



PARTICLE MEASUREMENT PROGRAMME

PMP-IWG Meeting – 13 December 2022

“GTR on Brake Emissions” Final Updates

Theo Grigoratos and Barouch Giechaskiel

DEFINITION OF FAMILIES

BRAKE EMISSIONS GTR - FAMILIES

- ✓ The current definition of the brake families provides guidance on brake emissions testing of OEM brakes – ***families for aftermarket brakes will be elaborated in the Euro 7 implementing regulation (or other regional regulations) with the aim of introducing them in the next GTR version;***
- ✓ The current definition of the brake families provides guidance ***on the selection of the appropriate vehicle parameters*** for testing the parent of the brake emissions family when the same brake is mounted on two or more vehicles;
- ✓ The current definition of the brake families does not elaborate on the calculation method for reporting emissions of the same brake when mounted in other vehicle types – this shall be decided in the corresponding regional regulations.

BRAKE EMISSIONS GTR - FAMILIES

A brake family is defined by a brake assembly considering the caliper, disc or drum, pad or shoe, and certain vehicle parameters:

- ✓ Type of caliper (floating or fixed caliper, number and size of pistons, type of retraction elements);
- ✓ Type of brake: disc (friction surface, single, dual, ventilated, solid, dimensions, mass) or drum-backplate assembly (friction surface, simplex, duplex, dimensions, mass);
- ✓ Type of friction material: pad (friction surface, size, shape, material, backing plate) or shoe (friction surface, size, design, material, backing plate).

Only vehicles that feature an identical brake assembly with respect to the characteristics listed above may be part of the same brake emissions family.

BRAKE EMISSIONS GTR - FAMILIES

The vehicle with the highest product of *wheel load* (Equation 8.1) and the *emissions coefficient* (Table 5.1) shall be chosen as parent of the brake emissions family **when multiple vehicles feature the same brake assembly.**

| | |
|--|------------|
| $WL_{n-f} = 0.5 \times M_{veh} \times FAF$ | (Eq. 8.1a) |
| $WL_{n-r} = 0.5 \times M_{veh} \times RAF$ | (Eq. 8.1b) |

*

| <i>Brake type</i> | <i>Vehicle Type</i> | <i>Friction Braking Share Coefficient (c)</i> |
|-----------------------|---------------------|---|
| Full-friction braking | ICE | 1.0 |
| Non-friction braking | NOVC-HEV Cat.1 | 0.63 |
| | NOVC-HEV Cat.2 | 0.40 |
| | OVC-HEV | 0.30 |
| | PEV | 0.15 |

- ✓ If the product of test wheel load and the emissions coefficient is the same for two or more vehicles, the vehicle with the lowest dynamic rolling radius shall be selected as the family high member;
- ✓ The brake assembly representing the brake emissions family high member shall be tested on the test stand as described in paragraphs 8.1.1. (full-friction braking) and 8.1.2. (non-friction braking) of the UN GTR.

BRAKE EMISSIONS GTR – FAMILIES EXAMPLE

Example added for illustration purposes

| <i>Brake type</i> | <i>Vehicle Type</i> | <i>Vehicle Mass [kg]</i> | <i>Brake Force Distribution [%]</i> | <i>Wheel Load [kg]</i> | <i>Friction Braking Share Coefficient (c)</i> | <i>WL*c [kg]</i> |
|-----------------------|---------------------|--------------------------|-------------------------------------|------------------------|---|------------------|
| Full-friction braking | ICE | 1500 | 70 | 525 | 1.0 | 525 |
| Non-friction braking | NOVC-HEV Cat.1 | 2000 | 70 | 700 | 0.63 | 441 |
| | NOVC-HEV Cat.2 | 2100 | 70 | 735 | 0.40 | 294 |
| | OVC-HEV | 2300 | 70 | 805 | 0.30 | 241.5 |
| | PEV | 2500 | 70 | 875 | 0.15 | 131.3 |

Example 1: The same brake is mounted on all 5 vehicle types: The highest product of Wheel Load ($0.5 \cdot M_{veh} \cdot BFD$) and the emissions coefficient (c) is for the ICE (last column). The lab tests the brake using the ICE vehicle parameters and reports the PM and PN by applying a friction braking share coefficient of 1.0;

Example 2: The same brake mounted in all non-friction braking vehicle types (NOVC-HEV Cat.1, NOVC-HEV Cat.2, OVC-HEV, PEV): The highest product of Wheel Load and the emissions coefficient is for the NOVC-HEV Cat.1 (last column). The lab tests using the NOVC-HEV Cat.1 vehicle parameters (2000 kg) and reports the PM and PN by applying a friction braking share coefficient of 0.63;

Example 3: The brake is mounted only in 1 vehicle type (PEV): The lab tests using the PEV vehicle parameters (2500 kg) and reports the PM and PN by applying a friction braking share coefficient of 0.15.

NON-FRICTION BRAKING METHOD

BRAKE EMISSIONS GTR – NON-FRICTION BRAKING

A simplified method that would tackle the existing issues and provide the means for testing brakes mounted in vehicles with regenerative capabilities:

- ✓ The current proposal applies the already defined concept for full-friction brakes and utilizes fixed coefficients for different vehicle types based on their “electrification level” to calculate PM and PN emissions;
- ✓ A common fixed coefficient is proposed for each vehicle type. Different vehicles types (PEV, OVC-HEV, NOVC-HEV Category 1 (mild-hybrids), NOVC-HEV Category 2 (full hybrids)) come with different fixed coefficients.





$$\text{FINAL BRAKE EMISSION FACTOR} = \text{FULL-FRICTION EMISSION FACTOR} * \text{FIXED COEFFICIENT}$$

BRAKE EMISSIONS GTR – COEFFICIENTS

| Vehicle | Type | Test type | Cycle | Initial SOC (%) | Engine motoring energy [%] | Regeneration braking energy [%] | Friction brakes energy [%] |
|---------|----------|-------------------------------------|---------------------|-----------------|----------------------------|---------------------------------|----------------------------|
| BEV1 | PEV | Full vehicle - chassis dyno | WLTC | 94 | 0.0 | 96.2 | 3.8 |
| BEV2 | PEV | Full vehicle - chassis dyno | WLTC | 75 | 0.0 | 85.3 | 14.7 |
| BEV2 | PEV | Full vehicle - chassis dyno | WLTC | 62 | 0.0 | 85.5 | 14.5 |
| BEV2 | PEV | Full vehicle - chassis dyno | WLTC | 55 | 0.0 | 87.2 | 12.8 |
| BEV3 | PEV | Full vehicle - chassis dyno | WLTC | 100 | 0.0 | 91.5 | 8.5 |
| BEV4 | PEV | Brake dyno - Full regen capacity | WLTP brake | N/A | 0.0 | 97.5 | 2.5 |
| BEV5 | PEV | Brake dyno - Full regen capacity | WLTP brake | N/A | 0.0 | 96.1 | 3.9 |
| PHEV1 | OVC-HEV | Full vehicle - chassis dyno | WLTC | 28 | 2.9 | 79.5 | 17.6 |
| PHEV1 | OVC-HEV | Full vehicle - chassis dyno | WLTC | 55 | 1.7 | 84.6 | 13.7 |
| PHEV1 | OVC-HEV | Brake dyno - Full regen capacity | WLTP brake | N/A | 0.0 | 76.0 | 24.0 |
| PHEV2 | OVC-HEV | Full vehicle - chassis dyno | WLTC | 11 | 2.5 | 72.2 | 25.2 |
| PHEV3 | OVC-HEV | Simulation - Full regen capacity | WLTC | 100 | 0.0 | 86.1 | 13.9 |
| PHEV3 | OVC-HEV | Simulation - Full regen capacity | WLTP brake | 100 | 0.0 | 82.9 | 17.1 |
| PHEV4 | OVC-HEV | Brake dyno - Full regen capacity | WLTP brake | N/A | 0.0 | 83.0 | 17.0 |
| PHEV4 | OVC-HEV | Brake dyno - Full regen capacity | WLTP brake | N/A | 0.0 | 83.7 | 16.3 |
| FHEV1 | NOVC-HEV | Brake dyno - Full regen (rear axle) | WLTP brake Trip #10 | N/A | 0.0 | 61.9 | 38.1 |
| MHEV1 | NOVC-HEV | Full vehicle - chassis dyno | WLTC | 45 | 13.4 | 38.6 | 48.0 |
| MHEV1 | NOVC-HEV | Full vehicle - chassis dyno | WLTC | 60 | 24.7 | 33.6 | 41.7 |
| MHEV2 | NOVC-HEV | Full vehicle - chassis dyno | WLTC | 73 | 3.5 | 43.8 | 52.8 |

BRAKE EMISSIONS GTR – COEFFICIENTS (Cycle shift)

As a next step the friction share over the WLTC exhaust cycle shall be extrapolated to the WLTP-Brake cycle to reflect the GTR testing conditions.

| Vehicle | Type | Test type | Cycle | Initial SOC (%) | Engine motoring energy [%] | Regeneration braking energy [%] | Friction brakes energy [%] |
|---------|---------|---|------------|-----------------|----------------------------|---------------------------------|--|
| PHEV1 | OVC-HEV | Full vehicle - chassis dyno | WLTC | 28 | 2.9 | 79.5 |  17.6 |
| PHEV1 | OVC-HEV | Brake dyno - Full regen capacity ¹ | WLTP brake | N/A | 0.0 | 76.0 |  24.0 |
| PHEV3 | OVC-HEV | Simulation - Full regen capacity ² | WLTC | 100 | 0.0 | 86.1 |  13.9 |
| PHEV3 | OVC-HEV | Simulation - Full regen capacity ² | WLTP brake | 100 | 0.0 | 82.9 |  17.1 |

¹ Brake simulated by a stakeholder assuming full SOC at the beginning

² Brakes simulated by a stakeholder assuming full SOC at the beginning

- Friction share increases shifting from the regulated WLTC exhaust cycle to the WLTP-Brake cycle by 23-36% for two PHEVs;
- JRC has not performed chassis dyno data with the WLTP-Brake cycle. OICA presented data showing low or no increase at low friction shares and 20% increase at higher shares.

BRAKE EMISSIONS GTR – COEFFICIENTS (Cycle shift)

| Vehicle | Type | Test type | Cycle | Initial SOC (%) | Engine motoring energy [%] | Regeneration braking energy [%] | Friction brakes energy [%] | Extrapolated Friction brakes energy at WLTP-Brake Cycle [%] |
|---------|----------|-------------------|---------------------|-----------------|----------------------------|---------------------------------|----------------------------|---|
| BEV1 | PEV | Full vehicle | WLTC | 94 | 0.0 | 96.2 | 3.8 | 4.6 |
| BEV2 | PEV | Full vehicle | WLTC | 75 | 0.0 | 85.3 | 14.7 | 17.7 |
| BEV2 | PEV | Full vehicle | WLTC | 62 | 0.0 | 85.5 | 14.5 | 17.4 |
| BEV2 | PEV | Full vehicle | WLTC | 55 | 0.0 | 87.2 | 12.8 | 15.3 |
| BEV3 | PEV | Full vehicle | WLTC | 100 | 0.0 | 91.5 | 8.5 | 10.2 |
| BEV4 | PEV | Brake dyno | WLTP brake | N/A | 0.0 | 97.5 | 2.5 | 2.5 |
| BEV5 | PEV | Brake dyno | WLTP brake | N/A | 0.0 | 96.1 | 3.9 | 3.9 |
| PHEV1 | OVC-HEV | Full vehicle | WLTC | 28 | 2.9 | 79.5 | 17.6 | 21.2 |
| PHEV1 | OVC-HEV | Full vehicle | WLTC | 55 | 1.7 | 84.6 | 13.7 | 16.4 |
| PHEV1 | OVC-HEV | Brake dyno | WLTP brake | N/A | 0.0 | 76.0 | 24.0 | 24.0 |
| PHEV2 | OVC-HEV | Full vehicle | WLTC | 11 | 2.5 | 72.2 | 25.2 | 30.3 |
| PHEV3 | OVC-HEV | Simulation | WLTC | 100 | 0.0 | 86.1 | 13.9 | 16.7 |
| PHEV3 | OVC-HEV | Simulation | WLTP brake | 100 | 0.0 | 82.9 | 17.1 | 17.1 |
| PHEV4 | OVC-HEV | Brake dyno | WLTP brake | N/A | 0.0 | 83.0 | 17.0 | 17.0 |
| PHEV4 | OVC-HEV | Brake dyno | WLTP brake | N/A | 0.0 | 83.7 | 16.3 | 16.3 |
| FHEV1 | NOVC-HEV | Brake dyno - Rear | WLTP brake Trip #10 | N/A | 0.0 | 61.9 | 38.1 | 38.1 |
| MHEV1 | NOVC-HEV | Full vehicle | WLTC | 45 | 13.4 | 38.6 | 48.0 | 57.6 |
| MHEV1 | NOVC-HEV | Full vehicle | WLTC | 60 | 24.7 | 33.6 | 41.7 | 50.1 |
| MHEV2 | NOVC-HEV | Full vehicle | WLTC | 73 | 3.5 | 43.8 | 52.8 | 63.3 |

BRAKE EMISSIONS GTR – COEFFICIENTS

| Vehicle Category | Non-Friction Braking Coefficient (c) |
|--|--------------------------------------|
| NOVC-HEV Category 1 (battery with nominal voltage \leq 60V) | 0.63 |
| NOVC-HEV Category 2 (battery with nominal voltage $>$ 60V) | 0.40-0.45 (to be finalized) |
| OVC-HEV | 0.30 |
| PEV | 0.15 |

- ✓ *The coefficients have been elaborated considering the worst performing vehicle in each category and applying a 20% correction to take into account the change of cycle (OICA correlation);*
- ✓ *Two tests with BEV2 have been treated as outliers due to their high values of friction share compared to other JRC, OICA, and third-party data;*
- ✓ *Only one single data point has been delivered for NOVC-HEV Category 2 – Additional data are under elaboration at JRC with the aim of updating the value by 23.12.*
- ✓ *A footnote will be added stating that “A detailed testing methodology to determine vehicle-specific coefficients will be included in the first amendment to this UN GTR”*

ADDITIONAL ITEMS

BRAKE EMISSIONS GTR – ADDITIONAL ITEMS

Non-friction braking vs. another term

Current definition 3.7.1: "Non-friction braking" in the context of this UN GTR means the decelerating of the vehicle by different technical means without using the friction braking system, e.g. such as regenerative braking.

Problem: The GTR discusses friction brake emissions also from vehicles featuring non-friction brake systems. Do we need a different term to cover the friction part of these systems?

Solution 1: Definition 3.7.1: "Non-friction braking" in the context of this UN GTR means the decelerating of the vehicle **also** by different technical means without using **solely** the friction braking system, e.g. such as regenerative braking.

Solution 2: Adoption of a different term to cover the friction braking in these vehicles – Would e.g. “Not full-friction brakes” or “Partly full-friction brakes” be acceptable?

BRAKE EMISSIONS GTR – ADDITIONAL ITEMS

Enclosure recommended values

Current text in 7.4.3 (a): Design the brake enclosure symmetrically to Plane A1... **It is recommended to design an enclosure with a length close to [PLACEHOLDER] mm** – Similar in 7.4.3. (b) and (g)

- ✓ PMP members reported that several enclosures that meet the requirements work – When it comes to temperature control smaller enclosures seems to work better. Speed uniformity is not a problem for smaller and bigger enclosures – Overall, need to avoid oversized enclosures.
- ✓ Proposal: **(a) It is recommended to design an enclosure with a length close to 1350 mm; (b) It is recommended to design an enclosure with a height close to 600 mm; (g) It is recommended to design an enclosure with an axial depth close to 400 mm.**

If these values are not acceptable to all PMP members (deadline 23.12.2022), JRC proposes to withdraw the recommended values for the enclosure dimensions from the GTR.

BRAKE EMISSIONS GTR – ADDITIONAL ITEMS

Definition of NOVC-HEV

Problem: There is no separation between full-hybrid vehicles and mild-hybrid vehicles. These two categories feature different regenerative braking levels.

Solution: 3.7.7. "Not off-vehicle charging hybrid electric vehicle" (NOVC-HEV) means a hybrid electric vehicle that cannot be charged from an external source. In this UN GTR, NOVC-HEV are categorized to "NOVC-HEV Category 1" and "NOVC-HEV Category 2" based on their battery nominal voltage.

3.7.8. "Not off-vehicle charging hybrid electric vehicle – Category 1" (NOVC-HEV Cat. 1) means a hybrid electric vehicle that features a battery with nominal voltage lower than or equal to 60V that cannot be charged from an external source.

3.7.9. "Not off-vehicle charging hybrid electric vehicle – Category 2" (NOVC-HEV Cat. 2) means a hybrid electric vehicle that features a battery with nominal voltage higher than 60V that cannot be charged from an external source.

Thank you



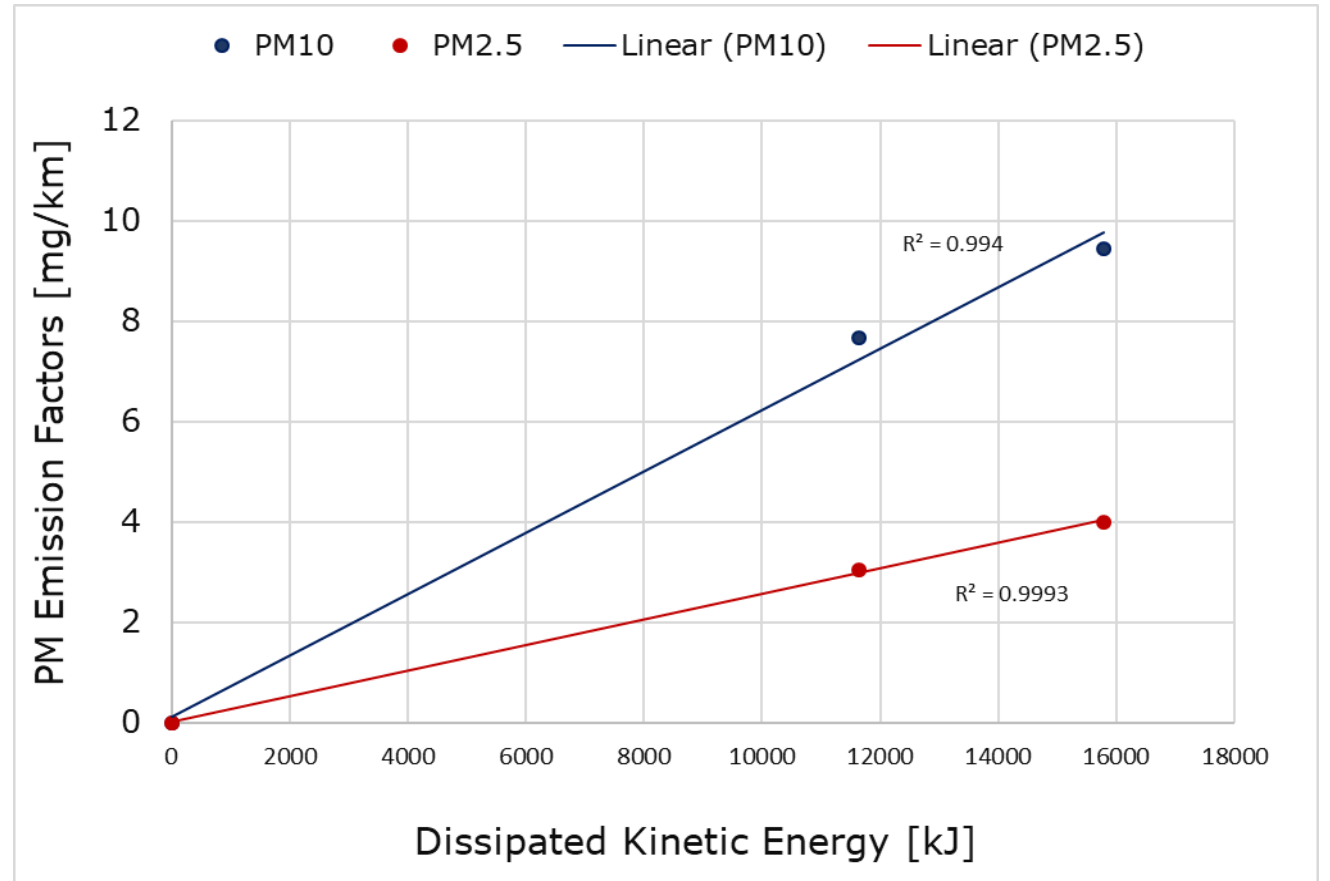
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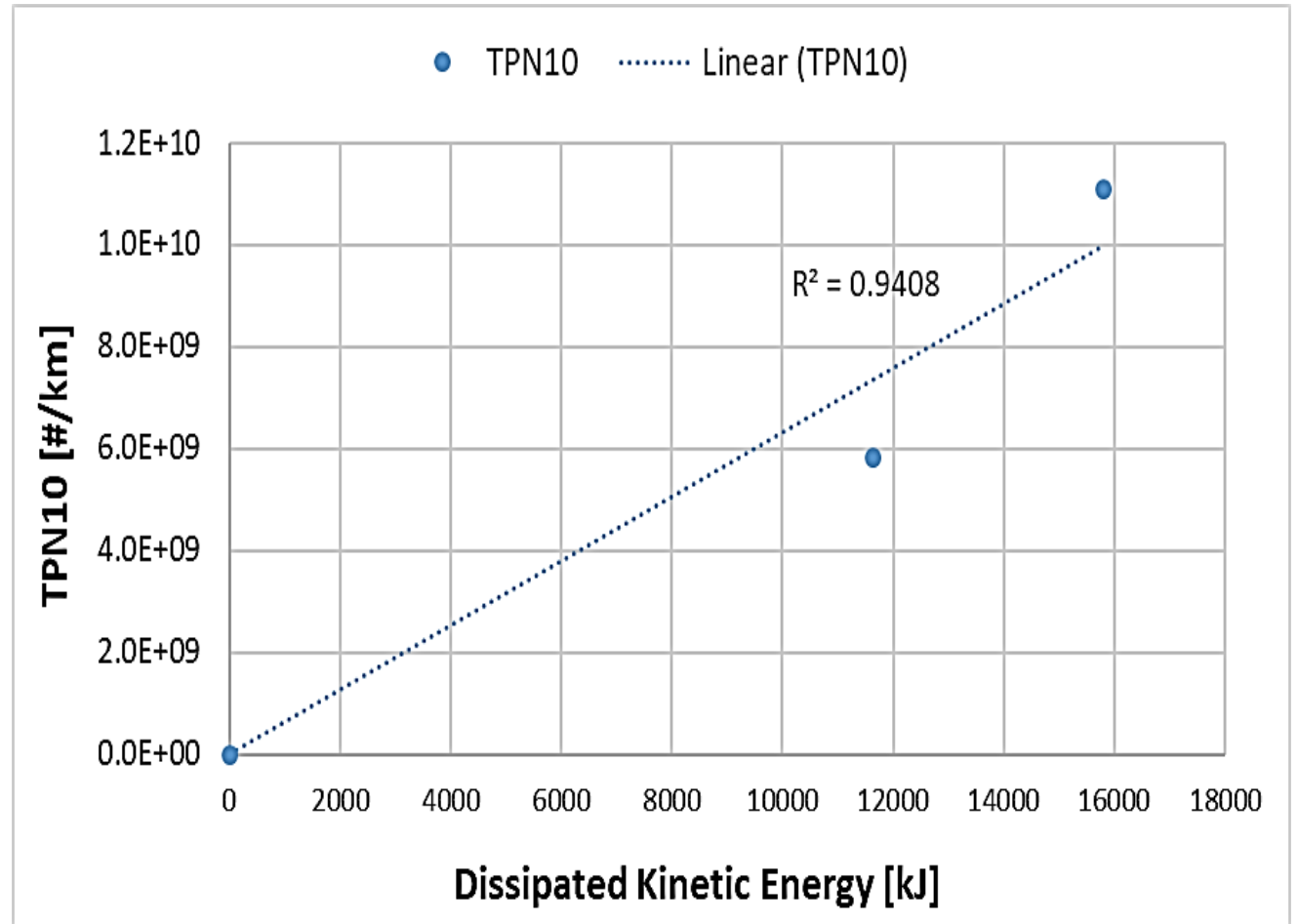
Friction Energy – Emissions linearity

- ✓ During the ILS Br5 was tested under two different payloads for its emissions – the graph plots the dissipated kinetic energy against the PM2.5 and PM10 emissions;
- ✓ Despite that it is very difficult to show linearity with only two data points – and assuming that zero friction energy results in zero emissions – the R^2 is high and looks like there is a good linearity between friction energy and PM emissions.



Friction Energy – Emissions linearity

- ✓ During the ILS Br5 was tested under two different payloads for its emissions – the graph plots the dissipated kinetic energy against the TPN10 emissions. Labs did not test SPN10 for this brake;
- ✓ Despite that it is very difficult to show linearity with only two data points – and assuming that zero friction energy results in zero emissions – the R^2 is high and looks like there is a good linearity between friction energy and TPN10.



Coefficients – Trip #10

| | WLTP-Brake Cycle | Trip #10 | Ratio |
|--|------------------|-------------|------------|
| Duration [s] | 15826 | 5272 | 33% |
| Number of Events [#] | 303 | 114 | 38% |
| Deceleration Rate [m/s ²] | 0.97 | 0.93 | N/A |
| Energy Dissipated [J/kg] | 15983 | 5555 | 35% |

- ✓ *Trip #10 of the WLTP-Brake cycle is representative of the entire cycle in terms of number of brake events and dissipated energy – additionally the severity of the brake events is comparable;*
- ✓ *Data collected over the Trip #10 of the WLTP-Brake cycle can be considered representative and are used for the elaboration of the coefficients.*