4th Public Workshop to Discuss Development of Regulations for Ocean-going Ship Main Engines and Auxiliary Boilers

Worldwide Marine Distillate Fuels Properties-DNV 2007 Data

March 5, 2008
Sacramento, CA
Overview

- ARB purchased data on marine distillate fuel properties from Det Norske Veritas (DNV)
- Presentation provides ARB analysis of DNV data
  - ARB’s views and conclusions (not DNV’s)
- Evaluation of DNV data is one part of the technical evaluation for the ship main engine rule
- Other studies include evaluations of fuel samples taken from enforcement efforts, lubricity testing, and long-term fuel switching study
DNV Petroleum Services Data

- DNV analyzes marine fuels worldwide for compliance with ISO specifications
- Extensive database of test results kept
- Results presented represent 2007 marine distillate data from 21 ports worldwide
  - Ports selling low, medium & high sulfur fuels
  - Preference to high volume bunkering ports
  - Preference to Pacific Rim ports
Fuel Data Analyzed from Bunkering Ports Worldwide

- Augusta (IT)
- Busan (KR)
- Dubai (AE)
- Durban (ZA)
- Fujairah (AE)
- Gibraltar (GI)
- Hamburg (DE)
- Hong Kong (HK)
- Houston (US)
- Kaohsiung (TW)
- Los Angeles (US)

- Panama Canal (PA)
- Rotterdam (NL)
- San Francisco (US)
- Seattle (US)
- Shanghai (CN)
- Singapore (SG)
- Suez (EG)
- Tokyo Bay (JP)
- Valparaiso (CL)
- Vancouver (CA)
Analysis of Distillate Fuel Properties

- **Sulfur Content**
  - Determine number of samples meeting 0.1% and 0.2% sulfur levels

- **Viscosity of Fuel**
  - Compare measured values with levels recommended by engine manufacturers
  - Evaluate relationship with sulfur content

- **Flash Point**
  - Determine compliance with ISO Specifications
Selected ISO Specifications for Marine Fuels

<table>
<thead>
<tr>
<th>Property</th>
<th>On-road Diesel*</th>
<th>DMA (MGO)</th>
<th>DMB (MDO)</th>
<th>IFO 180</th>
<th>IFO 380</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur (% by wt.)</td>
<td>0.0015 (15 ppm)</td>
<td>1.5</td>
<td>2.0</td>
<td>4.5 (IMO)</td>
<td>4.5 (IMO)</td>
</tr>
<tr>
<td>Viscosity (cSt @ 40 °C)</td>
<td>1.9 to 4.1</td>
<td>1.5 to 6.0</td>
<td>11 max.</td>
<td>180 max @ 50 °C**</td>
<td>380 max @ 50 °C**</td>
</tr>
<tr>
<td>Flash Point (°C min.)</td>
<td>52</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

* Onroad ASTM 975, S15 Specifications
** 180 cSt @ 50°C ~ 7 cSt @ 150C, 380 cSt @ 50 °C ~9 cst@150C per ISO 8217
### Range in Fuel Sulfur Content of Marine Distillate Fuels Analyzed*

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Min % S</th>
<th>Max % S</th>
<th>Ave % S</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMA</td>
<td>0.05</td>
<td>1.70</td>
<td>0.39</td>
</tr>
<tr>
<td>DMB</td>
<td>0.05</td>
<td>2.12</td>
<td>0.54</td>
</tr>
<tr>
<td>DMA+DMB</td>
<td>0.05</td>
<td>2.12</td>
<td>0.43</td>
</tr>
</tbody>
</table>

*DNV PS 2007 data. Samples tested at or below 0.05% sulfur listed as 0.05% sulfur
Fuel Sulfur Content Distribution

Percent of Samples by Sulfur Level (DMA+DMB)

DNV Petroleum Services 2007 Data
# Range in Fuel Viscosity of Marine Distillate Fuels Analyzed

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Min cSt</th>
<th>Max cSt</th>
<th>Ave cSt</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMA</td>
<td>1.53</td>
<td>9.72</td>
<td>3.51</td>
</tr>
<tr>
<td>DMB</td>
<td>1.97</td>
<td>9.93</td>
<td>3.93</td>
</tr>
<tr>
<td>DMA+DMB</td>
<td>1.53</td>
<td>9.93</td>
<td>3.61</td>
</tr>
</tbody>
</table>

DNV Petroleum Services 2007 Data
Fuel Viscosity Distribution

Percent of Samples by Viscosity Level (DMA+DMB)

Percent of Samples

Cumulative Percentage

Viscosity centistoke

DNV Petroleum Services 2007 Data
Average Viscosity Levels by Fuel Sulfur Range

Average Viscosity (40 deg C) by fuel sulfur range

Average Viscosity cSt

<table>
<thead>
<tr>
<th>Fuel Sulfur Range</th>
<th>Average Viscosity cSt</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-0.10</td>
<td>2.0</td>
</tr>
<tr>
<td>0.11-0.20</td>
<td>3.0</td>
</tr>
<tr>
<td>0.21-0.30</td>
<td>4.0</td>
</tr>
<tr>
<td>0.31-0.40</td>
<td>5.0</td>
</tr>
<tr>
<td>0.41-0.50</td>
<td>6.0</td>
</tr>
<tr>
<td>0.51-2</td>
<td>7.0</td>
</tr>
<tr>
<td>All</td>
<td>8.0</td>
</tr>
</tbody>
</table>

DNV Petroleum Services 2007 Data
Fuel Flash Point Distribution

Percent of Samples by Flash Point (DMA+DMB)

- Percent of Samples
- Cumulative Percentage

Flash Point deg C

DNV Petroleum Services 2007 Data
Percentage of Fuel Samples Below Flash Point Limit by Fuel Sulfur Range

Flashpoint below 60 deg C by Fuel Sulfur Range

DNV Petroleum Services 2007 Data
Conclusions

♦ Sulfur Content
  – Wide range in sulfur content depending on bunkering port
  – Significant number of samples have a low sulfur content
  – Samples meeting 0.2% sulfur are about double those at 0.1%

♦ Viscosity of Fuel
  – Viscosity of distillate fuels is significantly lower than residual
  – Little correlation between sulfur content and viscosity
  – Almost all fuel samples are above the 2cSt level recommended by engine manufacturers
  – Some fuel samples have borderline viscosity

♦ Flash Point
  – Not a strong correlation observed between sulfur % and flash pt.
  – Very few samples do not meet minimum flash point (~2%)
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