ABSTRACT

This paper presents the results of two related studies concerning the aerial application of dispersants. The first study characterized the interactions of various sized Corexit 9500 and 9527 dispersant droplets with oil films of from 0.1 mm to 3.0 mm thickness. A film thickness of 0.1 mm was selected as the end point since this is the thinnest oil film recommended for the application of dispersants. The results of the high speed video droplet impact analysis showed that droplet diameters of 1,000 microns will not pass through an oil slick of 0.1 mm and mix with the underlying water column and that slick thickness of 0.2 mm or more will prevent even 2,000 micron diameter droplets from passing through the slick. These droplet sizes are considerably larger than the current ASTM Standard recommended droplet size of 300-500 microns for dispersant application. Additionally, it was shown that droplets that do pass through an oil slick will in whole or in part rise back up to the oil water interface.

The second study characterized and compared the evaporation rates of Corexit 9500 and 9527 droplets with water over a 20 minute period under varying conditions of humidity and temperature. Under high evaporative conditions of high temperature (90°F) and low humidity (40%), droplets ranging from 0.25 to 1 mL showed 2-10% evaporative loss for Corexit 9500, 28-35% evaporative loss for Corexit 9527, and complete evaporative loss for water. When tested at low evaporative conditions of low temperature (40°F) and high humidity (95%), no evaporative loss was recorded for droplets of either 9500 or 9527, and water lost 18%.

INTRODUCTION

Historically it has been accepted that dispersant droplets of greater than 500 microns would pass through an oil slick, mix with the underlying water column and thus become ineffective in dispersing the oil slick. The first study evaluates the droplet diameters that will pass through oil films (slicks) of sizes from 0.1 mm to 3.0 mm and photographically evaluates the physical interaction of the dispersant droplet striking the oil slick.

The second study determines the amount of evaporation loss from droplets of Corexit 9500, Corexit 9527 and water over a 20 minute period under conditions of low and high temperature and humidity. This enables an estimate of the evaporative loss of dispersants when applied by aircraft from altitudes of 50 to 100 feet and whether these losses will substantially affect the dosage that is applied to a slick on the sea surface.

The results of these studies will assist in the design and operation of both aerial and boat mounted dispersant spray systems in delivering accurate dosages to surface oil slicks.

STUDY 1 - POST-ATOMIZATION IMPACT BEHAVIOR OF COREXIT 9500 AND 9527 ON OIL SLICKS

Experimental Procedures

Dispersant droplet tests were conducted at the LPCAT laboratory using Corexit®9500 and Corexit®9527 dispersants droplets of approximately 1,000 to 3,500 microns on slicks of approximately 0.1 to 3.0 mm of Intermediate Fuel Oil 380 (IFO 380) and Alaska North Slope (ANS) crude oil. Additionally, the dispersants were tested on an oil slick of soybean oil to provide better visual clarity. Tests using glass beads and water droplets were also conducted to demonstrate complete penetration and mixing.

Oil films were prepared by adding an appropriate amount of oil to fish tanks measuring 30.16 by 14.92 cm filled with about 2.9 liters of prepared sea water (Instant Ocean Sea Salt) and brought to ambient temperature which ranged from 15 °C to 22°C. The tanks were then agitated to produce an even oil film thickness over the surface. For slick thicknesses below 0.5 mm hexane was added to the oil to improve oil spreading and the hexane was then allowed to evaporate for at least 15 minutes before testing.

The oil slicks were then positioned under the droplet generator and droplets from 700 to 3,500 microns were generated using a DRT electrostatic nozzle, a burette, or a glass whisker from
heights of 29.8 to 152.4 cm (11.75 to 60 inches). These heights produced droplets traveling at 39-84% of their terminal velocity. The droplet was then videographed when impacting the oil slick using an APX camera processor with APX color camera head with F mount with a 105 mm F/2.8 macro lens with clear filter. All videos were taken in color at 3000 frames per second with a resolution of 512 x 1024. The video camera focus area was lighted with two 1000 watt Lowel DP lights, and 2 additional lights of 600 and 800 watts. The droplet impact videographs were then analyzed using Photron Fastcam Viewer version 2.4.3.5 software (Photron Ltd. Http://www.photron.com). With this setup and software the droplet size, velocity, and energy were measured and the physical interaction of the dispersant droplet with the oil slick was videographically recorded.

Test Results

The photographic sequence shown in Figure 1 illustrates the typical droplet-oil slick interaction of Corexit dispersant droplets with oil slicks. Soybean oil is shown in Figure 1 as the oil slick and red dye was added to the dispersant droplet for enhanced visual clarity. Similar results were obtained when fuel oil or crude oil were used.

![Image](https://example.com/image1.png)

**A:** Droplet just touching the oil film surface  
**B:** Maximum deformation of oil/water surface  
**C:** Maximum rebound height  
**D:** Thinnest connection to terminal liquid (droplet)  
**E:** Maximum width of secondary impact ion  
**F:** Maximum physical penetration  
**G:** Dispersant mixing in to surface (red dye).

Important observations from all tests of droplet-oil interactions (as illustrated in Figure 1) include the following:

- The droplet energy of impaction is dissipated by deformation of the droplet, the deformation of the oil slick, and the deformation of the water column as shown in frames B and E.
- The dispersant passes through the slick on the rebound and not on the initial impact as seen in frames B, E and F.
- Part of the dispersant droplet mixes into the oil slick as seen in frames C through G.
- Most of the dispersant droplet that passes through the slick into the water column rises to the oil slick as seen in frames F and G.
- A small portion of the dispersant droplet, shown by the thin red line at the bottom of frame G, may not resurface but remain in the water column. However, the video sequences were not run sufficiently long to determine the final disposition of this portion of the dispersant droplets.

Conclusions

The following conclusions were drawn from the results of the 114 dispersant droplet impact tests conducted for this study.

1. Dispersant droplets upon impact with an oil slick on sea water will penetrate into the underlying water column and then rise to the underside of the oil slick. This result is due to Corexit 9500 and 9527 dispersants having a specific gravity of 0.95 at 60° F (15.6 °C) and 0.98-1.02, respectively and the prepared sea water having a specific gravity of approximately 1.022. Therefore, simple penetration of the oil slick does not imply that the dispersant is lost into the water column, but continue to be available to disperse the oil slick.

2. Dispersant droplets with diameters under 1000 μm have insufficient energy at terminal velocity to strike an oil slick of 0.1 mm or less and mix with the underlying water column.

3. Oil slicks thicknesses of 0.3 mm will prevent even 2000 micrometer droplets from mixing with the underlying water column.

While the above conclusions accurately reflect the behavior of Corexit 9500 and 9527 dispersants, the behavior of water based dispersants may be considerably different and was not evaluated since it was outside the scope of this research project.

Dispersant Application Research Implications

Based on the results of the droplet impact research current ASTM Standards should be revised to state that dispersant application equipment may produce droplets with a Volume Median Diameter (VMD) of 1,000 microns rather than 300-500 microns as currently stated. The larger droplet size would reduce drift from aerial application and will permit the use of larger nozzles on boat spray boom systems and fire monitor systems.

Additionally, this research supports the concept of applying dispersant under calm sea conditions as the dispersant will not be lost into the water column, but continue to be available to disperse the oil when sufficient wave energy does occur.

**STUDY 2 - DETERMINATION OF EVAPORATION RATES FOR TWO OIL SPILL DISPERSANTS (COREXIT® 9500 AND COREXIT® 9527)**

**Experimental Procedures**

The evaporation rate of droplets of Corexit® 9500 and Corexit® 9527 dispersant was determined relative to water under four environmental conditions: cool/dry (40°F and 55% RH), cool/wet (40°F and 95% RH), hot/dry (90°F and 40% RH), and hot/wet (90°F and 95% RH). Evaporation measurements were made in a walk-in controlled environment chamber (Conviron model BDW80) located in Thorne Hall, at the Ohio Agricultural Research and Development Center (OARDC) at The Ohio State University (OSU).

A Mettler PM460 balance was placed in a cardboard box on a bench in the chamber to minimize air circulation around the balance and provide more stable readings. Sections of Parafilm "M" laboratory film (American National Can, Neenah, WI) were cut and placed on the balance. The tare reading from the balance was recorded both before and after measuring droplets. Droplets were measured and placed on the balance. The tare reading from the balance was recorded both before and after measuring droplets. Droplets were measured and placed on the balance. The tare reading from the balance was recorded both before and after measuring droplets. Droplets were
applied to the parafilm using a 5-μL syringe (Microliter #7105, Hamilton Company, Reno, NV).

The parafilm was placed on the balance, and a Time 0 reading was taken. Readings were then taken at 5-minute intervals for 20 minutes. The parafilm was removed and the tare reading was recorded again to correct for balance fluctuation. Temperature and relative humidity were recorded for each sample using an NIST Traceable Hygrometer-Thermometer (Fisher Scientific).

There were seven treatments – distilled water at one drop size (20 1-μL droplets), Corexit® 9500 and Corexit® 9527 at three drop sizes each (1-μL droplets (20), 0.5-μL droplets (40), 0.25-μL droplets (80)). There were five replicates per treatment.

The data were analyzed in SAS 9.1.3 for Windows (SAS Institute Inc. SAS Circle Box 8000, Cary, NC 27512-8000). This program estimates a loss rate in grams s⁻¹ per droplet. For analysis the data was divided into 5 minute intervals (0 to 5, 5 to 10, 10 to 15, 15 to 20). Thus, there are 80 five minute intervals for water, and 240 five minute intervals for the dispersants. These intervals are not autocorrelated because evaporation rate does not depend on droplet size, and therefore it does not matter that a droplet lost 0.003 grams in the first 5 minutes, it will have no effect on how much it loses in the second 5 minute interval.

Although the smallest material volume used in these tests represents a sizeable droplet and placing the material on a surface as a deposit does not represent aerial application conditions, the data generated is indicative of the rates of evaporation of droplets of these materials.

Test Results

Evaporation data generated is shown in Table 1 and the loss in mass versus time for each environmental condition is show in Figures 2-5 in Attachment 2.

**TABLE 1: AVERAGE PERCENTAGE EVAPORATION LOSS PER DROPLET OVER 20 MINUTES**

<table>
<thead>
<tr>
<th>Sample Size Material</th>
<th>Wet (90% RH)</th>
<th>Dry (40-50% RH)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cold (40°F = 4.4°C)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 Water</td>
<td>17.0 ± 4.5</td>
<td>33.0 ± 2.7</td>
</tr>
<tr>
<td>15 9500</td>
<td>-3.5 ± 5.9</td>
<td>-0.4 ± 6.7</td>
</tr>
<tr>
<td>15 9527</td>
<td>-4.7 ± 5.5</td>
<td>2.4 ± 3.7</td>
</tr>
</tbody>
</table>

| **Hot (90°F = 32.2°C)**                  |              |                 |
| 15 Water             | 65.0 ± 10.0  | 95.0 ± 3.5      |
| 15 9500              | 6.7 ± 5.8    | 6.3 ± 6.7       |
| 15 9527              | 28.9 ± 4.9   | 30.9 ± 5.7      |

Conclusions

1. Evaporation losses were greatest in the hot-dry condition (Table 1) and least in the cold-wet condition.
2. Water evaporates more than Corexit 9500 or 9527 and evaporation may be important when aerial applying water based dispersants with VMDs below 300 microns.
3. Corexit 9527 evaporates slightly more than Corexit 9500 in cold conditions and considerably more in hot conditions.
4. Increasing temperature increases evaporation and increasing humidity decreases evaporation.
5. The larger the droplet size, the less influence evaporation will have on changing the droplet size during application from aircraft altitudes of 50 feet or more and more dispersant will reach the ground (oil slick).
6. Under Cold & Wet conditions both Corexit dispersants absorbed water to gain weight as indicated by the negative weight loss in Table 1.
7. The loss of Corexit 9500, 9527 and water droplets during free fall from altitudes of 50, 75 and 100 feet is small as seen in Table 2 which was generated using the experimental evaporation data.

   a. A 1000 mm droplet contains a bit less than 0.524 microliters of liquid, or 0.524 milligrams of water. Table 2 shows the estimated size upon impact of a 1000 micrometer diameter droplet falling through air under a variety of conditions.

   b. Note the values in Table 2 have not been adjusted for the change in density between water and dispersants. The values have also not been corrected for the change in density due to temperature. The density values for the dispersants at these specific temperatures have not been measured. This is work that still needs to be done, but should not substantially change the relative values.

**TABLE 2: IMPACTING DROPLET SIZES FROM A GENERATED 1 MM DROPLET**

<table>
<thead>
<tr>
<th>Product</th>
<th>Original Size (μm)</th>
<th>Temp (°F)</th>
<th>RH</th>
<th>Final Size (μm) 50</th>
<th>Final Size (μm) 75</th>
<th>Final Size (μm) 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>9500</td>
<td>1000</td>
<td>38</td>
<td>45</td>
<td>998</td>
<td>997</td>
</tr>
<tr>
<td>9527</td>
<td>1000</td>
<td>38</td>
<td>97</td>
<td>999</td>
<td>994</td>
<td>991</td>
</tr>
</tbody>
</table>

* Based on a 1 mm water droplet having a terminal velocity of 4.26 m/s at the start of its fall

8. Evaporation will have little effect on Corexit dispersant droplets of 500 microns or more being aerial applied from altitudes of 50 to 100 feet as shown in Table 3.

**TABLE 3: ESTIMATED DROPLET SIZE STRIKING AN OIL SLICK WHEN APPLIED FROM 50 FEET AT 70°F AND 70% RH**

<table>
<thead>
<tr>
<th>Original Size (μm)</th>
<th>Water 9500</th>
<th>9527</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
<td>91</td>
</tr>
<tr>
<td>500</td>
<td>487</td>
<td>500</td>
</tr>
<tr>
<td>1000</td>
<td>957</td>
<td>1000</td>
</tr>
</tbody>
</table>

* Assumes that all chemical components of the dispersant have the same evaporation rate. It is likely that the less volatile chemicals in the dispersant's composition may still remain and provide a small droplet size of some dimension rather than completely evaporating.

**REFERENCES**

1. Post-atomization Impact Behavior of COREXIT 9500 and 9527 on Oil Slicks, API Report February 21, 2007
2. Determination of Evaporation Rates For Two Oil Spill Dispersants (COREXIT® 9500 And COREXIT® 9527. Report to ExxonMobil Research and Engineering, May 1, 2006.
Attachment 1
DROPLET IMPACT STUDY EXPERIMENTAL SETUP

Picture of laboratory set-up showing lights, and camera on the right, a burette held by a photo enlarger stage hangs over the supports that are ready to have a tank placed on them. There is a high voltage power supply used as part of the DRT nozzle system. The mirror in the middle of the table helps illuminate the underside of the slick. Two tanks are shown on the table.

Attachment 2
EVAPORATION GRAPHS OF COREXIT 9500, COREXIT 9527 AND WATER UNDER VARYING ENVIRONMENTAL CONDITIONS

FIGURE 2 – CHANGE IN DROPLET WEIGHT VERSUS TIME AT 90° F AND 41% RH

FIGURE 3 – CHANGE IN DROPLET WEIGHT VERSUS TIME AT 90° F AND 95% RH

FIGURE 4 – CHANGE IN DROPLET WEIGHT VERSUS TIME AT 41° F AND 55% RH

FIGURE 5 – CHANGE IN DROPLET WEIGHT VERSUS TIME AT 39° F AND 95% RH