FINAL REPORT

Chemical Dispersant Research: Dispersant Effectiveness Testing at Ohmsett Using Aircraft Application Dosages

for:

Bureau of Safety and Environmental Enforcement
U.S. Department of the Interior
381 Elden Street
Herndon, VA 20170

by:

S.L. Ross Environmental Research Ltd.
200-1140 Morrison Drive
Ottawa, ON
K2H 8S9

MAR Inc.
Leonardo, New Jersey
07737

May, 2014

This study was funded by the Bureau of Safety and Environmental Enforcement (BSEE), U.S. Department of the Interior, Washington, D.C., under Contract E12PC00007.

SL ROSS

Acknowledgements

This study was funded by the Bureau of Safety and Environmental Enforcement (BSEE), U.S. Department of the Interior, Washington, D.C., under Contract E12PC00007.

Disclaimer

This draft final report has not been reviewed by the Bureau of Safety and Environmental Enforcement (BSEE), nor has it been approved for publication. Approval, when given, does not signify that the contents necessarily reflect the views and policies of the BSEE, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use.

Executive Summary

The primary objective of the work was to determine the effectiveness of a chemical dispersant when applied at 5 gal/acres against Gulf of Mexico OCS light to medium crude oils to relatively thick oil slicks. A one-week dispersant effectiveness testing program was conducted at Ohmsett-The National Oil Spill Response Research & Renewable Energy Test Facility, located in Leonardo, New Jersey. Three US Gulf of Mexico crude oils were used in the test program and Corexit 9500 was used in all spray tests.

A 2.4 m diameter rigid containment ring made from 5 cm flexible ABS piping was used to contain the oil at the required thickness prior to dispersant application. The containment ring was lifted to release the oil, the spray bar was activated and the bridge and spray bar immediately moved over the slick to treat the oil slick. The wave paddle was then activated to introduce waves to the treated and uncontained slick. Control tests were also conducted with no dispersant applied. Oil remaining on the surface at the end of the test was quantified to determine the overall effectiveness of the dispersant application. LISST 100x particle size and Turner C3 fluorometry readings were taken during the test to further quantify the dispersions.

Water temperatures during the test program remained relatively constant at between 25 to 26°C. Air temperatures were 24 to 30°C. The measured dispersant application rates varied from 5.4 to 7.6 US gallons per acre. The oil thicknesses at the time of dispersant application ranged from 0.8 to 3.4 mm.

With one exception, the tests where low doses of dispersant were applied resulted in more dispersed oil than in the control tests. The effectiveness of the dispersant ranged from 10% to 35% even though the dispersant to oil ratios (DOR) ranged from only 1:170 to 1:550. However, none of the measured dispersant effectiveness values were high considering that the oils tested were relatively light and amenable to chemical dispersant use. For example, in previous tests at Ohmsett the same Neptune and Anadarko oils were found to be 89% & 95^{+}% dispersible by Corexit 9500 when applied at dose rates of 1:40 and 1:30, respectively (SL Ross 2011). The 5

US gallon/acre application limit often imposed in aircraft application operations would appear to not supply sufficient dispersant to achieve maximum dispersion of thicker patches of oil (1 mm and greater) that may exist in larger oil spills.

It is possible that the enclosed nature and short duration of the wave-basin test negatively biases the final dispersant effectiveness outcome. Researchers have demonstrated that surfactant contaminated water reduces the spreading of chemically treated oils thus keeping them artificially thick when compared to treated oils in an open ocean setting (Nedwed et. al. 2011). This elevated oil thickness may result in reduced dispersion due to the need for more mixing energy to generate small oil droplets. Based on this hypothesis the final DE estimates from these low dose basin tests could possibly be under-estimating the ultimate effectiveness of the low dose applications when used in a field setting.

It is recommended that regulators consider approving dispersant application rates higher than standard aircraft rates of 5 gallons/acre when thick oil (> 0.1 mm) is present. This may necessitate multiple passes by aircraft or use of vessel based application systems that are capable of delivering higher doses in a single pass. Test tank studies at Ohmsett have shown that multiple dose dispersant application can be as effective as applying the same amount of dispersant in a single application (SL Ross 2009).

Table of Contents

Chemical Dispersant Research: Dispersant Effectiveness Testing at Ohmsett Using Aircraft Application Dosages

1 Objectives

The primary objective of the work was to determine the effectiveness of a chemical dispersant when applied at 5 gal/acres against Gulf of Mexico OCS light to medium crude oils.

2 Background

Aircraft application systems have generally been designed to apply dispersant at an application rate of around 5 gallons/acre (USCG 2013, ASTM F1413-07). This is in part due to the minimum speed of dispersant application aircraft and the maximum dispersant delivery rate possible while still maintaining appropriate dispersant spray drop sizes. The 5 gallon/acre application rate also has its roots in long standing guidelines developed for 'best practice' for dispersant use that assumed the oil would be present on the water surface in relatively thin oil slicks (0.1 mm or 100 microns thick) (ITOPF web reference, ITOPF 1982).

One concern with this approach is that oil slicks can often be much thicker than the 0.1 mm value considered for the aircraft application dosage standard of 5 gallons/acre, especially during large volume oil spills. Windrows of thicker oil can develop due to Langmuir circulation patterns and density fronts. Significant patches of relatively fresh, black oil several mm thick were observed by the authors of this report during the BP Macondo incident. Weathered and emulsified oil was also present in streamers of oil that were several mm thick.

The goal of this study has been to conduct a number of modified Ohmsett dispersant effectiveness tests to determine the effectiveness of dispersant applied at 5 gal/acres against Gulf of Mexico light to medium OCS crude oils when the oil present is thicker than 0.1 mm. Tests have been conducted on oils with target thicknesses of 1 and 4 mm. The testing has been conducted using the moderate energy mixing level (34 to 35 cycles per minute (cpm) and 8.9 cm stroke) used in the standard Ohmsett dispersant test to give the dispersant ample opportunity to be effective. Testing was conducted using Corexit 9500 dispersant.

3 Oils and Dispersant Used in Test Program

Three US Gulf of Mexico crude oils were used in the test program. The oils and their basic fresh oil physical properties are shown in Table 3-1. The fresh oils were placed in the containment rings allowed to weather (evaporate) under calm conditions for up to 1 hour and then treated with dispersants. Small samples of the oils were also evaporated in trays in the Ohmsett laboratory to determine their densities as a function of percent evaporated. This data has then been used to determine the amounts of oil that evaporated prior to dispersant application and during the test periods by measuring the densities of oil collected just prior to dispersant application and at the end of each test. The evaporation-density curves for these oils are provided in Appendix A and can also be accessed via the hypertext links in Table 3-1. The linear volume percent evaporation versus density correlation from the weathering data is also provided in Table 3-1. The graphs also show the oil densities just prior to dispersant application at the beginning of each test.

Table 3-1 Test Oil Properties

Oil Name	Density (kg/m^3 @ 20 °C)	Viscosity (mPas)	Links to Evaporation Density Curves	Fraction Evaporated (y) – Density (ρ) Correlation
BHP Neptune	922	402 @ 15 °C[1]	#EvapNeptune	y=5.4142ρ-4.9938
Dorado	852	37 @ 20 °C[2]	#EvapDorado	y=7.165 ρ-6.1181
Anadarko	912	23 @ 15 °C[1]	#EvapAnadarko	y=11.453ρ-10.461

[1]Data from Fieldhouse et al 2010. [2] Measured at Ohmsett for this project

4 Test Methods and Equipment

A one-week dispersant effectiveness testing program was conducted at Ohmsett. Corexit 9500 was used in all tests at a target application rate of 5 gallons/acre to match the dose rate that was permitted in the BP Horizon spill response and is common in aircraft applications. The standard

Ohmsett dispersant effectiveness test was modified as follows in these tests to meet the test objectives.

The Ohmsett spray bar was fitted with eleven Spraying Systems Company 800050 flat fan nozzles to deliver the desired 5 gallons of dispersant per acre. The bridge was operated at 0.8 m/s (1.6 knots) during the spray and the dispersant was delivered over a 6.7 m (22 feet) spray width using the 11 nozzles that were spaced at 0.61 m (2 feet) apart.

A 2.4 m (8 feet) diameter rigid containment ring made from 5 cm (2 inch) flexible ABS piping was used to contain the oil. See Figure 4-1. Water flow from the bridge fire monitor was used to vigorously sweep the surface of the water inside the ring immediately before spilling the oil into the ring to remove any residual oil or surfactants to ensure an even spreading of the oil over the ring area. The oil was discharged into the circular containment ring under calm conditions. Eighteen liters of oil were used to achieve a 1mm thick slick and approximately 72 liters for the 4 mm thick slick. The oil was allowed to weather on the tank for approximately one hour prior to the application of the dispersant. A sample of the oil was taken from the ring just prior to dispersant application treatment (Figure 4-2) for density determination to estimate the amount of evaporation prior to dispersant application. The containment ring was lifted to release the oil (Figure 4-3), the spray bar was activated and the bridge and spray bar moved over the slick to treat the oil slick. The wave paddle was then started to introduce waves to the treated and uncontained slick. Because of the delay between releasing the slick and the onset of breaking waves the drift of the surface oil to the tank side walls was minimized by herding the oil to the tank center using the bridge fire monitors at low flow. The remainder of the test was conducted as in the standard Ohmsett dispersant effectiveness test. Detailed descriptions of the test protocol, and its development, and equipment used in the testing can be found in previous publications (SL Ross et al 2000a, 2000b, 2002a, 2002b, 2003a, 2003b, 2004, 2006). Oil remaining on the surface at the end of the test was collected to determine overall effectiveness and LISST particle size and Turner C3 fluorometry readings were taken during the test to further quantify the dispersion.

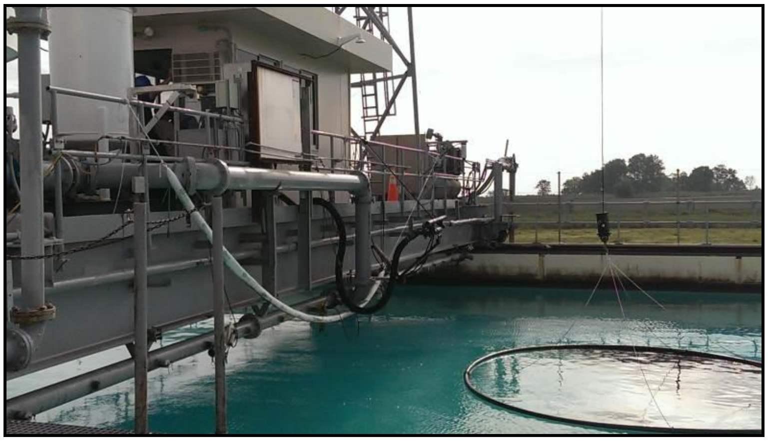

Figure 4-1 Oil Containment Ring Position During Oil Weathering Period

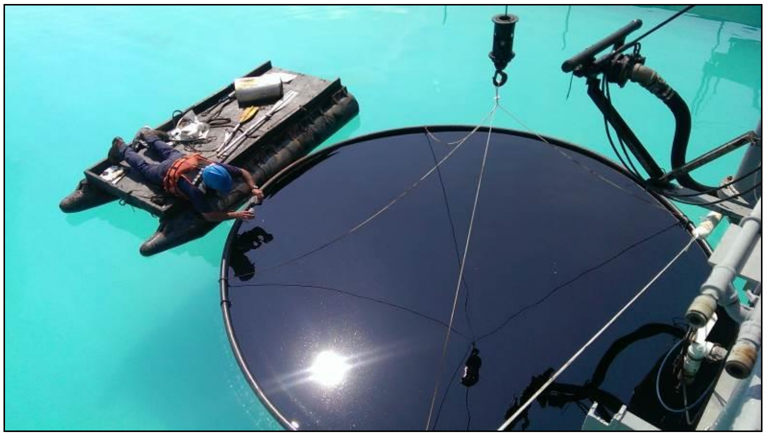

Figure 4-2 Oil Sampling Just Prior to Dispersant Application

Figure 4-3 Oil Containment Ring Lifted Prior to Dispersant Application

The oil discharge and dispersant spray systems used in the testing were the same as those used in previous dispersant tests at Ohmsett. Corexit 9500 dispersant was used in all of the tests where dispersant was applied.

The step-by-step procedures used for the dispersant effectiveness tests in this study were as follows.

1. The oil containment zone for the overall tank was established by placing booms across the north and south ends of the Ohmsett tank.
2. The main bridge was positioned at the southern quarter point within the boomed area.
3. The oil and dispersant were loaded into supply tanks on the main bridge deck.
4. The PVC oil containment ring was tethered to the main bridge crane and placed on the water on the south side of the main bridge.
5. The water inside the ring was vigorously flushed with clean water from the deck fire monitors to remove trace oil and surfactant from the area within the ring to promote the even spreading of oil.
6. The oil was placed inside the ring either using 20 liter pails (for the 1 mm thick slick tests) or using the on deck oil supply tank and pump (for the 4 mm thick oil tests).
7. The oil was allowed to weather on the tank for up to 60 minutes and a sample of the surface oil was taken for density measurement to determine the weathered state of the oil just prior to dispersant application.
8. The ring was lifted to free the oil and allow movement of the bridge for dispersant spray.
9. The bridge was driven over the released slick and sprayed with dispersant at a target application rate of 5 US gallons per acre.
10. The wave paddle was started with a 8.9 cm stroke and 34 to 35 strokes per minute.
11. The waves were left on for 30 minutes and the wave paddle stopped.
12. During the 30 minutes of wave action the LISST particle size analyzer and C3 fluorometer were towed through the tank to measure the in-water oil concentrations and drop sizes.
13. At the end of the test, immediately after the waves were stopped, the water current developed by the water spray from the bridge fire monitors was used to sweep any surface oil remaining on the water surface to a common collection area at one corner of the containment boom.
14. The oil was then removed from the water surface using a double-diaphragm pump and suction wand or a hand ladle and placed in a collection drum or a 20 L pail.
15. The collected oil and water was allowed to stand and most of the free water present was drained from the bottom of the collection container.
16. The remaining oil and water were then well mixed and a sample taken for water content and physical property determination.
17. The quantity of remaining liquid is measured and the amount of oil present determined by subtracting the amount of water present as determined using the water content analysis.
18. The effectiveness of the dispersant is reported as the volume of oil present prior to dispersant application minus the amount collected from the surface at the end of the test divided by the volume of oil present prior to dispersant application.
19. Each test was video taped for future visual reference.

5 Results

5.1 Dispersant Effectiveness Estimates

The test conditions and estimated Dispersant Efficiencies (DE) for all of the large-scale tank tests are summarized inTable 5-1. Test number 8 is not included in the table because an electrical storm passed shortly after the slick was sprayed and this necessitated evacuation of the bridge and aborting the test for safety. Water temperatures during the test program remained relatively constant at between 25 to 26°C (77 to 79°F). Air temperatures were 24 to 30°C (75 to 85°F). The dispersant application rates varied from 5.4 to 7.6 US gallons per acre. The oil thicknesses at the time of dispersant application ranged from 0.8 to 3.4 mm as estimated based on the volume of oil spilled minus the quantity evaporated and the approximate area of the containment ring covered by oil at the time it was lifted just prior to dispersant application. The quantity evaporated was determined by measuring the density of the oil just prior to lifting the ring and comparing this density to the evaporation curves provided in Appendix A. Test Oil Evaporation-Density CurvesThe dispersant to oil ratios in Table 5-1 were determined based on the calculated dispersant application rate and oil thickness estimates. The DOR values are much lower than manufacturers recommended dosages as standard aircraft application rates are designed to apply a 1:20 dosage on much thinner slicks (0.1 mm) than those studied in this test program.

The percentage of oil recovered is based on the amount of oil recovered at the end of the test after adjusting for emulsion water content and comparing this to the amount of oil present just prior to lifting the containment ring, adjusted for evaporative losses as described above.

The percentage of oil dispersed after evaporation adjustment in column 9 of Table 5-1 is the percentage of the oil volume that was present just prior to lifting the ring that was not recovered or not accounted for by evaporative losses. The collected oil densities were measured at the end of each test after dewatering them. These densities were then used to determine the total evaporative losses, again using the density curves presented in Appendix A.

The control and evaporation adjusted dispersant effectiveness (DE) values in column 10 were determined by subtracting the column 9 percent dispersed results for the control test from the percent dispersed value for the matching dispersant applied test. The values in column 10 provide an indication of the effectiveness of the dispersant for each of the oil types and thicknesses at the 5 to 7 gallons per acre aircraft dose rate used in the testing. With the exception of the thick Dorado oil slicks in tests 12 and 13 the dispersant applied tests resulted in more dispersed oil than in the control tests. In the dispersant applied test #13, slightly more oil (4%) was collected and the estimated evaporative loss was slightly higher (3%) than in the control test #12. Both of these amounts are small and are likely less than the repeatability/precision of the measurement capability in these large scale tests. These numbers indicate that there was no difference in the control and dispersant applied test for this oil, thickness and dispersant dose rate. In the remaining tests the effectiveness of the dispersant ranged from 10% to 35% even though the dispersant to oil ratios were quite low, ranging from 1:170 to 1:550. The relatively high DE measured for the thick Anadarko oil slick and thus the lower DOR ratio (1:550) is an outlier as it would be expected that a higher DE would be achieved with the higher DOR in test number 4, when compared to test 6, for the same oil. None of these DE values are high considering that the oils tested were relatively light and amenable to chemical dispersant use. In previous tests at Ohmsett the same Neptune and Anadarko oils were found to be 89% & 95^{+}% dispersible by Corexit 9500 when applied at dose rates of 1:40 and 1:30, respectively (SL Ross 2011).

Hypertext links are provided in Table 5-1 to video clip segments of each of the tests. The video records can be viewed by double-clicking on a link when accessing this document digitally. The clips are in order from the start of the test progressing through to the end of each test. The video clips provide a good record of the behavior of the oil in each of the tests completed. In the tests where dispersant was applied there is always a small amount of dispersed oil visible during the initial breaking waves that pass through the fringes of the treated slick that has the characteristic café au lait appearance that is indicative of small oil drop dispersion. These clouds are small in the dispersant applied slicks but they are not present at all in the control slicks.

Table 5-1 Tank Dispersant Effectiveness (DE) Test Results Summary

Oil	Target Oil Thickness (mm)	Water Temp °C	Air Temp °C	Dispersant Application Rate (gal/acre)	Estimated Actual Oil Thickness (mm)	DOR	% Oil Recovered	% Oil Dispersed After Evap. Adjustment	Control & Evap. Adjusted DE (%)	Links to Video Clips	Test #
Neptune	1	25.4	29.2	Control	1.0	0	39	43	-	Test 1 video	1
Neptune	1	25.4	29.4	6.1	2.0	1:350	16	64	21	Test 2 video	2
Neptune	4	26.0	23.3	Control	3.0	0	87	3	-	Test 9 video	9
Neptune	4	26.0	30.8	7.6	3.3	1:460	63	25	22	Test 7 video	7
Anadarko	1	25.4	29.4	Control	0.8	0	23	50	-	Test 3 video	3
Anadarko	1	25.4	29.6	6.5	1.1	1:170	11	60	10	Test 4 video	4
Anadarko	4	25.3	27.4	Control	3.1	0	47	38	-	Test 5 video	5
Anadarko	4	25.5	30.0	6.6	3.4	1:550	20	69	31	Test 6 video	6
Dorado	1	25.5	30.0	Control	0.7	0	47	33	-	Test 10 video	10
Dorado	1	24.6	23.6	5.4	1.0	1:190	14	68	35	Test 11 video	11
Dorado	4	26.1	26.8	Control	2.6	0	53	32	-	Test 12 video	12
Dorado	4	26.4	27.3	6.9	2.6	1:410	57	25	-7	Test 13 video	13

5.2 Dispersed Oil Concentrations and Drop Size Distributions

Up to six passes were made down the length of the test tank with the main bridge after the oil was discharged to measure in-water oil concentrations and drop size distributions. A LISST 100X particle size analyzer recorded data on oil drop sizes and in-water oil concentrations and a Cyclops C3 in-situ fluorometer recorded raw fluorescence of the entrained oil. These measurements were made to characterize the form of the oil (drop size distribution) and to confirm the presence of oil in the water column. Graphs of the oil drop size distributions and concentrations are provided in Appendix B. Oil Drop Size Distributions Hypertext links to these graphs are provided in Table 5-2.

The LISST 100x device sampled both oil concentration and oil drop size every few seconds as the bridge was moved back and forth dragging the device through the water at 1 m below the water surface. The oil concentration and VMD oil drop sizes have been plotted. The high concentration zones in the graphs correspond to the times that the LISST sensor was in the dispersed oil cloud.

In-water oil concentrations were also measured using a Turner Cyclops-3 in-situ fluorometer. The raw fluorescence values acquired by this device are plotted along with the LISST data. The Cyclops-3 identified the same concentration peaks and valleys as the LISST system in the raw trace. No attempt was made to calibrate the C3 raw data to oil concentration values as this has proven to be problematic in previous studies. The calibration of these fluorometers is problematic since raw fluorescence of an oil droplet suspension is a function of the gross oil concentration, composition of the oil and the droplet size distribution. It is difficult to achieve a dispersed oil sample of known oil concentration and appropriate drop size distribution with which to gather the calibration data. The concentration data has been scaled using the relationships provided in the graph legends to plot the results alongside the LISST results for comparison of concentration trends. The relationships were established through an offset and divisor that were selected based on a visual matching of the C3 trace with the LISST concentration trace. The Cyclops C3 fluorometer is useful in a field application since it confirms the presence of oil through fluorescence whereas the LISST merely records the distribution of particles present in the water regardless of their composition or origin. The two devices are thus complimentary in a field deployment.

The oil concentration plots by the LISST and C3 devices generally reveal more oil in the water column in the treated versus the untreated slick with the exception of the thick Dorado crude oil tests 12 and 13. The drop size plots are not as easily interpreted due to the scattered nature of the continuous data set. It is more instructive to review the drop size statistics that are presented in Table 5-2. The oil drop size data collected for each experiment have been analyzed to determine 1) the average VMD drop size, and 2) the volume percent of the oil present in the form of oil drops less than 70 microns in diameter (see Table 5-2) in those time periods when the measured concentration of oil was at least 2 times higher than the tank background oil concentration at the start of the test. The VMD oil drop size for the untreated slicks were higher than for the dispersant applied by spray runs with the exception of the Neptune and Dorado thick oil tests. The volumes of oil present in the water column in the form of drops less than 70 microns in diameter were also higher in the dispersant applied tests when compared to the untreated slicks with the same exceptions. The measured drop size data support the final DE estimates for the dispersant applied versus control tests reported in Table 5-1 and Table 5-2 with the exception of the thick slick Neptune tests 7 and 9. In this test pair the spray test oil drop sizes were as large or larger than the control test but the percentage of oil dispersed in the spray test was measurably higher than the control run. In the thick oil Dorado tests the drop sizes were larger in the spray tests and the final dispersed oil percentage was somewhat lower than the control test, as would be expected based on the drop size data.

Table 5-2 In-Water Oil Characterization and Graph Hypertext Links

Oil	Actual Dispersant Application Rate (gal/acre)	Oil Thickness (mm)	DOR	Links to Oil Drop Size / Concentration Graphs	Test #	Oil Drop Size (Average D50) (microns)	Volume % < 70 microns	Ave. Elevated Oil Conc. by LISST (ppm)	Peak Oil Conc. (ppm)	% Dispersed /Lost
BHP Neptune	Control	1	0	Figure 9-1	1	159	34	8	29	43
BHP Neptune	6.1	1	1:350	Figure 9-2	2	84	49	5	45	64
BHP Neptune	Control	4	0	Figure 9-8	9	135	29	4	46	3
BHP Neptune	7.6	4	1:460	Figure 9-7	7	165	26	21	122	25
Anadarko	Control	1	0	Figure 9-3	3	158	28	11	68	50
Anadarko	6.6	1	1:170	Figure 9-4	4	123	39	14	91	60
Anadarko	Control	4	0	Figure 9-5	5	149	26	10	108	38
Anadarko	6.6	4	1:550	Figure 9-6	6	137	32	25	97	69
Dorado	Control	1	0	Figure 9-9	10	168	27	73	358	33
Dorado	5.4	1	1:190	Figure 9-10	11	73	54	8	93	68
Dorado	Control	4	0	Figure 9-11	12	160	24	15	100	32
Dorado	6.9	4	1:410	Figure 9-12	13	167	24	43	130	25

6 Results Discussion

With one exception, the tests where low doses of dispersant were applied resulted in more dispersed oil than in the control tests. The effectiveness of the dispersant ranged from 10% to 35% even though the dispersant to oil ratios (DOR) ranged from only 1:170 to 1:550. However, none of the measured dispersant effectiveness values were high considering that the oils tested were relatively light and amenable to chemical dispersant use. For example, in previous tests at Ohmsett the same Neptune and Anadarko oils were found to be 89% & 95^{+}% dispersible by Corexit 9500 when applied at dose rates of 1:40 and 1:30, respectively (SL Ross 2011). The 5 US gallon/acre application limit often imposed in aircraft application operations would appear to not supply sufficient dispersant to achieve maximum dispersion of thicker patches of oil (1 mm and greater) that may exist in larger oil spills.

It is possible that the enclosed nature and short duration of the wave-basin test negatively biases the final dispersant effectiveness outcome. Researchers have demonstrated that surfactant contaminated water reduces the spreading of chemically treated oils thus keeping them artificially thick when compared to treated oils in an open ocean setting (Nedwed et. al. 2011). This elevated oil thickness may result in reduced dispersion due to the need for more mixing energy to generate small oil droplets. Based on this hypothesis the final DE estimates from these low dose basin tests could possibly be under-estimating the ultimate effectiveness of the low dose applications when used in a field setting.

It is recommended that regulators consider approving dispersant application rates higher than standard aircraft rates of 5 gallons/acre when thick oil is present. This may necessitate multiple passes by aircraft or use of vessel based application systems that are capable of delivering higher doses in a single pass. Test tank studies at Ohmsett have shown that multiple dose dispersant application can be as effective as applying the same amount of dispersant in a single application (SL Ross 2009).

7 References

ASTM F 1413 – 07. Standard Guide for Oil Spill Dispersant Application Equipment: Boom and Nozzle Systems.

Fieldhouse, B., A. Khelifa, N. Singh, T.S. Tong, B. Hollebone, C. Yang, and M. Landriault. Validation of the Two Models Developed to Predict the Window of Opportunity for Dispersant Use in the Gulf of Mexico. Task 3(a) – Oil properties of 10 New Oils. Report to Mineral Management Service, April 2010. MMS Project No. 0010004128.

International Tanker Owners Pollution Federation (ITOPF). 1982. Aerial Application of Oil Spill Dispersants. Technical Information Paper No. 3, London, International Tanker Owners Pollution Federation, 8 pp.

ITOPF: Use of Dispersants to Treat Oil Spills, Technical Information Paper 4 http://www.itopf.com/information-services/publications/documents/TIP4UseofDispersantstoTreatOilSpills.pdf

Nedwed, T., T. Coolbaugh, G. Canevari, J. Clark, A. Tidwell, E. Owens, 2011. Calm Seas Dispersant Use. Proceedings of the 2011 International Oil Spill Conference. API. 2011.

SL Ross. 2000a. Feasibility of Using Ohmsett for Dispersant Testing. Report to the MAR Inc., Atlantic Highlands, NJ. March, 2000.

SL Ross. 2000b. Ohmsett Dispersant Test Protocol Development. Report to the U.S. MMS, September, 2000.

SL Ross. 2002a. Dispersant Effectiveness Testing in Cold Water at Ohmsett. Report to U.S. Minerals Management Service, August 2002.

SL Ross. 2002b. Effectiveness Testing of Dispersants in Cold Water and Broken Ice at Ohmsett. Report to ExxonMobil Upstream Reseach Ltd. August 2002.

SL Ross. 2003a. Cold-Water Dispersant Effectiveness Testing on Five Alaskan Oils at Ohmsett. Report to U.S. Minerals Management Service, August 2003.

SL Ross. 2003b. Research into Techniques to Remove Dissolved Dispersant from Ohmsett Basin Water. Report to U.S. Minerals Management Service, July 2003.

SL Ross. 2004. Correlating the Results of Dispersant Effectiveness Tests Performed at Ohmsett with Identical Tests Performed At Sea. Report to U.S. Minerals Management Service, 2004.

SL Ross. 2006. Dispersant Effectiveness Testing On Viscous, U.S. Outer Continental Shelf Crude Oils. Report to U.S. Minerals Management Service, 2006.

SL Ross. 2008. Dispersant Effectiveness Testing On Viscous, U.S. Outer Continental Shelf Crude Oils: Phase II. Report to U.S. Minerals Management Service, 2008.

SL Ross. 2009. Low-Dose Repeat-Application Dispersant Testing. Report to U.S. Minerals Management Service, 2009.

SL Ross. 2010. Comparison of Large-Scale (Ohmsett) and Small-Scale Dispersant Effectiveness Test Results. Draft Report to U.S. Minerals Management Service, March 2010.

SL Ross. 2011. Comparison of Large-Scale (Ohmsett) and Small-Scale Dispersant Effectiveness Test Results. Report for Bureau of Ocean Energy Management, Regulation and Enforcement, U.S. Department of the Interior. June 2011.

US Coast Guard, 2013. Guidelines for the U.S. Coast Guard Oil Spill Removal Organization Classification Program.

8 Appendix A. Test Oil Evaporation-Density Curves

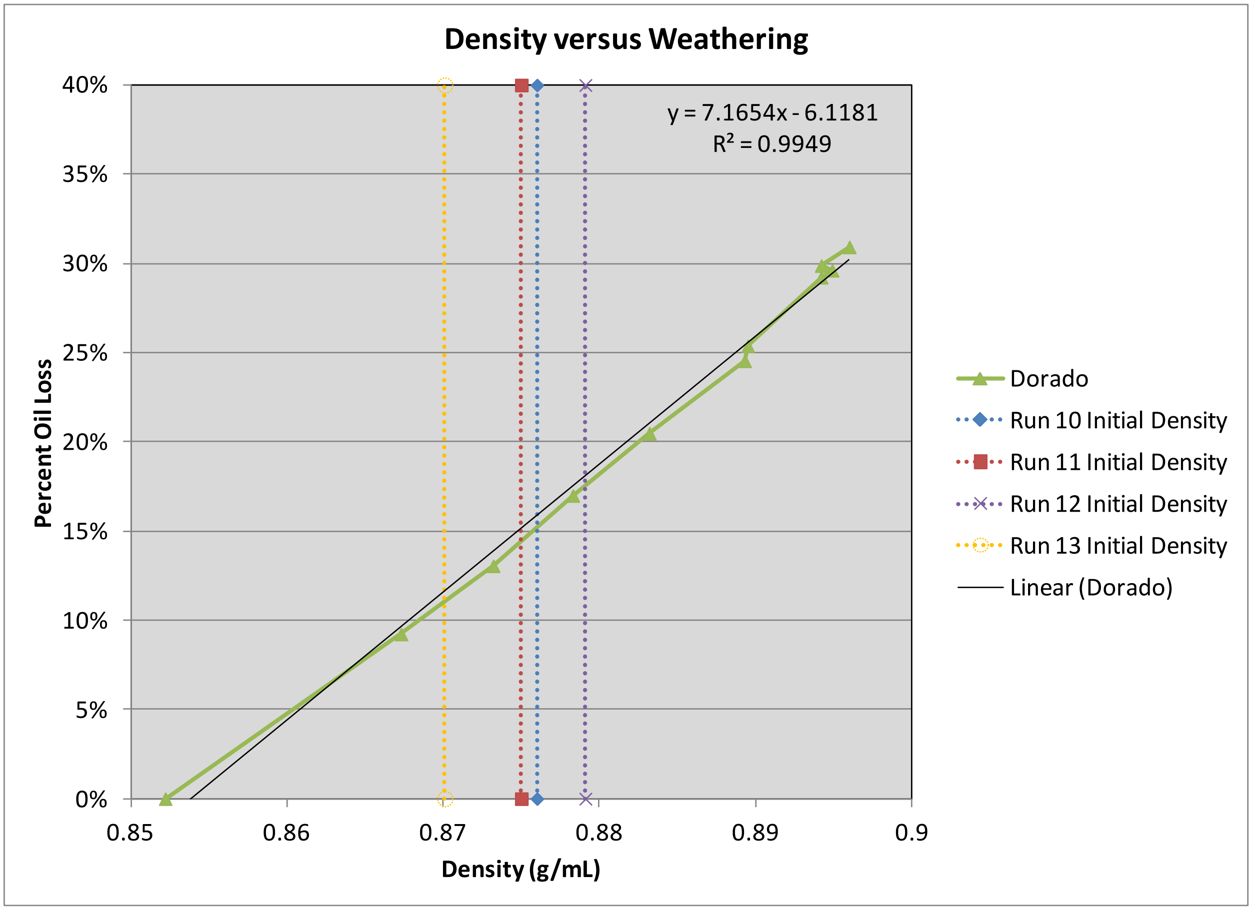

Figure 8-1 Dorado Crude Oil Density versus Volume Percent Evaporated

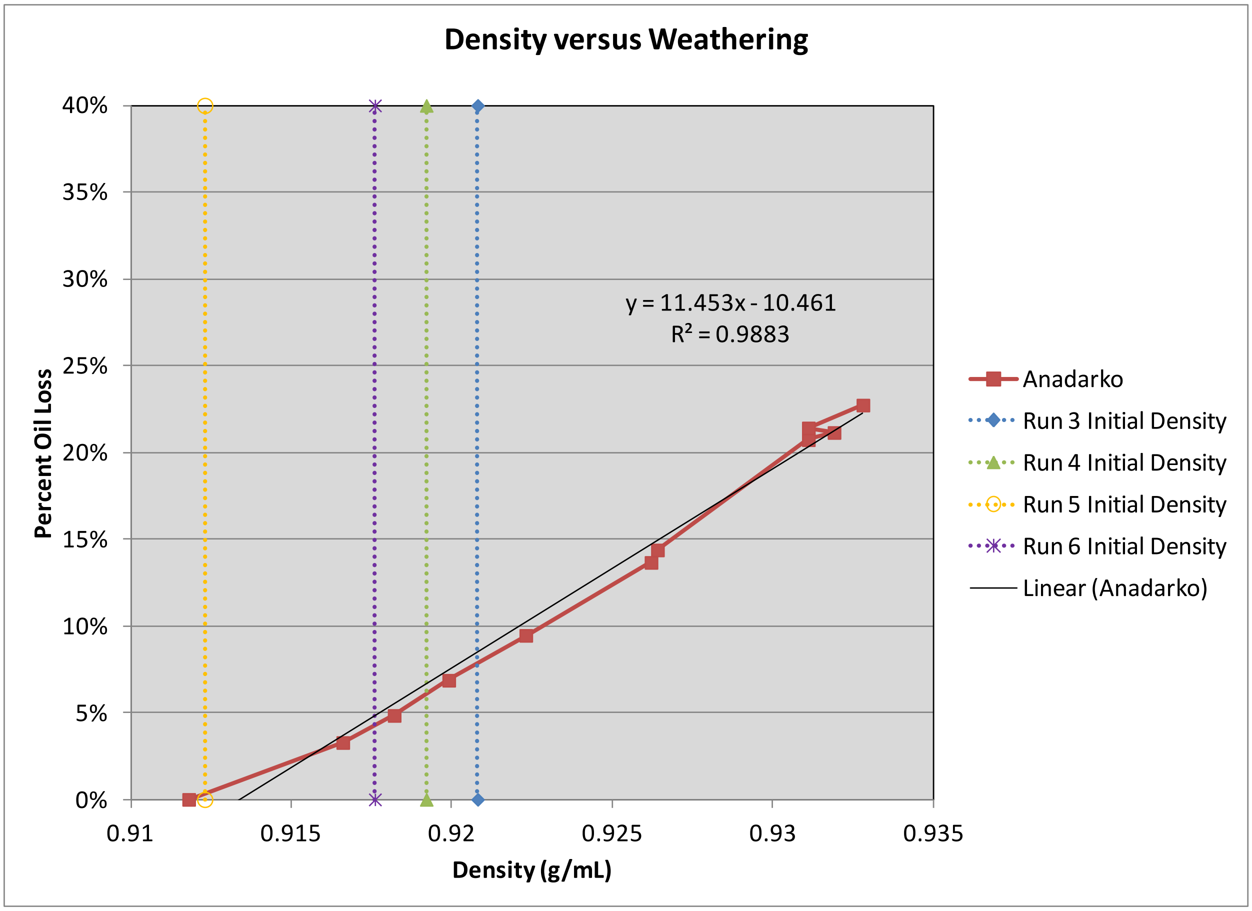

Figure 8-2 Anadarko Crude Oil Density versus Volume Percent Evaporated

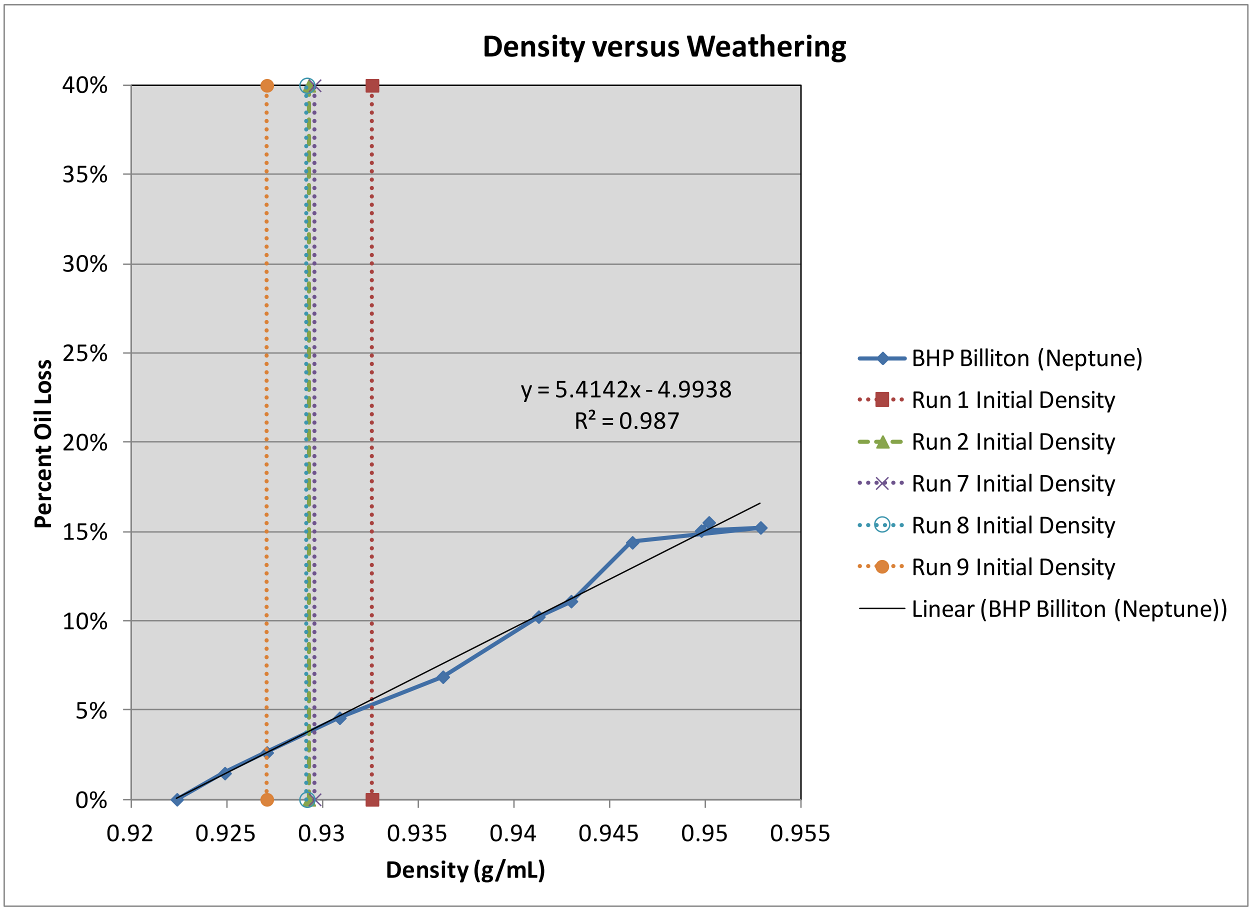

Figure 8-3 BHP Neptune Crude Oil Density versus Volume Percent Evaporated

Table 8-1 Collected Oil Densities After De-watering

Test Number	Oil Type, Thickness, Control or Spray Test	Collected Oil Density after De-watering (g/cc)
1	Neptune 1mm C	0.966
2	Neptune 1mm spray	0.9651
3	Anadarko 1mm C	0.944
4	Anadarko 1mm spray	0.9443
5	Anadarko 4mm C	0.927
6	Anadarko 4mm spray	0.9268
7	Neptune 4mm spray	0.953
9	NEPTUNE 4mm C	0.9461
10	Dorado 1mm C	0.904
11	Dorado 1mm spray	0.9
12	Dorado 4mm C	0.9
13	Dorado 4mm spray	0.894

9 Appendix B. Oil Drop Size Distributions

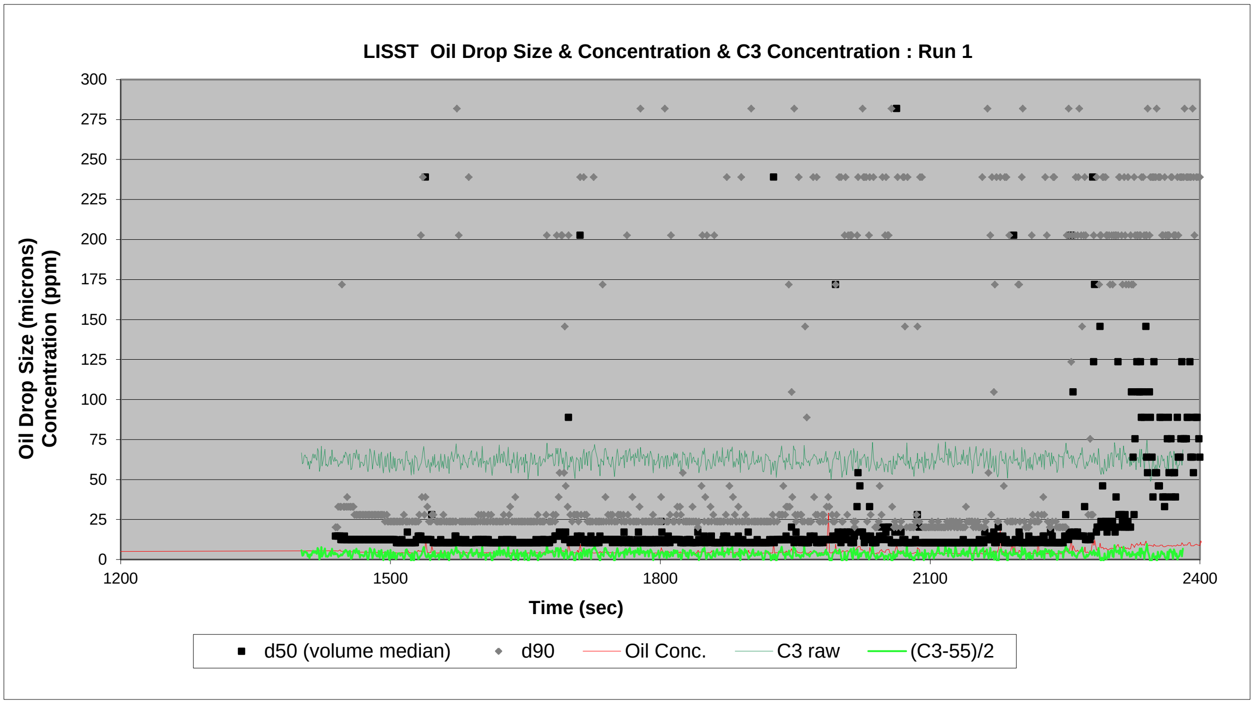

Figure 9-1 Test 1. Neptune Crude Oil, 1 mm Thickness, Control

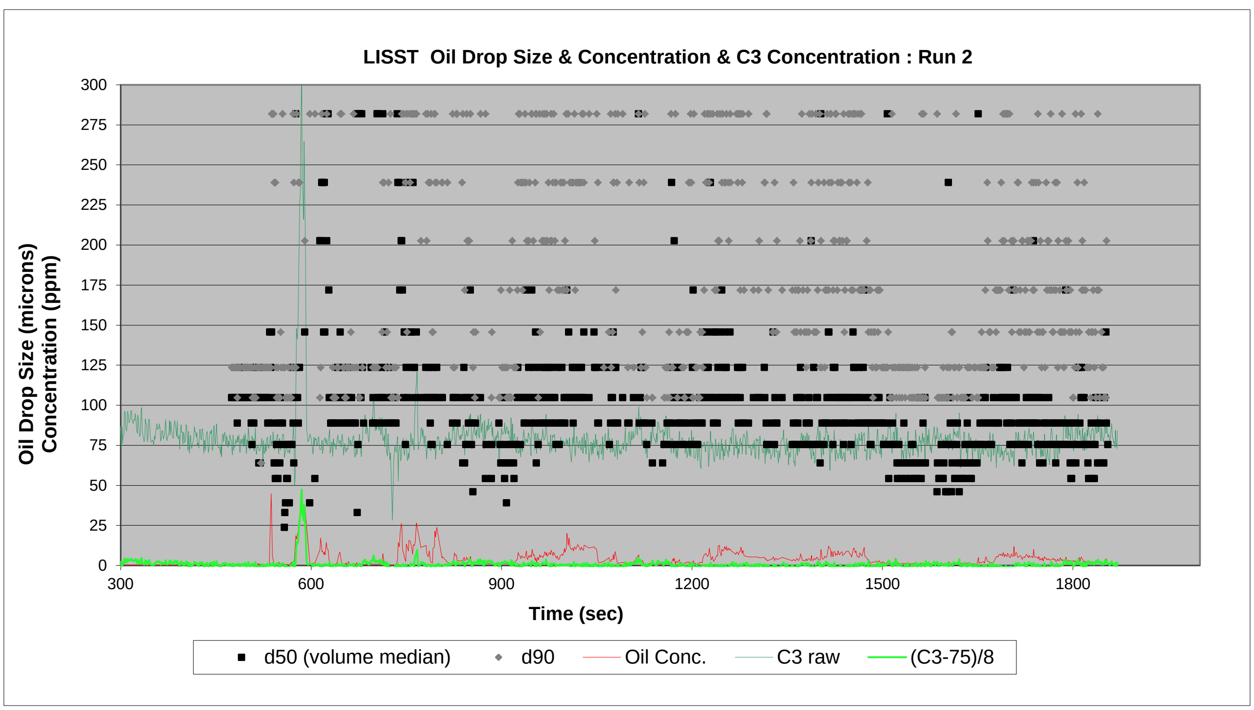

Figure 9-2 Test 2, Neptune Crude Oil, 1mm Thickness, Corexit 9500

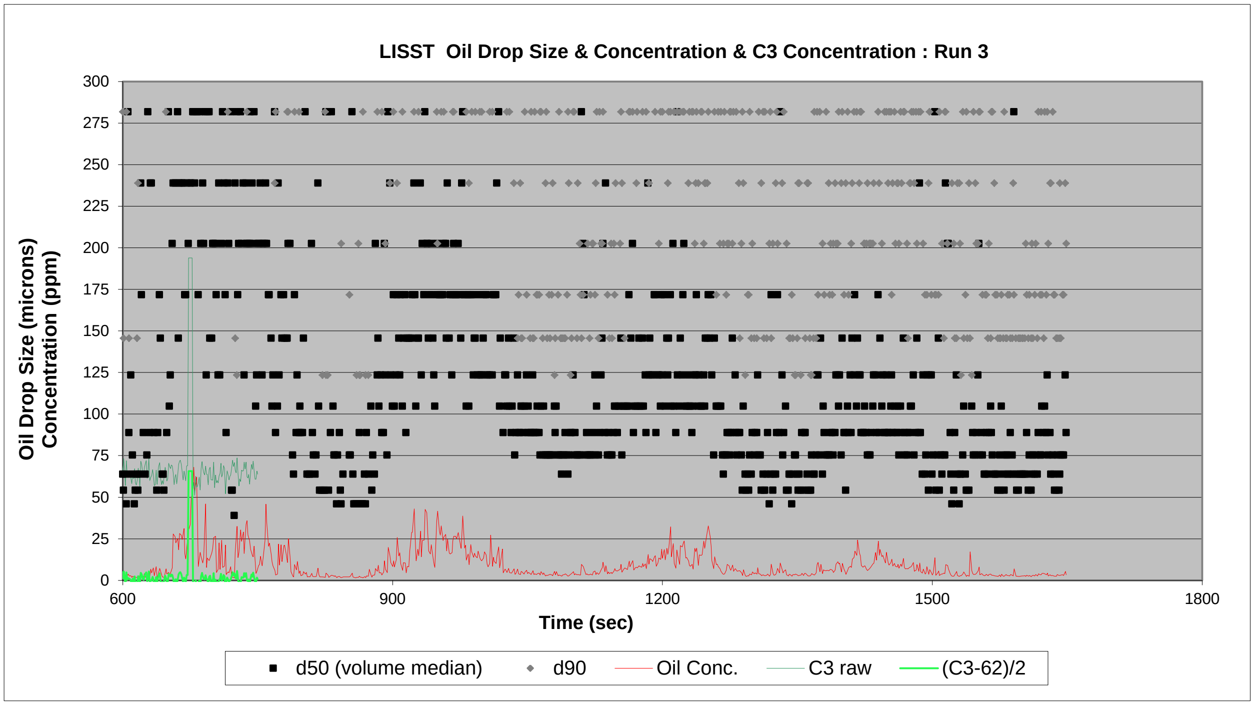

Figure 9-3 Test 3, Anadarko Crude, 1 mm Thickness, Control

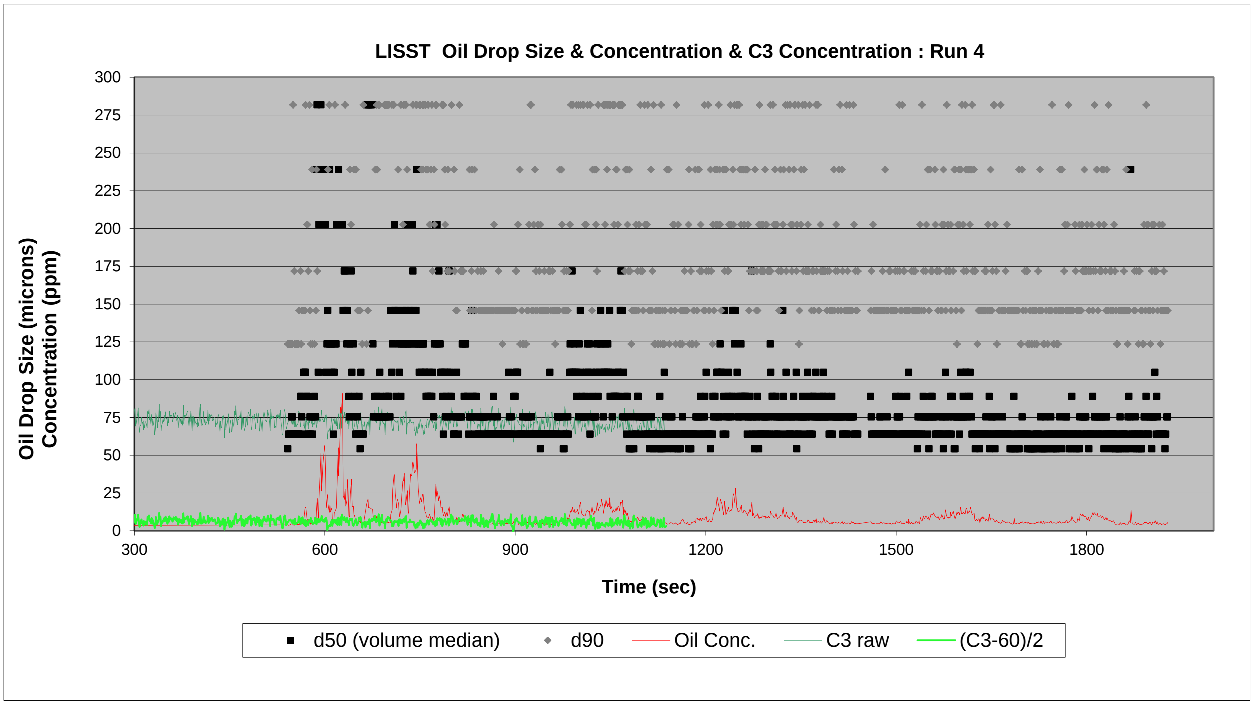

Figure 9-4 Test 4, Anadarko Crude, 1 mm Thickness, Corexit 9500

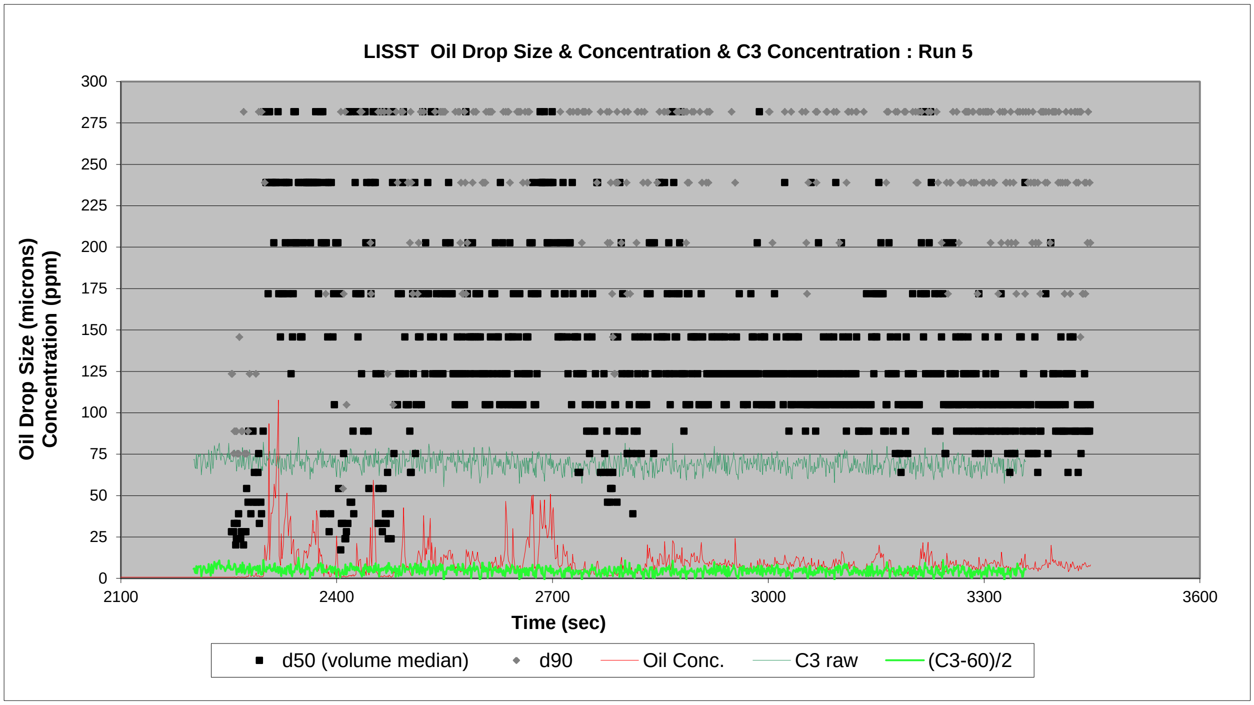

Figure 9-5 Test 5, Anadarko Crude, 4 mm Thickness, Control

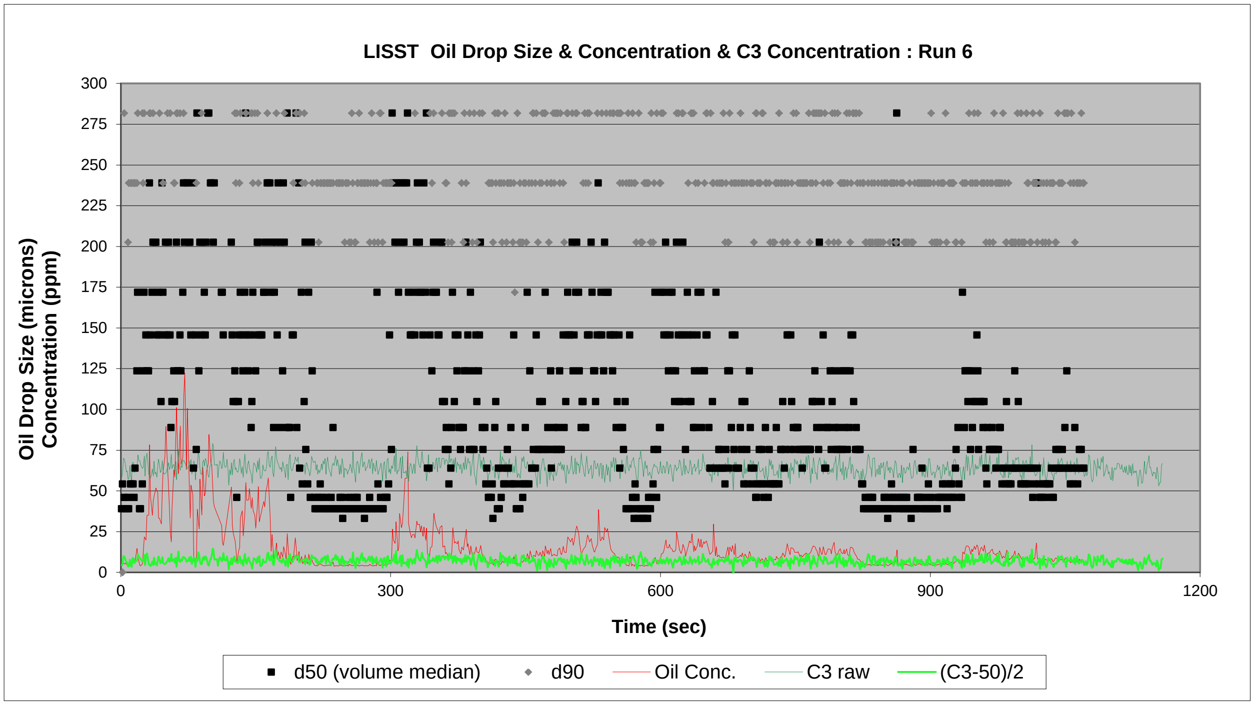

Figure 9-6 Test 6, Anadarko Crude, 4 mm Thickness, Corexit 9500

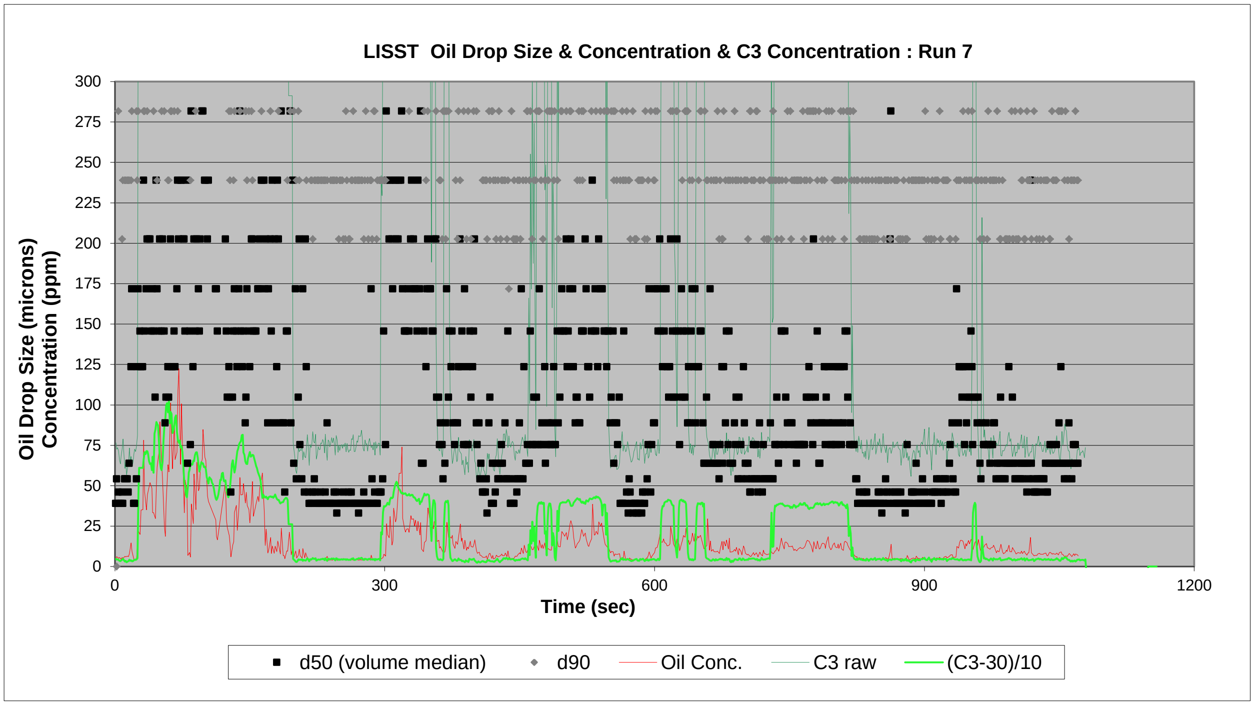

Figure 9-7 Test 7, Neptune Crude Oil, 4mm Thickness, Corexit 9500

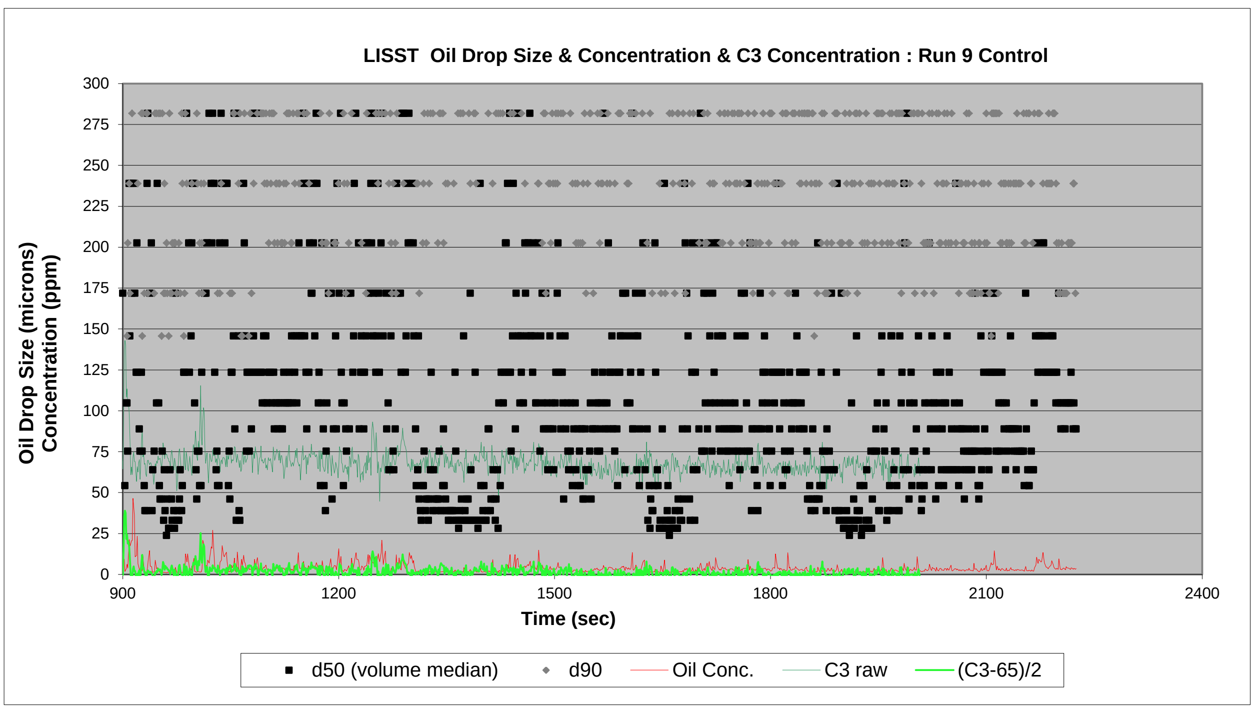

Figure 9-8 Test 9, Neptune Crude Oil, 4mm Thickness, Control

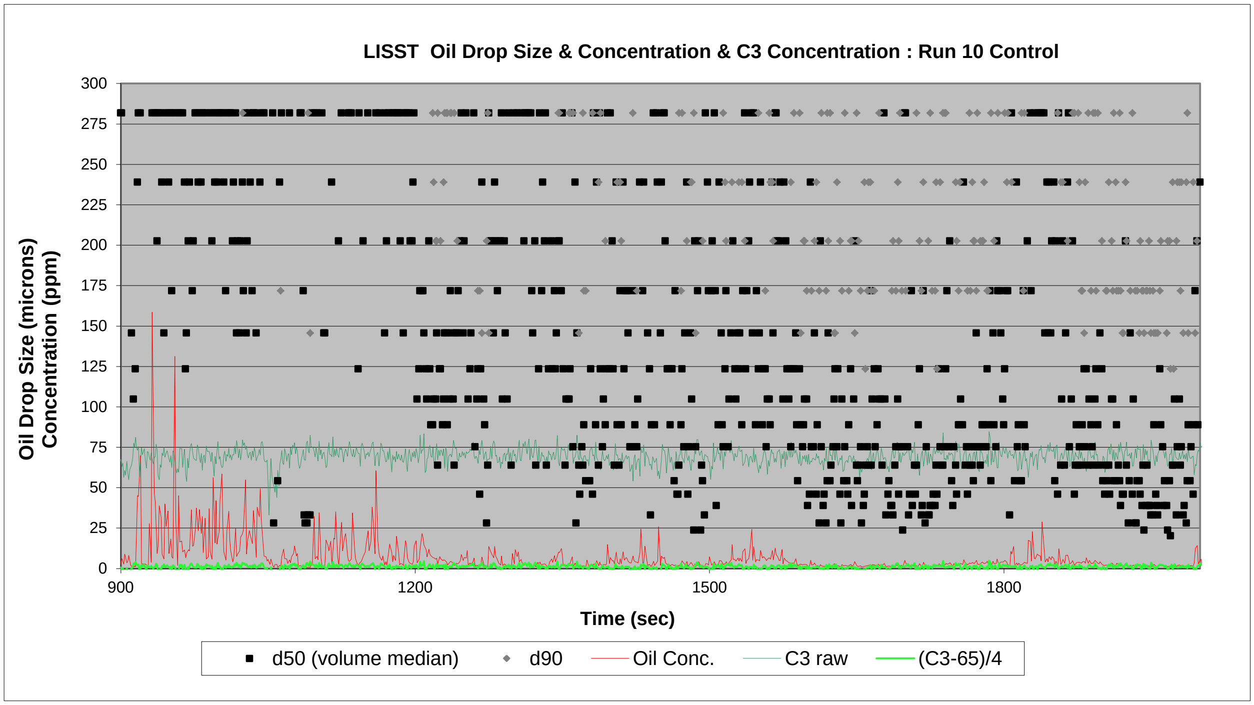

Figure 9-9 Test 10, Dorado Crude Oil, 1mm Thickness, Control

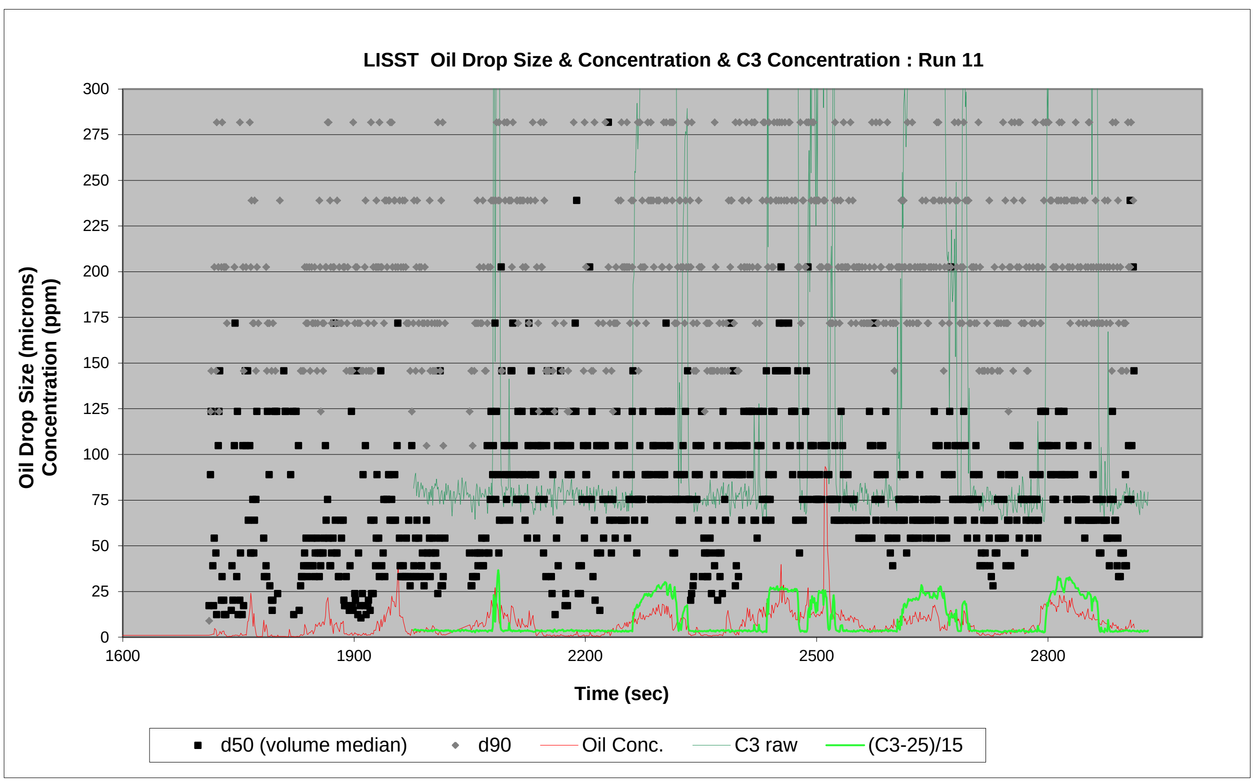

Figure 9-10 Test 11, Dorado Crude Oil, 1mm Thickness, Corexit 9500

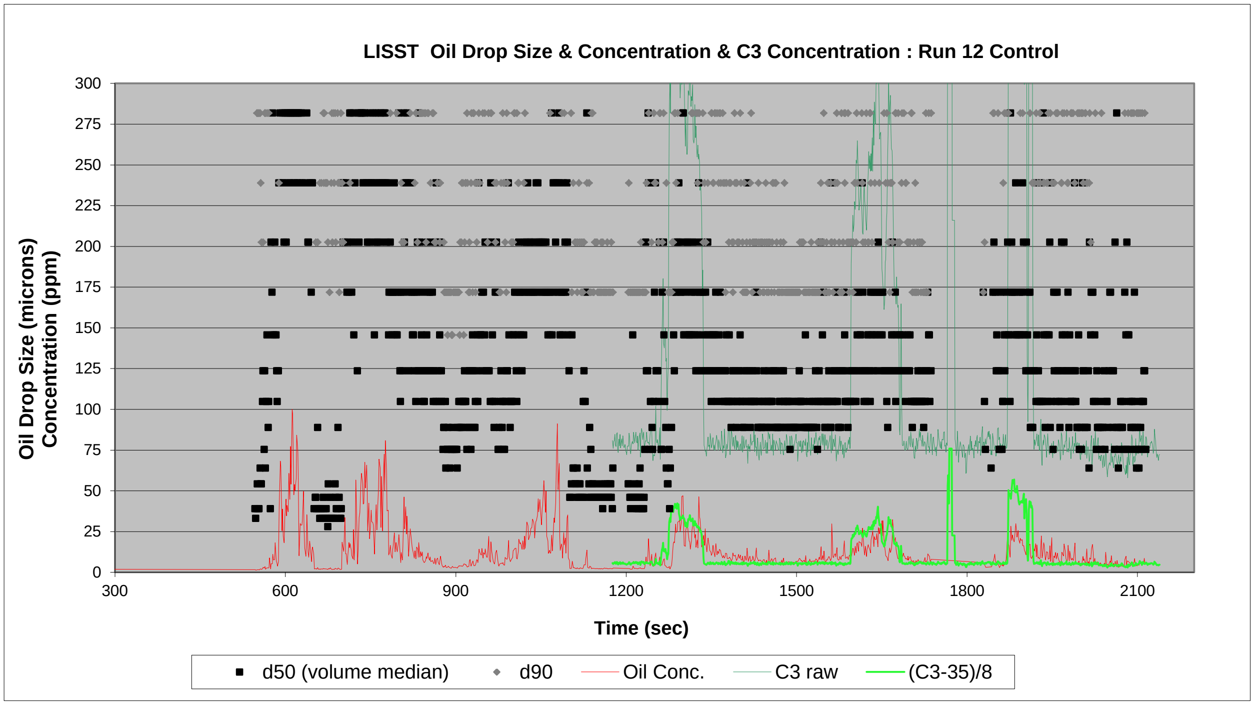

Figure 9-11 Test 12, Dorado Crude Oil, 4mm Thickness, Control

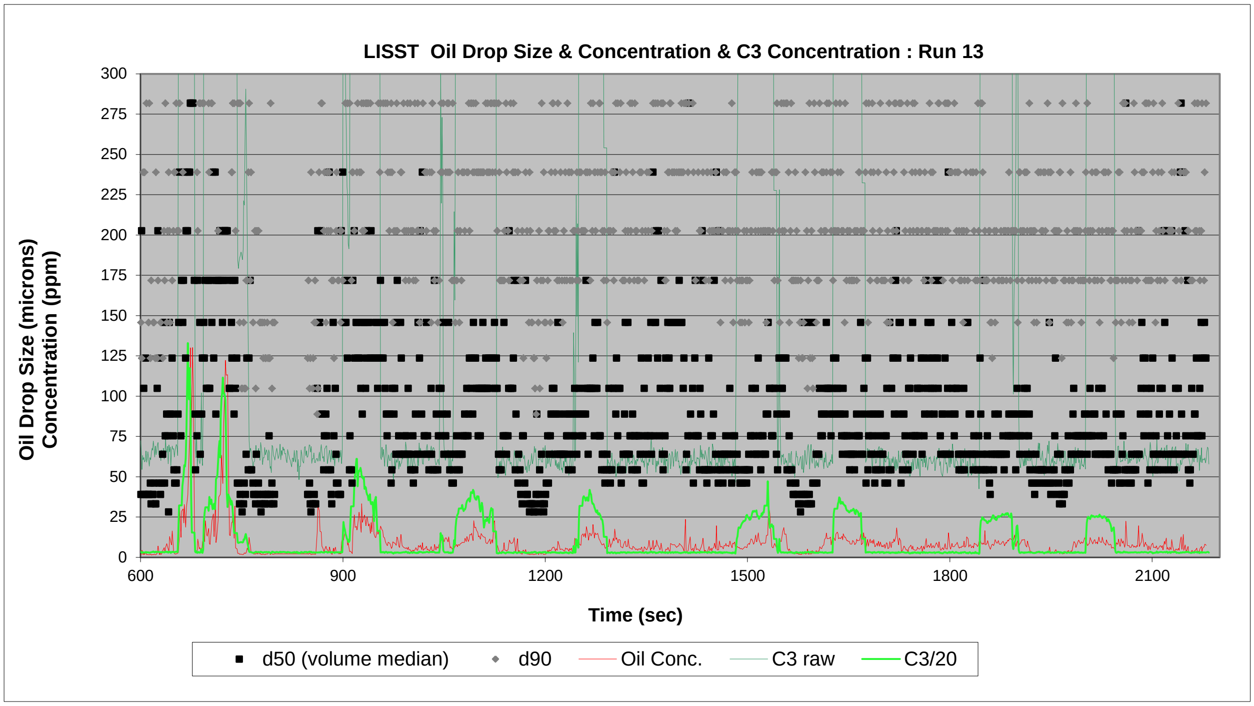

Figure 9-12 Test 13, Dorado Crude Oil, 4mm Thickness, Corexit 9500