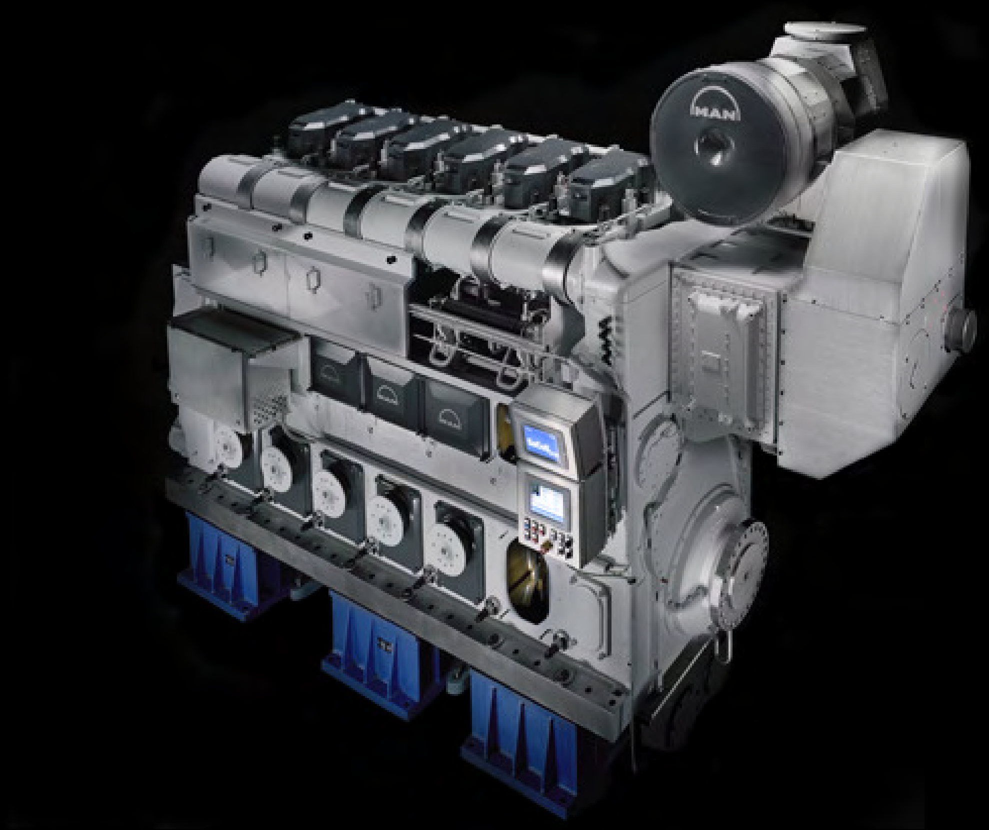


# On reduction and in service measurements of PM from large 4-stroke Diesel engines

# Outline

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

# Motivation

- 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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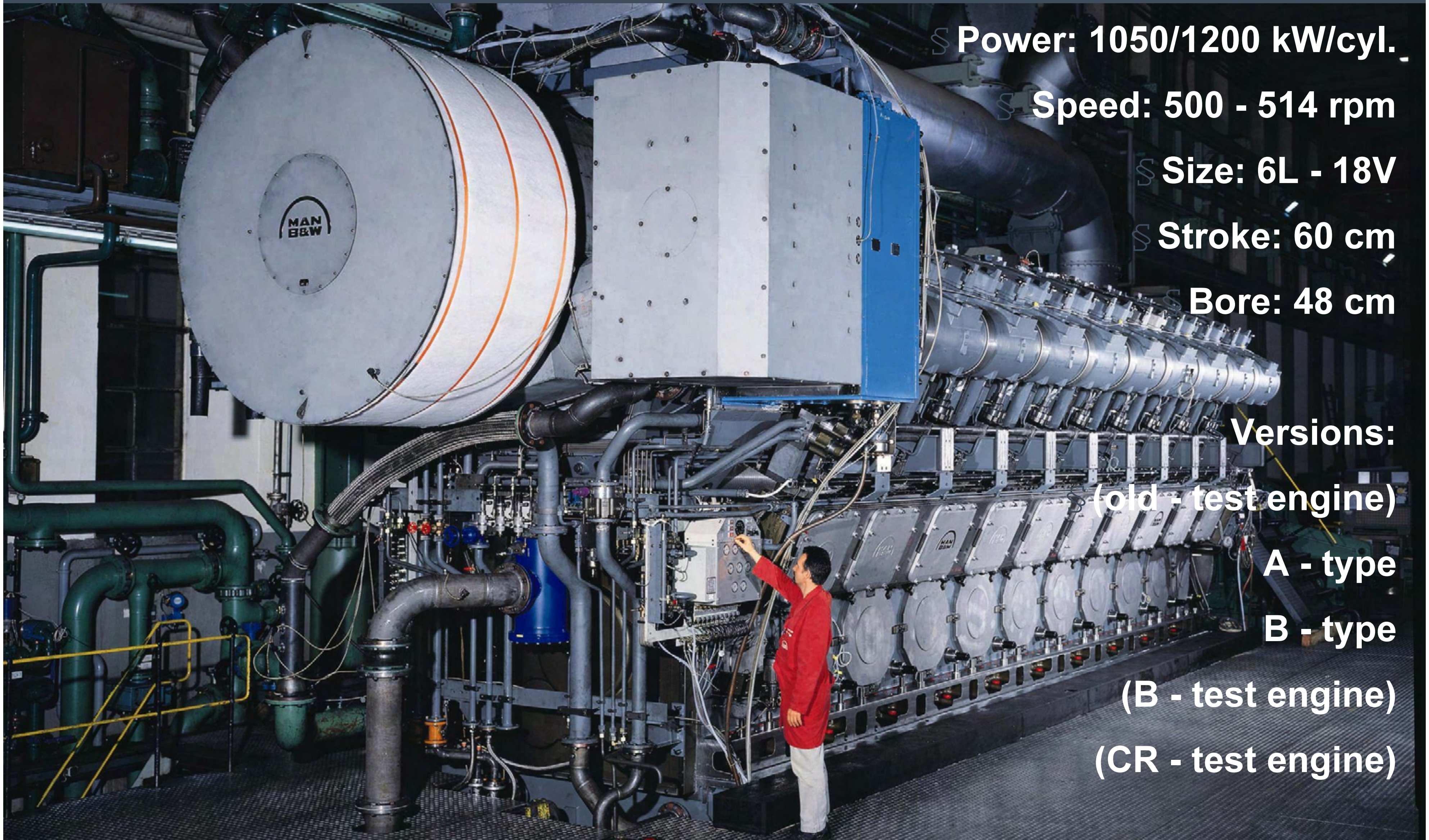
# Measurement methods

- **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 ($SO_4$), sulfate bound water ($H_2O$) 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.

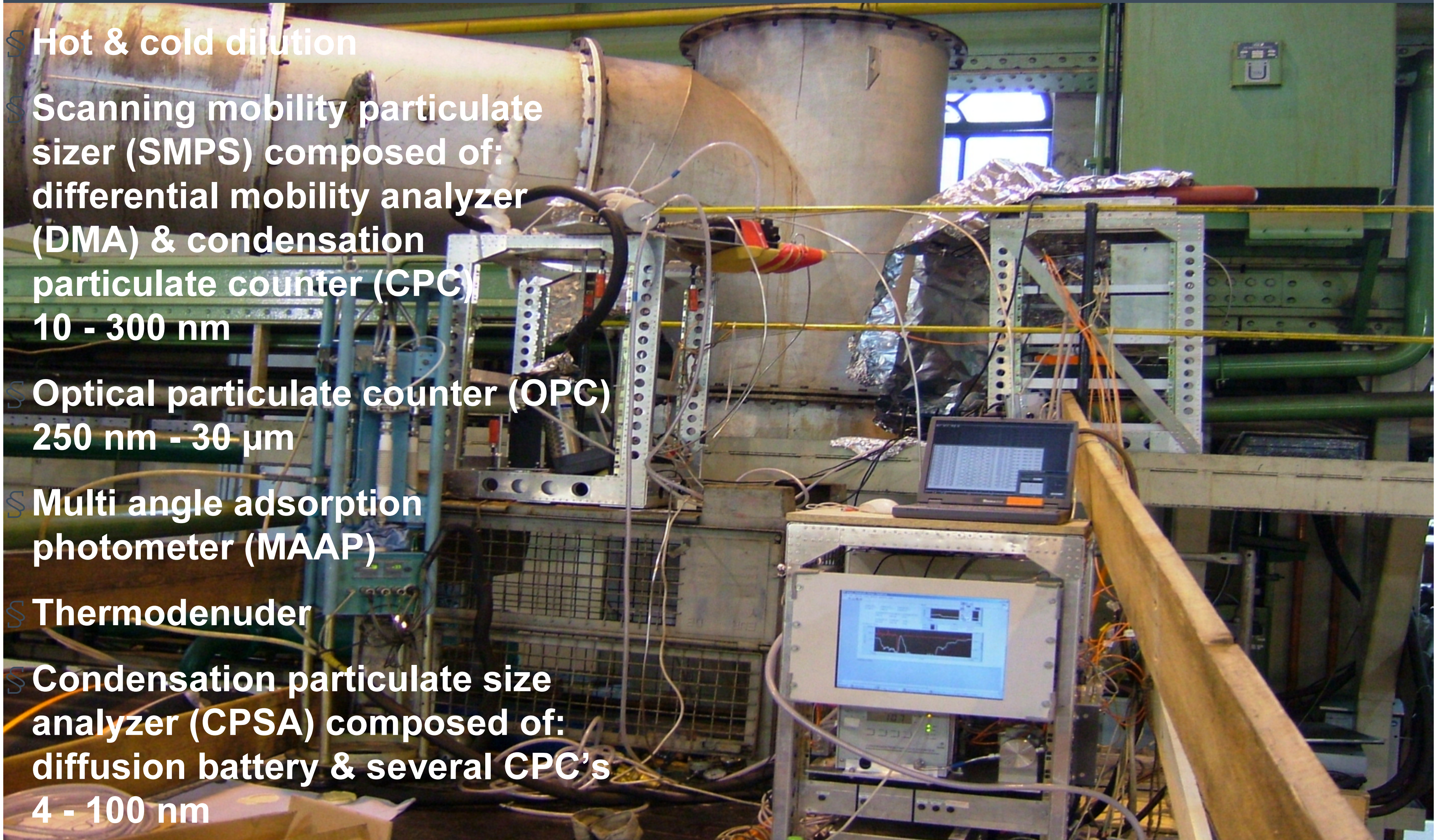
| | |
|---|---|
| old test engine towards A-type: | injection intensity |
| A towards B-type: | combustion chamber design |
| B towards B test engine: | piston design |
| B test engine towards CR: | injection system, piston design |

# 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

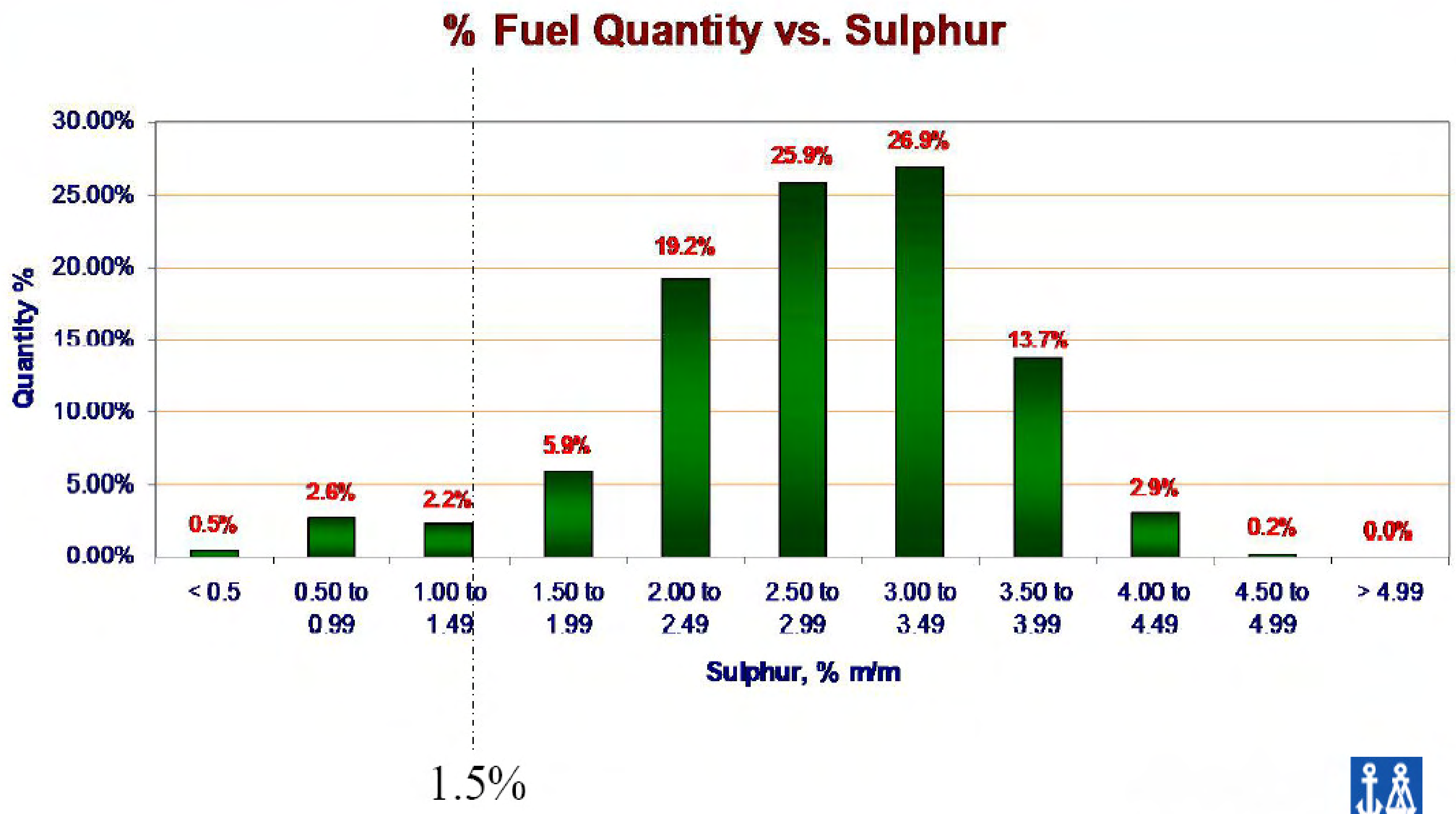
# DLR mobile aerosol measuring equipment: test bed set-up



- 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 µm
- 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

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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 [mm²/s] | 171 @ 50°C | 3.3 @ 40°C | 6.4 @ 40 °C | 2.6 @ 40°C |
| Density @ 15 °C [kg/m³] | 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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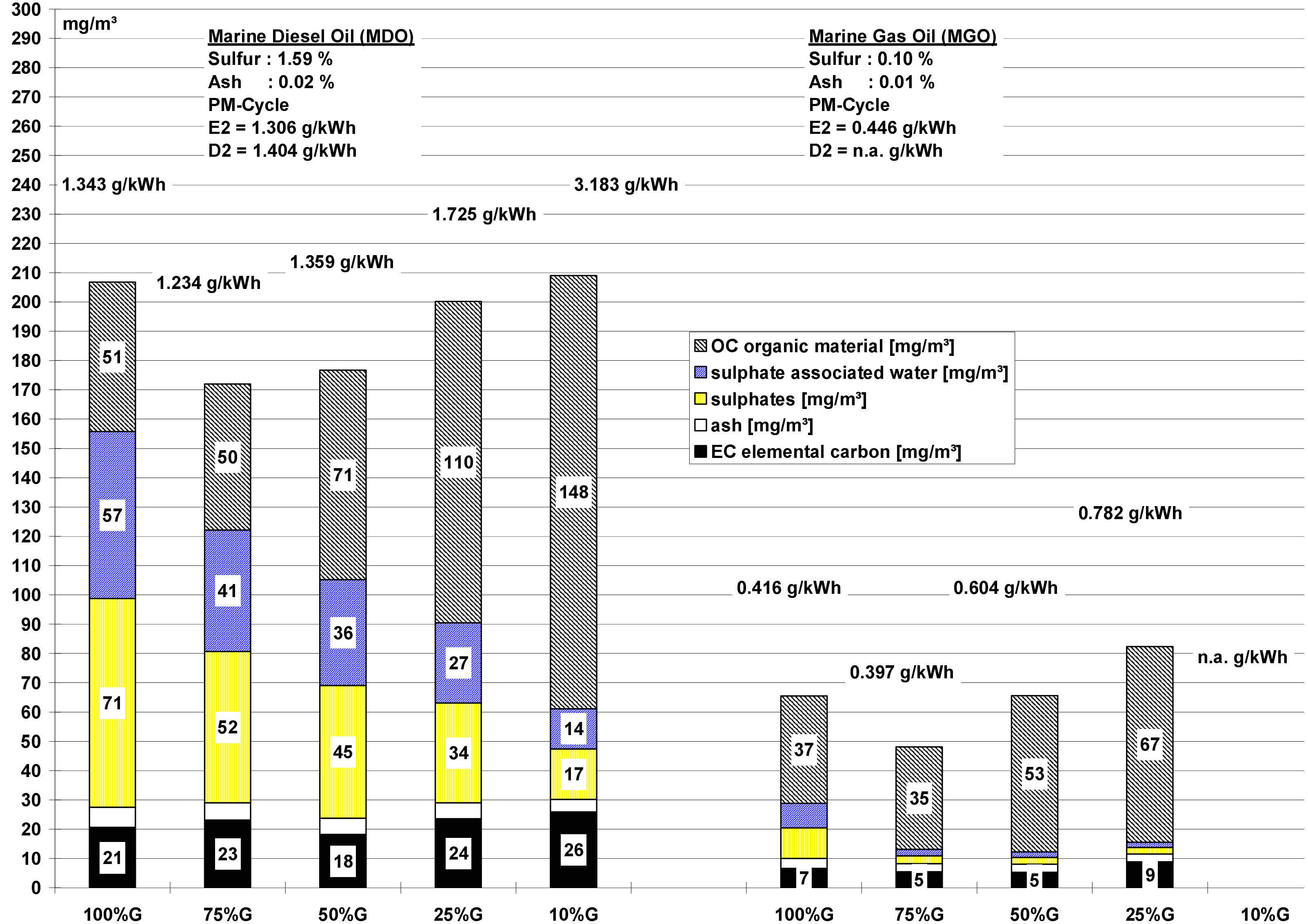
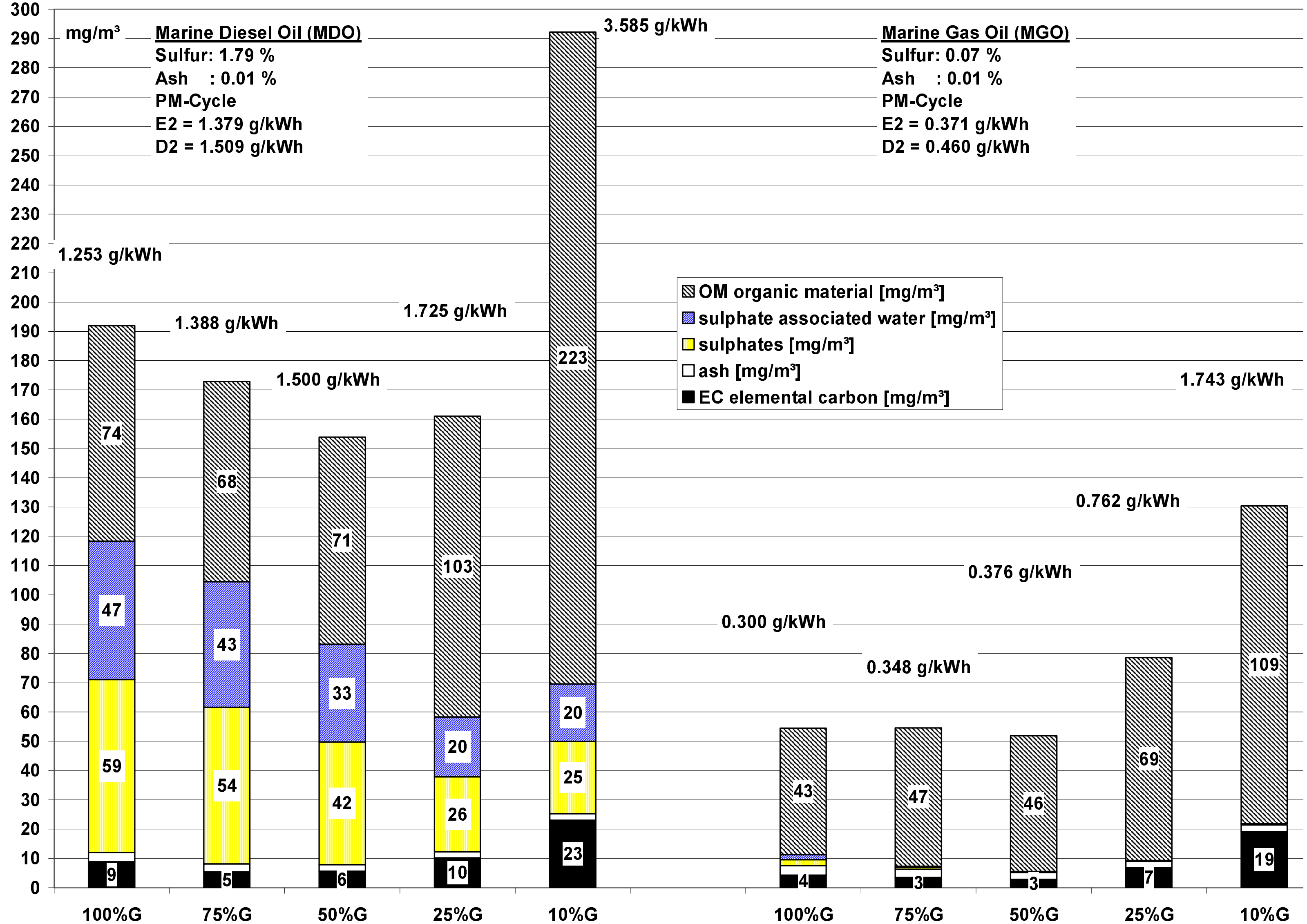
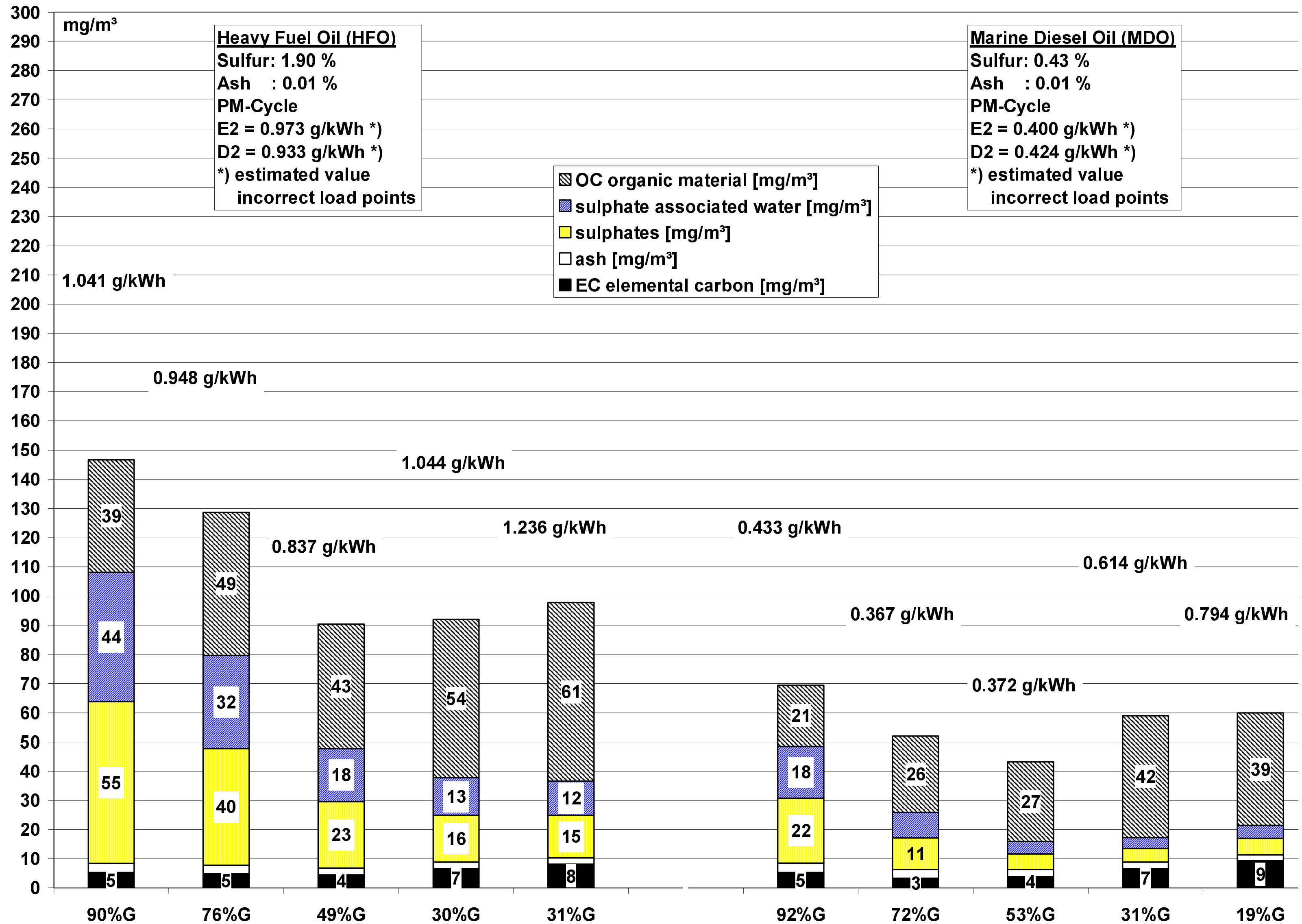
# PM emission and composition
# 6L48/60-old test engine MDO & MGO
# Test-bed measurement 29&30.03.2000



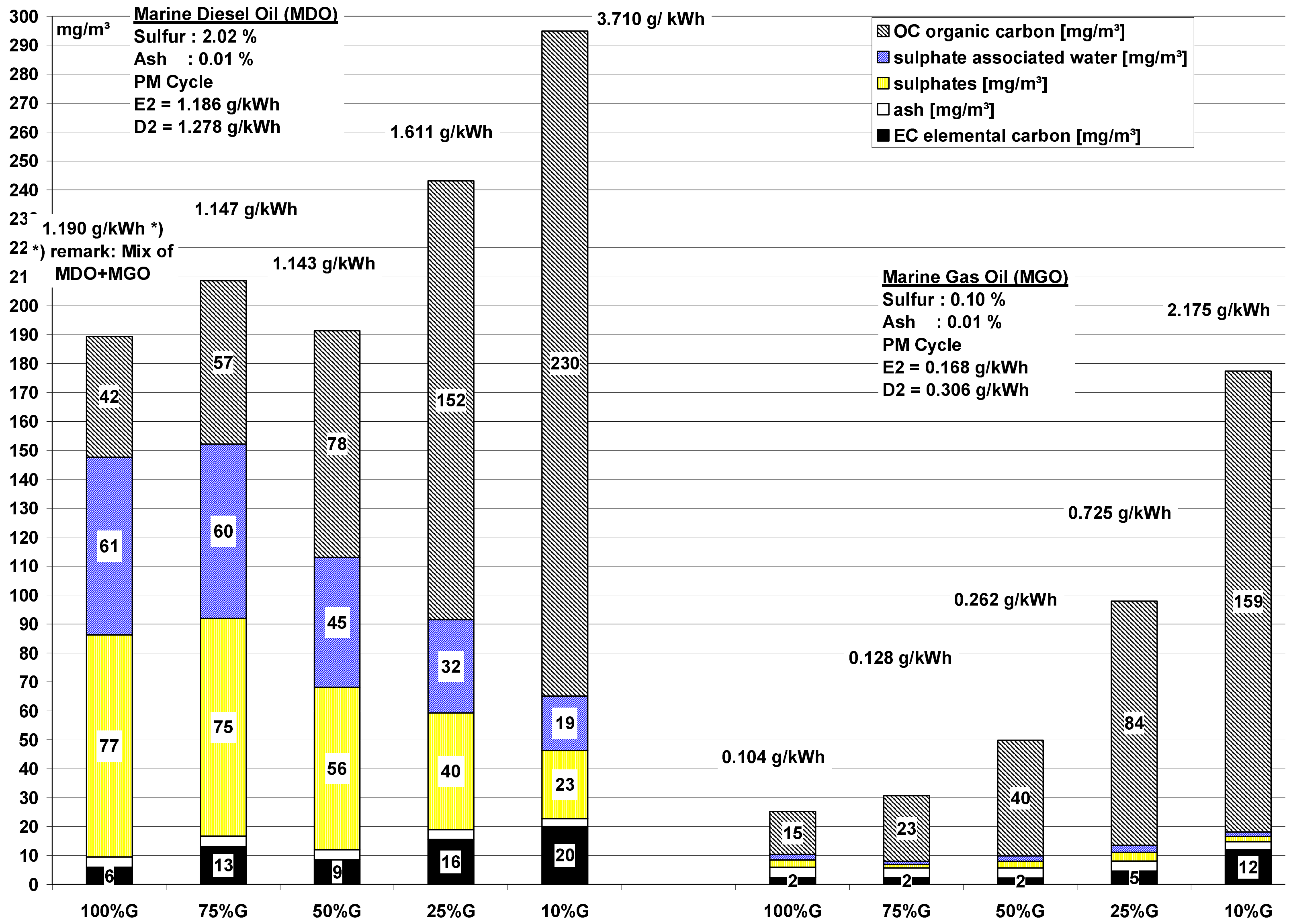
# PM emission and composition
# 6L48/60A serial engine MDO & MGO
# Test-bed measurement 27&30.08.2004



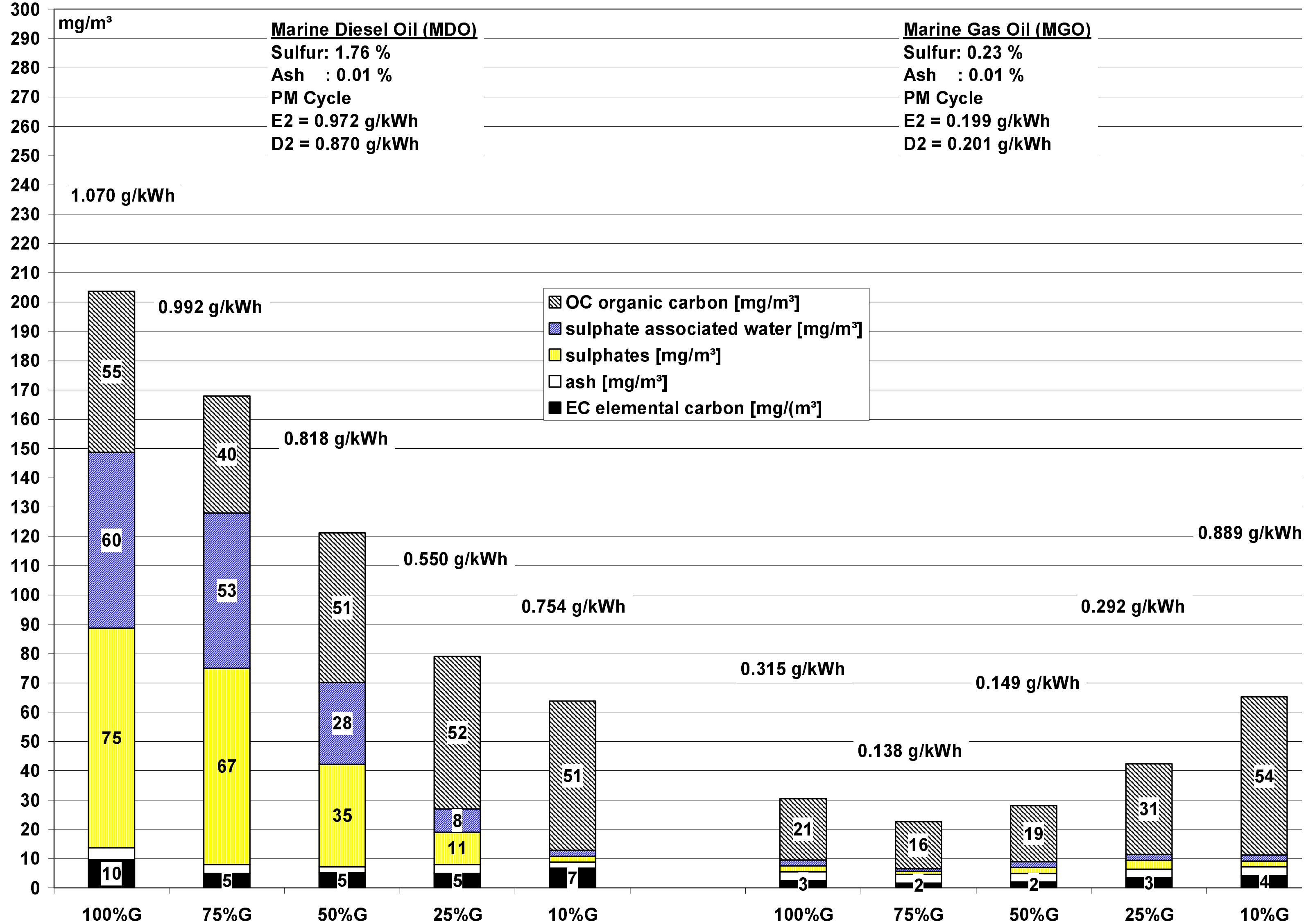
# PM emission and composition
# 6L48/60A serial engine HFO & MDO 15,000h ship measurement 18&19.04.2007



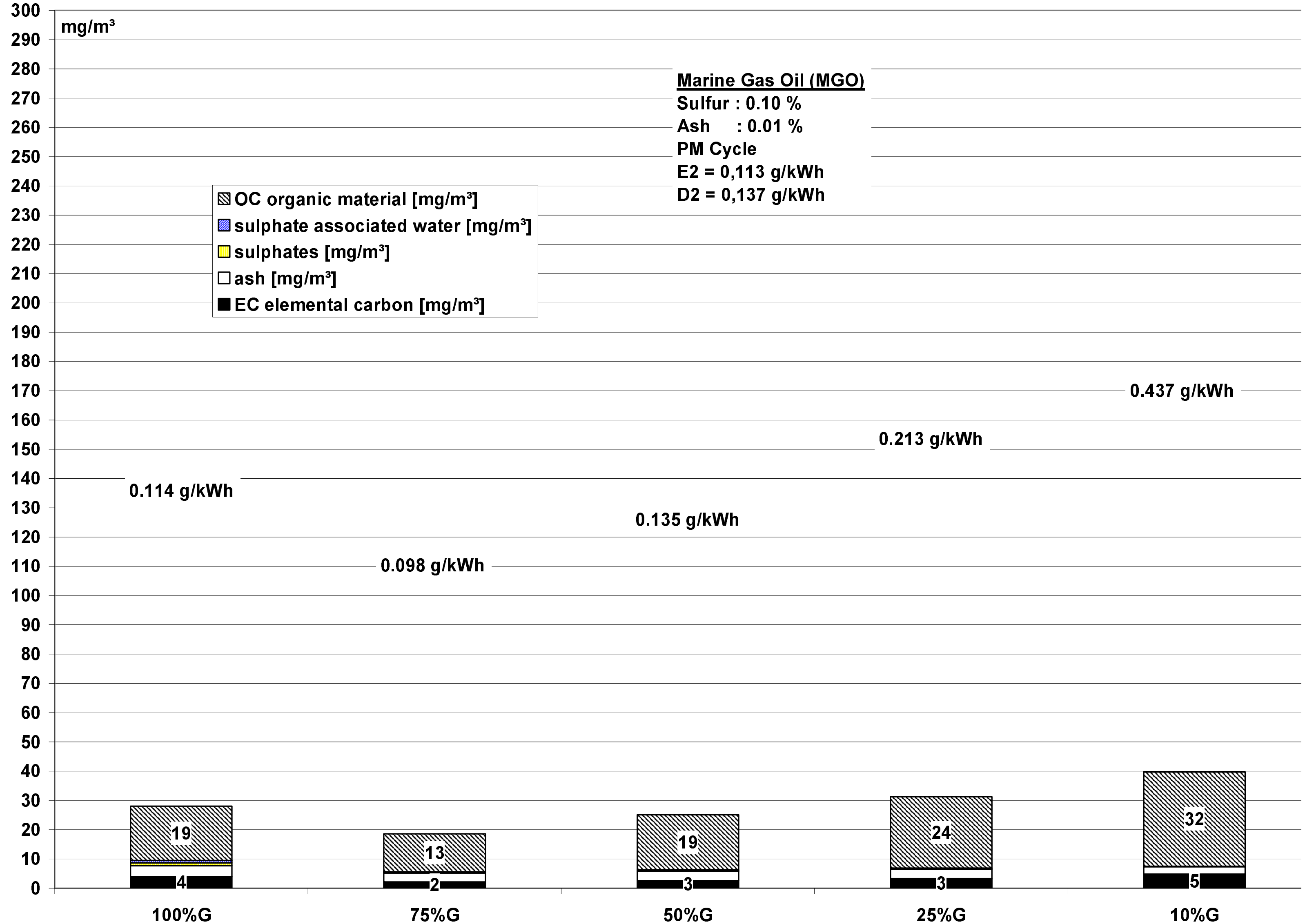
# PM emission and composition
# 6L48/60B serial engine MDO & MGO
# Test-bed measurement 25.10.2005



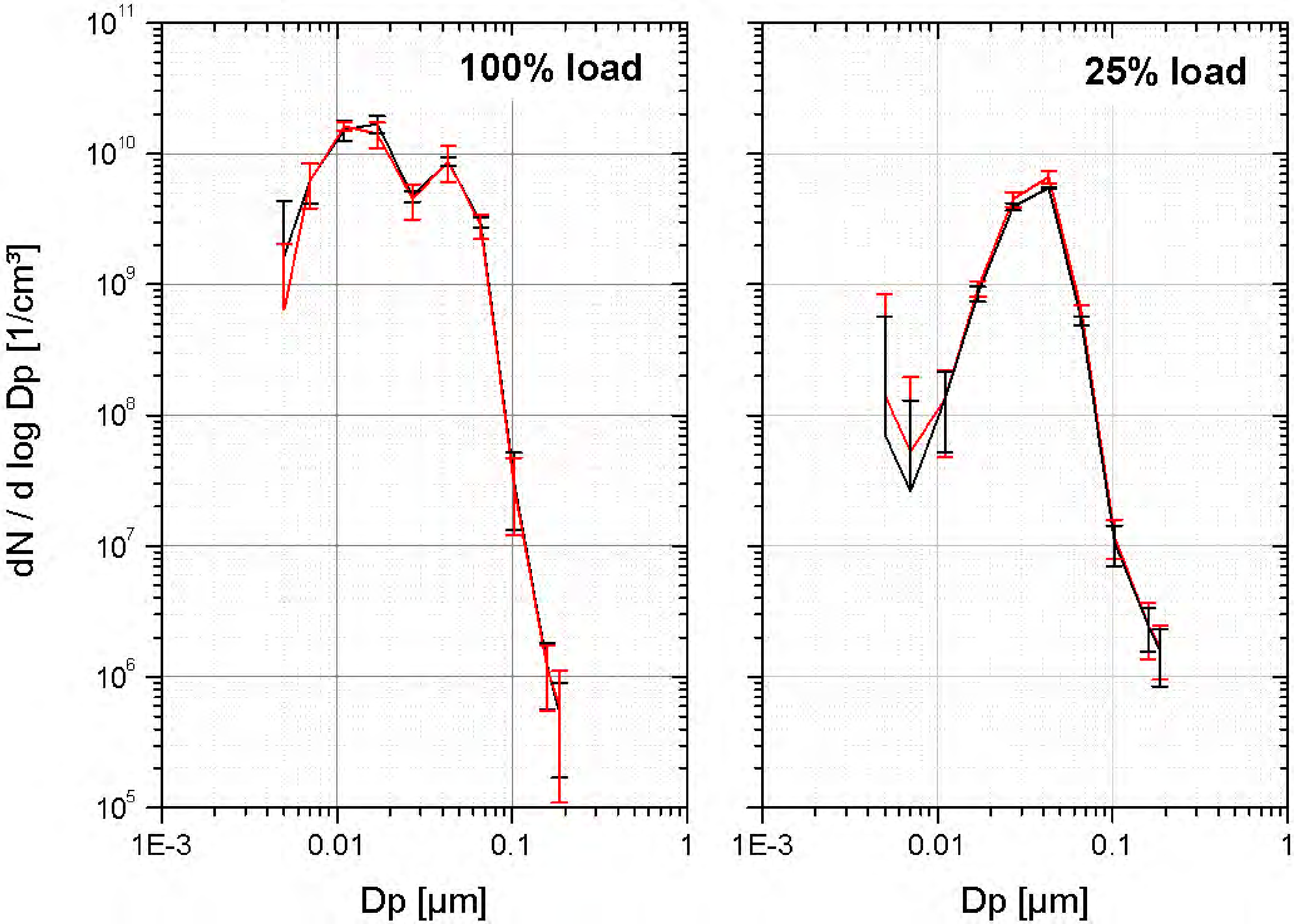
# PM emission and composition
# 6L48/60B-test engine MDO & MGO
# Test-bed measurement 14.02.2006



# 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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# Acknowledgements and References


## Acknowledgements:

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- Andreas Petzold, Jan Hasselbach: Institut für Physik der Atmosphäre DLR Oberpfaffenhofen, 82234 Wessling, Germany, for PM size distribution measurement.
- Claus Kurok: Germanischer Lloyd (GL), 20459 Hamburg, Germany, for chemical analysis of the PM filters.
- 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 !