



**On reduction and
in service
measurements of
PM from large
4-stroke Diesel
engines**

- **Motivation**
- **Methods**
- **Results**
- **Conclusions**
- **Acknowledgements and References**

- **There is still limited knowledge available today of particulate matter (PM) emissions from large four-stroke medium speed Diesel engines for ships compared to Diesel passenger cars and trucks. The detailed chemical composition and aerosol properties of the PM from marine Diesel engines are widely unknown.**
- **Over the last years, improvements have been achieved to reduce PM emission from large medium speed 4-stroke Diesel engines. Detailed PM measurements have been performed at several stages of a continuous development program and the influence of different types of fuel on the PM has been investigated.**
- **Furthermore, in service measurements have been performed to characterize the PM emission after approx. 15,000 hours of engine operation.**

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Measurement methods



- **PM measurement according to ISO-8178 (conclusively proven for fuel sulfur levels up to 0.8% only) with AVL 472 Smart Sampler Modular GEM140 dilution system on Quartz or Teflon fiber filters and fuel analysis performed by MAN Diesel SE**
- **Chemical analysis of the PM performed by Germanischer Lloyd (GL) thermographically and ionchromotographically for elemental carbon (EC), organic carbon (OC), sulfates (SO₄), sulfate bound water (H₂O) and ash**
- **PM number size distribution measured by Deutsche Luft und Raumfahrtgesellschaft (DLR) with differential mobility analyzer, online diffusion battery, multi-channel condensation particulate counter and with / without Thermodenuder**

48/60 engine type specification



- Power: 1050/1200 kW/cyl.
- Speed: 500 - 514 rpm
- Size: 6L - 18V
- Stroke: 60 cm
- Bore: 48 cm

Versions:
(old - test engine)
A - type
B - type
(B - test engine)
(CR - test engine)

Main development steps



- The focus is set on constituents which can be influenced by the engine. PM emission for different fuels will be shown and the influence of development / design improvements of the engine on elemental and organic carbon will be presented.
- old test engine towards A-type: injection intensity
- A towards B-type: combustion chamber design
- B towards B test engine: piston design
- B test engine towards CR: injection system, piston design

In service measurement on board 1 main engine running at anchor load



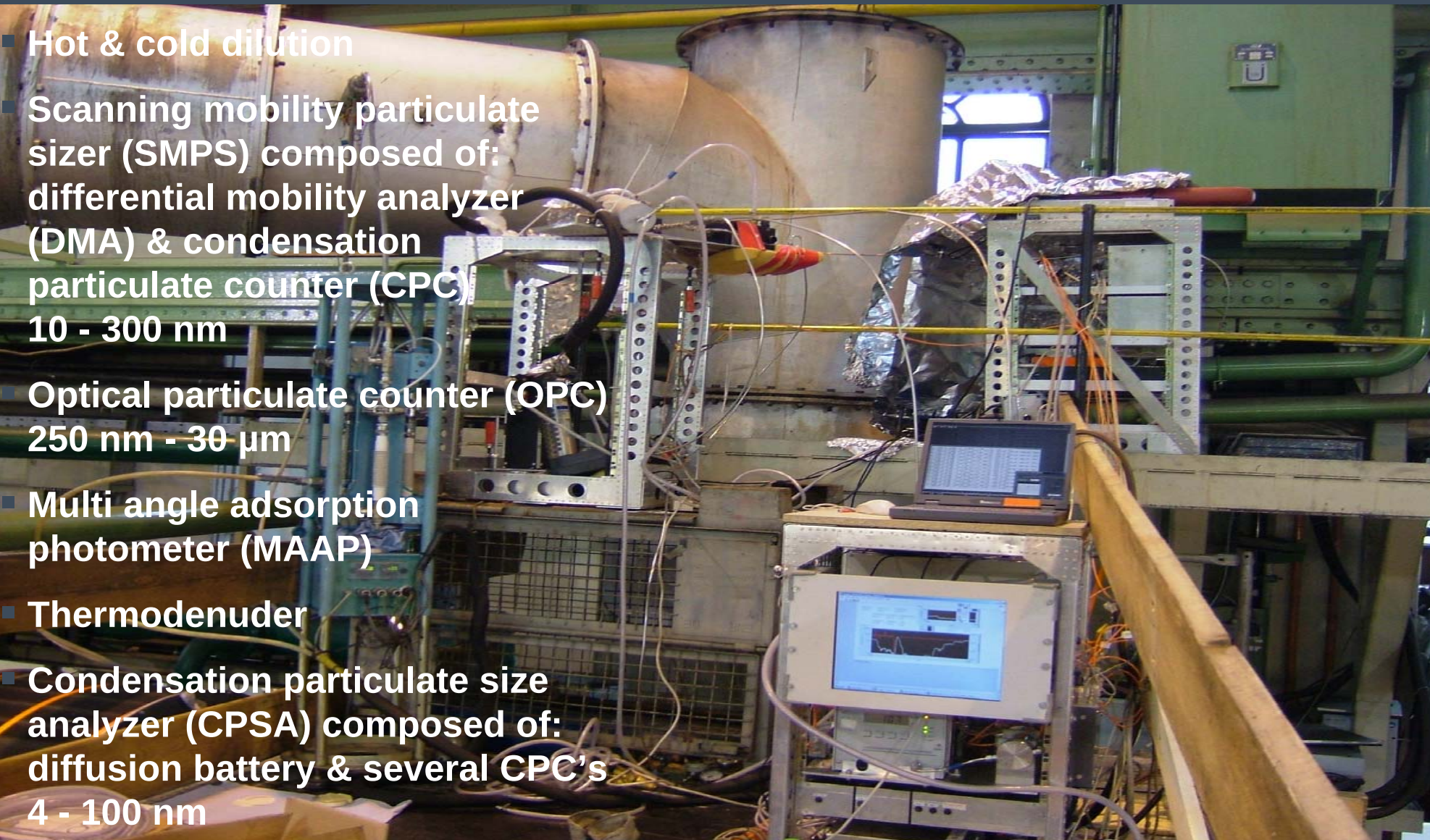
- Type: Double Hull Tanker
- Classification: American Bureau of Shipping (ABS)
- Year built: 2004
- Registry: USA
- Length 287 m
- GRT 110,693
- DWT 185,286 MT
- 1.3 million barrels
- Twin redundant propulsion system
- 4x 6L48/60A 25,200 kW



AVL 472 smart sampler modular GEM140: on board set-up



DLR mobile aerosol measuring equipment: test bed set-up

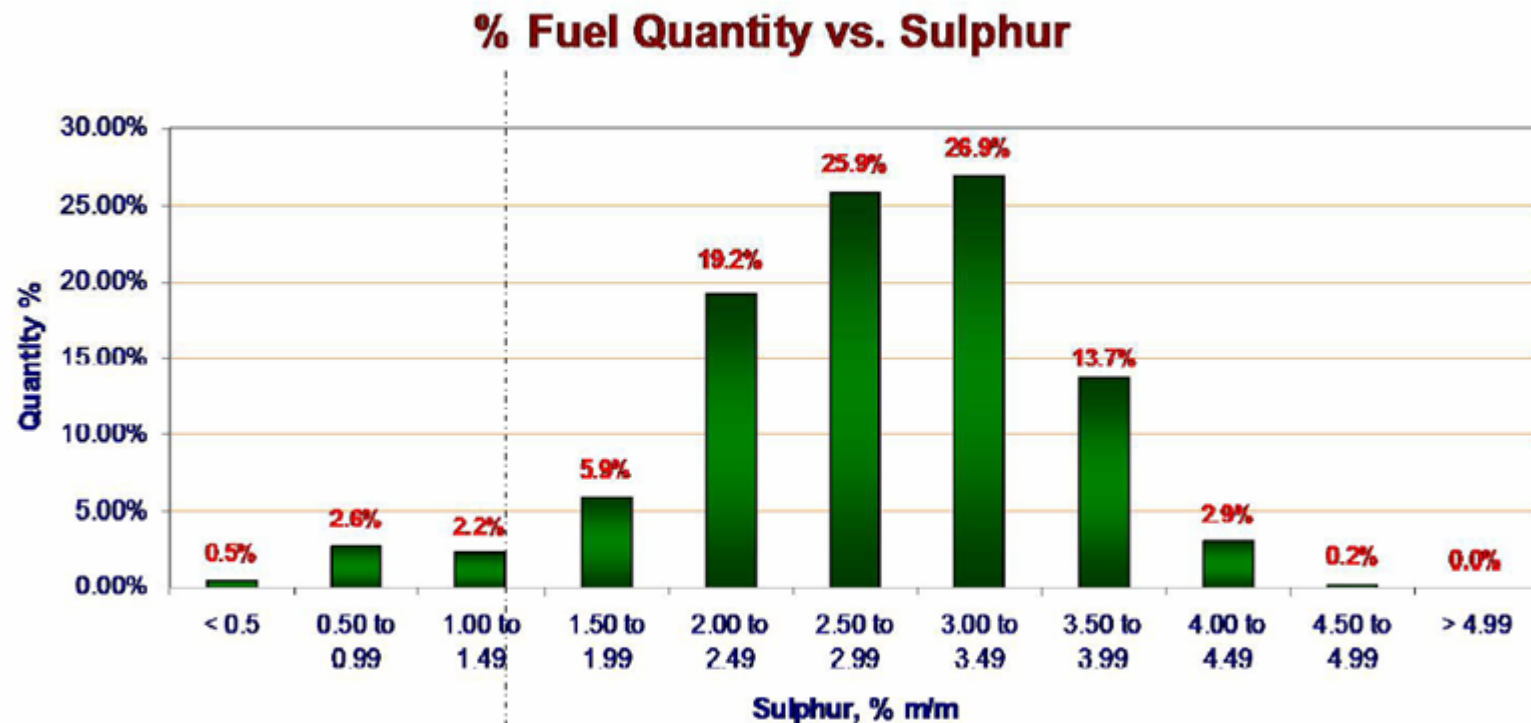


- Hot & cold dilution
- Scanning mobility particulate sizer (SMPS) composed of:
differential mobility analyzer (DMA) & condensation particulate counter (CPC)
10 - 300 nm
- Optical particulate counter (OPC)
250 nm - 30 μ m
- Multi angle adsorption photometer (MAAP)
- Thermodenuder
- Condensation particulate size analyzer (CPSA) composed of:
diffusion battery & several CPC's
4 - 100 nm

Quality of bunker oil for ships



2004 Worldwide fuel sulphur distribution



1.5%



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Fuel oil properties



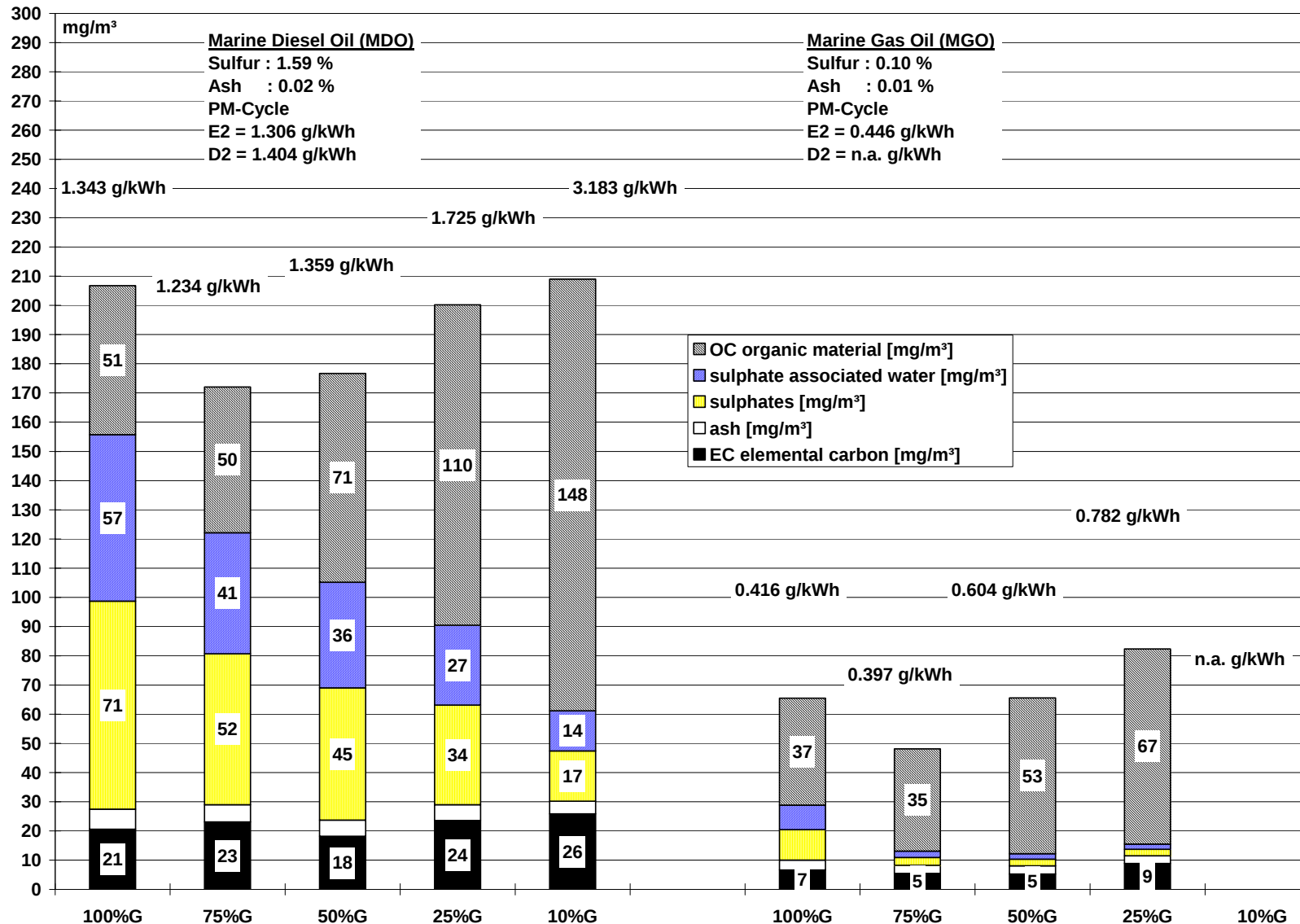
Fuel	Heavy Fuel Oil (HFO)	Marine Diesel Oil (MDO)	Marine Diesel Oil (MDO)	Marine Gas Oil (MGO)
	ship	ship	test bed exemplary	test bed exemplary
Category	residual	distillate	distillate	distillate
Type	RM 180	DM-B	DM-B	DM-A
Viscosity [mm ² /s]	171 @ 50°C	3.3 @ 40°C	6.4 @ 40 °C	2.6 @ 40°C
Density @ 15 °C [kg/m ³]	975	877	878	830
Hydrogen [% mass]	10.63	12.59	12.40	13.20
Carbon [% mass]	87.16	86.86	85.80	86.64
Sulfur [% mass]	1.90	0.45	1.79	0.07
Nitrogen [% mass]	0.31	0.10	0.01	0.09
Ash [% mass]	0.01	0.01	0.01	0.01
Lower Heat Value Hu [kJ/kg]	40756	42330	42159	43317

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PM emission and composition

6L48/60-old test engine MDO & MGO

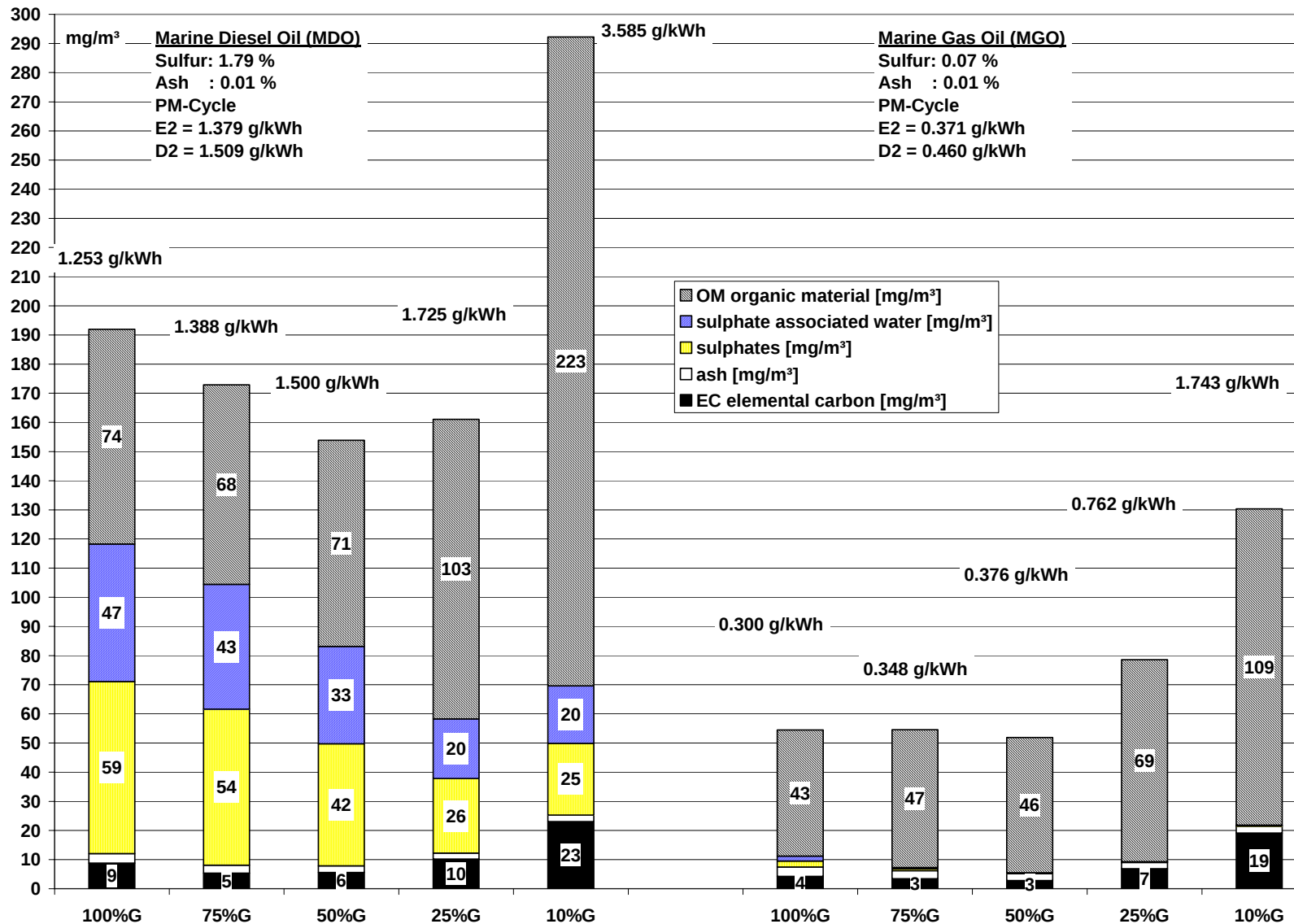
Test-bed measurement 29&30.03.2000



PM emission and composition

6L48/60A serial engine MDO & MGO

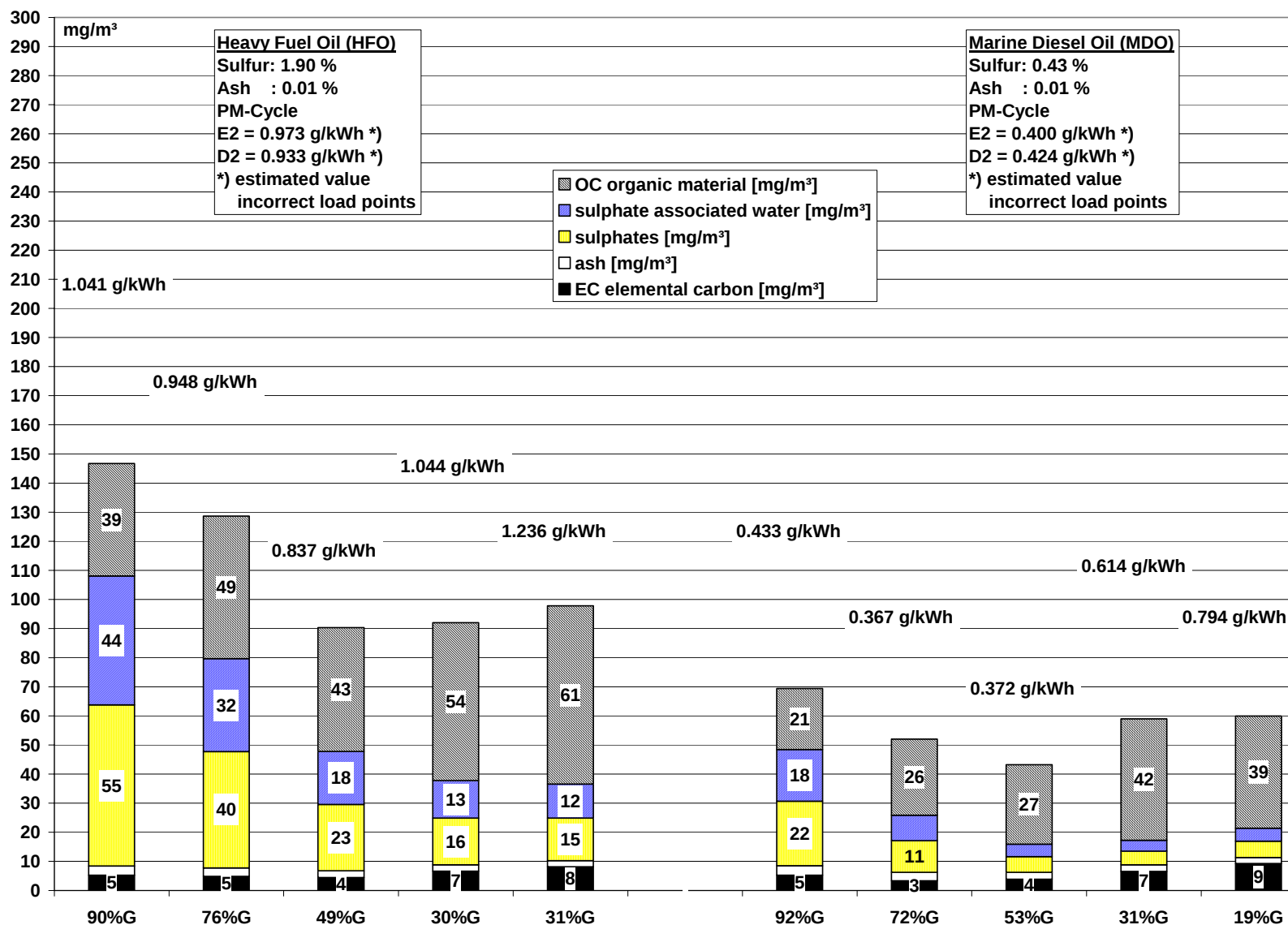
Test-bed measurement 27&30.08.2004



PM emission and composition

6L48/60A serial engine HFO & MDO 15,000h

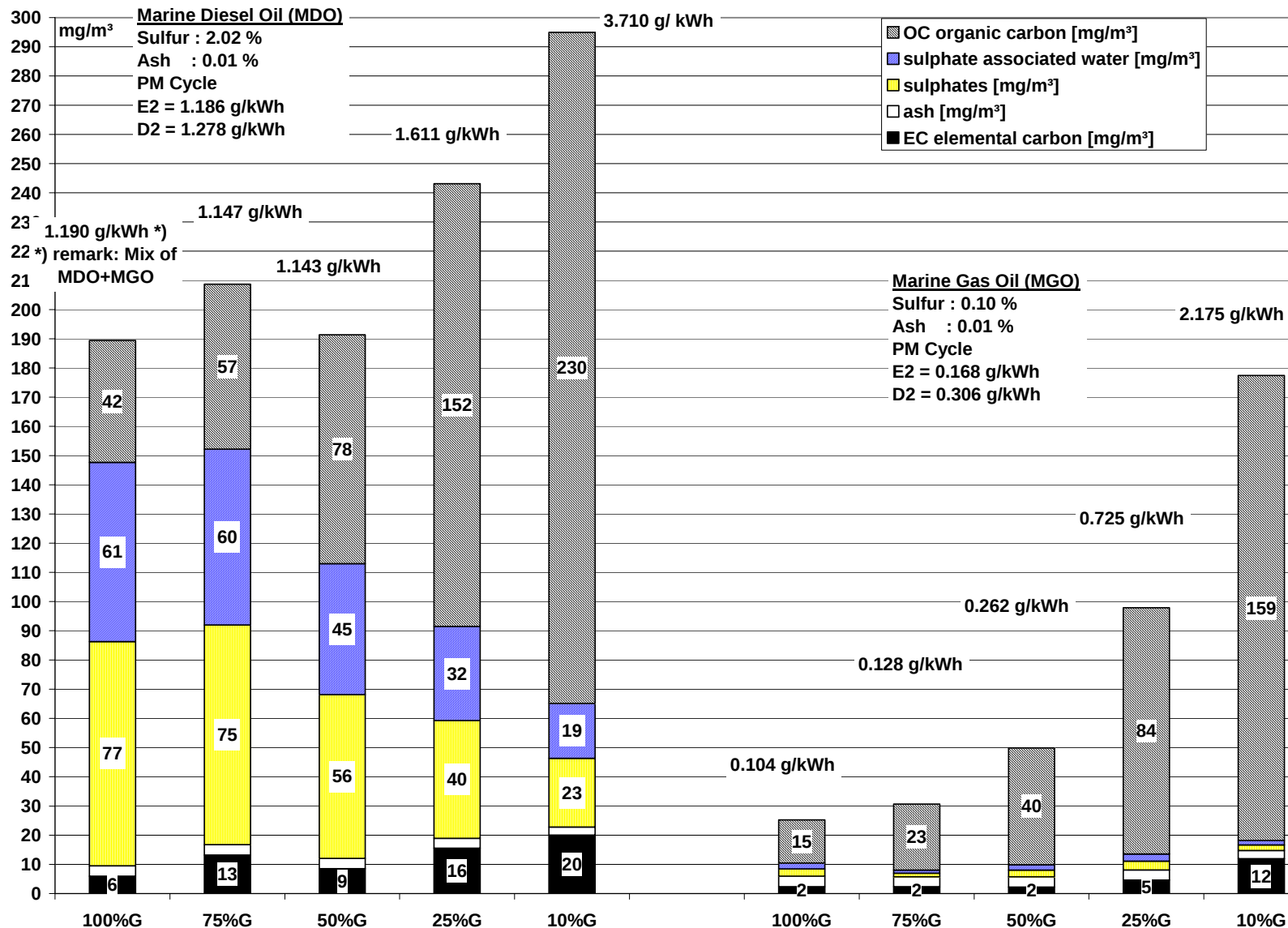
ship measurement 18&19.04.2007



PM emission and composition

6L48/60B serial engine MDO & MGO

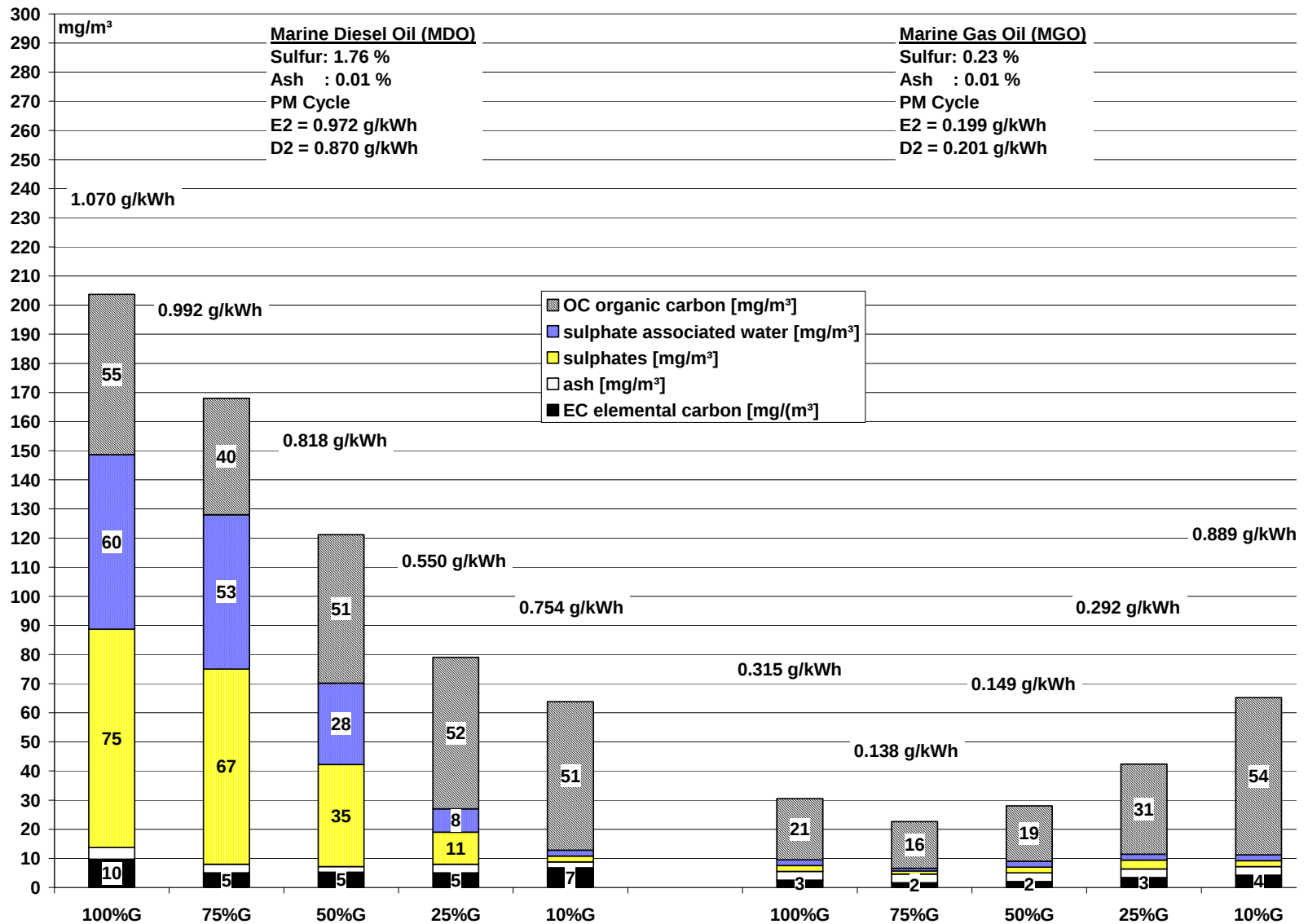
Test-bed measurement 25.10.2005



PM emission and composition

6L48/60B-test engine MDO & MGO

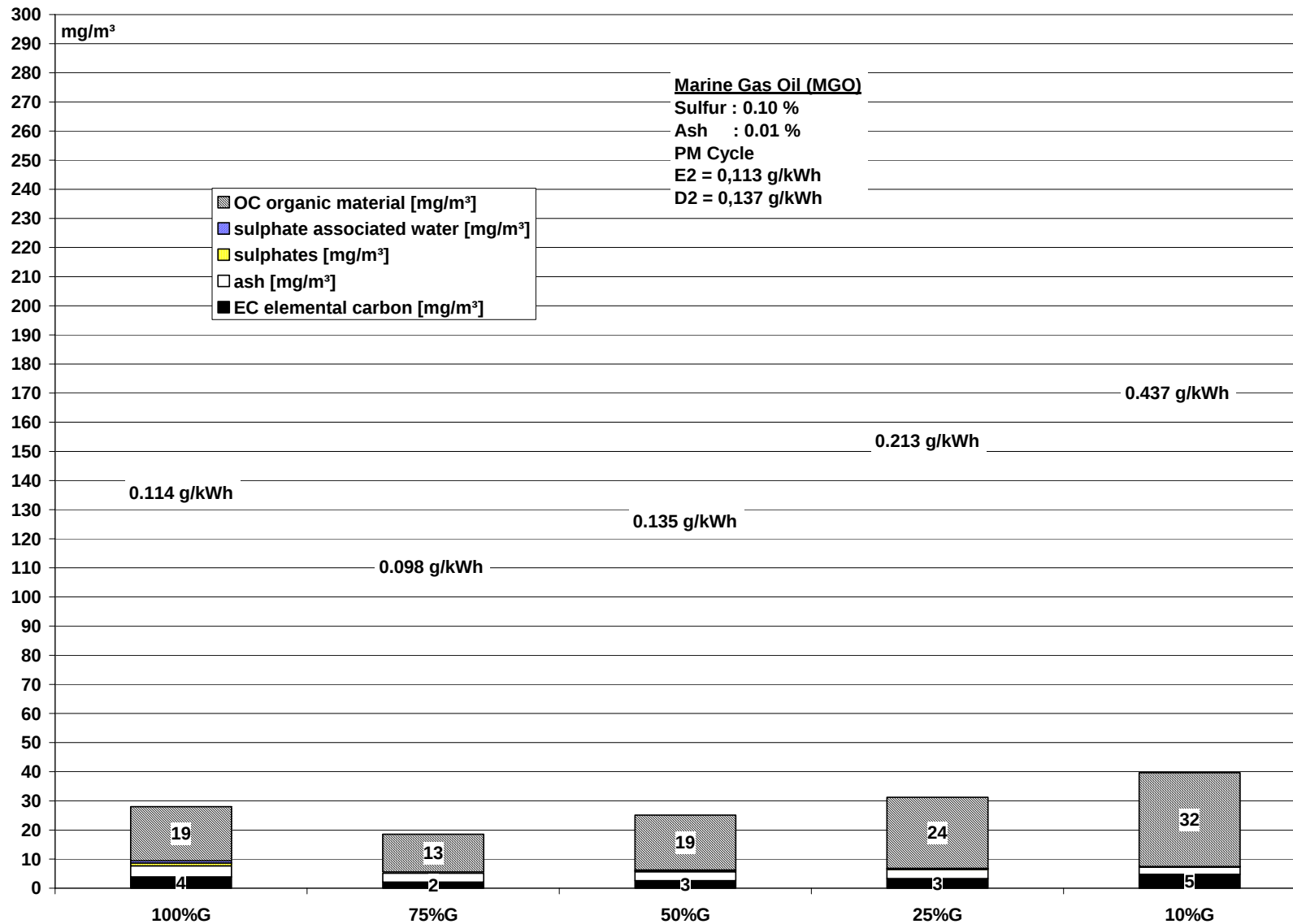
Test-bed measurement 14.02.2006



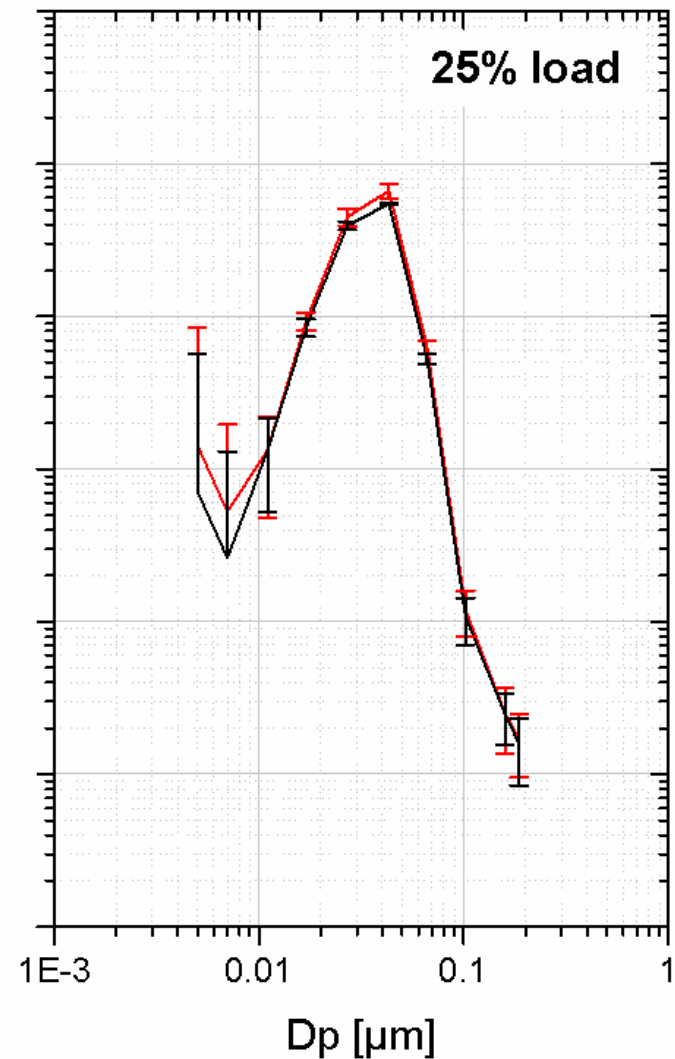
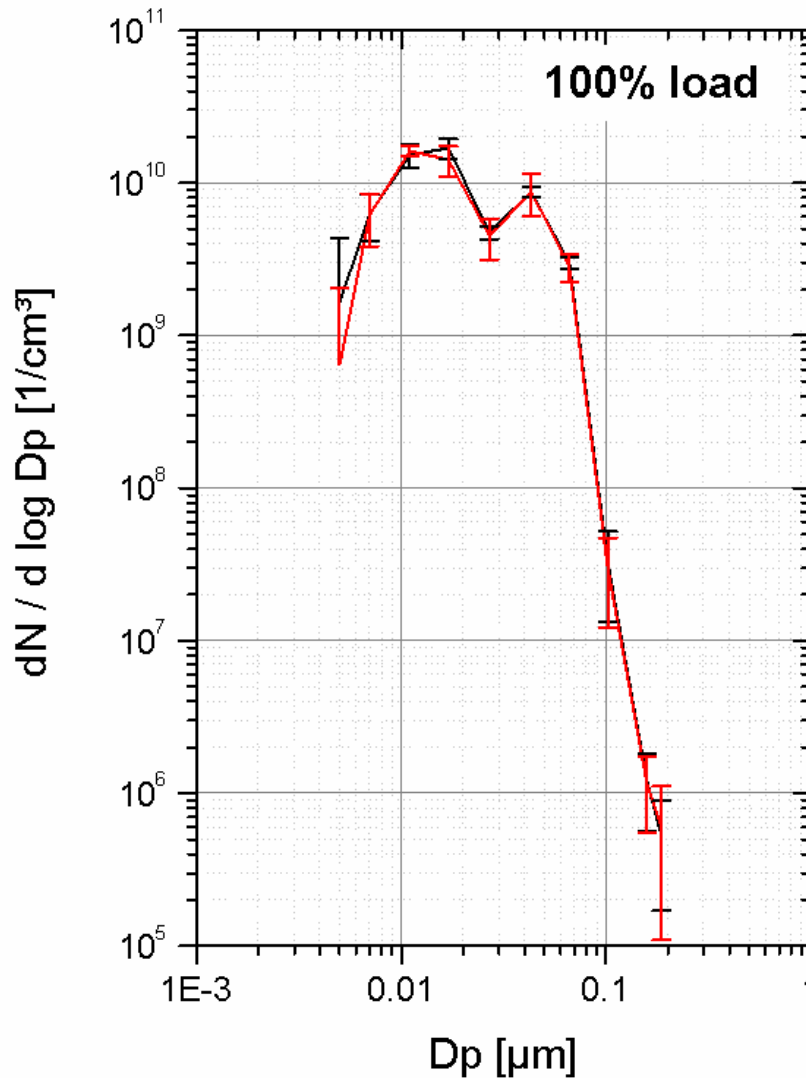
PM emission and composition

6L48/60CR-test engine MGO

Test-bed measurement 14.09.2006



PM number and size distribution



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Conclusions part I in general



- **PM emission and chemical composition is influenced by engine load and fuel composition.**
- **PM from large four-stroke medium speed Diesel engines for ships consists mainly of volatile material (organic material, sulfates, water) as opposed to small high speed four-stroke Diesel engines for cars and trucks.**
- **Fuels used for marine transport show a broad range of sulfur ($<0.5 - 4.5\%$) and ash ($<0.01 - 0.2\%$) contents and therefore the PM show significantly different amounts of sulfates, sulfate bound water and ash, according to the fuel composition. PM constituents related to this components cannot be influenced by the engine itself.**
- **The lower the fuel quality, the higher the absolute PM emissions. At high engine loads and for sulfur fuels the sulfates and sulfate bound water dominates the PM emission. At low engine loads and for low sulfur fuels the organic material dominates the PM emission.**

Conclusions part II in particular



- In this case with respect to the actual fuel quality, no deterioration in PM emission was found after 15,000 operating hours in service, provided that the engines are maintained according to the manufacturers guidelines. PM measurement results on board with HFO are better than MDO test-bed results and on board results with MDO are comparable to MGO test-bed results.
- Improvements on EC show a negative impact on OC and improvements at full load show a negative impact at part load and vice versa. Also improvements in NO_x and specific fuel oil consumptions show a drawback on PM.
- Number size distribution with and without Thermodenuder confirm the large volatile PM fraction of large medium speed marine Diesel engines. Aitken mode particles at 20 nm consist >99% and accumulation mode particles at 70 nm consist >90% of volatile material at 100% engine load.
- Residual fuels are expected to persist as the predominant fuel for ships in the future on a world wide basis.

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- Jack Thibault: Alaska Tanker Company (ATC), Portland, Oregon, USA, for the in service measurement opportunity.

Reference:

- Det Norske Veritas: Worldwide fuel sulfur distribution, 2004.

Thank you for your attention !



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