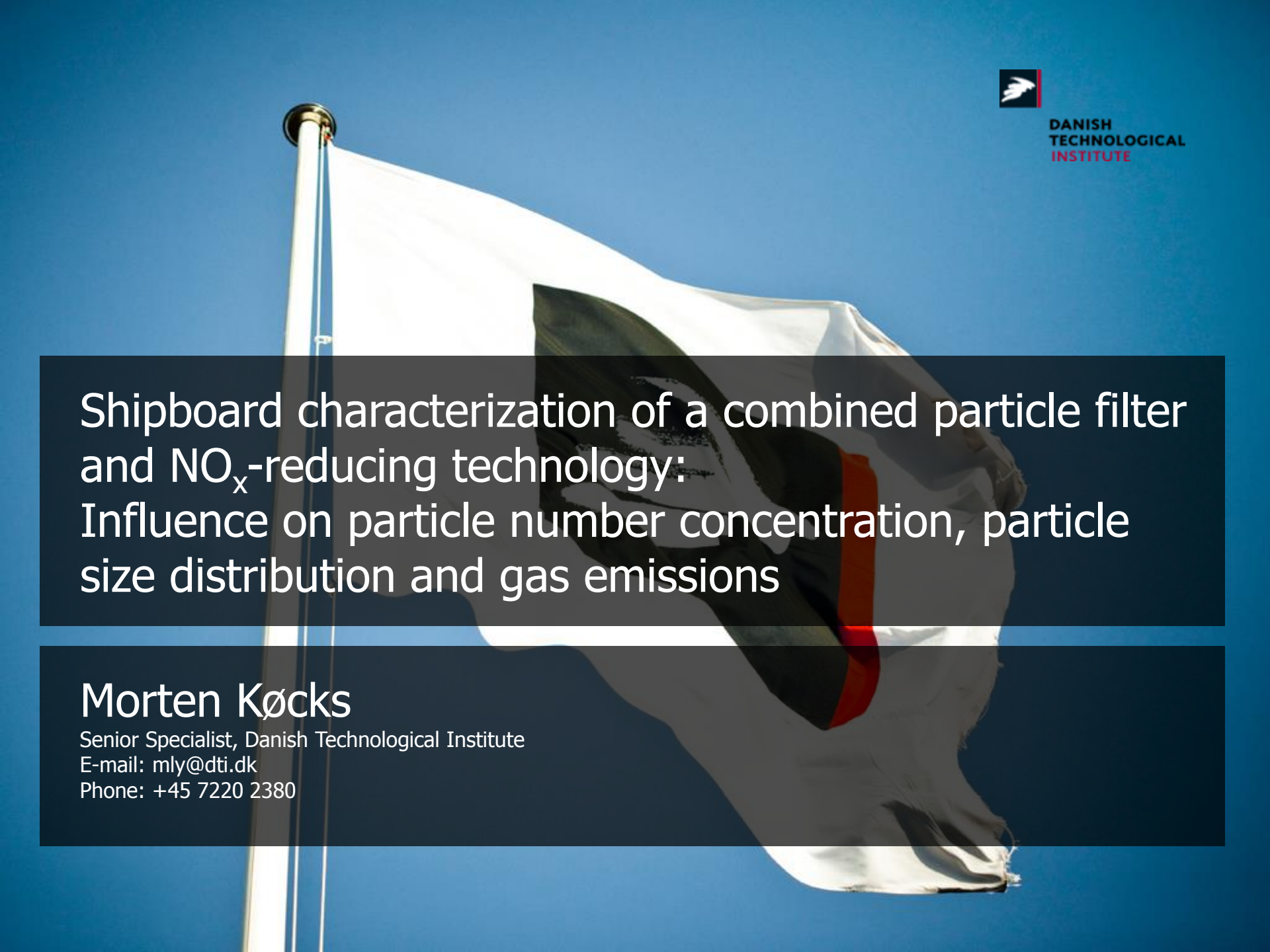

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Shipboard characterization of a combined particle filter and NO_x-reducing technology: Influence on particle number concentration, particle size distribution and gas emissions

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Emission regulation for ships

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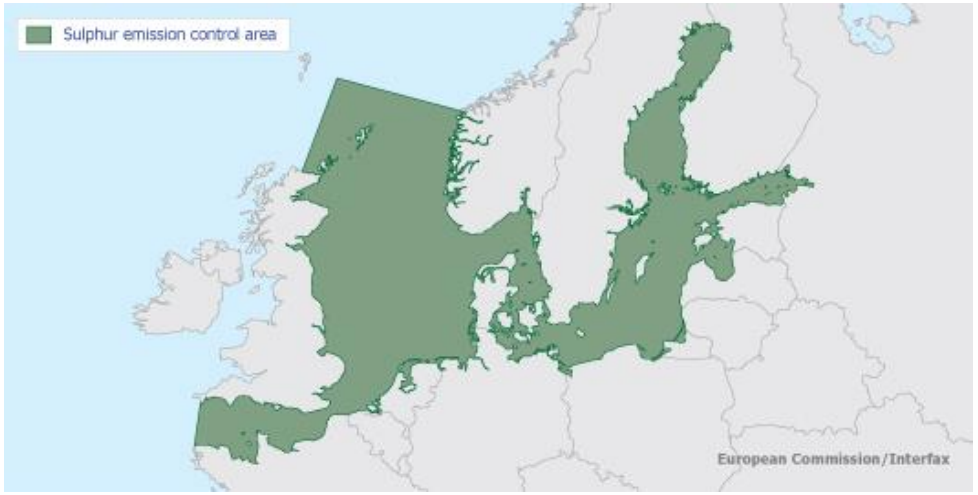
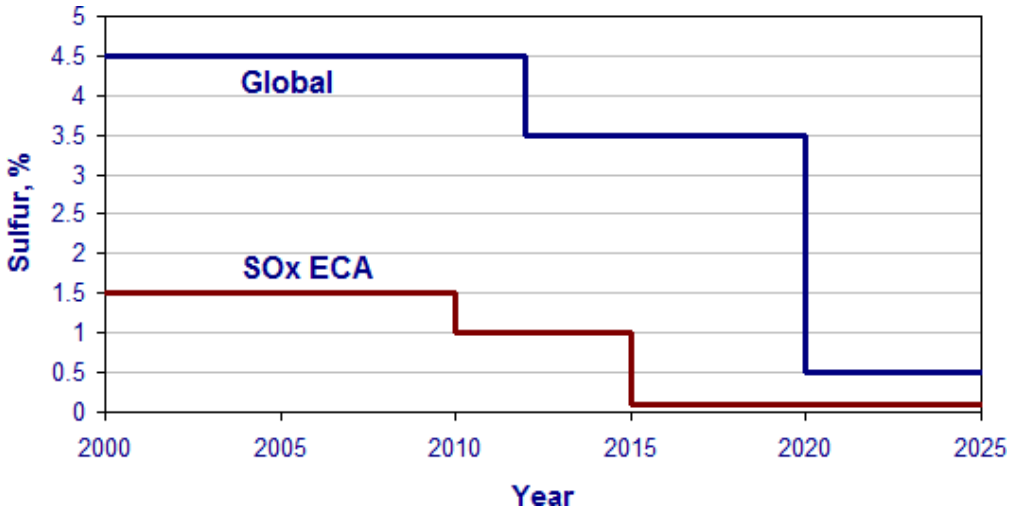
- Sulphur:
  - 2015: 0.1% S, ECA
  - 2020: 0.5% S, global
- NO_x:
  - 2011: Tier II, new ships, global
  - 2021: Tier III, new ships, NECA (~80% reduction)



- Mitigation options:
  - Low sulphur fuel
  - SOx scrubbers
  - EGR, SCR
  - Alternative fuels (LNG)
  - Battery operation
  - DPF
  - …



Why reduce ship emissions?

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- Estimated that pollution from ships in Danish waters acount for ~10 % of the total air pollution related society costs[1]
- PM/PN regulation from ships not yet introduced
- Local inconviniences:
  - Many islands in DK – connected by ferries
  - Harbour fronts – urban movement
  - Passenger inconvinience / work place environment

[1] "Air pollution impact on health in Denmark", DCE 2014

The ferry of interest

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Year built	1998 (operational 1999)
Length	49.9 m
Width	13.1 m
Speed	13.1 knots
Capacity	42 cars 395 passengers
Engine (x2)	MaK M20C, 1020 kW 4-stroke diesel engine
Operation	Svendborg (Funen) – Ærøskøbing (Ærø)

Project background

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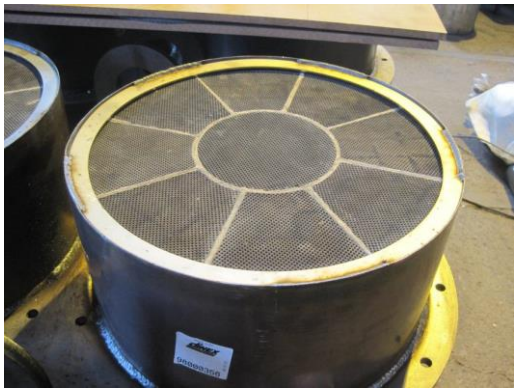
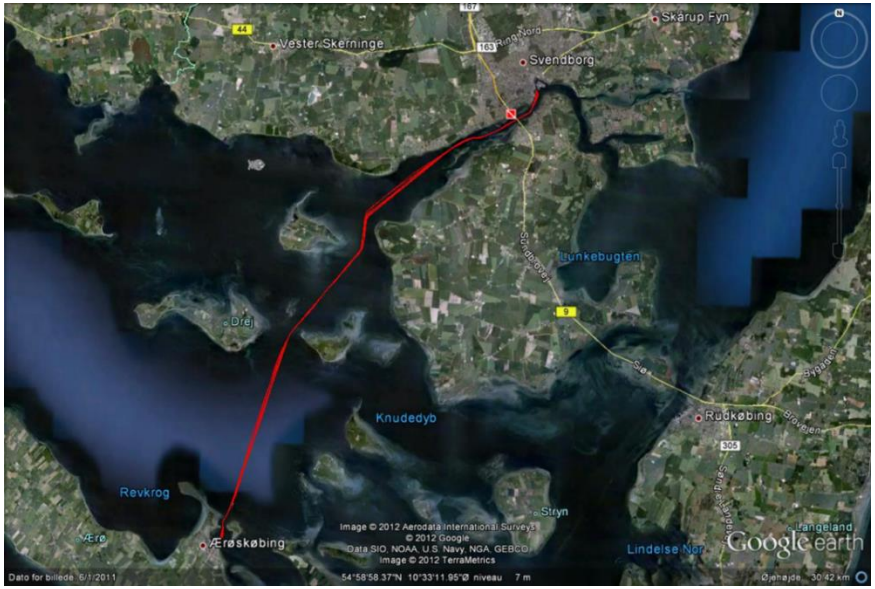
- Project objective:
  1. DPF retrofit on main engine 2010-2012
  2. DPF/SCR retrofit same engine 2013-2016





The filter

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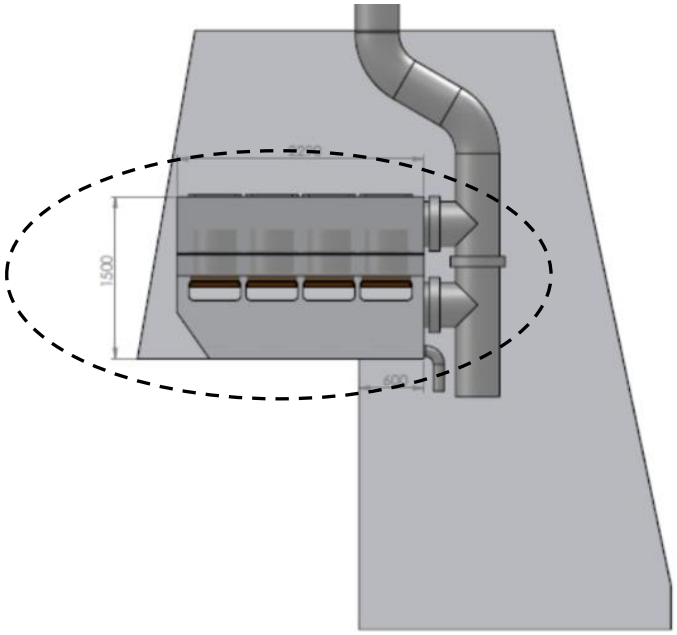

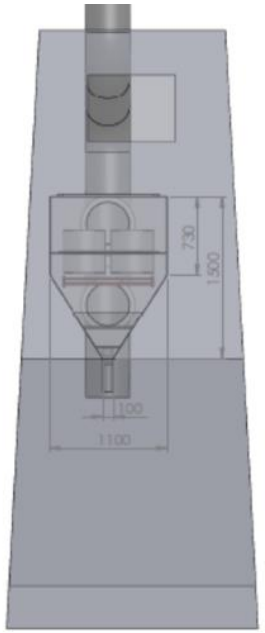

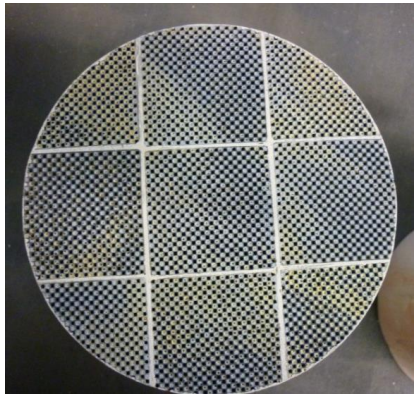

- 8 SiC DPF elements 15” x 15”
- Bypass possible
- Dinex F-SCR elements with integrated SCR coating (phase II)
- Daily active regeneration (electrical) + ash removal

Measurement location

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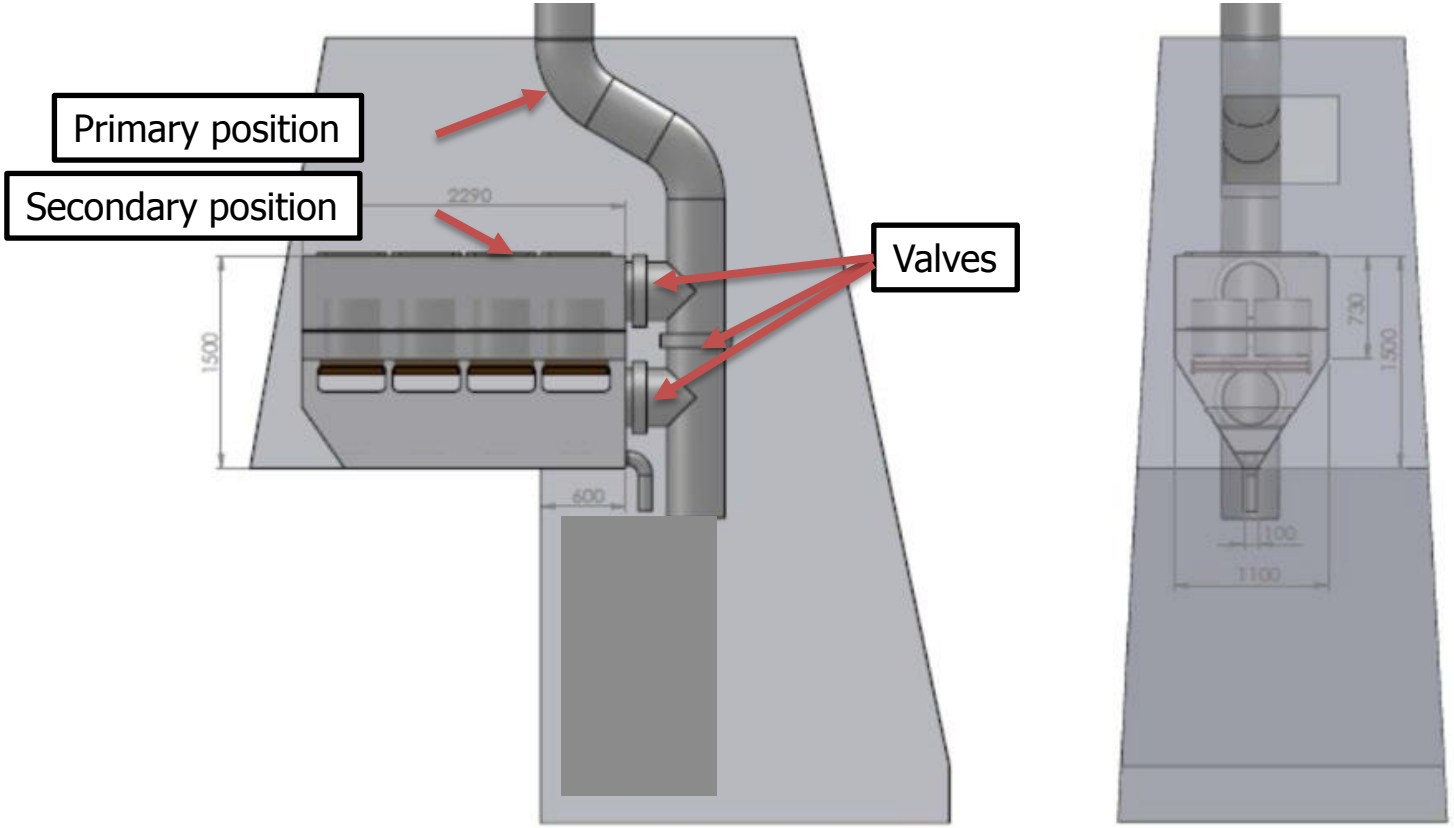

Experimental setup

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Exhaust

Rotating disc diluter 150°C → *Catalytic Stripper* 350°C → *Scanning mobility particle sizer* ~14-675 nm

FTIR / gas rack (NO_x)

Measurement equipment

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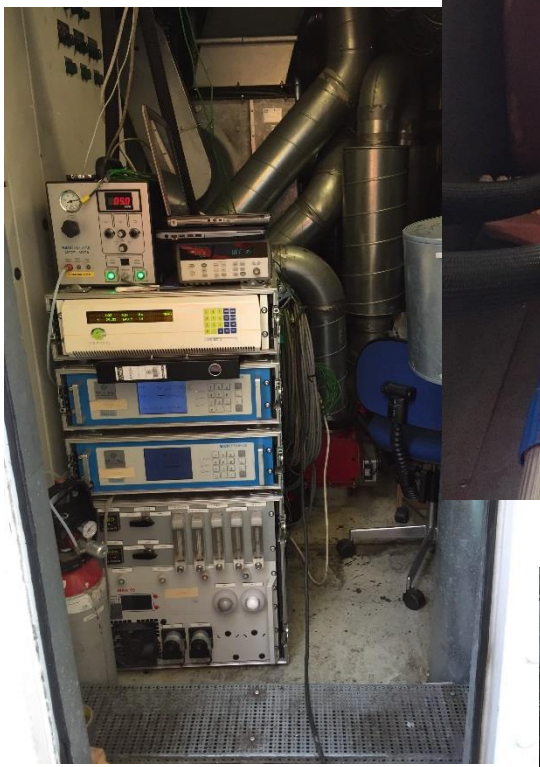

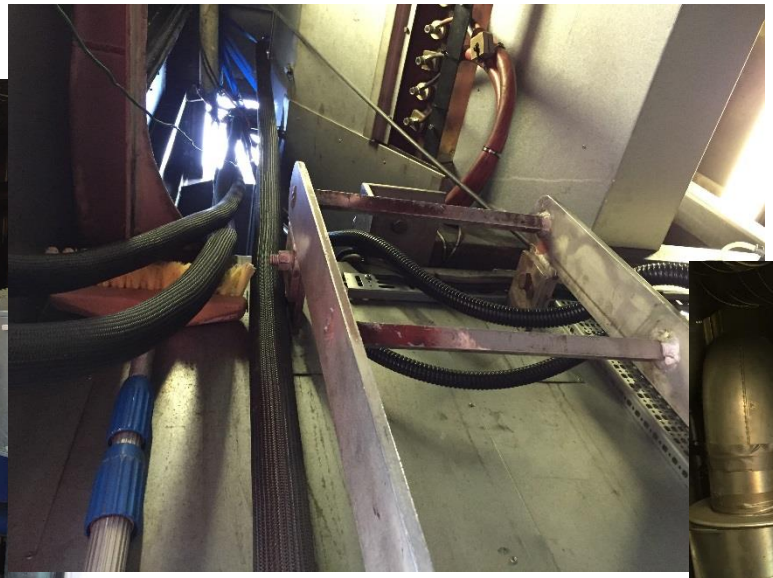

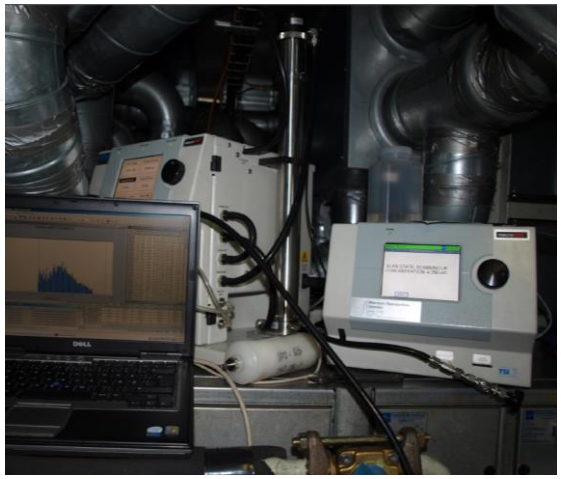

PSD as function of load

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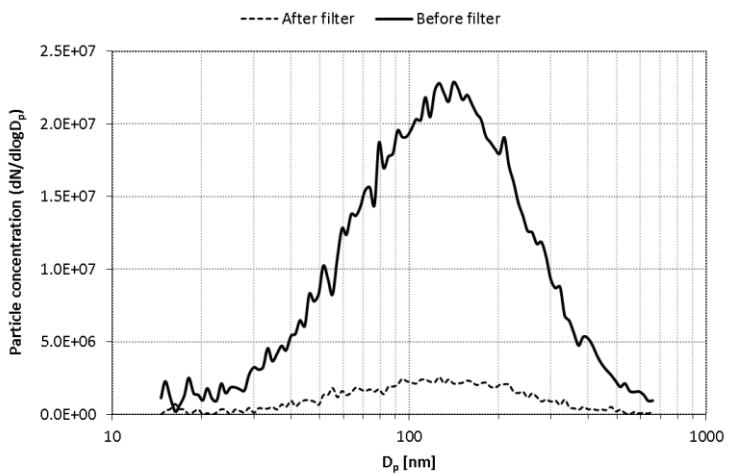
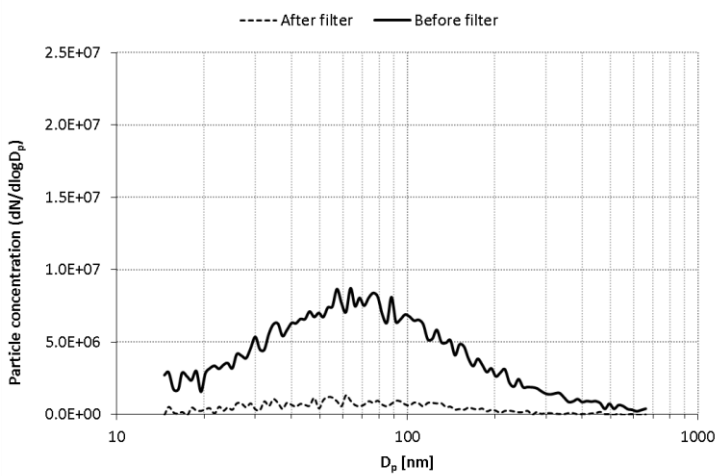
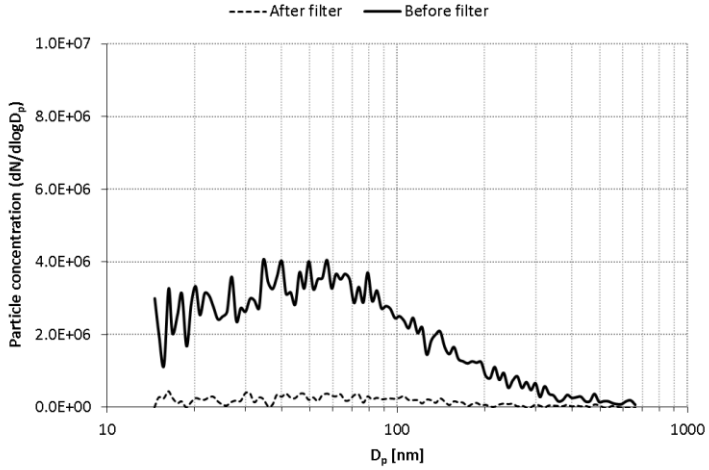
Idle



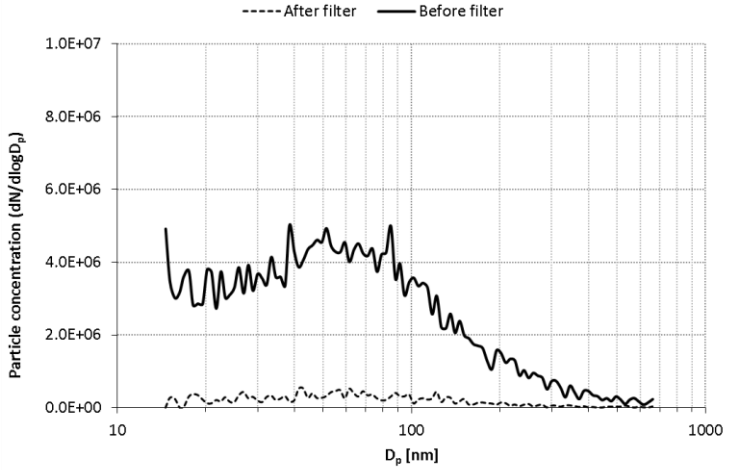
50 %



85 %



100 %



Number and size

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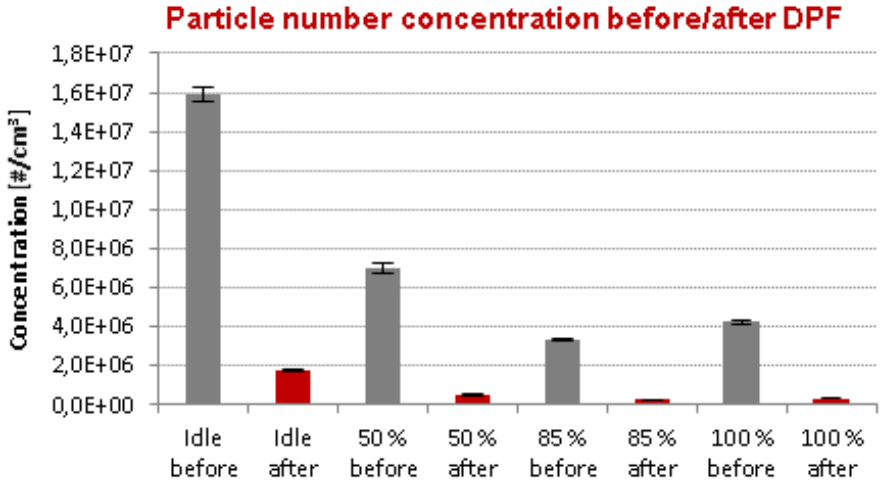

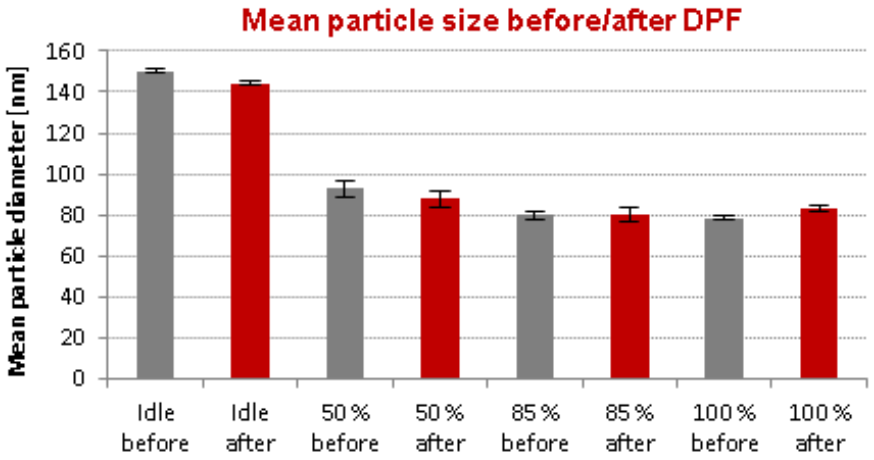

Effectivity of NO_x catalyst

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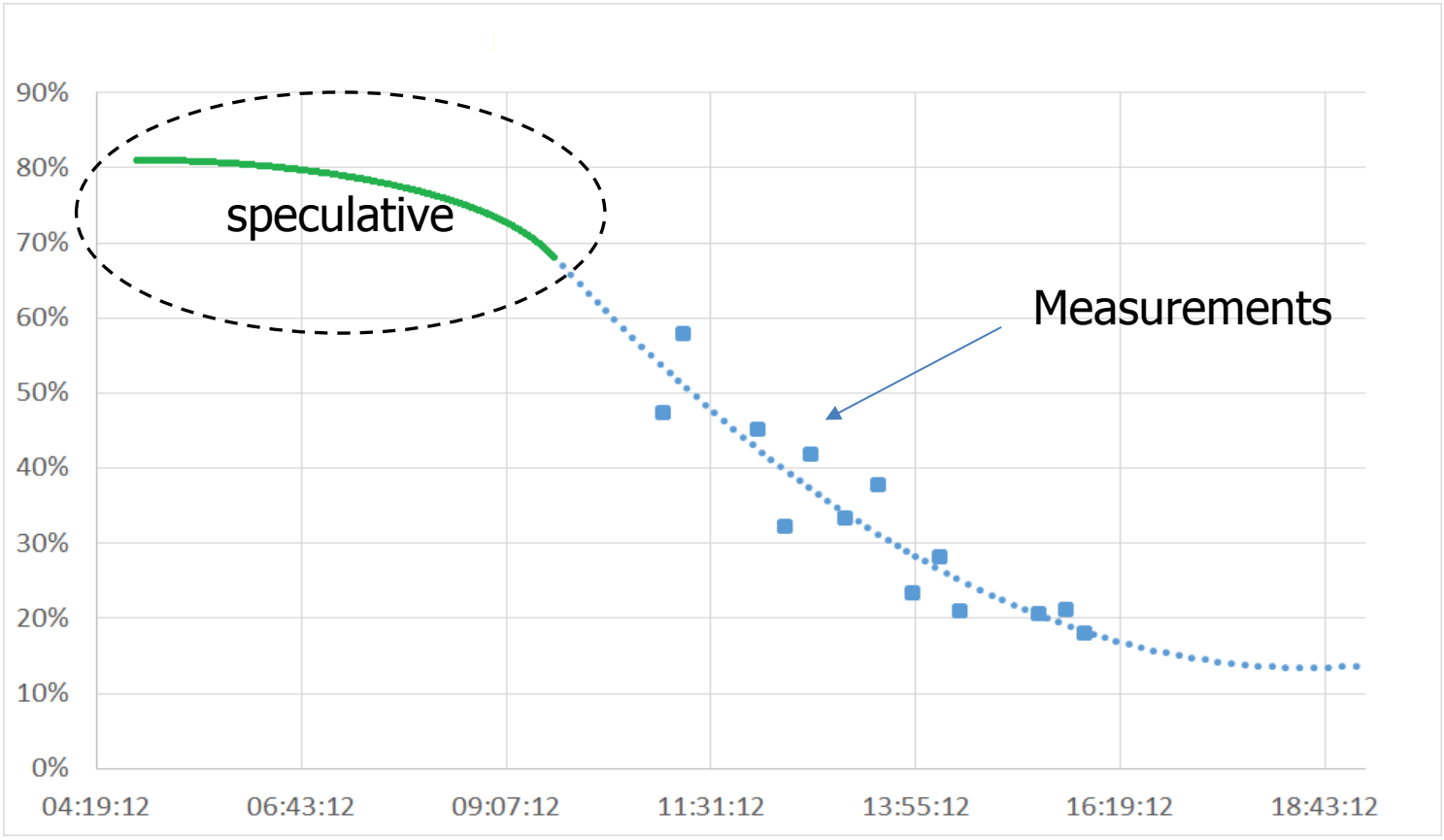

New Danish venture (2017-2020)

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- Increased focus on shipping emissions near cities and coastal areas
- 3 DPF and 2 SCR technologies from 3 different manufacturers to be matured, demonstrated and validated:
  1. DPF
  2. DPF+SCR (urea)
  3. DPF+SCR (pure ammonia)
- Breakthrough for DPF/SCR solutions to be expected
- Measurements in-stack + out-of-stack

Ministry of Environment and Food of Denmark
Environmental Protection Agency

Conclusion

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- Increased Danish and global focus on shipping emissions, not least near cities and costal areas
- It is possible to retrofit a ferry fueled with ~250-300 ppm sulphur marine diesel with an integrated DPF/SCR solution
- Main challenges include:
  - Demand of low exhaust back pressure
  - Limited space in engine room – retrofit solutions may be placed in the smoke stack
  - Active/forced daily regeneration of DPF and ash removal is required in this case
- On-board measured reductions:
  - PN reduction by >90%
  - NOx reduction of ~40%

Acknowledgements

- Ærøfærgerne A/S
- Dinex A/S
- Financial support from the Danish EPA

Poster #25

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Shipboard characterization of a combined particle filter and NO_x-reducing technology: Influence on particle number concentration, particle size distribution and gas emissions

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Introduction

Particle and gas emissions from diesel engines have profound impact on human health and as a result; emissions from marine engines are under scrutiny. Although regulations on NO_x-emissions from ships have been implemented and sulphur content in marine fuel is limited to 0.1% in emission control areas (ECAs), and globally limited to 0.5% in 2020, emissions from ship traffic is still a much-debated subject. Particle emissions are today unregulated but are expected to be regulated in the future. Different mitigation strategies are thus being exploited including emission-reducing technologies such as particle filters, NO_x-reducing SCR (Selective Catalytic Reduction) systems and scrubbers.

Figure 1: The ship's sailing route connecting the island of Ærø with Funen

In this study, emission data from a Danish inland ferry with a retrofitted, integrated particle filter and SCR system (Dinex F-SCR) is presented. All measurements were carried out on-board the ferry connecting the island of Ærø with Funen (Fig. 1). The ferry has two main engines (MaK M20C, 1020 kW 4-stroke diesel engine) both of them running on marine diesel, in which the sulphur content is limited to 0.1%.

Figure 2: Experimental setup with measurement equipment and chimney

Experimental

The emission was characterized at 4 points of engine load: Idle, 50%, 85% and 100% MCR (maximum continuous rating), and measured according to the ISO 8178 steady state method. Nanoparticle size distribution and number concentration was measured using a scanning mobility particle sizer (SMPS) (TSI) in connection with a rotating disc diluter (Testo) and further connected with a catalytic stripper (Catalytic Instruments) for measuring the solid particle fraction (Fig. 3). Gas emissions were measured using standard laboratory gas analyzer equipment as well as a Thermo Scientific Antaris IGS FTIR analyzer.

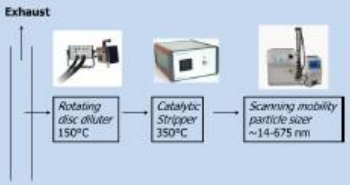

Figure 3: Setup for particle measurements

Results

The particle number concentration was in average reduced by more than 90% by the filter – similar to the results obtained from a previously tested filter without catalytic coating (phase I). The mean particle size was largest with the ferry operating in idle in the harbour during load and unload, and between 50 nm and 200 nm during all four engine loads tested.

A NO_x-reduction of at least 40% was measured when the system was put into operation. However, the efficiency of the filter dropped significantly during the day, probably due to soot contamination of the filter catalyst material. This shows that the efficiency might be even higher early in the morning during the first crossing. A solution for this problem could be more frequent regeneration.

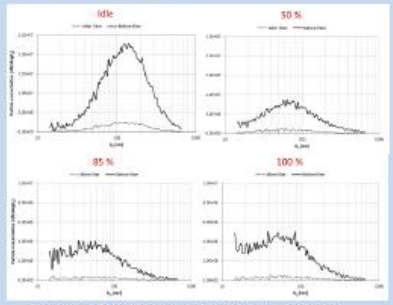

Figure 4: Particle size distributions for engine load: Idle, 50 %, 85 % and 100 % MCR, measured with SMPS during operation

Conclusion

- The installed particle filter in average reduced the particle emission with minimum 90% by number, measured in real-time during operation. The expected reduction was 99 % and the difference is very likely due to leaky bypass valves in the exhaust gas system as also indicated by further measurements.
- The NO_x-reduction was about 40% and the actual NO_x level measured after the filter was below the IMO TIER II regulation for ships and comparable to the EURO III norm for on-road heavy-duty diesel engines.

Following this work, a larger Danish project, co-financed by the Danish EPA, has just been initiated (2017-2020) where three different particle/NO_x-reducing technologies will be tested on three different ships.

This work was supported by the Danish Ministry of the Environment, Environmental Protection Agency, and part of collaboration between Danish Technological Institute, Ærøfærgerne A/S and Dinex A/S.