# Real-time characterization of particle emission from construction machinery during operation: Effect of emission-reducing technology on particle number and particle size

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## Introduction

Construction machines are responsible for a significant part of the total particle and $NO_x$ pollution in urban areas. The engines used in construction machines are regulated by the EU Stage standards, which are less stringent than the Euro standards with respect to $NO_x$ and PM. An important issue relating to construction machines is also that the construction site workers are working on and around the machines and hence continuously exposed to the emissions (Figures 1 and 2).

The goals of this work are to develop suitable and effective retrofit technology for selected construction machinery as well as to develop a method for online emission characterization during realistic and normal operating conditions. Shown here is real-time emission data from a Deutz TCD 2011 45-kW Stage IIIA diesel engine powering an VÖGELE Super 800 asphalt paver. In addition, effect of DPF (Diesel Particulate Filter) + SCR (Selective Catalytic Reduction) after-treatment is evaluated.

**Figures 1 and 2:** Typical exposure cases for construction site workers

## Experimental

Measurements were carried out from a van driving right next to the machines on a test facility. Gas and particle sample stream from the exhaust is transferred to the instruments inside the van (figures 3 and 4).

Particle size distribution (PSD) and number (PN) concentration are measured in the size interval 10-420 nm in 13 size bins using a NanoScan SMPS (TSI) connected after a rotating disc diluter (Matter) heated to 150 °C and a catalytic stripper heated to 350 °C (Catalytic Instruments) for removing the semi-volatile particle fraction. This setup is much similar to the Particle Measurement Program (PMP), defining Euro VI particle measurement, but gives additional particle size information.

Gas emissions (CO, $CO_2$, THC, NO, $NO_2$, $NO_x$, $NH_3$, and $N_2O$) are measured using Fourier-Transformed Infrared Spectroscopy (FTIR).

**Figures 3 and 4:** Experimental setup with measurement equipment inside the van driving next to the selected asphalt paver on a test facility

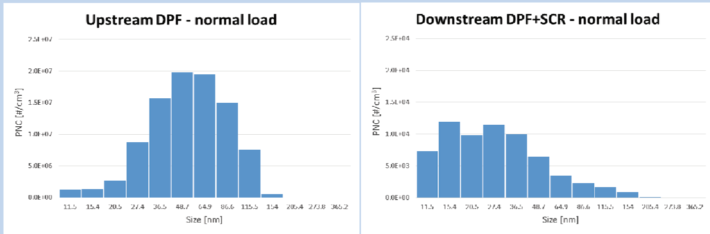
## Results

The selected asphalt paver was retrofitted with two different DPF+SCR solutions. Figures 5 and 6 show the size and position of the first system. The first system was oversized to ensure trouble-free engine operation, mainly with respect to DPF counter-pressure. The second solution was optimized for the particular machine, and a down-scaled version of SCR and DPF was implemented.

With respect to particle emission, the two tested DPF+SCR solutions reduce PN by more than 99.9 % in the size interval 23-420 nm, with 23 nm being the lower cut-off in PMP. Data were averaged over several measurement cycles during warm engine conditions.

In addition, the average measured PN concentration downstream DPF+SCR is about a factor of 5-10 below the PN reference value being suggested by the Swiss Federal Office for the Environment FOEN ($2.5x10^5$ particles/$cm^3$), for passing a DPF test. This reference value is analogous to the proposed limit in the future Stage V standard ($1x10^{12}$ particles/kWh), but is much easier to measure on-site. Interestingly, a significant amount of the particles measured downstream DPF+SCR have a size below the PMP limit of 23 nm, as also seen in figure 8.

**Figures 5 and 6:** The asphalt paver with the DPF+SCR solution, developed by Purefi A/S




**Figures 7 and 8:** Average PSD for the asphalt paver, averaged over several measurement cycles of normal operating conditions and measured with NanoScan SMPS. PSD are shown in the full measuring range of 10-420 nm. Note that the scales on the y-axes differ by a factor of 1,000 on the two figures

Average raw emission data for the regulated gases, measured during normal operation, are summarized in Table 1.

| | No after-treatment | With after-treatment | Reduction |
|---|---|---|---|
| $NO_x$ | 450 ppm | 50 ppm | 89% |
| THC | 150 ppm | 4 ppm | 97% |
| CO | 89 ppm | 0 ppm | 100% |

**Table 1:** Average emission data from the final after-treatment solution

The specific emissions were calculated for the engine at normal operation, which is close to full load. Table 2 shows the specific emissions compared to the Stage IIIA demands (for the untreated exhaust) and Stage IV (for the treated exhaust).

| | Untreated | Stage IIIA | Treated | Stage IV |
|---|---|---|---|---|
| THC+$NO_x$ | 4,45 g/kWh | 4,7 g/kWh | | |
| $NO_x$ | | | 0,37 g/kWh | 0,4 g/kWh |
| THC | | | 0,04 g/kWh | 0,19 g/kWh |
| CO | 0,57 g/kWh | 5 g/kWh | 0 g/kWh | 5 g/kWh |

**Table 2:** Specific emissions before and after the system, compared with Stage IIIA (conformity of the engine) and Stage IV (conformity for new engines from 2014)

The measured ammonia concentration was below the detection limit of 5 ppm. The Stage IIIA and Stage IV demand of 25 ppm $NH_3$ was thus met.

## Conclusions

- Development and implementation of DPF and SCR technology for the asphalt paver was successfully carried out.
- The measurement approach and setup with a van driving next to the construction equipment was successful. Real-time emission data were acquired with accurate instruments during realistic operating conditions.
- With the downscaled and optimized DPF+SCR retrofit solution, the asphalt paver was shown to be compliant with Stage IV limits on PN, NOx, THC and CO during the described measurement conditions (not standardized test according to ISO 8178).
- Particle emission was characterized according to PMP, measuring the solid particle fraction, but with additional size information, and with a DPF efficiency of >99.9 % (by number).
- A significant amount of the solid particles measured downstream DPF+SCR have a size below the PMP limit of 23 nm.

*This work was part of a 2-year project, co-financed by the Danish Environmental Protection Agency. The consortium is constituted by Danish Technological Institute and the companies NCC Roads A/S, Purefi A/S and LiqTech International A/S.*