DNV·GL

MARITIME ADVISORY GERMANY

PM measurement

Insight in practical experience of DNVGL

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ITTC workshop 2015-09-16

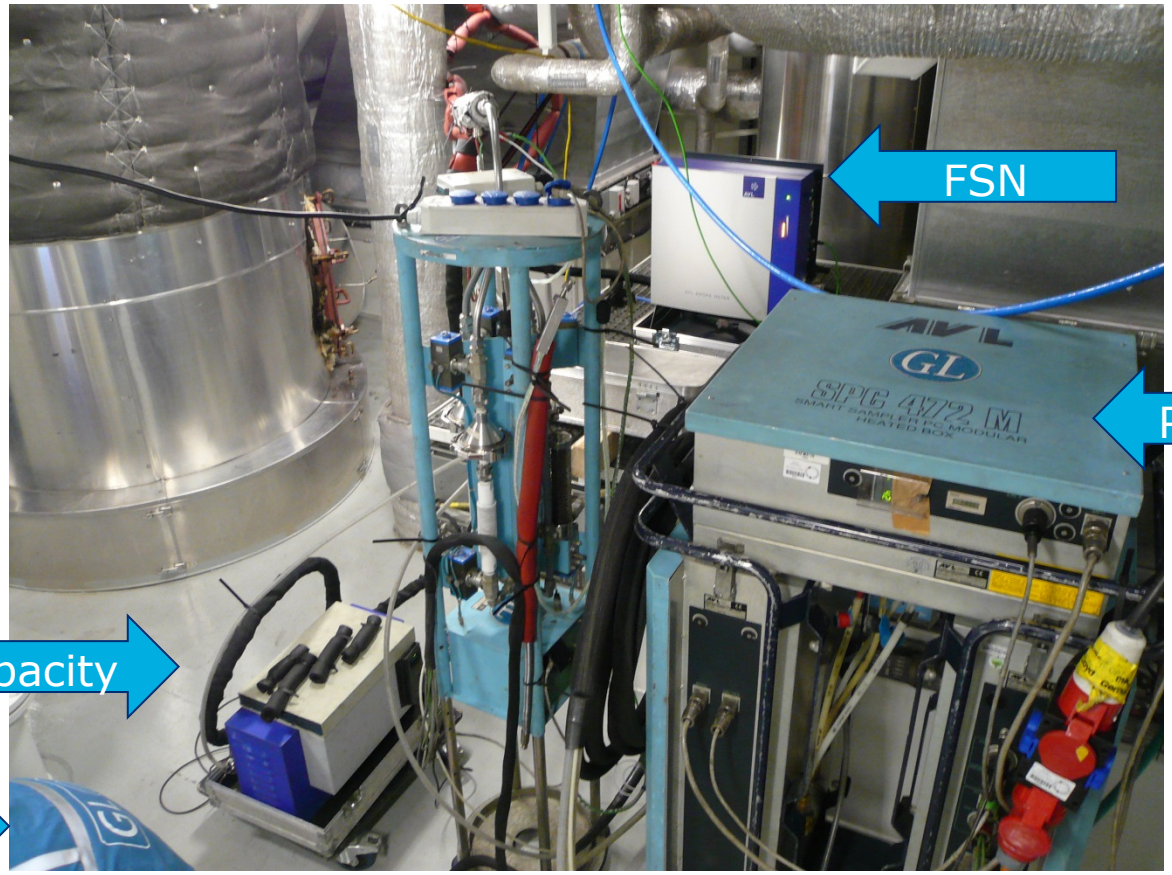
 DNV GL © 2013

Agenda

- ✓Activities of DNVGL (test equipment + jobs of laboratory)
- ✓Measurement principles in short
- ✓Sensitivities / biases (known and experienced)
- ✓Other obstacles from regulatory perspective
- ✓Conclusions

DNVGL Laboratory

Equipment for PM measurement



Developed with DNVGL for HFO application only, 2 devices built

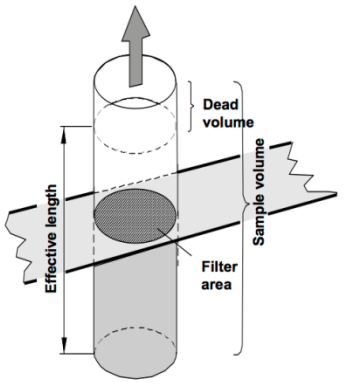
Jobs / experience

- Accredited as:
  - inspection body acc. to ISO 17020
  - laboratory acc. to ISO 17025
  - laboratory for Recreational Craft (94/25/EC)
- Notified body as Technical Service

  acc. to Rhine Vessel Inspection Regulations
- 20 years of experience
- Ca. 400 test bed measurements // 100 ships
- Regulations:
  - MARPOL Annex VI (NTC) // ISO 8178 // Constant lake
  - Nonroad mobile machinery // River rhine // EPA
- Frequent participation in research

Filter smoke number

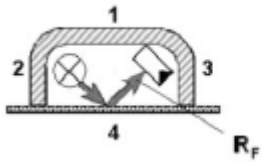
- Measurement of loss of light reflection (not only absorption)
- No denominator
- Temperature > 65°C (condensation of water) evtl. dilution
- Scoot: MIRA Correlation (ISO 8178)
- Calibration: grey value discs / reference scoot

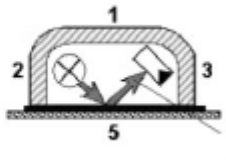


$$\text{Effective length} = \frac{\text{Sample volume} - \text{Dead volume} - \text{Leak volume}}{\text{Filter area}}$$

Positive:

- Cheap + Easy application
- Follows the impact principle of BC





Source: 1+ 2: AVL

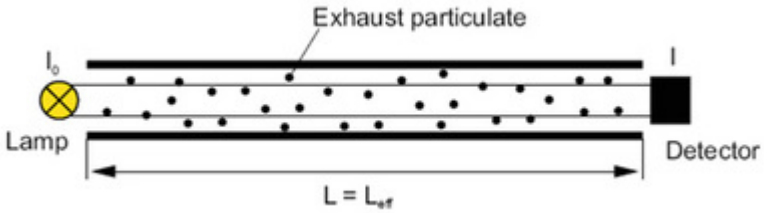
Challenges:

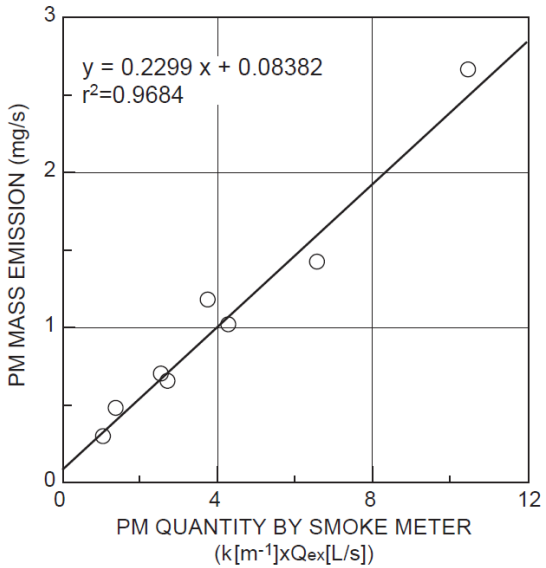
$$c_{Cw} = \left\{ \begin{array}{c} 0{,}00976983 \times SN + 0{,}0234416 \times SN^2 - 0{,}00728358 \times SN^3 \\ + 0{,}00164618 \times SN^4 - 0{,}0000895464 \times SN^5 \end{array} \right\} \times 1000$$

- Filter loading (concentration / sampling time)
- Other light absorbing material (Brown Carbon)
- Scattering (ash) + reflection (condensation of H2SOx @ 130°)

Opacity meter

- Extinction (scattering + absorption)
- Temperature > 65°C (condensation of water)
- Calibration: Optical transmission filters
- Correlation: Example Horiba
- Measures:
  - Liquids (hydrocarbons, water, sulphuric acids (HFO))
  - Solids (oxides, soot)





Positive:

- Fast (transient measurements)

Obstacles:

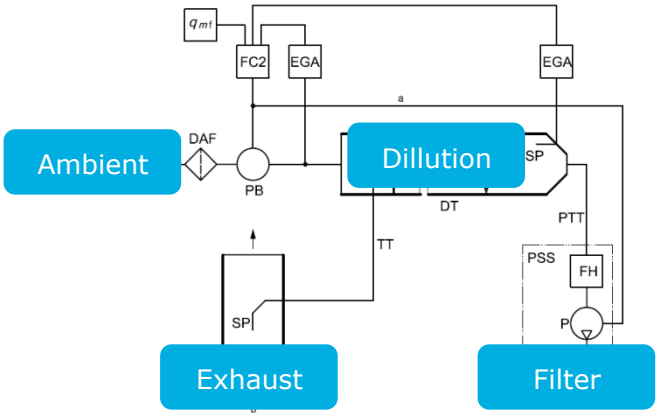
- Scattering / absorption liquids/solids (a.m.)
- Discarded by PPR1

Source:1:AVL; 2: Horiba

Particulate mass

Principles

- Measurement of increase of filter mass
- Measurement of gas flow (denominator)
- Force condensation of HC components:
  - dilution + cooling (47 ± 5°C)
- Calibration: Scale

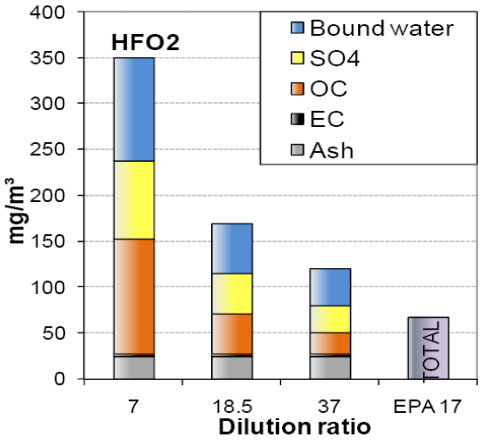


Positive:

- Can be very accurate, later analyses of filter possible
- Conversion into: g/kWh or g/kg_fuel

Obstacles:

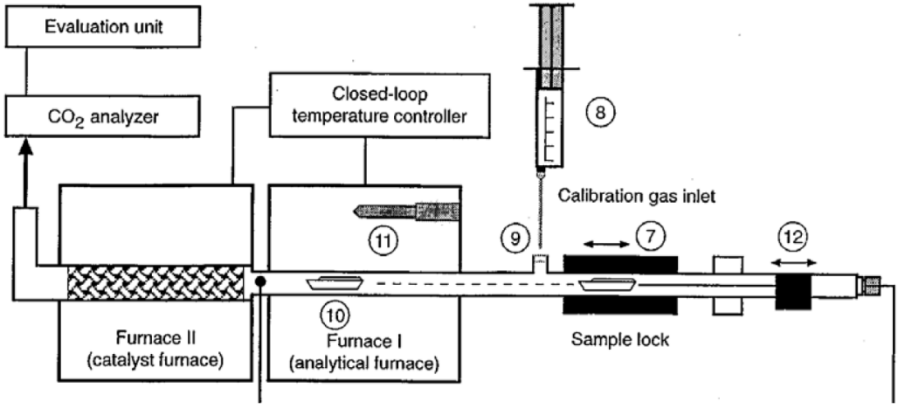
- Sensitive to dilution ratio / ambient temperature
- Long time for detailed analyses (no results on site)



Source:1: ISO 8178; 2: Ristimaki

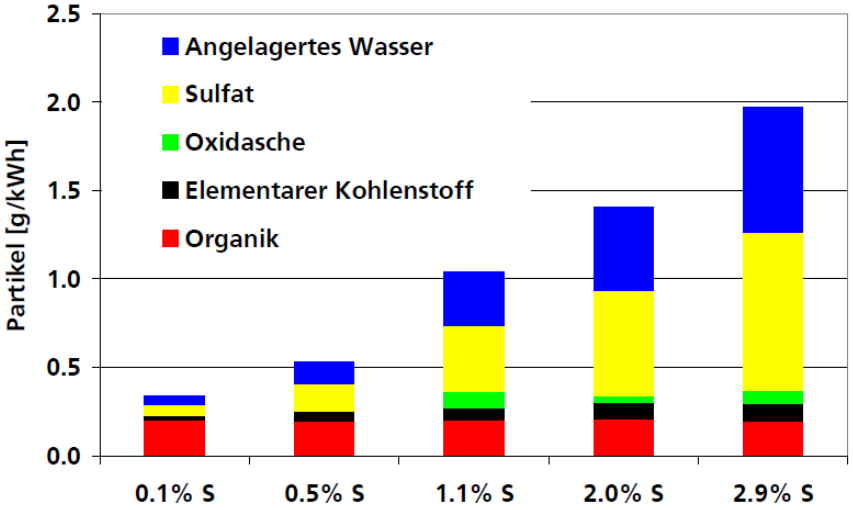
Chemical analyses based on VDI 2465 Part 1 + 2

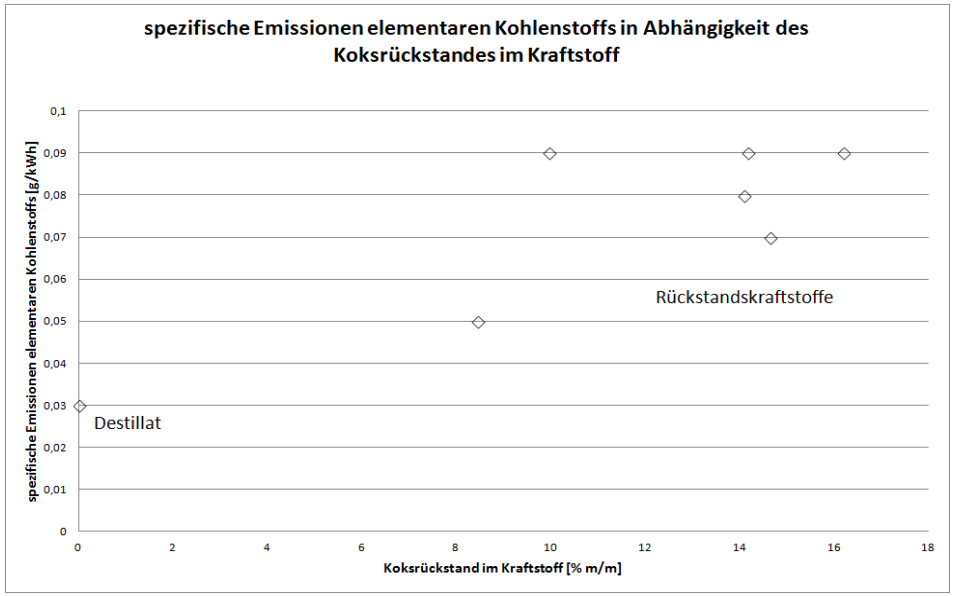
1. Vaporization of hydrocarbons (inert gas) >> Measurement if FID
2. Extraction of remaining hydrocarbons in solvent (toluol + isopropanol) - avoids charring and therefore overestimation of EC >> Analyses of the solved HC
3. Combustion of elemental carbon by adding oxygen + catalyst (Elemental carbon remains on filter (higher thermal stability + insoluble))
4. Measurement of CO2 by NDIR
5. Measurement of total change of mass for verification

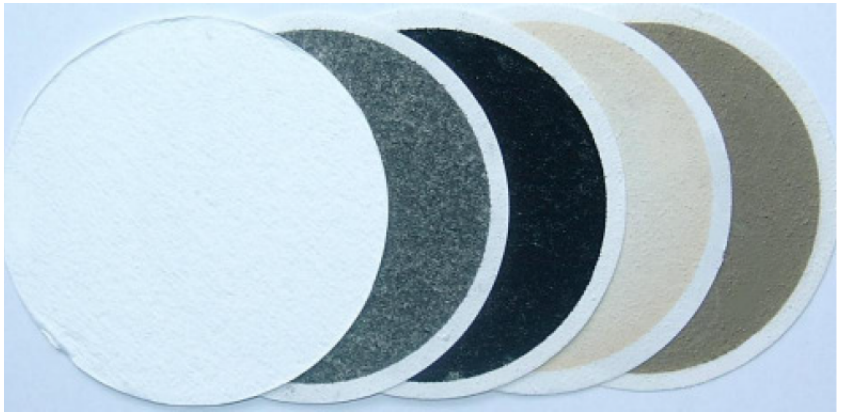


Example: Influence of fuel

- 2 Stroke engine @ test plant
- All engine settings constant (100% MCR)
- Different fuels (MDO and HFO)
- Linear correlation PM / Sulphur
- Ashes from ISO 8217_2010

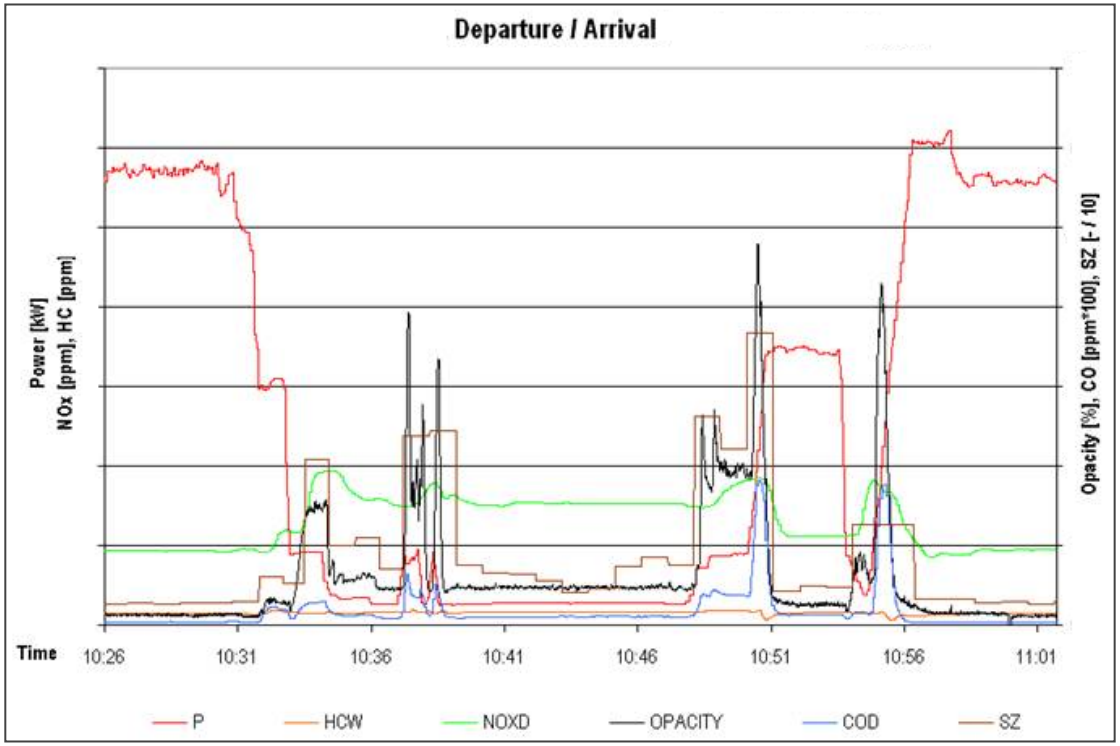




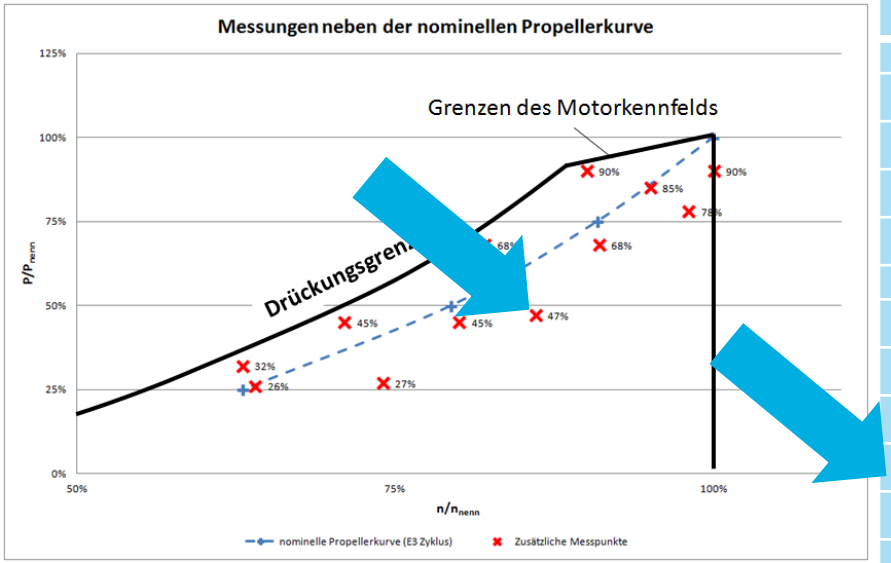


Example: Parallel measurement on ship

- Arrival and departure (High Speed DE)
- HC and CO indicator for quality of combustion
- Qualitative correlation of FSN and Opacity
- No quantitative correlation to mass by application of known correlation functions



Example: Deviation from nominal test curve

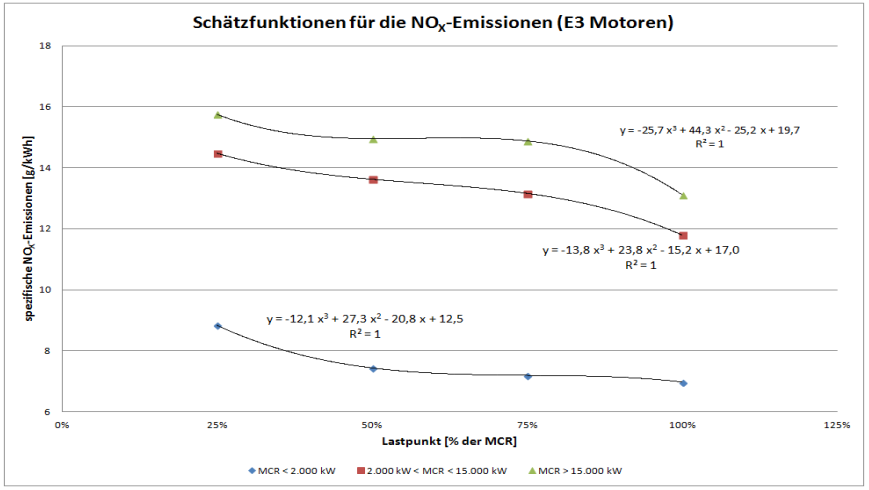


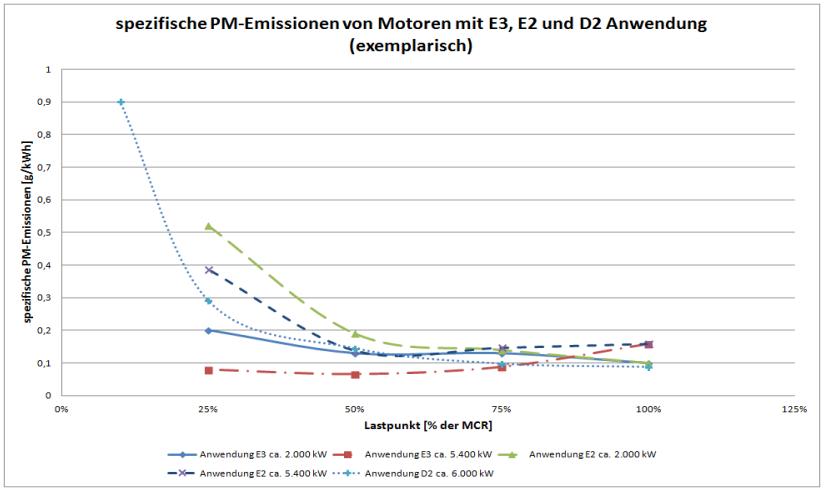
Torque	Speed	CO	HC	PM	EG Temp
32%	63%	50%	-49%	36%	7%
45%	71%	41%	-21%	29%	6%
68%	82%	33%	-26%	8%	5%
90%	90%	19%	0%	19%	0%
90%	100%	-28%	3%	-2%	-2%
78%	98%	-37%	8%	0%	-5%
68%	91%	-2%	-1%	14%	-3%
47%	86%	-51%	17%	54%	-7%
45%	80%	-19%	7%	20%	-3%
27%	74%	-143%	27%	-18%	-9%

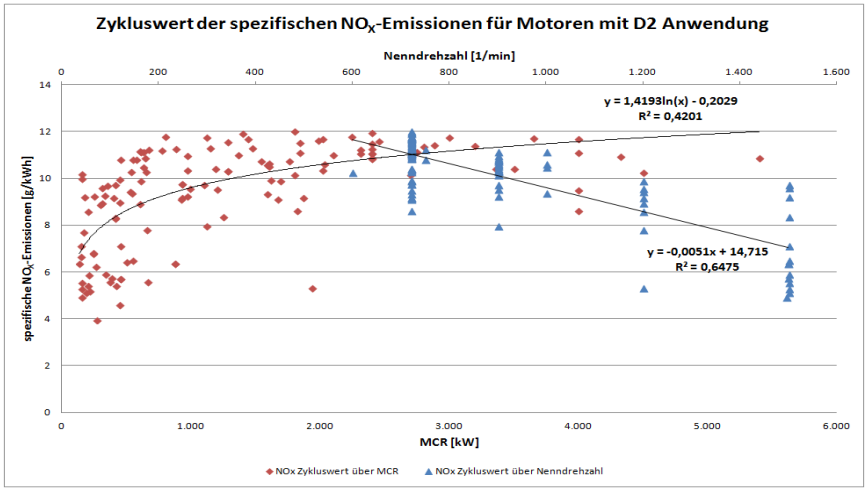
- PM: Significant increase from nominal curve (up to + 50%)
  - Assumption: caused by BC / Brown carbon (constant ash and sulphur content)
- Negative correlation of PM and HC positive to CO

Emission factors

- archive between 2000 and 2010
- 248 Engines
- 493 test cycles
- more than 2.000 load points



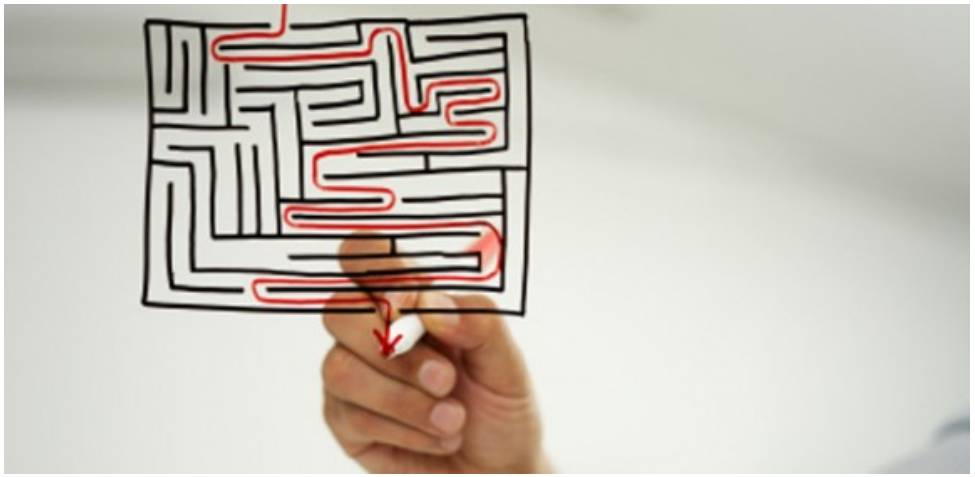




On board measurement – classificatory perspective

- In harbour measurement not possible
- Sea voyages typically 1 – 2 weeks
- Stability / accuracy of load points
- Determination of denominator challenging / not possible
  (power for kWh / fuel flow for mass)
- Availability of fuel oil (if standardized)
- Legal: Calibration of equipment
  (analysers AND power / SFOC measurement)

Conclusions



1. Different principles deliver different results, same methods tend to bias same (agree on one principle, not necessary to deliver real figure - see CLD)
2. Test conditions + procedures are to be well defined for comparison of engines
   > Sensitivities are to be well known
   > Test conditions to be monitored in order to make use of results (correction?)
3. Feasibility of later certification to be considered for current research work
   > Standard (e.g. ISO) required for regulatory application
   > Also denominator is challenging
   > conduction of measurement and availability of ship own equipment

Questions!

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