $F_{exhaust}$/<F_{total}> and FFV = F_{filter}/A_{filter}, where A_{filter} is the effective filter area.

Assume the error in weight gain is Δm_i, where this is, for example, the 2σ variability in tunnel blank measurements from the survey study. And assume that the uncertainty in the background correction is Δm_{bak}. Then propagate these weight errors to FTP average mass emission rate error via the following steps: Step 1 – find the error in M_i.

We assume that the uncertainty arises from two sources: the uncertainty in filter (i.e., weight gain) and the uncertainty in the tunnel background. We assume that errors in setting the filter and total CVS flow rates are negligible in comparison. Then the corresponding errors in PM emissions per phase are

$$\frac{dM_i}{dm_i}\Delta m_i = \frac{F_{total,i}}{F_{filter,i}}\,\Delta m_i \quad \text{(Eq.3.4.2-3)}$$

$$\frac{dM_i}{dm_{bak}}\Delta m_{bak} = -\frac{F_{total,i}}{F_{filter,i}}\,\Delta m_{bak} \quad \text{(Eq.3.4.2-4)}$$

Assuming these are statistically independent, the total error PM mass emitter per phase is

$$\Delta M_i = \left(\left(\frac{dM_i}{dm_i}\Delta m_i\right)^2 + \left(\frac{dM_i}{dm_{bak}}\Delta m_{bak}\right)^2\right)^{1/2} = \frac{F_{total,i}}{F_{filter,i}}\left(\Delta m_i^2 + \Delta m_{bak}^2\right)^{1/2}$$

(Eq.3.4.2-5)

Step 2 – propagate the error to the FTP weighted average. For the 3 phase, 3 filter case, this becomes

$$\frac{dPM_{wgt}}{dM_1}\Delta M_1 = \frac{0.43}{d_1 + d_2}\,\Delta M_1 \quad \text{(Eq.3.4.2-6)}$$

$$\frac{dPM_{wgt}}{dM_2}\Delta M_2 = \left(\frac{0.43}{d_1 + d_2} + \frac{0.57}{d_3 + d_2}\right)\Delta M_2 \quad \text{(Eq.3.4.2-7)}$$

$$\frac{dPM_{wgt}}{dM_3}\Delta M_3 = \frac{0.57}{d_3 + d_2}\ \Delta M_3 \text{ (Eq.3.4.2-8)}$$

Assuming again that the weighing errors for the three filters are statistically independent, the overall error in FTP average PM emission rate is

$$\Delta PM_{wgt} = \left(\left(\frac{dPM_{wgt}}{dM_1}\Delta M_1\right)^2 + \left(\frac{dPM_{wgt}}{dM_2}\Delta M_2\right)^2 + \left(\frac{dPM_{wgt}}{dM_3}\Delta M_3\right)^2\right)^{1/2} \quad \text{(Eq.3.4.2-9)}$$

In most cases the total CVS is constant for all three phases and so is the filter flow; thus, $F_{total,\,1} = F_{total,2} = F_{total,3} \equiv F_{total}$ and similarly for $F_{filter,i}$. Also, although independent, each weighing is expected to have the same 2σ error. This simplifies the result to

$$\Delta PM_{wgt} = \frac{1}{d_1 + d_2}\ \frac{F_{total}}{F_{filter}}(0.43^2 + 1 + 0.57^2)^{1/2}\left(\Delta m_{filter}^2 + \Delta m_{bak}^2\right)^{1/2} \quad \text{(3 filter)}$$

(Eq.3.4.2-10)

for the error in the 3 phase, 3 filter FTP average PM emissions rate. In the case of the 4 filter 4 phase test, the analogous result is

$$\Delta PM_{wgt} = \frac{1}{d_1 + d_2}\ \frac{F_{total}}{F_{filter}}(0.43^2 + 0.43^2 + 0.57^2 + 0.57^2)^{1/2}\left(\Delta m_{filter}^2 + \Delta m_{bak}^2\right)^{1/2}$$

(4 filter, 4 phase) (Eq.3.4.2-11)

In both cases, the error in FTP average PM scales with F_{total} and inversely with F_{filter}. Thus, decreasing average dilution factor from 7 to 5 (decreasing the F_{total} to 5/7 of its value, will lower ΔPM_{wgt} by 5/7. Similarly increasing FFV from 100 to 150 will increase filter flow by 1.5 and, hence, ΔPM_{wgt} by 1.5, which is what we expect.

The Part 1066 expression for the FTP PM weighted average for a three phase flow-weighted single filter is given by

$$PM_{wgt} = \frac{V_{total,1-3}}{\frac{V_{filter,1}}{0.43} + V_{filter,2} + \frac{V_{filter,3}}{0.57}}\left(\frac{m_{single} - m_{bak}}{0.43d_1 + d_2 + 0.57d_3}\right) \quad \text{(40 CFR 1066.820-3 \& 1066.605-3)}$$

(Eq.3.4.2-12)

Here, $V_{total,1\text{-}3}$ is the total 3 phase CVS volume. But, using the fact that $d_1 = d_3$ and that $V_{filter,i} = F_{filter,i} * t_i$ this can be simplified to the equivalent expression (actually these assumptions are necessary to derive the single filter flow-weighted expression; EPA just uses the "symmetrical" form above)

$$PM_{wgt} = \frac{F_{total}}{F_{filter}}\left(\frac{m_{single} - m_{bak}}{d_1 + d_2}\right) \quad \text{(Eq.3.4.2-13)}$$

Here, F_{filter} represents the normal flow rate, which is used for Phase 2 (e.g., corresponding to FFV = 100, 125, 150 cm/s), but then reduced to 43% in phase 1 and 57% in phase 3. In this case

$$\Delta PM_{wgt} = \frac{1}{d_1 + d_2}\,\frac{F_{total}}{F_{filter}}\left(\Delta m_{filter}^2 + \Delta m_{bak}^2\right)^{1/2} \quad \text{(single filter, 3 phase) (Eq.3.4.2-14)}$$

In the case of a single filter 4 phase test, the EPA formula is

$$PM_{wgt} = \frac{V_{total,1-4}\ (m_{single} - m_{bak})}{\left(\frac{V_{filter,1+2}}{0.43} + \frac{V_{filter,3+4}}{0.57}\right)(0.43(d_1 + d_2) + 0.57(d_3 + d_4))} \quad \text{(40 CFR 1066.820-4 \& 1066.605-4)}$$

(Eq.3.4.2-15)

Which can similarly be simplified to

$$PM_{wgt} = 0.57\ \frac{F_{total}}{F_{filter}}\left(\frac{m_{single} - m_{bak}}{d_1 + d_2}\right) \quad \text{(Eq.3.4.2-16)}$$

Where here F_{filter} is the normal value used in bags 3 and 4, but reduced to 75% to flow weight for bags 1 and 2. Thus the error in 4 phase single filter FTP average PM is

$$\Delta PM_{wgt} = 0.57\ \frac{1}{d_1 + d_2}\,\frac{F_{total}}{F_{filter}}\left(\Delta m_{filter}^2 + \Delta m_{bak}^2\right)^{1/2} \quad \text{(single filter, 4 phase) (Eq.3.4.2-17)}$$

In both of these single filter cases, the error in FTP mass rate still scales with F_{total} and inversely with F_{filter}. Noting that sqrt(0.43^2 + 1 +0.57^2) = 1.23 and sqrt(2*0.43^2 + 2*0.57^2) = 1.01 the relative errors in ΔPM_{wgt} scale as 1.23, 1.01, 1, and 0.57 for the 3 filter 3 phase, 4 filter 3 phase, 1 filter 3 phase, and 1 filter 4 phase tests, respectively. This seems consistent with the testing results; there was little difference between single filter 3 phase and 3 filter 3 phase variability (only 23% expected change), whereas there was a statistically significant reduction in variability for the single filter 4 phase testing (expected 54% reduction relative to 3 filter 3 phase test).

Step 3 – The above yields the propagation of error from the error in weight gain from the filter handling/measurement process and the error inherent in what the actual background level is for a given test relative to the facility average that is being used to represent m_{bak}. We still need to determine values for Δm_i and Δm_{bak} in order to get the measurement error in FTP wgt average, where the former can come from the filter survey work. There are two contributions to this: one is the "repeatability" within a given facility, and the other is the reproducibility between facilities. These could be assigned based on common practice as two times (or three times) the standard

deviation. Thus, $\Delta m_{i,repeat} = 2*stdev_{facility}$ and $\Delta m_{i,reprod} = 2*stdev_{interlab}$. If the latter is found by comparing facility average tunnel backgrounds, then total error is $\Delta m_{i,} = 2*(stdev^2_{facility} + stdev^2_{interlab})^{1/2}$ (which should be the same as the total population standard deviation).

The error contributed by the tunnel background (Δm_{bak}) comes from the difference between the actual tunnel background for a given test relative to the facility average used in the subtraction. How to interpret this is a bit tricky, since this is determined as a facility, or test site, average based on best engineering judgment. Thus, for a set of tests that utilize the same average background subtraction ($\Delta m_{bak} = 0$), no extra variability is introduced. However, when comparing tests from different sites or facilities, or made at different times, the uncertainties between the various background corrections should be accounted for. The maximum this can be is if a separate background filter is collected for each test, in which case $\Delta m_{bak} = \Delta m_{filter}$; thus, the filter sampling/weighing error propagated above, $\left(\Delta m^2_{filter} + \Delta m^2_{bak}\right)^{1/2}$ is in the range of Δm_{filter} to $2^{1/2}\Delta m_{filter}$.

Table 3-10 shows the predicted theoretical improvement factors for the modified parameters compared to the base condition of an individual 3-bag FTP (1 filter per phase), FFV = 100, and a minimum DF =7. If the combined conditions of composite filters, 150 FFV, and lower DF =3 are utilized with a 4-bag FTP, the overall improvement on the lower uncertainty would be a factor of 4.5. The extent to which such improvement is realized depends on whether the overall PM mass uncertainty is dominated by filter sampling / weighing variability or other variability (driver, vehicle, environmental). Thus, very little of this 4.5 improvement will be expected for the higher PM Source vehicle in Figure 3-31(a), whereas more of it can be realized at the PM emission levels of the lower PM Source.

Table 3-10 Predicted theoretical improvement compared base conditions

Filters Per Test	FTP Type	FFV 100 DF 11	FFV 100 DF 7	FFV 150 DF 7	FFV 150 DF 5
3	3-bag	0.6	1.0	1.5	2.1
4	4-bag	0.8	1.2	1.8	2.6
1	3-bag	0.8	1.2	1.8	2.6
1	4-bag	1.4	2.2	3.2	4.5

[1] Filter weight uncertainty is based on 50th percentile of 13 laboratories across the United States. The average tunnel blanks was higher at 3.6 µg see Section 4. This would have a direct impact on the overall theoretical improvement factor.

3.5 Gas-phase emissions: Confirmation and screening data

In this subsection, a summary of selected gaseous emissions is provided to support the conclusions in previous sections. NMHC emissions are shown to show that different sources of nucleation mode species were similar between tests, and weighted CO_2 emissions show the relative repeatability of the tests. Figure 3-31 shows the NMHC and CO_2 emissions from the confirmation testing results. NMHC emissions were slightly higher for the Higher PM Source vehicle, but not significantly enough to suggest that nucleation mode particle formation between the two sources may be different. The CO_2 emissions were also relatively similar and showed low variability, suggesting the tests were consistent and repeatable from a vehicle operation perspective. These results demonstrate that the testing was repeatable from a vehicle performance perspective.

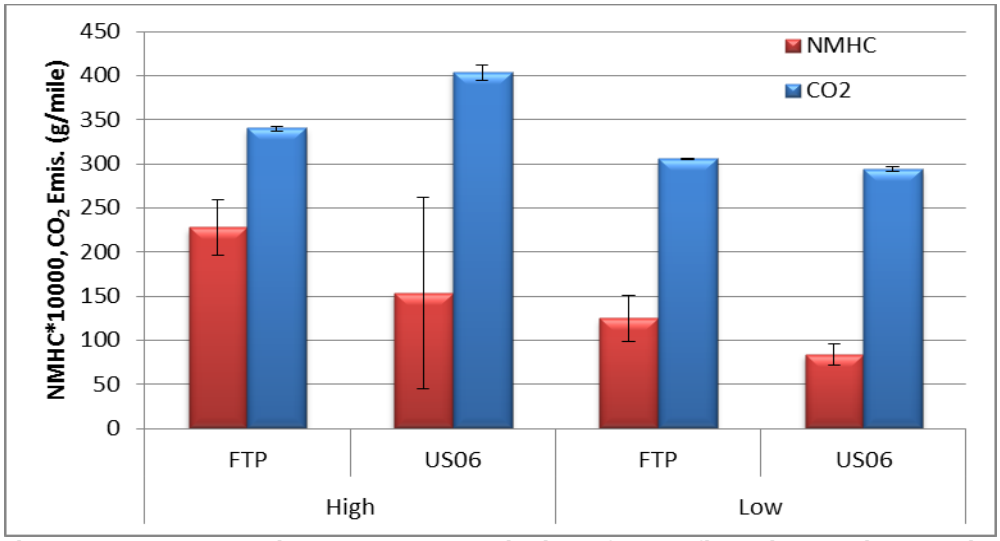

Figure 3-31 NMHC and CO_2 gaseous emissions for confirmation testing results

[1] Error bars represent single standard deviations. NMHC is multiplied by 10,000 to put CO_2 and NMHC on the same scale.

During the more aggressive US06 testing for the Higher PM Source vehicle, it was reported that the vehicle performance was in question. The PM results for the Higher PM Source US06 tests were limited. Figure 3-32 shows gaseous emissions for CO and CO_2 in the screening and confirmation testing for the Higher PM Source vehicle. The CO emissions were much higher during the US06 confirmation testing, because the vehicle overheated, but CO_2 was only slightly higher. The CO_2 for the FTP tests looked reasonable between the tests suggesting the issue was limited to the US06 test cycle and not the FTP test cycle.

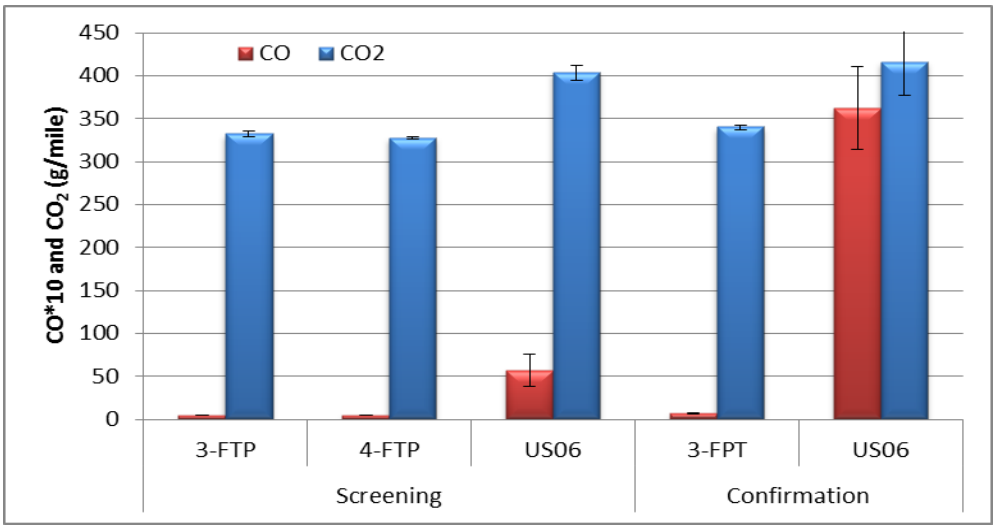

Figure 3-32 CO and CO_2 gaseous emissions for the Higher PM Source

4 Filter Survey Results

A filter survey was performed to assess the ability to weigh a filter and the uncertainty associated with the weighing process, and to consider practices that may reduce uncertainty in the weighing process. One of the survey's main goals was to characterize and quantify a lower detection limit based on weighing, to characterize this limit in light of the 40 CFR Part 1066 5 µg filter allowance, and to evaluate these results relative to the California 1 mg/mi PM emissions standard. Several approaches could be utilized for evaluating the lower detection limits of weighing a filter. One approach would be to create several filter contamination scenarios, then run filters through a single laboratory and compute the variability of the results. Another approach would be to collect filter results from numerous laboratories across North America and compute their variability. The latter approach was selected for this study because it provides a true metric of accuracy and uncertainty based on real-world application.

4.1 Survey description

Seventeen laboratories, representing industry, governmental agencies, research institutes, and academic institutions, were selected to be surveyed. Thirteen of the seventeen laboratories responded to the survey, and, of those, eleven provided filter data for this analysis. The survey requested raw data on quality control checks performed by each laboratory. The survey also made specific queries about influences on the filter weighing process. The elements influencing the filter weighing process were organized into four categories: environment, equipment, methods and procedures and quality assurance.

- *Environment*: Air flow, vibration, moisture, and temperature control particle count and gradients.
- *Equipment*, micro balance, air table, large marble mass, and static control.
- *Methods and procedures*, direct read vs double substitution weighing, human contact with the filters (static and particle sources), and duration of static neutralization.
- *Quality Control and Assurance:* reference checks, outlier filtering, redundant weighing, real time filter weighing feedback, and operator training on cause and effect.

All the laboratories conform to CFR protocols and thus meet the conditions for weighing a filter as defined by the 40 CFR Part 1065.590. The conditions for weighing a filter include temperature, humidity and buoyance correction in addition to other recommended practices for replicate weighing and handling as specified in 1065/1066. Table 4-1 provides a summary of specific details utilized for each laboratory. All the data utilized in this analysis are valid mass readings within the context of the 1065 regulation, as well as being representative of the current state of operation during actual use.

Although all laboratories met the specifications of 40 CFR Part 1065.590, the approaches used to meet these specifications were diverse. Table 4-1 lists the specific differences among the laboratories in the survey. The table shows the manufacturer and model for the micro balance and filter media, the static discharge method, weight methods, and other unique information for each laboratory. Three types of Teflon™ reference filters were evaluated: 1) Whatman, 2) Pall, and 3) MTL. Some laboratories also provided additional filter media information, such as for glass fiber filters. The micro balances were predominantly from two manufacturers: Sartorius and Mettler. This included the Sartorius SE2-F model and the Mettler UMX2 or XP2U micro balances.

Table 4-1 Summarized filter survey and specifications [2]

Laboratory	Micro Balance Mfg	Micro Balance Model	Filter Filter Mfg	Filter PartNo	Static Discharge	No. Filters/Yr	Weighing Method	Pre-Conditioning [3]
Lab 1	Sartorius	SE2-F	Whatman	7592-104	(4) P0-210	~50,000	Manual, average < 2.5 µg deviation	1 hr
Lab 2	Mettler Toledo	UMX2	Whatman	7592-104	(x) Po-210 within balance	~50,000	Robotic, 3 average substitution weighing	1 hr
Lab 3	Mettler Toledo	XP2U	Pall	R2PJ047	(4) Po-210	~50,000	Manual, 2 average, short-term	5 days
Lab 4	Mettler Toledo	XP2U	MTL	PT47	Po-210 & Faraday cage within balance	~50,000	Robotic, 3 average substitution weighing	n/a
Lab 5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Lab 6	Mettler Toledo	UMX[1]	MTL	PT47	(4) P0-210 within balance	~50,000	Robotic, 3 average substitution weighing	CFR
Lab 7	Mettler Toledo	UMT2 and XP2U	Whatman	7592-104	(5) Po-210 within balance	~5000	Once	n/a
Lab 8	Sartorius	SE2-F	Pall	R2PJ047	(2) Po-210	~5000	Once < 10 µg deviation.	n/a
Lab 9	n/a	n/a	n/a	n/a	n/a	~1000	Robotic, 3 average substitution weighing	n/a
Lab 10	Mettler Toledo	XP6	MTL	PT47	(4) Po-210 U-ionizer	~1000	n/a	n/a
Lab 11	Sartorius	SC2(-OCE)	Pall	R2PJ047	(4) Po-210	~1000	Manual, 3 average	n/a
Lab 12	Sartorius	SE2-F	Pall	R2PL047	(4) Po-210	~1000	Manual, once	n/a
Lab 13	Mettler Toledo	UMX2	Whatman	7592-104	(4) Po-210	~1000	Manual, 2 average < 3 µg spec, long-term	n/a

[1] Micro balance integrated into a robotic auto handler and software system [2] Conditioning chamber similar for most laboratories and includes humidity, temperature, air flow, and particle clean room specifications. Vibration isolation similar for most laboratories and includes large mass where micro-balance is placed. [3] Preconditioning is a process of allowing filter mass to stabilize before use for specified amount of time.

Three significant differences among the laboratories was the use of a robotic filter weighing, conditioning, and processing system. Robotic weighing allows for double substitution weighing compared to a direct read method, minimizes human influences on the filters, and provides a more rigorous routine operation for filter weighing control and timing. It has been suggested that the double substitution calculation provides a more sophisticated and accurate method for determining small mass differences of relatively heavy objects. This method accounts for process drift in the instrument from the calibration weight during the measurement by directly weighing the filter compared to a stable metal reference object of the same or very similar mass.

Each laboratory provided quality assurance filter data to University of California Riverside (UCR) in an Excel spreadsheet. UCR requested data as far back as 2010 including as much raw data as possible. Raw data included actual balance filter weight, date and time, relative humidity, dew temperature, barometric pressure, buoyance corrected values, and other information such as balance ID and operator. Filter data of interest included reference, tunnel, trip, dynamic, and static quality control (QC) filters. These are described below:

- **Reference** objects (various filter media and metallic objects) that never leave the weighing room, but are retired after batch conditions are met. This varied by laboratory. Reference filters were nominally replaced approximately every 40 days.
- **Trip** blank filters are carried from the weighing room to the CVS in a cassette and back to the weighing room at the end of the test without exposing the filter in the cassette to the sampling environment. This is the same as the reference filter, but with the added possibility of contamination during insertion into the cassette, a trip to the laboratory, spending a period of time in the laboratory, returning from the laboratory, and the removal from the cassette.
- **Static** blanks are the same as a trip blanks, except that the filter is loaded and unloaded into a filter holder in the CVS room and exposed to the environment for a short duration.
- **Dynamic** blank filters are the same as Static blanks, but they are left in a CVS filter holder during a test. They are not, however, exposed to the tunnel flow. An example of a dynamic blank would be to put a filter in an automated filter holder system, but never flowing air directly through the filter for any of the tests.
- **Tunnel** blanks filters are the same as the Static blanks (not the Dynamic blanks) in that the filters are taken to the laboratory and installed in filter holders. In addition, tunnel blanks are exposed to exhaust free air flowing through tunnel at typical conditions (sample time, CVS flow, temperature). This differs from a dynamic filter blank, since the dynamic filters are placed into the PM sampling system while exhaust emission tests are being conducted, even though exhaust is not ever drawn through the filter. Thus, tunnel blanks and the Dynamic filter blanks should show the largest filter weight gains in terms of blanks and are most representative of the true uncertainty of the overall process.

The idea behind these QC filters is to identify possible areas of contamination as the filter moves along its journey during emissions testing. The reference filter provides a metric of contamination just in the micro balance area, the trip blank shows contamination of the reference plus moving the filter to the laboratory, the static blank adds to the trip blank with the additional handling at the sampler, and the Dynamic and Tunnel blanks provide a final assessment of cross-contamination during an emission test (Dynamic blank) and full dilution air flow contamination (Tunnel blank).

The largest data set was for the reference filters and the second largest data set was for tunnel blanks, since these two filter checks are routine operations for all laboratories. A few laboratories provided additional information, such as static, trip, and dynamic filters. Each laboratory was numbered 1 through 13. If the laboratory performed some alternate process, such as using multiple micro

balances, these laboratories received an additional alphabetical designation after the number (such as 3a and 3b) to denote the different methods.

Static and Dynamic: A static filter is a filter that is exposed like a trip blank filter, but is also loaded and unloaded into the laboratories sampling system. The difference between this filter and the tunnel blank is that no flow is pulled through the filter, as discussed previously. For the static blank data, only Lab 5, 12 and 13 provided data, representing a total of 59 filters with an average of 15 filters per laboratory. Dynamic blanks are loaded and left in the loader during the course of one or more tests, but never sampled on, as discussed previously. For the dynamic blank data, only Lab 12 and 13 provided data, representing a total of 16 filters with an average of 8 filters per laboratory. For both the static and dynamic blanks, only Teflon™ filter data was provided. This data set is very small and may not represent the true variability and weight gain of true static and dynamic contamination sources. Due to limited data the static and dynamic blank results are located in Appendix F.

4.2 Reference filters

The reference filter is a filter that remains in the filter weighing chamber and is never removed. It is handled during the weighing operation and is eventually replaced with a new reference filter. The reference filter is used to characterize the drift in measurements over a testing session. The definition of a session is the beginning and ending of a weighing interval, as per 40 CFR Part 1065.390. A weighing interval is somewhat arbitrarily defined, as many manufacturers make several replicate reference filter weight measurements on a daily basis, and in some cases within one hour.

Reference filters are replaced routinely depending on each laboratories practice. Some laboratories replace their references monthly while others replace their references on an annual basis. Many laboratories have more than one reference object, which could include alumina objects with a 47 mm in diameter similar to the Teflon™ filters, a long-term reference object that has been kept greater than two years, and then a short-term reference that has been kept for three to six months. Laboratories may also keep two reference objects of the same type (i.e., alumina, long-term, or short-term). The reference filters considered in this analysis are based on short-term reference filter usage and not long-term effects. Only reference filters kept for a period of less than one year or less were used.

The reference object is handled routinely as part of the filter weighing process for each laboratory. In this study about half the laboratories handle the reference filter through robotic operations and the other half handle the filter with human effort. Most laboratories using human effort have more than one filter weighing operator handling the filters.

4.2.1 Analysis approach

The analysis was designed to evaluate the drift in the reference filter during the time it takes to conduct an emission test. Experience suggests reference filters gain and lose mass over time or by each handling event. As such, quantification of reference filter drift over different periods of time was needed. For the purpose of this analysis, filters were analyzed on two different time bases, termed short-term and long-term. The two analysis approaches provide the reader a feel for the uncertainty in weighing a filter that doesn’t leave the micro balance area for different time intervals.

For the short-term analysis, the reference object drift was evaluated based on adjacent filter weights. The short-term analysis should be considered the best case scenario of weighing a filter object. Differences in time as short as immediate back-to-back measurements were considered.

The long-term analysis considers the true impact of weighing a filter based on each laboratories operation in evaluating filters from the time of the pre-test weights through the post-test weights. This analysis extends beyond the time interval of the short-term analysis, because the time interval

between pre- and post-test weighing is longer than the typical weighing session interval. So, the evaluation of short-term differences in reference weighs within a given weighing session is not a fair assessment of the weighing variability for a test filter. The sampled filter is loaded into a cassette after it clears the pre-test process (tare). It is then placed in a "ready for testing" area. Eventually, it leaves the balance room and is loaded into a sampler holder to perform a test. The test is then performed. After the test is concluded, the filter returns back to the weighing chamber (for a single test or it may wait for a collection of tests to completed if an auto loader is being used). The filter is then removed from the cassette and conditioned a minimum of 30 minutes before being weighed for the post-test weight. The time difference between the last weight of the pre-test and the final post-test weight for the soiled filter may be as short as a few hours and as long as several days. Some laboratories utilize auto indexing filter systems where the filters may remain in the laboratory area for a few days. The duration of time in the laboratory area may also exceed a few days for unknown reasons, such as engine problems, program changes, or shift changes.

4.2.1.1 Short-term

For the short-term analysis, the variability of adjacent measurements of reference filters was evaluated. The definition of short-term variation depends on each laboratory's operational practices and varies from 20 minutes to approximately six hours. This broad time range is a result of the flexibility in the 1065 procedures for validating reference filter drift.

For each repeat pair of mass readings, the difference was computed. All the data was pooled from each laboratory and each unique operation within a laboratory to determine operational variability. The differences between adjacent reference filter weighings (longer than one hour) were computed. Then the variability was computed from these differences. The variability was computed by calculating the standard deviation of this sample, as shown in Equation 2. Because the differences contain two observations of the short-term variation (simulating pre and post-test filter weight differences), the variation in the differences is the square root of two times the standard deviation of the short-term variation (see Equation 1 and 4). Thus, the short-term variation is the standard deviation of the differences multiplied by the square root of two.

$$\boldsymbol{ShortTrmFilterStdev} = \sqrt{(\boldsymbol{Stdev_{pre-test}})^2 + (\boldsymbol{Stdev_{post-test}})^2} \qquad \textbf{(Eq. 4.2.1-1)}$$

$$\boldsymbol{Stdev} = \sqrt{\frac{(x-\bar{x})^2}{n}} \qquad \textbf{(Eq. 4.2.1-2)}$$

$$\boldsymbol{ShortTrmFilterStdev} = \sqrt{\left(\sqrt{\frac{(x-\bar{x})^2}{n}}\right)^2 + \left(\sqrt{\frac{(x-\bar{x})^2}{n}}\right)^2} \qquad \textbf{(Eq. 4.2.1-3)}$$

$$\boldsymbol{ShortTrmFilterStdev} = \sqrt{2\,\frac{(x-\bar{x})^2}{n}} \qquad \textbf{(Eq. 4.2.1-4)}$$

4.2.1.2 Long-term

For long-term filter variation, we consider filter variation over time periods closer to the differences between the time of a pre- and post-test filter weighing session. Because the time frame for the life of the reference filters is much longer than the time between pre and post-test mass readings, one needs to include a nominal time frame for pre- to post-test mass readings to scale any time trends seen in the reference filter data. As such, the long-term variation requires a more complex calculation approach.

For the long-term filter variation analysis, we wanted to consider the trend of the replicate measurements as a group and look at general trends. Based on the trends from this analysis, the

impact of time or number of weighing events on weighing variability can be evaluated. Some suggest that variability trends are correlated to time and others suggest these trends are correlated to the number of weighing events (i.e., each touch of the filter creates some contamination). Several filters were evaluated and no discernable difference was noticed between the "by event" compared to the "by time" analysis.

Figure 4-1 shows a selected filter's weight as a function of time, where in most cases the filter was weighed once per day, and Figure 4-2 shows the same filter weight as a function of weighing event (or each touch). In both cases the R^2 was approximately 0.9 indicating a strong correlation for both regression analysis. The "by-time" correlation, for the filter selected, suggests the filter gains weight on the order of 0.31 µg/day, where the "by event" correlation suggests the filter is gaining weight at around 0.17 µg/weighing. As a matter of convenience, the long-term analysis discussed below was done on a time basis and not on a weighing basis.

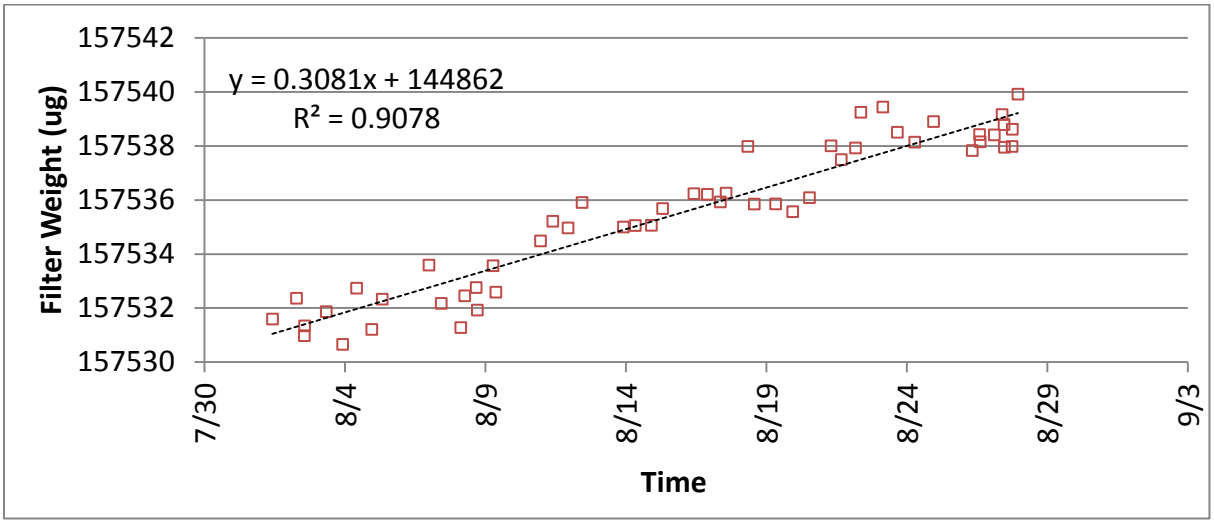

Figure 4-1 Long-term filter weight by date and time correlation.

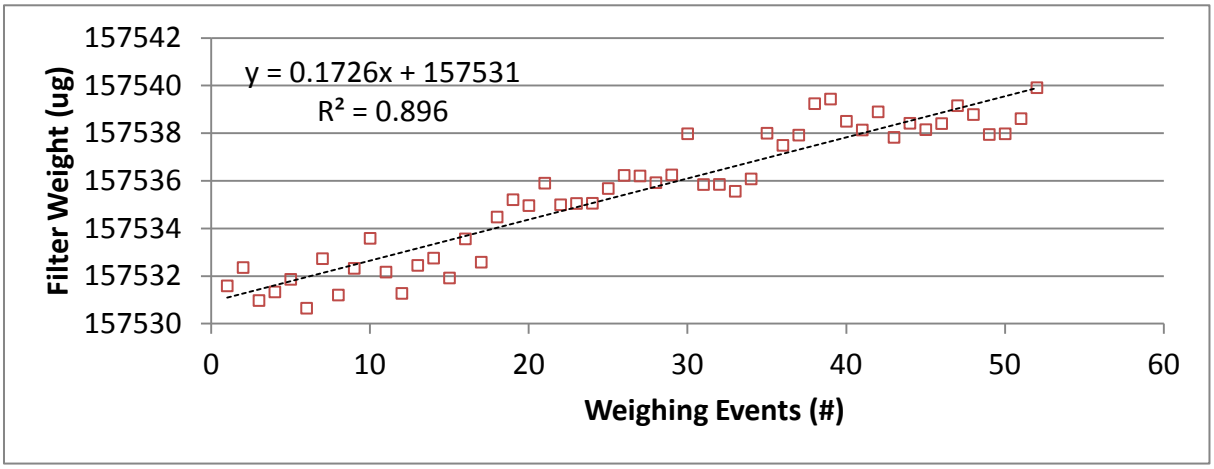

Figure 4-2 Long-term filter weight by weighing event correlation.

From the regression data, individual reference filter weights were pooled for a given filter ID to examine the data for time trends and normality. The data were also analyzed for outliers, such as filter ID typos or issues with the buoyance correction factor. The outlier analyses are discussed in greater detail in Appendix F. Analyses were done both with and without outliers, but the final analyses results utilized the data set with the outliers removed since they did not represent normal operation. The pooled data was analyzed based on each sets best fit regression statistics. The

statistics included the variation of the means (based on two observations) around the regression line (i.e., the standard error estimate (SEE)), the slope, and the intercept. The SEE returns the standard error of the predicted y-value for each x in the regression. The SEE is a measure of the amount of error in the prediction of y for an individual x.

4.2.2 Results

4.2.2.1 Short-term Results for Teflon™ Filters

The results of all the reference filter data are summarized in Table 4-2 below. The data in Table 4-2 has the outliers removed, as discussed earlier. Figure 4-3 and Figure 4-4 shows the reference filter variability between laboratories with the outliers included and Figure 4-5 shows the reference filter variability with the outliers removed. For the data with the outliers removed, the short-term reference filter variability ranged from 0.61 µg to 2.4 µg to 5.0 µg for the 5th, 50th and 95th percentiles.

The quality of the data is very diverse. Lab 1a provided 129 reference objects and weighed these objects on average 67±48 times. Laboratories 2 and 6 provided two and three reference filter objects, but weighed them on average 1062 and 134 times, respectively. From analyzing the data, it was found that the weighing precision of different reference filters differed between filters, with some filters showing higher variability and others showing relatively low variability. Additionally, the long-term analysis provided in the next subsection suggests the long-term effects are quite variable between reference filters. The laboratories that provided only two to three reference objects had a large 90% confidence interval, suggesting the variability for these laboratories may not be that well-characterized. More reference objects would improve this confidence.

Table 4-2 Statistical summary results of all Teflo analyzed reference filters.

Laboratory [1]		Sample Size [2]			Variation [3]		
Facility	Mfg	No Obj.	Ave N	Stdev N	Ave (ug)	Stdev (ug)	90% CI
Lab 1a	Whatman	129	67	48	4.9	2.7	0.7
Lab 1b	Whatman	55	67	37	4.5	2.8	1.0
Lab 2	Whatman	2	1062	0	1.8	0.3	8.2
Lab 3a	Pall	21	38	22	2.3	0.7	0.9
Lab 3b	Pall	40	48	28	2.0	0.8	0.5
Lab 3c	Pall	37	35	18	1.7	0.7	0.5
Lab 4	MTL	11	109	44	1.1	0.3	0.6
Lab 5	Pall	2	41	0	1.5	0.8	6.5
Lab 6	MTL	3	134	0	0.8	0.3	1.3
Lab 7	Whatman	6	86	45	2.4	0.6	2.0
Lab 8	Paul	1	2125		3.2		
Lab 9	MTL	1	96		0.6		
Lab 10	MTL						
Lab 11	Pall						
Lab 12	Pall	3	7	0	4.6	2.7	7.8
Lab 13	Whatman	6	35	6	5.0	4.0	4.1
	Total	317	3949				
	Ave	22.64	282	21	2.6	1.4	2.8
	Stdev	35.2	594	19	1.6	1.3	3.0

[1] Some data was not provided during the survey. If it was not known then a "N/A" was put in the data set to allow analysis to continue. [2] "No Ref Obj." this is the number of reference objects analyzed, "Average N" the average number of reference weights on each object, "Standard Deviation N" the single standard deviation of the number of weights on each filter, "Average Stdev (mg)" the average of the standard deviations of each filter weight, "Stdev of Average (mg)" the standard deviation for each different reference filter, "90% CI of Stdev (mg)" the 90% confidence interval. [3] Variation columns lists the results from Equation 4 labeled ShortTermFilterStdev. "Ave (µ)" this is the average of the equation 4 results, "Stdev (ug)" is the standard deviation of the equation 4 results, and "90% CI" is the 90% confidence interval of the equation 4 results.

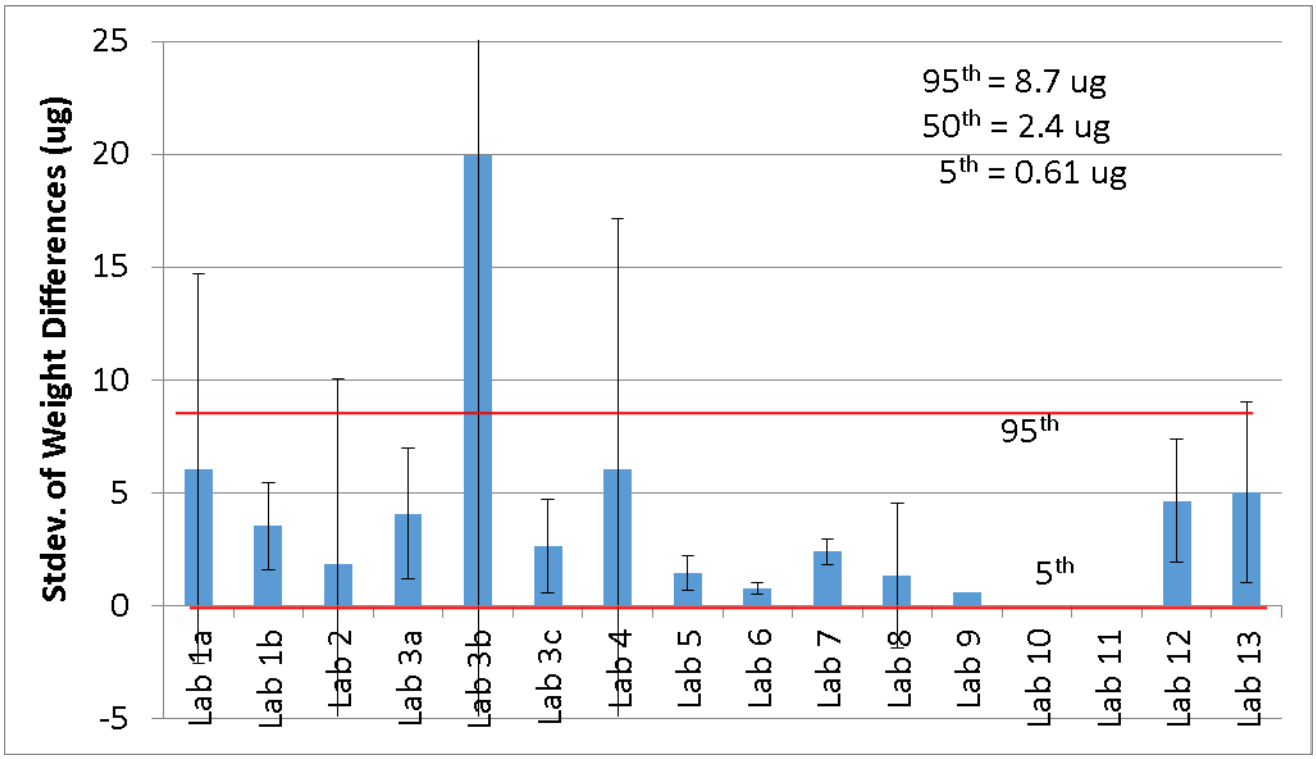

Figure 4-3 Average reference filter weight differences for the pooled filters (outliers included)
[1] Error bars represents the one standard deviation of the average results from equation 4 for each short-term pair evaluated.

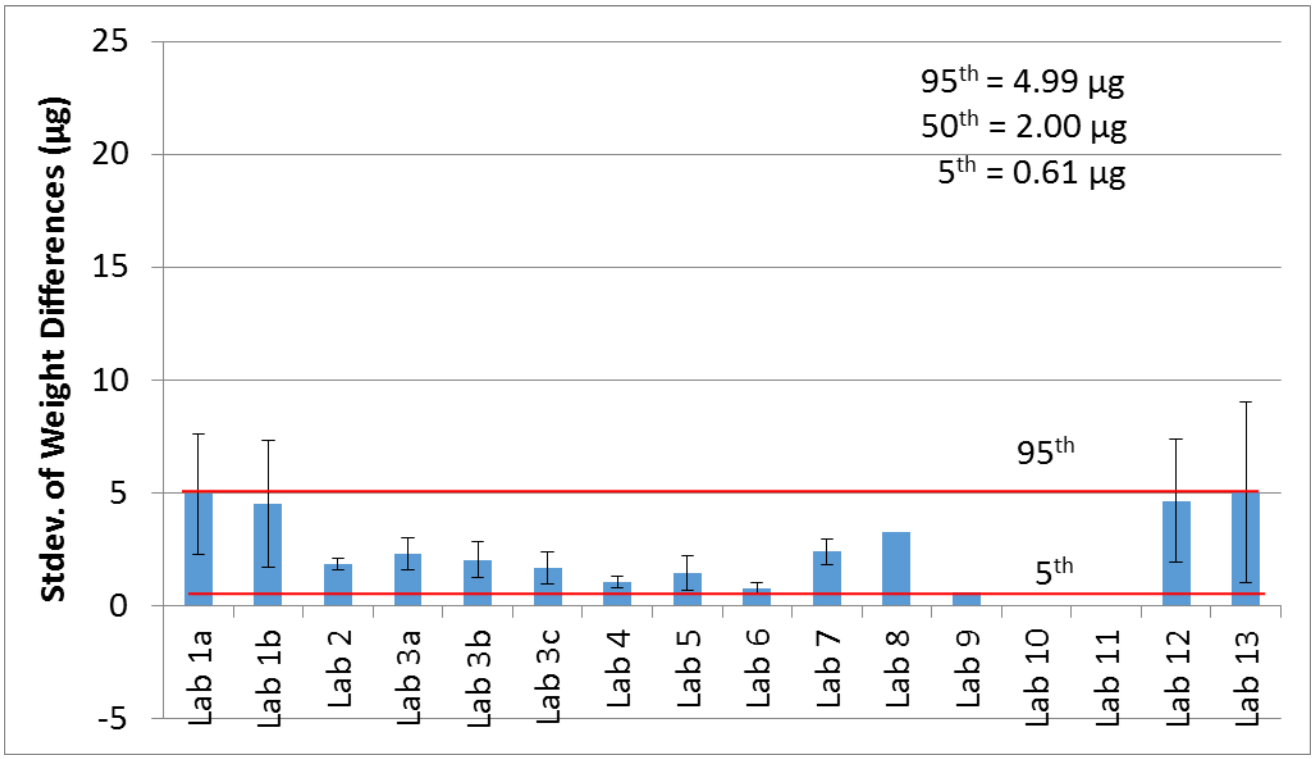

Figure 4-4 Average reference filter weight differences for the pooled filters (outliers removed)
[1] Error bars represents the one standard deviation of the average results from equation 4 for each short-term pair evaluated.

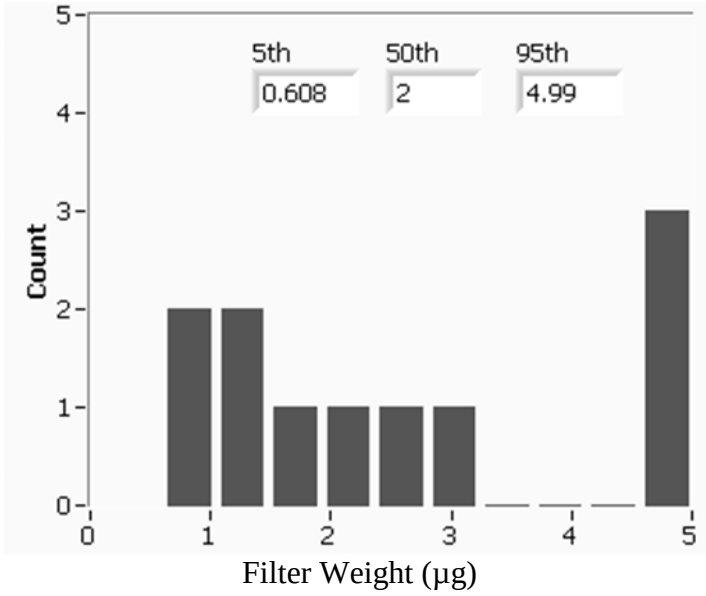

Figure 4-5 Overall laboratory 5th, 50th, and 95th percentile reference filter weight differences.

4.2.2.2 Long-term Results for Teflon™ Filters

The results of the long-term statistics were calculated for Labs 1, 3, 4, and 9. These laboratories were selected due to the availability of filter weights and time/date data. Table 4-3 shows the regression statistics for the slope and SEE in terms of weight gain as a function of time. The total number of reference objects tested ranged from 2 to 184. Each reference object was weighed on average from 42 (Lab 3) to 137 (Lab 9) times. The average long-term mass increase for the filters ranged from -0.03 µg/day (Lab 4) to 0.65 µg/day (Lab 1). The 95th percentile ranged from 0.5 µg/day (Lab 4) to 1.79 µg/day (Lab 1).

Table 4-3 Long-term reference filter analysis statistics (µg/day)

	Reference Objects		Slope Statistics (ug/day)					SEE Statistics (ug)				
Lab	No Obj.	# weights/ea.	Ave	Stdev	5th	50th	95th	Ave	Stdev	5th	50th	95th
Lab 4	11	109	-0.03	0.28	-0.61	0.01	0.50	0.95	0.21	0.00	0.79	1.26
Lab 9	2	137	0.03	0.03				0.86	0.86			
Lab 3	97	42	0.21	0.47	-0.42	0.17	0.82	2.20	1.31	0.88	1.78	5.37
Lab 1	184	67	0.65	0.61	-0.19	0.57	1.79	2.41	0.88	1.08	2.33	3.75

These statistics strongly suggest the length of time between or before weighings is critical for the determination of the mass loading. The impact appears to be more of a positive increase from pre- to post-test (tare to final) filter weighing. It also suggests the longer the time difference between pre- and post-test weights can contributes over 1 µg/day at the upper end of the statistics.

The long-term analysis assumed well behaved regression statistics. Figure 4-8 shows an example of a well behaved regression plot. The spread of the data is fairly random about the best fit line and one cannot see any defined behavior within the data. Figure 4-9 shows an example of a non-well behaved regression plot. The data in Figure 4-9 show a distinct trend with a slightly negative slope for the early dates and then an increase to a positive slope for the later dates. The overall slope is positive, but on an individual basis this data suggests the behavior varies and clearly shows two different slopes, one negative and one positive. This suggests the data provided is conservative and that the true variability is actually higher than estimated by this analysis.

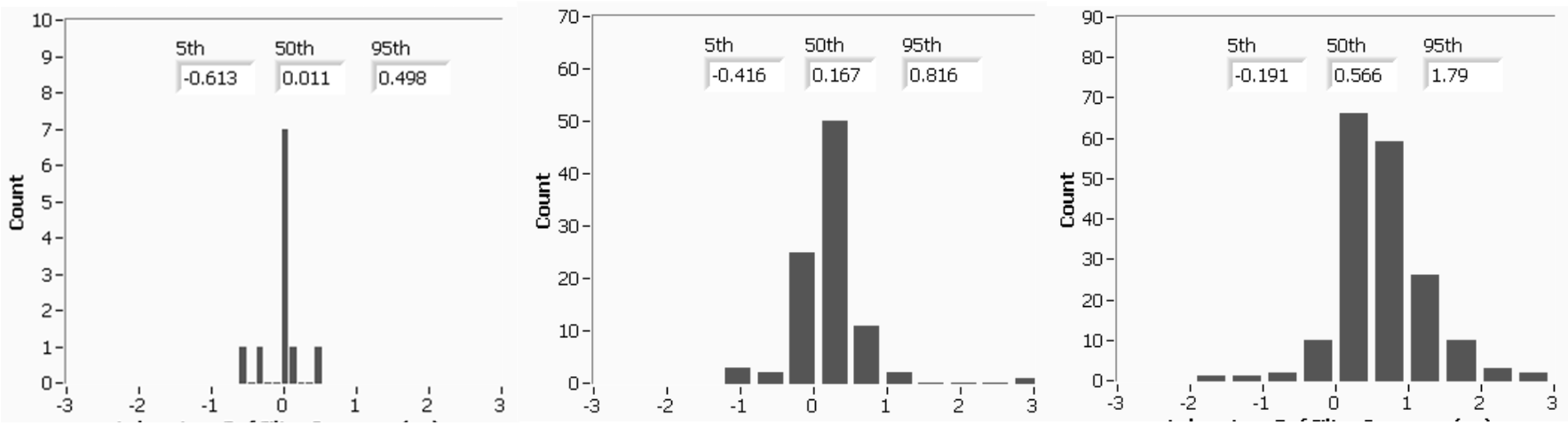

Figure 4-6 Percentile statistics for slope regression statistics x-axis is µg/day weight gain

[1] from left to right, Lab 4, Lab 3, and Lab 1 (Lab 9 not evaluated due to only two reference filters provided)

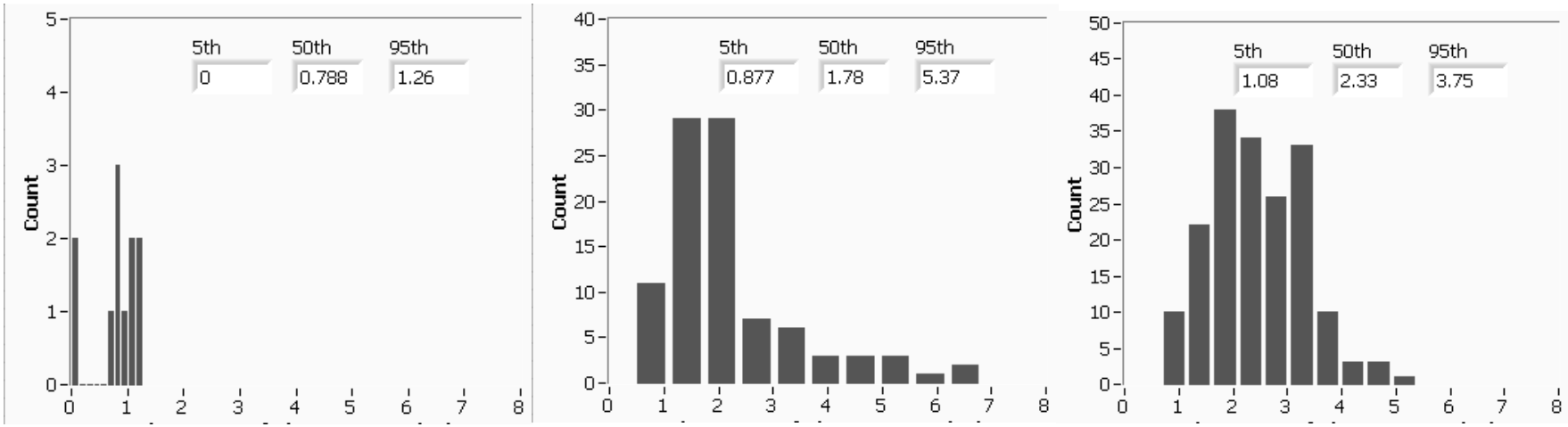

Figure 4-7 Percentile statistics for SEE regression statistics x-axis is µg/day weight gain

[1] from left to right, Lab 4, Lab 3, and Lab 1 1 (Lab 9 not evaluated due to only two reference filters provided)

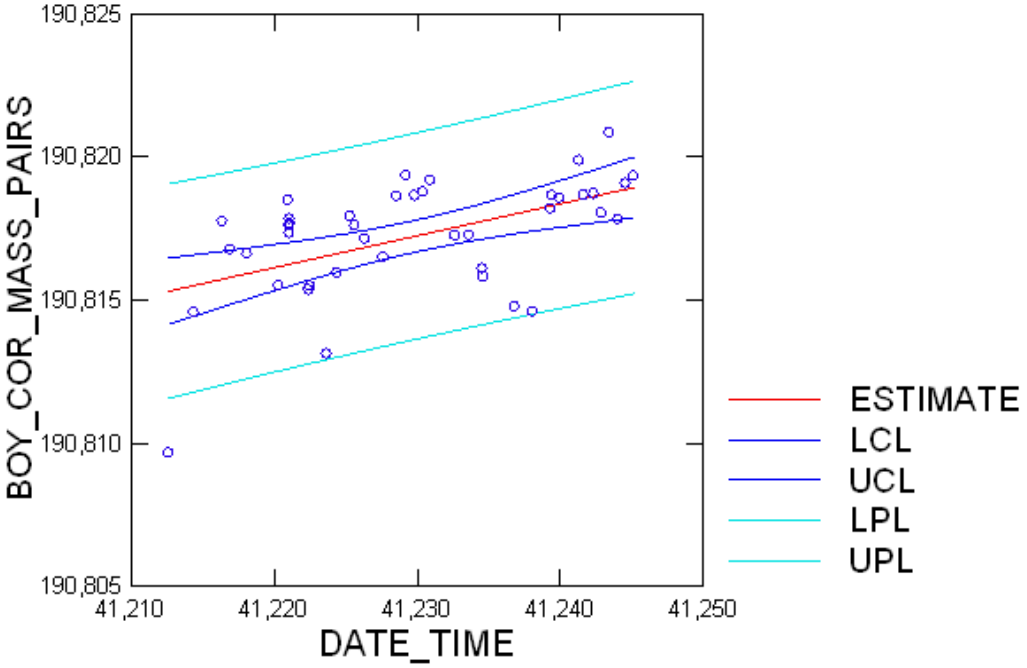

Figure 4-8 Reference filter (Lab 3) weight gain for a well behaved case (m=0.11 µg/day)
[1] LCL lower confidence limit, UCL upper confidence limit, LPL lower prediction limit, and UPL upper prediction limit

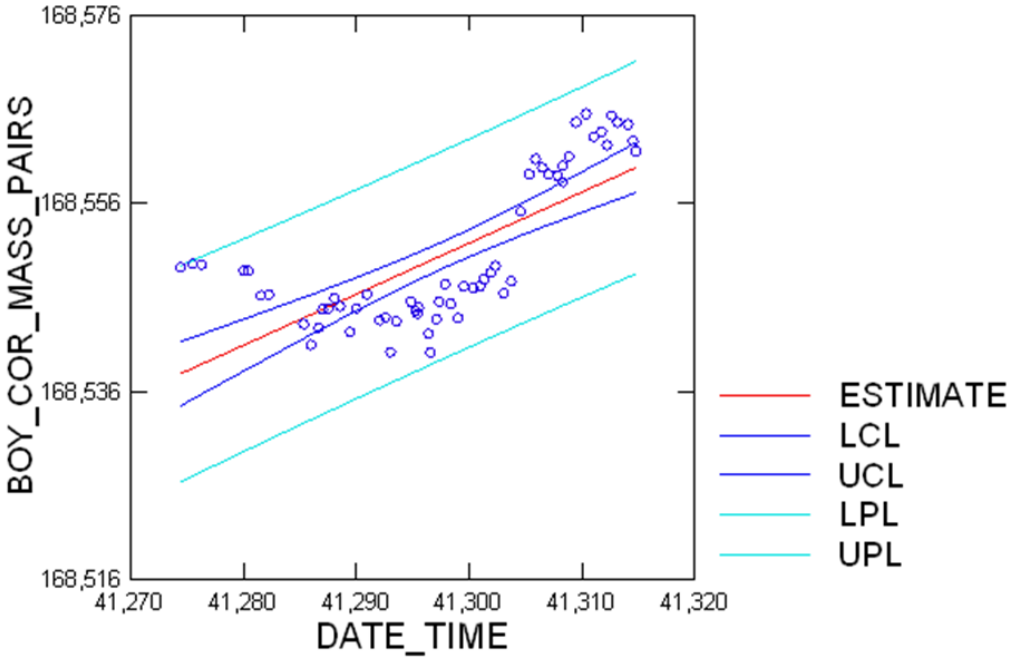

Figure 4-9 Reference filter (Lab 3) weight gain for a non-well behaved case (m=0.54 µg/day)
[1] LCL lower confidence limit, UCL upper confidence limit, LPL lower prediction limit, and UPL upper prediction limit

4.2.2.3 Metal Standards

Metal standards were also measured by one laboratory. The metal standards used were close in weight and physical dimension (47 mm) to the Teflon™ reference filters. The metal standards were weighed during the daily start-up operations of the microbalance as the Teflon™ reference filters, so they were subjected to the same contaminated air, handling, and soak times between weighing. Figure 4-10 shows 70 weights for one metal reference object spanning about three months of time. Figure 4-11 shows a metal reference weight gain over time for Laboratory 10 which showed a slope of -0.04 µg/day. Both results show no weight accumulation for the metal standard. Discussions with other E-99 project panel members suggested that these trends were also true for them, where the metal reference weights did not increase with time as the Teflon™ reference objects did. This suggests the PM contamination mechanism is not dust particles, but possibly some type of gas phase adsorption.

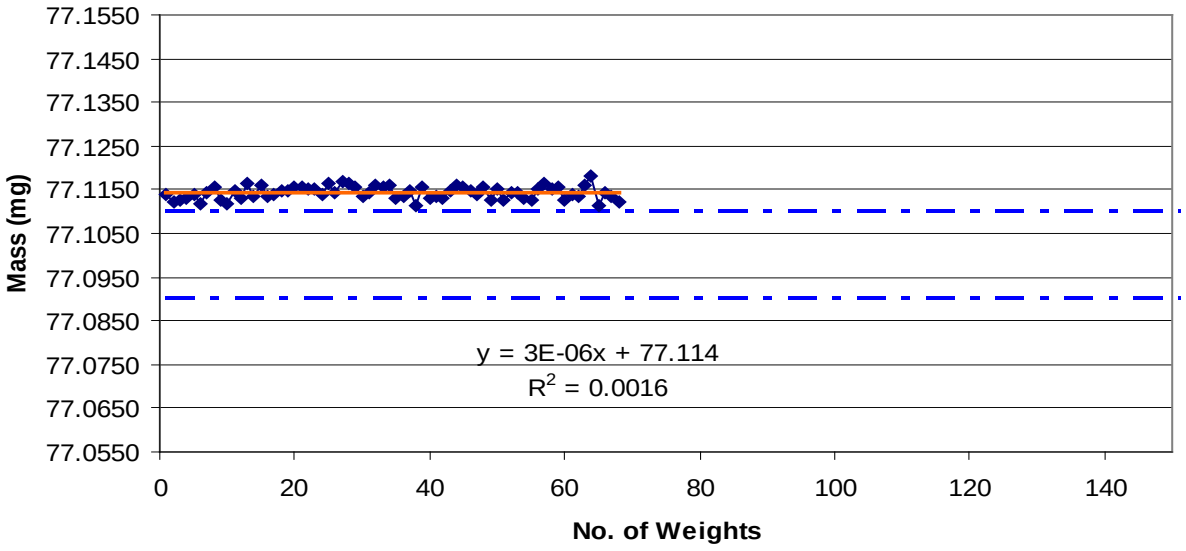

Figure 4-10 Metal reference weights utilized with reference filter weighing (Lab 13)

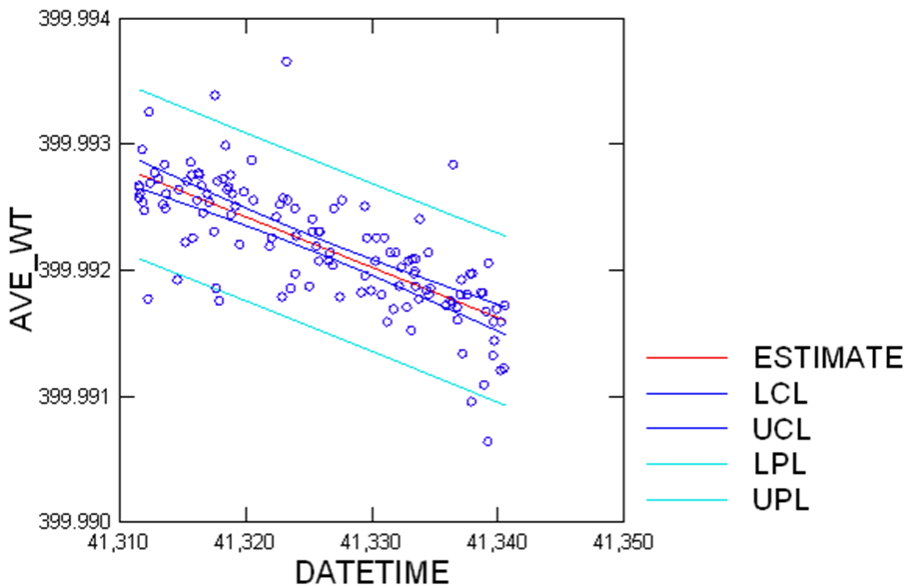

Figure 4-11 Automated system (Lab 6) metal weight reference weight change (-0.04 µg/day)
[1] LCL lower confidence limit, UCL upper confidence limit, LPL lower prediction limit, and UPL upper prediction limit

4.2.2.4 Glass Fiber Reference Filter Results

In the E-66 project the TX40 filters have been demonstrated higher artifact adsorption than Teflon™ filters [1, 2, 3]. These filters are not widely used; they were analyzed based on the limited data provided. Figure 4-12 shows the TX40 reference filter statistics for the three laboratories that provided TX40 glass fiber filter weights and date information. Each laboratory provided on average 20 different reference filters. Thus the analysis was limited to the long-term analysis. The 50th percentile TX40 reference filter was just below 0 at -0.01 with a 95th percentile of 0.42 µg. Although the TX40 glass fiber reference filters from the limited number laboratories evaluated here showed less variability than the Teflon™ filters, it is not clear if that trend would hold true for a larger population of filters/laboratories. Additionally, it has been demonstrated that the artifact issue with the TX40 is more prevalent for tunnel blanks and sample blanks. Overall, these results are not conclusive and more data are needed to compare these results to the Teflon™ reference blank results.

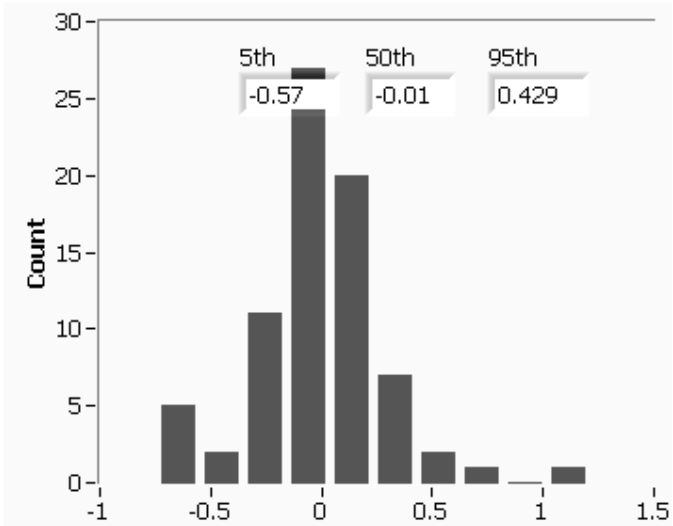

Figure 4-12 TX40 long-term filter regression slop statistics Lab 3 only

4.3 Tunnel blanks

Tunnel blanks provide an important measure of the sources of contamination that can be seen throughout the course of normal testing. This can include PM contamination desorbing from the inner surfaces of the sampling systems over time. Some PM may also adsorb to the walls the CVS system during an emission test. The net effect of the sampling system is not well known and could vary depending on the number of tests performed, the emission levels of the vehicles being tested, and the associated impact on the internal surfaces of the sampling system. For example, a sampler that runs 500 tests per year will be different than a sampler that runs over 50,000 tests per year. This survey should help assess these differences by identifying specific details about the operations and volume of filters and emission tests provided in addition to all the filter data analyzed.

UCR has been tracking filter contamination for several years as part of ongoing research with heavy-duty diesel mobile emissions laboratory (MEL). As part of the MEL operation, the following blanks reference (as per 1065), trip, static, dynamic, and tunnel blanks are regularly measured. These blanks are described in Johnson et al. [11]. Typically reference, trip, and static filters show about a 2-3 µg weight gain. Other laboratories have suggested a similar trend, but this data has not been widely published. Dynamic blanks taken in conjunction with testing done on clean sources (< 10 mg/bhp-h or 10 mg/mi) also show 2-3 µg weight gains, while those done in conjunction with testing on dirty sources (> 70 mg/hp-h or mg/mi) accumulate more contamination, and are more in the range of 5-15 µg. Tunnel blanks ranging from 10 minutes to 4 hours also show about 10-15 µg of weight gain when the tunnel is relatively “clean”. Some suggest the standard ambient temperature tunnel blank weight gain is from hydrocarbon artifacts or contaminants in the CVS, and others suggest it is from ambient air. Nevertheless, given that filter contamination from filter handling is on the order of 2-3 µg, and the expected measurement levels are on the order of 5-10 µg for some low emission vehicles, a better understanding of the background sources of this contribution is needed to minimize its impact.

Figure 4-13 shows the Teflon™ tunnel blank data for various laboratories with single standard deviation error bars. Table 4-4 lists the statistical results for each laboratory, and Table 4-5

shows the grand totals and overall statistics for the laboratories pooled together. Table 4-6 lists the interlaboratory comparison results with the grand total 50th percentile results listed in Table 4-5. The red lines in Figure 4-13 represent the 95th and 5th percentiles for the pool of laboratories. The subscripts on some laboratories (Lab 4a and Lab 4b) represent different sampling lines or systems utilized in their normal operation. For example, some laboratories have filters tested by phase and thus evaluate tunnel blanks by phase. The sample system contamination may vary with these different systems due to emissions loading differences. Each subscript (Lab 4a vs Lab 4b, for example) represents unique cases that needed to be treated independently. The 5th, 50th, and 95th percentiles pooled tunnel blank (n=615) mass increases were 1.1, 2.8, and 13.0 µg (see Figure 4-14a). The variability (single standard deviation) for the pooled laboratories varied from 0.32, 2.8, and 7.6 at the 5th, 50th, and 95th percentiles (see Figure 4-14b and Table 4-5). The tunnel blank data for the glass fiber filters were very limited and were not analyzed for this report.

Table 4-4 Summary statistics for each laboratory's tunnel blanks

Facility	No PTFE Obj. (N)	Average µg diff.	Stdev. µg diff.	90% CI of Mean	Facility	No PTFE Obj. (N)	Average µg diff.	Stdev. µg diff.	90% CI of Mean
Lab 1					Lab 7d	32	1.62	2.45	0.73
Lab 2					Lab 8f	54	3.00	5.81	1.32
Lab 3					Lab 8g	149	4.59	5.10	0.69
Lab 4a	21	5.54	6.24	2.35	Lab 9a	40	2.50	2.70	0.72
Lab 4b	26	1.49	1.70	0.57	Lab 9b	80	1.03	0.21	0.04
Lab 5	24	2.43	2.20	0.77	Lab 10				
Lab 6a	41	2.53	0.75	0.20	Lab 11				
Lab 6b	72	3.47	1.70	0.33	Lab 12	3	14.24	6.24	10.53
Lab 7c	10	5.10	4.85	2.81	Lab 13	39	7.82	7.88	2.13

Table 4-5 Grand total summery statistics for all laboratories pooled together

	No PTFE Obj. (N)	Average µg diff.	Stdev. µg diff.	90% CI of Mean
Grand Average	43.9	4.13	3.62	1.73
50th Percentile	-	2.76	2.80	-
Total N	615	-	-	-
StDev of Grand Average	-	3.45	2.36	2.66
90% CI of Grand Average	-	1.95	1.71	-

Table 4-6 Inter-laboratory percent comparison to the 50th percentile of all Labs.

Facility	No PTFE Obj. (N)	Average % diff.	Stdev. % diff.	Facility	No PTFE Obj. (N)	Average % diff.	Stdev. % diff.
Lab 1				Lab 7d	32	-41%	-12%
Lab 2				Lab 8f	54	8%	107%
Lab 3				Lab 8g	149	66%	82%
Lab 4a	21	101%	123%	Lab 9a	40	-9%	-4%
Lab 4b	26	-46%	-39%	Lab 9b	80	-63%	-92%
Lab 5a	24	-12%	-21%	Lab 10			
Lab 5b	24	-11%	4%				
Lab 6a	41	-8%	-73%	Lab 11			
Lab 6b	72	26%	-39%	Lab 12	3	416%	123%
Lab 7c	10	85%	73%	Lab 13	39	183%	182%

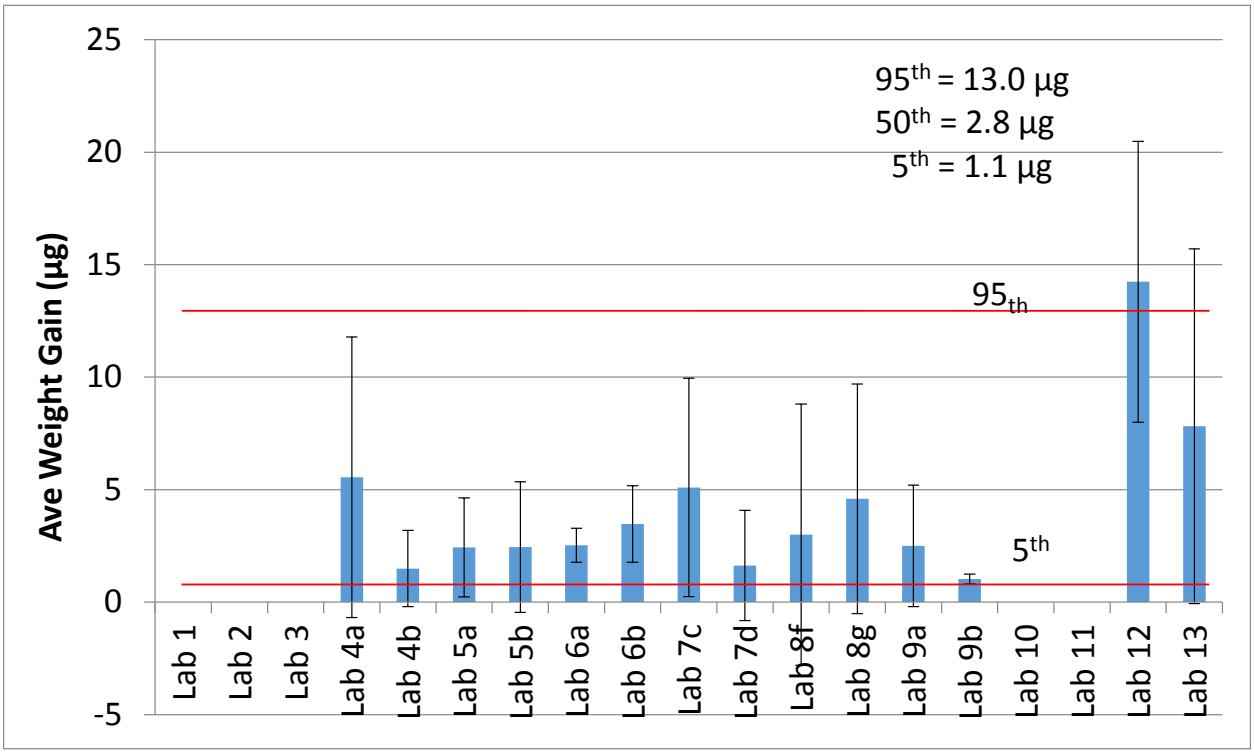

Figure 4-13 Tunnel blank net difference for each laboratory

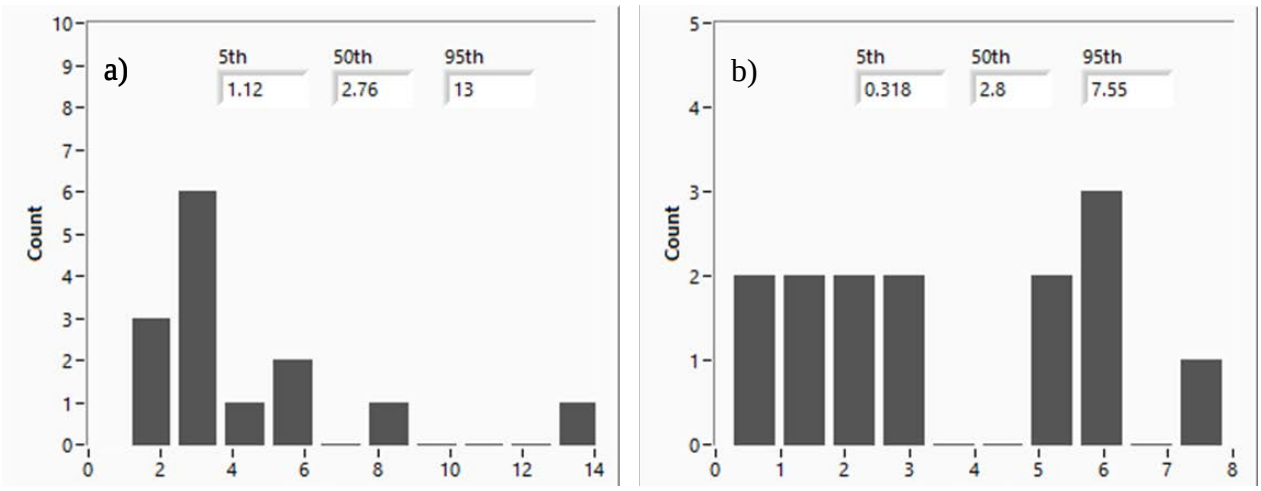

Figure 4-14 Tunnel blanks percentiles (a) weight gain (b) standard deviation

4.4 Survey Summary

A filter survey was performed to evaluate the ability for emissions test laboratories to weigh a filter, quantify its uncertainty, and to consider practices that may produce lower uncertainty in the weighing process. Thirteen North American laboratories, representing industry, agencies, research institutes, and academic institutes, responded to the survey; eleven laboratories providing filter data. Selected results from the filter survey include:

- The *reference* filter variability, within a given day over periods as short as an hour, ranged from 0.61 µg to 5.0 µg for the 5th and 95th percentiles and 2.0 µg for the 50th percentile (n>40,000 weights and 317 reference objects). The grand total average was 2.6 µg.
- *Reference* filters were found to gain weight on the order of 0.17 to 0.56 µg per day (50th percentile) and 0.8 to 1.8 µg per day (95th percentile). Metal reference objects didn't gain weight. This suggests that a gaseous phase adsorption artifact is occurring within the micro balance area. Future analysis should be performed on a per event basis to consider contamination by touch and not by time, since it is believed the contamination is not a function of time.
- Robotically weighed *reference* filters showed very low variability (0.8±0.3 µg) compared to filters weighed manually by people.
- Robotically weighed *reference* filters also showed a much lower mass gain per touch at 0.01 µg/event.
- *Tunnel blank* mean biases (n=615) were much higher than the reference filter mean bias and had a range from 1.1, 2.8, and 13.0 µg, for the 5th, 50th, and 95th percentile.
- Robotically weighted *tunnel blanks* were also high and within the range of manually weighted filters. Thus, the advantages of robotically weighed filters were lost for all but one laboratory that was able to maintain a tunnel blank value of 1.0±0.2 µg (n=80).
- The higher *tunnel blank* compared to the reference blank suggest the sample collection system is a relatively significant contamination source for Teflon™ gravimetric filters.
- It is expected a hot sample system may have higher and more variable PM artifact tunnel blank contribution compared to cold tunnel blank test. Thus, the *tunnel blank* values presented may be conservative.

- The one standard deviation (1σ) 50th percentile tunnel blank was 2.8 µg for all the laboratories pooled together and an average of 4.1 µg.

5 Summary and conclusions

With the introduction of more stringent PM regulations for light-duty vehicles, it is becoming more important to better understand and characterize the accuracy of PM measurements at lower PM levels using different methodologies. This study was designed to evaluate potential improvements in PM mass measurement using increased filter face velocity, reduced DF, and combining and using cumulative filters. This included FFVs from 175 to 100 cm/sec, changing DF from 7 to 3 with a partial flow sampling system, and 3-bag and 4-bag cumulative vs. individual filters. Two vehicles were used in this study: a Lower PM Source vehicle with a PM emission rate below 1 mg/mi and a Higher PM Source vehicle with a PM emission rate just below 3 mg/mi. These vehicles were tested over a series of FTPs and US06s over the course of two separate testing periods. A survey of filter weighing practices and reference/blank filter weights was also performed to better assess the ability to weigh a filter and the associated uncertainty with the weighing process, and to consider practices that may produce lower uncertainty in the weighing process. The goal of the E-99 project was to better understand the sensitivity of the measured $PM_{2.5}$ mass to various PM sampling procedural changes rather than suggesting modification to current federal methods.

A summary of the results and conclusions of this study are provided as follows. The results focus primarily on the results of the confirmation testing, where the most extensive testing was conducted under the conditions the most advantageous for PM mass measurement.

PM emission Characteristics of the Two Test Vehicles: Confirmation results

The PM emissions for the Higher PM Source were in close agreement; they averaged between 1.98 mg/mi to 1.85 mg/mi for the various PM probes sampled over the FTP cycle and between 2.53 to 2.29 mg/mi for the US06 test cycle. The Higher PM Source mean emissions showed a low relative error of -5.6% between the PFSS (DF=5 FFV=150) and Probe A (DF=7, FFV=150) and only -2.4% to Probe D. A relative error of 5% is a reasonable and relatively small error considering that a 20% variation in PM measurements between different laboratories was reported during PM mass and number cross lab correlations.

The Lower PM Source had a much lower overall PM emission levels, as well as a higher relative error among the different probes. The Lower PM Source showed an emission rate that varied between 0.12 to 0.09 mg/mi for the FTP test and 0.28 to 0.22 mg/mi for the US06 test. The difference between each of the probes and the overall average for all the probes was only 0.02 mg/mi. This suggests the Lower PM Source's FTP results were very repeatable and the mean differences were small.

Filter weights increased in proportion to increased FFVs and lower DFs for all test cycles and both filters. The Higher source filter weight varied from 417 µg to 205 µg for the PFSS and C100 samplers, respectively. The US06 test cycle showed lower filter weights compared to the FTP test cycle, partly due to the absence of the cold start, because the US06 is a shorter cycle, and because it has fewer transients than the FTP test. The Lower PM Source filter weights varied from 39 µg to 26 µg for the PFSS and C100, respectively. The Lower PM Source vehicle filter weights are close to the CVS tunnel blank average of 5±4 µg and the PFSS tunnel blank of 1±1 µg measured during the confirmation testing. The Higher source vehicle generally showed filter weights well above the tunnel contamination levels, while the Lower PM Source weights were close to the CVS contamination levels.

The physical and chemical characteristics of PM showed both differences and similarities between the vehicles. The PM composition for the Higher PM Source showed a higher percentage of soot or elemental carbon, while the PM composition for the Lower PM Source showed a higher percentage of organic aerosols. For both vehicles, the particle size distributions were predominantly in the accumulation mode with peaks from around 65-90 nm. There was not a significant nucleation mode mass contribution for either vehicle that might influence the method improvements. Additionally, the average PM size distribution is relatively consistent for both the Higher and Lower PM Sources, with slightly larger diameter particles for the Higher PM Source compared to the Lower PM Source.

The Impact of Filter Face Velocity, Dilution Factor, Combining or Collecting Cumulative Filters, and 3-bag vs. 4-bag FTPs:

Comparisons were made between FFV changes of 150 and 125, 150 and 100, and 125 and 100 cm/sec. The results showed that comparisons between mean differences for different flows were not statistically significant in most cases. These results suggest that increasing the FFV (from 100 to 150, flow-weighted, and at a DF=7) does not have a significant impact on the mean mass emission rates for Higher and Lower PM Sources. The PM net filter weights did increase for the higher FFV compared to lower FFV, thus the signal (i.e., filter mass) was increased, and the corresponding overall signal-to-noise ratio was affected. Although the f-test did not support a statistical improvement in the variance, as discussed next, the measurement signal was increased, which would help minimize the influence of contamination on the measurement. Tests conducted at a FFV of 175 cm/sec (screening tests) didn't show statistical mean differences, but the results indicated that filter overloading at this FFV could occur under different sampling conditions.

The dilution factor evaluation considered the differences between DF=5 and DF=7, where a PFSS was used to obtain the DF=5 and CVS measurements were used for the DF=7 results. The 4-bag Lower PM Source tests had p-values greater than 0.05 for all the combinations tested and all but one of the US06 tests, suggesting the mean differences are not statistically significant at a 95% confidence level. For the Higher PM Source, statistically significant differences in means at a 95% confidence level were found for the combined filter CVS probes for FFV = 150, 125, and 100 (and DF=7) compared to the PFSS, but not for the individually sampled filter base conditions case (Probe D100i). The Higher PM Source showed no statistically significant difference for the US06 tests. The US06 testing had a larger variability and fewer samples (n=2) due to testing complications. Although statistically significant differences in means were found, these differences were relatively small and could be attributed to errors in the exhaust flow, proportionality, flow measurements, or other proportional sampler details. These possible sources of bias between the CVS and PFSS sampler and the low mean relative errors suggest the lower DF may not be altering measurement methods. The DF=5 and FFV=150 for the PFSS PM sampler showed the largest net filter mass compared to all other probes for all but the US06 Higher PM Source test. The f-test p-values for most of the comparison cases were greater than 0.05, suggesting the PFSS does not have a statistically lower variability compared to the flow-weighted CVS probes with a FFV from 150 to 100, or compared to the individually collected filters (D100i) in most cases. Tests were also conducted at a DF=3 (screening phase), but the results indicated that filter overloading could occur at this FFV under different sampling conditions with the PM Sources utilized.

Combined filters have the advantage of collecting more PM mass on a single filter, but have a disadvantage of a reduced flow rate for some bags in order to flow weight the accumulated PM

mass as needed for the proper emission calculations. For the combined filters, the main comparisons were between CVS probes where PM was collected cumulatively over the full FTP vs. a probe where PM was collected individually for each FTP bag. The FTP Lower and Higher PM Source tests did not show a statistically significant difference in means for cumulative filters as compared to the filters collected individually by bag. The signal-to-noise ratio (as represented by the filter mass) did not necessarily improve for the combined filters. The typical filter mass collected for the cumulative filters was reduced, due to the flow-weighting conditions, when compared to the filter masses for all of the individual FTP bags added together. Although the signal-to-noise ratio didn't improve and the f-test showed no statistical improvement in variability for 1 filter 3 phase test, the f-test did show an improvement for 1 filter 4 phase test.

PM Filter Survey

Tunnel blank and reference filters were analyzed to evaluate the importance of variability, uncertainty, and detection limits for the gravimetric method. Trip, static, and dynamic blanks were also evaluated, but due to limited data no significant results could be presented.

The reference filter variability, measured within a given day over periods as short as an hour, ranged from 0.61 µg to 5.0 µg for the 5th and 95th percentiles and 2.0 µg for the 50th percentile (n>40,000 weights and 317 reference objects). Reference filters were found to gain weight on the order of 0.17 to 0.56 µg per day (50th percentile) and 0.8 to 1.8 µg per day (95th percentile). Metal reference objects didn't gain weight, which suggests some type of gaseous phase adsorption artifact within the micro balance area. Robotically weighed reference filters showed very low variability (0.8±0.3 µg) compared to manually weighed filters. Robotically weighed reference filters also showed a much lower mass gain per touch at 0.01 µg/event. No weight accumulation for the metal standard was found during this analysis. This suggests that the PM contamination mechanism is not dust particles, but possibly some type of gas phase adsorption.

Tunnel blank mean biases (n=615) were much higher than the reference filter mean bias and had a range from 1.1, 2.8, and 13.0 µg, for the 5th, 50th, and 95th percentile. Robotically weighed tunnel blanks were also high and within the range of manually weighed filters. Thus, the advantages of robotically weighed filters were lost for all but one laboratory that was able to maintain a tunnel blank value of 1.0±0.2 µg (n=80). The higher tunnel blank compared to the reference blank suggests that the sample collection system is a relatively significant contamination source for Teflon™ gravimetric filters. The one standard deviation (1σ) 50th percentile tunnel blank was 2.8 µg for all the laboratories pooled together.

General Screening and Confirmation Testing Observations

The primary use of the screening results was for selection and recommendations for conditions for the FFV and DF confirmation testing, but unique observations were found. Additional findings were made when considering all the data. Although these summary findings were not explored deeply, their mention is important as they represent significant impacts on the PM emissions from light-duty vehicles.

The Lower PM Source emissions varied as much as five times (0.5 to 0.1 mg/mi) between the screening and confirmation testing. This may be due environmental conditions. However the gaseous emissions did not show the same level of variability. The lower PM Source showed a relatively constant soot (EC) emissions rate of about 0.1 mg/mi for both the screening and confirmation testing; the volatile organics varied from test-to-test and appear to be the significant

contributor to the Lower PM Source variability. The EC composition fraction varied from 0.22 to 1 with an average of 0.67 for the FTP test cycle. The PM emission rate at the 0.22 fraction of EC was the highest emission rate reported at 0.5 mg/mi. This suggests the test-to-test variability may be a result of volatile organic PM for the Lower PM Source.

The Higher PM Source showed a lower overall variability (~2 times), but was still significant where most of the variability appeared to be test drift. The test vehicles' PM emissions appeared to be drifting during the screening phase; the vehicles demonstrated more stabilized PM emissions during confirmation testing. This observation is important, although not at the time explainable, it does allow one to consider the confirmation data as more robust. Additionally one should not try to draw conclusions with the screening results between non-paired tests sets due to the amount of vehicle emissions drift.

Future work

The E-99 testing project revealed several confounding influences for the quantification of vehicles PM emissions that suggest further investigation. These include understanding test-to-test variability (which exceed 100% between tests conducted over a 12 month time period), understanding PFSS to CVS comparison where 5-10% absolute bias was reported, characterizing PFSS dilution factor to identify possibly sources of bias between the CVS and the PFSS, and understanding sample contamination between tests where excessive exhaust temperatures may be contributing to PM emission measurement variability. To address these issues future tests should evaluate differences between different PFSS, noise sources, PFSS and CVS tunnel conditioning, sensitivity to exhaust flow measurement, sample proportionality issues, sample proportionality modeling, PFSS advantages and disadvantages, overall improvements recommended for both CVS and PFSS.

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Appendix A. Additional Information Related to Measuring Particle Mass

This appendix includes a discussion of theory for the measurement of PM mass with a filter type media. The appendix includes a discussion on the mass gain, alternative measurement methods, clean air systems, filter artifacts and contamination, filter efficiency and predictions, impacts from DF, and other details related to the measurement of PM mass on a filter.

A-1 Combined filters

The combined filter approach utilizes flow weighting throughout the different bags of the FTP to achieve the correct weighting for the emissions calculations. For the 3-phase FTP, the flow weighting reduces the Bag 1 FFV from the nominal 100 cm/sec to 43 cm/sec and Bag 3 to 53 cm/sec with Bag 2 at the nominal 100 cm/sec. This is overlaid by the green bars on the figure. This shows that the most PM is being emitted by the vehicle at the lowest FFV during Bag 1,. The 4 phase FTP captures more of the cold start since its weighting function is 0.75 for Phases 1 and 2 and 1.00 for Phases 3 and 4, as represented by the purple bar in Figure A-1.

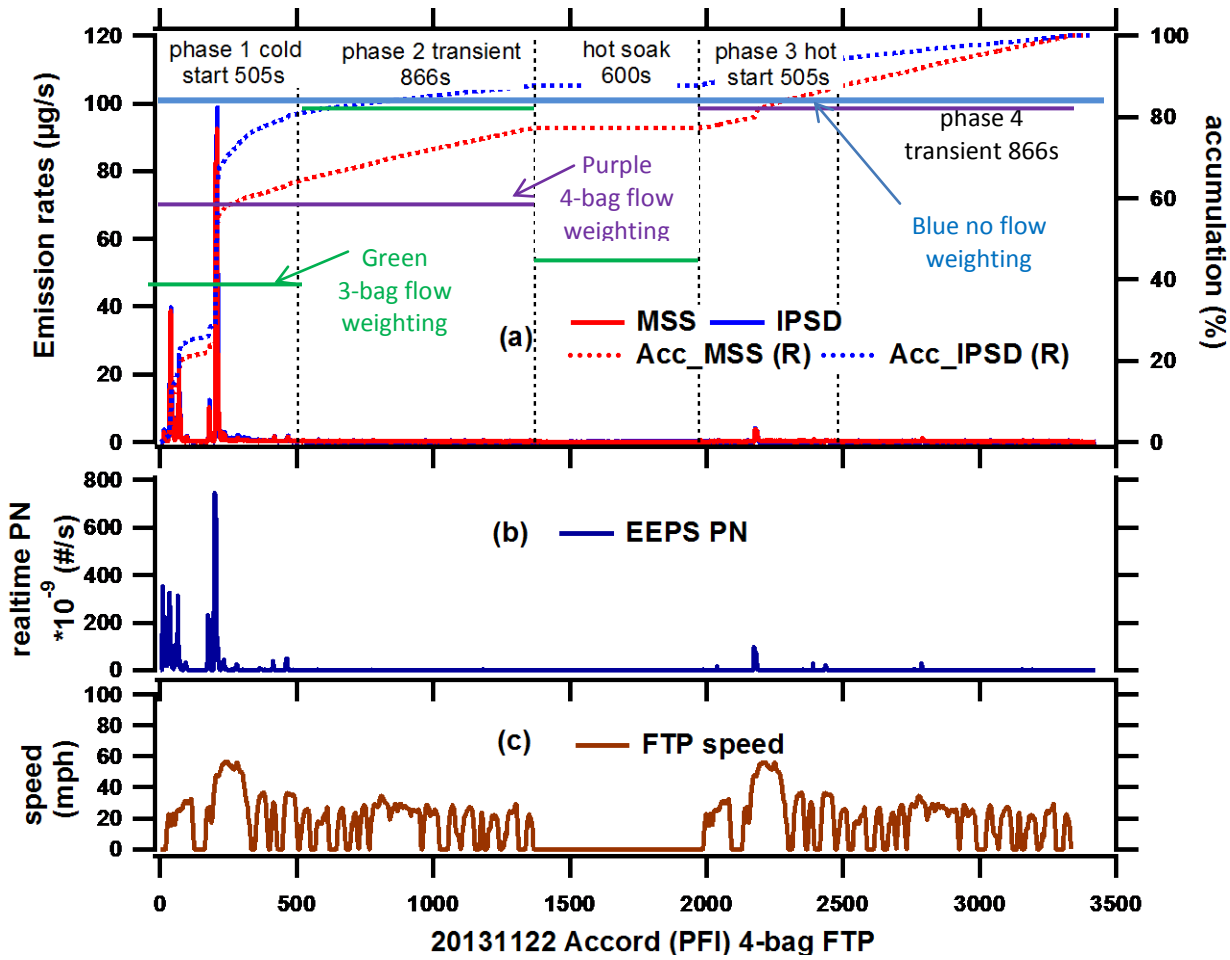

Figure A-1 Filter artifacts and contamination

A-2 Suspended vs. Gravimetric PM measurement methods

In addition to the traditional gravimetric PM mass measurement methods, PM mass can also be determined using suspended PM mass measurement method. This method involves measuring particles as a function of their size to obtain particle concentrations in different volume bins, then

multiplying that by effective density factors, and summing over the total volume of particles to get the total PM mass. In an ideal case, with no filter PM mass artifacts, the suspended PM mass and the gravimetric PM mass would be equal. Experience shows the two are different due to filter mass artifacts. As the suspended PM represents the gravimetric PM with no filter artifacts, it is important to understand the magnitude and nature of the suspended PM, even though it is not being regulated. This understanding should provide a baseline to the minimum PM mass in the exhaust. The quantity of semivolatile material collected on a filter from the engine exhaust is likely to depend more on the collection conditions; those conditions were identified in this phase of the project. However, it is argued that semivolatile material collected on a filter that results from adsorption of semivolatile material that is present in the engine exhaust should be considered part of the PM mass.

With new instruments, suspended PM mass can be measured by one of two methods. Park et al. [12] measured suspended PM using an APM (Aerosol Particle Mass Analyzer)-DMA (Differential Mobility Analyzer) for two steady state engine conditions of 75% and 10% engine load. They found that the suspended PM agreed within 2% of the gravimetric PM at 75% load. However, the gravimetric PM was two times higher than suspended PM at 10% load, likely due to the contribution of artifacts to the filter mass. Their technique is suitable for steady state conditions but not for transient cycles. Maricq and Xu [13] developed a similar method using a DMS-ELPI (Electrical Low Pressure Impactor) setup; their method is applicable to suspended PM from a transient cycle. Liu et al. [14] applied Maricq and Xu [13]'s idea to quantify suspended diesel PM and named the method Integrated Particle Size Distribution (IPSD) method. They used an Engine Exhaust Particle Sizer (EEPS) to measure real-time particle size distributions from transient cycles and used the particle effective density of Maricq and Xu [13] to determine the suspended PM. The IPSD method showed good promise, as it showed sensitivity an order of magnitude higher than the current gravimetric method. There are several uncertainties associated with the IPSD method. First, it is not clear how general the particle effective density function is. Park et al. [12] found that it varied slightly with engine load. It is unclear how much it might depend upon engine type, since GDI and traditional diesel engines might produce mainly carbonaceous aggregates, PFI engines and DPF-equipped diesel engines might behave differently. Second, it is known that unipolar chargers like those used in the DMS and EEPS overcharge agglomerates and shift their mobility size compared to what would be measured with traditional DMA and SMPS methods.

The quantification of suspended PM by the IPSD method can help to interpret low gravimetric PM measurements. Another advantage using the IPSD method to measure suspended PM is that it allows simultaneous measurement of PM, PN (particulate number) and PS (particulate active surface area). This is another reason why parallel measurements of suspended PM can improve understanding of very low PM level measurements. It can help provide information on how PM, PN and PS evolve from 10 mg/mi to 3 mg and 1 mg/mile and even sub 1 mg/mile level.

A-3 Filter impacts with increasing FFV

Filter efficiency

This section contains filter efficiency predictions made using an assumed particle size mass distribution using software developed at the University of Minnesota. Table A-0 shows the specifications for the filter media utilized in the filter survey and the Whatman filter utilized in the emissions testing part of this work. Figure A-2 shows particle size distribution utilized to calculate the PM filtration efficiency at different FFVs. Figure A-3 shows predicted filter

efficiencies at different FFVs and Table A-1 lists overall predicted mass collection efficiencies for a normally distributed PM aerosol. The efficiency curves assume that the filter has a solidity fraction of 0.41, a thickness of 40 µm, and an effective fiber diameter of 1 µm. If the filter specifications are slightly modified with a lower solidity fraction of 0.364 and a larger effective fiber diameter of 1 µm, the filter efficiency is reduced, as shown in Figure A-4 and Table A-2.

Table A-0 Specifications of Pall, Whatman and MTL filter medias

Vendor/Supplier	Pall	Whatman	MTL
Item #	R2PJ047	7592-104	PT47
Overall Diameter (mm)	47	46.2	46.2
Filter material	PTFE	PTFE	PTFE
Support ring	Polymethylpentene	Polypropylene	Teflon™
Thickness (µm)	46	40	40
Pressure drop (at 16.7 lpm) (inch of water)	3	11	6
Typical Aerosol Retention (as per ASTM D2986-95a)	99.99% at 1 and 2 µm; 99.79% at 3 µm	99.7% at 0.3 µm	

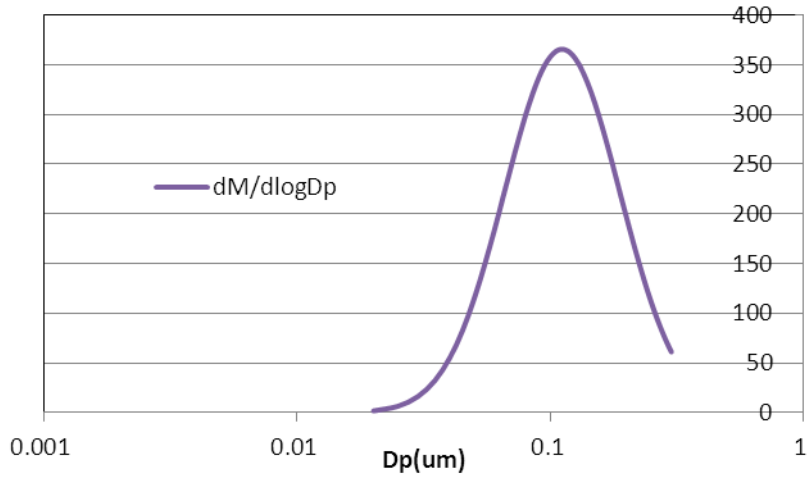

Figure A-2 Accumulation mode mass distribution used in FFV calculation

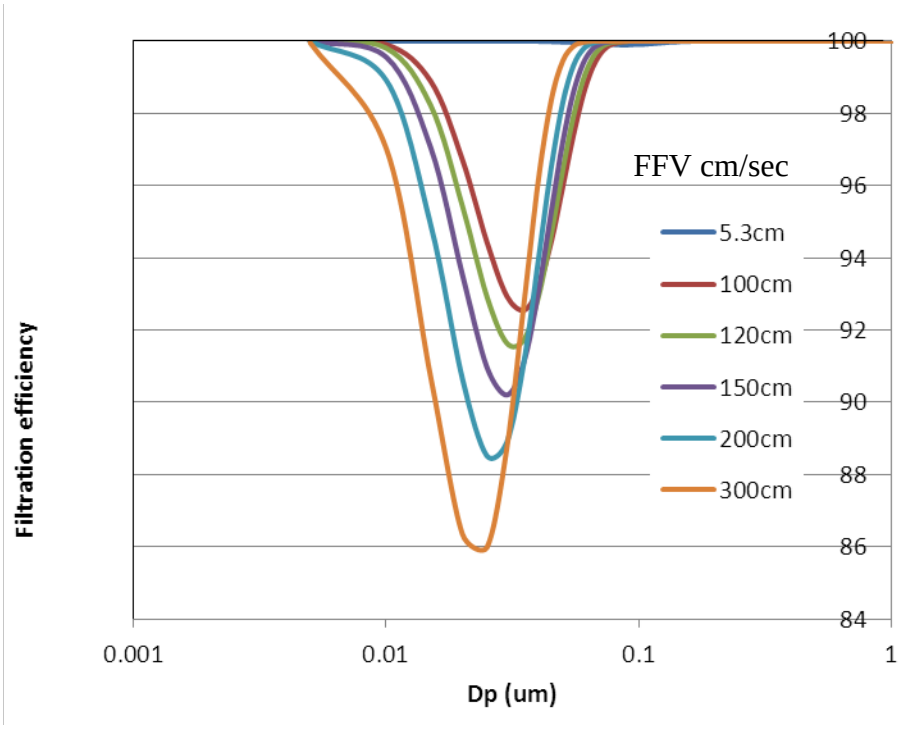

Figure A-3 PM filtration efficiency predictions as a function of FFV (cm/sec)

[1] Assumptions are solidity = 0.41, filter thickness = 40um, and effective fiber diameter = 1 µg.

Table A-1 Filtration efficiency predictions at different FFVs

Face velocity (cm)	5.3	100	120	150	200	300
Mass collection efficiency	1.000	0.994	0.994	0.995	0.996	0.997

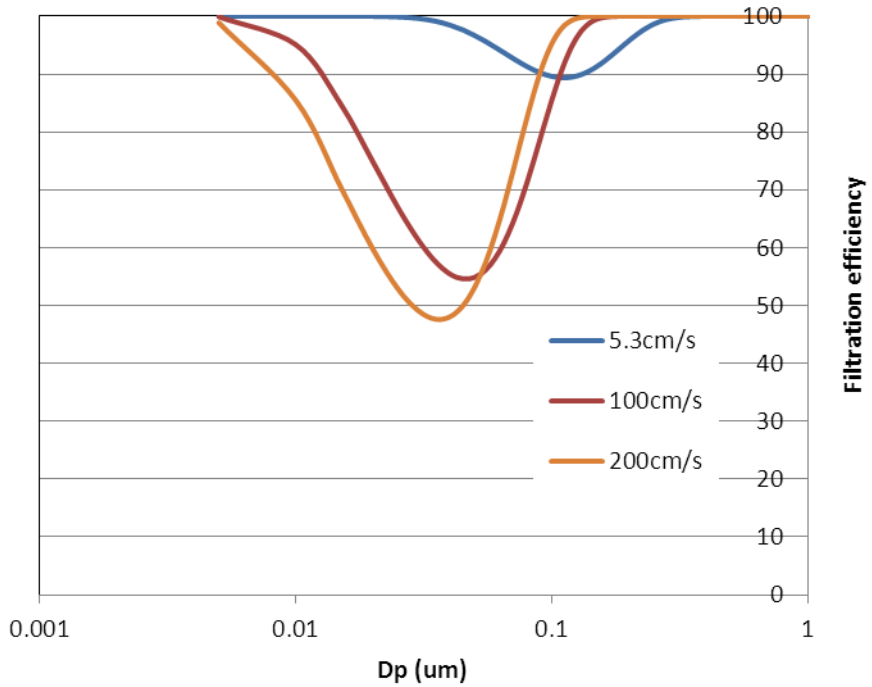

Figure A-4 PM filtration efficiency predictions as a function of FFV (cm/sec)

[1] Assumptions are solidity = 0.364, filter thickness = 40um, and the effective fiber diameter = 1.5 µg.

Table A-2 Filtration efficiency predictions at different FFVs (modified fiber dimensions)

Face velocity (cm/s)	5.3	100	200
Mass collection efficiency	0.93	0.84	0.88

Adsorption/Desorption

In principle, face velocity influences filter mass in two ways. A higher face velocity increases the rate of mass transfer so that the filter equilibrates with the gas phase more quickly, but to the extent that there is pressure drop across a filter it can decrease the adsorbed mass via volatilization. Adsorption on a filter (or on a particle) may be approximated by a simple adsorption isotherm of the form $V = V_m \frac{bp}{1+bp}$ [15], where V is the volume of gas adsorbed in equilibrium, V_m is the volume of a monolayer, b is a constant depending on the surface properties and adsorption energy, and p is the partial pressure of the adsorbing species. Changing the face velocity can only change equilibrium adsorption to the extent that it changes p, but it does change how rapidly equilibrium is obtained. This could have an impact for cumulative filters over all three bags of the certification FTP test, as a high face velocity would increase the rate at which adsorption comes into equilibrium with the lower partial pressure of semivolatiles associated with Bags 2 and 3.

A-4 PM mass gain theory

Gravimetric PM mass is defined as the material collected on a filter media at 47±5˚C from diluted exhaust with other requirements as specified in Part 1065. The definition includes contamination that might occur as a result of filter handling, CVS artifacts, as well as storage and release effects. Contamination from filter handling, which can occur during weighing, handling, transporting, and loading in and out of the CVS laboratory, is discussed in greater detail in Section 4. This subsection briefly describes potential artifacts/contamination from the CVS or storage and release throughout the sampling system.

Storage and release effects for the tailpipe, transfer line (between tailpipe and CVS) and CVS tunnel have also been reported by Maricq et al. [7]. They suggested the use of a partial flow dilution system directly off the tailpipe along with a preparation procedure for the vehicle can reduce storage/release (or history) effects. According to their study, the storage/release effects are more pronounced for more aggressive driving cycles like US06, as opposed to FTP.

To reduce the contribution of artifacts from CVS, an effective CVS tunnel cleaning procedure and criteria to determine frequency of tunnel cleaning are needed. For heavy-duty testing, a natural gas burner heats up the CVS to temperatures high enough to remove/oxidize accumulated material from previous tests. We have observed the release of hydrocarbons as a function of time and temperature during this natural gas heating procedure, and have documented its impacts on tunnel blank levels.

A-5 Reducing/quantifying artifact contribution

Part of the current dilemma with gravimetric PM mass measurement is that PM is operationally defined as the material collected at 47±5˚C from diluted exhaust with other requirements as specified in Part 1065. This definition does not distinguish between suspended PM and PM

artifacts due to semivolatile compounds. This section discusses information related to artifact contribution and methods to reduce it.

Chemical analysis of semi-volatiles on Teflon™ filters

The chemistry of condensable vapor can also be evaluated using specialized tools and methods employed to 'take apart' the secondary organic PM that is found in the atmosphere. These techniques can explore the semi-volatiles on Teflon™ filters. A determination of the vapor pressure and polarity range of individual hydrocarbons that directly influence this adsorption artifact becomes more necessary for low PM emitting vehicles. Similarly, desorption of semi-volatiles from the particles on the filter can lead to a negative filter mass bias. Highly controlled, synthetic chemical atmospheres can be used to evaluate and identify the components of vehicle exhaust and tunnel artifacts influencing this positive artifact. A volatility tandem differential mobility analyzer coupled with highly sensitive gas-phase (sub-ppb level) hydrocarbon measurements can identify the range of chemicals in these biases, allowing for characterization and minimization of their positive/negative artifacts.

Denuder

The E-66 study [1] investigated the use of a carbon denuder upstream of the filter to reduce condensable gas phase material; its results were inconsistent. Commercial grade denuders, such as an annular denuder at 47˚C with a counter flow stream of clean air to remove gas phase species, are available. The influence of the denuder on particle-bound semivolatiles is an issue.

Back-up Filters

Adsorption of organic materials to filter media has been reviewed by Turpin et al. [16]. They investigated different filter configurations, such as Teflon™-quartz and quartz-quartz, to understand both positive and negative filter artifacts in atmospheric filter measurements. Khalek et al. [17] measured PM emissions from GDI engines and corrected for adsorption artifact by subtracting mass collected by a quartz backup filter. It is debatable whether use of a quartz backup filter the right choice, since a quartz filter can adsorb much more artifacts than Teflon™ filter. Using a Teflon™ backup filter may be a more conservative approach. Use of a Teflon™ backup filter may under correct the artifact, if the backup filter does not have enough time to reach equilibrium [4], but using a quartz filter may tend to overcorrect the artifact due to higher levels of adsorption of gas phase materials. The E-66 study [1] found that filter weight gains by a Teflon™ backup filter during a transient cycle appeared to be negligible, within the uncertainty of the filter weighing measurement. Maricq et al. [7] also pointed out the difficulty of quantifying this correction, as the pressure drop across two in-series filters affects their relative adsorption. Swanson et al. [4] showed background vapor adsorption to a filter is not linearly proportional with the total volume of dilution air sampled due to competition between condensable gas phase material in the exhaust and the dilution air. Filter media can gain a few μg of mass during transporting to and from the test cell without any measurement. Also, the trace amounts of condensable organic material in the dilution air vary daily and from lab to lab.

Pre-baking filters

The E-66 study [1] investigated the effects of pre-baking filters at 52˚C. Although they found pre-baking does not improve measurement variability when they measured emissions at 70% of the 2007 Heavy-Duty PM standard, they recommended filter pre-baking for the emission measurements of DPF-equipped engines.

Potential Impact for NO_2

Figure A-5 shows an example of the effects of gaseous NO_2 adsorption at 200 ppm at 20 µg for both front- and back-loaded Teflon™ filters with polymethylpentene ring. Other filters are available with Teflon™ rings that are not expected to have the same mass gains. The filters conditioned with hydrocarbons (HC) at 200 ppm show a 4 µg PM increase. A list of other references for PM contamination is shown following Figure A-5.

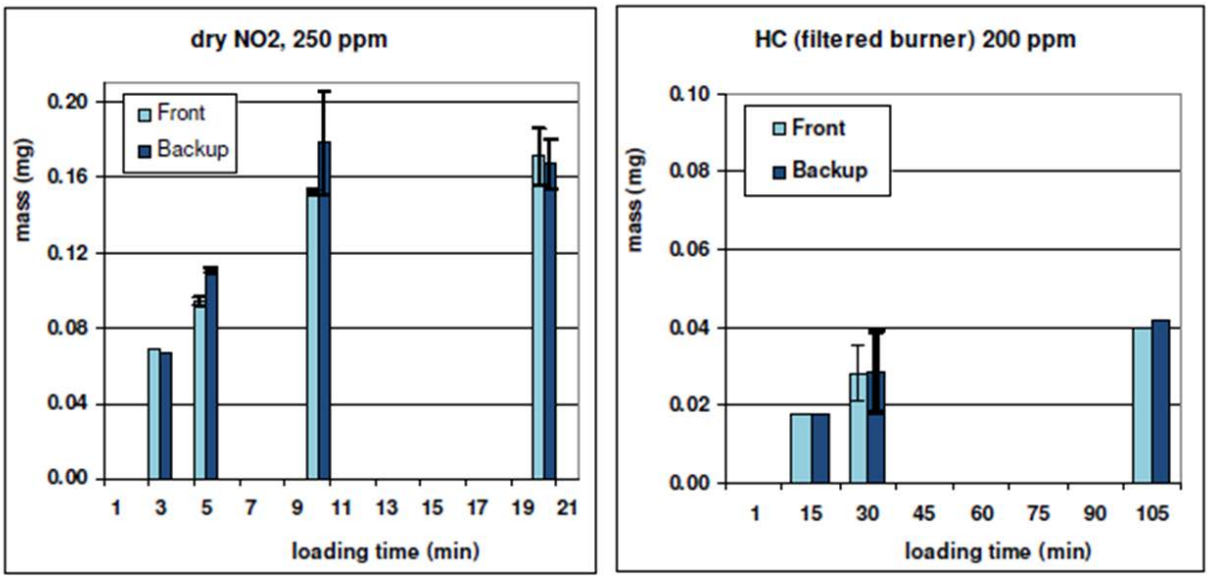

Figure A-5 Pall Teflo filter mass adsorption from various gas phase species (Arndt et al., AVL)

A-6 Improvements in filter weighing

Clean Air System

It is widely accepted that a blank filter accumulates measurable mass when inserted into the CVS system, even without running a vehicle [5, 6]. Possible explanations for this observation are the desorption of organic materials accumulated on the walls of the CVS during previous tests and the presence of semi-volatile materials in the dilution air that adsorb onto the sample filter. HEPA-filtered air, although required under Part 1065/1066, does not remove organic materials. Although it is not easy to build a gas cleaning air supply system for a CVS, and requires a large of volumetric flow, attempts were made by Tayama et al. [18] and Sun et al. [19].

A partial flow dilutor system can be economically configured to examine the effect of a clean air system on the reduction of artifact contribution to the filter mass. Additionally one could use a Donaldson® Pressure Swing Adsorption (PSA) system or its equivalent. Swanson et al. [20] examined a Donaldson® PSA system and reported the system removes all particle, water vapor and trace gas contaminants satisfying "Zero Air" grade J or ISO 8573 Class 2 air quality standards.

Robotic Arm

Swanson et al. [15] suggested that uncertainty in filter weighting of 1 µg (with 95% confidence) can be obtained through the use of robotic weighing and very tightly controlled environmental

conditions, while uncertainties of 3 to 10 µg may be seen for differential filter weights for manually weighed filters.

A-7 Humidity affects when reducing DF

Figures A-6 and A-7 show the real-time moisture conditions and condensation fraction at filter face conditions. At a DF of 1.5 minimum, the relative humidity is predicted to reach 90% for a short time.

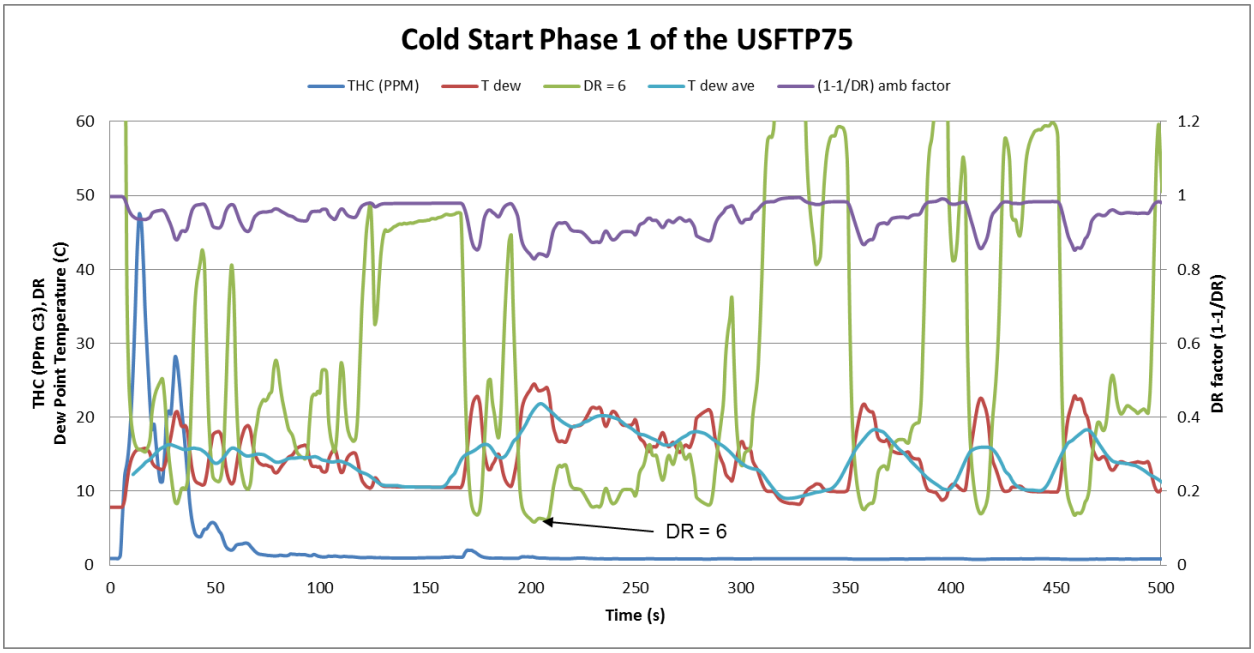

Figure A-6 Real time calculated moisture details for low DF testing (cold start FTP).

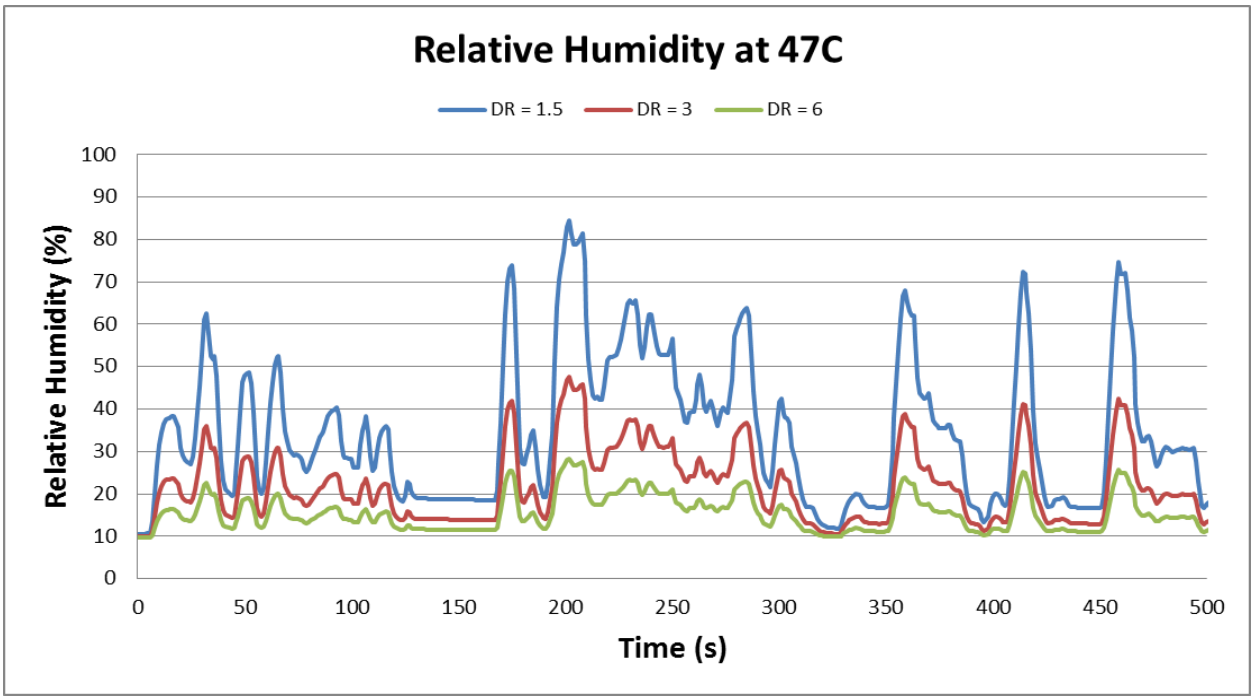

Figure A-7 Predicted relative humidity at 47°C for DF 1.5, 3 and 6 (Bag 1 FTP).

Appendix B. Selected Test Cycles

Below are the test cycles and preparation cycles used for the emissions testing for this study. These include 3 and 4-bag FTP tests, US06 emissions test cycle and the preparation LA4 and the US06 conditioning test cycles.

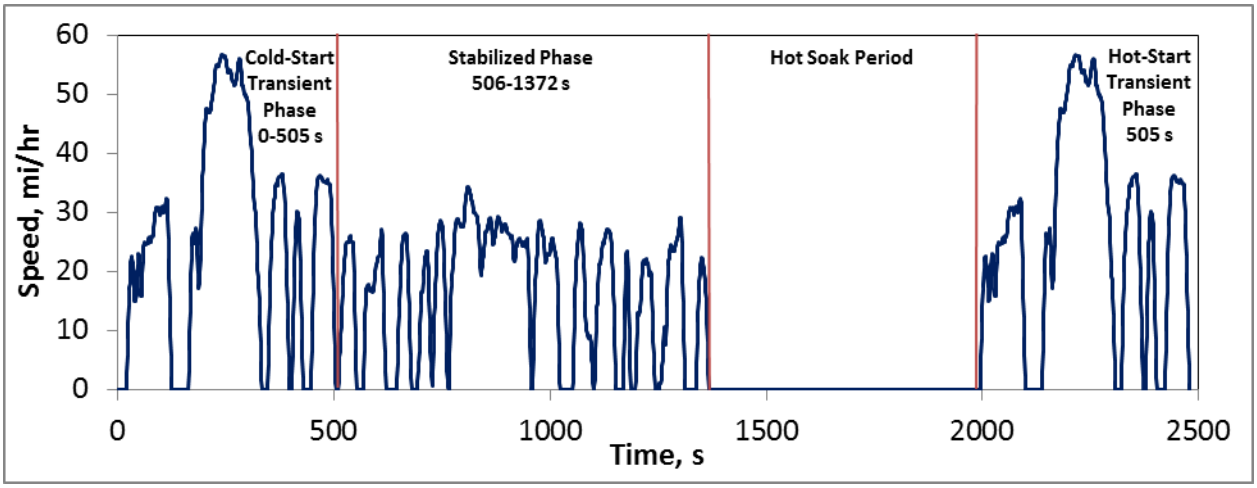

Figure B-1 FTP 3-bag test schedule

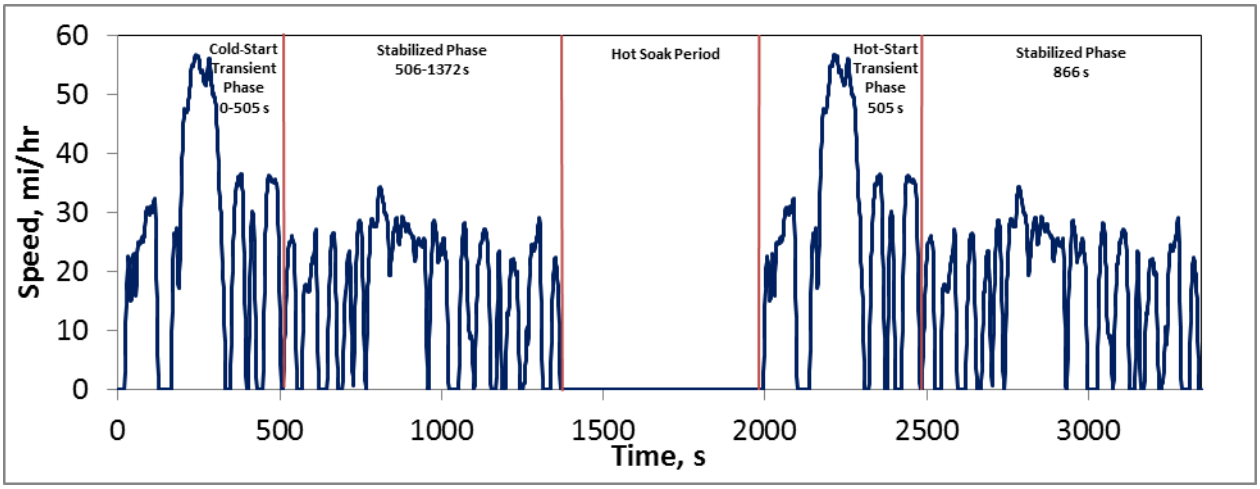

Figure B-2 FTP 4-bag test schedule

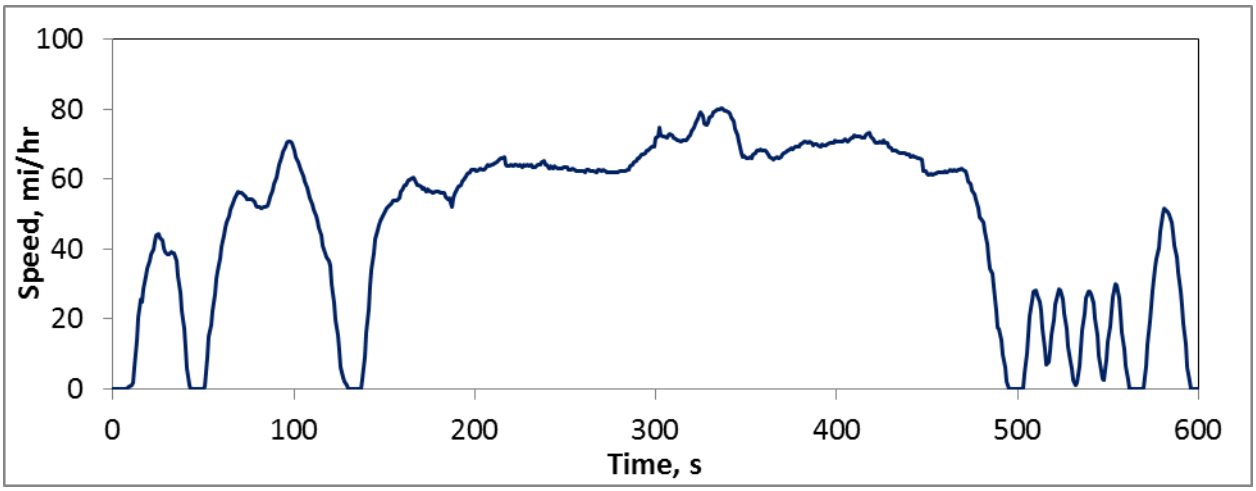

Figure B-3 US06 test schedule

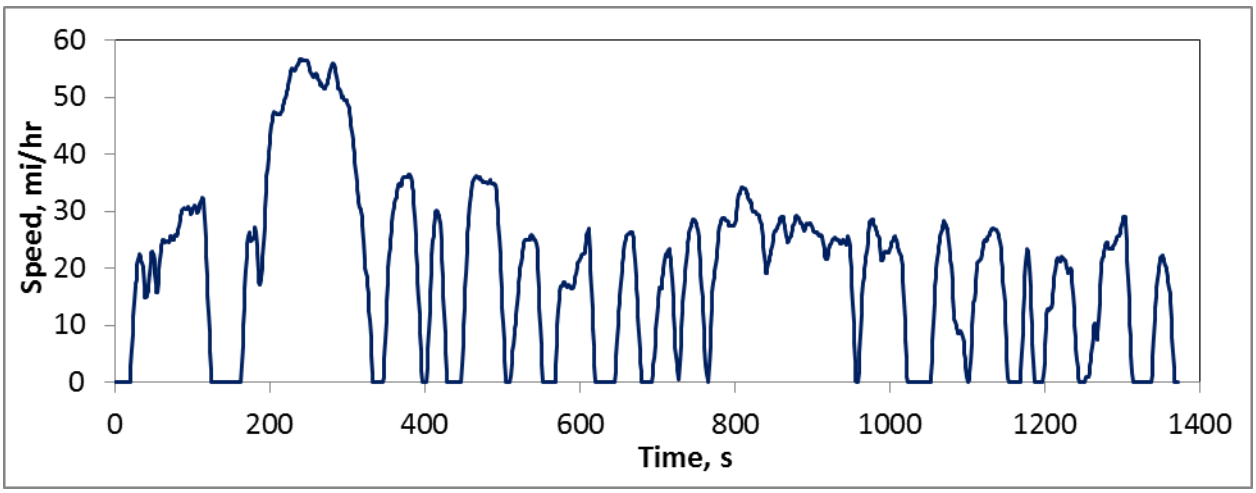

Figure B-4 LA4 preparation cycle

Appendix C. Quality Control and Assurance Checks

This section describes UCR's routine quality control checks and their results, including checks and procedures for the real time PM instruments (MSS, EEPS, CPCs), VERL gaseous instruments, CVS, CVS PM Sampler, PFSS PM Sampler, and other systems typical of vehicle emissions laboratories.

Micro Soot Sensor (MSS) QC

This section describes the QC performed for the MSS units and documents biases between units to help assess the soot measurements in the context of the full E-99 testing program.

Two AVL Micro Soot Sensors were used for real-time PM measurements for possible filter outlier description and quantitative analysis of the soot impact on PM emissions. Due to the length of testing, two different MSS units were utilized that had slightly different zero biases. One MSS is UCR's in-house MSS unit (designated MSS 1) and the other MSS is an AVL loaner system (designated MSS-2).

Preparation of the MSS units for testing included pollution window cleaning, calibration check with the internal calibration standard, linearity checks on the microphone, flow checks, filter replacement, and other internal checks. After successfully completing the startup checks and calibration, the units were prepared for testing. Testing validations included daily leak checks and zero checks.

UCR performed additional tunnel blanks with the MSS units. The tunnel blanks included 3-bag and 4-bag tunnel blanks in combination with Teflon™ and quartz filters. The real-time tunnel blank data for the MSS 1 and 2 units are shown in Figure C-1. Both units show a similar lower detection limit noise that oscillates about 2ug/m3 where the MSS 1 ranged from 0.001 to 0.003 mg/m3 and MSS 2 oscillated between -0.001 and +0.001. The average and single standard deviation tunnel blank MSS results are presented in Table C-1. The MSS1 tunnel blank data averaged 1.79 mg/mi for the 4-bag weighted FTP and 0.29 mg/mi for the 3-bag weighted FTP for MSS2. Since there was a slight bias between MSS 1 and MSS 2, UCR proposed normalizing the data set with an offset for MSS 1 which was utilized in the confirmation testing to make the two test groups more consistent. The normalizing factor included subtracting 1.5 mg/mi from the MSS 2 data used during the confirmation testing.

Table C-1 Average and standard deviation for MSS 1 and 2 tunnel blanks

	MSS 1		MSS 2	
Phase	ave	stdev	ave	stdev
1	1.47	0.10	0.333	0.13
2	1.62	0.07	0.285	0.14
3	1.93	0.14	0.253	0.08
4	2.00	0.15		
FTPw	1.79	0.12	0.29	0.12

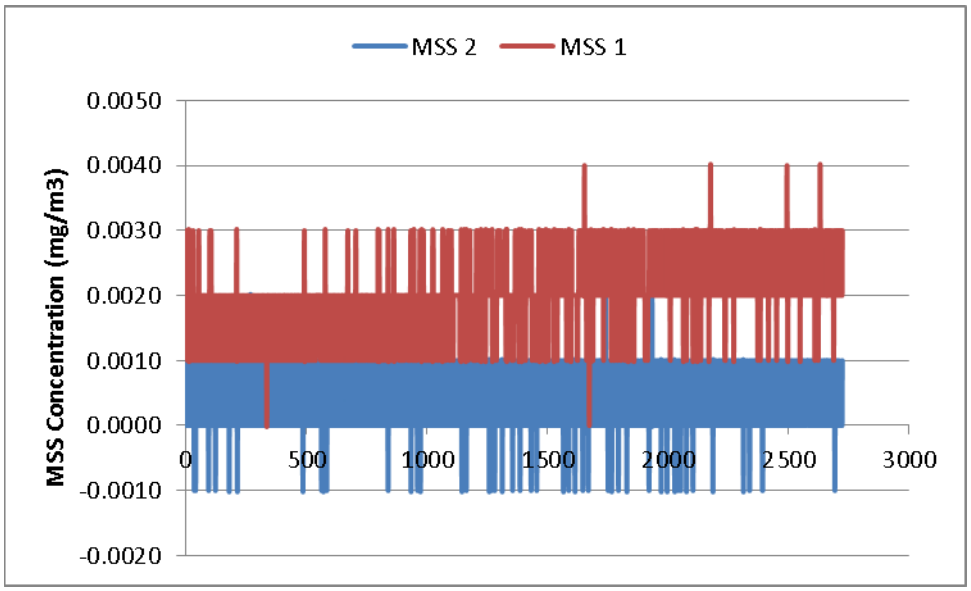

Figure C-1 MSS tunnel blank real time data

PM Sample Filter Preparation

The CVS and PFSS PM sampler warm ups were performed routinely every morning. This included starting up of the CVS heater, EFM power and integrated heater, PM Sampler oven and PFSS warm up systems. Figure C-2 shows an example of a typical startup temperature profile for the critical systems prior to testing an FTP cold start test. The CVS and PFSS PM samplers were set to 47°C where the PFSS average temperature was tightly controlled and maintained at 47°C±1C typically, and the CVS PM sampler enclosure was less well controlled, but still within specifications at a typical temperature of 47°C ±3°C as shown in Figure C-2.

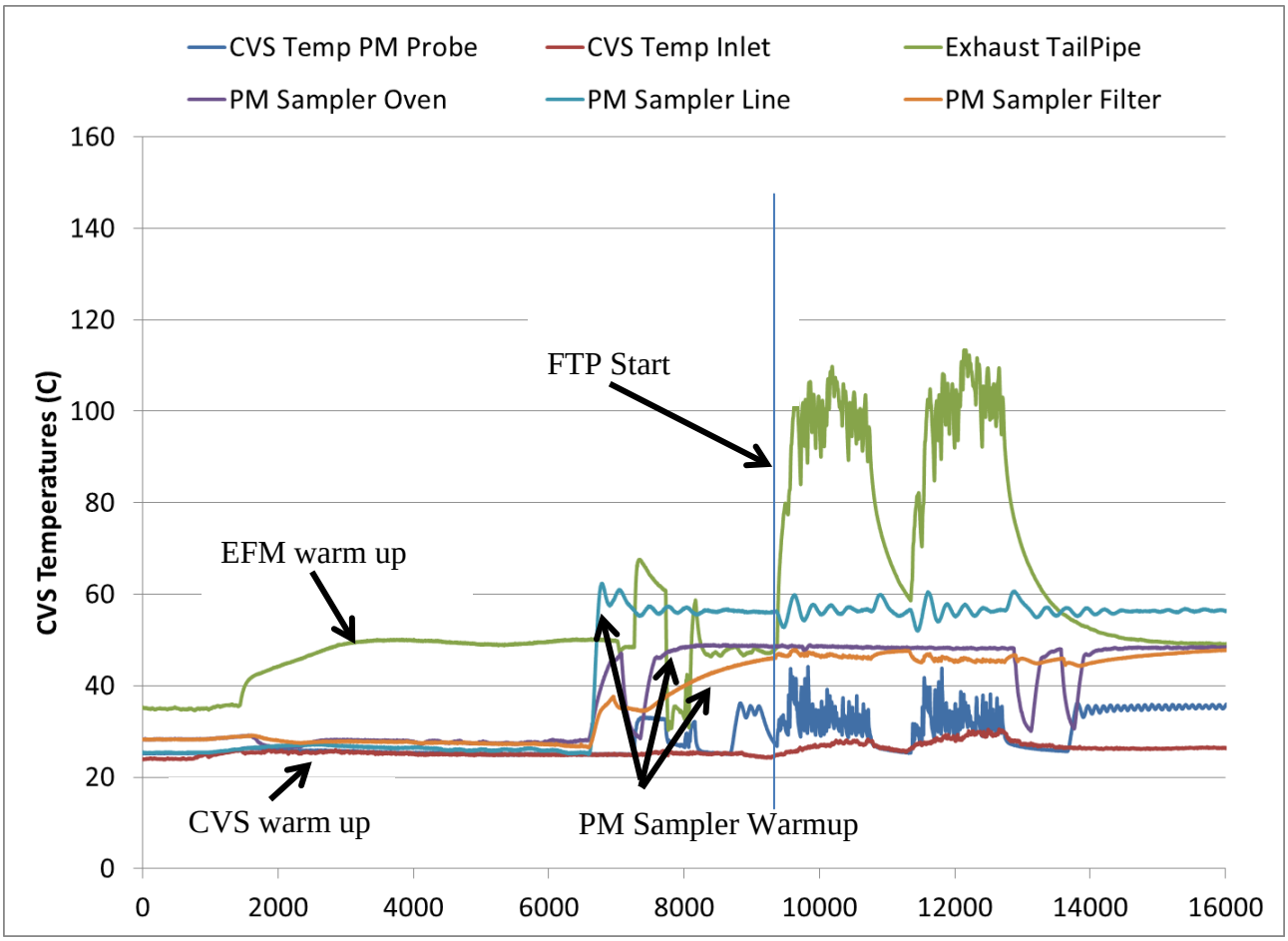

Figure C-2 Real-time temperature plot for CVS, exhaust, and CVS PM Sampler for a typical FTP

Propane Injections

The CVS verification check uses propane as a tracer gas, along with tunnel flow rate, to determine if there are any discrepancies in measured values. The verification check compares the injected propane with the response measured by the system for reference and bag measurements.

During the course of the E-99 program, three different tunnel flow rates were used. These flow rates were used to achieve a Dilution Factor of 7:1 for US06 and Phase 1 of the FTP. Multiple propane injections for each of the tunnel flow rates were conducted on a routine basis. Table C-2 shows the averages of percent difference between amount injected and the amount measured from bag samples. All CVS verification checks for the given specified tunnel flow rates were less than 2%.

Table C-2 Summary of propane injections

		Reference vs BAG (% dif)			
CVS Flow Rate (Nm3/min)	n	PI Bag	P2 Bag	P3 Bag	P4 Bag
3.79	7	0.8	0.6	0.4	0.2
4.07	8	0.6	-0.5	0.2	0.2
9.40	7	-0.8	-1.7	-1.8	-1.9

Tunnel Blanks Teflon™

TBs were collected during the screening and confirmation testing phases. Figures C-3 and C-4 show the tunnel blank data for the CVS and PFD samplers from the E-99 program. Figure C-3 shows the tunnel blank data for all UCR research programs and Figure C-4 show the tunnel blank data for the E-99 program. The tunnel blank and the average and 1σ standard deviation TB data for the screening and confirmation phases of this project was based on the results found in Figure C-4.

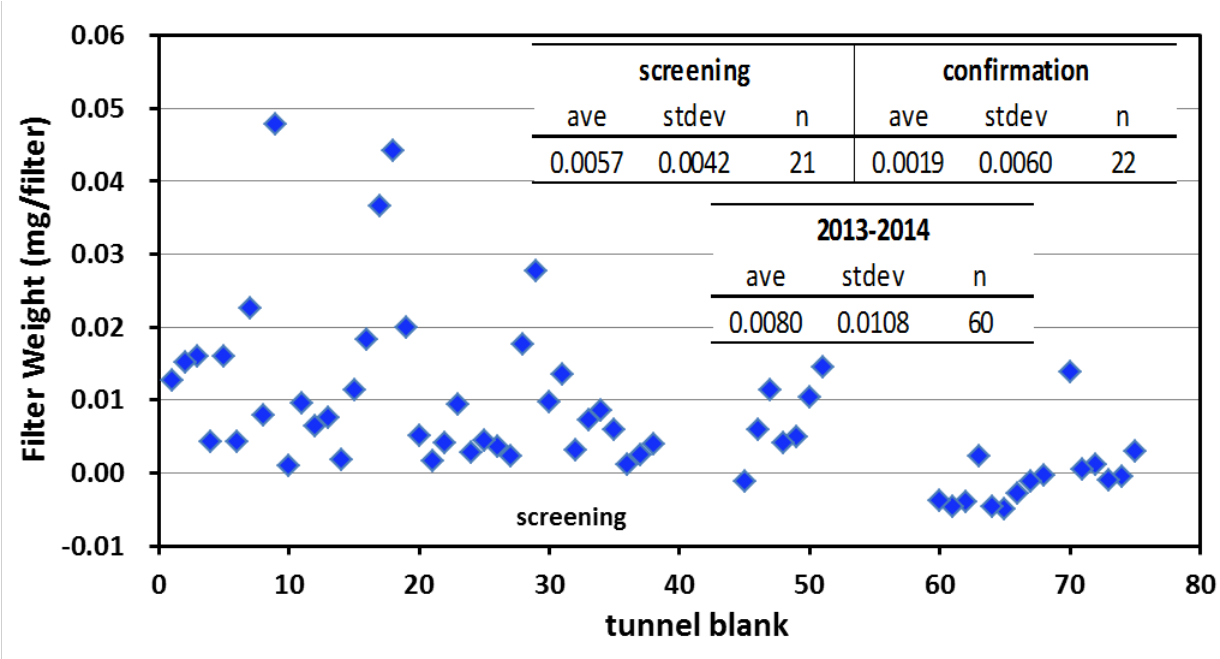

Figure C-3 Tunnel blanks for all UCR programs in 2013 and 2014

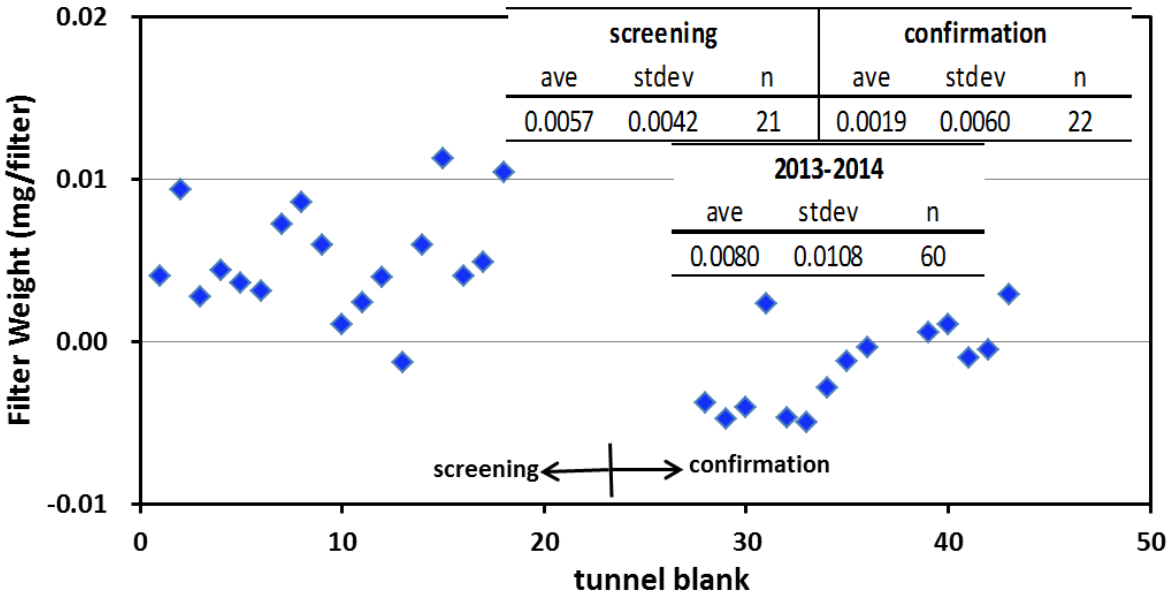

Figure C-4 Tunnel blanks for E-99 program

Tunnel Blanks Quartz

The tunnel blank quartz data includes EC and OC measurements from UCR's Sunset Laboratory batched analysis system. The EC/OC method used for this research was based on the NIOSH method. The EC and OC tunnel blank raw data (ug/filter) is presented in Figure C-5 and on a relative basis (mg/mi) in Figure C-6. OC relative tunnel blank results (mg/mi) are presented in Figure C-7.

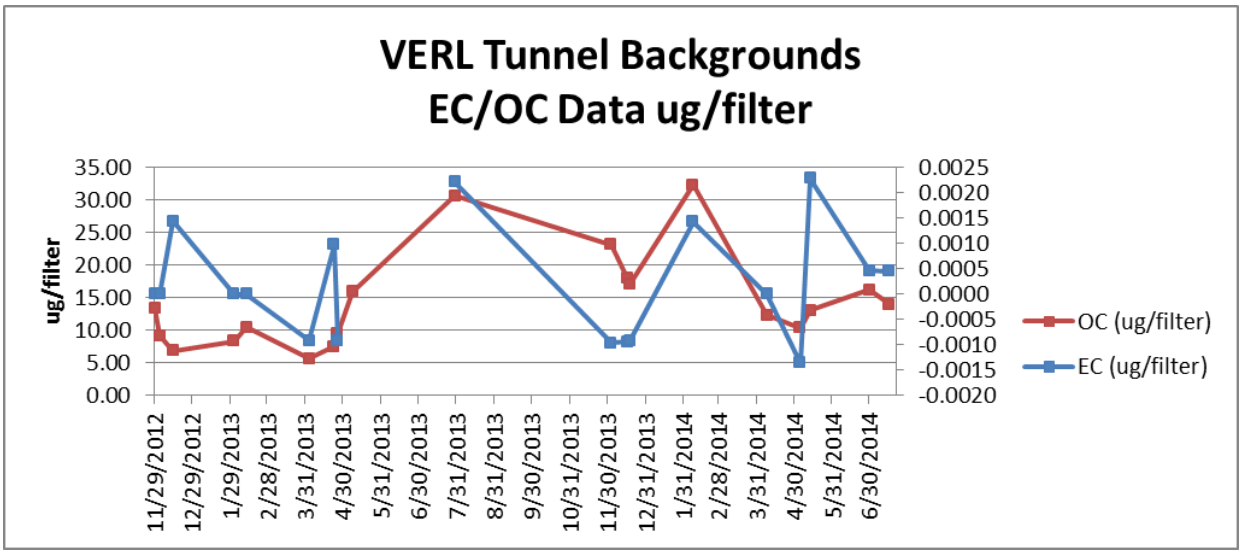

Figure C-5 EC and OC tunnel blanks for E-99 program (ug/filter)

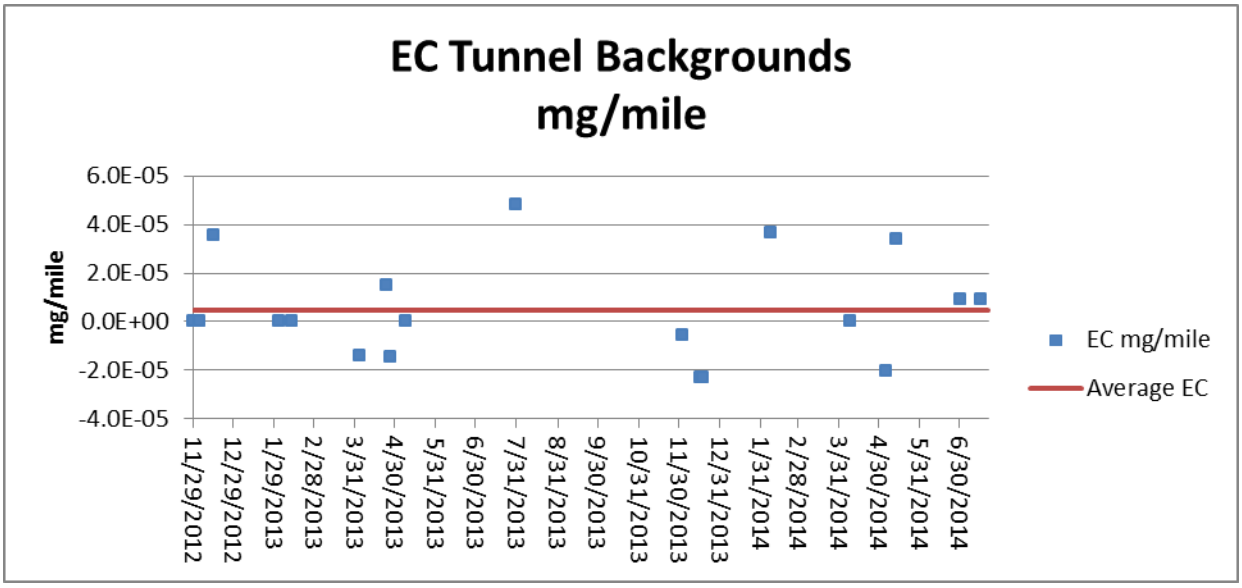

Figure C-6 Relative EC tunnel blank value for E-99 program (mg/mi)

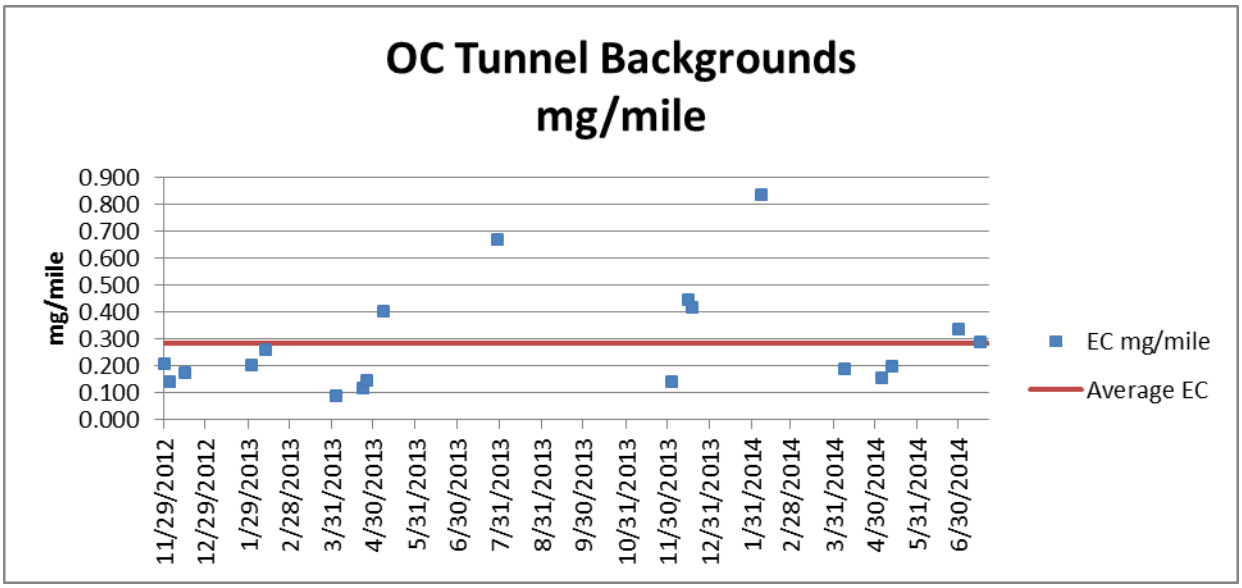

Figure C-7 Relative OC tunnel blank value for E-99 test program (mg/mi)

Other Real-Time PM instruments

The EEPS and the selected CPCs utilized during this testing program were checked for zero drift daily and were checked for leaks. No span calibrations with a CAST or other PSD generating system was utilized.

PM Sampler Flow Rates

The PM samplers utilized in this program were operated following best available practices. For the four CVS PM samplers, the flow controllers (MFCs) were sent out for recertification to a accredited flow calibration laboratory prior to testing. Each of the MFCs were found to be within specification. The PFSS flows were not recertified by UCR but were provided by the manufacturer in a calibrated and certified state. UCR did perform some internal secondary calibration standards to ensure that flow differences between UCR's flow meters were small. Although UCR is not a flow certification laboratory, it is expected a transfer standard using a mass flow meter would be capable of replicating similar (precise) results within a short time span.

Standard laboratory practices include leak check and flow rate checks on the Vehicle Emissions Research Lab (VERL) PM sampling system prior to every test and on selected PFSS tests. For the leak checks, the PM samplers were isolated at the probe and a vacuum of 25 inHg was maintained. Once 25 inHg was achieved an isolation valve downstream of the MFC and at the probe was isolated and the pressure drop over one minute was recorded. From this, the leakage rate could be estimated by knowing the sample volumes and time. All the probes passed the leak check requirements of 1065.

Appendix D. Calculation References and Details

This appendix includes calculations used from specific sections of 1066, including supporting text with some expanded explanation to relate them to the current testing program. The equations below were strictly followed unless noted otherwise. In addition, other calculations are described including the calculations of PM mass from the PFSS and the estimated DF using dilute CO_2 from the PFSS.

The following are the calculations performed for the CVS PM samplers, the PFSS PM sampler, and the flow-weighting calculations for the combined filter probes, which included Probes A, B, and C of the CVS and the PFSS probe. The PM flow-weighted mass calculations and composite PM test results for the cumulative filters were calculated using 40 CFR 1066.605(e) and 40 CFR 1066.820(c), respectively, along with the provisions in the associated CFR sections, and selected references from 40CFR Part 1066.

In this study, a PFSS was operated under the CVS mode (a mode specific to the manufacturer of the PFSS). In this mode, the PFSS simulates CVS sampling and it is controlled to maintain a constant PFSS tunnel flow rate (G_{tot}). The dilution air flow rate, G_{dil}, is controlled in such a way that the probe flow rate, G_p, into the tunnel is a constant fraction (proportional), r, of the total exhaust flow rate, G_{exh}, of the engine. The probe flow rate G_p is not measured but calculated from G_{tot} - G_{dil}. G_{tot} is the filter flow rate, and the volume through the filter V_{PMstd} is the G_{tot}*time interval of the test.

PM emissions

The PM emissions are the mass of the PM divided by the distance. For the single bag test, the calculation is straight forward: the PM divided by the distance. For the multi-phase FTP, the weighting i for the 3-bag test and the 4-bag test are shown below.

The 3-bag PM mass emission rate equation follows that of 1066.820-3,

$$e_{\text{PM-FTPcomp}} = \frac{m_{\text{PM}}}{\left(0.43 \cdot D_{\text{ct}}\right) + D_{\text{cs}} + \left(0.57 \cdot D_{\text{ht}}\right)} \quad \text{(40 CFR 1066.820-3)} \quad \text{(Eq. Appendix D-1)}$$

where m_{PM} is the combined PM mass emissions determined from Bag 1, Bag 2, and Bag 3, in mg. D_{ct} is the measured driving distance from the transient portion of the cold-start test (Bag 1), in miles. D_{cs} is the measured driving distance from the stabilized portion of the cold-start test (Bag 2), in miles. D_{ht} is the measured driving distance from the transient portion of the hot-start test (Bag 3), in miles.

The following equation from §1066.820(c)(3), was used for the 4-bag composite filters for PM measured as described in §1066.815(b)(5):

$$e_{\text{PM-FTPcomp}} = \frac{m_{\text{PM}}}{0.43 \cdot \left(D_{\text{ct}} + D_{\text{cs}}\right) + 0.57 \cdot \left(D_{\text{ht}} + D_{\text{hs}}\right)} \quad \text{(40 CFR 1066.820-4)} \quad \text{(Eq. Appendix D-2)}$$

Where:

m_{PM} = the combined PM mass emissions determined from the cold-start FTP test interval and the hot-start FTP test interval (Bag 1, Bag 2, Bag 3, and Bag 4), in grams, as calculated using Eq. 1066.605-4.

PM mass

The description of the calculation of PM mass is organized into two sections: CVS and PFSS PM mass calculations. The E-99 Panel members discussed in detail how the PFSS PM mass was calculated and its sensitivities. As a result of that discussion, it was decided to include a more thorough description of the PFSS method here. The CVS section is provided for consistency. A more detailed explanation can be found in 1066.

CVS PM emission rate:

1) The single bag emissions calculation 40 CFR 1066.605-2,

$$m_{PM} = \left(\frac{V_{mix}}{V_{PMstd}}\right)(M_{PMfil} - M_{PMbkgnd}) \quad \text{(40 CFR 1066.605-2)} \quad \text{(Eq. Appendix D-3)}$$

where m_{PM} is the mass of particulate matter over the test interval, V_{mix} is the total dilute exhaust volume (corrected for all CVS dilute sample flows), V_{PMstd} is the total volume through the filter, m_{PMfil} is the mass of particulate matter emissions collected on the filter over FTP tests, in mg. m_{PMbkgnd} is the mass of particulate matter in the background air which is typically utilized from the tunnel blank, in mg.

2) The m_{PM} is determined using the following equation with no secondary dilution flows,

$$m_{\mathrm{PM}} = \left(\frac{V_{\mathrm{mix}}}{\frac{V_{\mathrm{ct\text{-}PMstd}}}{0.43} + V_{\mathrm{cs\text{-}PMstd}} + \frac{V_{\mathrm{ht\text{-}PMstd}}}{0.57}}\right) \cdot \left(m_{\mathrm{PMfil}} - m_{\mathrm{PMbkgnd}}\right) \quad \text{(40 CFR 1066.605-3)} \quad \text{(Eq. Appendix D-4)}$$

where V_{mix} is the total dilute exhaust volume over the FTP test at standard reference conditions (101.325 kPa and 20 ºC corrected for all CVS dilute sample flows), in m^3/min. V_{ct}-PM_{std}, V_{cs}-PM_{std} and V_{ht}-PM_{std} are the total volume of dilute exhaust sampled through the filter over Phase 1, Phase 2 and Phase 3 of the FTP at standard reference conditions, respectively, in m^3/min. m_{PMfil} is the mass of particulate matter emissions collected on the filter over FTP tests, in mg. m_{PMbkgnd} is the mass of particulate matter in the background air which is typically utilized from the tunnel blank, in mg.

PFSS Volume Fraction "r" When testing with the partial flow system, a proportion of the exhaust was removed due to its sample flow rate. This sample caused a small bias in concentration and flow that did not reach the CVS sampler which needs to be corrected for. This correction is different than the raw gas sampling, where a constant gaseous sample flow is pulled from the exhaust as is typically performed for catalyst efficiency testing. The PFSS is a volume removed from the exhaust in proportion to the exhaust flow. The fraction is defined by the PFSS as a variable called volume fraction in percent denoted as "r". The volume fraction varied from 0.5 to 3% for the tests performed. If multiple PFSSs were utilized on the same exhaust, the impact would be a multiple of the number of PFSSs.

The correction applied to the CVS mass was based on the following equation

$$e_{\mathrm{PM\text{-}FTPcomp\text{-}cor.}} = e_{\mathrm{PM\text{-}FTPcomp}}\,(1/(1-r)) \quad \text{(Eq. Appendix D-5)}$$

where: $e_{PM\text{-}FTPcomp}$ is the final emission rate in mg/mi after all weighting functions are completed. For example if r = 2% (0.02) the calculation above will be $e_{PM\text{-}FTPcomp}$ /0.98 thus, increasing the CVS mass by the removed fraction.

PFSS PM emission rate: Two cases are considered: a single bag test and a multi-bag test. In this study, a cumulative filter was used to collect PM during both the 3- and 4-bag FTP. The PM emission rate for the 3-bag FTP calculation is presented in this summary in addition to the single bag case (such as the US06 test).

1) The single bag emissions calculation 40 CFR 1066.605-2 (with no secondary dilution flow),

$$m_{PM} = \left(\frac{V_{mix}}{V_{PMstd}}\right)(M_{PMfil} - M_{PMbkgnd}) \quad \text{(40 CFR 1066.605-2)} \quad \text{(Eq. Appendix D-6)}$$

where m_{PM} is the mass of particulate matter over the test interval, V_{mix} is the total dilute exhaust volume, V_{PMstd} is the total volume through the filter (denoted as $G_{tot} * t$ (t = sample time) by the PFSS), m_{PMfil} is the mass of particulate matter emissions collected on the filter over FTP tests, in mg. $m_{PMbkgnd}$ is the mass of particulate matter in the background air which is typically utilized from the tunnel blank, in mg.

All the parameters are measured except for V_{mix} which is calculated from the total diluted exhaust flow rate and the sample fraction according to the PFSS manufacturer following,

$$V_{mix} = \left(\frac{G_{tot} * t}{r}\right), \quad r = \left(\frac{G_p}{G_{exh}}\right) \text{, therefore we get} \quad V_{mix} = \left(\frac{G_{exh} * G_{tot} * t}{G_p}\right) \quad \text{(Eq. Appendix D-7)}$$

where G_{tot} is the average PFSS total dilute exhaust flow rate also called total filter flow rate (G_{tot}) which can be integrated into a volume which is the same as V_{PMstd} defined by the CFR. G_p is the average sample flowrate, t is the time interval for the sample period, and G_{exh} is the average exhaust flow rate measured from an exhaust flow meter. All flow rates are in standard conditions in units of m3/min.

If we substitute this into equation 1066.605-2 and simplify the terms while utilizing the PFSS nomenclature "G" instead of the CFR nomenclature for volume "V" we get the following,

$$m_{PM} = \left(\frac{G_{exh}}{G_p}\right)(M_{PMfil} - M_{PMbkgnd}) \quad \text{(Eq. Appendix D-8)}$$

where G_p is the average sample flowrate and G_{exh} is the average exhaust flow rate measured from an exhaust flow meter. All flow rates are in standard conditions in units of m3/min. m_{PMfil} is the mass of particulate matter emissions collected on the filter over FTP tests, in mg. $m_{PMbkgnd}$ is the mass of particulate matter in the background air which is typically utilized from the tunnel blank, in mg.

Or in terms of what is directly measured,

$$m_{PM} = \left(\frac{G_{exh}}{G_{tot} - G_{dil}}\right)(M_{PMfil} - M_{PMbkgnd}) \quad \text{(Eq. Appendix D-9)}$$

where G_{exh} is the average exhaust flow rate measured from an exhaust flow meter, G_{dil} is the dilution air flow rate, G_{tot} is the total filter flow rate, m_{PMfil} is the mass of particulate matter emissions collected on the filter over FTP tests, in mg. $m_{PMbkgnd}$ is the mass of particulate matter in

the background air which is typically utilized from the tunnel blank, in mg. All flow rates are in standard conditions in units of m^3/min

2) The m_{PM} is determined using the following equation with no secondary dilution flows,

$$m_{\mathrm{PM}} = \left(\frac{V_{\mathrm{mix}}}{\frac{V_{\text{ct-PMstd}}}{0.43} + V_{\text{cs-PMstd}} + \frac{V_{\text{ht-PMstd}}}{0.57}} \right) \cdot \left(m_{\mathrm{PMfil}} - m_{\mathrm{PMbkgnd}} \right) \quad \text{(40 CFR 1066.605-3) (Eq. Appendix D-10)}$$

where V_{mix} is the total dilute exhaust volume over the FTP test at standard reference conditions, in m^3/min. V_{ct}-PM_{std}, V_{cs}-PM_{std} and V_{ht}-PM_{std} are the total volume of dilute exhaust sampled through the filter over Phase 1, Phase 2 and Phase 3 of the FTP at standard reference conditions, respectively, in m^3/min. m_{PMfil} is the mass of particulate matter emissions collected on the filter over FTP tests, in mg. $m_{PMbkgnd}$ is the mass of particulate matter in the background air which is typically a measurement of the tunnel blank filter test, in mg.

The V_{mix} in Eq. 1066.605-3 is calculated by the following equation,

$$V_{\mathrm{mix}} = \frac{G_{\text{ct-tot}}}{r_{ct}} t_{ct} + \frac{G_{\text{cs-tot}}}{r_{cs}} t_{cs} + \frac{G_{\text{ht-tot}}}{r_{ht}} t_{ht} \quad \text{(Eq. Appendix D-11)}$$

where $G_{\text{ct-tot}}$, $G_{\text{cs-tot}}$ and $G_{\text{ht-tot}}$ represent the constant tunnel flow rate passing the PFSS filter over Bag 1, Bag 2 and Bag 3, respectively, in m^3/min. $r_{\text{ct-tot}}$, $r_{\text{cs-tot}}$ and $r_{\text{ct-tot}}$ represent the fraction ratio of the total exhaust flow passing the PFSS filter over Bag 1, Bag 2 and Bag 3, respectively. The fractional ratio is defined by the PFSS as,

$$r_{ct} = \frac{G_{\text{ct}-p}}{G_{ct-exh}}, \quad r_{cs} = \frac{G_{\text{cs}-p}}{G_{cs-exh}}, \text{ and } \quad r_{ht} = \frac{G_{\text{ht}-p}}{G_{ht-exh}} \quad \text{(Eq. Appendix D-12)}$$

where $G_{\text{ct-p}}$, $G_{\text{cs-p}}$ and $G_{\text{ht-p}}$ represent the sample probe flow rate being sampled in proportion to the exhaust flow by the PFSS over Bag 1, Bag 2 and Bag 3, respectively, in m^3/min. This flow is actually measured by the difference of the total flow (G_{tot}) and the dilution flow (G_{dil}). $G_{\text{ct-exh}}$, $G_{\text{cs-exh}}$ and $G_{\text{ht-exh}}$ represent the total exhaust flow rate measured by the exhaust flow meter over Bag 1, Bag 2 and Bag 3, respectively, in m^3/min. Thus, 1066.605-3 equations reduces to (utilizing the PFSS nomenclature),

$$\frac{\left(\frac{G_{ct-tot} * t_{ct} * G_{ct-exh}}{G_{ct-p}} + \frac{G_{cs-tot} * t_{cs} * G_{cs-exh}}{G_{cs-p}} + \frac{G_{ht-tot} * t_{ht} * G_{ht-exh}}{G_{ht-p}} \right) * \left(m_{PMfilt} - m_{PMbkgnd} \right)}{\left(\frac{G_{ct-tot} * t_{ct}}{0.43} + G_{cs-tot} * t_{cs} + \frac{G_{hs-tot} * t_{hs}}{0.57} \right)}$$

(Eq. Appendix D-13)

where the terms have been previously defined.

PFSS PM mass summary: The PM mass calculations for a PFSS utilize exhaust flow, probe sample flow (proportional to the exhaust flow), and background-corrected filter mass for the calculation of total PM mass. Probe sample flow is not measured but is calculated from the difference of filter total flow and dilution flow. Dilution factor is not part of the PM mass calculation but utilized to set the

conditions for the PM formation within the sampler. However, since a bias in DF (G_{tot}/G_p) may result in a bias in PM mass, the DF bias should be considered in the discussion. In general the measurements that influence the PFSS PM mass measurement are exhaust, filter, and sample flows in addition to filter weight.

Appendix E. Additional Vehicle Results

This appendix contains individual vehicle results for the vehicle recruitment, screening and confirmation testing phases of this research. The results include tests on the main results on the Honda Accord PFI, the Ford Escape GDI, as well as other vehicles that were tested as part of the recruitment process, which include two Kia Optima's, a Kia Rio, and a WV Jetta. Other vehicles were also screened as part of other testing programs such as the Hyundai and Mercedes. These vehicles are not included with this research as they were funded by other programs.

Screening tests were also conducted on several other vehicles to determine if these vehicles might be suitable candidates for inclusion in the main test program (screening and confirmation). Table E-1a shows the specifications for the PFI and GDI vehicles tested as part of this research. Table E-1b shows the specifications for the GDI vehicles that were tested, but were not selected.

Table E-1a. Test vehicles used for the screening and confirmation testing

#	MY	OEM	Model	California Certification	Type	Engine Size	Mileage	Designation
1	2012	Honda [1]	Accord	PZEV II	PFI	2.4 L	31,144	Lower PM Source
2	2014	Ford [2]	Escape	SULEV II	GDI	1.6 L	25,678	Higher PM Source

GDI = Gasoline direct injection; PFI = port fuel injection.
[1] The Honda has a GVW of 4299 lb and conformed to regulations EPA T2B2 LDV and included WV-TWC/TWC/A/F Sensor/HO2S/SFI aftertreatment. The engine family for this vehicle was CHNXV02.4MC3.
[2] The Ford Escape has a GVW of 4520 lb and conformed to US EPA T2B5 LDT2 and included TWC/HO2S/AFS/CAC/TC/DFI aftertreatment. The engine family for this vehicle was EFMT01.62E9.

Table E-1b GDI test vehicles evaluated, but not used

#	MY	OEM	Model	California Certification	Type	Engine Size	Mileage	Engine Family
3	2013	Kia	Optima	ULEV II	GDI	2.4 L	12,442	DKMXV02.44GE
4	2013	Hyundai	Accent	ULEV II	GDI	2.0L	13,934	DKMV01.6DBE
5	2013	Kia	Optima [1]	ULEV II	GDI	2.4 L	26,000	DKMXV02.44GE
6	2013	Kia	Rio	ULEV II	GDI	1.6L	32,707	DKMXV01.6DBE
7	2013	Volkswagen	Jetta	SULEV II	GDI	2.0 L	100-800	DVWXV02.02PA

GDI = Gasoline direct injection; PFI = port fuel injection
[1] This Kia Optima had a PM emission rate less than 3 mg/mi and thus met the criteria, but was not selected because the Ford Escape was also tested at the same time and had a more desirable emission rate and stability.

The individual emissions test results for each vehicle are provided in the next several Tables. Table E-2, E-3, E-4 and E-5 provide the FTP results for both the screening and confirmation test periods. Table E-6 shows the US06 data for both vehicles and both testing periods (screening and confirmation). Table E-7 and E-8 show the cycle average and single standard deviation gaseous emissions results for the GDI and PFI vehicles respectively.

Table E-2 FTP PM (mg/mi) and filter weights (confirmation and screening): Part 1

FTP emission results E-99

aborted, invalid, evlauation test. Not used in the analysis of E-99 objectives

outlier results, but still used in the analysis.

Confirmation and Screening data

									Back Ground Corrected Particulate Emissions mg/mile																								NET Filter Weights mg/filter (not back ground corrected)								
Year/Make/Model	Type	Test	Test Phase	Run	Date	Fuel Content	Test Name	Mileage	EC+OC	EC	OC	EC Probe A	OC Probe A	EC PFSS	OC PFSS	A	B	C	D1	D2	D3	D4	D_Tot		PFSS (Flow)	MSS1	MSS2	MSS3	MSS4	MSS	MSS(BL)	A	B	C	D1	D2	D3	D4	D_Tot	PFSS
2012 Honda Accord	PFI	3FTP	Screening	Prelim1	11/5/2013	CARB III LEV E-10	131105_1431_FTP_HAcc_E99_Prelim1	31,219				-	-	-	-	0.36	0.31	0.52	0.95	0.20	0.36	-	0.40		0.20	0.47	0.05	0.07	-	0.14	(0.00)	0.078	0.055	0.060	0.045	0.014	0.020	-	0.079	0.025
2012 Honda Accord	PFI	3FTP	Screening	R1	11/14/2013	CARB III LEV E-10	131114_1612_3FTP_HAcc_E99_R1	31,245	0.347	0.170	0.111	-	-	-	-	0.46	0.46	0.56	1.06	0.14	0.54	-	0.44		0.40	0.41	0.07	0.14	-	0.16	0.00	0.092	0.077	0.062	0.048	0.011	0.027	-	0.086	0.048
2012 Honda Accord	PFI	3FTP	Screening	R2	11/15/2013	CARB III LEV E-10	131115_1342_3FTP_HAcc_E99_R2	31,256	0.597	0.188	0.256	-	-	-	-	0.31	0.31	0.41	0.82	0.02	0.41	-	0.30		0.36	0.41	0.06	0.10	-	0.14	0.01	0.066	0.053	0.048	0.039	0.006	0.022	-	0.067	0.044
2012 Honda Accord	PFI	3FTP	Screening	R3	11/20/2013	CARB III LEV E-10	131120_1353_3FTP_HAcc_E99_R3	31,346	0.418	0.115	0.189	-	-	-	-	0.21	0.22	0.27	0.77	0.34	0.27	-	0.41		0.18	0.40	0.05	(0.05)	-	0.13	(0.00)	0.044	0.038	0.033	0.037	0.019	0.016	-	0.071	0.031
2012 Honda Accord	PFI	3FTP	Screening	R4	11/21/2013	CARB III LEV E-10	131121_1546_3FTP_HAcc_E99_R4	31,356	0.374	0.108	0.166	-	-	-	-	0.17	0.14	0.17	0.64	0.11	0.23	-	0.25		0.11	0.38	0.06	0.05	-	0.12	0.00	0.037	0.027	0.023	0.032	0.010	0.014	-	0.055	0.032
2012 Honda Accord	PFI	3FTP	Screening	R5	11/22/2013	CARB III LEV E-10	131122_1006_3FTP_HAcc_E99_R5	31,367	0.400	0.115	0.178	-	-	-	-	0.20	0.24	0.27	0.70	0.15	0.27	-	0.30		0.21	0.37	0.04	0.05	-	0.11	(0.01)	0.044	0.044	0.034	0.035	0.011	0.016	-	0.063	0.036
2012 Honda Accord	PFI	4FTP	Screening	Fault1	11/26/2013	CARB III LEV E-10	131126_1538_4FTP_HAcc_E99_Fault1	31,386				-	-	-	-	0.50	0.42	0.58	2.05	0.10	0.28	0.14	0.57		0.11	0.33	0.04	0.05	0.03	0.10	0.00	0.180	0.121	0.115	0.088	0.009	0.016	0.011	0.124	0.026
2012 Honda Accord	PFI	4FTP	Screening	Fault2	11/27/2013	CARB III LEV E-10	131127_1327_4FTP_HAcc_E99_Fault2	31,400				-	-	-	-	0.44	0.37	0.49	1.21	0.29	0.57	0.27	0.55		0.14	0.37	0.05	0.07	0.05	0.12	0.00	0.158	0.111	0.098	0.054	0.017	0.028	0.016	0.115	0.043
2012 Honda Accord	PFI	4FTP	Screening	Fault3	12/4/2013	CARB III LEV E-10	131204_1226_4FTP_HAcc_E99_Fault3	31,431				-	-	-	-	0.22	0.22	0.24	0.73	0.04	0.04	(0.07)	0.15		0.12	0.52	0.05	0.05	0.04	0.14	0.00	0.082	0.068	0.049	0.034	0.007	0.007	0.002	0.050	0.060
2012 Honda Accord	PFI	4FTP	Screening	R6	1/14/2014	CARB III LEV E-10	140114_1359_4FTP_HAcc_E99_R6	31,502	0.394	0.083	0.195	-	-	-	-	0.28	0.22	0.26	0.36	(0.22)	(0.05)	(0.19)	(0.04)		0.15	0.40	0.07	0.08	0.08	0.14	0.00	0.100	0.066	0.053	0.020	(0.005)	0.003	(0.003)	0.015	0.033
2012 Honda Accord	PFI	4FTP	Screening	R7	1/15/2014	CARB III LEV E-10	140115_1140_4FTP_HAcc_E99_R7	31,156	0.388	0.106	0.176	-	-	-	-	0.33	0.22	0.32	0.89	(0.10)	0.10	(0.11)	0.16		0.12	0.55	0.06	0.06	0.05	0.16	(0.00)	0.116	0.065	0.063	0.041	0.001	0.009	0.000	0.052	0.036
2012 Honda Accord	PFI	4FTP	Screening	R8	1/16/2014	CARB III LEV E-10	140116_1446_4FTP_HAcc_E99_R8	31,531	0.427	0.102	0.203	-	-	-	-	0.33	0.23	0.34	0.59	(0.12)	0.04	(0.11)	0.07		0.12	0.51	0.06	0.07	0.05	0.15	(0.01)	0.110	0.065	0.062	0.028	0.000	0.006	0.001	0.035	0.057
2012 Honda Accord	PFI	3FTP	Screening	R9	1/17/2014	CARB III LEV E-10	140117_0924_3FTP_HAcc_E99_R9	31,546	0.513	0.204	0.193	-	-	-	-	0.19	0.16	0.18	0.72	(0.19)	(0.12)	-	0.02		0.17	0.40	0.04	0.04	-	0.12	(0.00)	0.040	0.031	0.024	0.034	(0.003)	0.000	-	0.031	0.031
2012 Honda Accord	PFI	3FTP	Screening	Outlier	1/24/2014	CARB III LEV E-10	140124_1405_3FTP_HAcc_E99_Outlier	31,572				-	-	-	-	0.36	0.39	0.76	0.35	(0.04)	0.18	-	0.10		0.12	0.20	0.05	0.06	-	0.09	0.00	0.075	0.067	0.085	0.020	0.003	0.013	-	0.036	0.032
2012 Honda Accord	PFI	3FTP	Screening	R10	1/28/2014	CARB III LEV E-10	140128_1538_3FTP_HAcc_E99_R10	31,590	0.534	0.101	0.270	-	-	-	-	0.25	0.34	0.37	0.91	0.07	(0.02)	-	0.22		0.12	0.20	0.05	0.06	-	0.08	0.00	0.051	0.056	0.041	0.041	0.008	0.004	-	0.053	0.051
2012 Honda Accord	PFI	3FTP	Screening	R11	1/29/2014	CARB III LEV E-10	140129_0845_3FTP_HAcc_E99_R11	31,601	0.585	0.163	0.263	-	-	-	-	0.22	0.24	0.28	0.75	0.08	0.18	-	0.25		0.18	0.26	0.04	0.06	-	0.09	(0.00)	0.046	0.043	0.034	0.036	0.008	0.012	-	0.056	0.046
2014 Ford Escape	GDI	3FTP	Screening	Prelim1	6/25/2014	CARB III LEV E-10	140625_1423_3FTP_FEsc_E99_Prelim1	25,298	3.312	2.561	0.469	-	-	-	-	2.43	-	2.36	7.77	1.90	1.12	-	2.90		1.90	5.97	1.35	0.79	-	2.15	-	0.459	0.000	0.263	0.342	0.090	0.053	-	0.485	0.217
2014 Ford Escape	GDI	3FTP	Screening	Prelim2	6/26/2014	CARB III LEV E-10	140626_1244_3FTP_FEsc_E99_Prelim2	25,309	4.513	3.334	0.737	-	-	-	-	1.97	2.04	1.93	5.34	1.54	0.84	-	2.14		1.88	4.16	1.34	0.81	-	1.78	-	0.393	0.331	0.210	0.230	0.072	0.040	-	0.342	0.215
2014 Ford Escape	GDI	3FTP	Screening	Prelim3	6/27/2014	CARB III LEV E-10	140627_1344_3FTP_FEsc_E99_Prelim3	25,320	1.875	1.435	0.275	-	-	-	-	2.11	1.93	1.89	5.04	1.50	1.13	-	2.13		1.81	4.06	1.29	0.89	-	1.76	-	0.382	0.296	0.195	0.205	0.067	0.049	-	0.321	0.208
2014 Ford Escape	GDI	3FTP	Screening	R1	7/1/2014	CARB III LEV E-10	140701_1030_3FTP_FEsc_E99_R1	25,350	1.292	0.959	0.208	-	-	-	-	1.35	1.28	1.15	2.92	0.92	0.44	-	1.20		1.03	2.55	1.04	0.57	-	1.23	0.01	0.237	0.195	0.120	0.120	0.043	0.022	-	0.185	0.114
2014 Ford Escape	GDI	3FTP	Screening	R2	7/2/2014	CARB III LEV E-10	140702_1044_3FTP_FEsc_E99_R2	25,361	1.483	1.124	0.225	-	-	-	-	1.51	1.45	1.38	3.78	1.05	0.63	-	1.50		1.37	2.97	1.03	0.67	-	1.33	0.01	0.275	0.222	0.142	0.152	0.048	0.030	-	0.230	0.208
2014 Ford Escape	GDI	3FTP	Screening	R3	7/3/2014	CARB III LEV E-10	140703_1349_3FTP_FEsc_E99_R3	25,373	1.926	1.408	0.324	-	-	-	-	1.60	1.55	1.53	3.93	1.41	0.73	-	1.75		1.46	3.28	1.15	0.69	-	1.47	0.01	0.287	0.233	0.155	0.157	0.062	0.033	-	0.253	0.368
2014 Ford Escape	GDI	4FTP	Screening	R4	7/4/2014	CARB III LEV E-10	140704_1456_4FTP_FEsc_E99_R4	25,384	1.805	1.405	0.250	-	-	-	-	1.57	1.37	1.36	3.88	0.92	0.73	0.56	1.37		1.26	3.31	1.07	0.69	0.58	1.29	(0.00)	0.407	0.302	0.239	0.155	0.043	0.033	0.028	0.258	0.241
2014 Ford Escape	GDI	4FTP	Screening	R5	7/5/2014	CARB III LEV E-10	140705_1354_4FTP_FEsc_E99_R5	25,399	1.662	1.311	0.220	-	-	-	-	1.46	1.37	1.33	3.34	1.21	0.88	0.64	1.39		1.24	2.78	1.16	0.77	0.65	1.24	(0.00)	0.373	0.299	0.232	0.133	0.054	0.038	0.031	0.256	0.327
2014 Ford Escape	GDI	4FTP	Screening	R6	7/6/2014	CARB III LEV E-10	140706_1435_4FTP_FEsc_E99_R6	25,414	1.991	1.584	0.255	-	-	-	-	1.86	1.59	1.57	4.57	1.39	0.67	0.67	1.64		1.40	3.67	1.20	0.78	0.66	1.44	(0.01)	0.469	0.343	0.269	0.178	0.061	0.030	0.032	0.301	0.615
2014 Ford Escape	GDI	4FTP	Screening	Outlier	7/19/2014	CARB III LEV E-10	140719_1448_4FTP_FEsc_E99_Outlier	25,578				-	-	-	-	1.50	1.46	1.42	3.82	1.63	0.95	0.72	1.63		1.28	3.06	1.19	0.77	0.77	1.34	(0.01)	0.381	0.316	0.246	0.151	0.072	0.041	0.034	0.297	0.563
2014 Ford Escape	GDI	3FTP	Screening	R7	7/20/2014	CARB III LEV E-10	140720_1755_3FTP_FEsc_E99_R7	25,593	1.580	1.111	0.294	-	-	-	-	1.54	1.56	1.54	3.28	1.13	0.83	-	1.50		1.49	2.92	1.27	0.84	-	1.49	(0.01)	0.253	0.222	0.158	0.133	0.051	0.038	-	0.222	0.242
2014 Ford Escape	GDI	3FTP	Screening	R8	7/21/2014	CARB III LEV E-10	140721_1156_3FTP_FEsc_E99_R8	25,604	1.722	1.306	0.260	-	-	-	-	1.68	1.65	1.57	3.99	1.14	0.88	-	1.66		1.48	3.46	1.25	0.83	-	1.60	0.00	0.273	0.234	0.159	0.160	0.051	0.039	-	0.250	0.337
2014 Ford Escape	GDI	3FTP	Screening	R9	7/22/2014	CARB III LEV E-10	140722_1359_3FTP_FEsc_E99_R9	25,615	1.724	1.311	0.258	-	-	-	-	1.70	1.74	1.64	4.16	1.27	0.99	-	1.79		1.56	3.38	1.36	0.92	-	1.66	0.00	0.271	0.241	0.163	0.163	0.055	0.042	-	0.260	0.585
2014 Ford Escape	GDI	3FTP	Screening	Eval	7/13/2014	CARB III LEV E-10	140713_1443_3FTP_FEsc_E99_Eval	25,528	1.452	1.134	0.199	-	-	-	-	1.84	1.64	1.61				-			1.47					1.40	0.00	0.291	0.265	0.258	0.235	0.235	0.235	-	0.235	0.250
2014 Ford Escape	GDI	3FTP	Confirmation	R1b	11/4/2014	CARB III LEV E-10	141104_1310_3FTP_FEsc_E99_R1b	25,763	-	-	-	-	-	-	-	1.95	1.92	1.96	5.04	1.36	1.09	-	2.05		1.90	4.73	1.40	0.93	-	1.96	0.02	0.288	0.242	0.197	0.235	0.070	0.054	-	0.359	0.430
2014 Ford Escape	GDI	3FTP	Confirmation	R2b	11/5/2014	CARB III LEV E-10	141105_1529_3FTP_FEsc_E99_R2b	25,804	-	-	-	-	-	-	-	1.97	2.01	2.05	4.40	1.44	0.91	-	1.91		1.88	4.16	1.58	0.97	-	1.95	0.02	0.290	0.252	0.206	0.205	0.074	0.047	-	0.326	0.424
2014 Ford Escape	GDI	3FTP	Confirmation	R3b	11/6/2014	CARB III LEV E-10	141106_1331_3FTP_FEsc_E99_R3b	25,838	-	-	-	-	-	-	-	2.02	2.06	2.07	4.23	1.63	0.99	-	1.99		1.89	4.14	1.70	1.00	-	2.01	0.02	0.296	0.258	0.208	0.198	0.082	0.050	-	0.330	0.427
2014 Ford Escape	GDI	3FTP	Confirmation	R4b	11/7/2014	CARB III LEV E-10	141107_1346_3FTP_FEsc_E99_R4b	25,857	-	-	-	-	-	-	-	2.04	2.04	2.12	4.47	1.39	1.00	-	1.92		1.93	4.43	1.57	1.03	-	2.02	0.02	0.305	0.260	0.216	0.212	0.072	0.051	-	0.335	0.435
2014 Ford Escape	GDI	3FTP	Confirmation	R5b	11/11/2014	CARB III LEV E-10	141111_1246_3FTP_FEsc_E99_R5b	25,876	-	-	-	-	-	-	-	1.88	1.93	1.84	5.01	1.08	0.62	-	1.77		1.74	4.77	1.20	0.76	-	1.82	0.03	0.280	0.245	0.188	0.238	0.057	0.033	-	0.328	0.393
2014 Ford Escape	GDI	3FTP	Confirmation	R6b	11/12/2014	CARB III LEV E-10	141112_0933_3FTP_FEsc_E99_R6b	25,894	-	-	-	-	-	-	-	1.91	1.86	1.87	4.25	1.27	0.73	-	1.74		1.73	4.15	1.49	0.84	-	1.86	0.02	0.285	0.236	0.190	0.202	0.066	0.038	-	0.306	0.392
2012 Honda Accord	PFI	4FTP	Confirmation	R1b	10/29/2014	CARB III LEV E-10	141029_1027_4FTP_HAcc_E99_R1b	32,930	-	-	-	-	-	-	-	0.10	0.09	0.12	0.32	0.04	0.07	(0.06)	0.08		0.09	0.27	0.06	0.05	0.06	0.10	0.02	0.031	0.025	0.027	0.020	0.007	0.008	0.002	0.038	0.035
2012 Honda Accord	PFI	4FTP	Confirmation	R2b	10/30/2014	CARB III LEV E-10	141030_1011_4FTP_HAcc_E99_R2b	32,953	-	-	-	-	-	-	-	0.09	0.07	0.09	1.04	(0.00)	0.07	0.01	0.24		0.08	0.25	0.05	0.05	0.06	0.09	0.01	0.030	0.022	0.021	0.055	0.005	0.008	0.006	0.074	0.036
2012 Honda Accord	PFI	4FTP	Confirmation	R3b	11/4/2014	CARB III LEV E-10	141104_0930_4FTP_HAcc_E99_R3b	33,023	-	-	-	-	-	-	-	0.10	0.11	0.15	0.41	(0.03)	(0.10)	(0.03)	0.04		0.09	0.35	0.07	0.06	0.07	0.12	0.01	0.033	0.031	0.032	0.025	0.003	0.000	0.004	0.032	0.036
2012 Honda Accord	PFI	4FTP	Confirmation	R4b	11/5/2014	CARB III LEV E-10	141105_1007_4FTP_HAcc_E99_R4b	33,051	-	-	-	-	-	-	-	0.08	0.07	0.08	0.41	0.03	(0.11)	(0.02)	0.05		0.10	0.33	0.07	0.06	0.07	0.12	0.02	0.028	0.022	0.020	0.025	0.006	0.000	0.004	0.035	0.040
2012 Honda Accord	PFI	4FTP	Confirmation	R5b	11/6/2014	CARB III LEV E-10	141106_0932_4FTP_HAcc_E99_R5b	33,089	-	-	-	-	-	-	-	0.10	0.11	0.10	0.35	0.10	(0.03)	0.01	0.09		0.10	0.31	0.08	0.07	0.08	0.13	0.03	0.031	0.029	0.024	0.022	0.010	0.004	0.006	0.041	0.040
2012 Honda Accord	PFI	4FTP	Confirmation	R6b	11/7/2014	CARB III LEV E-10	141107_0937_4FTP_HAcc_E99_R6b	33,127	-	-	-	-	-	-	-	0.15	0.13	0.12	0.41	0.08	0.07	(0.00)	0.12		0.11	0.39	0.07	0.06	0.07	0.13	0.02	0.045	0.034	0.028	0.025	0.009	0.008	0.005	0.047	0.047
2012 Honda Accord	PFI	4FTP	Confirmation	Eval	11/11/2014	CARB III LEV E-10	141111_1015_4FTP_HAcc_E99_Eval	33,196	-	-	-	0.061	0.060	0.041	0.041	-	0.14	-	-	-	-	-	-		-	0.34	0.07	0.06	0.08	0.13	0.00		0.037	-	-	-	-	-	-	-
2012 Honda Accord	PFI	4FTP	Confirmation	Eval	11/12/2014	CARB III LEV E-10	141112_1102_4FTP_HAcc_E99_Eval	33,227	-	-	-	0.065	0.055	0.045	0.038	-	0.12	-	-	-	-	-	-		-	0.38	0.06	0.05	0.06	0.12	0.00		0.033	-	-	-	-	-	-	-

[1] Run #1 (R1), Preliminary tests (not part of the main study by prep emission tests for evaluation and setup), evaluation (eval to verify current settings), R1b where "b" subscript represents the confirmation testing and no subscript represents the screening results. The MSS had a zero drift during usage of two different MSS units utilized. The data was corrected for the zero drift. The MSS values are as reported and the MSS(BL) data are the relative PM emission rate for the MSS zero offset in mg/mi. The MSS data reported are corrected for the blank value.

Table E-3 FTP background data, probe volumes and baro/RH test conditions (confirmation and screening): Part 2

FTP emission results E-99

aborted, invalid, evlauation test. Not used in the analysis of E-99 objectives

outlier results, but still used in the analysis.

Confirmation and Screening data

									ckground Correct		CVS PM Probe Volumes (L)																	PFSS Volume (L)										
Year/Make/Model	Type	Test	Test Phase	Run	Date	Fuel Content	Test Name	Mileage	CVS ug	PFSS ug	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4	Gtotal 1	Gtotal 2	Gtotal 3	Gtotal 4	Gprob 1	Gprob 2	Gprob 3	Gprob 4	Test Baro inHg	Test Baro mbar	Test RH%
2012 Honda Accord	PFI	3FTP	Screening	Prelim1	11/5/2013	CARB III LEV E-10	131105_1431_FTP_HAcc_E99_Prelim1	31,219	5	3	424.4	1578.5	559.9	-	321.8	1291.4	753.1	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	218.1	865.4	293.4	-	32.0	81.1	36.4	-	29.1	984.7	
2012 Honda Accord	PFI	3FTP	Screening	R1	11/14/2013	CARB III LEV E-10	131114_1612_3FTP_HAcc_E99_R1	31,245	5	3	397.3	1593.5	532.7	-	321.8	1291.6	432.1	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	218.1	865.4	293.4	-	32.0	81.1	36.4	-	28.8	976.0	
2012 Honda Accord	PFI	3FTP	Screening	R2	11/15/2013	CARB III LEV E-10	131115_1342_3FTP_HAcc_E99_R2	31,256	5	3	397.3	1593.5	532.7	-	321.8	1291.6	432.0	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	218.1	865.4	293.5	-	32.3	78.1	35.6	-	28.7	971.6	
2012 Honda Accord	PFI	3FTP	Screening	R3	11/20/2013	CARB III LEV E-10	131120_1353_3FTP_HAcc_E99_R3	31,346	5	3	397.3	1593.8	532.8	-	321.8	1291.6	432.1	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	218.1	865.4	293.5	-	39.8	114.0	43.5	-	28.9	978.5	
2012 Honda Accord	PFI	3FTP	Screening	R4	11/21/2013	CARB III LEV E-10	131121_1546_3FTP_HAcc_E99_R4	31,356	5	3	397.3	1462.4	532.7	-	321.8	1291.4	432.0	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	218.1	865.4	293.3	-	75.9	187.6	83.0	-	28.9	978.2	
2012 Honda Accord	PFI	3FTP	Screening	R5	11/22/2013	CARB III LEV E-10	131122_1006_3FTP_HAcc_E99_R5	31,367	5	3	397.3	1594.0	532.8	-	321.8	1291.4	432.1	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	218.1	865.4	293.5	-	39.8	114.0	43.5	-	28.9	979.9	
2012 Honda Accord	PFI	4FTP	Screening	Fault1	11/26/2013	CARB III LEV E-10	131126_1538_4FTP_HAcc_E99_Fault1	31,386	5	3	695.3	1594.6	695.4	1594.5	570.0	1286.8	569.8	1150.3	375.6	858.8	375.6	858.8	403.7	692.3	403.7	692.3	385.9	877.5	385.9	877.5	56.1	79.2	45.8	77.0	29.0	983.3	
2012 Honda Accord	PFI	4FTP	Screening	Fault2	11/27/2013	CARB III LEV E-10	131127_1327_4FTP_HAcc_E99_Fault2	31,400	5	3	695.3	1594.4	650.2	1594.0	570.0	1292.2	570.0	1292.2	375.6	858.8	375.6	858.8	403.7	692.3	403.7	692.3	385.9	877.5	385.9	877.5	78.5	111.8	64.4	101.0	28.9	977.4	
2012 Honda Accord	PFI	4FTP	Screening	Fault3	12/4/2013	CARB III LEV E-10	131204_1226_4FTP_HAcc_E99_Fault3	31,431	5	3	695.3	1594.6	695.3	1594.5	570.0	1292.2	570.0	1292.1	375.6	858.8	375.6	858.8	403.7	692.3	403.7	692.3	385.9	877.5	385.9	877.5	129.8	186.7	107.7	174.1	28.8	977.0	
2012 Honda Accord	PFI	4FTP	Screening	R6	1/14/2014	CARB III LEV E-10	140114_1359_4FTP_HAcc_E99_R6	31,502	5	3	695.3	1192.4	930.0	1592.0	570.0	977.4	753.9	1292.8	375.6	644.1	500.8	858.8	403.7	692.3	403.7	692.3	385.9	661.7	511.7	877.5	56.5	79.2	48.0	76.1	29.2	990.2	
2012 Honda Accord	PFI	4FTP	Screening	R7	1/15/2014	CARB III LEV E-10	140115_1140_4FTP_HAcc_E99_R7	31,156	5	3	695.3	1192.4	929.2	1593.4	570.0	977.4	754.0	1292.6	375.6	644.1	500.8	858.8	403.7	692.3	403.7	692.3	385.9	661.7	511.7	877.5	76.4	109.9	64.0	104.8	29.2	988.8	
2012 Honda Accord	PFI	4FTP	Screening	R8	1/16/2014	CARB III LEV E-10	140116_1446_4FTP_HAcc_E99_R8	31,531	5	3	695.3	1192.4	930.1	1595.0	570.0	977.4	753.9	1292.8	375.6	644.1	500.8	858.8	403.7	692.3	403.7	692.3	385.9	661.7	511.7	877.5	127.6	138.0	143.9	176.5	29.1	984.9	
2012 Honda Accord	PFI	3FTP	Screening	R9	1/17/2014	CARB III LEV E-10	140117_0924_3FTP_HAcc_E99_R9	31,546	5	3	415.2	1567.0	516.6	-	321.8	1291.3	432.1	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	331.3	1297.9	436.3	-	45.7	107.5	43.2	-	29.2	987.7	
2012 Honda Accord	PFI	3FTP	Screening	Outlier	1/24/2014	CARB III LEV E-10	140124_1405_3FTP_HAcc_E99_Outlier	31,572	5	3	416.2	1565.3	515.6	-	323.2	1290.3	432.1	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	331.3	1297.9	436.0	-	66.6	161.7	72.7	-	29.2	988.5	
2012 Honda Accord	PFI	3FTP	Screening	R10	1/28/2014	CARB III LEV E-10	140128_1538_3FTP_HAcc_E99_R10	31,590	5	3	415.6	1563.4	514.6	-	323.2	1291.4	432.1	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	331.3	1298.1	436.0	-	117.0	275.1	124.0	-	29.1	984.6	
2012 Honda Accord	PFI	3FTP	Screening	R11	1/29/2014	CARB III LEV E-10	140129_0845_3FTP_HAcc_E99_R11	31,601	5	3	418.3	1561.5	513.5	-	323.3	1290.2	432.1	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	331.3	1298.3	435.9	-	68.2	166.2	73.7	-	29.1	985.0	
2014 Ford Escape	GDI	3FTP	Screening	Prelim1	6/25/2014	CARB III LEV E-10	140625_1423_3FTP_FEsc_E99_Prelim1	25,298	5	3	397.3	1324.2	532.8	-	-	-	-	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	218.1	865.2	293.3	-	35.4	85.2	41.5	-	28.9	977.8	
2014 Ford Escape	GDI	3FTP	Screening	Prelim2	6/26/2014	CARB III LEV E-10	140626_1244_3FTP_FEsc_E99_Prelim2	25,309	5	3	397.3	1593.8	532.8	-	321.8	1291.6	432.1	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	218.1	864.9	293.6	-	35.9	85.7	41.4	-	28.9	978.0	
2014 Ford Escape	GDI	3FTP	Screening	Prelim3	6/27/2014	CARB III LEV E-10	140627_1344_3FTP_FEsc_E99_Prelim3	25,320	5	3	397.3	1462.4	532.7	-	321.8	1291.4	432.0	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	218.1	865.3	293.2	-	36.0	87.0	42.3	-	28.9	977.2	
2014 Ford Escape	GDI	3FTP	Screening	R1	7/1/2014	CARB III LEV E-10	140701_1030_3FTP_FEsc_E99_R1	25,350	5	3	379.3	1462.9	496.7	-	321.8	1271.9	432.1	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	218.1	864.9	293.6	-	33.9	82.8	40.2	-	28.9	978.2	
2014 Ford Escape	GDI	3FTP	Screening	R2	7/2/2014	CARB III LEV E-10	140702_1044_3FTP_FEsc_E99_R2	25,361	5	3	379.3	1589.0	496.7	-	321.8	1289.6	432.1	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	218.1	865.3	293.3	-	46.9	115.3	56.4	-	28.9	979.0	
2014 Ford Escape	GDI	3FTP	Screening	R3	7/3/2014	CARB III LEV E-10	140703_1349_3FTP_FEsc_E99_R3	25,373	5	3	379.3	1589.0	496.7	-	321.8	1289.6	432.1	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	218.1	864.9	293.5	-	79.4	190.3	91.9	-	28.9	977.3	
2014 Ford Escape	GDI	4FTP	Screening	R4	7/4/2014	CARB III LEV E-10	140704_1456_4FTP_FEsc_E99_R4	25,384	5	3	559.9	960.1	740.5	1269.8	468.8	804.0	634.3	1087.8	375.6	644.1	500.8	858.8	403.7	692.3	403.7	692.3	385.8	661.7	511.6	877.5	59.5	63.7	71.5	85.2	28.9	980.3	
2014 Ford Escape	GDI	4FTP	Screening	R5	7/5/2014	CARB III LEV E-10	140705_1354_4FTP_FEsc_E99_R5	25,399	5	3	559.9	960.1	740.5	1269.8	468.8	804.0	634.3	1087.9	375.6	644.1	500.8	858.8	403.7	692.3	403.7	692.3	385.8	661.7	511.6	877.4	82.9	86.8	99.0	115.0	29.0	982.5	
2014 Ford Escape	GDI	4FTP	Screening	R6	7/6/2014	CARB III LEV E-10	140706_1435_4FTP_FEsc_E99_R6	25,414	5	3	559.8	960.1	740.4	1269.8	468.8	804.0	634.3	1087.8	375.6	644.1	500.8	858.8	403.7	692.3	403.7	692.3	385.8	661.7	511.6	877.4	137.9	145.3	165.2	197.0	29.0	980.4	
2014 Ford Escape	GDI	4FTP	Screening	Outlier	7/19/2014	CARB III LEV E-10	140719_1448_4FTP_FEsc_E99_Outlier	25,578	5	3	559.9	960.1	740.5	1269.8	468.8	804.0	634.6	1081.7	375.6	644.1	500.8	858.8	403.7	692.3	403.7	692.3	385.8	661.7	511.6	877.4	135.8	142.6	161.9	190.1	28.9	980.2	
2014 Ford Escape	GDI	3FTP	Screening	R7	7/20/2014	CARB III LEV E-10	140720_1755_3FTP_FEsc_E99_R7	25,593	5	1	352.2	1387.6	469.6	-	303.4	1207.6	404.5	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	331.3	1225.5	436.1	-	50.4	119.3	57.9	-	28.9	980.0	
2014 Ford Escape	GDI	3FTP	Screening	R8	7/21/2014	CARB III LEV E-10	140721_1156_3FTP_FEsc_E99_R8	25,604	5	1	352.2	1382.8	469.6	-	303.4	1203.6	404.5	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	331.3	1180.4	435.7	-	70.2	169.1	81.0	-	29.0	983.0	
2014 Ford Escape	GDI	3FTP	Screening	R9	7/22/2014	CARB III LEV E-10	140722_1359_3FTP_FEsc_E99_R9	25,615	5	1	352.2	1382.8	469.6	-	303.4	1210.0	404.5	-	215.3	858.8	285.5	-	403.7	692.3	403.7	-	331.3	1029.6	435.7	-	118.2	285.8	137.1	-	29.0	983.6	
2014 Ford Escape	GDI	3FTP	Screening	Eval	7/13/2014	CARB III LEV E-10	140713_1443_3FTP_FEsc_E99_Eval	25,528	5	1	496.7	851.7	496.7	-	505.6	867.1	505.6	-	500.8	858.8	500.8	-	403.7	-	-	-	511.6	877.4	511.3	-	77.6	80.7	68.1	-	28.9	977.0	
2014 Ford Escape	GDI	3FTP	Confirmation	R1b	11/4/2014	CARB III LEV E-10	141104_1310_3FTP_FEsc_E99_R1b	25,763	5	1	319.0	1269.9	424.5	-	268.8	1088.0	358.7	-	215.4	858.9	285.5	-	475.6	815.6	475.6	-	331.3	1314.3	436.2	-	67.8	164.4	81.8	-	29.1	985.8	
2014 Ford Escape	GDI	3FTP	Confirmation	R2b	11/5/2014	CARB III LEV E-10	141105_1529_3FTP_FEsc_E99_R2b	25,804	5	1	316.1	1262.5	424.5	-	266.7	1081.2	358.7	-	215.4	858.9	285.5	-	475.6	815.6	475.6	-	331.3	1220.4	435.7	-	68.2	162.3	80.5	-	29.1	984.2	
2014 Ford Escape	GDI	3FTP	Confirmation	R3b	11/6/2014	CARB III LEV E-10	141106_1331_3FTP_FEsc_E99_R3b	25,838	5	1	316.1	1262.5	424.5	-	266.7	1081.2	358.7	-	215.4	858.9	285.5	-	475.6	815.6	475.6	-	331.3	1210.8	436.1	-	70.7	162.2	81.0	-	29.1	985.6	
2014 Ford Escape	GDI	3FTP	Confirmation	R4b	11/7/2014	CARB III LEV E-10	141107_1346_3FTP_FEsc_E99_R4b	25,857	5	1	316.1	1267.5	424.5	-	266.7	1085.2	358.7	-	215.4	858.9	285.5	-	475.6	815.6	475.6	-	331.3	1314.5	435.8	-	69.7	162.8	80.4	-	29.1	984.8	
2014 Ford Escape	GDI	3FTP	Confirmation	R5b	11/11/2014	CARB III LEV E-10	141111_1246_3FTP_FEsc_E99_R5b	25,876	5	1	316.1	1268.2	424.5	-	266.7	1085.9	358.7	-	215.4	858.9	285.5	-	475.6	815.6	475.6	-	331.3	1250.7	436.2	-	69.8	166.3	80.7	-	29.0	980.6	
2014 Ford Escape	GDI	3FTP	Confirmation	R6b	11/12/2014	CARB III LEV E-10	141112_0933_3FTP_FEsc_E99_R6b	25,894	5	1	316.5	1269.4	424.5	-	266.9	1087.1	358.7	-	215.4	858.9	285.5	-	475.6	815.6	475.6	-	331.3	1292.7	436.1	-	70.0	167.3	81.4	-	29.0	982.8	
2012 Honda Accord	PFI	4FTP	Confirmation	R1b	10/29/2014	CARB III LEV E-10	141029_1027_4FTP_HAcc_E99_R1b	32,930	5	1	560.0	960.3	740.6	1270.0	469.1	804.4	634.6	1088.3	375.7	644.2	500.9	858.9	475.6	815.6	475.6	815.6	574.6	985.4	767.5	1316.2	116.6	124.4	130.2	160.1	29.1	984.0	
2012 Honda Accord	PFI	4FTP	Confirmation	R2b	10/30/2014	CARB III LEV E-10	141030_1011_4FTP_HAcc_E99_R2b	32,953	5	1	560.0	960.3	740.6	1270.1	469.1	804.4	634.6	1088.3	375.7	644.2	500.9	858.9	475.6	815.6	475.6	815.6	574.6	985.4	767.5	1316.2	115.9	125.6	130.5	162.1	29.0	982.5	
2012 Honda Accord	PFI	4FTP	Confirmation	R3b	11/4/2014	CARB III LEV E-10	141104_0930_4FTP_HAcc_E99_R3b	33,023	5	1	560.0	960.3	740.6	1270.1	469.1	804.4	634.6	1088.3	375.7	644.2	500.9	858.9	475.6	815.6	475.6	815.6	574.6	865.4	767.5	1316.2	115.7	124.3	128.0	157.3	29.2	988.7	
2012 Honda Accord	PFI	4FTP	Confirmation	R4b	11/5/2014	CARB III LEV E-10	141105_1007_4FTP_HAcc_E99_R4b	33,051	5	1	560.0	960.3	740.6	1270.1	469.1	804.4	634.6	1088.3	375.7	644.2	500.9	858.9	475.6	815.6	475.6	815.6	574.6	985.4	767.5	1316.3	114.3	122.6	128.4	156.8	29.1	986.6	
2012 Honda Accord	PFI	4FTP	Confirmation	R5b	11/6/2014	CARB III LEV E-10	141106_0932_4FTP_HAcc_E99_R5b	33,089	5	1	560.0	960.3	740.6	1270.1	469.1	804.4	634.7	1088.3	375.7	644.2	500.9	858.9	475.6	815.6	475.6	815.6	574.6	985.4	767.5	1316.2	115.7	123.4	129.7	158.4	29.2	988.7	
2012 Honda Accord	PFI	4FTP	Confirmation	R6b	11/7/2014	CARB III LEV E-10	141107_0937_4FTP_HAcc_E99_R6b	33,127	5	1	560.0	960.3	740.6	1270.1	469.1	804.4	634.7	1088.3	375.7	644.2	500.9	858.9	475.6	815.6	475.6	815.6	574.6	985.4	767.5	1316.3	116.7	124.4	127.3	157.2	29.1	986.6	
2012 Honda Accord	PFI	4FTP	Confirmation	Eval	11/11/2014	CARB III LEV E-10	141111_1015_4FTP_HAcc_E99_Eval	33,196	5	1	560.0	960.3	740.6	1270.1	469.1	804.4	634.7	1088.3	375.7	644.2	500.9	858.9	475.6	815.6	475.6	815.6	574.6	985.4	767.5	1316.3	116.7	124.4	127.3	157.2	29.0	980.8	
2012 Honda Accord	PFI	4FTP	Confirmation	Eval	11/12/2014	CARB III LEV E-10	141112_1102_4FTP_HAcc_E99_Eval	33,227	5	1	560.0	960.3	740.6	1270.1	469.1	804.4	634.7	1088.3	375.7	644.2	500.9	858.9	475.6	815.6	475.6	815.6	574.6	985.4	767.5	1316.3	116.7	124.4	127.3	157.2	29.0	981.2	

[1] Run #1 (R1), Preliminary tests (not part of the main study by prep emission tests for evaluation and setup), evaluation (eval to verify current settings), R1b where "b" subscript represents the confirmation testing and no subscript represents the screening results.

Table E-4 FTP gaseous emissions, CVS volume, DF, miles (confirmation and screening): Part 3

FTP emission results E-99
aborted, invalid, evlauation test. Not used in the analysis of E-99 objectives
outlier results, but still used in the analysis.
Confirmation and Screening data
Background corrected PM2.5, but not for EC/OC.

									Vmix (m^3) not corr for Instr. Flow					Dilution Factor					Corr Vmix (m^3)					Mileage (miles)					THC Emissions (g/mile)						NMHC Emissions (g/mile)					
Year/Make/Model	Type	Test	Task	Run	Date	Fuel Content	Test Name	Mileage	P1	P2	P3	P4	BG	P1	P2	P3	P4	BG	P1	P2	P3	P4	BG	P1	P2	P3	P4	BG	THC-1	THC-2	THC-3	THC-4	3THC-w	4THC-w	NMHC-1	NMHC-2	NMHC-3	NMHC-4	3NMHC-w	4NMHC-w
2012 Honda Accord	PFI	3FTP	Screening	Prelim1	11/5/2013	CARB III LEV E-10	131105_1431_FTP_HAcc_E99_Prelim1	31,219	31.96	54.78	32.01	-	118.75	6.68	11.13	7.87	-	25.68	33.52	59.55	33.89	-	126.96	3.56	3.81	3.55	-	10.93	0.049	0.001	0.003	-	0.012	-	0.045	0.002	0.002	-	0.011	-
2012 Honda Accord	PFI	3FTP	Screening	R1	11/14/2013	CARB III LEV E-10	131114_1612_3FTP_HAcc_E99_R1	31,245	33.29	57.09	33.28	-	123.66	7.01	11.48	8.22	-	26.71	34.83	61.79	35.12	-	131.74	3.58	3.82	3.57	-	10.97	0.060	0.002	0.003	-	0.014	-	0.054	0.002	0.002	-	0.013	-
2012 Honda Accord	PFI	3FTP	Screening	R2	11/15/2013	CARB III LEV E-10	131115_1342_3FTP_HAcc_E99_R2	31,256	32.48	56.04	32.69	-	121.21	6.96	11.74	8.40	-	27.10	34.01	60.74	34.53	-	129.29	3.58	3.81	3.56	-	10.95	0.064	0.001	0.003	-	0.015	-	0.058	0.001	0.002	-	0.013	-
2012 Honda Accord	PFI	3FTP	Screening	R3	11/20/2013	CARB III LEV E-10	131120_1353_3FTP_HAcc_E99_R3	31,346	32.81	56.26	32.81	-	121.88	7.10	12.32	8.18	-	27.60	34.35	60.97	34.65	-	129.96	3.56	3.64	3.56	-	10.76	0.073	0.000	0.003	-	0.016	-	0.066	0.000	0.001	-	0.014	-
2012 Honda Accord	PFI	3FTP	Screening	R4	11/21/2013	CARB III LEV E-10	131121_1546_3FTP_HAcc_E99_R4	31,356	32.22	55.24	32.35	-	119.82	6.94	11.58	8.61	-	27.13	33.76	59.82	34.20	-	127.77	3.57	3.82	3.52	-	10.91	0.082	0.001	0.003	-	0.018	-	0.074	0.001	0.001	-	0.016	-
2012 Honda Accord	PFI	3FTP	Screening	R5	11/22/2013	CARB III LEV E-10	131122_1006_3FTP_HAcc_E99_R5	31,367	31.80	53.85	32.32	-	117.97	7.01	11.92	8.55	-	27.48	33.34	58.55	34.17	-	126.05	3.57	3.81	3.56	-	10.94	0.069	0.002	0.002	-	0.016	-	0.061	0.000	0.001	-	0.013	-
2012 Honda Accord	PFI	4FTP	Screening	Fault1	11/26/2013	CARB III LEV E-10	131126_1538_4FTP_HAcc_E99_Fault1	31,386	32.94	56.71	33.02	56.73	179.40	7.09	11.67	8.61	12.04	39.42	34.09	58.24	34.17	58.26	184.76	3.57	3.81	3.56	3.82	14.75	0.067	0.001	0.002	0.001	0.015	0.015	0.060	0.001	0.001	0.001	0.013	0.013
2012 Honda Accord	PFI	4FTP	Screening	Fault2	11/27/2013	CARB III LEV E-10	131127_1327_4FTP_HAcc_E99_Fault2	31,400	32.67	56.21	32.75	56.38	178.01	6.96	11.42	8.19	12.24	38.82	34.89	60.91	34.93	61.08	191.80	3.55	3.80	3.53	3.79	14.66	0.059	0.001	0.003	0.001	0.014	0.014	0.053	0.001	0.002	0.001	0.012	0.012
2012 Honda Accord	PFI	4FTP	Screening	Fault3	12/4/2013	CARB III LEV E-10	131204_1226_4FTP_HAcc_E99_Fault3	31,431	32.41	55.94	32.95	56.66	177.95	6.99	11.71	8.59	12.56	39.86	34.62	60.64	35.16	61.36	191.79	3.54	3.78	3.54	3.81	14.67	0.075	0.001	0.010	0.000	0.019	0.019	0.058	0.001	0.009	0.001	0.017	0.017
2012 Honda Accord	PFI	4FTP	Screening	R6	1/14/2014	CARB III LEV E-10	140114_1359_4FTP_HAcc_E99_R6	31,502	32.05	55.02	32.40	55.71	175.17	6.79	11.23	8.21	11.90	38.14	34.27	58.82	35.13	60.42	188.64	3.58	3.81	3.57	3.80	14.75	0.057	0.006	0.007	0.005	0.017	0.017	0.051	0.006	0.006	0.005	0.015	0.015
2012 Honda Accord	PFI	4FTP	Screening	R7	1/15/2014	CARB III LEV E-10	140115_1140_4FTP_HAcc_E99_R7	31,156	32.36	55.54	32.43	55.62	175.95	6.74	11.30	8.29	11.86	38.18	34.58	59.35	35.17	60.32	189.42	3.56	3.81	3.56	3.82	14.75	0.078	0.000	0.002	0.000	0.017	0.017	0.071	0.002	0.002	0.001	0.016	0.016
2012 Honda Accord	PFI	4FTP	Screening	R8	1/16/2014	CARB III LEV E-10	140116_1446_4FTP_HAcc_E99_R8	31,531	34.17	58.42	33.93	58.28	184.79	7.01	11.38	8.51	12.02	38.92	36.39	62.22	36.67	62.98	198.26	3.57	3.83	3.57	3.84	14.81	0.054	0.000	0.002	0.000	0.012	0.012	0.048	0.000	0.001	0.000	0.010	0.010
2012 Honda Accord	PFI	3FTP	Screening	R9	1/17/2014	CARB III LEV E-10	140117_0924_3FTP_HAcc_E99_R9	31,546	33.13	56.39	32.87	-	122.39	7.00	12.28	9.88	-	29.16	34.68	61.06	34.70	-	130.45	3.47	3.82	3.56	-	10.85	0.091	0.001	0.001	-	0.019	-	0.081	0.001	0.001	-	0.017	-
2012 Honda Accord	PFI	3FTP	Screening	Outlier	1/24/2014	CARB III LEV E-10	140124_1405_3FTP_HAcc_E99_Outlier	31,572	32.16	54.98	32.07	-	119.21	6.73	11.47	8.18	-	26.38	33.71	59.66	33.89	-	127.26	3.57	3.81	3.56	-	10.94	0.065	0.001	0.003	-	0.015	-	0.058	0.001	0.002	-	0.013	-
2012 Honda Accord	PFI	3FTP	Screening	R10	1/28/2014	CARB III LEV E-10	140128_1538_3FTP_HAcc_E99_R10	31,590	33.37	57.25	33.45	-	124.07	6.79	11.38	8.21	-	26.38	34.93	61.92	35.27	-	132.12	3.57	3.82	3.54	-	10.92	0.082	0.000	0.002	-	0.018	-	0.074	0.000	0.001	-	0.016	-
2012 Honda Accord	PFI	3FTP	Screening	R11	1/29/2014	CARB III LEV E-10	140129_0845_3FTP_HAcc_E99_R11	31,601	32.84	56.19	32.70	-	121.74	6.55	11.00	8.05	-	25.60	34.40	60.86	34.52	-	129.79	3.56	3.78	3.56	-	10.90	0.077	0.000	0.002	-	0.017	-	0.070	0.000	0.001	-	0.015	-
2014 Ford Escape	GDI	3FTP	Screening	Prelim1	6/25/2014	CARB III LEV E-10	140625_1423_3FTP_FEsc_E99_Prelim1	25,298	31.40	53.64	31.43	-	116.46	6.21	10.67	7.11	-	23.99	32.67	58.08	33.27	-	124.02	3.55	3.81	3.56	-	10.92	0.128	0.002	0.004	-	0.029	-	0.103	0.002	0.002	-	0.023	-
2014 Ford Escape	GDI	3FTP	Screening	Prelim2	6/26/2014	CARB III LEV E-10	140626_1244_3FTP_FEsc_E99_Prelim2	25,309	32.34	55.28	32.34	-	119.97	6.40	10.94	7.30	-	24.64	33.88	59.98	34.18	-	128.05	3.57	3.84	3.55	-	10.96	0.103	0.002	0.004	-	0.023	-	0.080	0.001	0.002	-	0.018	-
2014 Ford Escape	GDI	3FTP	Screening	Prelim3	6/27/2014	CARB III LEV E-10	140627_1344_3FTP_FEsc_E99_Prelim3	25,320	34.23	58.70	34.31	-	127.25	6.82	11.69	7.76	-	26.26	35.77	63.28	36.15	-	135.20	3.55	3.81	3.56	-	10.93	0.100	0.001	0.004	-	0.023	-	0.077	0.001	0.002	-	0.017	-
2014 Ford Escape	GDI	3FTP	Screening	R1	7/1/2014	CARB III LEV E-10	140701_1030_3FTP_FEsc_E99_R1	25,350	34.51	59.08	34.46	-	128.04	6.91	11.70	7.77	-	26.37	36.03	63.63	36.26	-	135.92	3.55	3.82	3.54	-	10.91	0.092	0.002	0.005	-	0.022	-	0.073	0.002	0.002	-	0.017	-
2014 Ford Escape	GDI	3FTP	Screening	R2	7/2/2014	CARB III LEV E-10	140702_1044_3FTP_FEsc_E99_R2	25,361	35.15	60.00	34.97	-	130.11	6.93	11.71	7.72	-	26.36	36.67	64.69	36.77	-	138.13	3.53	3.82	3.58	-	10.93	0.074	0.001	0.004	-	0.017	-	0.054	0.001	0.002	-	0.012	-
2014 Ford Escape	GDI	3FTP	Screening	R3	7/3/2014	CARB III LEV E-10	140703_1349_3FTP_FEsc_E99_R3	25,373	34.89	59.71	34.84	-	129.45	6.80	11.60	7.81	-	26.22	36.41	64.41	36.65	-	137.47	3.55	3.82	3.56	-	10.93	0.085	0.001	0.003	-	0.019	-	0.064	0.001	0.001	-	0.014	-
2014 Ford Escape	GDI	4FTP	Screening	R4	7/4/2014	CARB III LEV E-10	140704_1456_4FTP_FEsc_E99_R4	25,384	34.91	59.93	34.83	59.52	189.19	7.02	11.60	8.01	11.73	38.35	36.90	63.34	37.28	63.71	201.23	3.57	3.85	3.56	3.85	14.84	0.090	0.000	0.004	0.001	0.020	0.020	0.070	0.001	0.002	0.001	0.016	0.016
2014 Ford Escape	GDI	4FTP	Screening	R5	7/5/2014	CARB III LEV E-10	140705_1354_4FTP_FEsc_E99_R5	25,399	34.76	59.60	34.78	59.60	188.74	7.01	11.76	8.05	11.90	38.72	36.75	63.01	37.23	63.79	200.78	3.54	3.79	3.54	3.80	14.68	0.078	0.000	0.003	0.001	0.017	0.017	0.060	0.000	0.001	0.000	0.013	0.013
2014 Ford Escape	GDI	4FTP	Screening	R6	7/6/2014	CARB III LEV E-10	140706_1435_4FTP_FEsc_E99_R6	25,414	34.75	59.71	34.79	59.59	188.84	7.04	11.80	8.07	11.80	38.71	36.74	63.13	37.23	63.78	200.88	3.55	3.80	3.56	3.83	14.73	0.080	0.000	0.004	0.000	0.018	0.018	0.060	0.001	0.001	0.000	0.013	0.013
2014 Ford Escape	GDI	4FTP	Screening	Outlier	7/19/2014	CARB III LEV E-10	140719_1448_4FTP_FEsc_E99_Outlier	25,578	34.62	59.25	34.58	59.39	187.84	6.97	11.52	7.94	11.65	38.09	36.63	62.69	37.06	63.64	200.02	3.56	3.81	3.55	3.82	14.75	0.116	0.000	0.004	0.001	0.025	0.025	0.096	0.001	0.002	0.001	0.021	0.021
2014 Ford Escape	GDI	3FTP	Screening	R7	7/20/2014	CARB III LEV E-10	140720_1755_3FTP_FEsc_E99_R7	25,593	34.61	59.12	34.46	-	128.18	6.84	11.78	7.83	-	26.45	36.08	63.55	36.21	-	135.84	3.55	3.80	3.55	-	10.91	0.104	0.002	0.003	-	0.023	-	0.084	0.002	0.002	-	0.019	-
2014 Ford Escape	GDI	3FTP	Screening	R8	7/21/2014	CARB III LEV E-10	140721_1156_3FTP_FEsc_E99_R8	25,604	34.71	59.56	34.71	-	128.98	6.86	11.67	7.87	-	26.40	36.19	63.97	36.46	-	136.62	3.56	3.82	3.54	-	10.93	0.086	0.002	0.003	-	0.020	-	0.066	0.002	0.001	-	0.015	-
2014 Ford Escape	GDI	3FTP	Screening	R9	7/22/2014	CARB III LEV E-10	140722_1359_3FTP_FEsc_E99_R9	25,615	34.75	59.58	34.73	-	129.06	6.90	11.62	7.86	-	26.38	36.22	64.00	36.48	-	136.70	3.54	3.80	3.54	-	10.88	0.101	0.009	0.008	-	0.028	-	0.081	0.009	0.007	-	0.023	-
2014 Ford Escape	GDI	3FTP	Screening	Eval	7/13/2014	CARB III LEV E-10	140713_1443_3FTP_FEsc_E99_Eval	25,528	34.49	59.06	34.49	-	128.03	7.15	11.74	8.07	-	26.95	34.49	59.06	34.49	-	128.03	3.57	3.83	3.56	-	10.95	0.101	0.002	0.004	-	0.023	-	0.081	0.001	0.002	-	0.018	-
2014 Ford Escape	GDI	3FTP	Confirmation	R1b	11/4/2014	CARB III LEV E-10	141104_1310_3FTP_FEsc_E99_R1b	25,763	34.74	59.34	34.61	-	128.69	6.68	11.43	7.63	-	25.74	36.18	63.59	36.31	-	136.08	3.55	3.80	3.55	-	10.90	0.121	0.002	0.003	-	0.027	-	0.098	0.002	0.001	-	0.022	-
2014 Ford Escape	GDI	3FTP	Confirmation	R2b	11/5/2014	CARB III LEV E-10	141105_1529_3FTP_FEsc_E99_R2b	25,804	34.41	58.88	34.40	-	127.70	6.68	11.42	7.53	-	25.62	35.86	63.12	36.11	-	135.08	3.54	3.80	3.56	-	10.90	0.118	0.002	0.003	-	0.026	-	0.096	0.002	0.001	-	0.021	-
2014 Ford Escape	GDI	3FTP	Confirmation	R3b	11/6/2014	CARB III LEV E-10	141106_1331_3FTP_FEsc_E99_R3b	25,838	34.23	58.67	34.27	-	127.17	6.50	11.40	7.57	-	25.48	35.67	62.90	35.97	-	134.54	3.55	3.79	3.56	-	10.90	0.110	0.001	0.000	-	0.023	-	0.088	0.001	0.000	-	0.019	-
2014 Ford Escape	GDI	3FTP	Confirmation	R4b	11/7/2014	CARB III LEV E-10	141107_1346_3FTP_FEsc_E99_R4b	25,857	34.12	58.61	34.29	-	127.02	6.47	11.21	7.52	-	25.21	35.56	62.86	35.99	-	134.41	3.55	3.81	3.55	-	10.91	0.139	0.001	0.003	-	0.030	-	0.116	0.001	0.001	-	0.025	-
2014 Ford Escape	GDI	3FTP	Confirmation	R5b	11/11/2014	CARB III LEV E-10	141111_1246_3FTP_FEsc_E99_R5b	25,876	34.12	58.66	34.33	-	127.11	6.40	11.16	7.48	-	25.05	35.56	62.90	36.03	-	134.50	3.55	3.78	3.55	-	10.88	0.153	0.002	0.006	-	0.034	-	0.125	0.002	0.003	-	0.028	-
2014 Ford Escape	GDI	3FTP	Confirmation	R6b	11/12/2014	CARB III LEV E-10	141112_0933_3FTP_FEsc_E99_R6b	25,894	34.37	58.99	34.46	-	127.82	6.56	11.21	7.53	-	25.29	35.81	63.23	36.16	-	135.21	3.57	3.81	3.54	-	10.92	0.125	0.001	0.006	-	0.028	-	0.100	0.001	0.003	-	0.022	-
2012 Honda Accord	PFI	4FTP	Confirmation	R1b	10/29/2014	CARB III LEV E-10	141029_1027_4FTP_HAcc_E99_R1b	32,930	32.17	55.00	32.08	54.93	174.18	6.95	11.84	8.40	11.14	38.33	34.19	58.47	34.56	59.17	186.39	3.58	3.79	3.57	3.80	14.74	0.064	0.000	0.001	0.00	0.014	0.014	0.057	0.001	0.001	0.00	0.013	0.013
2012 Honda Accord	PFI	4FTP	Confirmation	R2b	10/30/2014	CARB III LEV E-10	141030_1011_4FTP_HAcc_E99_R2b	32,953	31.99	54.78	31.97	54.73	173.47	6.91	10.93	8.41	11.50	37.75	34.01	58.26	34.45	58.98	185.70	3.55	3.82	3.56	3.82	14.76	0.064	0.000	0.001	0.00	0.013	0.013	0.056	0.001	0.001	0.00	0.012	0.012
2012 Honda Accord	PFI	4FTP	Confirmation	R3b	11/4/2014	CARB III LEV E-10	141104_0930_4FTP_HAcc_E99_R3b	33,023	31.25	53.44	32.03	54.76	171.48	6.81	10.83	8.37	11.57	37.58	33.27	56.92	34.51	59.01	183.71	3.58	3.85	3.57	3.81	14.82	0.062	0.000	0.002	0.00	0.013	0.014	0.056	0.002	0.001	0.00	0.013	0.013
2012 Honda Accord	PFI	4FTP	Confirmation	R4b	11/5/2014	CARB III LEV E-10	141105_1007_4FTP_HAcc_E99_R4b	33,051	32.13	54.98	32.16	54.95	174.22	7.01	11.20	8.50	11.62	38.33	34.15	58.46	34.63	59.19	186.43	3.57	3.82	3.55	3.81	14.75	0.038	0.000	0.002	0.00	0.008	0.009	0.035	0.001	0.001	0.00	0.008	0.008
2012 Honda Accord	PFI	4FTP	Confirmation	R5b	11/6/2014	CARB III LEV E-10	141106_0932_4FTP_HAcc_E99_R5b	33,089	32.03	54.84	32.02	54.78	173.67	6.91	11.11	8.49	11.63	38.14	34.05	58.31	34.50	59.03	185.88	3.57	3.82	3.57	3.81	14.77	0.075	0.000	0.001	0.00	0.016	0.016	0.066	0.001	0.001	0.00	0.014	0.014
2012 Honda Accord	PFI	4FTP	Confirmation	R6b	11/7/2014	CARB III LEV E-10	141107_0937_4FTP_HAcc_E99_R6b	33,127	31.80	54.43	31.95	54.67	172.85	6.79	10.97	8.47	11.61	37.83	33.83	57.90	34.43	58.92	185.07	3.57	3.81	3.55	3.78	14.71	0.081	0.000	0.001	0.00	0.017	0.017	0.072	0.001	0.001	0.00	0.015	0.015
2012 Honda Accord	PFI	4FTP	Confirmation	Eval	11/11/2014	CARB III LEV E-10	141111_1015_4FTP_HAcc_E99_Eval	33,196	31.76	54.40	31.84	54.48	172.48	6.97	10.98	8.22	11.37	37.53	33.79	57.87	34.32	58.73	184.70	3.57	3.81	3.57	3.80	14.75	0.052	0.000	0.002	0.00	0.011	0.011	0.047	0.001	0.001	0.00	0.010	0.010
2012 Honda Accord	PFI	4FTP	Confirmation	Eval	11/12/2014	CARB III LEV E-10	141112_1102_4FTP_HAcc_E99_Eval	33,227	31.76	54.42	31.81	54.48	172.47	6.77	10.90	8.21	11.48	37.36	33.79	57.88	34.29	58.73	184.69	3.59	3.81	3.55	3.81	14.76	0.062	0.000	0.002	0.00	0.013	0.013	0.056	0.001	0.001	0.00	0.012	0.012

[1] Run #1 (R1), Preliminary tests (not part of the main study by prep emission tests for evaluation and setup), evaluation (eval to verify current settings), R1b where "b" subscript represents the confirmation testing and no subscript represents the screening results.

Table E-5 FTP gaseous emissions, CVS volume, DF, miles (confirmation and screening): Part 4

FTP emission results E-99
aborted, invalid, evlauation test. Not used in the analysis of E-99 objectives
outlier results, but still used in the analysis.
Confirmation and Screening data

									CH4 Emissions (g/mile)						CO Emissions (g/mile)						NOx Emissions (g/mile)						CO2 Emissions (g/mile)						Fuel Economy (miles per gallon)						
Year/Make/Model	Type	Test	Task	Run	Date	Fuel Content	Test Name	Mileage	CH4-1	CH4-2	CH4-3	CH4-4	3CH4-W	4CH4-W	CO-1	CO-2	CO-3	CO-4	3CO-w	4CO-w	NOx-1	NOx-2	NOx-3	NOx-4	3NOx-w	4NOx-w	CO2-1	CO2-2	CO2-3	CO2-4	3CO2-w	4CO2-w	FE-1	FE-2	FE-3	FE-4	3Bag FE-w	4Bag FE-w	Driver
2012 Honda Accord	PFI	3FTP	Screening	Prelim1	11/5/2013	CARB III LEV E-10	131105_1431_FTP_HAcc_E99_Prelim1	31,219	0.005	0.000	0.001	-	0.001	-	0.393	0.082	0.154	-	0.167	-	0.023	0.000	0.009	-	0.007	-	335	328	287	-	318	-	25.8	26.3	30.1	-	27.1	-	Mark
2012 Honda Accord	PFI	3FTP	Screening	R1	11/14/2013	CARB III LEV E-10	131114_1612_3FTP_HAcc_E99_R1	31,245	0.007	0.000	0.001	-	0.002	-	0.319	0.045	0.095	-	0.116	-	0.035	0.002	0.007	-	0.010	-	329	328	282	-	316	-	26.2	26.3	30.6	-	27.3	-	Mark
2012 Honda Accord	PFI	3FTP	Screening	R2	11/15/2013	CARB III LEV E-10	131115_1342_3FTP_HAcc_E99_R2	31,256	0.008	0.000	0.001	-	0.002	-	0.414	0.070	0.058	-	0.138	-	0.021	0.001	0.003	-	0.006	-	323	317	273	-	306	-	26.7	27.3	31.6	-	28.2	-	Mark
2012 Honda Accord	PFI	3FTP	Screening	R3	11/20/2013	CARB III LEV E-10	131120_1353_3FTP_HAcc_E99_R3	31,346	0.008	0.001	0.002	-	0.003	-	0.375	0.067	0.113	-	0.145	-	0.017	0.000	0.003	-	0.005	-	321	317	281	-	308	-	26.8	27.3	30.7	-	28.1	-	Mark
2012 Honda Accord	PFI	3FTP	Screening	R4	11/21/2013	CARB III LEV E-10	131121_1546_3FTP_HAcc_E99_R4	31,356	0.010	0.000	0.002	-	0.003	-	0.377	0.068	0.082	-	0.136	-	0.022	0.000	0.003	-	0.005	-	322	315	266	-	303	-	26.7	27.4	32.4	-	28.5	-	Mark
2012 Honda Accord	PFI	3FTP	Screening	R5	11/22/2013	CARB III LEV E-10	131122_1006_3FTP_HAcc_E99_R5	31,367	0.009	0.002	0.002	-	0.003	-	0.420	0.073	0.062	-	0.142	-	0.017	0.000	0.004	-	0.005	-	316	300	265	-	294	-	27.3	28.8	32.6	-	29.4	-	Mark
2012 Honda Accord	PFI	4FTP	Screening	Fault1	11/26/2013	CARB III LEV E-10	131126_1538_4FTP_HAcc_E99_Fault1	31,386	0.008	0.000	0.001	0.000	0.002	0.002	0.341	0.062	0.056	0.061	0.118	0.118	0.018	0.000	0.003	0.000	0.005	0.005	319	306	263	296	297	294	27.0	28.2	32.8	29.2	29.1	29.4	Mark
2012 Honda Accord	PFI	4FTP	Screening	Fault2	11/27/2013	CARB III LEV E-10	131127_1327_4FTP_HAcc_E99_Fault2	31,400	0.007	0.000	0.001	0.001	0.002	0.002	0.360	0.053	0.084	0.075	0.125	0.132	0.023	0.001	0.009	0.000	0.007	0.007	334	329	286	307	318	312	25.8	26.3	30.2	28.1	27.1	27.7	Mark
2012 Honda Accord	PFI	4FTP	Screening	Fault3	12/4/2013	CARB III LEV E-10	131204_1226_4FTP_HAcc_E99_Fault3	31,431	0.009	0.000	0.001	0.000	0.002	0.002	0.502	0.060	0.054	0.056	0.150	0.149	0.026	0.000	0.002	0.001	0.006	0.006	331	320	273	298.165	309	303	26.0	27.0	31.6	28.958	27.9	28.484	Mark
2012 Honda Accord	PFI	4FTP	Screening	R6	1/14/2014	CARB III LEV E-10	140114_1359_4FTP_HAcc_E99_R6	31,502	0.007	0.000	0.001	0.001	0.002	0.002	0.406	0.059	0.125	0.080	0.149	0.156	0.018	0.000	0.004	0.000	0.005	0.005	334	321	283	311	313	310	25.8	26.9	30.5	27.8	27.5	27.8	Mark
2012 Honda Accord	PFI	4FTP	Screening	R7	1/15/2014	CARB III LEV E-10	140115_1140_4FTP_HAcc_E99_R7	31,156	0.008	0.000	0.000	0.000	0.002	0.002	0.429	0.055	0.105	0.076	0.146	0.153	0.025	0.001	0.003	0.001	0.006	0.006	341	322	281	310	315	311	25.2	26.8	30.7	27.8	27.4	27.7	Mark
2012 Honda Accord	PFI	4FTP	Screening	R8	1/16/2014	CARB III LEV E-10	140116_1446_4FTP_HAcc_E99_R8	31,531	0.007	0.000	0.000	0.000	0.001	0.001	0.414	0.068	0.081	0.074	0.143	0.145	0.022	0.000	0.006	0.000	0.006	0.007	344	334	285	318	322	318	25.1	25.9	30.3	27.2	26.8	27.2	Mark
2012 Honda Accord	PFI	3FTP	Screening	R9	1/17/2014	CARB III LEV E-10	140117_0924_3FTP_HAcc_E99_R9	31,546	0.011	0.000	0.001	-	0.002	-	0.460	0.070	0.051	-	0.144	-	0.027	0.000	0.004	-	0.007	-	338	303	231	-	290	-	25.5	28.5	37.3	-	29.7	-	Mark
2012 Honda Accord	PFI	3FTP	Screening	Outlier	1/24/2014	CARB III LEV E-10	140124_1405_3FTP_HAcc_E99_Outlier	31,572	0.008	0.000	0.001	-	0.002	-	0.462	0.079	0.163	-	0.182	-	0.024	0.000	0.002	-	0.006	-	333	318	274	-	309	-	25.9	27.1	31.5	-	27.9	-	Mark
2012 Honda Accord	PFI	3FTP	Screening	R10	1/28/2014	CARB III LEV E-10	140128_1538_3FTP_HAcc_E99_R10	31,590	0.009	0.000	0.001	-	0.002	-	0.452	0.048	0.051	-	0.133	-	0.020	0.000	0.003	-	0.005	-	342	332	286	-	321	-	25.2	26.0	30.2	-	26.9	-	Mark
2012 Honda Accord	PFI	3FTP	Screening	R11	1/29/2014	CARB III LEV E-10	140129_0845_3FTP_HAcc_E99_R11	31,601	0.009	0.000	0.001	-	0.002	-	0.318	0.083	0.089	-	0.133	-	0.020	0.000	0.004	-	0.005	-	349	340	284	-	326	-	24.7	25.4	30.4	-	26.5	-	Mark
2014 Ford Escape	GDI	3FTP	Screening	Prelim1	6/25/2014	CARB III LEV E-10	140625_1423_3FTP_FEsc_E99_Prelim1	25,298	0.029	0.000	0.003	-	0.007	-	1.592	0.274	0.298	-	0.554	-	0.039	0.005	0.015	-	0.015	-	350	333	311	-	331	-	24.5	25.9	27.8	-	26.1	-	Mark
2014 Ford Escape	GDI	3FTP	Screening	Prelim2	6/26/2014	CARB III LEV E-10	140626_1244_3FTP_FEsc_E99_Prelim2	25,309	0.026	0.000	0.003	-	0.006	-	1.280	0.300	0.349	-	0.516	-	0.031	0.012	0.015	-	0.017	-	350	333	311	-	330	-	24.5	25.9	27.7	-	26.1	-	Mark
2014 Ford Escape	GDI	3FTP	Screening	Prelim3	6/27/2014	CARB III LEV E-10	140627_1344_3FTP_FEsc_E99_Prelim3	25,320	0.027	0.000	0.003	-	0.006	-	1.357	0.243	0.347	-	0.503	-	0.039	0.011	0.033	-	0.023	-	348	330	309	-	328	-	24.6	26.1	27.9	-	26.3	-	Mark
2014 Ford Escape	GDI	3FTP	Screening	R1	7/1/2014	CARB III LEV E-10	140701_1030_3FTP_FEsc_E99_R1	25,350	0.023	0.001	0.003	-	0.006	-	1.149	0.287	0.474	-	0.517	-	0.031	0.008	0.015	-	0.014	-	346	331	311	-	329	-	24.8	26.0	27.7	-	26.2	-	Mark
2014 Ford Escape	GDI	3FTP	Screening	R2	7/2/2014	CARB III LEV E-10	140702_1044_3FTP_FEsc_E99_R2	25,361	0.023	0.001	0.003	-	0.006	-	1.298	0.289	0.312	-	0.504	-	0.040	0.006	0.014	-	0.015	-	353	336	314	-	334	-	24.3	25.6	27.5	-	25.8	-	Mark
2014 Ford Escape	GDI	3FTP	Screening	R3	7/3/2014	CARB III LEV E-10	140703_1349_3FTP_FEsc_E99_R3	25,373	0.024	0.000	0.002	-	0.006	-	1.063	0.264	0.267	-	0.430	-	0.042	0.006	0.008	-	0.014	-	356	338	311	-	335	-	24.1	25.5	27.7	-	25.8	-	Mark
2014 Ford Escape	GDI	4FTP	Screening	R4	7/4/2014	CARB III LEV E-10	140704_1456_4FTP_FEsc_E99_R4	25,384	0.024	0.000	0.000	0.000	0.005	0.005	1.242	0.271	0.251	0.298	0.466	0.474	0.031	0.006	0.017	0.007	0.014	0.014	347	331	309	329	328	328	24.7	26.1	27.9	26.2	26.3	26.3	Mark
2014 Ford Escape	GDI	4FTP	Screening	R5	7/5/2014	CARB III LEV E-10	140705_1354_4FTP_FEsc_E99_R5	25,399	0.021	0.000	0.000	0.000	0.004	0.004	1.009	0.255	0.447	0.245	0.465	0.461	0.035	0.006	0.012	0.006	0.014	0.014	349	330	308	329	328	327	24.6	26.2	28.0	26.2	26.3	26.3	Mark
2014 Ford Escape	GDI	4FTP	Screening	R6	7/6/2014	CARB III LEV E-10	140706_1435_4FTP_FEsc_E99_R6	25,414	0.023	0.000	0.000	0.000	0.005	0.005	1.109	0.242	0.385	0.267	0.461	0.469	0.032	0.006	0.040	0.006	0.021	0.021	347	328	306	328	326	326	24.7	26.3	28.2	26.3	26.4	26.4	Mark
2014 Ford Escape	GDI	4FTP	Screening	Outlier	7/19/2014	CARB III LEV E-10	140719_1448_4FTP_FEsc_E99_Outlier	25,578	0.023	0.000	0.000	0.000	0.005	0.005	1.415	0.316	0.471	0.299	0.587	0.582	0.040	0.007	0.007	0.006	0.014	0.013	348	333	306	332	329	329	24.7	25.9	27.9	26.0	26.1	26.2	Mark
2014 Ford Escape	GDI	3FTP	Screening	R7	7/20/2014	CARB III LEV E-10	140720_1755_3FTP_FEsc_E99_R7	25,593	0.023	0.000	0.002	-	0.005	-	1.314	0.279	0.358	-	0.516	-	0.032	0.005	0.046	-	0.022	-	350	330	307	-	328	-	24.5	26.1	28.0	-	26.3	-	Mark
2014 Ford Escape	GDI	3FTP	Screening	R8	7/21/2014	CARB III LEV E-10	140721_1156_3FTP_FEsc_E99_R8	25,604	0.023	0.000	0.002	-	0.005	-	1.515	0.299	0.334	-	0.561	-	0.029	0.005	0.007	-	0.011	-	349	334	308	-	330	-	24.6	25.8	28.0	-	26.1	-	Mark
2014 Ford Escape	GDI	3FTP	Screening	R9	7/22/2014	CARB III LEV E-10	140722_1359_3FTP_FEsc_E99_R9	25,615	0.023	0.000	0.002	-	0.005	-	1.177	0.281	0.473	-	0.520	-	0.026	0.005	0.014	-	0.012	-	350	337	309	-	332	-	24.5	25.6	27.8	-	25.9	-	Mark
2014 Ford Escape	GDI	3FTP	Screening	Eval	7/13/2014	CARB III LEV E-10	140713_1443_3FTP_FEsc_E99_Eval	25,528	0.024	0.000	0.002	-	0.006	-	1.581	0.292	0.381	-	0.584	-	0.032	0.006	0.007	-	0.012	-	318	306	284	-	302	-	26.9	28.2	30.4	-	28.5	-	Mark
2014 Ford Escape	GDI	3FTP	Confirmation	R1b	11/4/2014	CARB III LEV E-10	141104_1310_3FTP_FEsc_E99_R1b	25,763	0.026	0.000	0.002	-	0.006	-	1.739	0.323	0.583	-	0.689	-	0.045	0.005	0.008	-	0.014	-	360	342	316	-	338	-	23.8	25.2	27.2	-	25.4	-	Mark
2014 Ford Escape	GDI	3FTP	Confirmation	R2b	11/5/2014	CARB III LEV E-10	141105_1529_3FTP_FEsc_E99_R2b	25,804	0.026	0.000	0.002	-	0.006	-	1.623	0.339	0.244	-	0.579	-	0.041	0.005	0.004	-	0.012	-	358	339	319	-	337	-	24.0	25.4	27.0	-	25.5	-	Mark
2014 Ford Escape	GDI	3FTP	Confirmation	R3b	11/6/2014	CARB III LEV E-10	141106_1331_3FTP_FEsc_E99_R3b	25,838	0.026	0.000	0.000	-	0.005	-	1.316	0.328	0.267	-	0.517	-	0.040	0.006	0.004	-	0.012	-	365	339	315	-	338	-	23.5	25.4	27.4	-	25.5	-	Mark
2014 Ford Escape	GDI	3FTP	Confirmation	R4b	11/7/2014	CARB III LEV E-10	141107_1346_3FTP_FEsc_E99_R4b	25,857	0.027	0.000	0.002	-	0.006	-	1.695	0.374	0.795	-	0.764	-	0.042	0.005	0.014	-	0.015	-	365	343	318	-	341	-	23.5	25.1	27.1	-	25.3	-	Mark
2014 Ford Escape	GDI	3FTP	Confirmation	R5b	11/11/2014	CARB III LEV E-10	141111_1246_3FTP_FEsc_E99_R5b	25,876	0.032	0.000	0.003	-	0.008	-	1.800	0.379	0.709	-	0.766	-	0.040	0.005	0.014	-	0.015	-	368	348	320	-	344	-	23.2	24.8	26.9	-	25.0	-	Mark
2014 Ford Escape	GDI	3FTP	Confirmation	R6b	11/12/2014	CARB III LEV E-10	141112_0933_3FTP_FEsc_E99_R6b	25,894	0.029	0.000	0.003	-	0.007	-	1.464	0.371	0.515	-	0.638	-	0.040	0.006	0.012	-	0.014	-	361	345	320	-	342	-	23.7	25.0	26.9	-	25.2	-	Mark
2012 Honda Accord	PFI	4FTP	Confirmation	R1b	10/29/2014	CARB III LEV E-10	141029_1027_4FTP_HAcc_E99_R1b	32,930	0.008	0.000	0.000	0.00	0.002	0.002	0.385	0.062	0.092	0.16	0.138	0.167	0.017	0.001	0.002	0.00	0.004	0.004	325	302	271	325	299	305	26.5	28.6	31.8	26.5	28.9	28.3	Mark
2012 Honda Accord	PFI	4FTP	Confirmation	R2b	10/30/2014	CARB III LEV E-10	141030_1011_4FTP_HAcc_E99_R2b	32,953	0.009	0.000	0.000	0.00	0.002	0.002	0.431	0.079	0.074	0.08	0.151	0.150	0.014	0.000	0.003	0.00	0.004	0.004	327	325	271	312	310	307	26.3	26.6	31.9	27.7	27.8	28.1	Mark
2012 Honda Accord	PFI	4FTP	Confirmation	R3b	11/4/2014	CARB III LEV E-10	141104_0930_4FTP_HAcc_E99_R3b	33,023	0.007	0.000	0.000	0.00	0.001	0.001	0.395	0.104	0.142	0.08	0.175	0.167	0.021	0.000	0.005	0.00	0.006	0.006	323	319	272	312	307	305	26.7	27.0	31.7	27.7	28.1	28.3	Mark
2012 Honda Accord	PFI	4FTP	Confirmation	R4b	11/5/2014	CARB III LEV E-10	141105_1007_4FTP_HAcc_E99_R4b	33,051	0.004	0.000	0.000	0.00	0.001	0.001	0.399	0.143	0.065	0.08	0.175	0.156	0.020	0.000	0.007	0.00	0.006	0.006	323	319	271	312	307	304	26.7	27.0	31.9	27.7	28.1	28.3	Mark
2012 Honda Accord	PFI	4FTP	Confirmation	R5b	11/6/2014	CARB III LEV E-10	141106_0932_4FTP_HAcc_E99_R5b	33,089	0.010	0.000	0.000	0.00	0.002	0.002	0.437	0.142	0.096	0.06	0.191	0.167	0.028	0.000	0.005	0.00	0.007	0.007	327	320	268	310	307	304	26.4	26.9	32.2	27.9	28.1	28.4	Mark
2012 Honda Accord	PFI	4FTP	Confirmation	R6b	11/7/2014	CARB III LEV E-10	141107_0937_4FTP_HAcc_E99_R6b	33,127	0.010	0.000	0.000	0.00	0.002	0.002	0.421	0.064	0.079	0.08	0.142	0.147	0.020	0.000	0.005	0.00	0.006	0.006	330	323	270	313	310	307	26.1	26.7	32.0	27.6	27.8	28.1	Mark
2012 Honda Accord	PFI	4FTP	Confirmation	Eval	11/11/2014	CARB III LEV E-10	141111_1015_4FTP_HAcc_E99_Eval	33,196	0.006	0.000	0.000	0.00	0.001	0.001	0.378	0.087	0.100	0.07	0.151	0.146	0.018	0.000	0.004	0.00	0.005	0.005	322	323	276	317	310	308	26.8	26.7	31.3	27.2	27.8	28.0	Mark
2012 Honda Accord	PFI	4FTP	Confirmation	Eval	11/12/2014	CARB III LEV E-10	141112_1102_4FTP_HAcc_E99_Eval	33,227	0.007	0.000	0.000	0.00	0.002	0.002	0.336	0.059	0.092	0.08	0.126	0.132	0.015	0.000	0.003	0.00	0.004	0.004	330	326	277	314	313	310	26.2	26.5	31.1	27.5	27.6	27.9	Mark

[1] Run #1 (R1), Preliminary tests (not part of the main study by prep emission tests for evaluation and setup), evaluation (eval to verify current settings), R1b where "b" subscript represents the confirmation testing and no subscript represents the screening results.

Table E-6 USO6 emissions, PM and test configuration data (confirmation and screening)

US06 emission results E-99
aborted, invalid, evlauation test. Not used in the analysis of E-99 objectives
outlier results, but still used in the analysis.
Confirmation and Screening data

											Gaseous Emissions (g/mile)							Particulate Emissions mg/mile												NET Filter Weights (mg/filter)					PM Probe Accumulated Volumes (L)					
Year/Make/Model	Type	Test	Test Phase	Run	Date	Mileage	Vmix (m^3) not corr for Instr. Flow	Dilution Factor	Corr Vmix (m^3)	Mileage (miles)	THC	NMHC	CH4	CO	NOx	CO2	F.E. (mpg)	EC+OC	EC	OC	A	B	C	Dt_100	PFSS_C (CO2)	PFSS_Q (Flow)	MSS	Driver	Pre conditions	A	B	C	D	PFSS	A	B	C	D	PFSS_Tot_Gtotal	PFSS_Tot_Gprob
2012 Honda Accord	PFI	US06	Screening	R1	11/18/2013	31,298	65.17	6.79	68.47	7.98	0.023	0.019	0.005	1.065	0.012	298	28.8	-	-	-	1.52	1.45	1.73	1.41	1.43	1.26	0.65	Kurt	FTP, US06 prep, 5 min soak, US06 test 1	0.190	0.149	0.119	0.080	0.088	1104	898	595	480	608	84
2012 Honda Accord	PFI	US06	Screening	R2	11/18/2013	31,311	65.29	6.80	68.59	7.98	0.028	0.016	0.014	1.444	0.021	304	28.2	-	-	-	0.88	0.80	0.97	1.00	0.78	0.69	0.29	Kurt	US06 test 1, 5 min soak, US06 test 2	0.113	0.084	0.069	0.058	0.068	1104	898	595	480	608	119
2012 Honda Accord	PFI	US06	Screening	R3	11/18/2013	31,322	65.17	6.84	68.47	7.96	0.023	0.011	0.014	1.032	0.013	303	28.3	-	-	-	0.84	0.78	0.85	0.80	0.56	0.49	0.26	Kurt	US06 test 2, 5 min soak, US06 test 3	0.107	0.082	0.060	0.047	0.080	1104	898	595	480	608	197
2012 Honda Accord	PFI	US06	Screening	R4	3/26/2014	31,693	37.90	3.91	41.21	7.98	0.011	0.009	0.003	0.006	0.638	316	27.2	-	-	-	0.38	0.29	0.32	0.25	-	-	-	Mark	FTP, US06 prep, 5 min soak, US06 test 1	0.086	0.055	0.042	0.028	0.000	1105	896	595	480	-	-
2012 Honda Accord	PFI	US06	Screening	R5	3/26/2014	31,701	37.87	3.92	41.18	7.98	0.009	0.007	0.002	0.006	0.853	315	27.3	-	-	-	0.18	0.15	0.21	0.11	-	-	-	Mark	US06 test 1, 5 min soak, US06 test 2	0.043	0.032	0.029	0.016	0.000	1104	898	595	480	-	-
2012 Honda Accord	PFI	US06	Screening	R6	3/26/2014	31,709	37.90	4.05	41.21	7.98	0.009	0.008	0.002	0.004	0.502	305	28.3	-	-	-	0.12	0.16	0.18	0.08	-	-	-	Mark	US06 test 2, 5 min soak, US06 test 3	0.031	0.034	0.025	0.013	0.000	1104	898	595	480	-	-
2014 Ford Escape	GDI	US06	Screening	R1	7/10/2014	25,453	93.12	7.17	96.07	7.98	0.011	0.005	0.008	3.159	0.058	393	21.7	0.890	0.440	0.281	1.05	0.91	0.94	1.05	1.33	1.17	0.51	Mark	FTP, US06 prep, 5 min soak, US06 test	0.082	0.062	0.051	0.047	0.037	882	754	595	480	608	74
2014 Ford Escape	GDI	US06	Screening	R2	7/12/2014	25,501	93.23	6.74	96.18	7.97	0.032	0.015	0.019	8.324	0.124	412	20.3	0.982	0.583	0.249	1.05	1.00	0.95	1.04	1.25	1.10	0.70	Mark	US06 prep, 5 min soak, US06 test	0.082	0.068	0.052	0.047	0.108	882	754	595	480	608	238
2014 Ford Escape	GDI	US06	Screening	R3	7/14/2014	25,539	93.17	6.96	96.12	7.98	0.033	0.018	0.017	5.689	0.067	402	21.0	0.986	0.419	0.355	0.75	0.60	0.63	0.71	0.95	0.83	0.42	Mark	US06 prep, 5 min soak, US06 test	0.060	0.043	0.036	0.033	0.048	882	754	595	480	608	136
2014 Ford Escape	GDI	US06	Screening	R4	7/22/2014	25,626	93.73	6.91	96.67	7.98	0.052	0.035	0.020	4.019	0.250	409	20.8	2.410	1.355	0.659	2.97	2.87	2.82	3.26	3.30	2.90	1.41	Mark	FTP, US06 prep, 5 min soak, US06 test	0.221	0.183	0.144	0.135	0.202	882	748	595	480	911	168
2014 Ford Escape	GDI	US06	Screening	R5	7/22/2014	25,635	93.06	6.78	96.01	7.99	0.023	0.008	0.017	6.425	0.074	411	20.5	1.304	0.629	0.422	1.35	1.33	1.07	1.40	1.38	1.21	0.69	Mark	US06 prep, 5 min soak, US06 test	0.104	0.088	0.058	0.061	0.119	882	748	595	480	912	228
2014 Ford Escape	GDI	US06	Screening	R6	7/23/2014	25,643	93.91	7.11	96.86	7.99	0.024	0.011	0.016	6.549	0.058	394	21.3	0.894	0.450	0.278	0.65	0.63	0.62	0.59	0.95	0.84	0.51	Mark	US06 prep, 5 min soak, US06 test	0.052	0.044	0.035	0.028	0.137	882	748	595	480	905	372
2012 Honda Accord	PFI	US06	Confirmation	7	10/29/2014	32,930	35.34	3.55	38.28	7.99	0.019	0.013	0.007	4.173	0.006	317	26.7	-	-	-	0.54	0.49	0.56	0.40	0.53	0.47	0.16	Mark	US06 prep, 5 min soak, US06 test	0.104	0.082	0.075	0.052	0.068	877	750	595	565	912	203
2012 Honda Accord	PFI	US06	Confirmation	Invalid	10/30/2014	32,968	61.23	6.17	64.14	7.98	0.018	0.012	0.006	4.242	0.006	302	27.8	-	-	-	-0.03	1.44	1.53	1.60	1.38	1.21	0.18	Mark	US06 prep, 5 min soak, US06 test	0.001	0.137	0.118	0.117	0.174	861	735	595	565	912	200
2012 Honda Accord	PFI	US06	Confirmation	R1b	11/5/2014	33,066	63.63	6.74	66.57	7.97	0.010	0.008	0.003	1.641	0.006	292	29.3	-	-	-	0.18	0.17	0.21	0.18	0.22	0.19	0.13	Mark	4FTP, US06 prep, 1.5 min soak, US06 test	0.024	0.021	0.020	0.017	0.028	880	753	595	565	912	190
2012 Honda Accord	PFI	US06	Confirmation	R2b	11/6/2014	33,104	63.51	6.74	66.45	7.98	0.009	0.007	0.002	1.456	0.005	291	29.4	-	-	-	0.21	0.18	0.19	0.12	0.23	0.20	0.13	Mark	4FTP, US06 prep, 1.5 min soak, US06 test	0.027	0.021	0.019	0.013	0.030	879	751	595	565	912	188
2012 Honda Accord	PFI	US06	Confirmation	R3b	11/7/2014	33,142	63.40	6.63	66.34	7.97	0.011	0.009	0.003	1.195	0.005	297	28.9	-	-	-	0.20	0.28	0.24	0.26	0.22	0.19	0.12	Mark	4FTP, US06 prep, 1.5 min soak, US06 test	0.026	0.030	0.022	0.023	0.029	876	748	595	565	912	192
2012 Honda Accord	PFI	US06	Confirmation	R4b	11/10/2014	33,173	63.17	6.61	66.11	7.97	0.009	0.007	0.003	0.402	0.006	297	29.0	-	-	-	0.26	0.25	0.20	0.20	0.20	0.17	0.12	Mark	4FTP, US06 prep, 1.5 min soak, US06 test	0.032	0.027	0.019	0.018	0.026	875	748	595	565	912	179
2012 Honda Accord	PFI	US06	Confirmation	R5b	11/11/2014	33,211	63.64	6.79	66.59	7.96	0.012	0.010	0.003	0.375	0.006	292	29.5	-	-	-	0.30	0.24	0.27	0.24	0.26	0.23	0.11	Mark	4FTP, US06 prep, 1.5 min soak, US06 test	0.035	0.026	0.024	0.021	0.034	880	753	595	565	912	179
2012 Honda Accord	PFI	US06	Confirmation	R6b	11/12/2014	33,242	63.53	6.71	66.47	7.97	0.012	0.010	0.003	0.766	0.006	294	29.2	-	-	-	0.24	0.17	0.12	0.10	0.24	0.21	0.11	Mark	4FTP, US06 prep, 1.5 min soak, US06 test	0.029	0.020	0.013	0.012	0.031	876	749	595	565	912	181
2012 Honda Accord	PFI	US06	Confirmation	Eval	11/21/2014	33,272	63.53	6.89	63.53	7.97	0.010	0.008	0.002	0.680	0.007	274	31.4	0.434	0.131	0.190	0.24	0.13	0.19	0.14	-	-	-	Mark	4FTP, US06 prep, 1.5 min soak, US06 test	0.025	0.011	0.013	0.010	-	862	738	592	564	-	-
2014 Ford Escape	GDI	US06	Confirmation	overheat	10/28/2014	25,689	85.15	6.03	85.15	7.81	0.155	0.068	0.100	34.604	0.071	375	20.1	-	-	-								Mark	US06 prep, 1.5 min soak, US06 test											
2014 Ford Escape	GDI	US06	Confirmation	overheat	11/3/2014	25,739	89.64	5.71	92.59	7.95	0.205	0.093	0.130	41.671	0.072	420	17.8	-	-	-	2.62	2.04	2.22	2.31	2.86	2.51	1.05	Mark	US06 prep, 1.5 min soak, US06 test	0.203	0.137	0.118	0.117	0.174	882	754	595	565	911	201
2014 Ford Escape	GDI	US06	Confirmation	overheat	11/5/2014	25,815	91.45	5.67	94.39	7.90	0.191	0.095	0.111	32.396	0.165	451	17.2	-	-	-	1.93	1.91	2.01	1.90	2.64	2.32	1.18	Mark	US06 prep, 5 min soak, US06 test	0.147	0.125	0.105	0.095	0.160	880	754	595	565	912	202

[1] Run #1 (R1), Preliminary tests (not part of the main study by prep emission tests for evaluation and setup), evaluation (eval to verify current settings), R1b where "b" subscript represents the confirmation testing and no subscript represents the screening results. The MSS had a zero drift during usage of two different MSS units utilized. The data were corrected for the zero drift. The MSS values are as reported and the MSS(BL) data are the relative PM emission rate for the MSS zero offset in mg/mi. The MSS data reported are corrected for the blank value. The Ford Escape GDI US06 Rxb tests were aborted due to overheating during the test cycle and an inability to maintain the target speed. Discussions with the E-99 Panel produced a recommendation to stop testing on the US06 cycles to prevent further problems with this GDI vehicle. Therefore only three GDI US06 tests were performed.

Table E-7 GDI summary of emissions

				Weighted Average Emissions							Weighted Standard Deviation						
				Gaseous (g/mile)						mpg	Gaseous (g/mile)						mpg
Year/Make/Model	Type	Test	Fuel Content	THC	NMHC	CH_4	CO	NO_x	CO_2	FE	THC	NMHC	CH_4	CO	NO_x	CO_2	FE
2014 Ford Escape	GDI	3FTP	CARB III LEV E-10	0.018	0.014	0.005	0.452	0.014	307	28.1	0.002	0.002	0.000	0.047	0.001	1.681	0.154
2014 Ford Escape	GDI	4FTP	CARB III LEV E-10	0.017	0.013	0.004	0.432	0.015	301	28.6	0.002	0.002	0.000	0.008	0.003	3.554	0.340
2014 Ford Escape	GDI	3FTP	CARB III LEV E-10	0.022	0.018	0.005	0.495	0.014	303	28.4	0.004	0.004	0.000	0.025	0.006	1.715	0.162
2014 Ford Escape	GDI	US06	CARB III LEV E-10	0.028	0.014	0.016	5.069	0.129	386	21.9	0.013	0.011	0.004	1.842	0.088	7.940	0.490
2014 Ford Escape	GDI	3FTPb	CARB III LEV E-10	0.027	0.022	0.006	0.614	0.013	314	27.5	0.003	0.003	0.001	0.094	0.001	2.412	0.220

[1] The 3-bag FTP is denoted as 3FTP, 4-bag as 4FTP and the confirmation results are denoted as subscript "b".

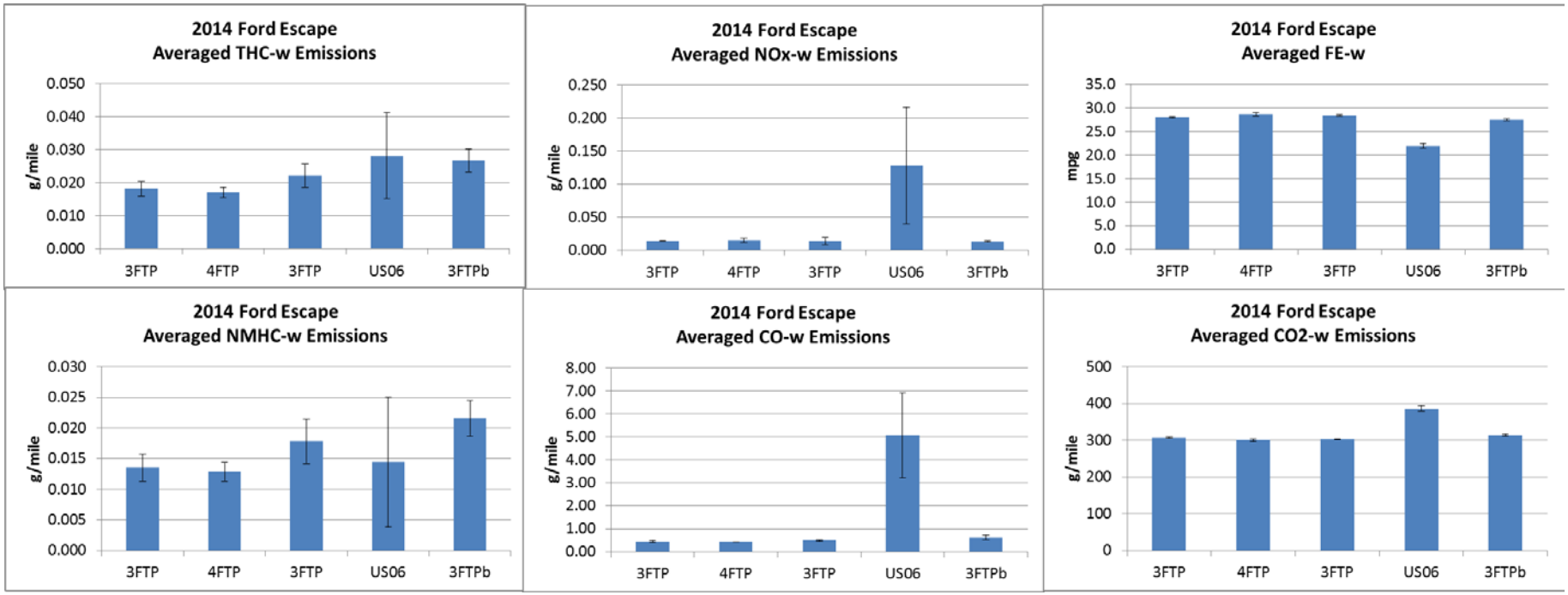

Figure E-1 GDI average and single standard deviation error bar summary figures

Table E-8 PFI summary of emissions

				Weighted Average Emissions							Weighted Standard Deviation						
				Gaseous (g/mile)						mpg	Gaseous (g/mile)						mpg
Year/Make/Model	Type	Test	Fuel Content	THC	NMHC	CH_4	CO	NO_x	CO_2	FE	THC	NMHC	CH_4	CO	NO_x	CO_2	FE
2012 Honda Accord	PFI	3FTP	CARB III LEV E-10	0.015	0.013	0.002	0.127	0.006	281	31.1	0.001	0.001	0.001	0.011	0.002	8.50	0.939
2012 Honda Accord	PFI	4FTP	CARB III LEV E-10	0.014	0.013	0.001	0.138	0.005	285	30.7	0.003	0.003	0.000	0.006	0.001	1.64	0.175
2012 Honda Accord	PFI	3FTP	CARB III LEV E-10	0.017	0.015	0.002	0.127	0.006	284	30.7	0.001	0.001	0.000	0.007	0.001	15.80	1.742
2012 Honda Accord	PFI	US06	CARB III LEV E-10	0.012	0.010	0.003	0.857	0.010	283	30.7	0.005	0.004	0.001	0.319	0.006	5.59	0.578
2012 Honda Accord	PFI	4FTPb	CARB III LEV E-10	0.013	0.011	0.002	0.145	0.005	277	31.1	0.003	0.002	0.000	0.008	0.001	1.03	0.115
2012 Honda Accord	PFI	US06b	CARB III LEV E-10	0.010	0.008	0.003	0.913	0.005	276	31.2	0.001	0.001	0.000	0.506	0.000	2.28	0.235

[1] The 3-bag FTP is denoted as 3FTP, 4-bag as 4FTP and the confirmation results are denoted as subscript "b".

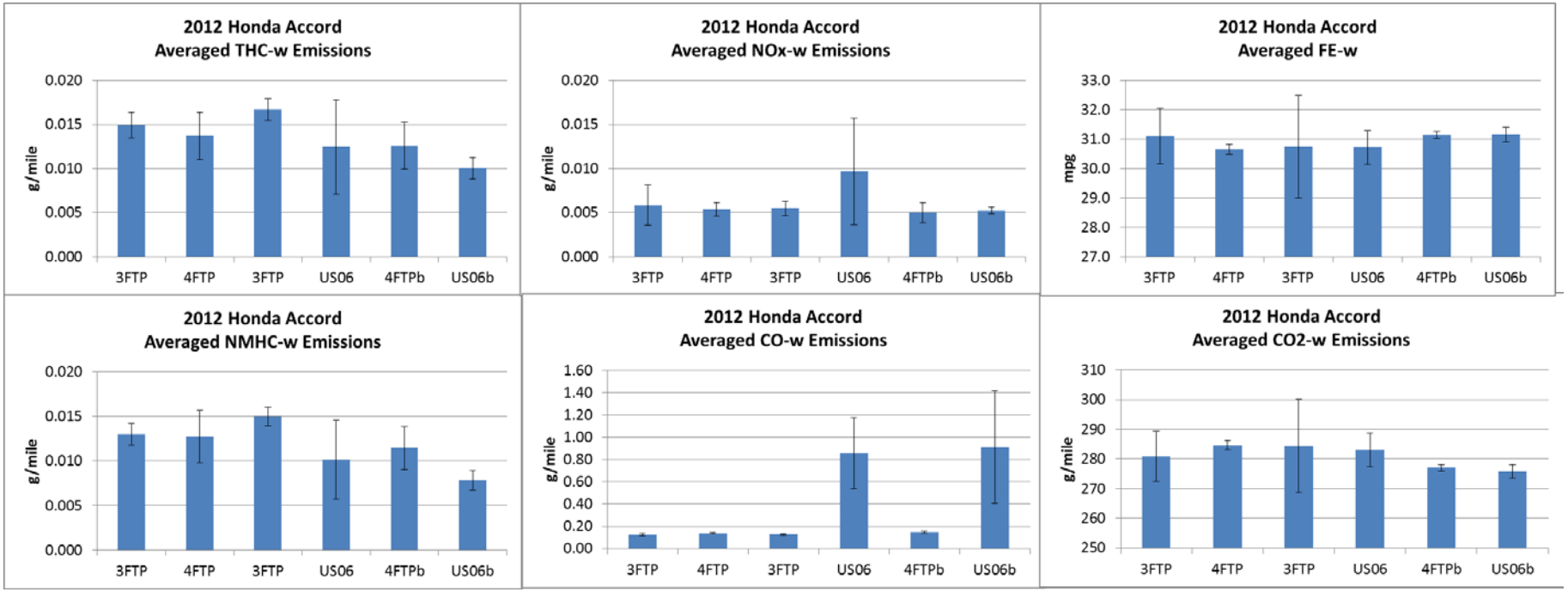

Figure E-2 PFI average and single standard deviation error bar summary figures

Appendix F. Additional filter survey information

Outlier exclusions

This section discusses a few outliers, their sources, and how they were accounted for in the reduction of the data. The point of this analysis was to consider a properly operating filter-weighing operation. Two examples are provided in this discussion. One is from Lab 3 and another is from Lab 4. Lab 1, Lab 2, and Lab 13 also had outliers that required similar investigations. It is expected the other data sets provided to UCR were filtered prior to their submission.

Data filtering, a necessary process for most measurement systems, is especially necessary for filter weighing. Data filtering was considered on a case-by-case basis. Not all laboratories provided the same level of data for the filter survey. A few laboratories provided raw and semi-raw filter data sets with a large history of results, as shown in Table 4-2 (Labs 1, 2, 3, and 4). The large data sets, while rich in information, needed to be evaluated carefully for outliers.

Figure F-1 shows the difference in variability for short-term replicate reference filter weights for 40 selected reference filters weighed on average 40 times each. A single outlier(identified as #31) showed a variability that was higher by a factor of 700 compared to other weighings in the data set (see Figure F-1). When the outlier was removed, the average variability for Lab 3b dropped from 100 µg to 2.0 µg. An analysis of the raw data shows that the #31 filter weight changed from 131 mg to over 141 mg just before it was retired (see Figure F-2). Reference filter #32 had a weight of 141 mg and was only 3 µg different from the last measurement of filter #31. It appears the filter ID between #31 and #32 may have been switched with the last weighing or there was a filter ID typo. In summary, the outlier filter weight did not represent normal operation and was discarded from the overall analysis.

Lab 4 showed two outliers out of a total of eleven filters. Figure F-3 shows the difference in variability for short-term replicate reference filter weights for 11 selected reference filters, weighed on average 109 times each. The variabilities for Filter #4 and #5 were over 25 times higher than the other reference filters. These points did not appear to represent normal weighing variability and were considered suspicious. The source of the variability was investigated further by plotting Filter #4's 109 individual filter weights as a function of time (see Figure F-4). The non-buoyance corrected filter weight was very stable, but the corrected value had a significant deviation on 7/12/2010. The correction factor is provided in Figure F-4 on the secondary y-axis. The correction factor shows that the correction value changed from 1.0004 to 1.00001 on 7/12. This correction shifted the standard deviation of the short-term difference variability from 24 µg to 5 µg if the outliers were removed. This real outlier would not be caught by the balance methods unless both the filter scale value and buoyance correction were checked in real-time. The outlier was removed since it does not represent best weighing operation practices, even though it may represent a real condition. The condition is fixable and was brought to the attention of Lab 4.

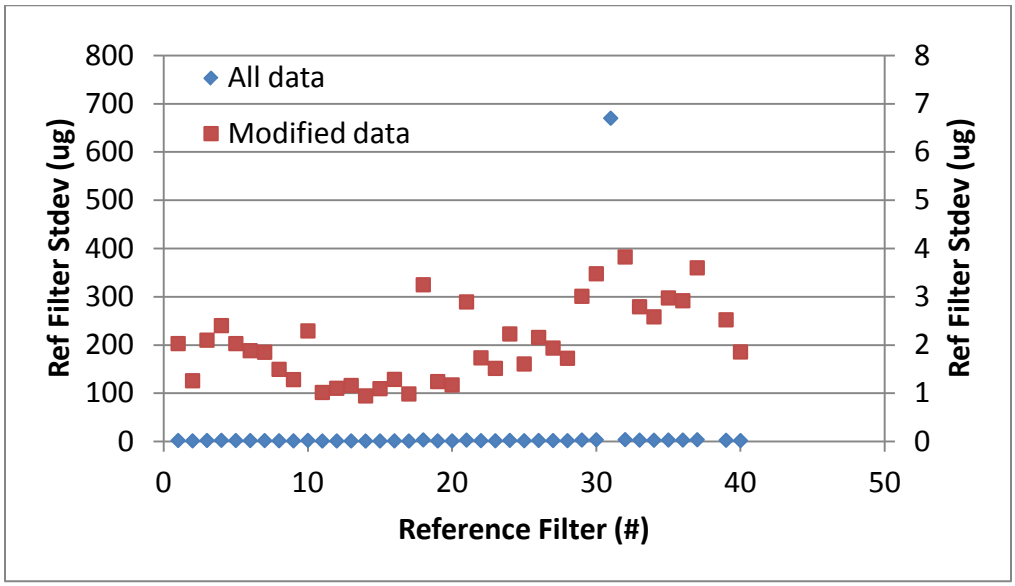

Figure F-1 Lab 3b unique reference filters provided where #31 appears to be an outlier

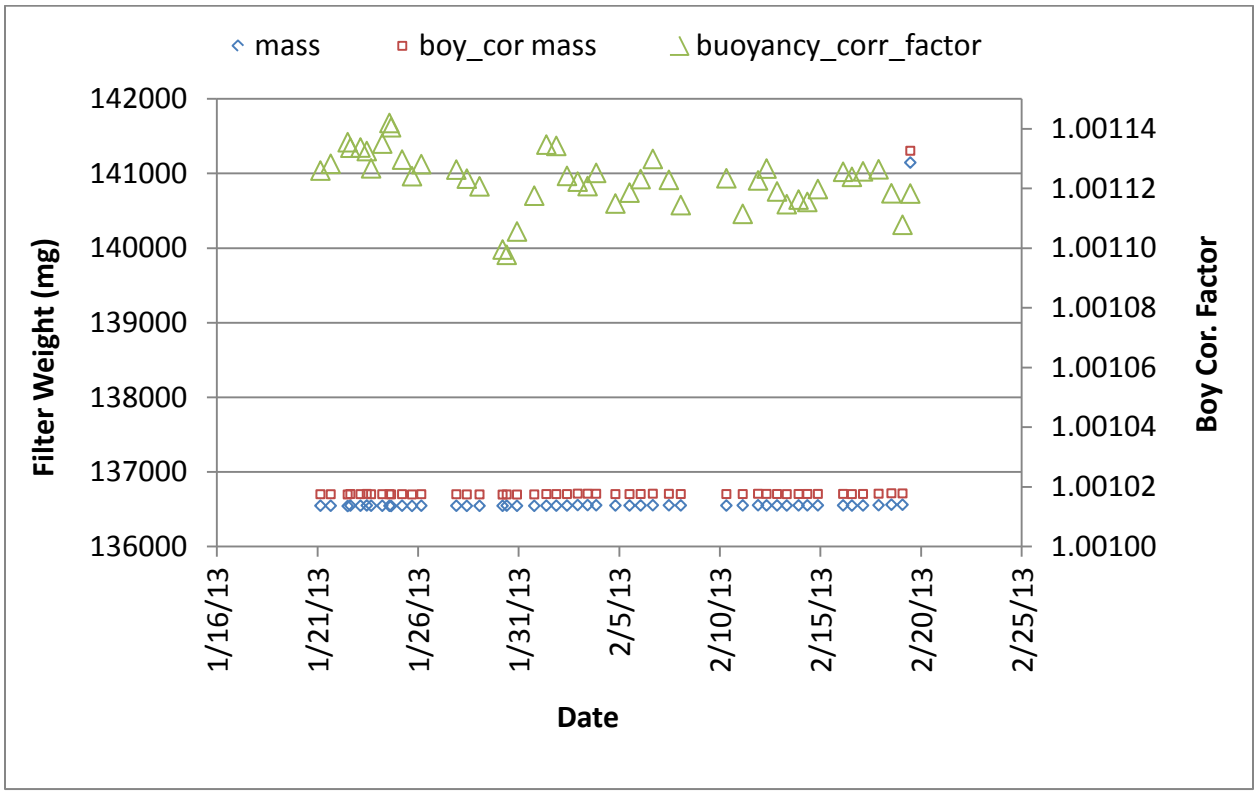

Figure F-2 Lab 3b shows an outlier for filter ID #31 sampled at the end of the sequence

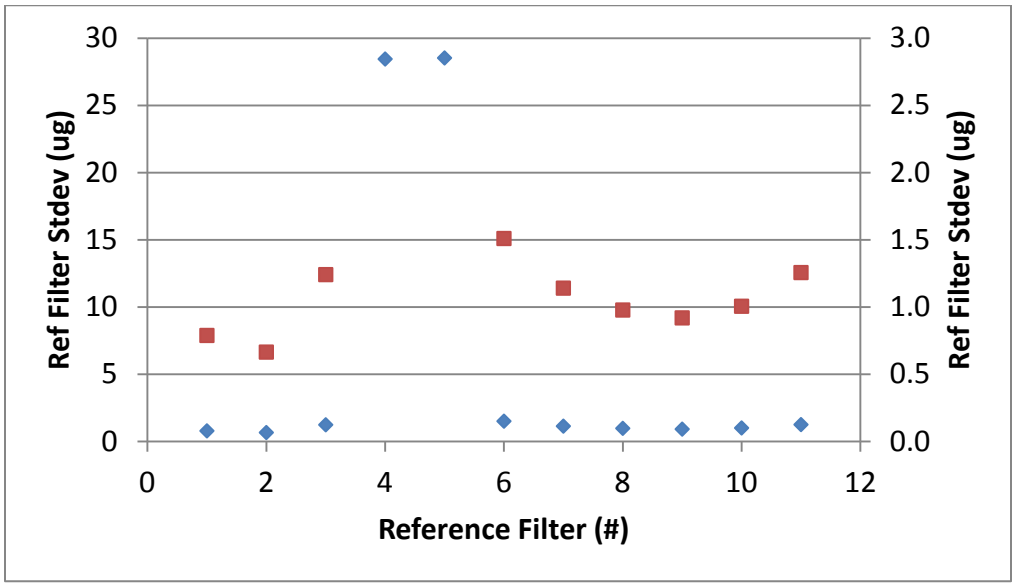

Figure F-3 Lab 4 reference filter standard deviation of difference measurements

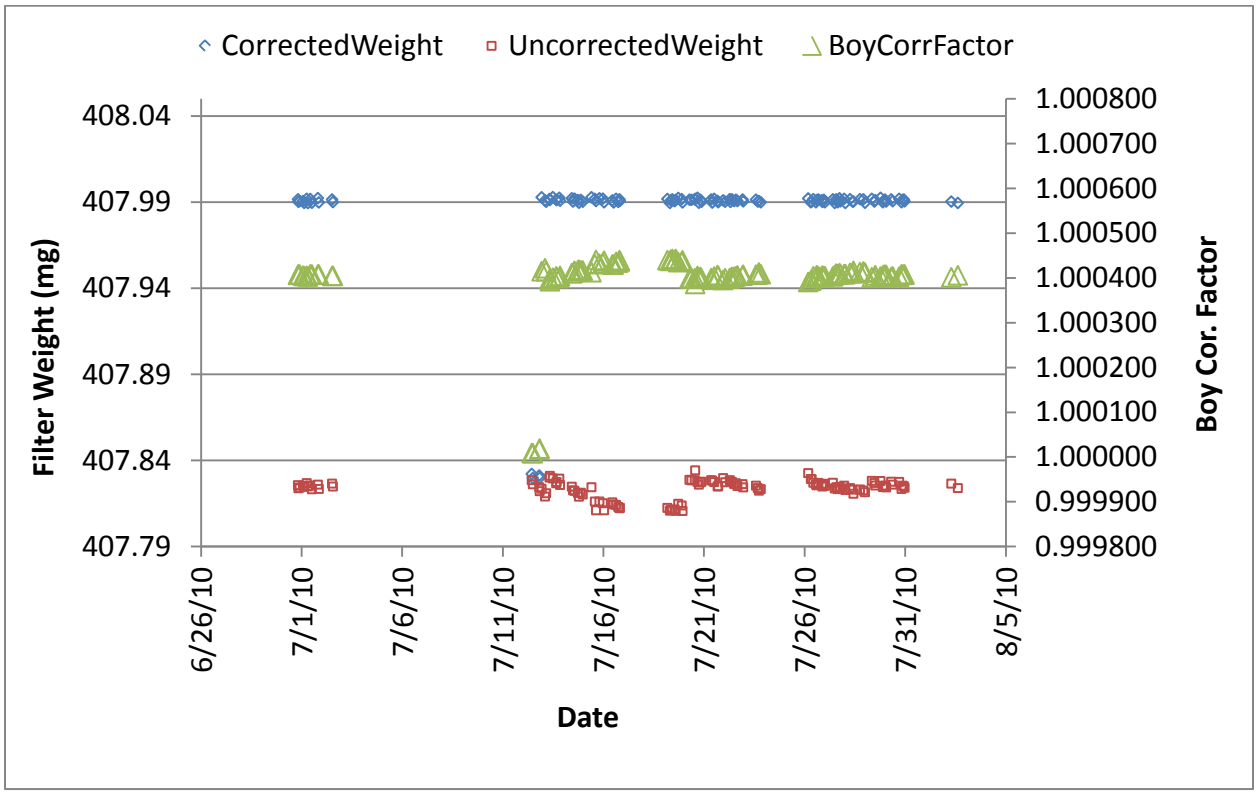

Figure F-4 Lab 4 reference filter weights and correction factors for #4

Static and dynamic blanks

A static filter is a filter that is exposed like a trip blank filter, but is also loaded and unloaded into the laboratory's sampling system. The difference between this filter and the tunnel blank is that no flow is pulled through the filter, as discussed previously. For the static blank data, only Labs 5, 12 and 13

provided data, representing a total of 59 filters with an average of 15 filters per laboratory. Dynamic blanks are loaded and left in the loader but never sampled on during the course of one or more tests. For the dynamic blank data, only Labs 12 and 13 provided data, representing a total of 16 filters with an average of 8 filters per laboratory. For both the static and dynamic blanks, only Teflon™ filter data were provided. This data set is very small and may not represent the true variability and weight gain of static and dynamic contamination sources.

Figure F-5 shows the static and dynamic filter data in one figure with error bars represented by one standard deviation. Due to the low sample size, the 90% confidence interval was similar to the single standard deviation. The percentile statistics are presented for the static and dynamic filters pooled together to increase the sample size. In general, the static filter weight gain was less than 5 µg and the dynamic QC filter showed a slightly higher weight gain. These differences are not statistically significant (at the 90% confidence interval (CI)) due the variability in the measurements.

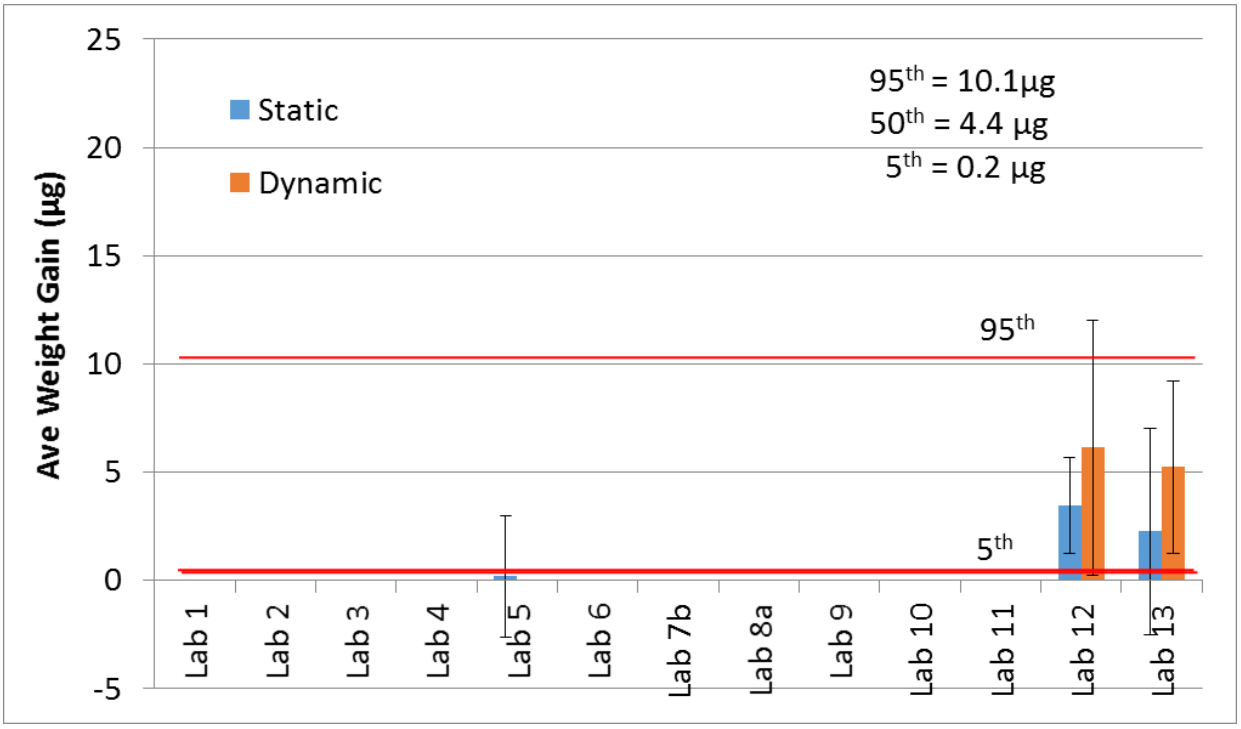

Figure F-5 Static and dynamic blank net difference for each laboratory

A trip blank filter is a filter that is exposed like a reference filter, but gets loaded into a cassette, travels to the laboratory, returns from the laboratory (without any laboratory handling), and is removed from the cassette and then weighed. Labs 1, 4, 6, 7, 9, 12 and 13 provided trip blank data. A total of 157 filters were available in this analysis with an average of 20 trip filters each from six laboratories. For the trip blank data, only Teflon™ filter data were provided to UCR.

Figure F-6 shows the average trip blank weight gain and 5th through 95th percentile statistics for the pooled data. The trip blank filters averaged 1.3 µg for the 50th percentile increases. The trip filter increases varied from -4.4 µg to +4.1 µg for the 5th and 95th percentile, respectively. It is interesting this QC filter was the only filter that showed a significant negative weight change. It is suspected that these trends would change with a larger data set and become positive. Additional analysis is needed to confirm these trip filter observations.

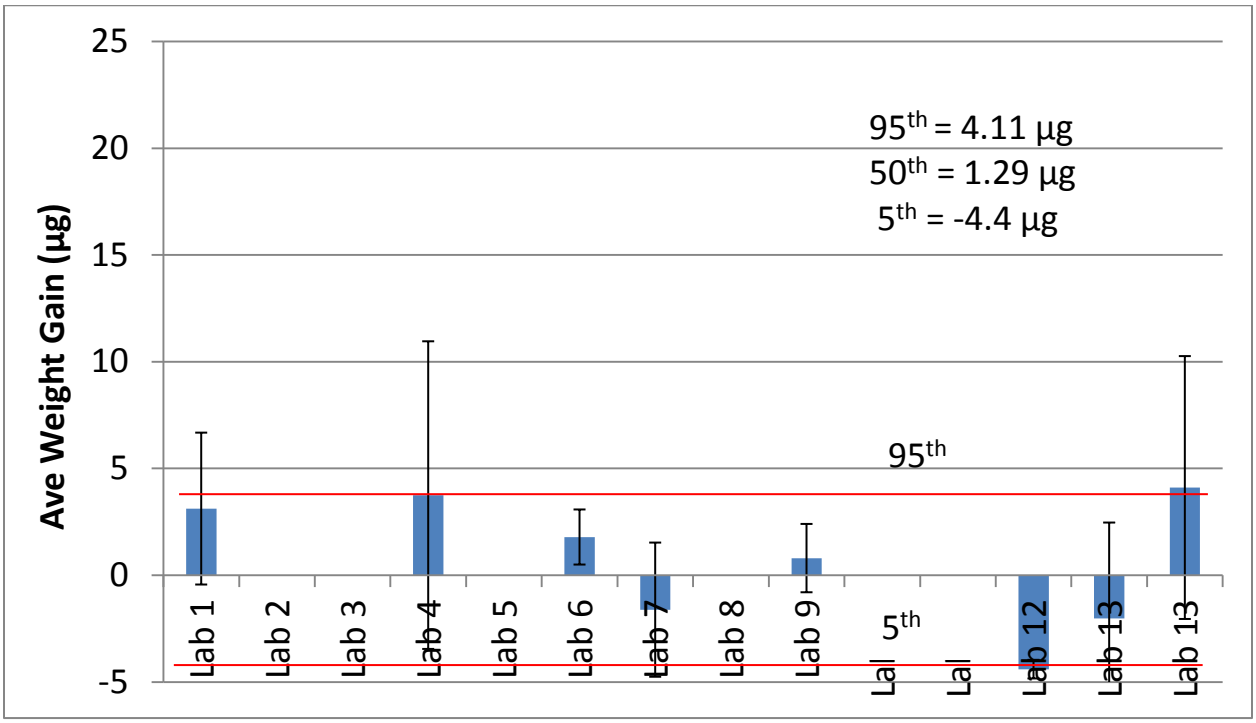

Figure F-6 Trip blank net difference for each laboratory

Appendix G. PFSS details and configurations

This appendix describes some special configuration details of the PFSS and the exhaust flow meter. The CO_2 of the PFSS was measured to verify its DF as described in Section 3. The sample for the CO_2 gaseous PEMS was connected to the CO_2 sample connection at the exit of the PFSS (see Figure G-1).

The PFSS used in the E-99 project has a "CO_2 sample port" that was utilized on limited tests during the screening portion of the test program. The "CO_2 sample port" allows a gaseous sample of the PFSS diluted sample (proportional to the exhaust) to be analyzed by a gaseous instrument such as a gaseous PEMS. The sample port is connected internally to the PFSS between the smooth approach venturi (SAO) G_{tot} measurement system and the vacuum pump venturi as shown in Figure G-1. This means the sample pressure inlet to the gaseous PEMS will be similar to the exit of the gravimetric filter. At high FFVs and nominal filter loading, accumulating PM from vehicles, will create a vacuum pressure > 5 inHg vacuum. These pressures are significantly higher than what a gaseous PEMS was designed for (positive pressure +0.5 inHg to -1 inHg typical) where error may results due to the much lower vacuum on the PEMS.

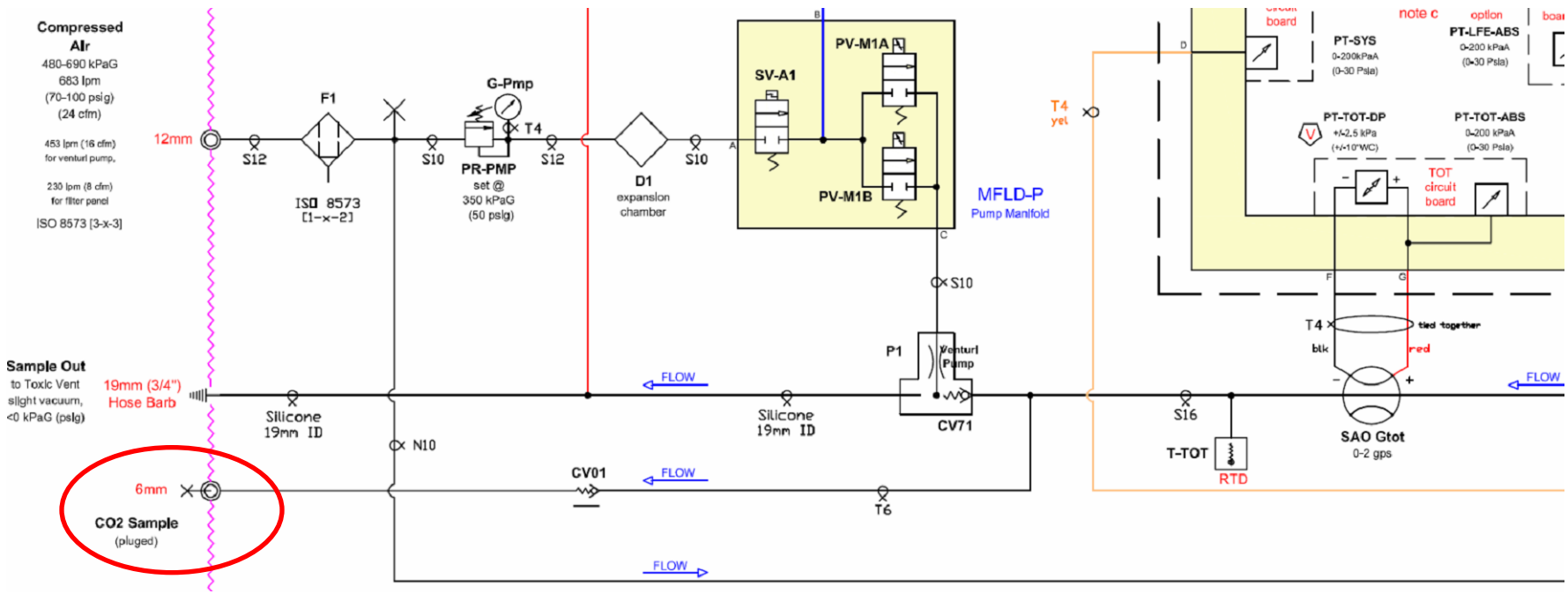

Figure G-1 Partial flow CO_2 sample port location (between venturi pump and post SAO Gtot)

Figure G-2 shows an available port on the PFSS that can be used for particle number assessment while still collecting PM mass with that flow. UCR tried this port, but was not comfortable with the results and thus stopped using it. Additional experience is needed to utilize this “add on” sample port.

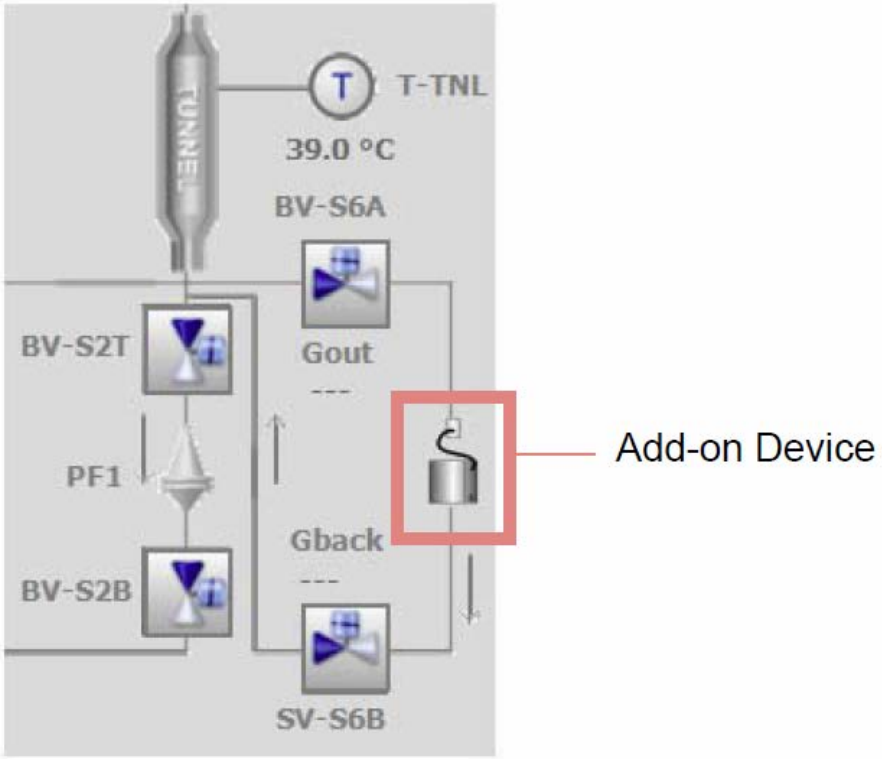

Figure G-2 Partial flow “add on” PM mass or number measurement location

Appendix H. Real-Time Instruments

Real-time PM mass measurements are useful to help understand gravimetric filter weight gains during transient testing. This is especially important for light filter loadings (< 50 µg). There are several instruments available for real-time PM mass measurements, but not all correlate well with the gravimetric mass filter. Maricq et al. [7] and Kirchner et al. [21] found good correlation between PM and PN from GDI emissions. They measured PM using a Dekati Mass Monitor (DMM) and an AVL micro soot sensor (MSS), respectively, and both PM and PN were sampled after hot dilution. Other studies have shown that PFI emissions include ~80% OC [22], while GDI emissions are known to be EC dominant. Tt is expected that the selected real-time instruments would be valuable in identifying filter outliers through the real-time data and trends with soot, OC and EC for the two vehicles.

A variety of real-time instruments were utilized for the two different phases of this study. These instruments were not available on all tests, but were utilized as available to help characterize and explain any excursions during testing. These instruments are described below, categorized by their sampling location.

A TSI 3776 condensation particle counter (CPC). This is a standard CPC with a lower size cut off with a d50 of 2.5 nm that is used for measuring particle number concentrations (The d50 is a cut off diameter of 50% efficiency at the specified diameter). This CPC was only used in the screening tests.

A TSI 3022 CPC. This is a standard CPC with a lower size cut off d50 of 7 nm used for measuring particle number concentrations. This CPC was only used in the confirmation tests.

AVL's 483 micro soot sensor (MSS) An AVL MSS was used to characterize the PM soot or the elemental carbon fraction of the PM mass in real time. The MSS measures the modulated laser light absorbed by particles from an acoustical microphone. This absorption has a strong correlation to the elemental carbon fraction in the exhaust and tends to provide information on the non-semivolatile composition of the PM in real time. This instrument is important since one of the main differences between GDIs and PFIs is the fraction of soot in the exhaust. This instrument was utilized for both the screening and confirmation phases of the testing.

An Engine Exhaust Particle Sizer (EEPS) - The EEPS measures the size distribution of engine-exhaust particle emissions in the range from 5.6 to 560 nm with a one second response time. It measures particle size distributions distributed over 22 channels. The EEPS was used for both the screening and the confirmation testing. The EEPS can also be used to obtain a measurement of total PM via the integrated particle size distribution (IPSD) methodology, where effective density is assigned to the particles in each size range and an integration is performed over the volume in each size range to provide a mass for each size range, which is then integrated into overall size ranges to get a total PM mass. The IPSD methodology for obtaining total PM mass is described below.

IPSD Method utilizing the EEPS instrument

Liu et al. (2009) have proposed the Integrated Particle Size Distribution (IPSD) Method, in which they determine total particle mass by integrating the fractional mass obtained by multiplying effective density of particles by particle volume concentrations for each volume bin from the particle size distribution measurement instrument as shown in Eq. AH-1.

$$PM_{IPSD} = \sum_i \rho_{eff} \cdot \left(\frac{\pi D_{p,i}^3}{6} \right) \cdot n_i \qquad \text{(Eq. Appendix H-1)}$$

The volume bins and distributions are obtained from the PSDs. The particle effective density is defined as particle mass per mobility diameter defined particle volume, and it is a function of particle size. The effective particle density can be influenced by particle composition and morphology. Interestingly, Maricq and Xu (2004) found particle effective density functions are similar between light duty diesel exhaust particles and gasoline direction injection exhaust particles. A density distribution factor - particle effective density expressed in terms of particle mobility diameter – as developed by Maricq and Xu (2004) was chosen for accumulation mode particles (> 30 nm in diameter) as shown in Eq. Appendix H-2 and Figure H-1.

$$\rho_{eff} = 1.2378 \cdot e^{-0.0048 \cdot D_p} \qquad \text{(Eq. Appendix H-2)(2)}$$

For nucleation mode particles below 30 nm in diameter, a density (1.46 g/cm^3) of hydrated sulfuric acid was assumed following Zheng et al. (2012)'s calculation. Figure 3 shows the effective particle density distribution applied in this study for the IPSD method. A constant density (1 g/cm^3) profile for PFI vehicles to examine the difference in using two different density estimates. The particle mass was calculated by the equation (2) using the density distribution.

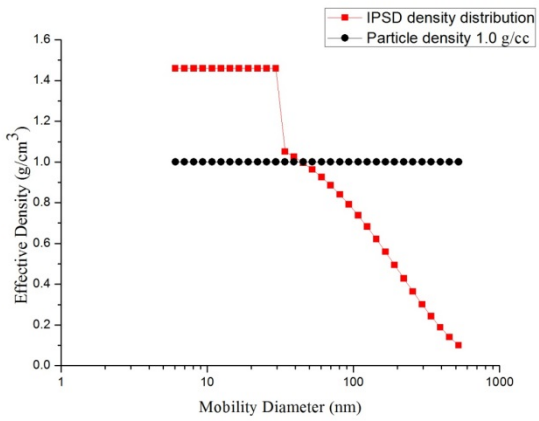

Figure H-1. Particle Effective Density Profile used in this Study

A Dekati Mass Monitor (DMM) - The DMM has a mobility section and cascade impactors in series to measure particle size distributions in real-time, based on aerodynamic diameter and particle effective density. The DMM measures particle size distributions distributed over six electrometer channels. Although the DMM does not provide as good a size resolution as the EEPS, it can provide better sensitivity at low particle emission levels due to the smaller number of electrometer channels. This is especially important at lower PM emission levels, where the EEPS may be near its individual channel detection limits, because the charged particles are distributed among 22 electrometer channels. The DMM was used only in the screening tests.

Appendix I. CVS Sample System Description

The Vehicle Emissions Research Laboratory (VERL) at CE-CERT'S laboratory can measure exhaust emissions under conditions that are representative of real-world driving conditions. An advanced 48-inch electric chassis dynamometer capable of simulating dynamic, high-speed accelerations and decelerations is a key component of the laboratory. The facility also contains separate dilution tunnels for sampling gasoline and diesel exhaust, an analytical system for sampling both regulated and unregulated gaseous emissions, and a particulate collection system (see Figure I-1). It is equipped with a Fourier Transform Infrared (FTIR) analytical system to quantify thirty low-level toxic compounds in vehicle exhaust, including N_2O and NH_3.

The laboratory has developed and demonstrated instrumentation including tunable diode lasers and differential optical adsorption spectrometers for specialized measurements at very low levels. The laboratory is also used in an ongoing program to develop instrumentation for real-time, on-board measurement of low-level emissions from light-duty vehicles.

Figure I-1 Vehicle Emissions Research Laboratory

Other major equipment in VERL includes:

- A 48-inch Burke E. Porter Model 3900-3595 2WD single-roll electric chassis dynamometer.
- A Pierburg Positive Displacement Pump - Constant Volume Sampler, which is used to sample exhaust for both gaseous and particle emissions.
- A Pierburg AMA-4000 Exhaust Emissions Measuring System for measurement of regulated emissions (e.g., THC, CH_4, CO, CO_2, and NO_x).
- A PM sampling system designed for three phases of the FTP system with flow rates up to 100 slpm. We will make some addition changes to provide filter face temperatures ranging from 25°C to 52°C.
- A Micro-Orifice Uniform Deposit Impactor (MOUDI), manufactured by MSP Corporation, to collect size-resolved particulate samples.
- FTIR Multi-Component Exhaust Gas Analyzer. The AMA-FTIR is a modular design that consists of the FTIR spectrometer that allows for the measurement of a variety of exhaust species at the same time.

- A driver's aid, which provides a driving cycle (vehicle speed vs. time) trace for the driver to follow while driving on the chassis dynamometer during the emissions test.

An Analytical Services Laboratory is associated with VERL for analysis of gaseous and particulate samples from vehicle exhaust, as well as analysis of fuel samples. The laboratory is equipped with several Hewlett-Packard gas chromatographs, an Agilent gas chromatograph/mass spectrometer, and a Mettler Toledo UMX2 ultra-microbalance with a 0.1 measurement capability. Standard tests in the laboratory include aldehyde and ketone analysis; C_8-C_{20} analysis, detailed C_1-C_4 and C_4-C_{12} hydrocarbon analysis, gas chromatograph analysis, Method 5.1 analysis, PAH analysis, and elemental and organic particulate matter measurements.

Appendix J. Statistical support data

This section includes statistical support data for the screening and confirmation testing. The data provides the reader a feel for the values used, their standard deviation, and sample size which was allowed to vary to maximize the number of repeats by combining the data into a large pool.

Table J-1 Average test results organized by FFV screening combined phases (mg/mi)

Test Cycle	Vehicle	CVS DF = 7 (mg/mi)															DF Varies (mg/mi)					
		A175			A/B150			B125			C100			D100i			PFSS100			PFSS150		
		ave	stdev	n	ave	stdev	n	ave	stdev	n	ave	stdev	n	ave	stdev	n	ave	stdev	n	ave	stdev	n
3-bag	low	0.249	0.095	8	0.265	0.103	8	-	-	-	0.314	0.126	8	0.272	0.130	8	0.252	0.122	5	0.156	0.031	3
3-bag	high	1.486	0.126	3	1.426	0.136	3	1.649	0.092	3	1.353	0.188	3	1.481	0.272	3	1.288	0.225	3	1.513	0.034	3
4-bag	low	0.314	0.030	3	0.224	0.006	3	-	-	-	0.305	0.039	3	0.063	0.102	3	0.130	0.020	3	-	-	-
4-bag	high	-	-	-	1.627	0.206	3	1.446	0.128	3	1.418	0.129	3	1.469	0.148	3	1.302	0.086	3	-	-	-
US06	low	0.661	0.540	6	0.612	0.512	6	-	-	-	0.718	0.610	6	0.619	0.554	6	0.810	0.400	3	-	-	-
US06	high	-	-	-	1.316	0.861	6	1.236	0.859	6	1.184	0.835	6	1.363	0.995	6	1.341	0.779	6	-	-	-

Table J-2 Average test results organized by DF screening combined phases (mg/mi)

Test Cycle	Vehicle	CVS DF = 7 (mg/mi)						PFSS FFV = 100 (mg/mi)									PFSS FFV=150 (mg/mi)								
		B150			C100			DF=7			DF=5			DF=3			DF=7			DF=5			DF=3		
		ave	stdev	n	ave	stdev	n	ave	stdev	n	ave	stdev	n	ave	stdev	n	ave	stdev	n	ave	stdev	n	ave	stdev	n
3-bag	low	0.265	0.103	8	0.314	0.126	8	0.380	0.022	2	0.181	-	1	0.116	0.007	2	0.167	-	1	0.000	-	1	0.121	-	1
3-bag	high	1.533	0.156	6	1.469	0.177	6	1.494	-	1	1.484	-	1	1.560	-	1	1.034	-	1	1.370	-	1	1.461	-	1
4-bag	low	0.224	0.006	3	0.305	0.039	3	0.153	-	1	0.121	-	1	0.117	-	1	-	-	-	-	-	-	-	-	-
4-bag	high	1.627	0.206	3	1.418	0.129	3	1.265	-	1	1.242	-	1	1.401	-	1	-	-	-	-	-	-	-	-	-
US06	low	1.022	0.384	3	1.199	0.480	3	1.258	-	1	0.686	-	1	0.488	-	1	-	-	-	-	-	-	-	-	-
US06	high	1.316	0.861	6	1.184	0.835	6	1.167	-	1	2.897	-	1	1.100	-	1	2.897	-	1	1.209	-	1	0.837	-	1

Table J-3 Average test results organized by FFV confirmation testing only (mg/mi)

Test Cycle	Vehicle	CVS DF=7 (mg/mi)												PFSS DF=5 (mg/mi)		
		A150			B125			C100			D100i			PFSS150		
		ave	stdev	n	ave	stdev	n	ave	stdev	n	ave	stdev	n	ave	stdev	n
4-bag	low	0.103	0.023	6	0.096	0.021	6	0.111	0.023	6	0.104	0.072	6	0.093	0.013	6
3-bag	high	1.961	0.061	6	1.970	0.079	6	1.984	0.112	6	1.897	0.121	6	1.846	0.086	6
US06	low	0.236	0.041	6	0.219	0.048	6	0.210	0.053	6	0.189	0.064	6	0.199	0.020	6
US06	high	2.296	0.094	2	1.992	0.094	2	2.132	0.154	2	2.124	0.291	2	2.411	0.134	2