Dispersant Effectiveness as a Function of Energy Dissipation Rate

A collaboration of
U.S. Environmental Protection Agency
Fisheries and Oceans Canada
Temple University
Louisiana State University
Coastal Response Research Center
(National Oceanic and Atmospheric Administration)
Investigators

- Albert D. Venosa, U.S. EPA, Cincinnati, OH
- Kenneth Lee, Fisheries and Oceans Canada
- Michel C. Boufadel, Temple University
- Scott Miles, Louisiana State University
- Zhengkai Li, DFO Canada
- Tom King, DFO Canada
- Paul Kepkay, DFO Canada
Goals and Objectives

- Measure energy dissipation rates of a range of wave energies
  - Regular wave
  - Spilling breaker
  - Plunging breaker

- Quantify natural rates of dispersion of crude oils under these wave conditions

- Quantify effectiveness of 2 dispersants in enhancing dispersion of 2 reference crude oils at the 3 different energy dissipation rates

- Develop analytical tools for monitoring dispersion in the field
EPA/DFO Wave Tank

- Wave tank originally fabricated 2 years ago (16 m x 2 m x 0.6 m)
- Wave tank doubled in length to 32 m to accommodate more wave types and bigger breakers
- Wave tank is able to generate reproducible breaking waves at precise locations
  - Methods have been developed that define the energy dissipation rate at various breaking wave energies
- Can be operated in either batch mode or continuous flow to simulate dilution by ocean currents
Regular Waves
Spilling Breaker
Plunging Breaker
Wave Absorbers
Testing Dispersion Effectiveness

- **Hypothesis:** energy dissipation rate, $\varepsilon$, is sufficient to accurately evaluate dispersant effectiveness (DE)
- **Approach:** DE measured at 3 different wave periods using 2 dispersants and 2 oils under batch conditions

- **Dispersants on NCP Product Schedule**
  - C9500
  - SPC1000

- **Crude oils**
  - Weathered Mesa Light
  - Unweathered ANS

- **3 different $\varepsilon$’s:**
  - Regular wave
  - Spilling breaker
  - Plunging breaker
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Dispersants</th>
<th>Oils</th>
<th>Waves</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water</td>
<td>MESA</td>
<td>Regular</td>
</tr>
<tr>
<td>2</td>
<td>Corexit</td>
<td>MESA</td>
<td>Regular</td>
</tr>
<tr>
<td>3</td>
<td>SPC1000</td>
<td>MESA</td>
<td>Regular</td>
</tr>
<tr>
<td>4</td>
<td>Water</td>
<td>ANS</td>
<td>Regular</td>
</tr>
<tr>
<td>5</td>
<td>Corexit</td>
<td>ANS</td>
<td>Regular</td>
</tr>
<tr>
<td>6</td>
<td>SPC1000</td>
<td>ANS</td>
<td>Regular</td>
</tr>
<tr>
<td>7</td>
<td>Water</td>
<td>MESA</td>
<td>Spiller</td>
</tr>
<tr>
<td>8</td>
<td>Corexit</td>
<td>MESA</td>
<td>Spiller</td>
</tr>
<tr>
<td>9</td>
<td>SPC1000</td>
<td>MESA</td>
<td>Spiller</td>
</tr>
<tr>
<td>10</td>
<td>Water</td>
<td>ANS</td>
<td>Spiller</td>
</tr>
<tr>
<td>11</td>
<td>Corexit</td>
<td>ANS</td>
<td>Spiller</td>
</tr>
<tr>
<td>12</td>
<td>SPC1000</td>
<td>ANS</td>
<td>Spiller</td>
</tr>
<tr>
<td>13</td>
<td>Water</td>
<td>MESA</td>
<td>Plunger</td>
</tr>
<tr>
<td>14</td>
<td>Corexit</td>
<td>MESA</td>
<td>Plunger</td>
</tr>
<tr>
<td>15</td>
<td>SPC1000</td>
<td>MESA</td>
<td>Plunger</td>
</tr>
<tr>
<td>16</td>
<td>Water</td>
<td>ANS</td>
<td>Plunger</td>
</tr>
<tr>
<td>17</td>
<td>Corexit</td>
<td>ANS</td>
<td>Plunger</td>
</tr>
<tr>
<td>18</td>
<td>SPC1000</td>
<td>ANS</td>
<td>Plunger</td>
</tr>
</tbody>
</table>
General Approach

• Create oil slick on water surface
• Start breaking or regular waves
• DOR = 1:25 in all experiments
• No-dispersant controls are also done, using water as the sprayed “dispersant”
• All experiments done in triplicate
• Dispersed oil measured at 3 depths and 4 locations along the length of the wave tank
  ▪ Measurements conducted at 5, 30, 60, and 120 min
  ▪ One rep done at 240 min (re-coalescence experiment) under quiescent conditions
Analytical and Wave Settings

- Oil distribution measurements in tank (3 methods):
  - Fluorometry
  - Laser particle analyzer (LSST-100X)
  - Spectrophotometric analysis of grab samples at 4 different locations, 1 upstream and 3 downstream from initial oil slick

- Total analyses: 3 dispersants x 2 oils x 3 wave types x 3 replicates x 4 sampling locations x 3 depths = 864 total analyses
RESULTS: Dispersant Effectiveness vs. $\varepsilon$
No Dispersant Control

![Graph showing average plume concentration over time for ANS and MESA](Image)

- Regular Wave
- Spiller
- Plunger

Time, Min: 5, 30, 60, 120, 180, 240

Average Plume Concentration, mg/L

Recoalescence Zone

- ANS
- MESA
Corexit 9500

**Time, Min**

**Average Plume Concentration, mg/L**

<table>
<thead>
<tr>
<th>Time, Min</th>
<th>ANS</th>
<th>Recoalescence Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>240</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Regular Wave**
- **Spiller**
- **Plunger**
SPC 1000

**ANS**

**Recoalescense Zone**

**MESA**

**Average Plume Concentration, mg/L**

- **Regular Wave**
- **Spiller**
- **Plunger**

Time, Min:
- 5
- 30
- 60
- 120
- 180
- 240

Coastal Response Research Center
RESULTS:
Particle Size Distribution
Mass Mean Diameter under Regular Non-Breaking Waves (8m downstream)

No Dispersant Control

Corexit 9500
Mass Mean Diameter under Spilling Breaking Waves (8m downstream)

No Dispersant Control

Corexit 9500

MMD (µm)

near surface
middle
near bottom

Depth cm

Time (min)

Depth (cm)

Time (min)
Mass Mean Diameter under Plunging Breaking Waves (8m downstream)

No Dispersant Control

Corexit 9500

Depth cm

120 80 40

Time (min)

115 75 45 15

Depth (cm)

120 80 40

Time (min)

115 75 45 15

MMD (µm)

near surface
middle
near bottom
Results: Fluorometry
Contour plots of EEMs (excitation-emission matrix spectra) of Brent Blend crude in seawater.

QA Question About Sample Storage
Effect of Refrigerator Storage Time on Oil Concentration in Samples

Oil Concentration, mg/L vs. time, days

- Time, days: 0, 10, 20, 30, 40, 50, 60, 70
- Oil Concentration: 5, 6, 7, 8, 9, 10
SUMMARY AND PRELIMINARY CONCLUSIONS
SUMMARY AND CONCLUSIONS (preliminary)

• Breaking waves are important for effective and lasting dispersion
  ▪ Breaking waves shear oil slick into tiny droplets that don’t easily recoalesce
  ▪ Breakers push oil downwards into water column where currents may carry the dispersed oil away (to be verified next)

• Regular waves disperse oil somewhat but do not impart sufficient energy to break up the oil into small droplets or push the droplets down deeply into the water column

• Chemical dispersants cause a huge difference in total dispersed oil and particle size distribution compared to no dispersant for all 3 wave conditions

• Correlations between DE and $\varepsilon$ will enable more meaningful explanations of the data presented
Acknowledgement

Funding for this project was provided by the Coastal Response Research Center

www.crrc.unh.edu
Acknowledgment

Cost sharing also provided by the U.S. Environmental Protection Agency (EPA) and Fisheries and Oceans Canada (DFO)
Thank you. Questions?