

# Real-time measurements of cost-efficient filter solutions for small construction machines



DANISH  
TECHNOLOGICAL  
INSTITUTE

**Thomas Nørregaard Jensen**  
Consultant, Ph. D.  
tnje@teknologisk.dk  
+45 72 20 32 46

**Stig Koust Hansen**  
Consultant, Ph. D.  
stko@teknologisk.dk  
+45 72 20 11 51

**Morten Køcks**  
Product Manager, MSc. Physics  
mly@teknologisk.dk  
+45 72 20 23 80

## Introduction

In 2019 the Stage V standard regulating non-road mobile machinery (NRMM) has become effective. This is expected to give rise to stricter demands from contractors and public authorities to existing NRMM. To accommodate these demands, new exhaust gas aftertreatment systems are developed and tested in a new Danish EPA-supported project by aftertreatment company Purefi A/S, Danish Technological Institute and contracting company, Per Aarsleff A/S. The main focus of the project is on developing simple and cost-effective aftertreatment systems for construction machines in the range from 19 kW to 56 kW. This will give the machine owners the possibility of effectively reducing particle and NOx emissions from existing machines rather than replacing them with new Stage V machines. These new solutions will entail improved air quality on construction sites and in the immediate environment in urban areas.

Category	Jgn.	Net Power		Date	CO	HC	NOx	PM	PN
		kW							
NRE-v/c-1	CI	P < 8		2019	8.00	7.50 <sup>a,c</sup>		0.40 <sup>b</sup>	-
NRE-v/c-2	CI	8 ≤ P < 19		2019	6.60	7.50 <sup>a,c</sup>		0.40	-
NRE-v/c-3	CI	19 ≤ P < 37		2019	5.00	4.70 <sup>a,c</sup>		0.015	1×10 <sup>12</sup>
NRE-v/c-4	CI	37 ≤ P < 56		2019	5.00	4.70 <sup>a,c</sup>		0.015	1×10 <sup>12</sup>
NRE-v/c-5	All	56 ≤ P < 130		2020	5.00	0.19 <sup>c</sup>	0.40	0.015	1×10 <sup>12</sup>
NRE-v/c-6	All	130 ≤ P ≤ 560		2019	3.50	0.19 <sup>c</sup>	0.40	0.015	1×10 <sup>12</sup>
NRE-v/c-7	All	P > 560		2019	3.50	0.19 <sup>d</sup>	3.50	0.045	-

## Methodology

The efficiency of the retrofit emission system has been tested on a representative compact excavator by direct measurement in the exhaust gas with and without the system installed. Numerous parameters are investigated, including NOx and CO2 emissions (by a portable emission measurement system). The particle number concentration and size distribution has been measured with a TSI scanning mobility particle sizer after utilizing a Testo rotating disc diluter and a catalytic stripper from Catalytic Instruments. Additionally, ambient measurements of the surrounding air quality have been conducted using a condensation particle counter (TSI CPC 3007) and dust monitor (TSI DustTrak DRX).



## Measured reduction of NOx and CO

System 3 has a NOx reduction efficiency above 95% when the engine is warm (load above 50%). At the same engine loads, System 2 reduces the NOx emission with 40-50%, while System 1 has no effect on NOx, as expected.

System	Months of operation	Engine load	NOx	CO
			Efficiency	
System 1 DPF	0	Idle	-4.8%	81.7%
		50%	1.1%	74.6%
		100%	-1.6%	73.4%
System 2 SCR-coated DPF	3	Idle	5.9%	74.4%
		50%	47.2%	55.7%
		100%	41.2%	51.9%
System 3 DPF + SCR	3	Idle	24.2%	88.6%
		50%	96.7%	76.6%
		100%	95.4%	73.8%

## 3 systems installed on a Takeuchi TB260

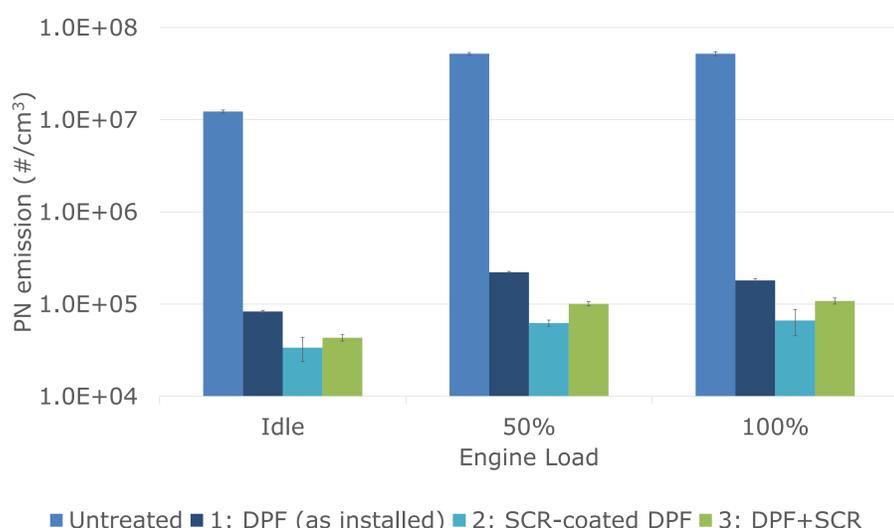
Three different systems have been developed and tested on a 33 kW Takeuchi TB260 machine. Besides a DOC the three developed systems consist of:

- 1) DPF
- 2) SCR-coated DPF
- 3) DPF + SCR



## PN emission in the size range 10-420 nm

The developed exhaust systems have been tested at three engine loads: idle, 50% and 100%. The measured particle removal efficiencies of the systems are between 99.4% and 99.9%.



## Ambient measurements

Ambient measurements performed in the surroundings of the machine show particle number concentrations on the same level as the background level. A similar result is seen when the particle number concentration inside the cabin is considered.



## Conclusions

Characterization of the emissions of the three developed exhaust gas aftertreatment systems has demonstrated a particle emission reduction of more than 99% and a NOx-reduction between 40% and 95% depending on aftertreatment system and engine load. Furthermore, ambient measurements in the surroundings have shown particle number concentration unaffected by the operating excavator, hence demonstrating very efficient exhaust gas systems. In conclusion, three different exhaust gas systems have been developed with different complexity, efficiencies and price tags. This allows for the machine owner to choose the right exhaust gas system for each specific application.