Investigation of brake wear particle emissions from various friction couples in an enclosed brake dynamometer

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Introduction

With stringent emissions standards in effect for engine exhaust particles, brake wear emissions are increasingly coming into focus within the automotive and brake industry. Estimates of the contribution of various sources to total particle emissions are shown in Figure 1, along with specific contributions from components relating to road transport. The current Euro VI standards for engine tailpipe emissions from passenger cars are 4.5 mg/km for particle mass and 6 x 10^{11} /km for particle number.

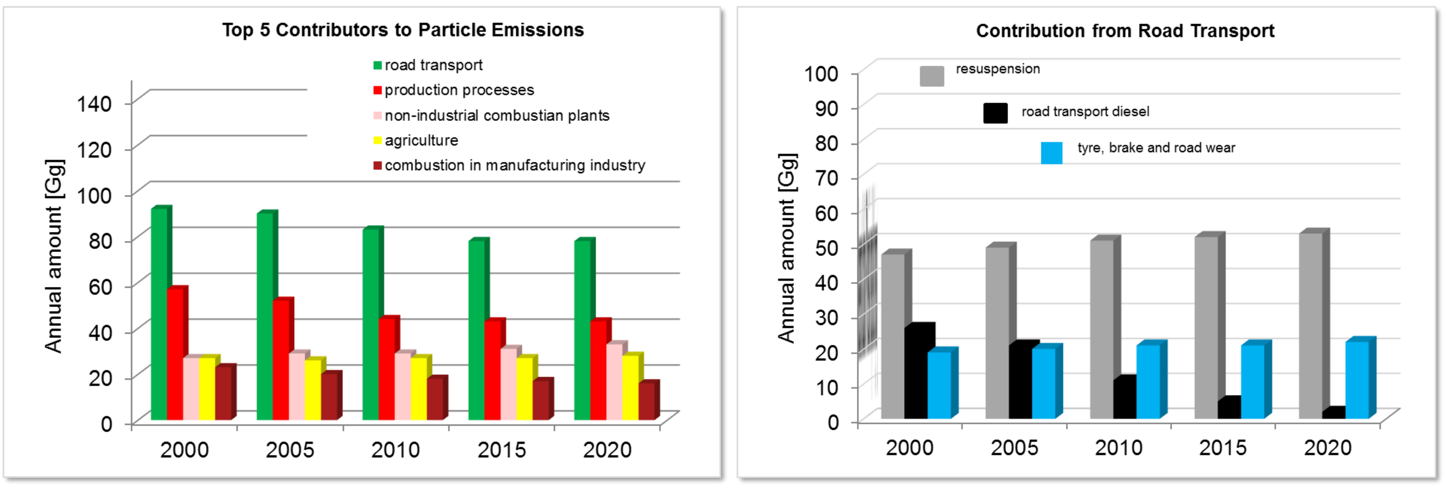

Figure 1: General sources of particle emissions (left) and divided by components of road transport (right), estimated by Umweltbundesamt Germany in 2013

The two most widely-used friction material concepts for light-duty vehicles are NAO (non-asbestos organics) and L/M (low metallic). Depending on the requirements, NAO pads are usually applied in North America and Asia while L/M pads are mostly used in Europe. As yet, no common agreement exists for the way in which particles emitted by the brakes are to be measured. Tests will run on a representative dynamometer with specified equipment for testing, sampling and analysis; details are currently being evaluated in the UNECE-PMP Group. Research and development must cover pads/linings and discs/drums in their combinations and in relation to the brake system to which they apply (and additional measures such as recuperative braking or secondary dust sampling will need to be taken into account if they are not examined on the dyno).

TMD Friction's current study in collaboration with Cambustion and MS4 demonstrates a well-suited method for measuring brake emissions on an enclosed inertia dynamometer, using a CVS (constant volume sampling) approach with controlled cooling air flow and isokinetic sampling. By using this method the potential of various friction couples to reduce brake emissions can be investigated; particle size, total number and mass are measured during a test schedule comprising urban and extra-urban sections.

Method

In order to devise a test schedule representative of real driving conditions, urban and extra-urban sections of a brake emissions cycle were recorded on a vehicle driven in Cologne (urban) and through the Bergisches Land (extra-urban). See Table 1 for details. Five friction couples were tested that comprised combinations of NAO or L/M pads with grey cast iron disc (coated or uncoated) and each test was repeated twice.

	Type of test [-]	Distance [km]	Stops [#]	Stops per km [#/km]	Energy per km [kJ/km]	Energy per stop [kJ]
Cologne city cycle	Urban	75	188	2,5	333	133
Bergisch land cycle	Extra-urban	232	332	1,4	283	198

Table 1: Urban and extra-urban sections forming the brake emissions test cycle

The emissions cycle was run on an enclosed inertia dynamometer with recirculating cooling air. As shown in Figure 2, the air passes through an upstream HEPA filter. The temperature and humidity of the cooling air is controlled (20°C, 50% RH) and brake particles are sampled isokinetically in the exhaust duct (at a position more than 8 pipe diameters downstream of the brake housing). The CVS principle means calculations of particle mass and number per km can be made.

Emissions were measured concurrently by a Cambustion DMS500, a Dekati ELPI and a TSI Dusttrak DRX. The cooling air flow rate was set to 70 m^3/hr to ensure that emissions during low energy brake applications in the urban section were comfortably above background noise (which is assumed to originate from particles re-entrained from the surfaces of the housing and downstream duct).

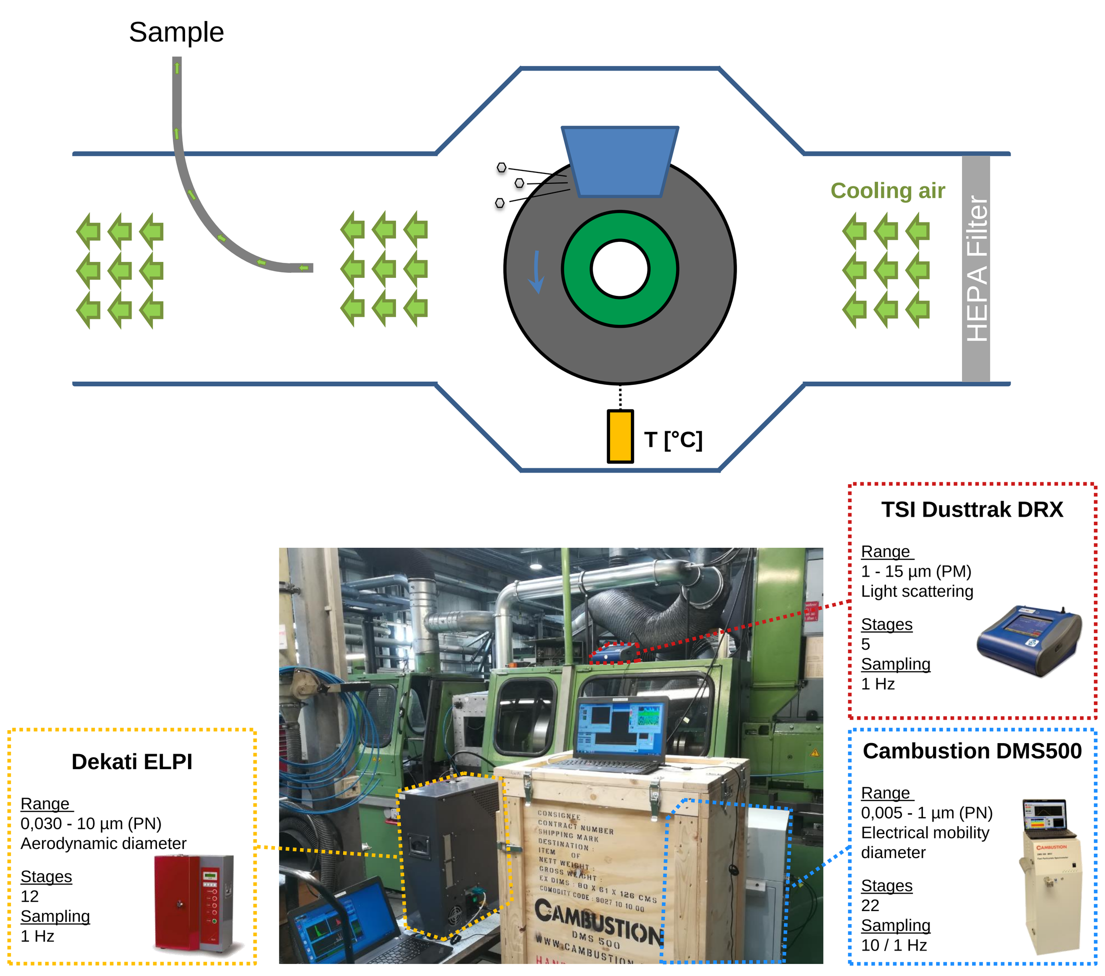

Figure 2: Schematic of brake dyno housing with filtered cooling air (top) and instruments used to measure particle emissions (bottom)

Brake particle mass emissions

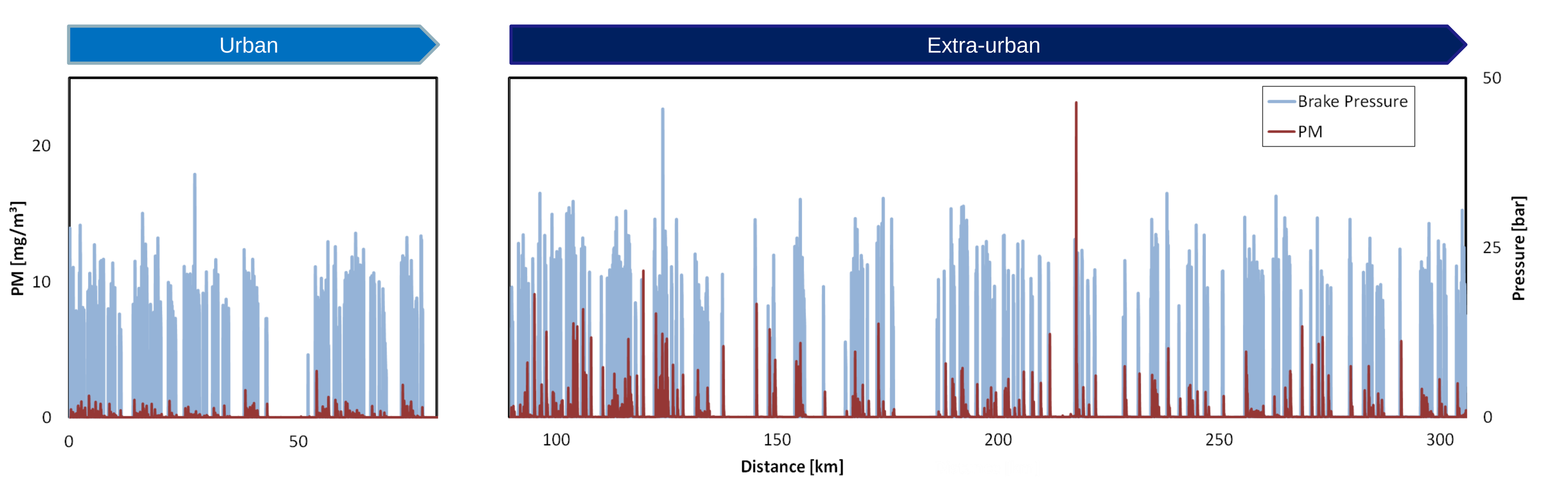

Figure 3: Brake pressure and particle mass emissions (measured by Dusttrak) during entire test cycle for friction couple with highest emissions

Figure 3 shows an entire brake dyno test for the friction couple with greatest particle mass emissions. Significantly higher emissions occurred in the extra-urban section, where an average of 0.18 mg/km was measured. For the urban part the average value was 0.07 mg/km.

As shown in Figure 4, a useful correlation was observed between emitted particle mass and total wear determined by weighing for all five friction couples. Mass emissions were significantly reduced by using low wear materials.

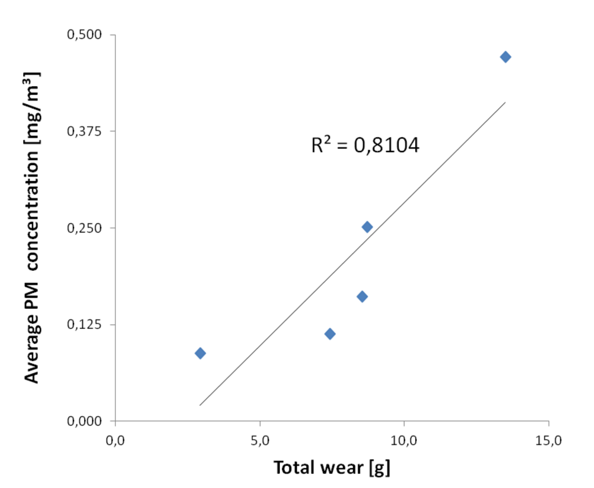

Figure 4: Average mass concentration of emitted brake wear particles versus measured loss of mass from friction couple

Brake particle number emissions

Total particle number emissions during the urban section of the test cycle generally fell well below the Euro VI limit. In the case of the friction couple with the highest number emissions, the urban average was 1.5 x 10^8 /km. Subsequently, the extra-urban average was 1.6 x 10^{11} /km; while this value is still sub-Euro VI, the maximum was 1.4 x 10^{13} /km, which exceeds the limit by a factor of >20. As shown in Figure 5, these extremely high emissions occur when the brake disc temperature for this particular pad and disc combination exceeds 150°C.

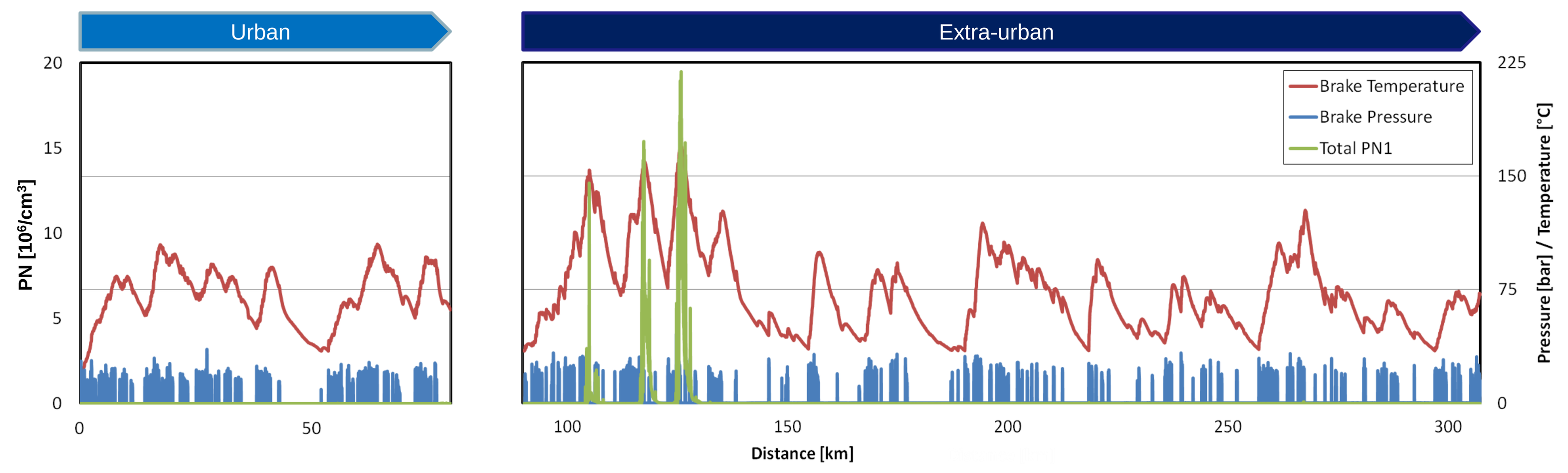

Figure 5: Brake temperature, pressure and total particle number emissions (measured by DMS500) during entire test cycle for friction couple with highest emissions

As shown in Figure 6, the total number concentration for particle release varies significantly between the friction couples:

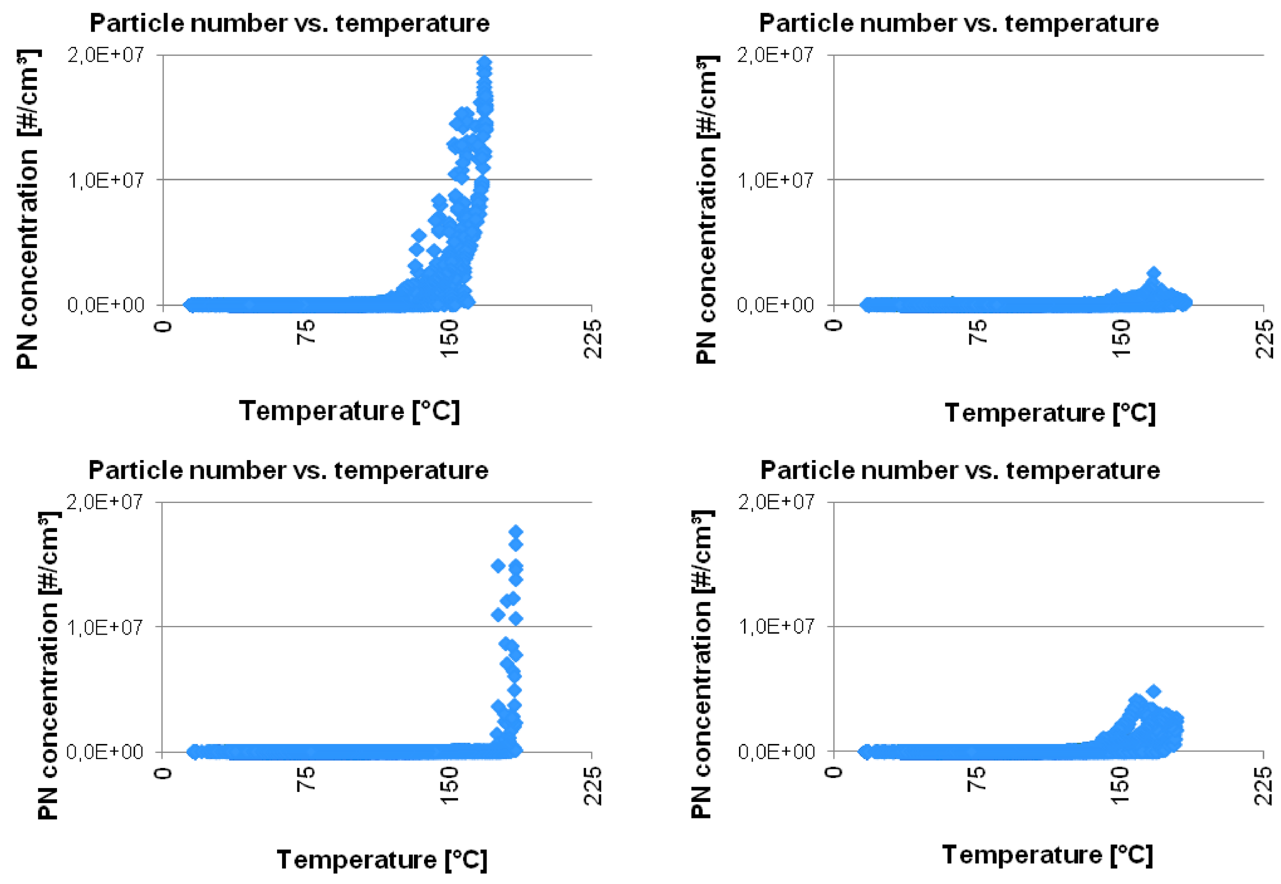

Figure 6: Total particle number emissions versus brake temperature for four different combinations of pad and disc materials

Brake particle size distribution

In most cases when the DMS500 measurements are averaged over the entire test cycle, a bi-modal distribution is evident with a small mode <20 nm and a large mode between 150 nm and 200 nm. The data shown in Figures 7 and 8 again apply to the friction couple that had the highest total particle number.

As shown in the 5 minute portion of the extra-urban part in Figure 7, repeated brake applications lead to the temperature-driven release of high concentrations of small particles from friction material.

The DMS500 contour plot in Figure 8 displays particle size information along the same time range as in Figure 7, with dynamic spectra shown at two features of interest. For this friction couple, the mode falls below 10 nm at the no.1 label when the brake temperature exceeds 140ºC; a little later at the no.2 label when the disc has cooled, the size distribution shifts up and the total number decreases.

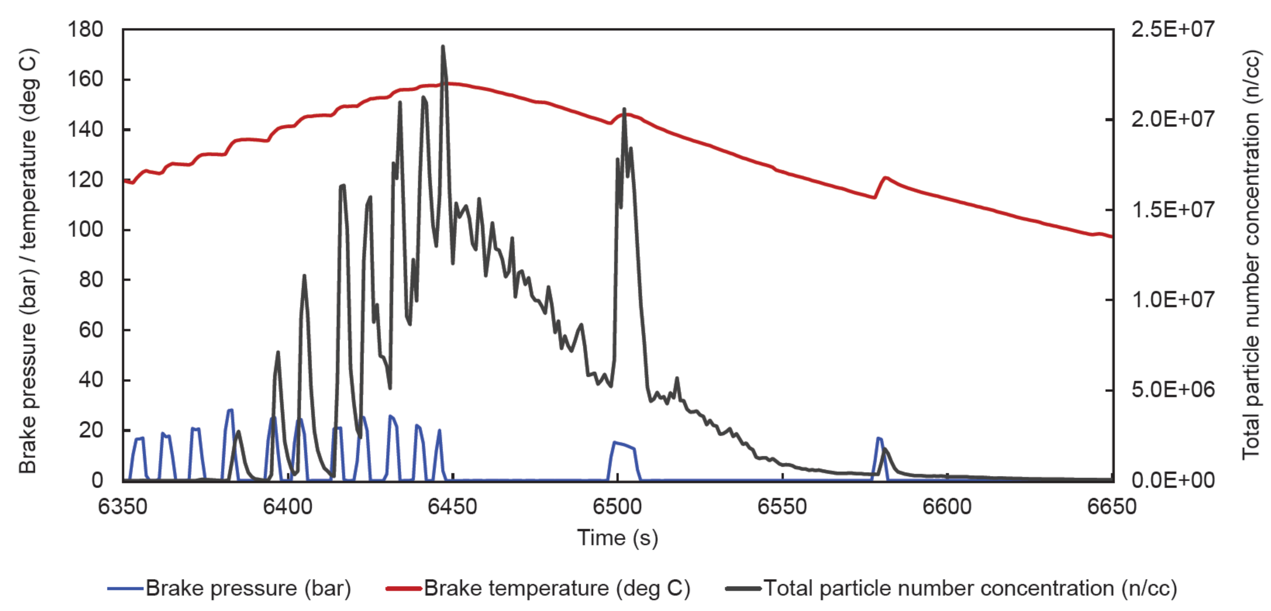

Figure 7: DMS500 total number (n/cc) during portion of extra-urban drive cycle, with brake pressure & temperature from dynamometer transmitted to DMS500 analog inputs

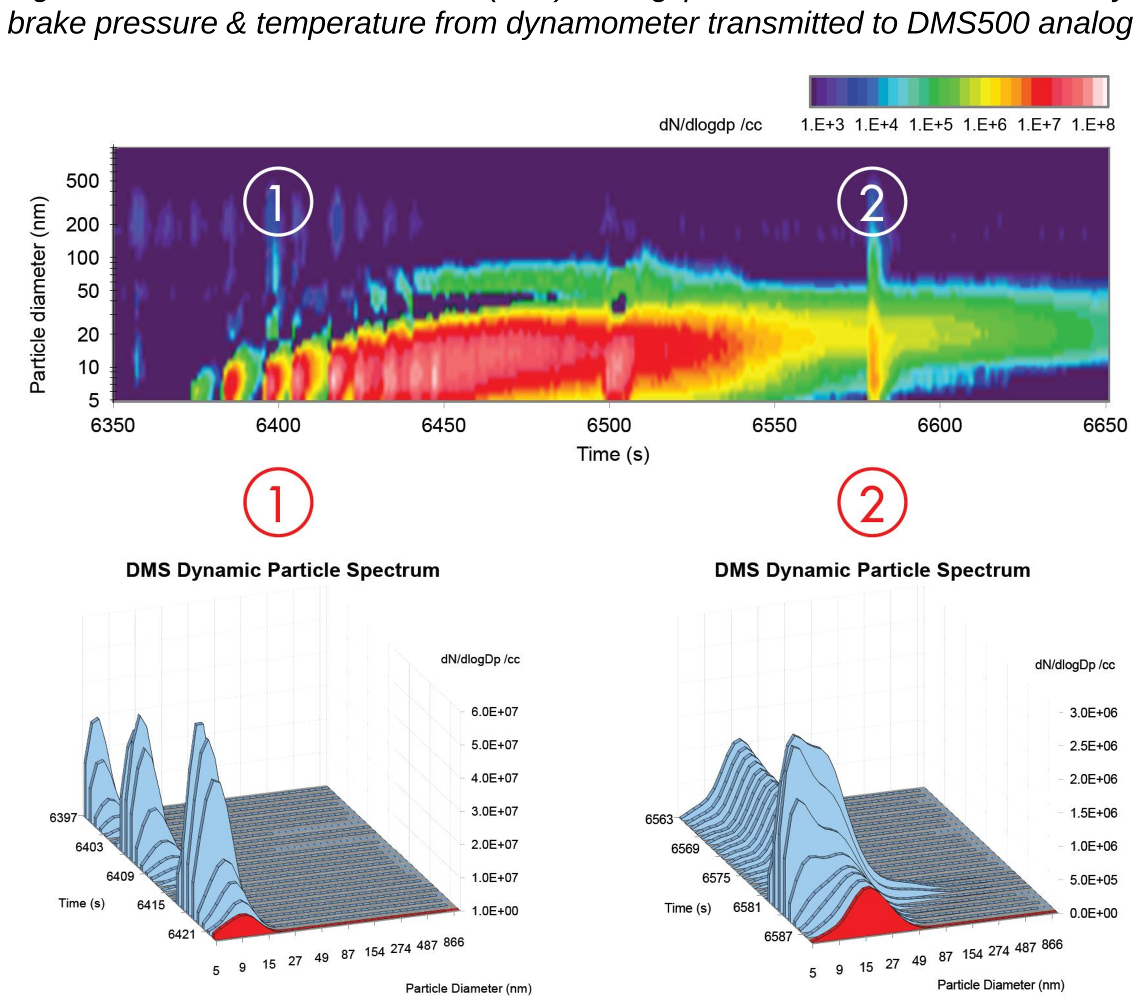

Figure 8: DMS500 contour plot (top) and dynamic particle spectra (bottom)

Conclusions

- An enclosed brake dynamometer set-up with controlled cooling air flow for repeatable brake emissions measurements and a test schedule representative of urban and extra-urban driving were developed.
- The results suggest that in urban areas the levels of particle number and mass emitted by friction brakes will fall comfortably below the Euro VI limits for engine exhaust.
- Particle mass emissions can be correlated with weighed loss of friction material.
- Particle number emissions during high demand braking events (in the extra urban part of the cycle) can significantly exceed the Euro VI limit. In these instances a certain disc temperature threshold is exceeded, leading to high concentration releases of sub-20 nm particles.
- Specification of low wear pad and disc linings can drastically reduce particle emissions.
- **Future work** will include estimation of particle losses before sampling, detailed analysis of the particle size distribution at different points in the test cycle and chemical analysis of size-segregated particulate matter collected in the ELPI stages.