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Measurement of emissions from diesel fired heaters for buses

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Measurements are performed in April 2018
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1 Introduction

Movia Public Transport (Trafikselskabet Movia) has commissioned FORCE Technology to conduct a study of emissions from diesel fired heaters using conventional B7 diesel (diesel containing 7 vol% of biodiesel), 100% HVO (Hydrotreated Vegetable Oil) and 100% biodiesel (FAME, Fatty Acid Methyl Esters). The purpose of this study is to assess to what extend local emissions from diesel heaters in buses may be reduced by using alternative fuels.

Today new diesel buses must comply with the strict Euro VI regulation of engine gas exhausts. In contrast to the emissions from the Euro VI engines, emissions from diesel fired heaters are not equally strictly regulated. In 2016, the Danish Technological Institute conducted a study for Movia on exhaust gas emissions from diesel-powered heaters that revealed significantly higher levels of emissions of NO_X and particles than the emissions from Euro VI bus engines[1].

Among Movia's owners (municipalities and regions) there is a strong focus on mitigating negative health impacts of local air pollutants - particularly from NO_X and particles. The elimination of local air pollution from bus operation is a key priority and an increasing number of municipalities are demanding zero emission bus operation. The application of electric buses is today the most relevant zero emission bus solution. It is challenging for the driving range of electric buses to heat the passenger area entirely with an electricity based heating system. Thus, the use of a diesel heater may significantly reduce the costs of applying electric buses. If the use of alternative diesel fuels offers an environmentally and financially attractive alternative to pure electric heating of electric buses such solutions may be strong drivers for a cost-efficient transition of Movia's bus fleet towards zero emission vehicles.

Special thanks to Brian Christiansen from Arriva Denmark and Erik Fabricius Mansig from DAKA ecoMotion for providing fuels and to Michael Hartmann Nielsen from Arriva Denmark for providing test facilities.

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2 Measurements

2.1 Test setup

FORCE Technology has in April 2018 performed measurement of emissions in the exhaust gas from two diesel fired heaters (Stroco 3500, 30 kW, 24V, and Spheros Thermo 300, 30 kW, 24V). The test was performed at Arriva Denmark's facilities at Stilling near Skanderborg, Denmark.

The diesel fired heaters were installed on a test bench and a sample line of stainless steel was mounted on their exhaust pipe (see Figure 1). The sample line was thermal isolated to avoid condensation of water throughout the test. Measurements of gasses and particles were performed on a straight section of the sample line to avoid turbulense that could interfere on the results. Following parameters were measured in the exhasust gas: NO_X ($NO + NO_2$), CO, CO_2, O_2, PM (particle mass) and PN (particle number). Exhaust flow and temperature were also measured in order to express the

[1] Oliefyrede busvarmere, Danish Technological Institute, December 2016.

emission parameters in eg. mg/m^3 (ref. CO_2) or g/h. In order to compare results from the different diesel fired heaters, average concentrations were expressed at reference conditions (10% CO_2).

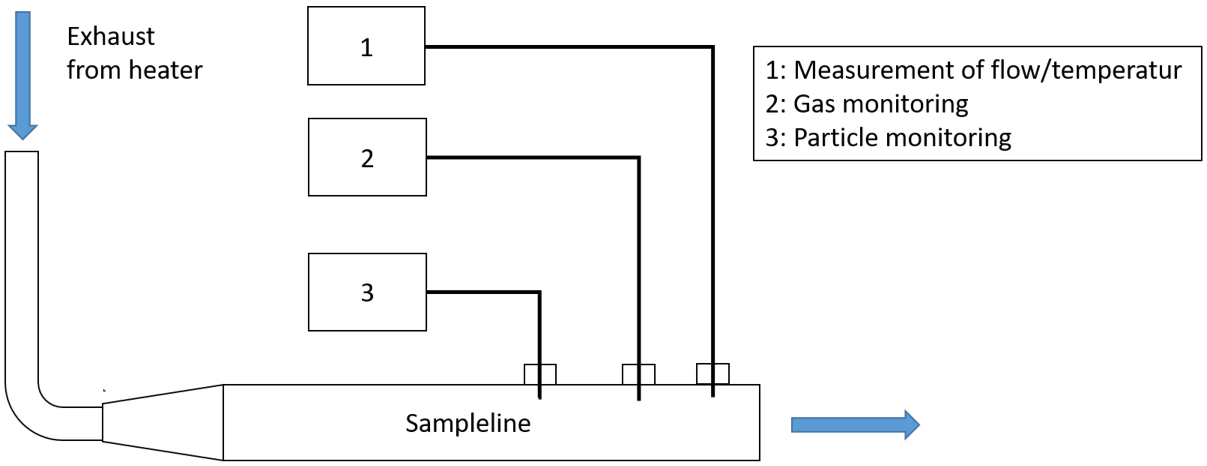

Figure 1: Measurement set-up for emission monitoring of exhaust from diesel fired heaters.

The emission test was performed with three different types of fuels; Conventional B7 diesel (7 volume percentage of biodiesel), 100% HVO (Hydrotreated Vegetable Oil) and 100% biodiesel FAME (Fatty Acid Methyl Esters) on each diesel fired heater.

Measurements were performed 45 minutes after start-up of the diesel heater to insure warm and stable conditions during test. Gasses were measured as one-minute mean values and particles were measured as one second mean values. Emissions were recorded continuously for 45 – 60 minutes on each fuel type. The fuel tank was then interchanged with a new fuel tank containing the next fuel to be tested and the diesel heater was left to stabilize for approximately 45 minutes. Then measurements were repeated. Average emissions where calculated taking the last 30 minutes of the recorded data for each type of fuel. Zero gas and accredited span gases were applied to the monitors before and after the measurements to correct for instrument drifts. A HEPA filter was used to establish a baseline before the start of each particle measurement.

The oil pressure was set at standard conditions for each of the two diesel fired heaters; Stroco 3500 (0.8 MPa) and Spheros Thermo 300 (1 MPa). The Spheros Thermo 300 was running unstable during measurements on FAME. The test therefore had to be shortened and average emissions were only calculated over a period of 10 minutes. Measurements on the Stroco 3500 proceeded without incidence.

2.2 Measurement methods

The applied methods and their uncertainties are described in Appendix A.

3 Results and discussions

3.1 Nitrogen oxide and nitrogen dioxide, NO_X

Figure 2 and Table 1 show the results of the NO_X measurements at reference conditions (10% CO_2). For the Stroco 3500, NO_X concentrations were relative constant with B7 and HVO whereas the concentration of NO_X using FAME were slightly lower. This could indicate that the heater burns better with

FAME, however the oxygen content is also higher for FAME compared to B7 and HVO (see section 3.4). FAME contain more oxygen compared to ex. B7, but other parameters, like fuel pressure, type of nozzles and viscosity of the fuel will also affect the emissions from the heaters.

Results from the Spheros Thermo 300 show that emitted NO_X concentrations from HVO and FAME were very similar whereas the NO_X concentrations from B7 were lower. Results show that oxygen content using B7 fuel was higher compared to HVO and FAME which, just like in the case of the Stroco 3500, is likely to result in a lower NO_X concentration.

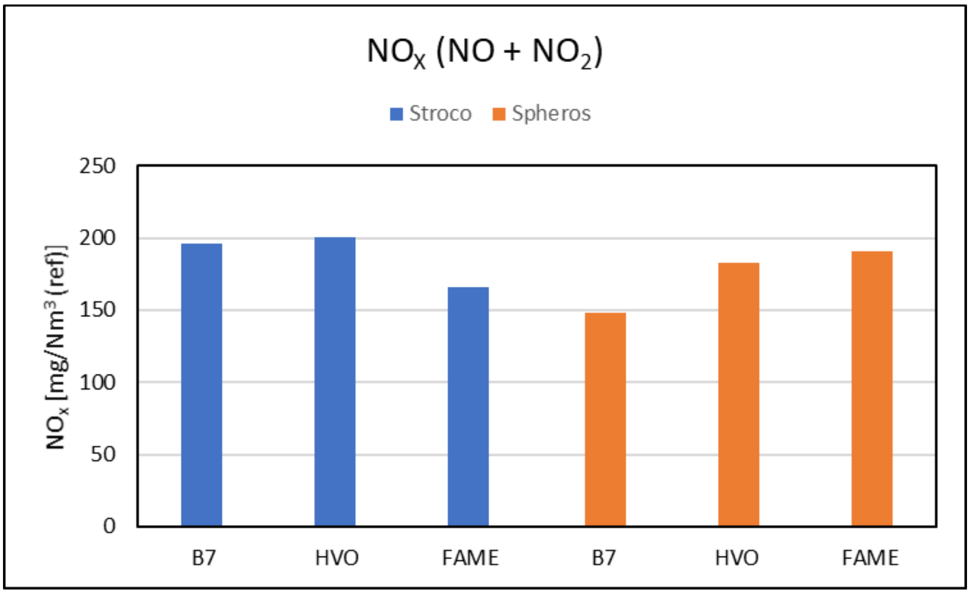

Figure 2: Average concentrations of NO_X emitted from the Stroco 3500 and the Spheros Thermo 300 diesel fired heater using different types of fuel.

Table 1: Measured concentrations of NO_X for different types of fuel. Concentrations are given at reference conditions (10% CO_2).

Fuel type	Emission parameters	Unit	Stroco 3500	Spheros Thermo 300
B7	NO_X	mg/Nm^3 (ref)	196	148
HVO	NO_X	mg/Nm^3 (ref)	201	183
FAME	NO_X	mg/Nm^3 (ref)	166	190
B7	NO_X	g/h	9.6	8.0
HVO	NO_X	g/h	9.7	10
FAME	NO_X	g/h	7.9	10

3.2 Carbon monoxide, CO

Figure 3 and Table 2 show the results of the CO measurements at reference conditions. The CO emissions from the Spheros Thermo 300 show higher concentration for all three types of fuel compared with the Stroco 3500. The highest concentration is found with FAME. O_2 concentrations (see section 3.4) from the Spheros Thermo 300 were significantly lower which suggest that the heater runs at more rich conditions.

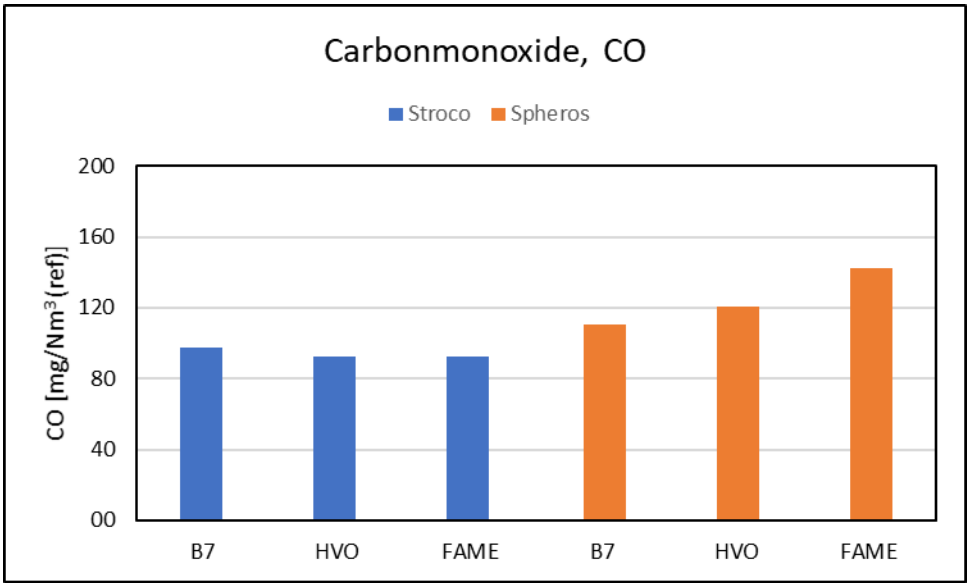

Figure 3: Average concentrations of CO emitted from the Stroco 3500 and the Spheros Thermo 300 diesel fired heater using different types of fuel.

Table 2: Measured concentrations of CO for different types of fuel. Concentrations are given at reference conditions (10% CO_2).

Fuel type	Emission parameters	Unit	Stroco 3500	Spheros Thermo 300
B7	CO	mg/Nm^3 (ref)	98	111
HVO	CO	mg/Nm^3 (ref)	93	121
FAME	CO	mg/Nm^3 (ref)	92	142
B7	CO	g/h	4.8	6.0
HVO	CO	g/h	4.4	6.7
FAME	CO	g/h	4.5	7.5

3.3 Carbon dioxide, CO_2

Figure 4 and Table 3 show the results of the recorded CO_2 concentrations. CO_2 is mainly used as a support parameter to analyse the result of the NO_X, CO, PN and PM measurements.

The CO_2 concentrations are generally higher for the Spheros Thermo 300 compared to the Stroco 3500. This could be a result of a lower air intake to the burner which leads to a lower O_2 content and a higher CO_2 concentration in the exhaust gas. This is also supported by the higher concentrations of CO in the exhaust from the Spheros Thermo 300.

Table 3: Measured concentrations of CO_2 for different types of fuel.

Fuel type	Emission parameters	Unit	Stroco 3500	Spheros Thermo 300
B7	CO_2	Vol% (dry)	8.9	11.1
HVO	CO_2	Vol% (dry)	9.2	11.6
FAME	CO_2	Vol% (dry)	8.5	12.3

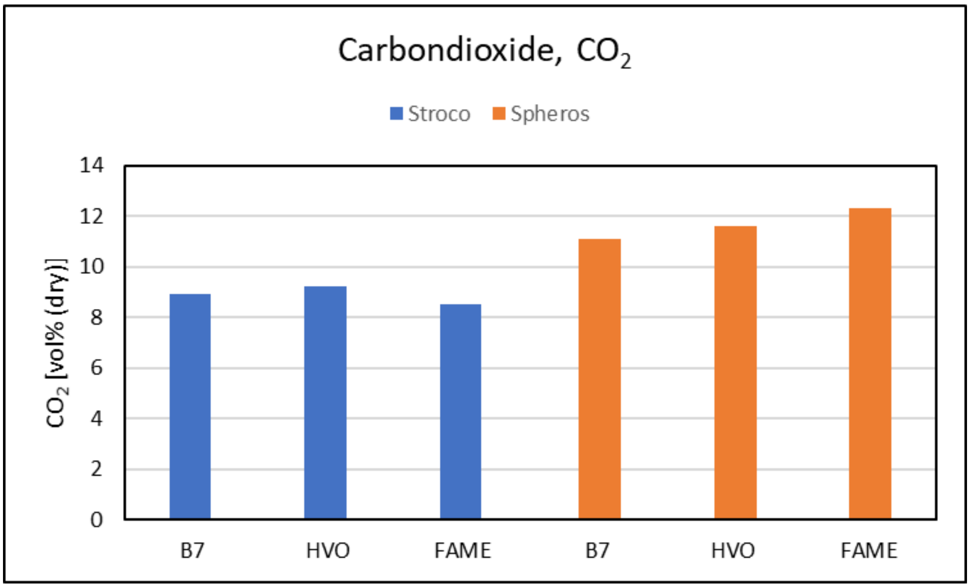

Figure 4: Average concentrations of CO_2 emitted from the Stroco 3500 and the Spheros Thermo 300 diesel fired heater using different types of fuel.

3.4 Oxygen, O_2

Figure 5 and Table 4 show the results of the measured O_2 concentrations. O_2 is measured for the same reasons as for CO_2 and are mainly used as a parameter for diagnostics. In general, the O_2 concentration shows the opposite behaviour compared to the CO_2 concentration. Comments about how the O_2 concentration affect eg. NO_X and CO can be found in section 3.1 and 3.2 respectively.

Table 4: Measured concentrations of O_2 for different types of fuel.

Fuel type	Emission parameters	Unit	Stroco 3500	Spheros Thermo 300
B7	O_2	Vol% (dry)	8.0	6.1
HVO	O_2	Vol% (dry)	7.8	4.7
FAME	O_2	Vol% (dry)	9.1	4.7

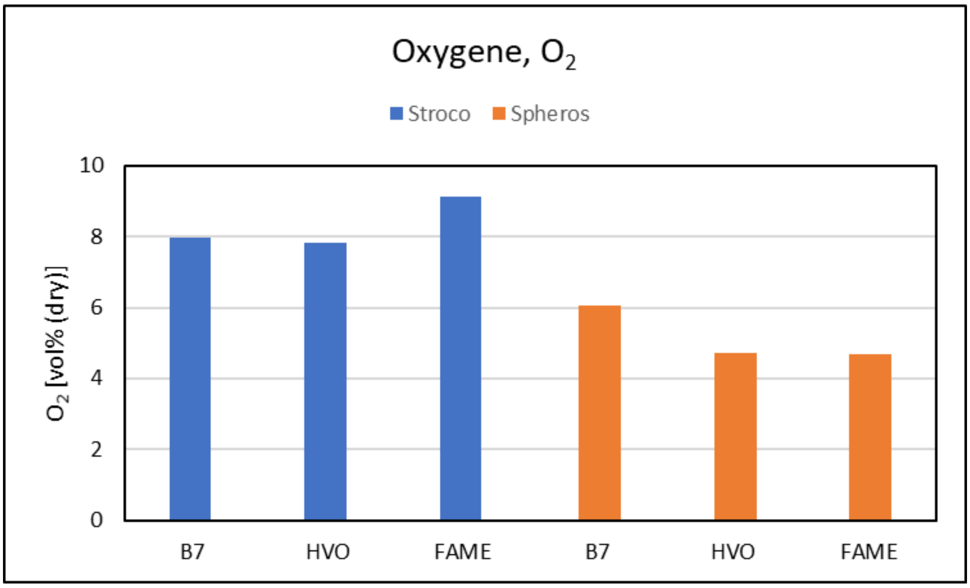

Figure 5: Average concentrations of O_2 emitted from the Stroco 3500 and the Spheros Thermo 300 diesel fired heater using different types of fuel.

3.5 Particle number, PN

Figure 6, Table 5 and Table 6 show the measurements of PN at reference conditions. The vertical axis is given as a logarithmic scale. Particle emission concentration ranges from $4.1 \cdot 10^6$ #/Ncm^3 (B7 at Stroco 3500) to $6.2 \cdot 10^4$ #/Ncm^3 (HVO at the Spheros Thermo 300). Lowest recorded concentrations of PN were observed with HVO fuel regardless of the type of diesel fired heater. Results also show that Spheros has lower emissions of particle compared to Stroco under the measured test conditions.

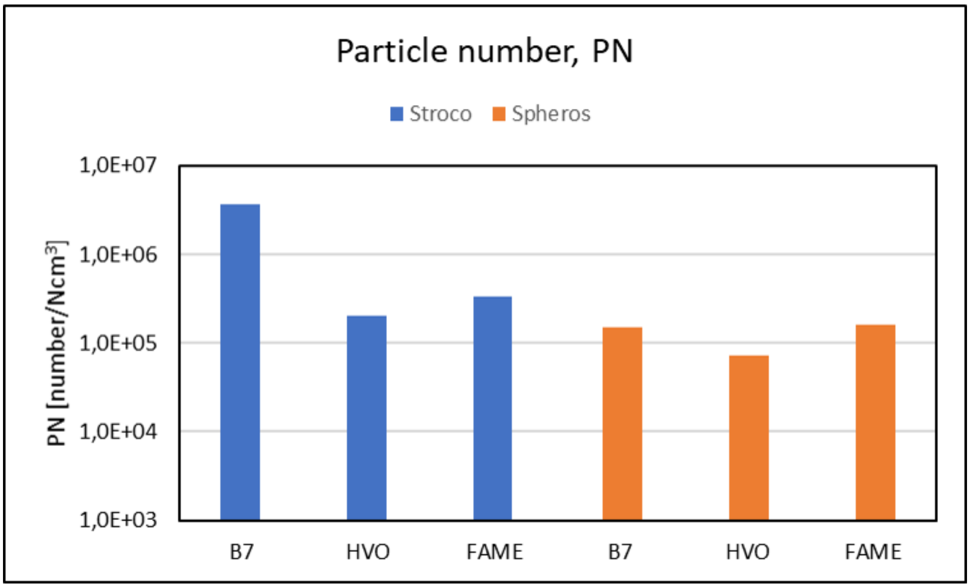

Figure 6: Average concentrations of PN emitted from the Stroco 3500 and the Spheros Thermo 300 diesel fired heater using different types of fuel.

Table 5: Measured concentrations of PN [#/Ncm^3 (ref)] for different types of fuel. Concentrations are given at reference conditions (10% CO_2).
Reduction [%] of PN relative to B7 calculated as $(PN_{B7}-PN_{fuel\ type})/PN_{B7}$ *100%.

Fuel type	Emission parameters	Unit	Stroco 3500	Spheros Thermo 300
B7	PN	#/Ncm^3 (ref)	$4.1 \cdot 10^6$	$1.4 \cdot 10^5$
HVO	PN	#/Ncm^3 (ref)	$2.2 \cdot 10^5$	$6.2 \cdot 10^4$
FAME	PN	#/Ncm^3 (ref)	$3.9 \cdot 10^5$	$1.3 \cdot 10^5$
HVO	PN	%	94.8	55.2
FAME	PN	%	90.6	4.5

Table 6: Measured concentrations of PN [#/h] for different types of fuel. Reduction [%] of PN relative to B7 calculated as $(PN_{B7}-PN_{fuel\ type})/PN_{B7}$ *100%.

Fuel type	Emission parameters	Unit	Stroco 3500	Spheros Thermo 300
B7	PN	#/h	$1.9 \cdot 10^{14}$	$7.7 \cdot 10^{12}$
HVO	PN	#/h	$1.0 \cdot 10^{13}$	$3.4 \cdot 10^{12}$
FAME	PN	#/h	$1.8 \cdot 10^{13}$	$7.3 \cdot 10^{12}$
HVO	PN	%	94.7	55.0
FAME	PN	%	90.5	4.8

3.6 Particle mass, PM

Figure 7, Figure 8, Table 7 and Table 8 show the results of the measured PM concentrations at reference conditions. Particle emission concentrations follow the same pattern as observed with PN and ranges from 0.87 mg/Nm^3 (B7 with Stroco 3500) to 0.0044 mg/Nm^3 (HVO with Spheros Thermo 300). Lowest recorded concentrations of PM were observed with HVO fuel within the test sequence of each type of diesel fired heater. Results show that Spheros have lower emissions of particles compared to Stroco given the measured test conditions.

Table 7: Measured concentrations of PM [mg/Nm^3 (ref)] for different types of fuel. Concentrations are given at reference conditions (10% CO_2).
Reduction [%] of PM relative to B7 calculated as $(PM_{B7}-PM_{fuel\ type})/PM_{B7}$ *100%.

Fuel type	Emission parameters	Unit	Stroco 3500	Spheros Thermo 300
B7	PM	mg/Nm^3 (ref)	0.87	0.022
HVO	PM	mg/Nm^3 (ref)	0.044	0.0044
FAME	PM	mg/Nm^3 (ref)	0.081	0.019
HVO	PM	%	94.9	79.6
FAME	PM	%	90.7	10.8

Table 8: Measured concentrations of PM [mg/h] for different types of fuel. Reduction [%] of PM relative to B7 calculated as $(PM_{B7}-PM_{fuel\ type})/PM_{B7}$ *100%.

Fuel type	Emission parameters	Unit	Stroco 3500	Spheros Thermo 300
B7	PM	mg/h	40	1.2
HVO	PM	mg/h	2.1	0.3
FAME	PM	mg/h	3.8	1.1
HVO	PM	%	94.8	79.5
FAME	PM	%	90.6	11.0

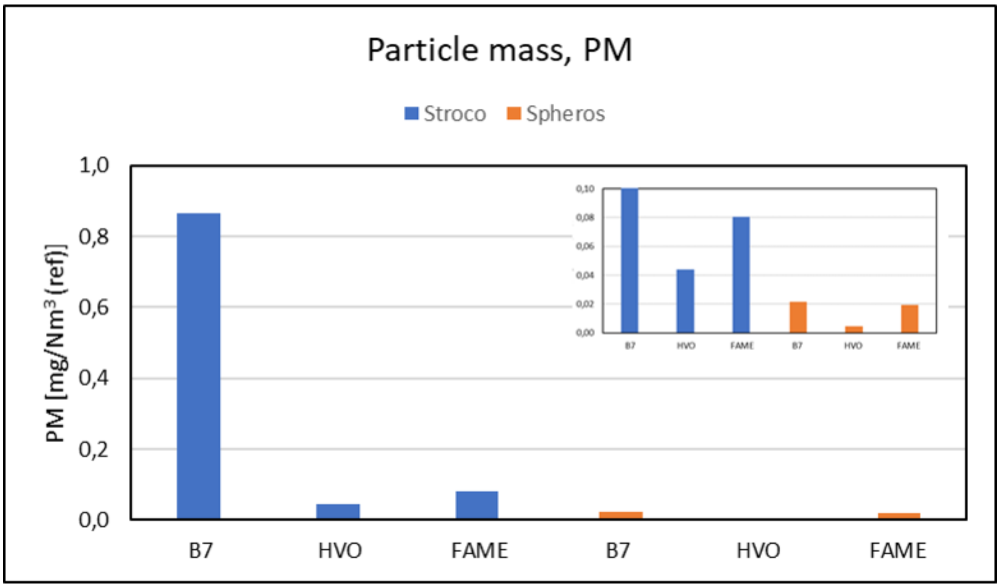

Figure 7: Average concentrations of PM emitted from the Stroco 3500 and the Spheros Thermo 300 diesel fired heater using different types of fuel. The inserted graph shows a zoom of the x-axis.

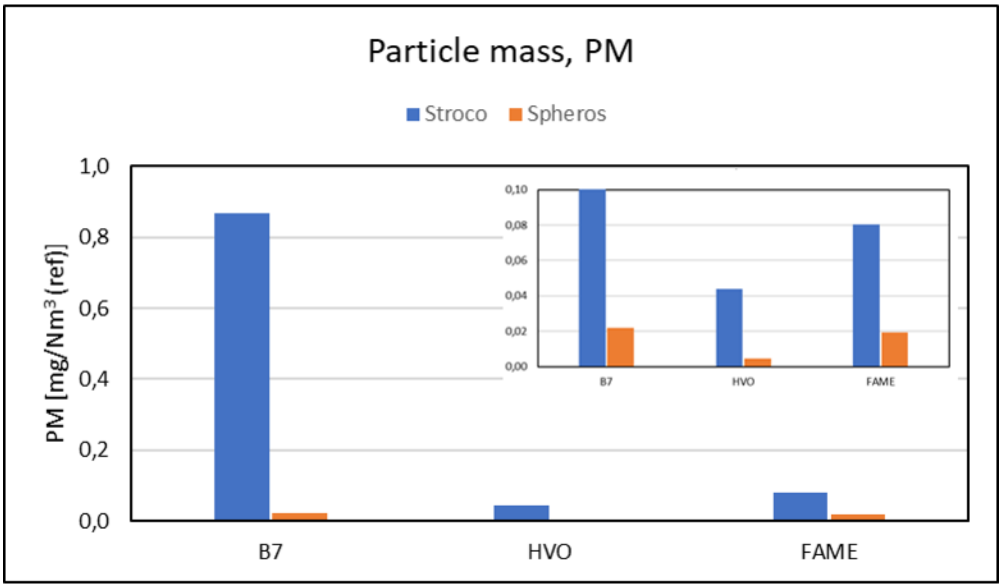

Figure 8: Comparison of the emitted PM concentration of the different diesel fired heaters. The inserted graph shows a zoom of the x-axis.

4 Summary and conclusion

In April 2018 FORCE Technology performed measurement of emission concentrations in the exhaust gas from two diesel fired heaters (Stroco 3500, 30kW and Spheros Thermo 300, 30kW). The test was performed at Arriva Denmark's facilities at Stilling near Skanderborg, Denmark under steady state conditions. On each of the diesel fired heaters, the test was performed with three different types of fuels; Conventional B7 diesel (7 volume percentage of biodiesel), 100% HVO (Hydrotreated Vegetable Oil) and 100% biodiesel FAME (Fatty Acid Methyl Esters). NO_X, CO, CO_2, O_2, PM and PN were monitored continuously during the test. Average emission concentrations were calculated taking the last 30 minutes of the recorded data for each type of fuel. The Spheros Thermo 300 was running unstable during measurements on FAME and therefore the test had to be shortened and average emissions were only calculated over a period of 10 minutes. Recorded values were converted to reference conditions at 10% CO_2 to compare the results from the different diesel fired heaters.

Results from the test showed that particle emissions were reduced by use of HVO and FAME compared to conventional B7 diesel. Lowest emissions of PN and PM were observed with HVO fuel within the test sequence of each type of diesel fired heater. In general, the Spheros Thermo has lower emissions of particle compared to the Stroco at measured test conditions.

The concentration of CO and NO_X in the exhaust gas were less affected by the fuel type. Differences in the emitted concentrations is considered to be related to the setting of the different heaters, eg. oil pressure or fuel nozzles.

Appendix A Measurement method and measurement uncertainty

<u>NO_X-Concentration:</u>
In a partial flow of flue gas, free of particles, the NO_X-concentration is determined by a chemiluminescence monitor with a built-in converter (NO_2 to NO). Selected monitors can monitor NO_X, NO_2 and NO. NO_2-measured value is the difference between NO_X and NO measured values. NO_X results are calculated as NO_2 equivalents.
Instrument: Eco Physics CLD
Range: 0 – 1000 ppm
Lower detection limit: 1% of FS
Uncertainty: 5 % of measured value (95% confidence interval)

<u>O_2-Concentration:</u>
In a dry partial flow of the flue gas free of particles, the O2-concentration is determined by means of a paramagnetic monitor.
Instrument: ABB EL3020
Range: 0 – 25 Vol %
Lower detection limit: 1% of FS
Uncertainty: 4 % of measured value (95% confidence interval)

<u>CO-Concentration:</u>
In a dry partial flow of flue gas free of particles, the CO-concentration is determined by a non-dispersive infrared (NDIR) monitor.
Instrument: ABB EL3020
Range: 0 – 1000 ppm
Lower detection limit: 1 % of FS
Uncertainty: 4 % of measured value (95% confidence interval)

<u>CO_2-Concentration:</u>
In a dry partial flow of flue gas free of particles, the CO_2-concentration is determined by a nondispersive infrared (NDIR) monitor.
Instrument: ABB EL3020
Range: 0 – 20 Vol %
Lower detection limit: 1 % of FS
Uncertainty: 4 % of measured value (95% confidence interval)

<u>Particle number (PN) and particle mass (PM):</u>
A hot partial gas flow is lead through a diffusion charger where the electrical signal from the charged particle are converted into particle number and particle mass.
Instrument: Pegasor Mi2
Size range PN: 23 nm – 2500 nm
Concentration range, PN: 0 – 10^9 #/cm^3
Concentration range, PM: 0 – 250 mg/m^3
Lower detection limit: 23 nm / 0,001 mg/m^3

<u>Gas temperature:</u>
The gas temperature is measured with a pt100-thermocouple or a NiCr/NiAl-thermocouple connected to a digital thermometer or data logger.
Range: -40 - 600°C