Current BC testing efforts in Japan

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Goal

• To establish the measurement and evaluation methods of BC for marine diesel engines
• To determine the correction factors to evaluate BC values obtained by various BC measurement methods

Procedure

• To evaluate measurement and sampling methods for marine diesel engines
• To specify the influence factors on BC measurement
<table>
<thead>
<tr>
<th>Engine</th>
<th>A1</th>
<th>A2</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>4 stroke Middle speed</td>
<td>2 stroke Low speed</td>
<td></td>
</tr>
<tr>
<td>N. of cylinders</td>
<td>3</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Cylinder bore</td>
<td>230mm</td>
<td>190mm</td>
<td>330mm</td>
</tr>
<tr>
<td>Piston stroke</td>
<td>380mm</td>
<td>260mm</td>
<td>1050mm</td>
</tr>
<tr>
<td>Rated power max.</td>
<td>257 kW</td>
<td>750 kW</td>
<td>1275 kW</td>
</tr>
<tr>
<td>Speed max.</td>
<td>420 rpm</td>
<td>1000 rpm</td>
<td>162 rpm</td>
</tr>
<tr>
<td>Fuel injection control</td>
<td>Mechanical</td>
<td>Electronic</td>
<td>Electronic</td>
</tr>
<tr>
<td>Fuel</td>
<td>HFO(2.6%) MDO(0.6%) LS MDO(0.08%)</td>
<td>MDO(0.6%) LS MDO(0.08%)</td>
<td>HFO(2.5%) LS MDO(0.085%)</td>
</tr>
</tbody>
</table>

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Marine diesel engines

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Measurement methods for lab testing

> Methods discussed at IMO

- FSN / Filter Smoke Meter
- Multi-Angle Absorption Photometry (MAAP)
- Photo Acoustic Spectrometry (PAS)
- Thermal Optical Analysis (TOA)
  - Laser Induced Incandescence (LII)*

> Other measurements

- PM gravimetric analysis (PM)
- Light extinction and scattering method
  / Laser Smoke Meter (LSM)

* LII equipment was not available in this study.
## Instruments for lab testing

<table>
<thead>
<tr>
<th>Method</th>
<th>Instrument</th>
<th>Measurement conditions</th>
<th>Dilution ratio</th>
<th>Heating option</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSN</td>
<td>415S AVL</td>
<td>Sampling line: 70°C</td>
<td>******</td>
<td>Auto-range presampling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measurement unit: 70°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAAP</td>
<td>MAAP 5012 Thermo Scientific</td>
<td>Dilution unit: 150°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>External diluter MD-9E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1000 - 3000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAS</td>
<td>MSS 483 AVL</td>
<td>Dilution cell: 120°C</td>
<td>4 – 8</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sampling line: 65°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measurement cell: 52°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOA</td>
<td>Model-5 Sunset Laboratory</td>
<td></td>
<td></td>
<td>TOR, TOT NIOSH, IMPROVE</td>
</tr>
<tr>
<td>PM</td>
<td>ISO 8178-1:1996</td>
<td>Dilution tunnel 7 – 26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSM</td>
<td>LEX-635s* Tsukasa Sokken</td>
<td>Sampling line: 120°C</td>
<td>******</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Measurement cell: 120°C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sampling for TOA and PM

ISO 8178-1:1996

Partial flow dilution tunnel connected directly to the exhaust pipe

- 1. PTFE coated glass fibre filter (TX40HI-20-WW, Pall)
- 2. Tissuequartz filter (2500 QAT-UP, Pall)
- TOA (OC/EC analysis TOR/TOT) measured by both IMPROVE & NIOSH protocols

Gravimetric analysis weighted before and after sampling
Results of BC measurements for lab testing

MDO

A1
4 stroke

B
2 stroke

Engine load

25%  50%  75%  100%

Note:
1) BC concentration values in these figures are “as-displayed” values on each instrument.
Relation between measurement methods

**MDO**

- **Graph**:
  - Graph shows the relationship between BC concentration (MSS) and BC concentration (FSN, LSM).
  - Equation: $y = 1.3514x$, $R^2 = 0.9788$

**HFO**

- **Graph**:
  - Graph shows the relationship between BC concentration (MSS) and BC concentration (FSN, LSM).
  - Equation: $y = 1.8373x$, $R^2 = 0.9936$

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**Note:**

1) BC concentration value of MSS was corrected concerning particle losses due to thermophoresis inside the sampling line.

2) BC concentration unit: mg/Nm$^3$-wet (0°C, 1 atm)
Onboard testing

Cement carrier “Pacific Seagull”
Azuma Shipping Co.

Jan. 2014  FSN, LSM
Feb. 2015  FSN, MSS

ME : Low speed 2 stroke engine

HFO (2.42%)
Issues to be discussed

Factors
- Engine operation
  - Engine type
  - Operating conditions
  - Fuel
  - Lubricant oil
  ...
- Sampling condition
  - Sampling line
  - Sampling point
  - Dilution
  ...

Effects
- Particle property
  - PM composition (OC/EC)
  - PM morphology
    (aggregates, particle size)
  ...
- Particle losses
  - Electrostatic deposition
  - Thermophoresis
  - Diffusion
  ...

Results
- Measured value
  - FSN
  - PAS
  - MAAP
  - LII
  - TOA

Correction factors
Future plans:

1. The NMRI will conduct further experimental research on BC measurement.

2. LII method will be also tested in November of this year in the NMRI.

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