Particle Emissions From Tyre Wear – Results from the Phase 1 study for the UK DfT

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AGENDA

Introduction to non-exhaust emissions

Measurement of Brake and Tyre Wear

System design and testing

Results

Conclusions

Non Exhaust Emissions (NEE)

Brake Wear
Friction between the brake disc and brake pads occur when the brake pedal is pressed – releasing particles.

Road surface wear
Friction between the tyre tread and road surface

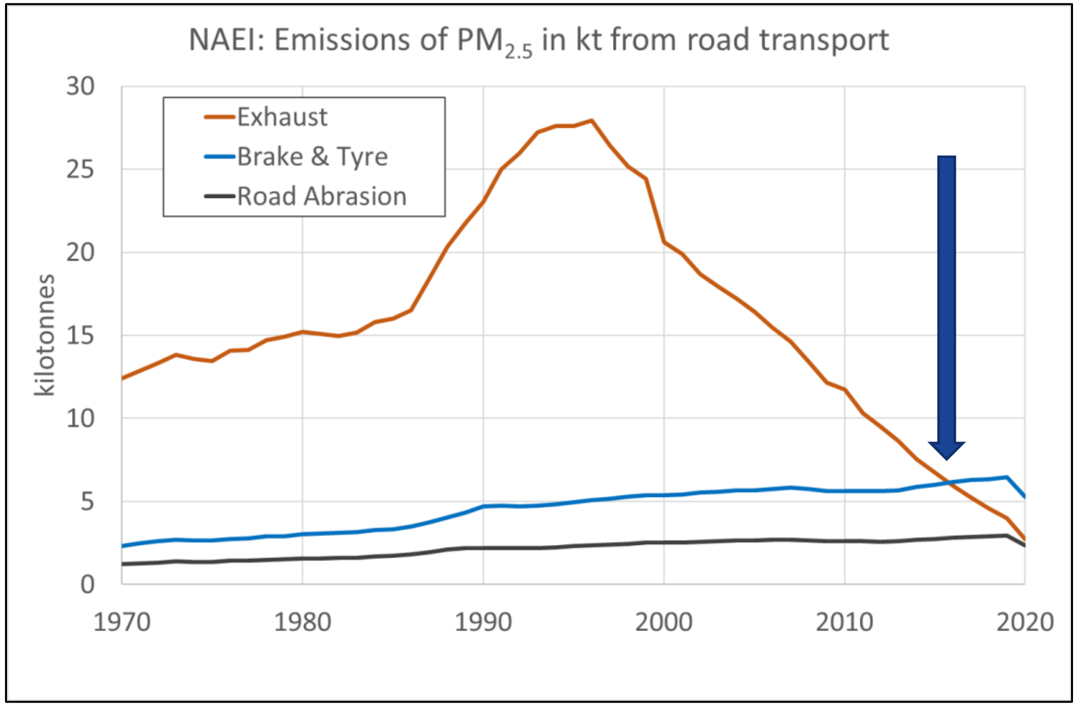
Re-suspension of road dust

Tyre Wear
Friction between the tyre tread and road surface releases particles from the tyres.

https://www.cvsltd.co.uk/car-leasing/volkswagen-caddy/

Non-exhaust emissions (NEE) in the UK

- Emissions of PM from exhausts has decreased since the mid-90s
- However, the contribution of NEE to particulate matter (PM) from traffic has increased
- In the UK, Brake and Tyre wear emissions are now the primary source of PM_{10} and $PM_{2.5}$ from road transport
- There is a transition towards zero (exhaust) emission vehicles on the road. Resulting in a need to measure, understand, and control non-exhaust emissions



Data source: https://naei.beis.gov.uk/

Non-exhaust emissions (NEE) in the UK

Department
for Environment
Food & Rural Affairs

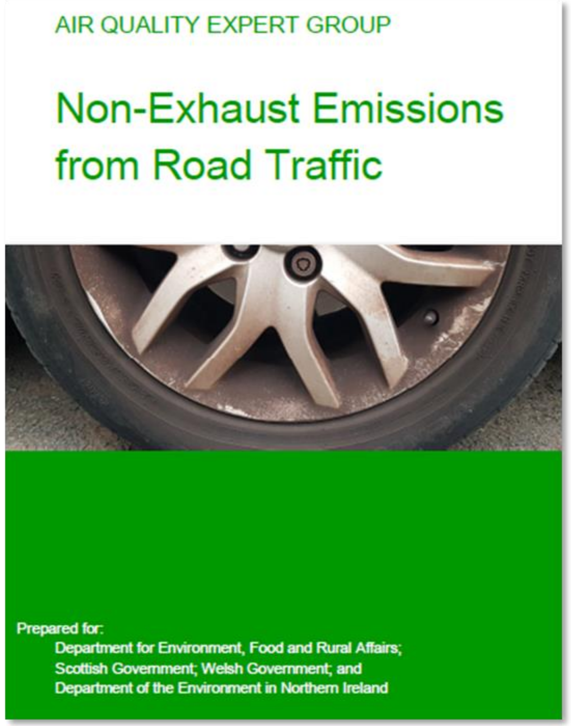
Department
for Transport

Office for Low Emission
Vehicles

Consultation outcome

Brake, tyre and road surface wear call for evidence: summary of responses

Updated 11 July 2019


AIR QUALITY EXPERT GROUP

Non-Exhaust Emissions from Road Traffic

Prepared for:
Department for Environment, Food and Rural Affairs;
Scottish Government; Welsh Government; and
Department of the Environment in Northern Ireland

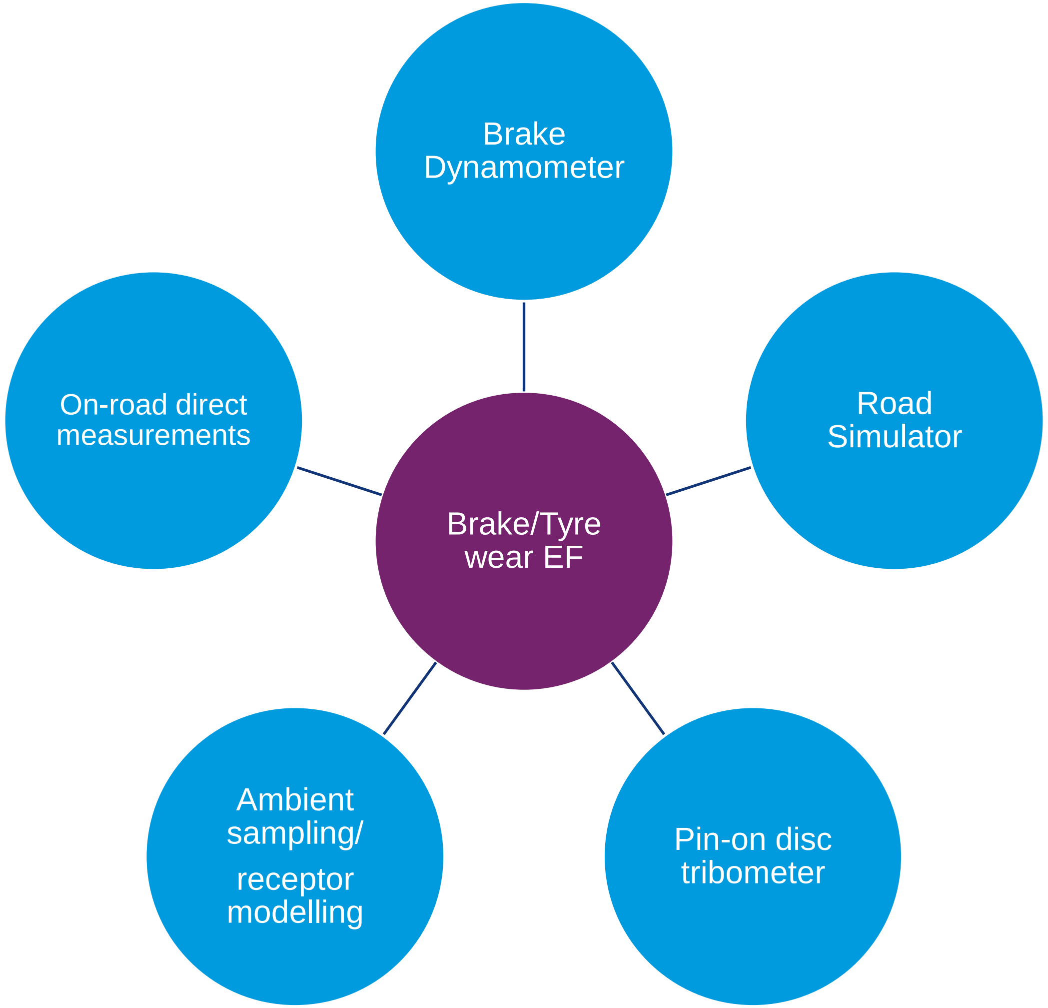
Measurement of Brake and Tyre Wear

To determine the impact of NEE on PM in the atmosphere, emission factors (EF) need to be determined. These will depend on many variables such as:

- Vehicle type
- Vehicle weight
- Driving style
- Brake and tyre materials
- Road surface
- Temperatures

Studies have used different methods to estimate NEE PM EFs and this can result in varying results.

A standard regulated method (similar to that used for exhaust emissions) is needed to assess NEE



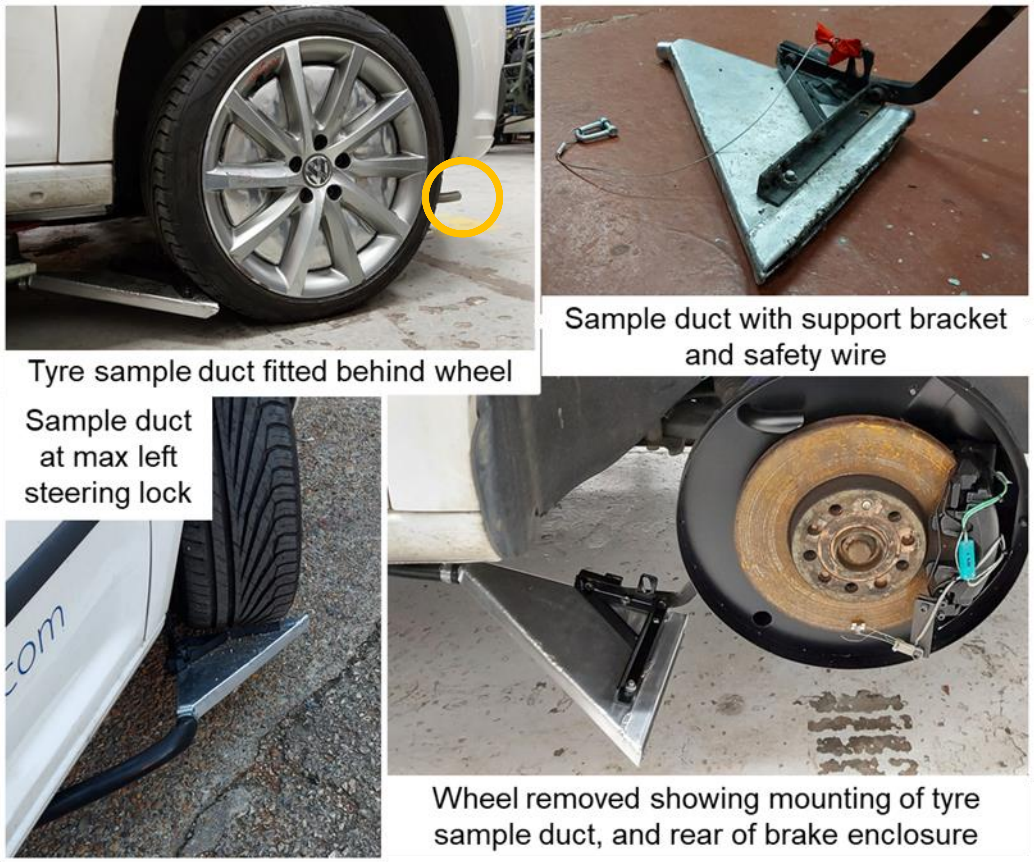
Measurement of Brake and Tyre Wear

Ricardo Energy & Environment and Ricardo Automotive and Industrial, in collaboration with the Arup AECOM consortium, are supporting the Department for Transport in the UK to develop an effective system and methodology for measuring and characterising particles emitted from brake and tyre wear under **real driving** conditions **(Phase 1)**.

In developing the system there was a need to consider:

- A common sampling system and measurement equipment which can be used for both brake and tyre wear
- Representative sample collection of particles from brake or tyre wear
- Repeatable and reproducible measurements
- Careful consideration of background particles (i.e. re-suspension of road dust, tailpipe emissions)
- Power and spatial demands of the system

System Design – Tyre Wear Sampling

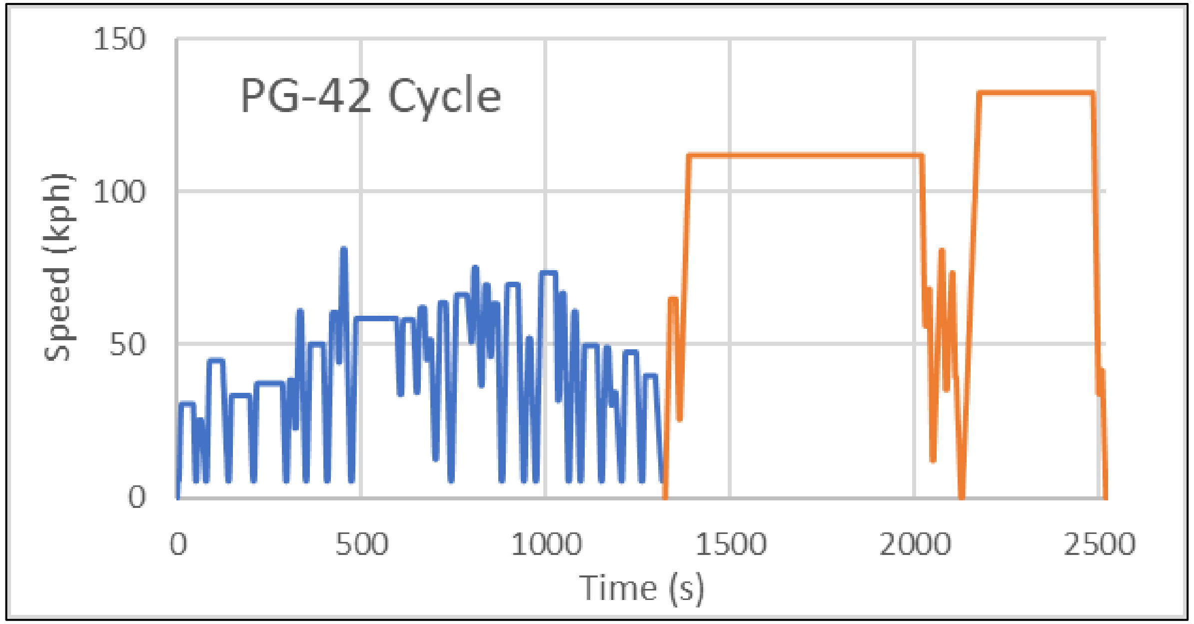


- Open duct to draw sample from behind the tyre-road contact patch into the measurement system.
- Inlet fabricated to be slightly wider than the tyre, and just above the road and angled to keep sufficient entry velocity for the sample flow and allow large material to drop out
- The duct was mounted to a bracket which in turn was fixed to the rear of the wheel hub carrier, so that the duct position is fixed relative to the wheel and swings with the wheel as it steers.
- Sample probes for monitoring background ambient particulates were fitted to the front of the vehicle

Test Plan and Drive Cycles

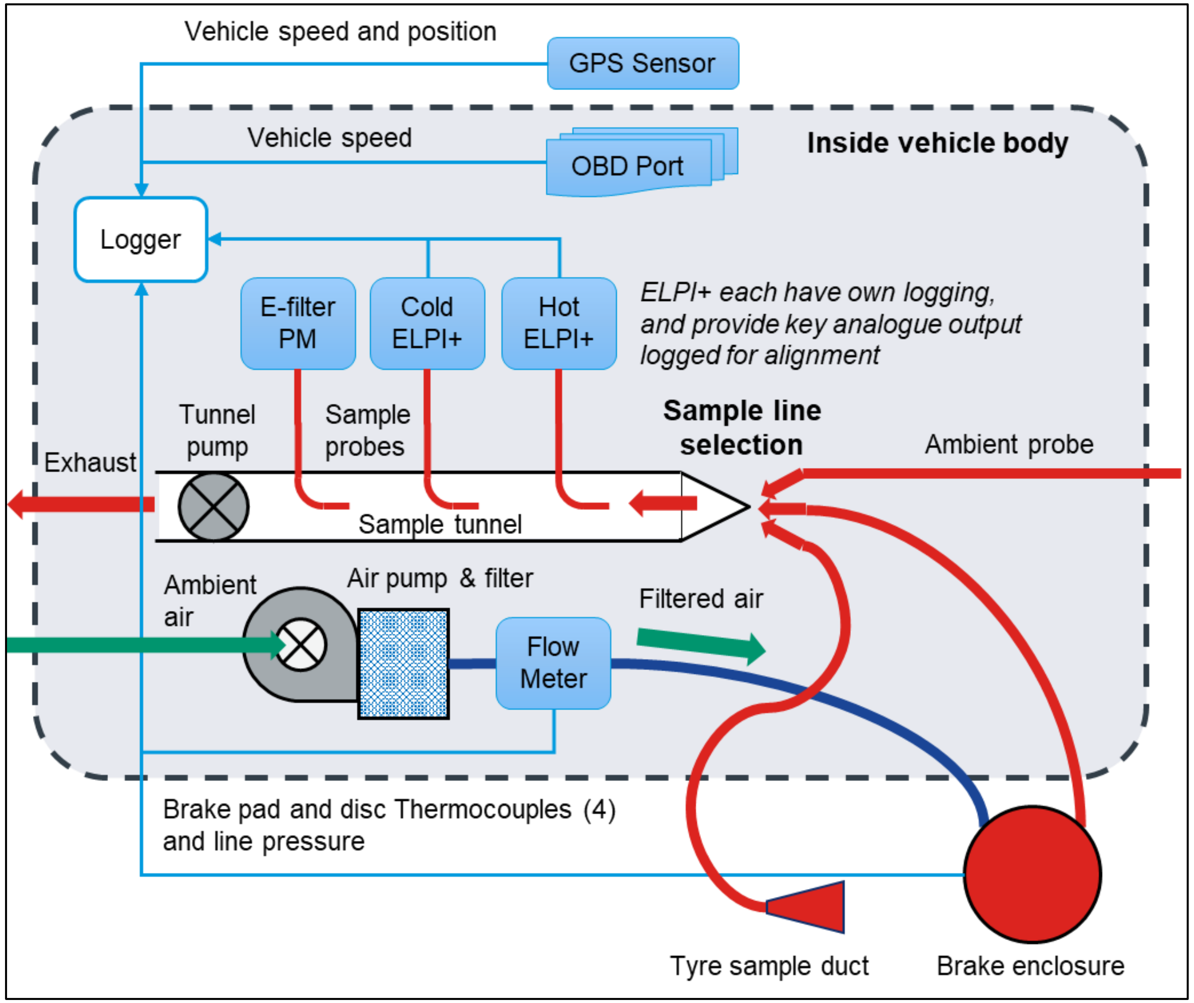
Tests	Details
Background sampling	Sampling background emissions from different inlets
Chassis Dyno	PG-42 cycles - sampling from brake and tyres
On-road/Track	Urban driving; track braking events of different magnitudes

Repeated measurements were undertaken for all tests



PG-42 - 42 minutes cycle based on high particle emitting sections of two well-known braking cycles: Worldwide Harmonized Light Vehicles Test Procedure (WLTP) and Los Angeles City Traffic (LACT).

System Design – Instrumentation

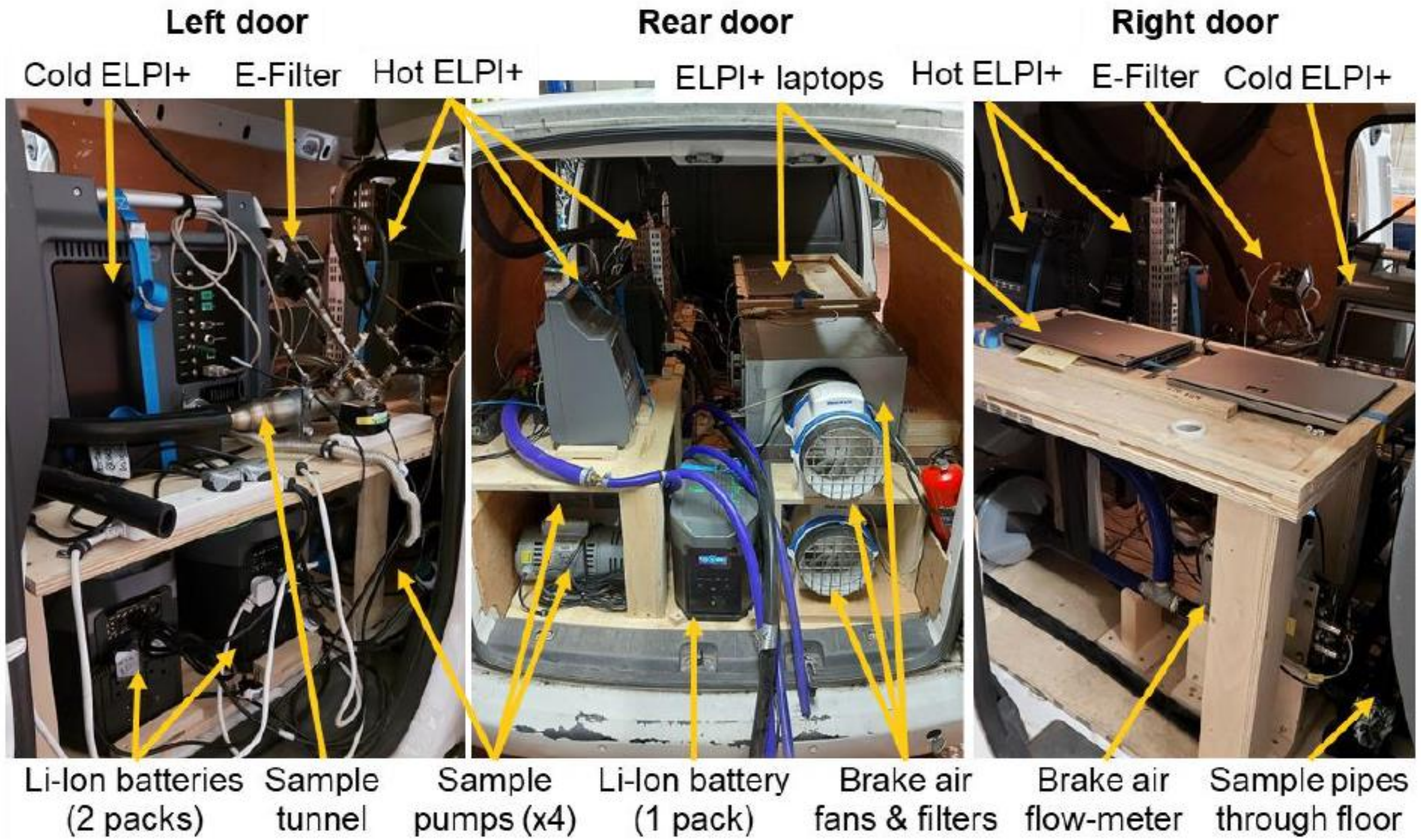


Sample analysis included:

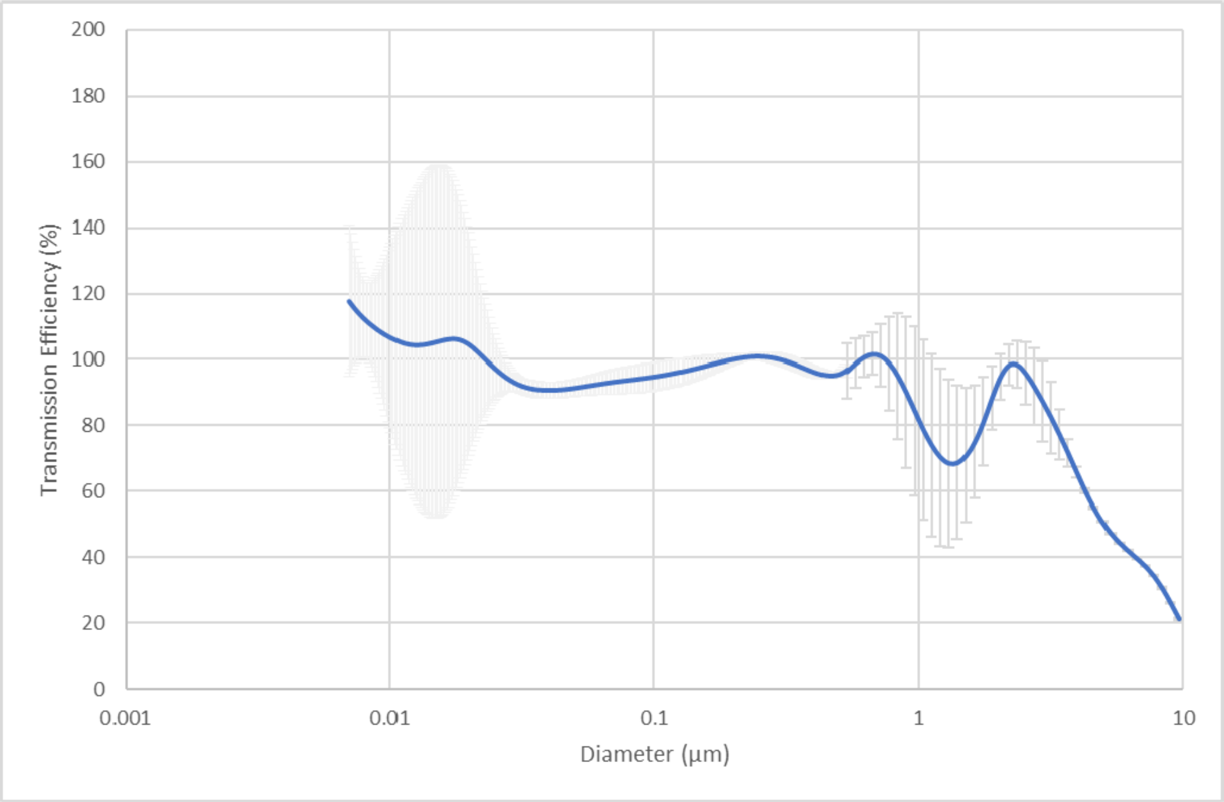
- Combination of two Dekati® Electrical Low Pressure Impactors (ELPI+) for real-time particle size distribution and concentration (size range 6 nm – 10 µm)
  - “Cold” ELPI+ measures solid and volatile particles
  - “Hot” ELPI+ includes a 180°C heated inlet to remove the volatile component of the PM
- Dekati® eFilter for real-time PM mass concentration measurements – also includes a filter for reference gravimetric determination and analysis
- PN23 system (raw) used in parallel from tunnel for lab tests

The entire system was installed to a small light duty van and measurements undertaken from the front tyre

VW Caddy vehicle

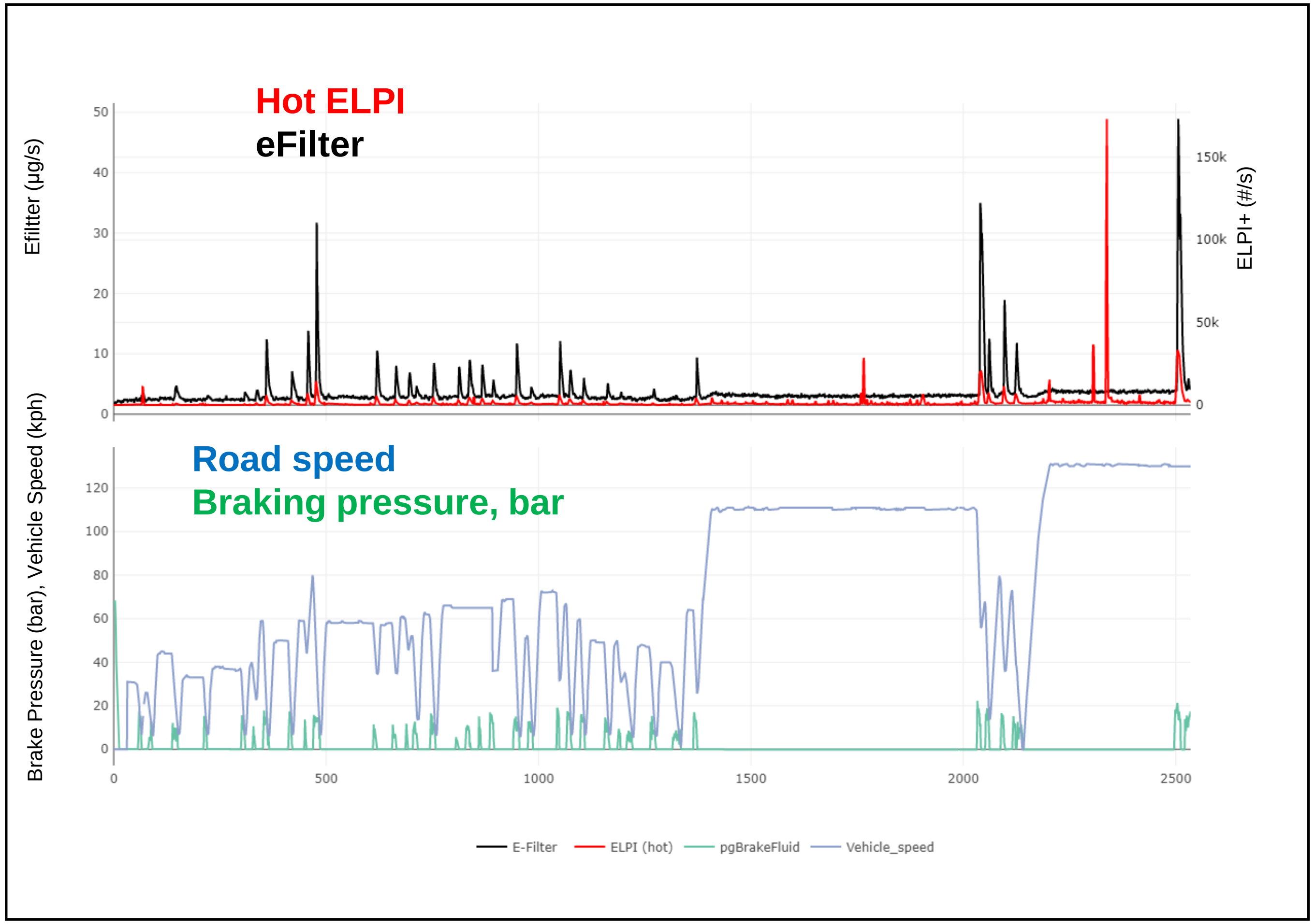


Particle penetration through sampling system



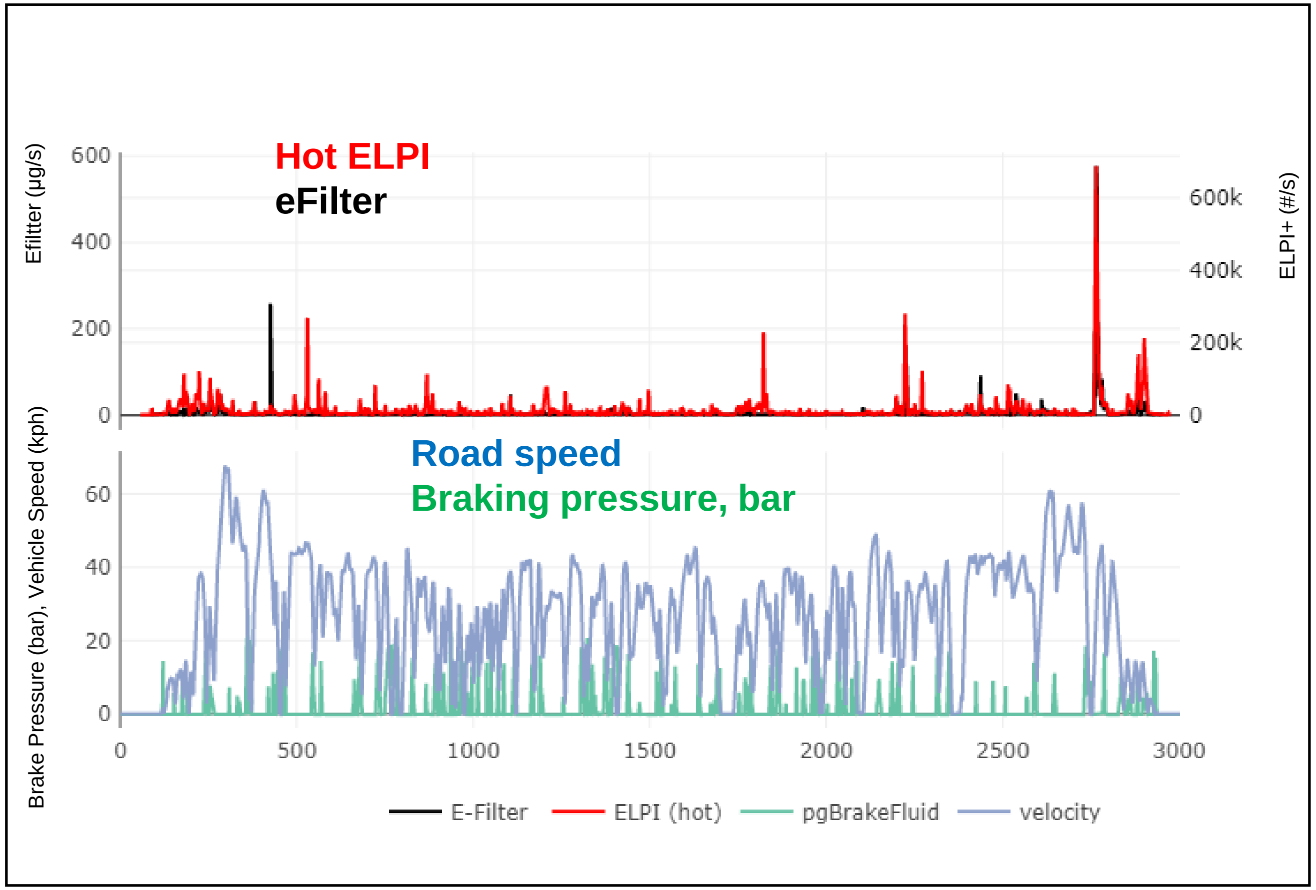
- Penetration close to 100% for particles up to ~3µm
  - Hence under-sampling of larger particles, which will have impacted PM_{10} determination by eFilter and gravimetry
  - $PM_{2.5}$ quantification likely to be more representative, and a more realistic objective for on-board sampling

Real time tyre emissions – Chassis Dynamometer



- Spikes of particle number emissions were observed from the ELPIs, both during braking events but also during accelerations and cruises
  - Indicating particles maybe be lost following, as well as during, braking events
- eFilter mass emissions appear to be closely related to the braking events
  - Most mass is lost immediately on braking
- Masses measured were an order of magnitude lower for tyre emissions than for the brake emissions
  - The efficiency of the tyre scoop is uncertain, and is to be explored in further work

Real time tyre emissions – Urban Road

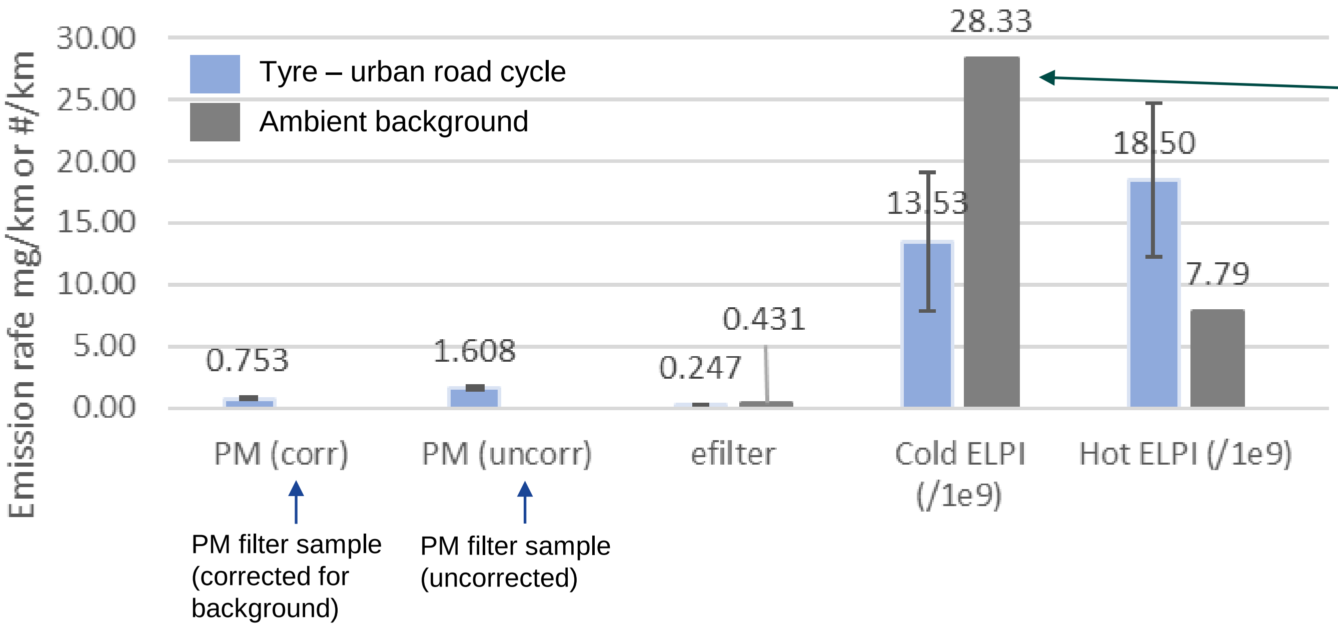


- Some urban braking events coincide with an emissions peak, however, not all do
- Peaks of both mass and number can also be observed that are not related to instantaneous braking events
- Emissions of both mass and number were higher on the urban road, compared to the chassis dyno, despite less severe braking events
  - Substantial contribution from source(s) other than braking

Background sampling and measurement – on road

Background (ambient) measurements of particles were undertaken on the road using background sample probes, located at the front of the vehicle.

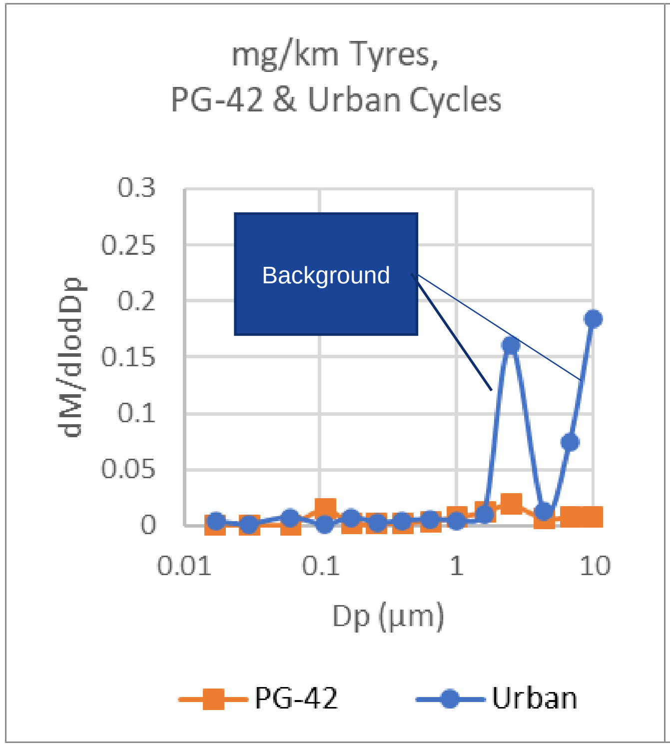
The average background values were then used to compare with measured emissions from the on-road tyre sampling.



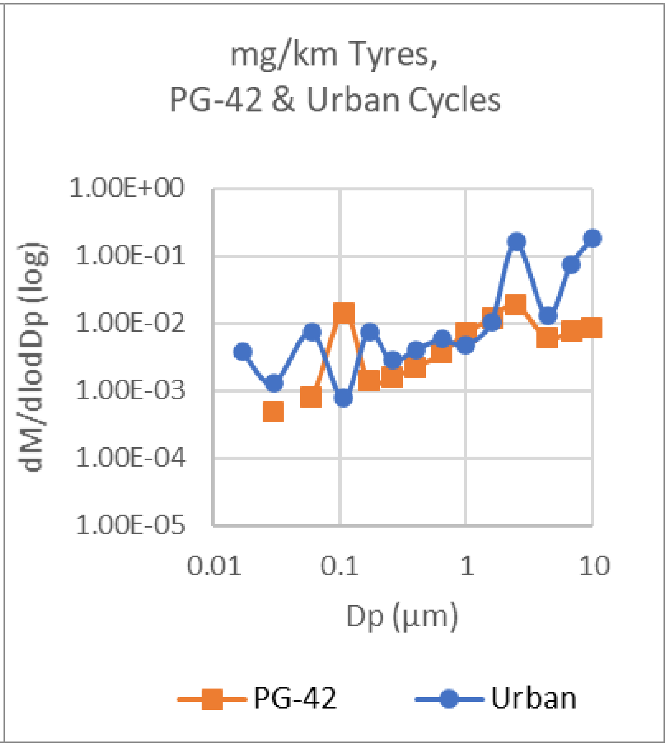
Average ambient background emissions higher than the tyre emissions for eFilter and cold ELPI during on road tests

Real time tyre emissions – particle mass size distributions

Mass Weighted Particle Size Distributions, Cold ELPI

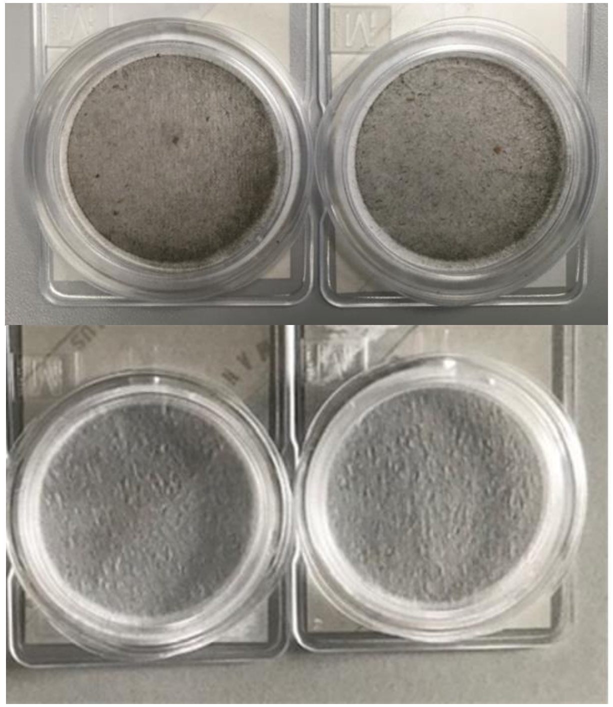


linear scale



log scale

- Chassis dyno PG-42 emissions are much lower than urban, despite the increased braking severity
  - Background contribution very high from >1µm materials

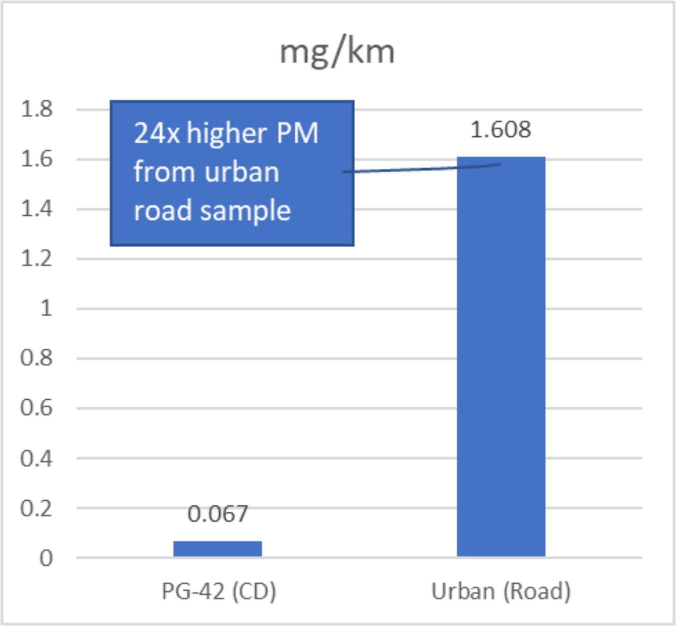


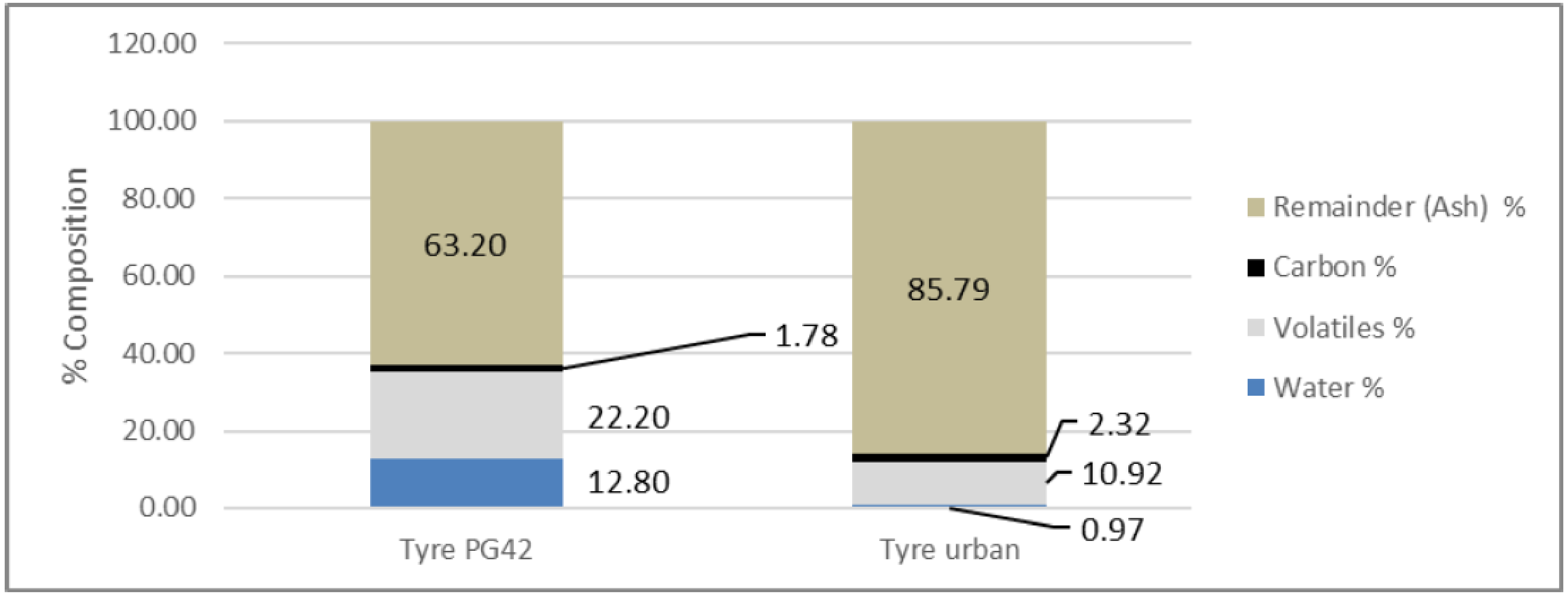
Urban testing PM filters are dirty & contaminated with discrete large particulates

Chassis Dyno filters show uniform PM material

Bulk Chemical Composition Tyre Filter Samples

Thermogravimetric analyses of filters from PG-42 (dyno) and Urban (on-road) Tyre tests



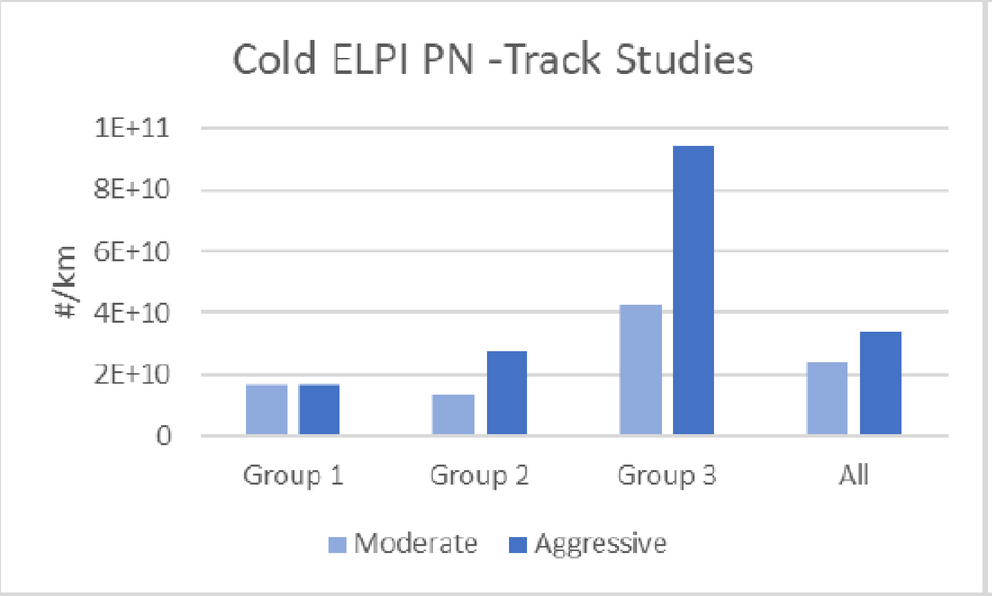


Substantially higher PM from urban road testing than from the chassis dyno, despite the more aggressive PG-42 cycle

PG-42 analysis shows ~63% of the PM material to be inorganic (non-oxidisable materials/ash) and the remainder volatiles;
Urban road testing showed substantially higher non-oxidisable materials, likely solid materials thrown up from the road surface from the tyre tread

Real time tyre emissions – Test Track

Data from three consecutive repeat sets of braking from 80kph and slower, are grouped and the integrated particle number for the cold ELPI calculated for each group.



Integrated particle numbers from moderate and aggressive tyre emissions tests

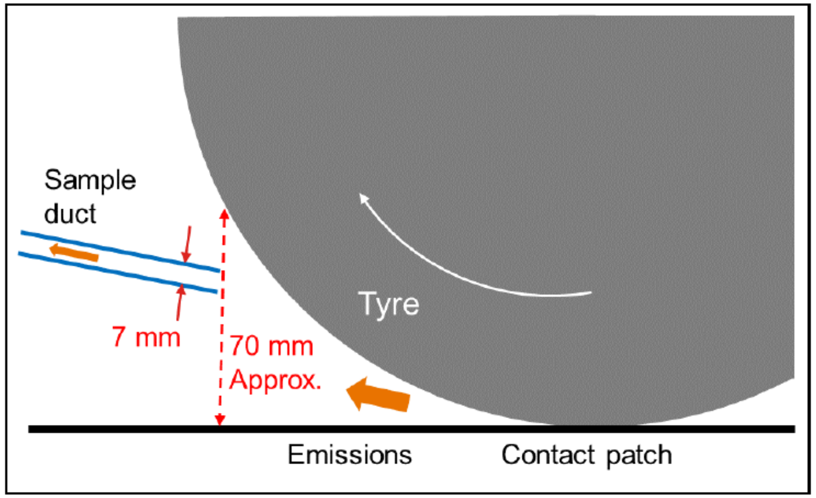
- Higher PN is measured by the cold ELPI as the aggressive braking tests proceed, than from the moderate braking tests
  - As the tyres heated up from repeated braking, an ‘out-gassing’ of volatile particles was observed
  - (*The effect is also present with the hot ELPI, though less apparent, which suggests that many of these particles are volatile below ~200°C*)
- Background contributions could be very significant to both mass and number
  - and were highly variable day to day

Tyre Inlet/Scoop Sampling Efficiency

- An estimate of the total material lost from a single tyre of 5 -10 mg/km was estimated in two ways
  1. Mass loss from a tyre is ~1,000 to 1,500g over the lifetime of a tyre (e.g., Grigoratos et al)
     - Tyre lifetime is 20,000km, and ~10% of the mass is PM10. => PM10 emissions of 5 mg/km to 7.5 mg/km.
  2. Density of crumb rubber (1.2 g/cm^3), initial tread depth of 8mm and end-of-life tread depth of 1.6mm, tyre tread area of ~122,000mm^2 (from Ricardo measurements) it can be calculated that total mass loss in 20,000km would be ~316g per mm of tread lost and 2022g over the vehicle lifetime.
     - This equates to ~100mg/km total mass loss and ~10mg/km PM10 per tyre.
- Calculated values are substantially higher than measured by the tyre sample duct approach used in this project
  - Typical emissions values from the PG-42 cycle were in the range 0.03 mg/km to 0.06 mg/km measured by eFilter and gravimetry.
  - It is clear that the tyre sample duct employed will not collect all the emissions from the tyre, but establishing a ratio of the mass of sample collected to the total mass emissions of the tyre (the mass collection efficiency) for such an open system is a challenge.

Approaches taken to estimate efficiency (1)

- **Either** consider the proportion of the gap between the tyre and the road that is filled by the sample duct opening
  - This is approximately a ratio 10:1 for the collection efficiency if emissions are aspirated homogenously from the contact patch
  - We know that the sampling system under-samples PM10, so we can assume the ratio of 1:10 or 10% is the ***upper bound*** for the collection efficiency of the sample duct.
- **OR** compare the ratio of the area of the sample duct opening to that of the tyre contact surface - the raised area of the tread that makes contact with the road
  - Measurements estimated the duct area to be approximately 1/150th of the total tyre tread area
  - Assuming that the whole circumference of the tyre contact surface sheds particles at the same rate during braking this ratio of 1:150 or 0.67% is taken to be a ***lower bound*** for the collection efficiency of the sample duct
- Hence the range of efficiencies lies between 10:1 and 150:1



Approaches taken to estimate efficiency (2)

- The mass emitted by the tyre would be the measured mass emissions rate (e.g., mid-range of measurements) 0.045 mg/km * the duct sampling efficiency
- If the efficiency is assumed to be somewhere between the two, e.g.: 1 in 100, then mass emissions = 0.045*100 = 4.5 mg/km (PM10)
- This value is broadly consistent with the values identified in (1) and (2) above considering that larger particles may not be aspirated (i.e., are deposited on the road surface), but further work is required to establish the validity of this estimate
- Similarly, work is required to determine the collection efficiency of the scoop for particle number rather than particulate mass, as this may be significantly higher than for mass

Summary

- An on-road system for measuring brake and tyre wear was developed and installed to a small light duty van
- Testing was successfully undertaken in a chassis dynamometer facility; on a nearby test-track; and on-road in an urban environment
- Non-volatile PN, and PM, emissions can be related to individual braking events on the chassis dynamometer, but not easily on the track or road
- Exact quantification of $PM_{2.5}$ and PN emissions is dependent on the sampling duct efficiency, which is currently unknown. This is to be investigated. Without correction, measured levels were lower than brakes on a per km basis
- Tyres: Repeated aggressive braking events appear to lead to outgassing of volatile particles from tyres, many of these particles are eliminated by the hot ELPI, heated to 200°C

Planned further work, Phase 2

- Focus on PN10 (using PN-PEMS type devices), both total and non-volatile particles
- Continue with real-time mass and a filter-based approach to enable chemical analysis and visualisation of the PM materials collected
- Optimise sampling system, e.g., for power consumption, size, flow rate …
- Explore and validate sample duct for sampling measurements for tyre wear
  - Use of a visible tracer to understand efficiency of the tyre scoop
  - Investigate a “full tyre” enclosure methodology
- Test power of the measurement system to discriminate between tyre types
  - Study specific influences on tyre particle emissions on chassis dyno (& tracks)
    - E.g., tyre compositions, tyre sizes, vehicle weight…
  - Evaluate emission-reducing technologies

Report of Phase 1 will be available for download from the DfT website soon

