Use of hydrotreated vegetable oil reduces particle number emissions of a heavy duty diesel engine

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Introduction

Diesel exhaust emissions are a major concern for light and heavy duty vehicles due to adverse health and environmental effects. As well as increasing the air pollution components, e.g. NO_x, SO_x and PM, diesel vehicles emit CO_2. One way to reduce the net CO_2 emissions is to increase the amount of bio-components in the fuel. The resulting change of the chemical and physical structure of the fuel may also change the characteristics of emitted nanoparticles and other pollutants.

Hydrotreated vegetable oil (HVO) is one renewable diesel fuel (Kuronen et al. 2007). According to Hartikka et al. (2012), the use of HVO reduced the emissions of all the regulated emission components in the 14 tested Euro IV heavy duty vehicles. The NO_x, PM, CO and HC emissions were reduced on average by 8%, 34%, 25% and 26%, respectively. The use of HVO has also been observed to reduce soot particle number emissions compared to fossil diesel. At the same time, the structure and oxidation properties of the soot particles were unaffected indicating that similar particle filters can be used (Happonen et al. 2010).

Experimental

Particle emissions of a Euro IV 10.6 l truck engine were studied on an engine dynamometer. Test fuels were 100% fossil diesel fuel, complying with the EN590 standard, and 100% HVO fuel. Tests were conducted during the 13-step European stationary cycle (ESC) where the step length of two minutes was used. The exhaust sampling was performed at three locations: engine-out, downstream of a diesel oxidation catalyst (DOC) and downstream of a diesel particulate filter (DPF).

The particle size distributions were measured with two ELPIs (Electrical low pressure impactor, Dekati), two EEPSs (Engine exhaust particle sizer, TSI), an SMPS (Scanning mobility particle sizer, TSI) and a Nano-SMPS. Particle number concentration was measured with a UCPC (Ultrafine condensation particle counter, TSI). The exhaust sampling was conducted with two dilution systems. A double ejector dilution (DED) was used for one ELPI, while the exhaust sample for all the other instruments was diluted with a porous tube diluter (PTD). A thermodenuder (TD) (Rönkkö et al. 2011) was applied after the PTD sampling occasionally to remove the semivolatile particle fraction. Also typical exhaust gas components and filter smoke number (FSN) were measured.

Results and discussion

Nonvolatile particle emission factors measured with the ELPI after the DED are shown in Figure 1. Generally, the particle number emissions were lower with HVO fuel compared to fossil fuel. The differences were especially remarkable at the ESC points 7, 9 and 11 where the engine ran at low load. The exhaust smoke concentrations were also considerably affected by fuel. The particle number concentrations measured with different instruments were in a very good agreement.

The studied DPF performed with about 99% dry particle reduction efficiency depending on the engine load conditions. The highest particle reduction rates were detected during low load conditions when the exhaust flow velocities and temperatures were also low. The lowest particle reduction was at high load.

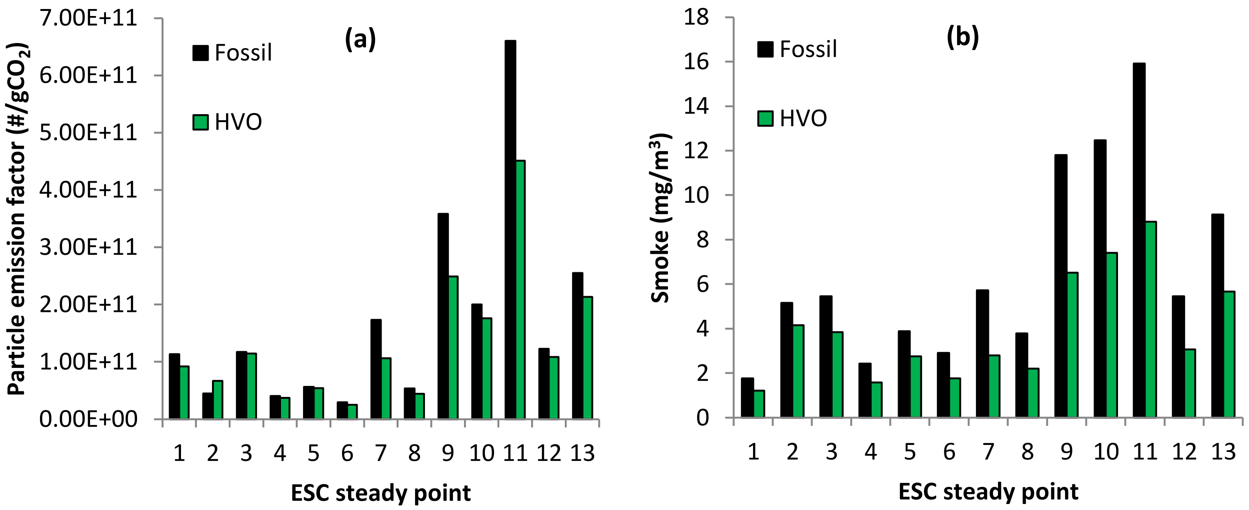

Figure 1. Particle engine-out number emission factors (a) and smoke concentrations (b) with a fossil diesel fuel (Fossil) and hydrotreated vegetable oil (HVO) at ESC cycle steady test points. Particle number concentrations were measured with the ELPI after the DED sampling.

Somewhat unexpectedly, nucleation mode particles with both fuels were observed to exist solely after the DOC, not engine-out or after the DPF (Figure 2). Nucleation particles were detected during the test points of high exhaust temperature even though very low fuel sulphur contents suggest low nucleation rates. The formation and detection of the nucleation mode particles were thus linked to oxidation reactions in the DOC and perhaps the storage and release mechanisms of sulphur compounds. Also it appears that some components affecting the detectable nucleation mode particle size and number were removed inside the DPF. These components may have been for instance sub-3 nm solid nucleation core particles or sulphur containing gaseous compounds.

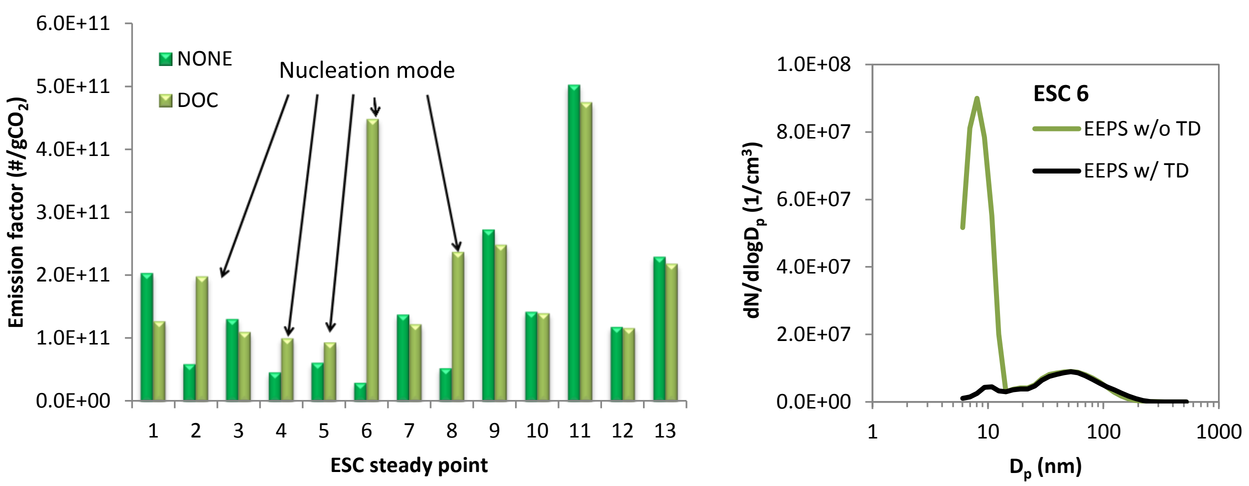

Figure 2. Particle number emission factors measured without aftertreatment and after the DOC with a UCPC after the PTD dilution with HVO. In ESC 6, particle number size distributions of the EEPS are shown with (w/) and without (w/o) the TD.

Acknowledgements

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References

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Background

Diesel exhaust particles

- Consist of two modes
  - Soot mode (SM), carbonaceous agglomerates
  - Nucleation mode (NM)
    - Semivolatile formed in the exhaust dilution from sulphur, hydrocarbons etc.
    - Nonvolatile
- Using hydrotreated vegetable oil (HVO) exhaust particle emissions may change compared to using fossil fuel
  - HVO content in fuel can be 0-100%
- Exhaust aftertreatment affects the particle emissions
  - Particle filters remove soot
  - Oxidation catalysts remove hydrocarbons but oxidize SO_2
    → Can cause formation or enhanced growth of NM particles

Methods

Engine, aftertreatment, fuels, driving operation

- Engine 10.6 l TD, Euro IV emission level with a pDPF
- Sampling locations
  - Without aftertreatment (NONE)
  - After a diesel oxidation catalyst (DOC)
  - After a diesel particulate filter (DPF)
- Two fuels
  - Fossil diesel fuel, EN 590
  - Hydrotreated vegetable oil (HVO)
- Tests during 13-step European stationary cycle (ESC) with 2 min steps

Experimental setup

- Sampling
  - Double ejector (DED) sampling at NONE always
  - Porous tube diluter (NONE, DOC, DPF)
- Thermodenuder (TD) with low nanoparticle losses to study the semivolatile particle fraction
- Particle instrumentation: CPC, ELPIx2, Nano-SMPS, Long-SMPS, EEPSx2, APC, Smoke, PPS, PM
- Dilution ratio from CO_2 concentrations

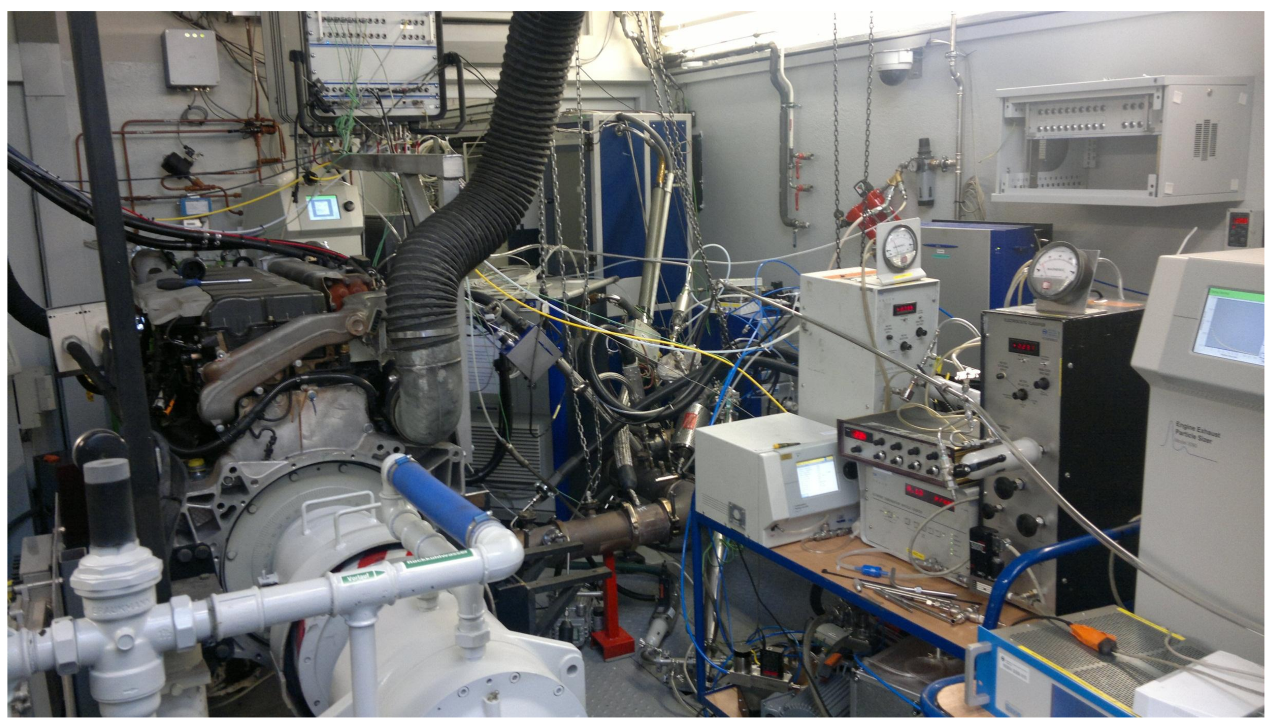

Figure 1. Experimental assembly in the engine dynamometer studies.

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Results

Instrumental comparison

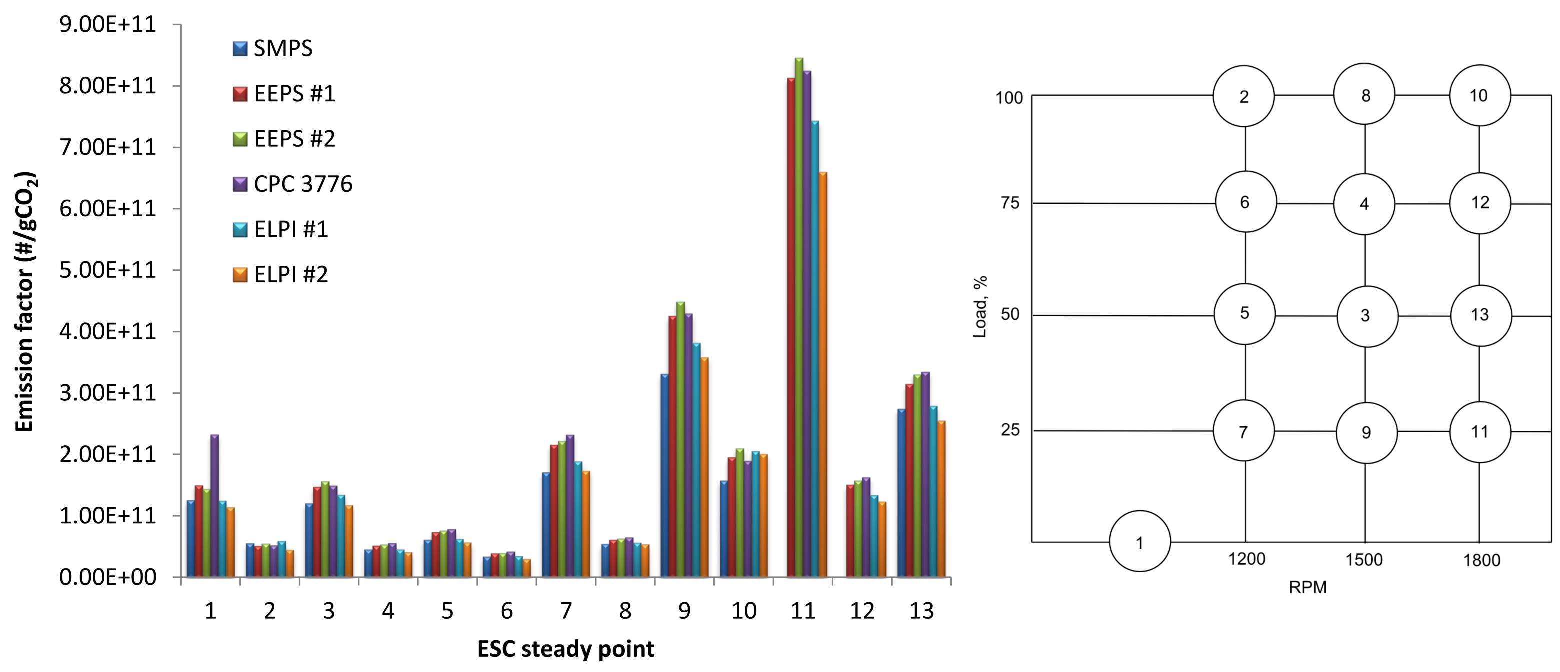

Figure 2. Particle number emission factors measured with various instruments at ESC cycle. Fuel fossil, no aftertreatment, ELPI 2 after the DED dilution, SMPS & EEPS #1 after the TD.

HVO reduces particle number and mass

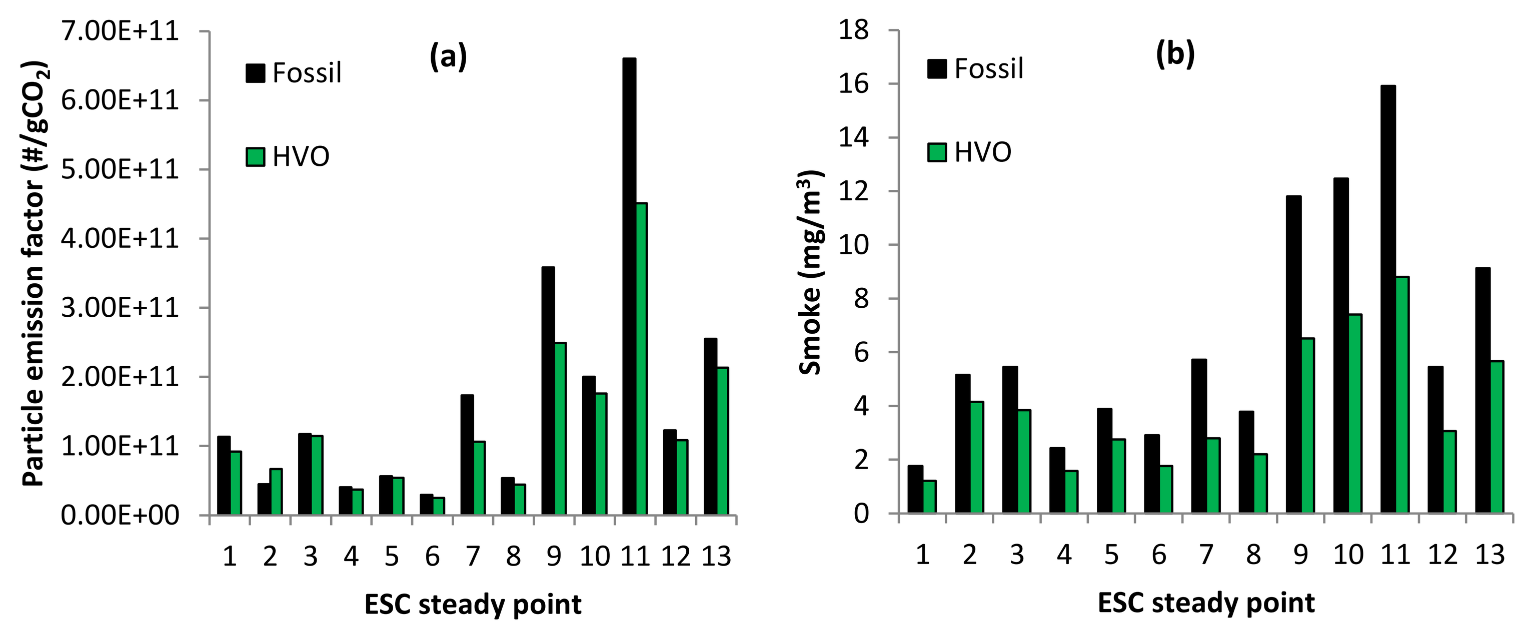

Figure 3. Engine out soot particle number emission factors (a) measured by an ELPI and exhaust smoke concentrations (b).

Nucleation mode after the DOC

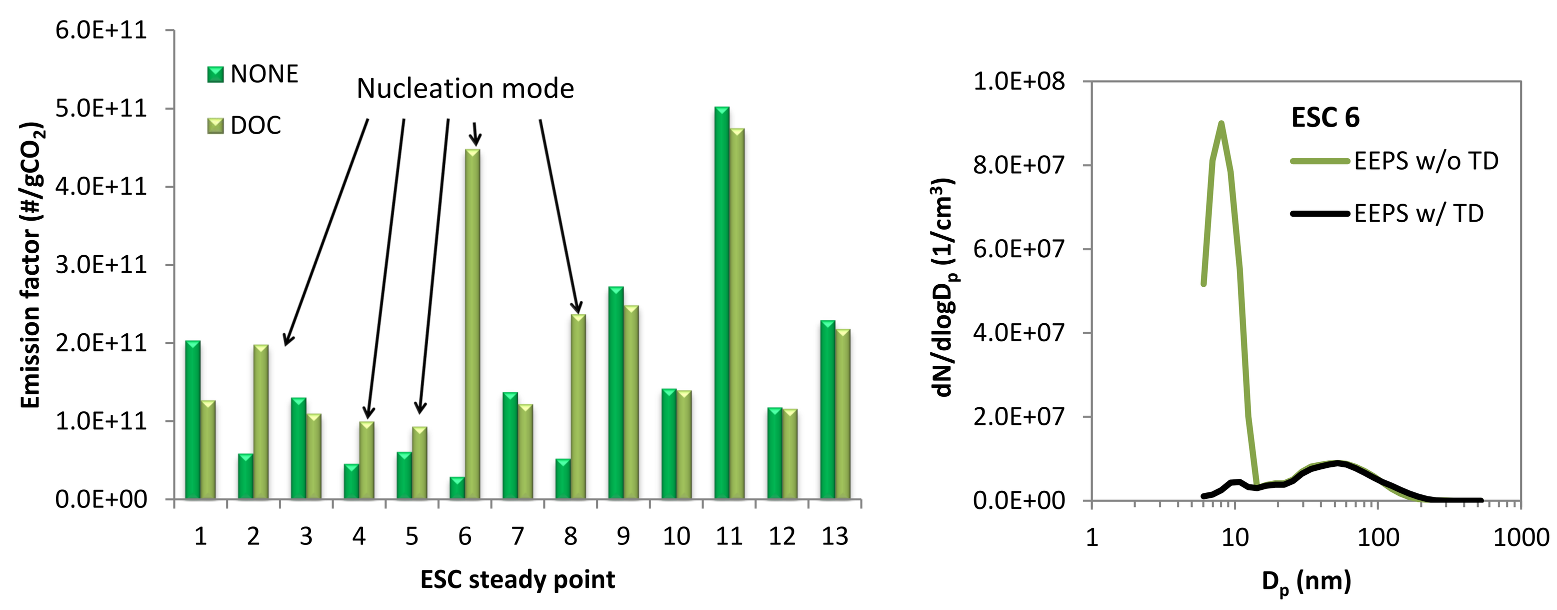

Figure 4. Particle number emission factors measured without aftertreatment and after the DOC with a CPC after the PTD dilution. In ESC 6, particle number size distributions of EEPS are shown with (w/) and without (w/o) the TD.

DPF performance with HVO

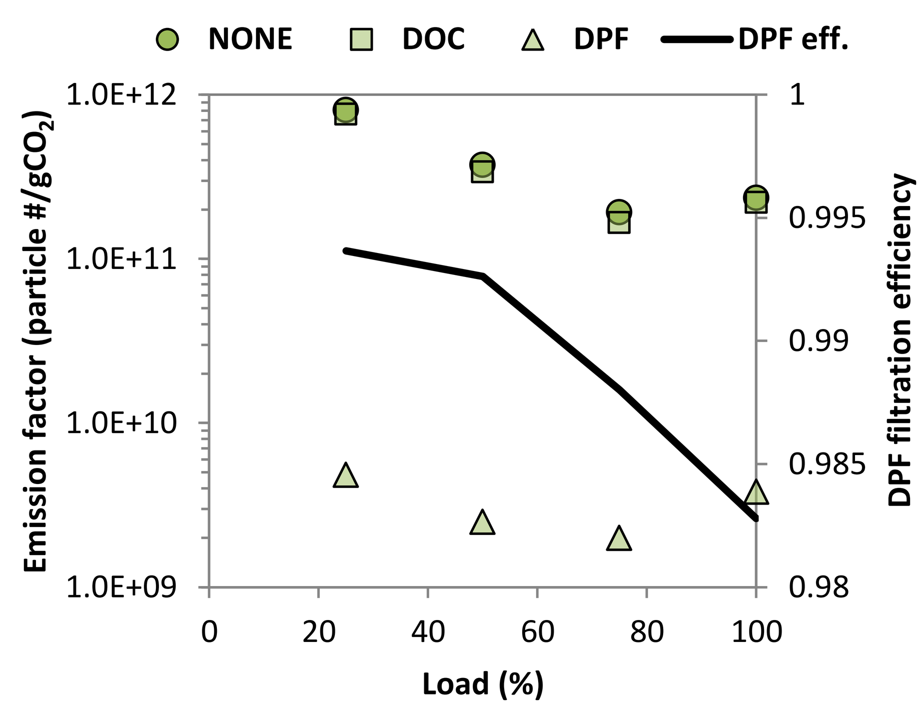

Figure 5. Particle number emission factors without aftertreatment (NONE), after the DOC and after the DPF at different engine loads (high engine speed, HVO fuel). Particle concentrations were measured with an EEPS.

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