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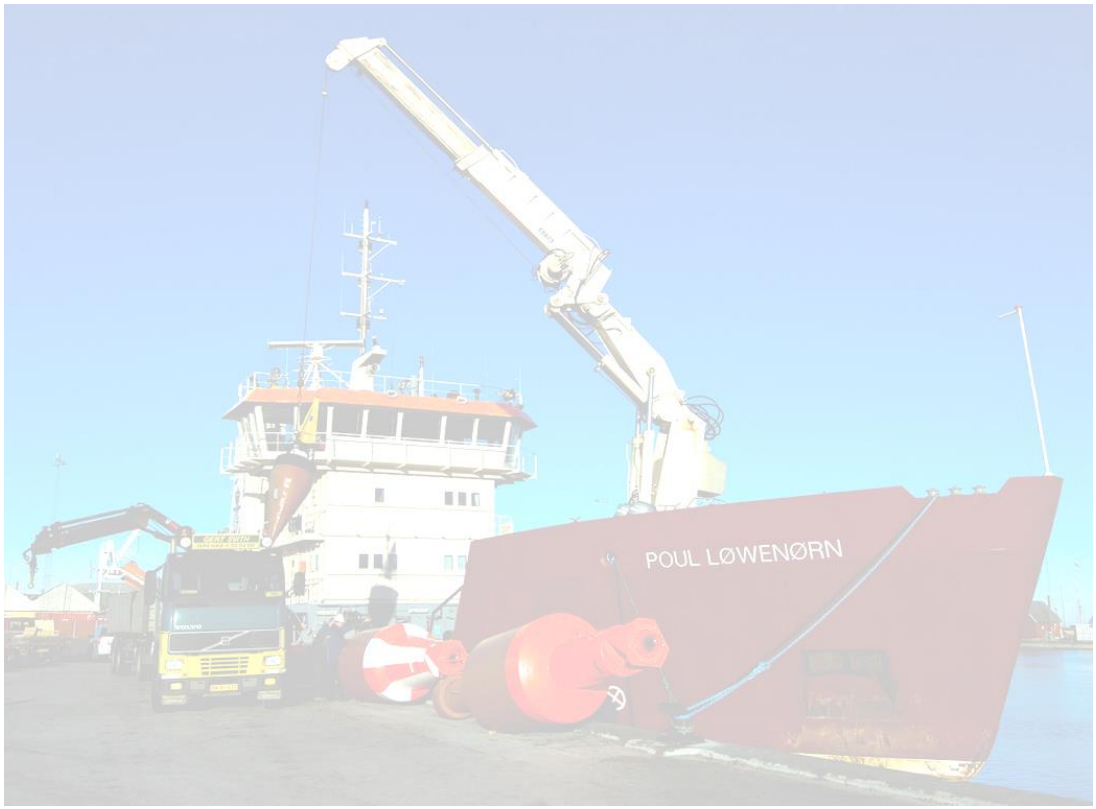
Emission measurement before and after mounting Exilator particle filter system



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TEST REPORT

Initials: JNH/LSHA Order no.: 659838

Requisitioner: Contact person: Erik Lissner

Company: EXILATOR

Address: Tigervej 11

City: DK – 4600 Køge

Phone: +45 60646575

Subject: Diesel Generator: 405 kW

Type: Nordhavn A/S GASI 28-07

Motor: 750HP Cummins VTA-28-D

Delivery date: (2001 informed by requisitioner)

Dates: Measurements were performed: 10.03.2015 and 14.09.2015 on board of The Danish Maritime Authority's Poul Løwenørn

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Procedure: ISO 8178, E2 test cycle (4-mode steady state).

Result: See paragraph 4.

Remarks: See paragraph 1.

Terms: This test report may be reproduced in extracts only if the laboratory has approved the extract in writing.

Place: Aarhus

Date: 29.09.2015

Signature: Jesper Norre Holm
Engineer

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1 Remarks

The four main engines on board of Poul Løwenørn are diesel generators (genset), which produce electricity for the propulsion and the general power consumption of the ship. The system for controlling the four gensets is programmed to start up an aditional genset when needed. Therefore, it wasn't possible according to the chief engineer to stress the relevant genset (DG3) to more than the 340 kW measured on the generator.

The measurements, which this report is based upon, have following starting points:

- 100% load = 340kW measured on the generator
- The efficiency of the engine and the generator is measured as one total system

This report contains data from the measurement after the filter was mounted. In order to compare with status before the measurement see Table 5, chapter 5.

2 Generator

The generator is a Nordhavn A/S GASI 28-07.

Engine type:	*750HP Cummins VTA-28-D*
Cylinder volume:	*28 l*
Performance:	*405 kW at 1500 o/min.*

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Figure 1: Test equipment (before mounting of filter). At the right you see the generator DG3, on which we perform measurements. In the background you see particulate counter, test probes and heated lines, which are mounted in the exhaust manifold above the passage. The back pressure transmitter is placed next to the engine connected to the outlet on the first bending after the turbo. At the front of the engine room the gas analysis instruments and the gas cooler are placed.

3 Test procedure

The purpose of the task is to measure the emissions from the engine after the Exilator particle filter system is installed and compare the results to the measurements made before installing the filter. Thereby, the efficiency of the filter system can be determined. In this case, it is possible to assess if the particle emission is reduced to the extent requested and to which extent the filter changes the NO_x emission. Furthermore, it is also possible to conclude how much back pressure the Exilator filter adds to the exhaust system.

Gas emission is measured by using Danish Technological Institute's gas analyzer equipment and particle number are measured with an AVL particle counter. The efficiency is measured on the entire unit (engine + generator), because the engine coupled directly to a generator. Specific emissions are calculated on the basis of the entire unit. The power has been logged from a PLC in the control room and the fuel consumption is noted manually from the computer of the ship in each mode.

3.1 Test cycle

The genset was tested in accordance with ISO 8178, E2 test cycle (4-mode steady state). Weighing and load points in the 4-mode test is stated in the table below.

Table 1: The used load- and weighting factors

Mode no.	RPM	Load %	Duration	Weighting %
1	1500	25	27 min.	15
2	1500	50	15 min.	15
3	1500	75	26 min.	50
4	1500	100	15 min.	20

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3.2 Test equipment

Test equipment has been used and built up in accordance with the directions in DS EN ISO 8178.

Table 2: List of equipment

Component	Brand	Model	Measuring range	Measuring method	Uncertainty
Power			0-10V	1)	1 kW
Fuel consumption				1)	1 l/h
Temperature	RS Components	Type K	0-800ºC	Thermocouple	-
Data logger	Agilent	34970A	0-10V	Analog	-
Weather station	Rosenborg	68700	-	-	-
NO_x	Ecophysics	CLD 822 S	0-1400 ppm	Heated CLD	±5 %
CO_2	Sick Maihak	Sidor	0-20 % $_{vol}$	IR	±5 %
CO_2	Sick Maihak	Sidor	0-1 % $_{vol}$	IR	±5 %
CO	Sick Maihak	Sidor	0-1000 ppm	IR	±5 % + 5 ppm
HC	Sick/Maihak	3006	0-1000 ppm	Heated FID	±5 % + 5ppm
Particle counter	AVL	498 Advanced	23nm til 2.5µm UNECE-R83	CPC	-
Differencial pressure transmitter	Huba Control	692.902007141	0-200mbar	strain gauge pressure transmitter	-

1) Power and fuel consumption have been measured with the instruments on the ship

Table 3: Ambient - and engine test data

Load	%	**100**	**75**	**50**	**25**
Time	h:m	16:44	15:45	15:05	12:53
Ambient air pressure	mbar	1009	1009	1009	1009
Intake air temperature	°C	33	32	30	39
Relative ambient air humidity	%	58	58	58	58
Required engine speed	rpm	1500	1500	1500	1500
Engine power	kW	340	258	170	85
Specific fuel consumption	g/kWh	248	249	278	338
Measured fuel flow	g/s	23,4	17,8	13,1	8,0
Calculated airflow	kg/s	0,67	0,61	0,57	0,48
Exhaust massflow	kg/s	0,70	0,63	0,58	0,49

4 Test results

Table 4 – Gaseous emission data

Load	**%**	**100**	**75**	**50**	**25**
Time	h:m	16:44	15:45	15:05	12:53
NOx	ppm	1093	700	397	180
NO_2	ppm	261	215	183	129
HC	ppm	29	32	28	54
CO raw	ppm	3	4	4	2
CO_2 raw	%	7,52	6,25	4,90	3,51
O2	%	10,1	11,9	13,8	15,7
NO_x mass flow	g/s	1,37	0,79	0,41	0,20
NO_2 mass flow	g/s	0,33	0,24	0,19	0,14
HC mass flow	g/s	0,01	0,01	0,01	0,01
CO mass flow	g/s	0,002	0,002	0,002	0,001
CO_2 mass flow	g/s	72,0	54,8	40,5	24,1

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Table 5 – Particle emissions

Load	%	100	75	50	25
Time	h:m	16:44	15:45	15:05	12:53
Particulate number concentration PNC	#/cm3	5,64E+05	5,29E+05	4,30E+05	3,73E+05
Particulate number emission	#/kWh	3,21E+12	3,59E+12	4,11E+12	5,96E+12

Table 6 – Back pressure

Load	%	100	75	50	25
Time	h:m	16:44	15:45	15:05	12:53
Back pressure average	mbar	50	43	38	28
Back pressure maximum	mbar	51	52	39	33

Table 7 – Exhaust temperature

Load	%	100	75	50	25
Time	h:m	16:44	15:45	15:05	12:53
Exhaust temperature	°C	489	454	402	324

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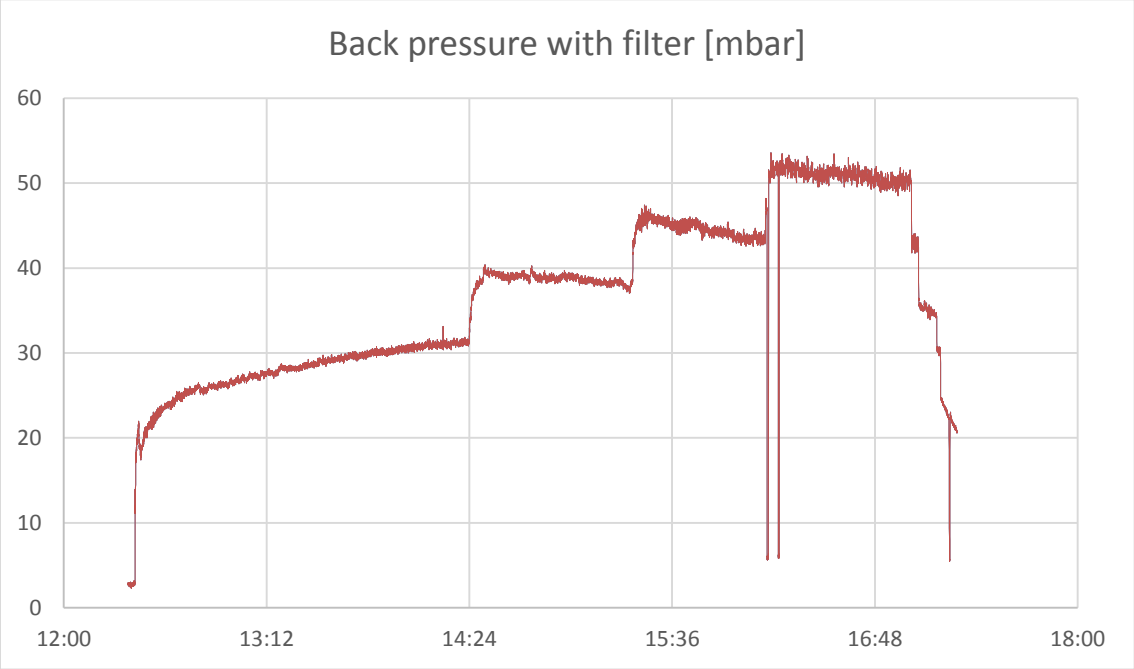
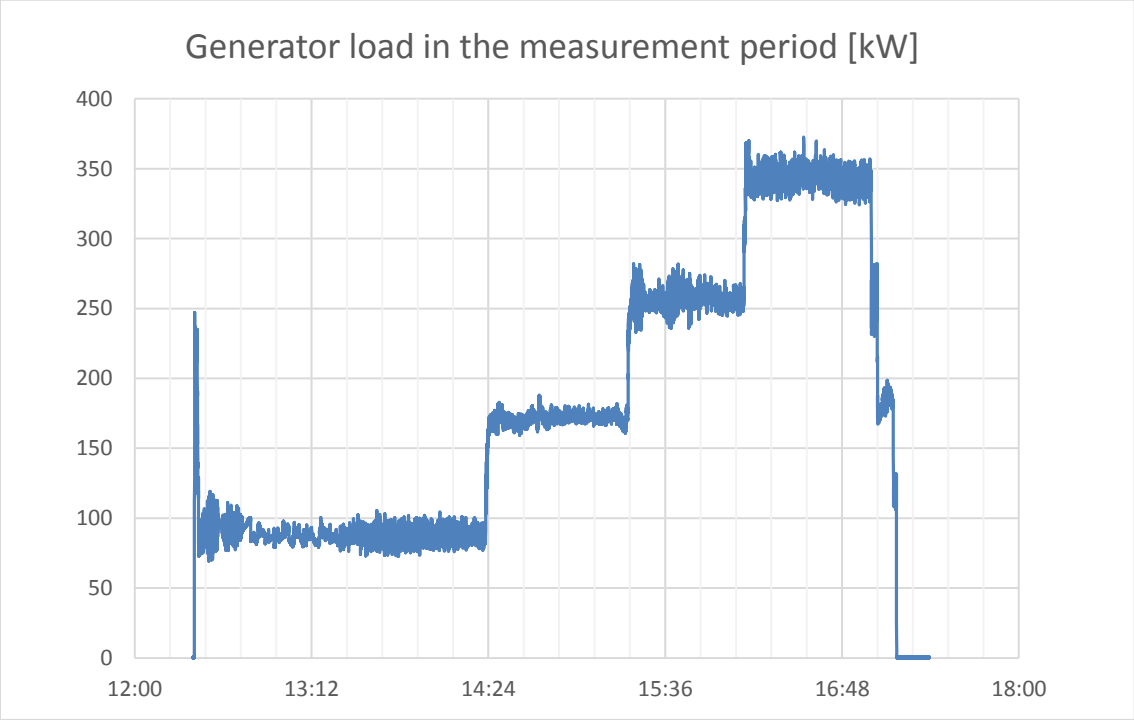
Graph 1 – Back pressure measured in the exhaust over the entire measure period



(Please note that at approx. 16:10 zero point for back pressure meter measured. Therefore, there are two vertical jumps in the graph)

Graph 2 – Load throughout the measurement period



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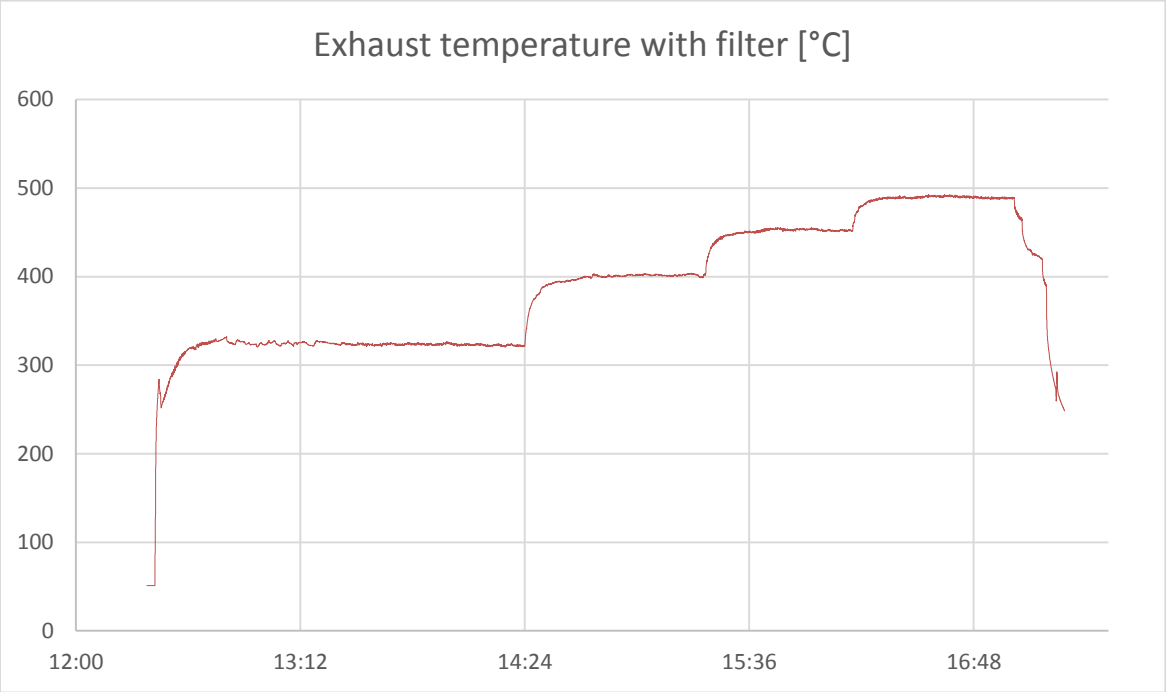
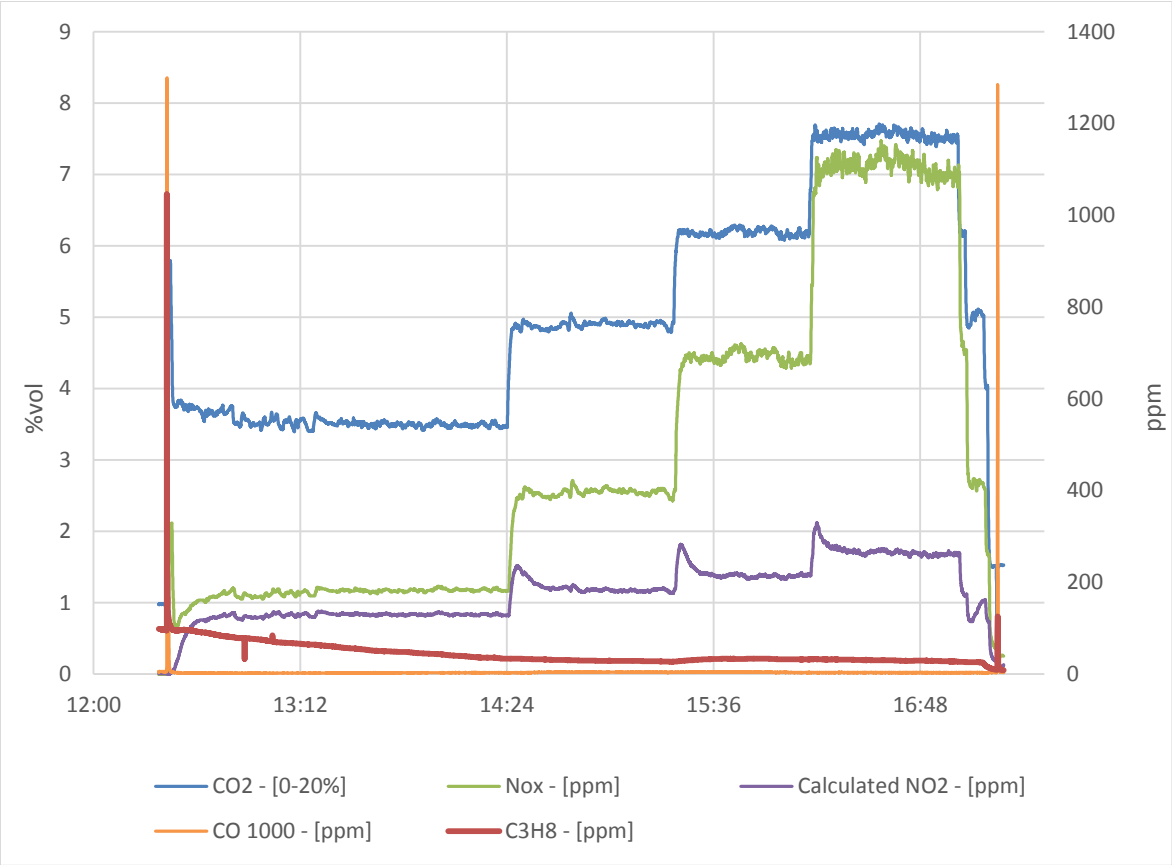
Graph 3 – Exhaust temperature over the entire measure period



Graph 4 – Raw data for gas emissions over the entire measure period



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5 Summary

The particulate filter system from Exilator reduces the number of particles by 98%, when comparing the weighted results of the measurements. During the test, the maximum back pressure did not exceed 52 mbar. At 25 % load, the average temperature before the filter is 324°C and backpressure raises evenly by about 5 mbar in the 27 minutes of measuring (see graph 1 for back pressure measurement). However, the back pressure is reduced at loads over 25%, indicating that the soot is burned. Graph 3 shows the temperature before the filter in the four load points 25, 50, 75 and 100%. Graph 2 shows the load on the generator in kW.

Mounting of the Exilator filter system reduces the specific NOx emissions by 11% (weighted values). However, the NO_2 emission increases by 82%, if you compare the weighted values before and after mounting the filter. The NO_2 increase caused by catalytic oxidation of NO in the filter is therefore: ΔNO2/NO = 15%.

The emission of CO is virtually eliminated by Exilator filter system, which is reduced by 99%.

HC values indicates that the system has emitted some hydrocarbon compounds that gave an increase. In graph 4 the measurement results of the raw gasses are showed. The graph shows that the hydrocarbons (graph: C3H8) slowly decreases through the measurements. When comparing weighted values for HC before and after installation of the filter, emissions increase by 150%. The reason for this is that the engines fuel control is layed out to run 1500 RPM and will therefore during start give full fuel rate to reach the desired RPM. This gives a large amount of unburned fuel in the exhaust gasses right at startup. Before the filter was installed, these gases emitted into the atmosphere, but now they caught by the filter. From here the hydrocarbons evaporate slowly, especially during the first mode at 25 % load. HC levels is low for both measurements.

The following table shows the weighted emissions before and after the installation of Exilator filter (weighting was performed according to ISO 8178, E2 see Table 1). The change in emissions is seen in percent in the last column.

Table 5 – Comparison of results with and without Exilator filters

Weigted emissions		Without filter	Exilator filter	Reduction
NOx	g/kWh	13.02	11.60	-11%
NO2	g/kWh	1.98	3.60	+82%
NO	g/kWh	11.04	8.00	-28%
HC	g/kWh	0.06	0.15	+150%
CO	g/kWh	3.66	0.03	-99%
Specific fuel comsumption	g/kWh	254	257	+1%
Pn	#/kWh	1.87E+14	3.66E+12	-98%
PNC	#/cm3	2.48E+07	4.98E+05	-98%

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