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On the experience of first DPF operation at a medium speed 4-stroke Diesel engine on board a commercial ocean going vessel

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R&D engineering medium speed

Advanced development - After treatment

Disclaimer

All data provided on the following slides is for information purposes only, explicitly non-binding and subject to changes without further notice.

Outline

- Motivation & Methods
- Execution
- Results
- Conclusions & Proposed Measures

Motivation

- DPF successfully reduces PM emission in automotive & NRMM applications
- Gain first experience with DPF technology for ocean going vessels
- Market study of commercially available marine DPF systems
- Consideration of operating conditions and fuel & lube oil quality
- Demonstrate ability to meet future US-EPA Tier-4 PM emission limits
- Identify possible DPF challenges

Methods
part 1/2

- Commercial ocean going vessel selected to collect realistic operational data & experience inside an emission controlled area (ECA*)
- Auxiliary Diesel engine selected on a multi engine configuration due to safety requirements (no emergency lane or ADAC / AAA towing service at sea)
- Operation on low sulfur DM-A grade distillate marine fuel according to ISO-8217 for future ECA* limits, EU 2005-33-EC Directive or future California waters code of regulations
- Lube oil quality adapted for low sulfur fuel operation

*) ECA according to International Maritime Organization (IMO) Revised MARPOL Annex VI and NO_x Technical Code 2008

Methods
part 2/2

- DPF layout as full flow system for the entire exhaust gas volume flow for realistic conditions
- PM emission measured with mobile partial flow dilution system according to ISO-8178, collected on quartz fiber filters for subsequent chemical characterization
- PM constituents analyzed for elemental carbon (EC) & organic carbon (OC) by a thermo-graphic method on the basis of VDI-2465/2 as well as for sulfates by an ion-chromatographic method
- Up to the knowledge of MAN Diesel & Turbo SE this is the first installation worldwide of a DPF on a commercial ocean going vessel under this operating conditions

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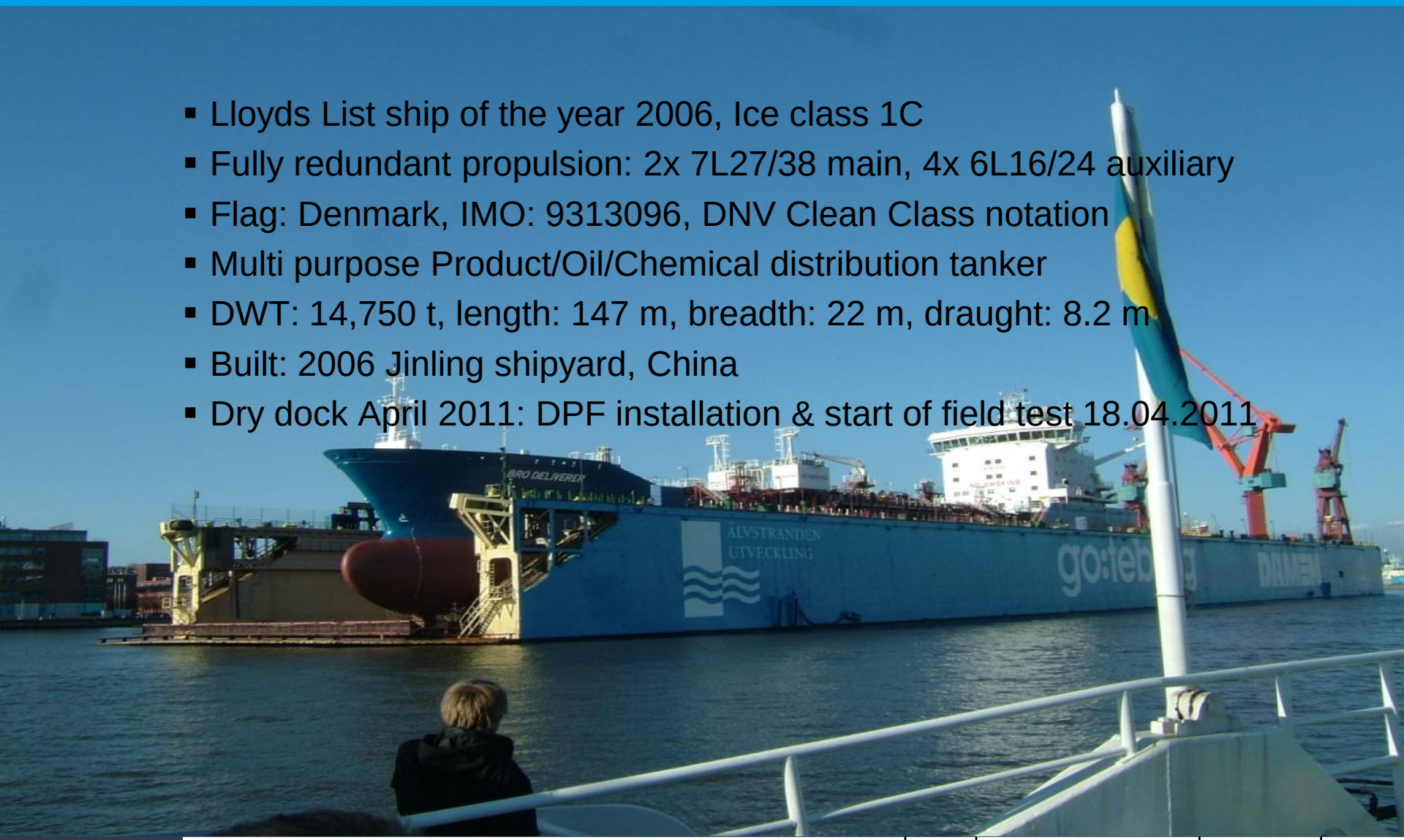
Selected vessel for field test

Bro Deliverer



- Lloyds List ship of the year 2006, Ice class 1C
- Fully redundant propulsion: 2x 7L27/38 main, 4x 6L16/24 auxiliary
- Flag: Denmark, IMO: 9313096, DNV Clean Class notation
- Multi purpose Product/Oil/Chemical distribution tanker
- DWT: 14,750 t, length: 147 m, breadth: 22 m, draught: 8.2 m
- Built: 2006 Jinling shipyard, China
- Dry dock April 2011: DPF installation & start of field test 18.04.2011

Selected DPF for field test

HUG NautiClean

- **Only 2 suppliers** could be shortlisted (HUG & ETB) from market study, decision for HUG due to:

- VERT certified, approved by Lloyds Register & Germanischer Lloyd
- With warranty for the intended application

- SiC closed wall flow filter with active burner regeneration (most sulfur tolerant system)
- Already proven for inland waterway vessels & recreational yachts with automotive/NRMM derived engines (most referenced system)
- Modular design

Source: HUG engineering nauticlean schematic

http://www.hug-eng.ch/schema_nauticlean_partikelfilter.html?file=tl_files/pdf/Schemas%20PDF/C.01546_nauticlean_DE.pdf

6L 16/24
engine data

MAN-ZJMD	Zhenjiang Marine Diesel Works, China
▪ Bore / Stroke	160 / 240 mm
▪ Power	540/515 / 600/570 kW
▪ Speed	1000 / 1200 rpm (50 / 60Hz)
▪ Configuration	6 cylinder in-line 4-stroke cycle
▪ Fuel capability	Heavy Fuel Oil (HFO) residual RMG-700 grade
▪ Application	Auxiliary engine D2-cycle
▪ Operation	6000 hrs/year
▪ Average load	50 – 60 %

Additional field test modifications:

- Retrofit of cylinder-units from IMO Tier-I to actual Tier-II components for reduced lube oil consumption
- **Engine & turbocharger matching for higher backpressure of 100 mbar instead of serial allowed 30 mbar**

Fuel & lube oil data

analytical results from field test

Marine Gas Oil (MGO) DM-A grade (average)

▪ Lower heating value [kJ/kg]	42683	
▪ Carbon [% m/m]	86.85	
▪ Hydrogen [% m/m]	12.95	
▪ Nitrogen [% m/m]	0.13	
▪ **Sulfur [ppm m/m]**	**700**	(future IMO ECA limit: 1000 ppm)
▪ **Ash [ppm m/m]**	**93**	(ISO limit: 100 ppm)

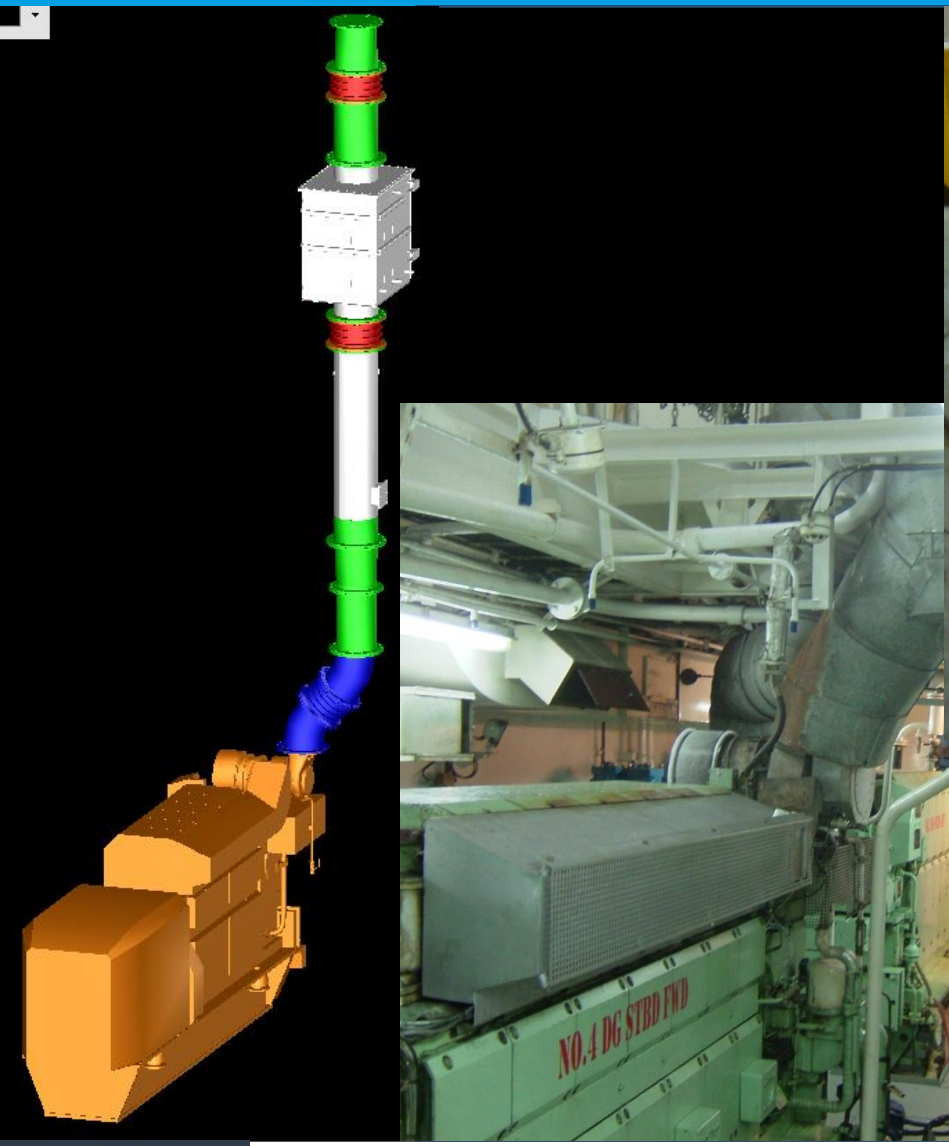
Lube oil quality adjusted for fuel sulfur content

▪ Sulfur	free: automotive	low: DM-A grade	high: RM-grade
▪ Type (example)	Castrol EDGE	BP Energol DS3-154	Shell Argina T40
▪ SAE grade	5W-30	40	40
▪ BN [mg KOH/g]	6	15	30
▪ **Sulfated ash [% m/m]**	**0.6**	**2.1**	**3.7**

DPF
design data

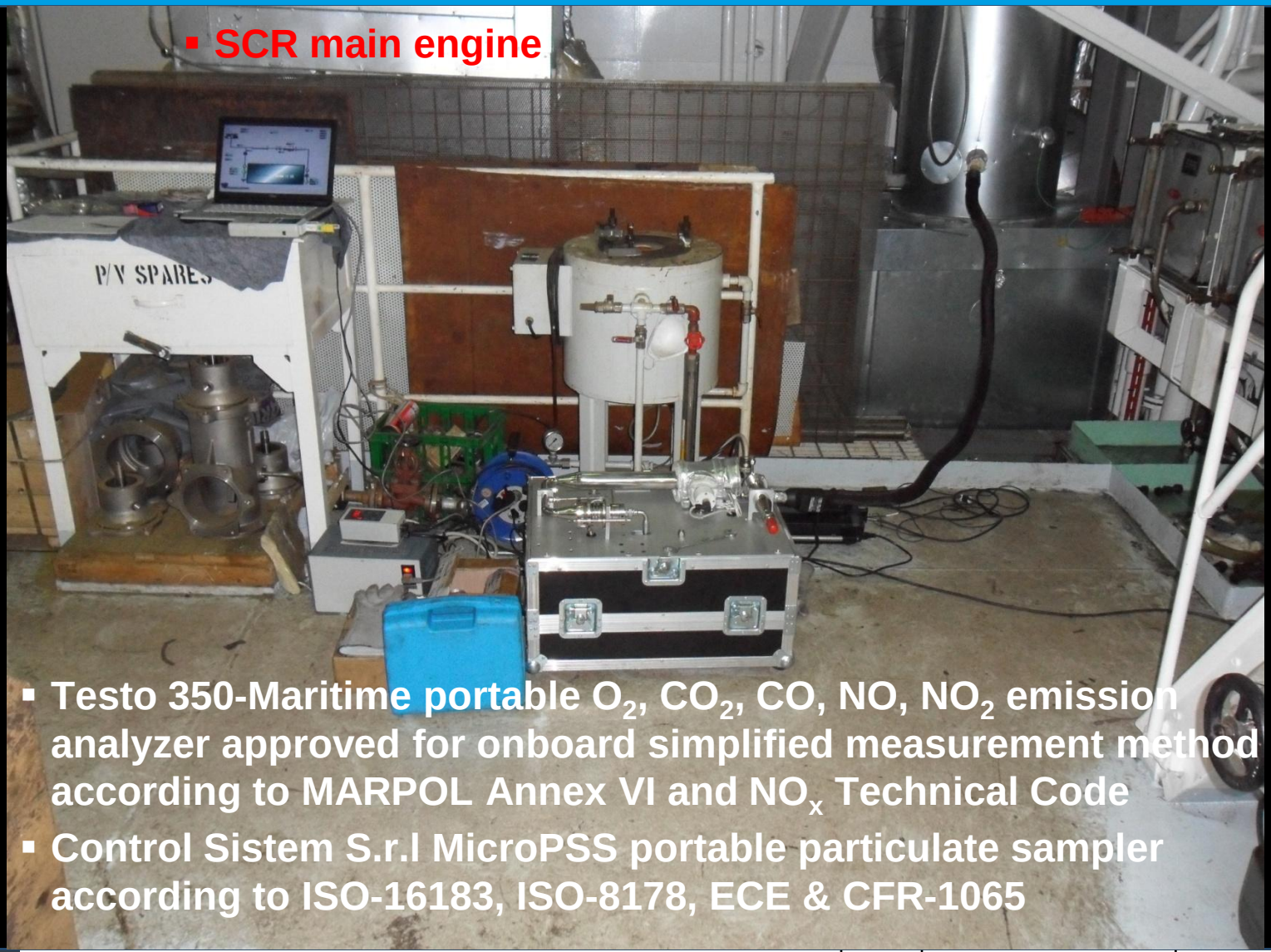
- Initial back pressure — <80 mbar @ 100% load
- Size — 950 x 770 x 1200 mm (comparable to engines SCR size)
- Burner — full flow controllable 25 - 250 kW
- Regeneration triggered — every 24 hrs or if back pressure >100 mbar
- **PM reduction — >95% (>97% according to VERT criteria)**
- **Design maintenance interval — 3000 – 4000 h expected**

DPF
installation study



Measurement setup

MicroPSS & Testo 350-Maritime



- **SCR main engine**

- **Testo 350-Maritime portable O_2, CO_2, CO, NO, NO_2 emission analyzer approved for onboard simplified measurement method according to MARPOL Annex VI and NO_x Technical Code**
- **Control Sistem S.r.l MicroPSS portable particulate sampler according to ISO-16183, ISO-8178, ECE & CFR-1065**

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Results

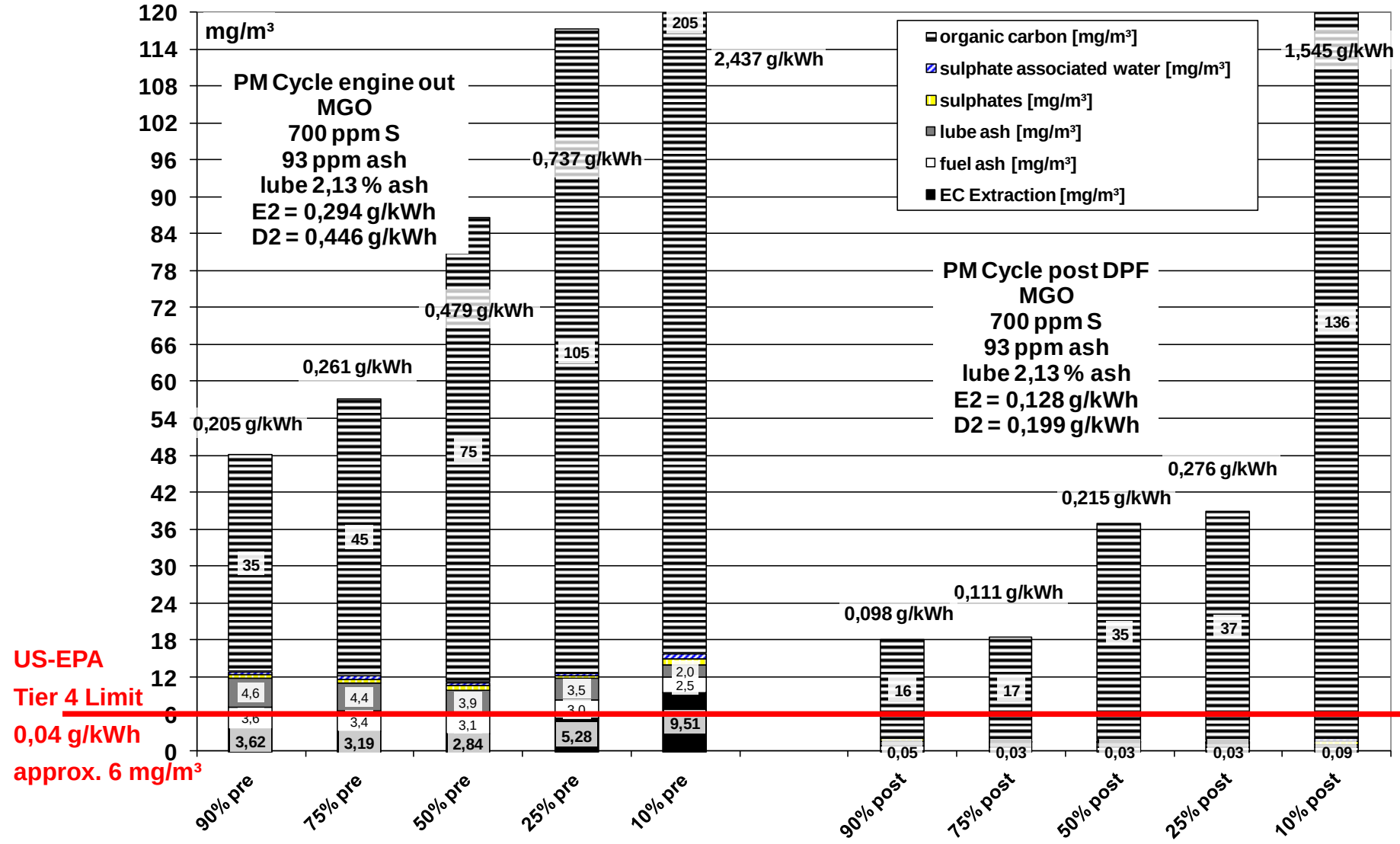
PM samples

Teflon Quartz

Teflon Quartz

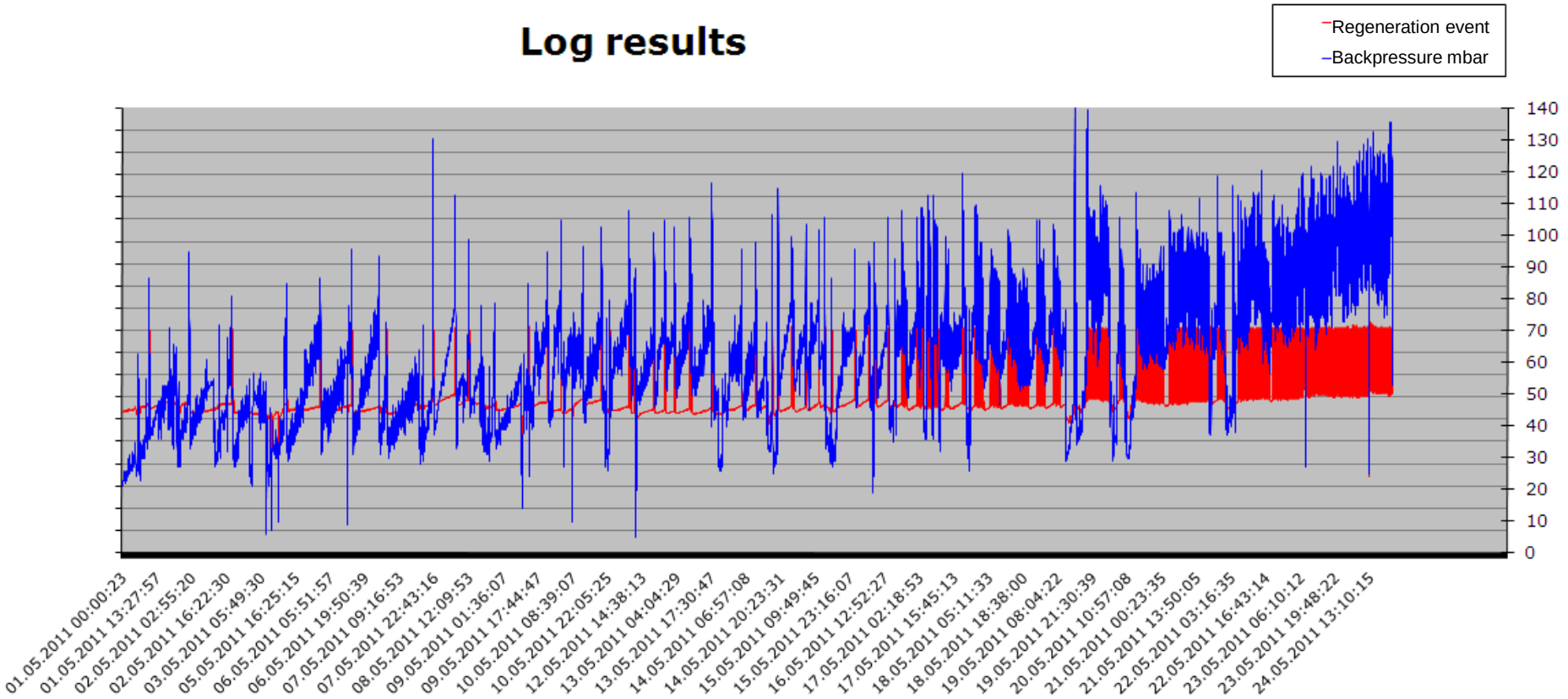
Results

PM emission & composition



Results

DPF backpressure development



Results
summary

- After ~700 operating hours backpressure limitation exceeded by ash accumulation
- Backpressure rise at 50 - 60% engine load from approx. 30 to 80 mbar
- Reduction

EC	99 %
OC	30 – 60 %
Sulfate + sulfate associated H_2O	40 – 60 %

- PM emission typical for HFO-design engines dominated by OC
- US-EPA Tier-4 PM-limit of 0.04 g/kWh with DPF still exceeded

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Conclusions & Proposed Measures

DPF total PM–Reduction: 55%

Conclusions & Proposed Measures

- DPF technology from automotive/NRMM applications can not be simply transferred to large medium speed marine Diesel engines
- DPF technology not ready for commercially operated marine medium or low speed Diesel engines
- Achieved PM-reduction only 55% versus 97% according to VERT criteria
- Extension of ash cleaning interval by factor of 10 – 20 for customer satisfaction
- DPF elements with higher ash penetration or storage capacity needed
- DPF with higher OC oxidation capability at sulfur insensitivity needed
- Disappointing DPF market situation for large marine Diesel engines, more market players desired
- Cost of DPF incl. installation not reasonable vs. engine cost
- Max. ash limit according to fuel standard must be considered for layout
- Lube oil quality (sulfated ash amount) is predetermined by HFO-operation of engines outside ECA
- Marine lube oil “top-up only” philosophy & “shared” lube oil system design to be reconsidered
- Max. DPF size limited, a reasonable DPF size is comparable to SCR size

Acknowledgements & References

- A.P. Møller - Mærsk A/S, Denmark
- Hug Engineering AG, Switzerland

Thank you for your attention!

Do you have any questions?

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