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Impact of FAME in Diesel on Particle Emissions from Euro 4-compliant Light-duty Vehicles

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By 2020, EU legislation will require that 10% of the total road fuel energy demand must be met by the use of renewable fuels. Although many types of bio-blending components are being considered to achieve this requirement, Fatty Acid Methyl Esters (FAMEs) are likely to be used for most diesel fuel blending. Many different FAME types are in use throughout Europe and the rest of the world, but Rapeseed Methyl Ester (RME) is currently the most common and was chosen for this study.

The objective of this study was to evaluate the impact of higher RME levels on vehicle fuel consumption and emissions and to measure the effect of different driving cycles on these parameters. Three Euro 4-compliant light-duty diesel vehicles were selected for this study that were equipped with direct injection, high injection pressure and common rail diesel engines. All vehicles featured exhaust gas recirculation (EGR) and some type of diesel oxidation catalyst (DOC). Two vehicles (1 and 3) were also equipped with Diesel Particulate Filters (DPF) using two different DPF regeneration strategies. Before starting the vehicle testing, the DPF regeneration interval for both vehicles was investigated and steps were taken to ensure that no automatic regenerations occurred during measurements.

Four FAME/diesel blends were blended and tested: a reference diesel fuel (B0) and 3 blends of this B0 fuel with RME at 10% v/v (B10), 30% v/v (B30), and 50% v/v (B50). The base fuel complied with the European EN 590 specification and had less than 10mg/kg sulphur content. A single batch of European Rapeseed Methyl Ester (RME) was used that complied with the European EN 14214 specification and contained 1,000 ppm of a commercial antioxidant additive to ensure oxidation stability. Finally, a fully-formulated diesel performance additive package that is widely used in Europe was added to all test fuels in order to ensure fuel system cleanliness throughout the vehicle test programme. The oxidation stability of the three RME/diesel blends was monitored throughout the study (using the Rancimat test) and only minor reductions in oxidation stability were observed.

From existing literature on similar fuels, it was apparent that a robust experimental design would be required in order to make repeatable and reliable measurements and to use these results to interpret the effect of RME concentration on fuel consumption and emissions. The vehicle testing protocol was statistically designed in order to provide robust results for fuel consumption and all regulated emissions, including Particulate Mass (PM), over both the regulatory New European Driving Cycle (NEDC) and 'real-world' ARTEMIS driving cycle. Two steady-state conditions (50 and 120 km/h) were also included in order to provide additional measurements of Particle Number (PN) and particle size distribution. All test measurements on a single vehicle and fuel were completed in one working day, allowing a randomized block testing scheme to be used. This provided five different measurements for each B0 fuel and four measurements for each RME/diesel blend. The results shown in this poster represent the averages of these measurements.

Ultrafine particle emissions are of increasing concern due to their potential impact on both air quality and health. Under the auspices of the UNECE, the 'Particle Measurement Programme' (PMP)[1] developed a standard protocol for measuring dry (solid) particles and a limit on tailpipe PN concentrations has been added to the EU's light-duty vehicle emissions regulation based on this protocol.

Solid PN emissions were measured in this study using a procedure compliant with PMP while an alternative procedure was used to measure total PN emissions. Selected filter papers that had been used to collect the PM emissions over the NEDC and ARTEMIS Urban cycle were also analysed in order to speciate the PM

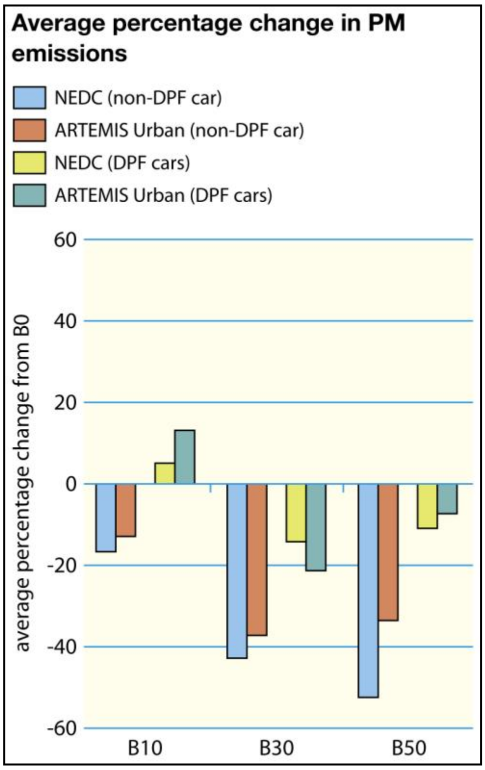
[1] Andersson, J., et al. (2007) Particle Measurement Programme (PMP): Light-duty Inter-laboratory Correlation Exercise (ILCE_LD) – Final Report (EUR 22775 EN) GRPE-54-08-Rev.1.

into the following contributions: total Soluble Organic Fraction (SOF), fuel- and lube-derived SOF, ionic components (nitrates and sulphates plus water), and elemental carbon (by difference). This poster addresses different aspects of the particulate emissions only and more details on the fuel consumption and other regulated emission measurements over the NEDC can be found in SAE 2010-01-1484.

The following conclusions can be drawn from this study:

PM Emissions:

- For the non-DPF-equipped Vehicle 2, the PM emissions for the B0 fuel were 15-48 times higher than those from the DPF-equipped vehicles, depending on the vehicle and driving cycle.
- The PM emissions from Vehicle 2 decreased by more than 50% at the highest RME content over the NEDC, consistent with previously published literature.



PM Composition:

- For Vehicle 2, increasing the RME content in the fuel appeared to reduce the %elemental carbon and increase the %SOF over both the NEDC and ARTEMIS cycles. The percentage fuel-derived SOF was consistently higher than the percentage lube-derived SOF and the %SOF values were higher over the ARTEMIS Urban cycle than they were over the NEDC.
- Although the total PM emissions from the DPF-equipped vehicles (1 and 3) were very low, nitrate anion represented a higher percentage of the PM mass compared to the PM from Vehicle 2.
- While sulphate was a small percentage of the PM from Vehicle 2, no sulphate was measured in the PM from Vehicles 1 and 3.

PN Emissions:

- Solid PN emissions from the DPF-equipped vehicles (1 and 3) were about three orders of magnitude lower than from the non-DPF-equipped vehicle and close to the testing facility's background levels.
- For the non-DPF-equipped Vehicle 2, a trend towards lower solid PN emissions with increasing RME content was observed over all test conditions. This is consistent with the reduction in total PM and the change in percentage elemental carbon.

Particle Size Distribution:

- Increasing the RME content in the fuel resulted in a shift of particle emissions toward lower mobility diameters and increased the variability in the particle emissions measurement.
- Especially at the 120 kph steady-state condition, the change in particle size distribution showed that accumulation mode particles are reduced as the RME content increases. This is consistent with the reduction in total PM and solid PN emissions and the change in percentage elemental carbon as described above.

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Impact of FAME in diesel on particle emissions from Euro 4 compliant vehicles

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Study background and objectives

- The European Renewable Energy Directive (RED) will require 10% (energy basis) renewables in road fuels by 2020.
- Fatty Acid Methyl Esters (FAME) are most likely to fulfil the need for diesel fuel blending in the near term.
- Open questions remain regarding the impact of higher FAME levels on fuel consumption, regulated and unregulated emissions, and vehicle performance.
- Objectives of this vehicle test programme on biodiesel blends:
  - Fuel consumption and tailpipe emissions from modern vehicles
  - Effect of driving cycle (NEDC, ARTEMIS and single speeds)
  - Focus on Particle Number (PN) and Particulate Mass (PM)
  - *See SAE 2010-01-1484 for fuel consumption results*
- Three light-duty (LD) diesel vehicles certified to Euro 4 emissions limits.
- Four biodiesel blends from mixtures of EN590 diesel and FAME:
  - B0, B10, B30 and B50
  - Using a single batch of Rapeseed Methyl Ester (RME)
- Statistically designed and repeatable vehicle testing schedule.

Diesel fuel properties

Fuel property	Units	Test method	B0	B10	B30	B50
Derived Cetane Number (DCN)		IP 498	55.5	56.1	56.3	58.1
RME content	% v/v	EN 14078	<0.1	10.7	30.6	50.9
Oxygen	% m/m	In-house method	<0.04	1.1	3.3	5.4
Density at 15°C	kg/m^3	EN ISO 12185	823.1	829.1	841.0	853.0
Lower Heating Value (LHV)	MJ/kg	ASTM D240/IP12	42.89	42.32	41.22	40.06
Volumetric LHV (VLHV)	MJ/l	Calculated	35.30	35.09	34.66	34.17

Fully-formulated diesel performance additive package added to all fuels to ensure consistent fuelling performance throughout the test programme.

Light-duty diesel vehicles

Vehicle characteristics	Vehicle 1	Vehicle 2	Vehicle 3
Model year	2009	2004	2005
Euro certification	Euro 4	Euro 4	Euro 4
Cylinders	4	4	4
Displacement	2.2L	2.2L	2.0L
Fuel injection system	Common rail direct injection	Common rail direct injection	Common rail direct injection
Transmission	Automatic	Manual	Manual
Diesel particulate filter (DPF)	Catalysed DPF with in-cylinder fuel injection	No DPF	Fuel-borne catalyst with in-cylinder fuel injection

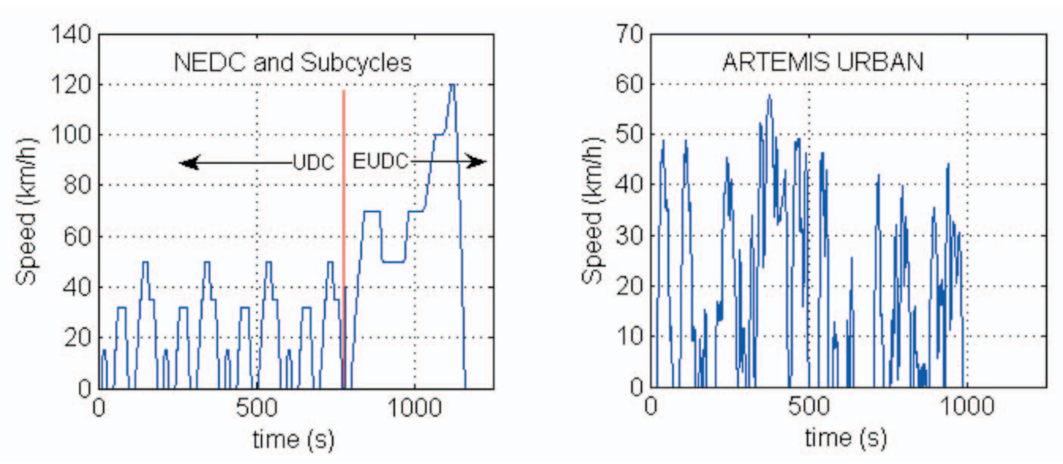
Vehicle 3 is the 'golden vehicle' that was previously used in the European Particle Measurement Programme (PMP)[1]

[1] *Andersson, J.,* et al. *(2007)* Particle Measurement Programme (PMP): Light-Duty Inter-laboratory Correlation Exercise (ILCE_LD)—*Final report (EUR 22775 EN) GRPE-54-08-Rev.1*

Daily test procedure

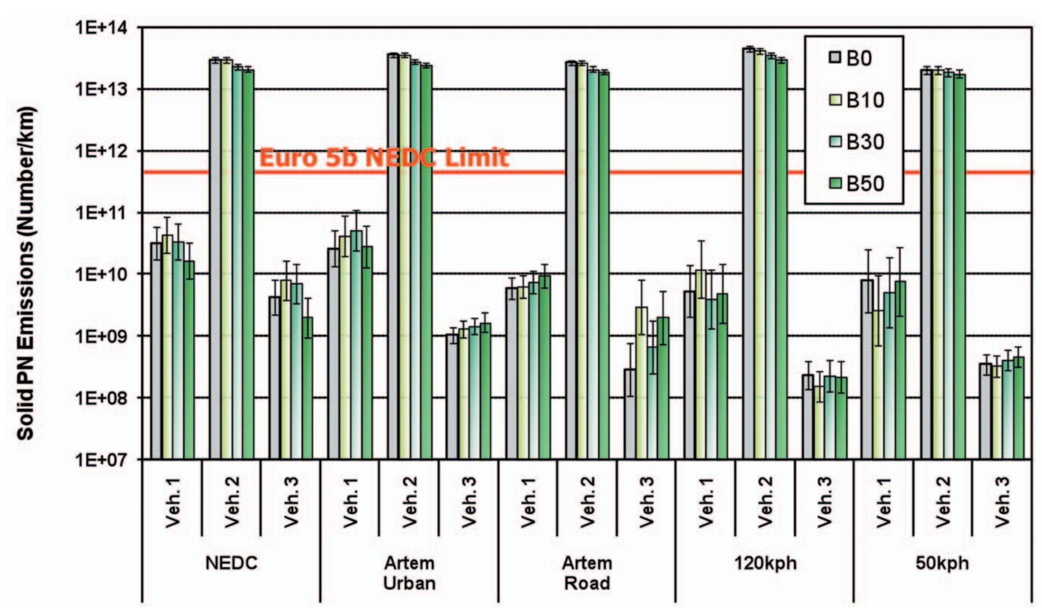
- Standardised daily test procedure essential for controlling variability and measuring small differences between fuels and vehicles.
- B0 fuel tested five times, each BXX fuel tested four times
  - Minimum 17 days testing per vehicle
- One full day per fuel per vehicle:
  - Pre-condition vehicle on test fuel (avoiding DPF regenerations)
  - Cold soak vehicle overnight
  - Complete fuel consumption and emissions measurements:
    - New European Driving Cycle (NEDC)
    - ARTEMIS Urban and Road
    - 50 and 120 km/h steady state

Driving cycles



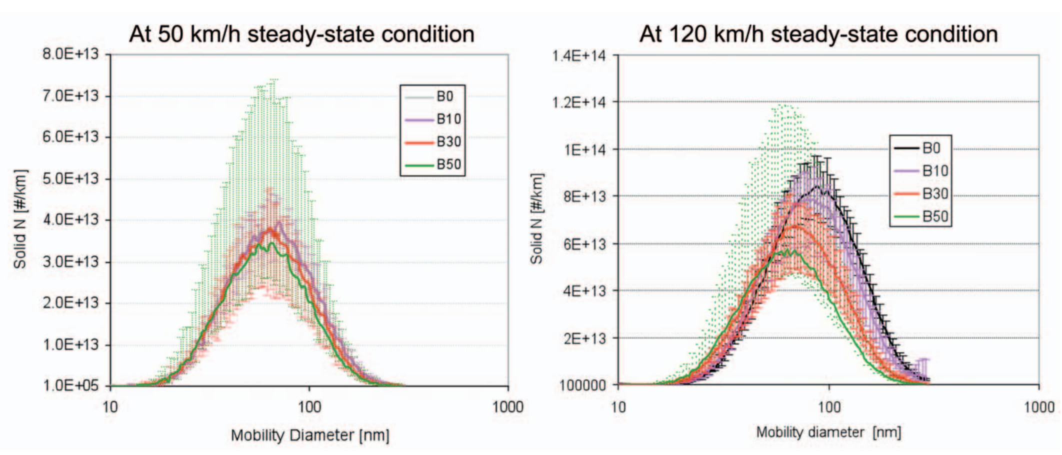
- *NEDC regulatory cycle begins with a cold engine and emphasizes a comparatively low speed and load operating range.*
- *Data also collected over ARTEMIS cycle and two steady-state speeds (50 and 120 km/h).*

Solid PN emissions: all vehicles



- *Solid PN emissions about 1000 times higher from non-DPF-equipped vehicle compared to DPF-equipped vehicles.*
- *Small reductions in solid PN emissions with increasing RME (Vehicle 2).*

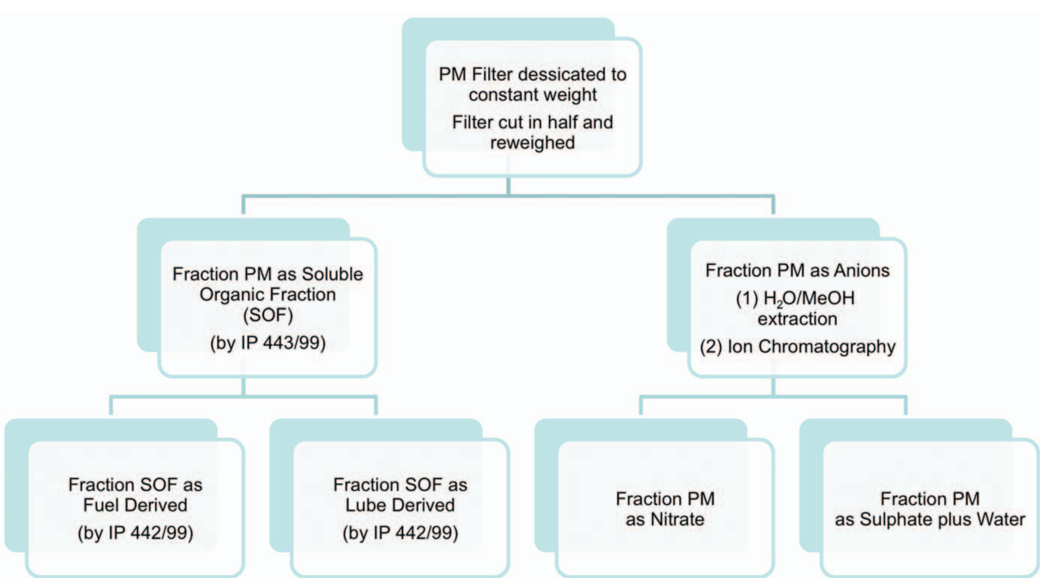
Particle size distribution: Vehicle 2



Increasing RME:

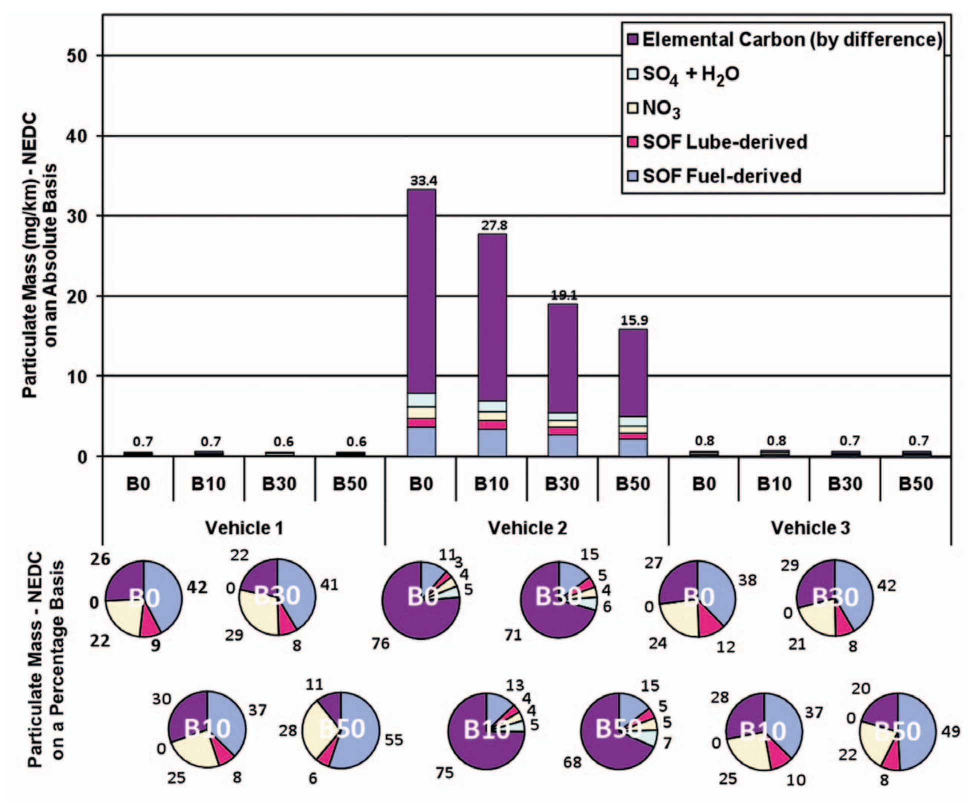
- *Shifts particle size distribution to lower mobility diameters*
- *Reduces accumulation mode particles at 120 km/h*
- *Increases variability in emissions measurement*

PM speciation protocol



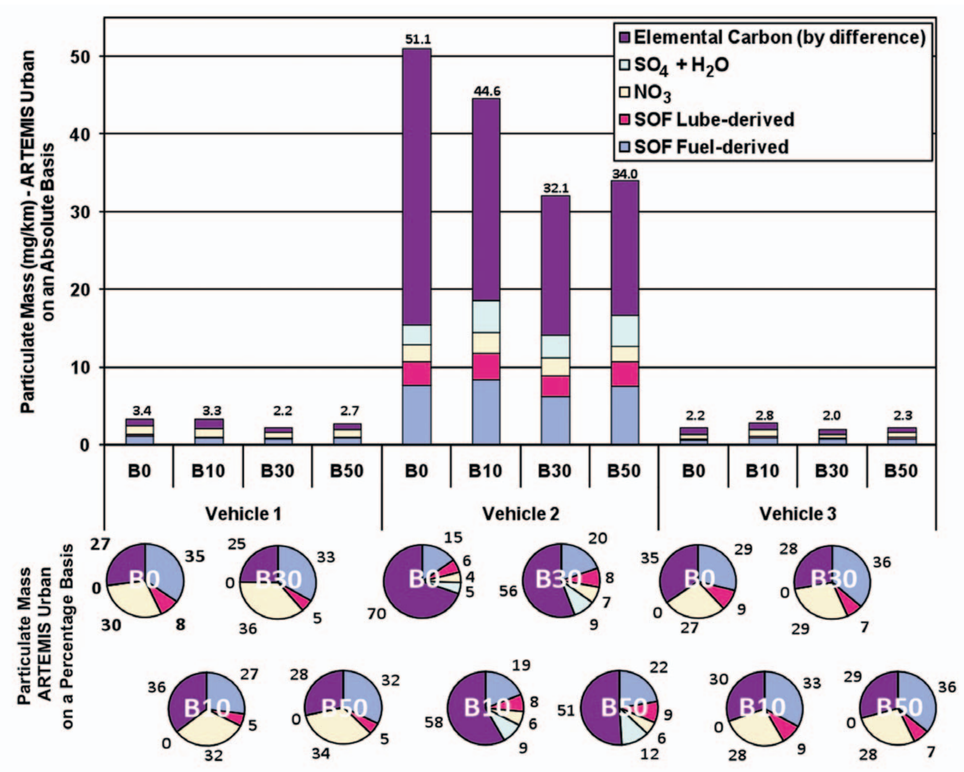
Elemental carbon calculated by difference from sum of (1) fuel- and lube-derived SOF, (2) nitrate, and (3) sulphate plus water.

PM: all vehicles, NEDC



- *Increasing RME content decreases tailpipe PM in Vehicle 2*
- *Elemental carbon dominates PM composition in Vehicle 2 compared to DPF-equipped vehicles*

PM: all vehicles, ARTEMIS Urban



- *PM emissions are higher over the ARTEMIS Urban cycle compared to NEDC*
- *Similar trends in PM emissions with increasing RME content*

Conclusions: particle emissions

As the RME content in diesel fuel increased up to 50% v/v:

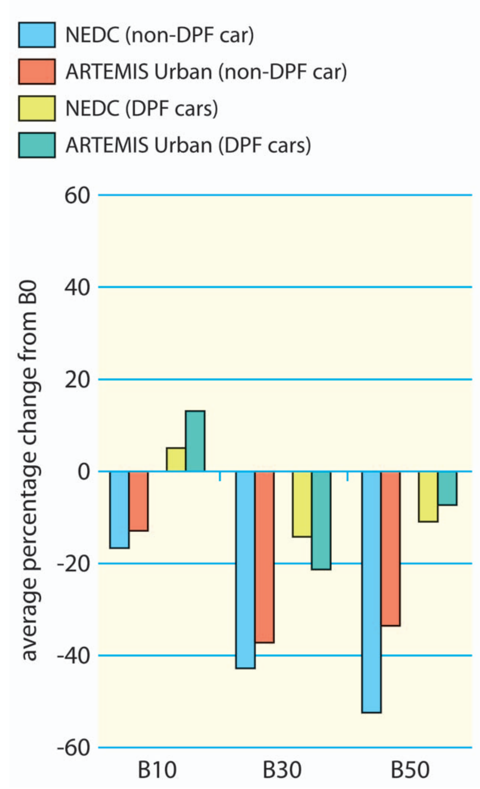
- *PM decreased for the non-DPF vehicle over the NEDC and ARTEMIS Urban*
  - *Consistent with HD diesel engine performance*
- *Small decrease in solid PN emissions for the non-DPF-equipped vehicle*

PM composition:

- *Dominated by elemental carbon for the non-DPF equipped vehicle*
- *Fuel-derived SOF larger than lube-derived SOF for all PM samples*
- *No sulphate measured in PM from DPF-equipped vehicles*

Analysis of other regulated and unregulated emissions (carbonyl compounds) has been completed and will be reported separately.

Average percentage change in PM emissions



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