European Commission

PARTICLE MEASUREMENT PROGRAMME

PMP-IWG

TASK FORCE 2 – BRAKE EMISSIONS

PRELIMINARY ANALYSIS ON PM DATA FROM THE ILS

Joint Research Centre

PRELIMINARY ANALYSIS – PM EMISSIONS

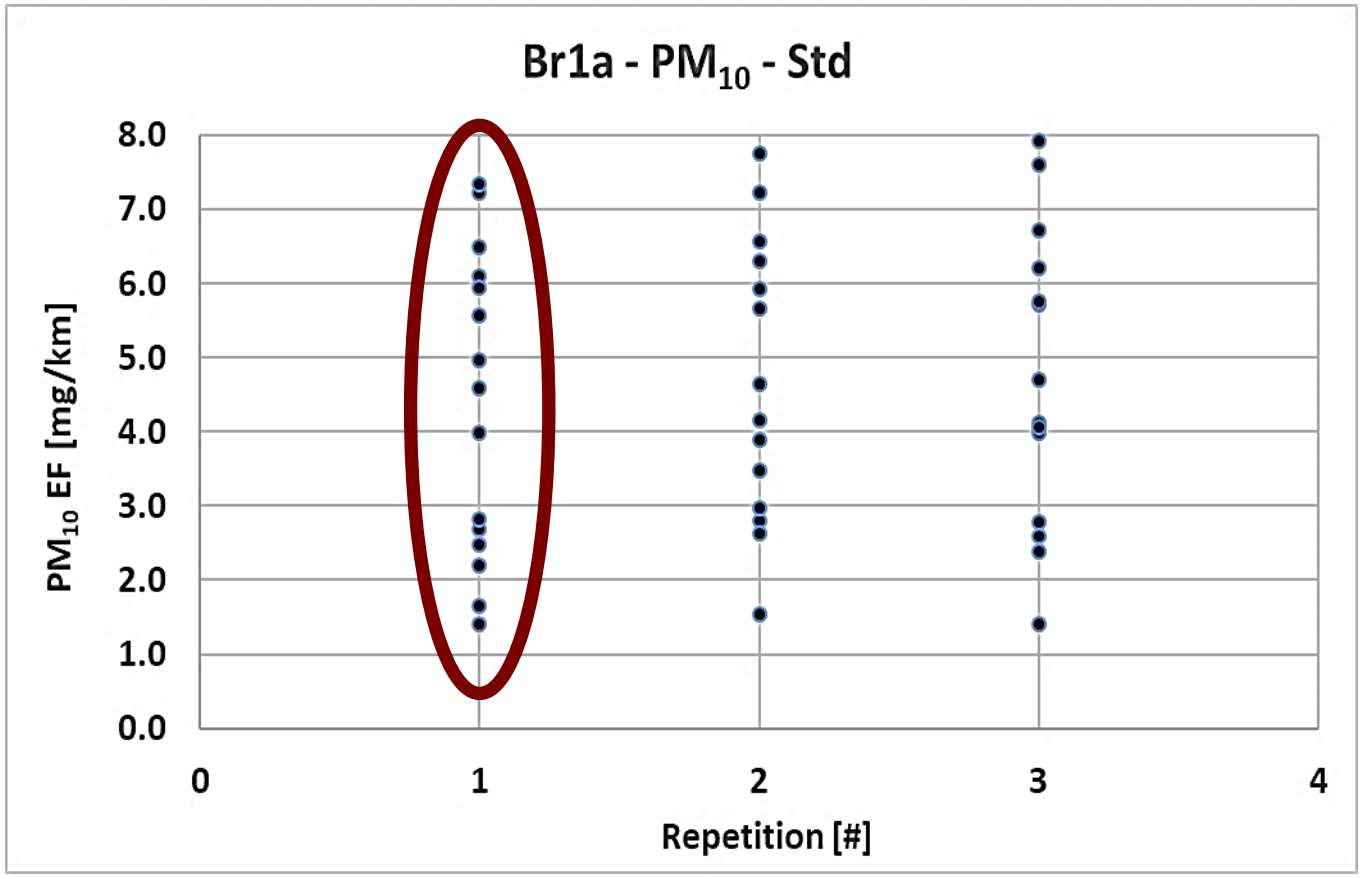
The analysis* presented hereafter has been conducted using the Br1a as reference and crosschecked for its validity using data from Br2.

The main reasons for selecting Br1a include:

- ✓ All Laboratories submitted PM emission results for Br1a – This was not the case with other mandatory brakes which were not all tested by all Labs;
- ✓ Br1a has been used as benchmark during the previous ILS campaign and has been the most commonly used brake by many labs over the last years;
- ✓ Wear data submitted by 12 Labs for Br1a show a low measurement variability for wear (<14%), thus allowing to use wear rate as a safe indicator;

** All EFs presented in the analysis refer to a per brake level – Variability is calculated using one Standard Deviation and is used for illustration purposes*

PRELIMINARY ANALYSIS – PM10 EMISSIONS

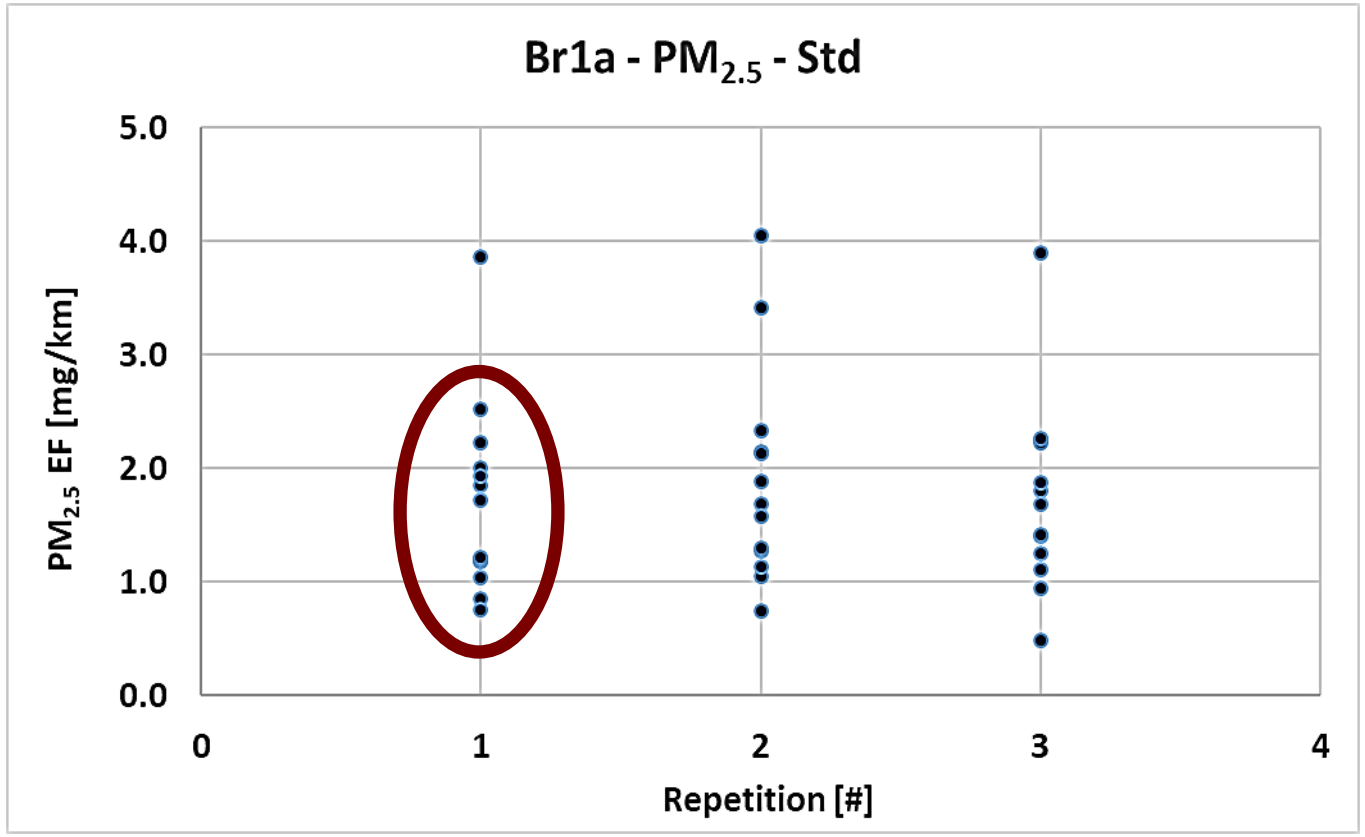


- ✓ Data from three repetitions from all labs are plotted together;
- ✓ Only standard emissions tests have been considered;
- ✓ No filters were applied or data removed at this stage

Br1a - Std	PM10 EF
AVERAGE	4.58 mg/km
50th Percentile	4.58 mg/km
STDEV	1.95 mg/km
VARIABILITY	42.6%

Unfiltered data show a variance of PM_{10} EFs between 1.4-7.9 mg/km at a brake level. This results in a high measurement variability of approximately 43%.

PRELIMINARY ANALYSIS – PM2.5 EMISSIONS



- ✓ Data from three repetitions from all labs are plotted together;
- ✓ Only standard emissions tests have been considered;
- ✓ No filters were applied or data removed at this stage

Br1a - Std	PM2.5 EF
AVERAGE	1.77 mg/km
50th Percentile	1.68 mg/km
STDEV	0.86 mg/km
VARIABILITY	48.3%

Unfiltered data show a variance of $PM_{2.5}$ EFs between 0.5-4.1 mg/km at a brake level. This results in a high measurement variability of approximately 48% - Most data points are found between 1.0-2.0 mg/km

FIRST CONCLUSION – NEED FOR DATA FILTERING

The measured PM_{10} and $PM_{2.5}$ levels deviate significantly. As is it does not allow for a meaningful analysis to understand the influence of various parameters

There is a need to investigate whether the Labs carried out the ILS exercise correctly and identify important deviations from the protocol that could lead to questionable PM results:

1. Errors that have been identified by the Labs that led to request for not taking into account the submitted data;
2. Labs' non-compliance with the TF2 protocol focusing mainly on important requirements that seem to be most relevant to PM emissions;
3. High-level quality check using tools like PM2.5/PM10 and PM10/Wear ratios to identify possible issues;

Combining the results from steps 1-3 will allow for a more robust statistical analysis and the identification of significant correlations in the remaining dataset

DATA FILTERING – STEP 1

1. Errors that have been identified by the Labs that led to request for not taking into account the submitted PM data:

- ✓ Two Labs contacted JRC after the submission of the results to inform that they identified serious issues with either the setup or other important parts of the protocol;
- ✓ The Labs requested not to consider their PM data in the subsequent analysis since they significantly underestimated PM emission levels;
- ✓ Indeed, the measured PM emission levels at both Labs were between the very low and the low edge of the overall range;
- ✓ The application of the applied approach for filtering the data verified the underestimation of the PM emission levels for both Labs

DATA FILTERING – STEP 2

2. Labs' non-compliance with the TF2 protocol – Focus on important requirements that seem to be most relevant to PM emissions – This step was used only as a guide:

- ✓ The compliance of the Labs against the mandatory specs was checked – This included*: *Speed violations, Initial trips' temperature, System and tests background, Average and 1Hz cooling air temperature and relative humidity, Disc rotation direction, Sampling plane location, Use of reference filters, Filters' coating, Charge neutralizer, Filters' conditioning, Weighing room specs, Microbalance resolution, Use of Dilution, Pre-classifier setpoint, Length/sample flow ratio*

- ✓ The compliance of the Labs against the recommended specs of the TF2 protocol as well as against the points agreed for the ILS was checked – Additional parameters that were checked are*: *Friction work over the WLTP-Brake cycle, Average Trip #10 temperature, Average Trip #10 IBT and FBT, Air flow measurement location, Air flow deviation, Caliper orientation, PM flowsplit angle, Nozzle diameter, Cycle duration, Number of brake events, Bedding procedure, Execution of one WLTP-Brake cycle per filter*

** The list is still under processing and will expand – Existing parameters will not be removed*

DATA FILTERING – STEP 2

Lab	Compliance Mandatory	Compliance Overall	Non-Compliant Parameters with TF2 specifications (Most critical in red)
Lab-B	40%*	50%*	Speed violations, System background, Dyno climatics, Microbalance resolution, Filters conditioning, **Impactor substrate coating, Pre-classifier cutpoint, Air Flow deviations**
Lab-C	75-95%	>75%	1Hz Dyno climatics (RH), **Caliper orientation, Low friction work,** Air flow measurement location, **One filter for PM10 – PM2.5**
Lab-D	35-50%*	>40%*	Speed violations, System background, **Dyno climatics, Microbalance resolution, Caliper Orientation,** Filters conditioning, No dilution system, **Cycle duration, No PM2.5 measurement**
Lab-F	70-80%	>65%	System background, 1Hz Dyno climatics (RH), **Disc rotation direction, Caliper Orientation,** Weighing room specs, **PM flowsplit angle**
Lab-G	80-85%*	>65%*	Initial trips temperature, No dilution system, Air flow measurement location, **Air Flow deviations**
Lab-H	55-60%	>65%	System background, Weighing room specs, **Charge neutralizer, Microbalance resolution,** Filters conditioning, No dilution system
Lab-J	50-80%*	>60%*	Weighing room specs, **Impactor substrate coating,** Filters conditioning, No dilution system
Lab-K	70%	>65%	**Caliper orientation, Sampling plane location (0D)**, No dilution system, **No use of recommended impactor substrates**

** Non-compliance might have been inflatted – There were unresolvable issues with some or all submitted EED files*

DATA FILTERING – STEP 2

Lab	Compliance Mandatory	Compliance Overall	Non-Compliant Parameters with TF2 specifications (Most critical in red)
Lab-L	75-85%	>65%	**Caliper orientation, Sampling plane location (5.5D),** Weighing room specs, Air flow measurement location, **Air Flow deviations**
Lab-M	65-85%	>65%	**Caliper orientation**, Reference filters, Filters conditioning, Weighing room specs
Lab-N	90-100%	>85%	
Lab-P	90%	>80%	Initial trips temperature, System background, **Caliper orientation,** Air flow measurement location, **Low friction work**
Lab-Q	70-90%	>70%	Initial trips temperature, **Sampler/filter combination, Flow rate deviation, Low friction work**
Lab-R	55-65%	>60%	Initial trips temperature, System background, Reference filters, **Charge neutralizer,** No dilution system, **Pre-classifier cutoff, One filter for PM10**
Lab-S	85-90%	>85%	Weighing room specs
Lab-T	70-90%*	>65%*	Initial trips temperature, Reference filters, **Microbalance resolution**

** Non-compliance might have been inflatted – There were unresolvable issues with some of the submitted EED files*

DATA FILTERING – STEP 3

3. High-level quality check using tools like $PM_{2.5}/PM_{10}$ and PM_{10}/Wear ratios to investigate possible issues in the submitted PM data:

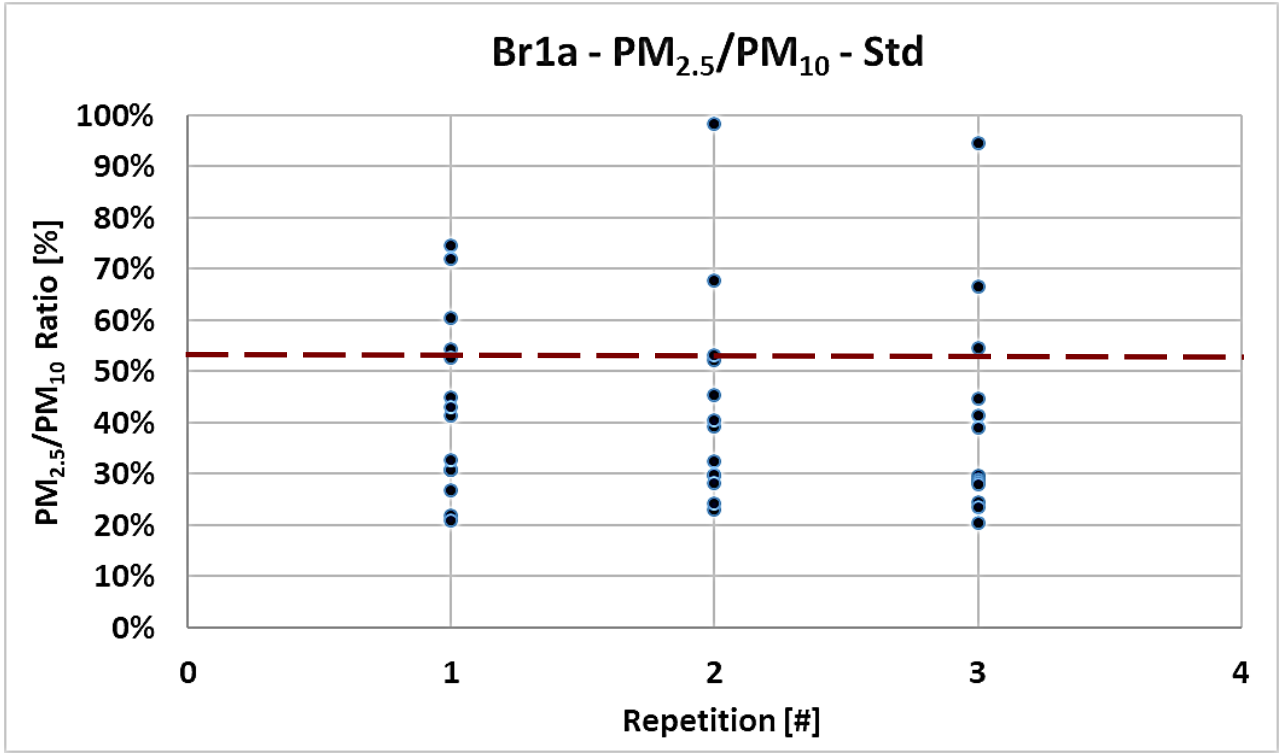
- ✓ The $PM_{2.5}/PM_{10}$ ratio is a good indicator of possible particle losses in the setup – High to very high ratios indicate underestimation of the coarse size fraction – possible problems in sampling and/or measuring bigger particles;
- ✓ The PM_{10}/Wear ratio can be also used as an indicator of losses for big particles in the setup – Wear measurement proved to be robust among the labs (Br1a); therefore, very low ratios point towards issues in sampling and/or measuring the PM coarse size fraction;

The indicators discussed above ***cannot alone provide evidence of "problematic" measurement in a given setup;*** however, ***combined with the actual EF levels and the compliance discussed in Step*** 2 can give a very good picture of each Labs' capability to measure PM correctly

DATA FILTERING – STEP 3 – Br1a

3a. High-level quality check using $PM_{2.5}/PM_{10}$ ratio to identify possible issues in the PM measurement:

Br1a - Std	PM2.5/PM10 Ratio
AVERAGE	42.4%
STDEV	19.4%
VARIABILITY	45.8%
MIN VALUE	20.4%
5th Percentile	21.7%
25th Percentile	28.4%
50th Percentile	39.2%
75th Percentile	52.8%
95th Percentile	75.6%
MAX VALUE	98.3%

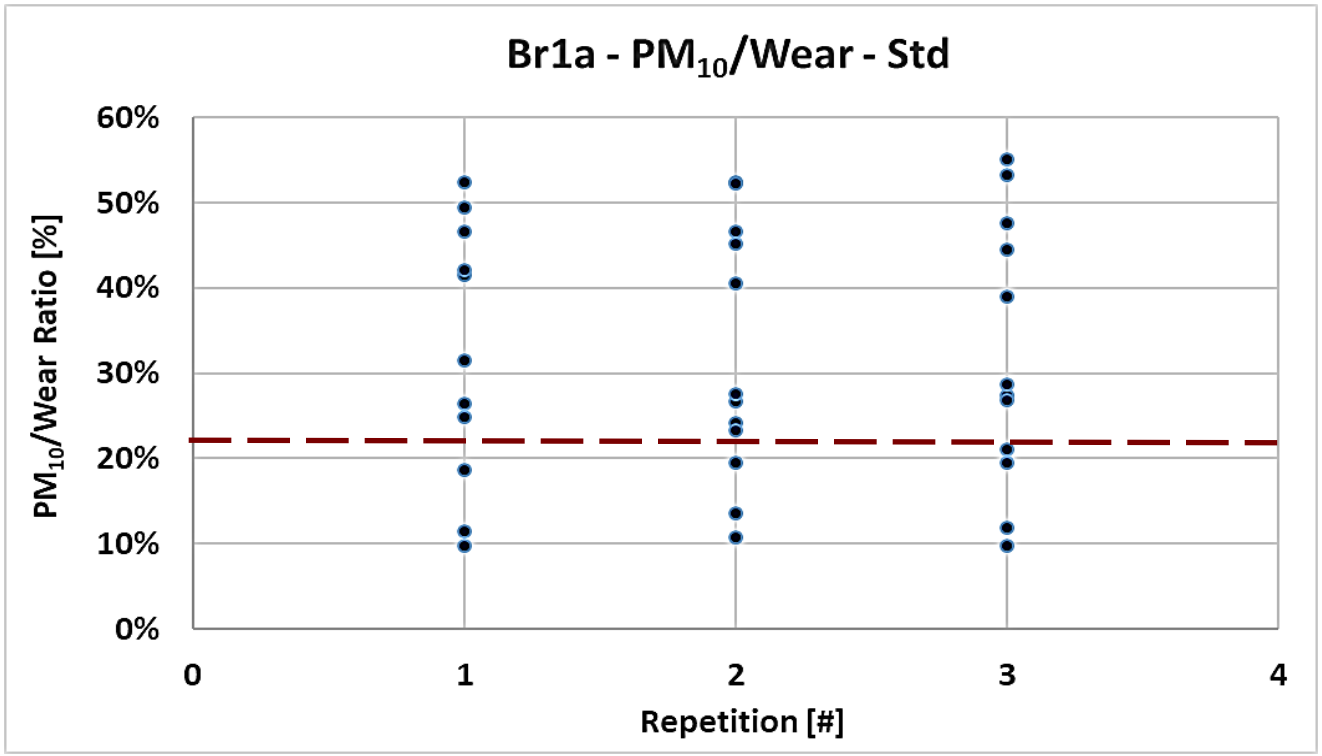


Labs with $PM_{2.5}/PM_{10}$ ratio higher than 52.8% might have underestimated the PM_{10} fraction

DATA FILTERING – STEP 3 – Br1a

3b. High-level quality check using PM_{10}/Wear ratio to identify possible issues in the PM measurement:

Br1a - Std	PM10/Wear Ratio
AVERAGE	32.0%
STDEV	14.7%
VARIABILITY	46.0%
MIN VALUE	9.8%
5th Percentile	10.5%
25th Percentile	20.3%
50th Percentile	27.6%
75th Percentile	45.9%
95th Percentile	52.7%
MAX VALUE	55.1%

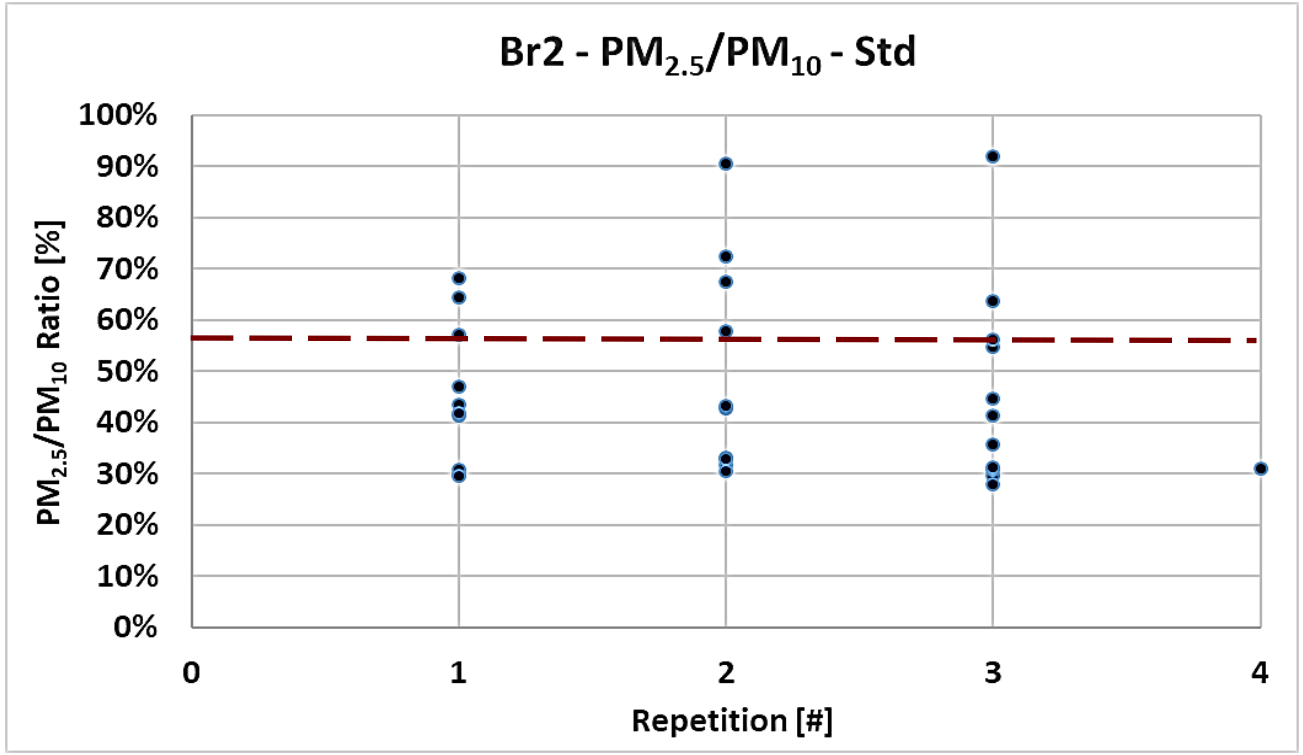


Labs with PM_{10}/Wear ratio lower than 20.3% might have underestimated the PM_{10} fraction

DATA FILTERING – STEP 3 – Br2

3a. High-level quality check using $PM_{2.5}/PM_{10}$ ratio to identify possible issues in the PM measurement:

Br1a - Std	PM2.5/PM10 Ratio
AVERAGE	46.7%
STDEV	17.8%
VARIABILITY	38.1%
MIN VALUE	27.9%
5th Percentile	29.5%
25th Percentile	31.1%
50th Percentile	42.3%
75th Percentile	57.3%
95th Percentile	80.5%
MAX VALUE	91.9%

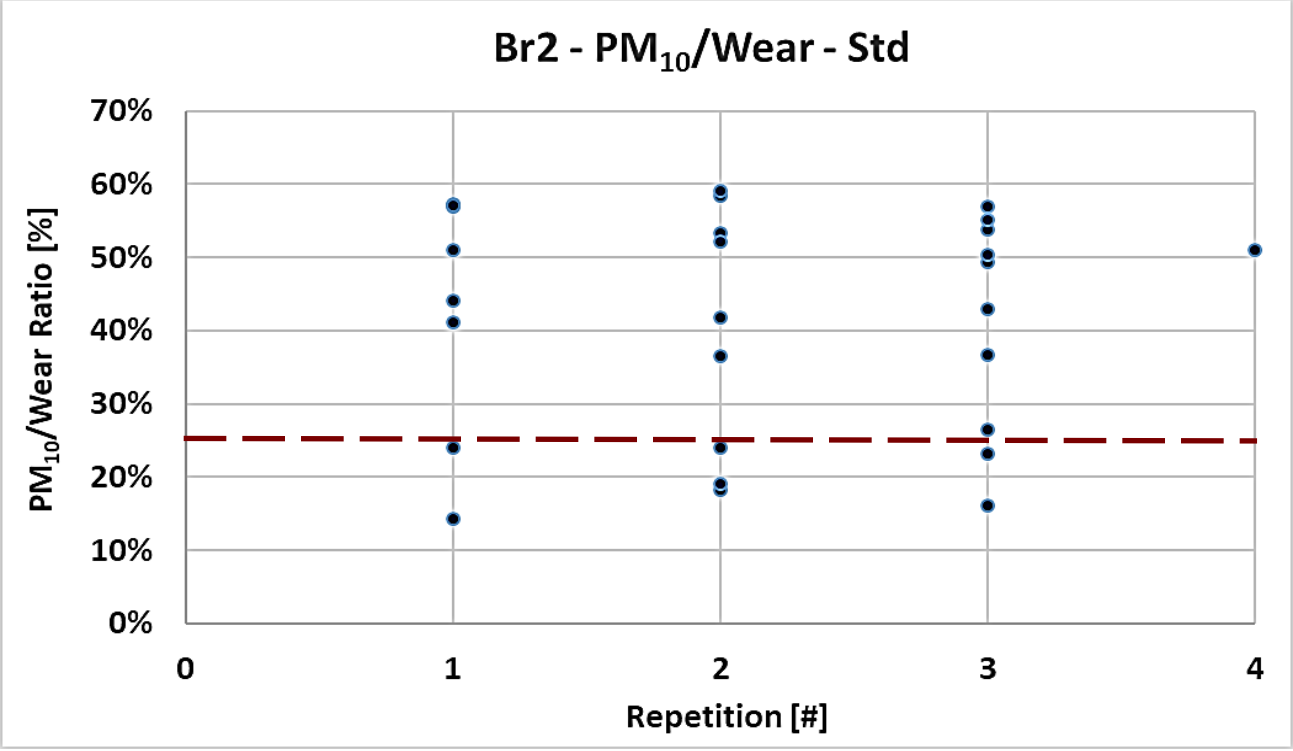


Labs with $PM_{2.5}/PM_{10}$ ratio higher than 57.3% might have underestimated the PM_{10} fraction

DATA FILTERING – STEP 3 – Br2

3b. High-level quality check using PM_{10}/Wear ratio to identify possible issues in the PM measurement:

Br1a - Std	PM10/Wear Ratio
AVERAGE	41.8%
STDEV	15.1%
VARIABILITY	36.1%
MIN VALUE	14.2%
5th Percentile	16.8%
25th Percentile	25.8%
50th Percentile	46.8%
75th Percentile	54.1%
95th Percentile	58.0%
MAX VALUE	59.0%



Labs with PM_{10}/Wear ratio lower than 20.3% might have underestimated the PM_{10} fraction

PM EMISSIONS
COMBINED FILTERS

DATA FILTERING – COMBINED CRITERIA LAB B

Lab	Compliance Mandatory	Compliance Overall	Non-Compliant Parameters with TF2 specifications (Those considered in red)
Lab-B	40%*	50%*	Speed violations, System background, Dyno climatics, Microbalance resolution, Filters conditioning, **Impactor substrate coating, Pre-classifier cutpoint, Air Flow deviations**

Lab-B	$PM_{2.5}$ EF (mg/km)	PM_{10} EF (mg/km)
Test 1	0.86	1.41
Test 2	1.05	1.54
Test 3	0.94	1.41
Lab Average	**0.95**	**1.46**
All Labs Avg.	**1.77**	**4.58**
Filtered Avg.	1.99	5.81

PM Emission Levels – Br1a

$PM_{2.5}/PM_{10}$ (%)	PM_{10}/Wear (%)	$PM_{2.5}/PM_{10}$ (%)	PM_{10}/Wear (%)
60.5%	9.8%	68.1%	14.2%
67.8%	10.7%	67.3%	18.2%
66.7%	9.8%	63.6%	16.0%
65.0%	**10.1%**	**66.3%**	**16.2%**
42.4%	**32.0%**	**46.7%**	**41.8%**
32.9%	41.6%	35.2%	52.4%

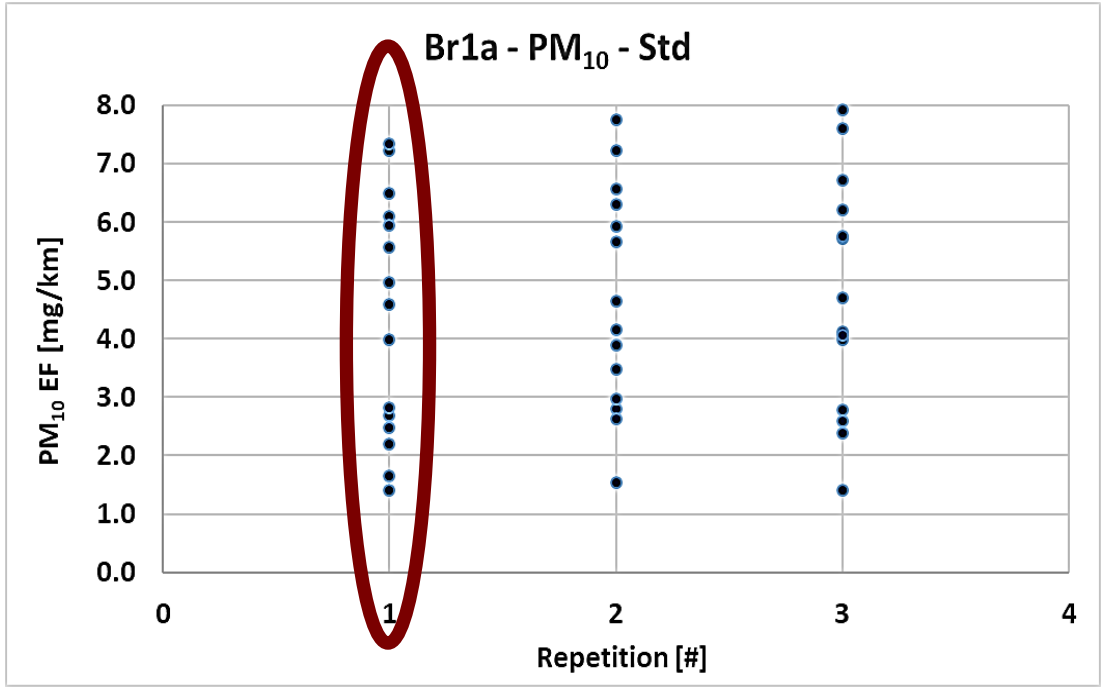
Examined Ratios – Br1a + Br2

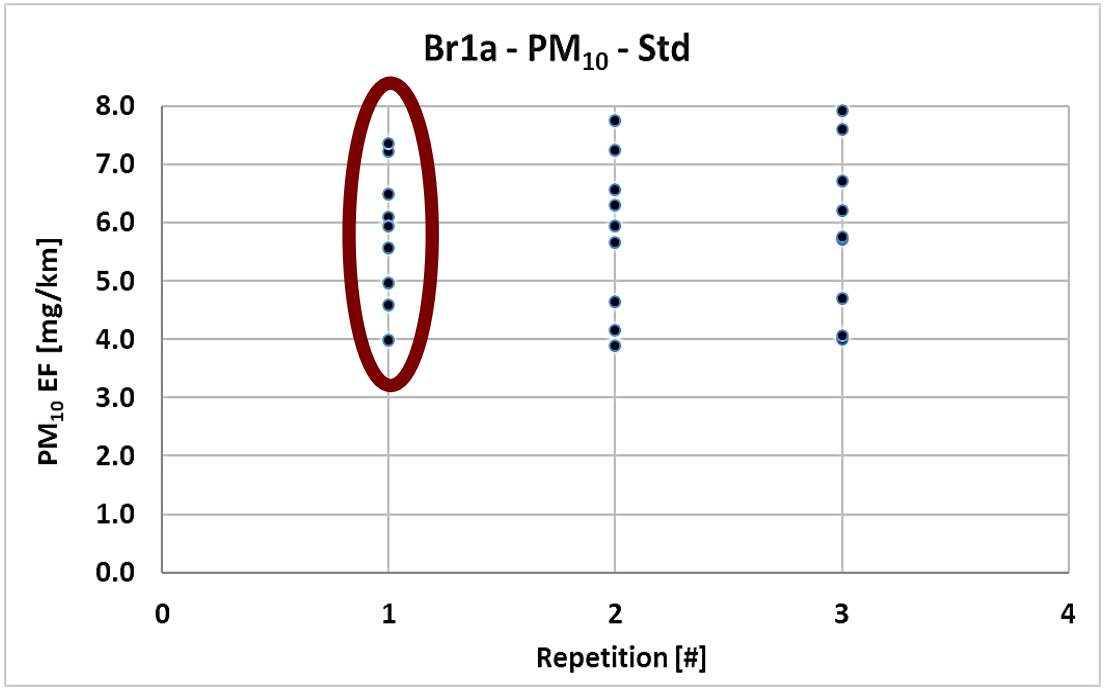
Lab-B	$PM_{2.5}$ EF (mg/km)	PM_{10} EF (mg/km)
Test 1	0.86	1.41
Test 2	1.05	1.54
Test 3	0.94	1.41
Lab Average	**0.95**	**1.46**
Std Deviation	**0.09**	**0.08**
VARIABILITY	**10.1%**	**5.2%**

Lab's Measurement Variability

Low PM_{10} EFs (<50%), high $PM_{2.5}/PM_{10}$ ratio (>75th percentile), low PM_{10} /Wear ratio (<25th percentile)
=> Possible underestimation of PM_{10} – Lab confirmed

PRELIMINARY ANALYSIS – PM10 EMISSIONS

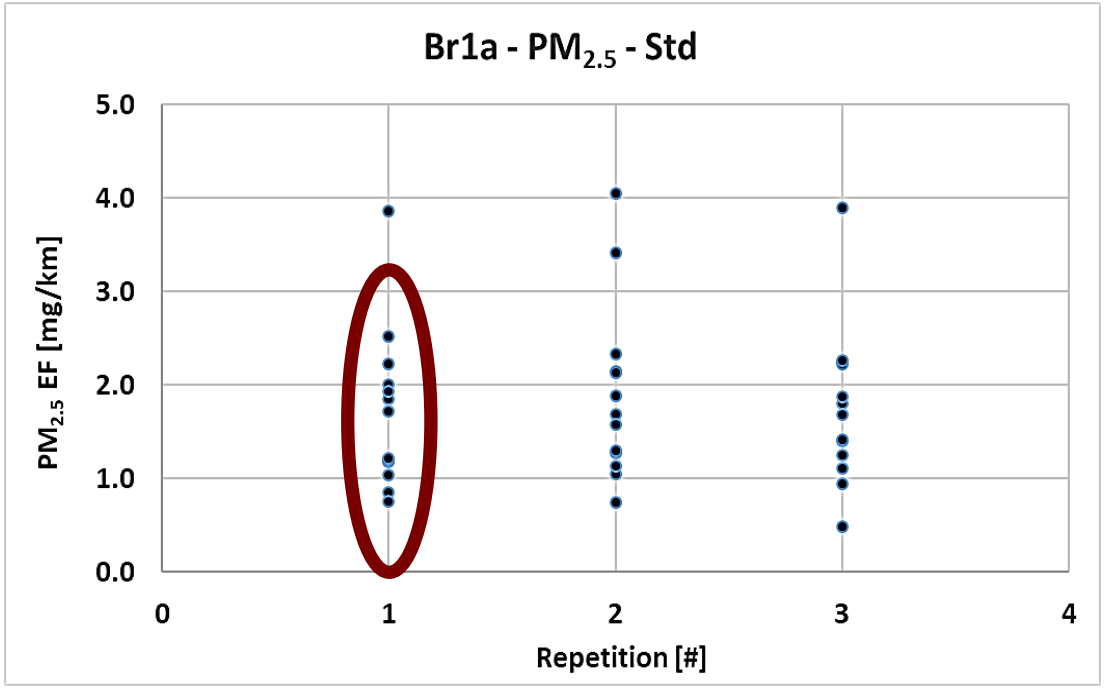


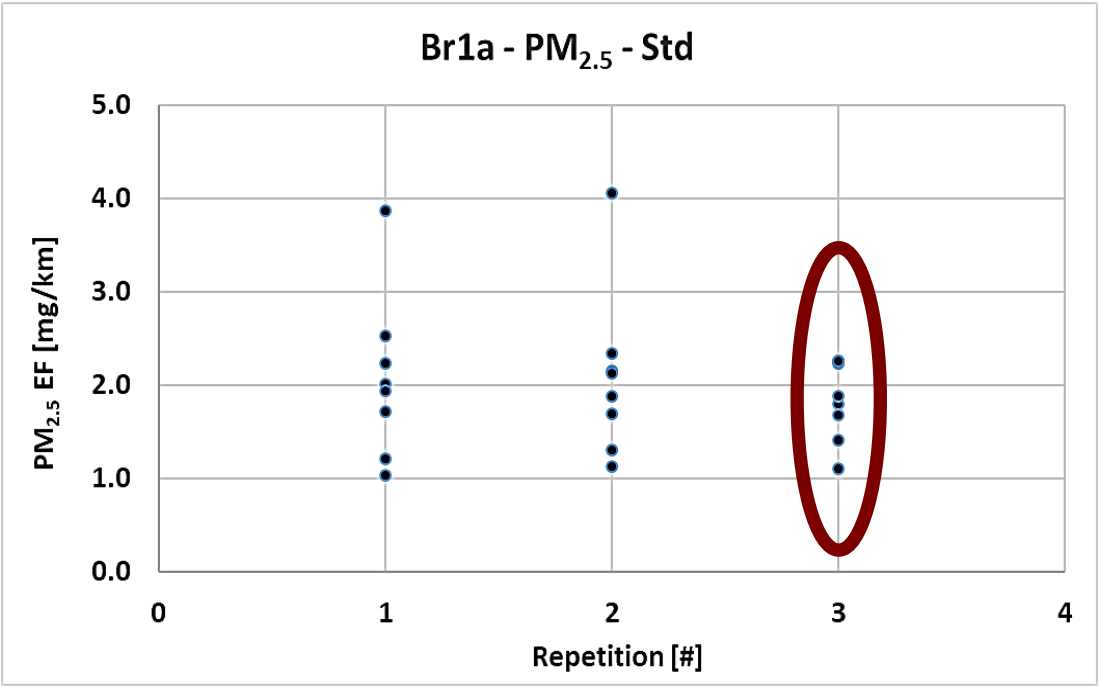


Br1a - Std	PM10 EF
AVERAGE	4.58 mg/km
50th Percentile	4.58 mg/km
STDEV	1.95 mg/km
VARIABILITY	42.6%

Br1a - Std	PM10 EF
AVERAGE	5.81 mg/km
50th Percentile	5.93 mg/km
STDEV	1.26 mg/km
VARIABILITY	21.6%

PRELIMINARY ANALYSIS – PM2.5 EMISSIONS

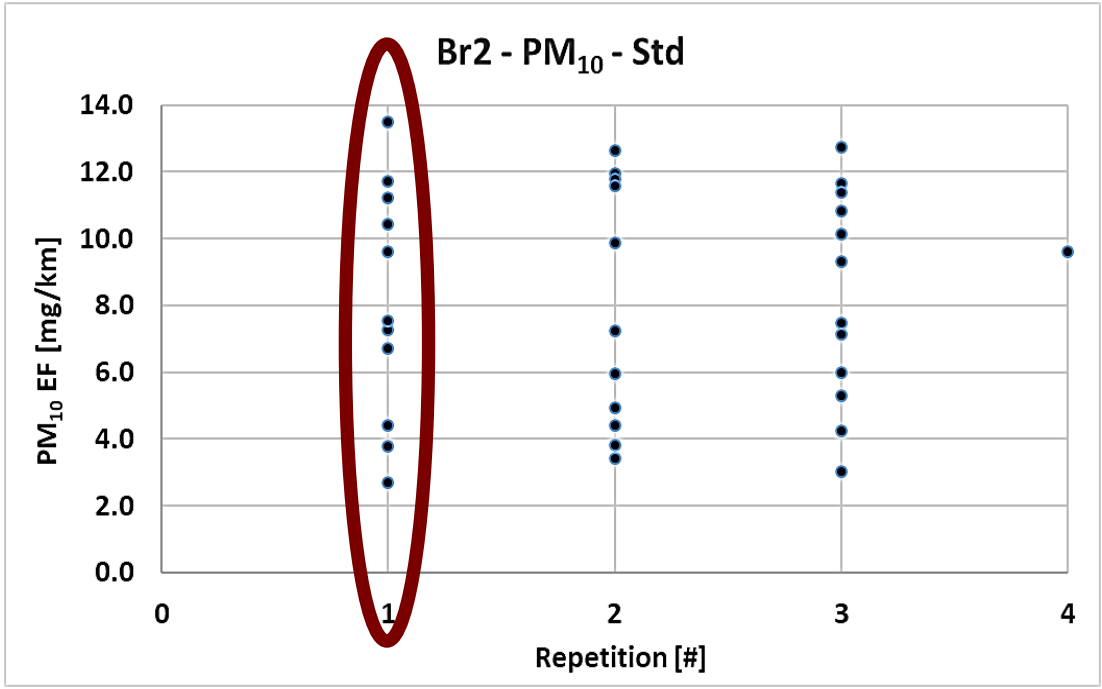


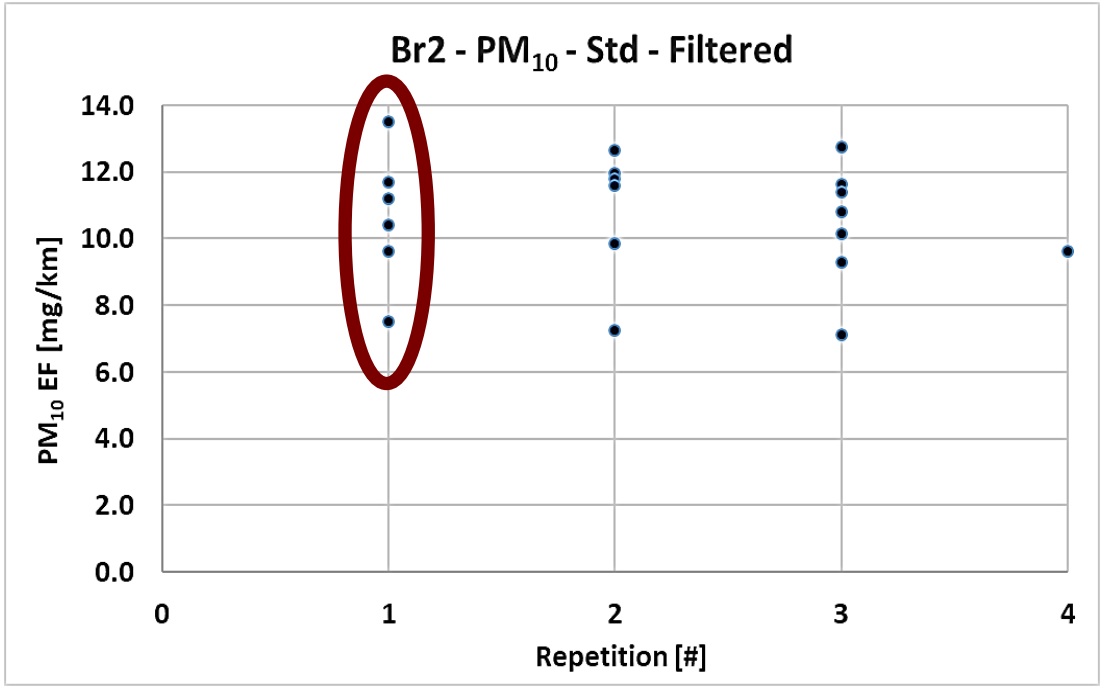


Br1a - Std	PM2.5 EF
AVERAGE	1.77 mg/km
50th Percentile	1.68 mg/km
STDEV	0.86 mg/km
VARIABILITY	48.3%

Br1a - Std	PM2.5 EF
AVERAGE	1.99 mg/km
50th Percentile	1.91 mg/km
STDEV	0.74 mg/km
VARIABILITY	37.3%

PRELIMINARY ANALYSIS – PM10 EMISSIONS

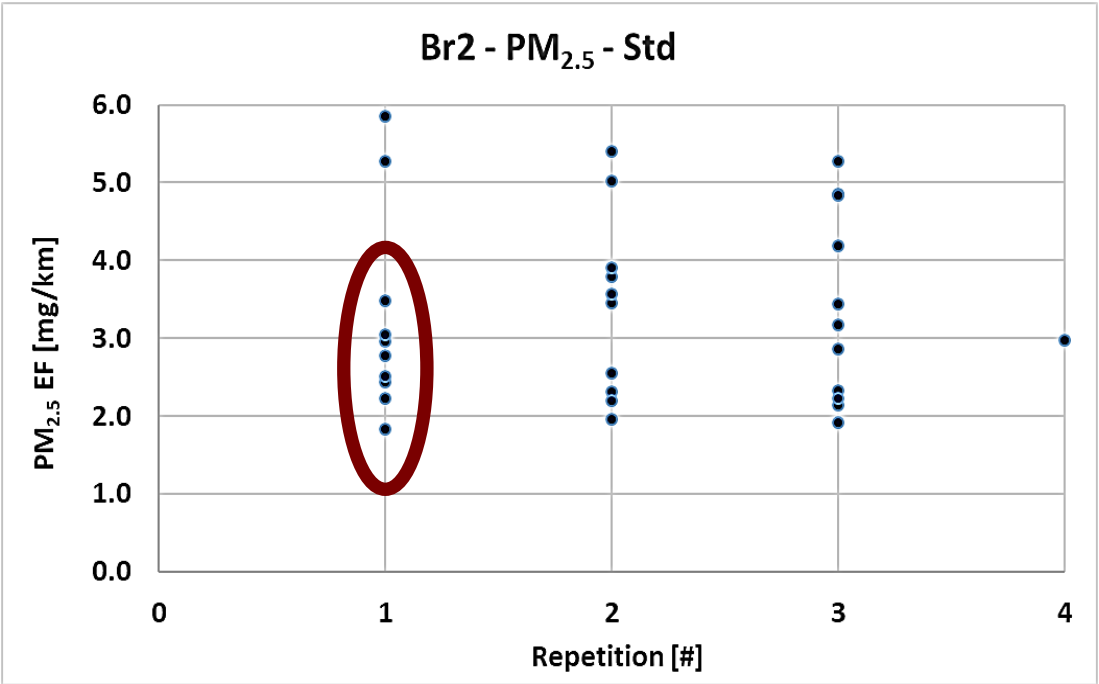


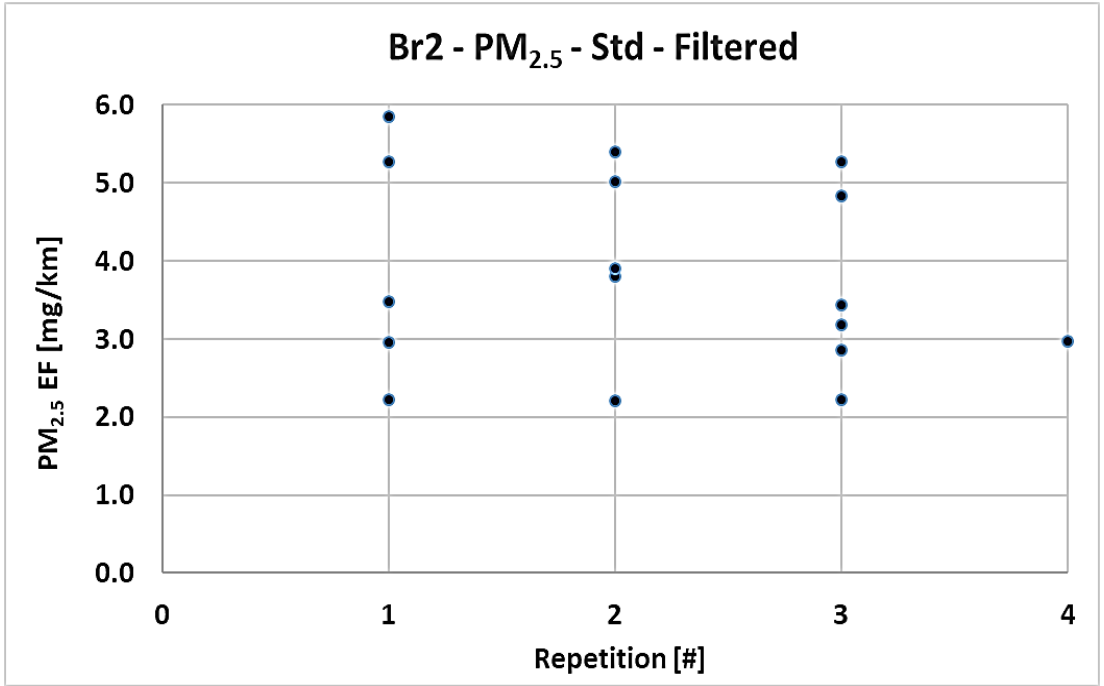


Br1a - Std	PM10 EF
AVERAGE	8.15 mg/km
50th Percentile	7.53 mg/km
STDEV	3.31 mg/km
VARIABILITY	40.6%

Br1a - Std	PM10 EF
AVERAGE	10.59 mg/km
50th Percentile	11.02 mg/km
STDEV	1.81 mg/km
VARIABILITY	17.1%

PRELIMINARY ANALYSIS – PM2.5 EMISSIONS





Br1a - Std	PM2.5 EF
AVERAGE	3.34 mg/km
50th Percentile	3.01 mg/km
STDEV	1.18 mg/km
VARIABILITY	35.5%

Br1a - Std	PM2.5 EF
AVERAGE	3.82 mg/km
50th Percentile	3.48 mg/km
STDEV	1.23 mg/km
VARIABILITY	32.2%

FIRST CONCLUSION(S)

- ✓ The measurement variability for PM_{10} and $PM_{2.5}$ is high when all data are considered. However, some Labs experienced significant issues, while others did not meet important specs of the TF2 protocol;
- ✓ There is a need to appropriately filter the data in order to allow for a robust statistical analysis and enable the identification of possible significant correlations in the remaining dataset;
- ✓ A three-step approach was followed taking into account the Labs' input, the overall Labs' compliance with the TF2 specs, the PM emission levels, and a high-level quality check using two indicators;
- ✓ Filtering of the data shows a significant improvement in the overall measurement variability; however, there is still a need to identify other issues in the dataset not related to bigger particle losses.

Thank you

European Commission