

**Mar 16, 2005 - July 15, 2005**

**Final Report**

**ANALYSIS OF DISPERSANT EFFECTIVENESS OF HEAVY FUEL OILS AND  
WEATHERED CRUDE OILS AT TWO DIFFERENT TEMPERATURES USING  
THE BAFFLED FLASK**

**Contract No. 69-C-00-159  
Task Order #89**

Submitted to:

**Paul de Percin, Project Officer  
Albert D. Venosa, EPA Task Order Manager  
National Risk Management Research Laboratory  
U.S. Environmental Protection Agency**

Submitted by:

**Makram T. Suidan, Project Manager  
George A. Sorial, Task Order Leader**

**Department of Civil and Environmental Engineering  
University of Cincinnati**

## **Abstract**

In the last few years, dispersants have been widely used as the primary response measure for marine oil spills around the world. Until recently, the U.S. Environmental Protection Agency (EPA) protocol for testing the effectiveness of dispersants in the laboratory was the Swirling Flask Test (SFT), which was found to give widely varying results in the hands of different testing laboratories. As a result, EPA developed an improved laboratory dispersant testing protocol, called the Baffled Flask Test (BFT). This protocol uses two crude oils (South Louisiana and Prudhoe Bay) at one temperature, 20°C. Recent interest in the dispersability of heavy refined oils such as IFO 180 and IFO 380 at different temperatures has emerged. SFT tests were conducted at the University of Cincinnati on these two oils with Corexit 9500 as the dispersant. The test gave very poor results, dispersant effectiveness being less than 10% at a dispersant-to-oil ratio (DOR) of 1:10, mixing speed of 200 rpm, and a temperature of 16±1 °C. Under the same conditions the Baffled Flask Test (BFT) showed good dispersant effectiveness on both fuel oils. It was deemed that further tests with SFT would be fruitless. Further evaluations using the BFT to determine the effectiveness of three commercially available dispersants, Corexit 9500 (C9500), Super Dispersant 25 (SD25), and Agma on IFO 180 and IFO 380 oils were conducted. This report describes experiments to study the effect of different variables such as DOR, mixing speed, and temperature on dispersant effectiveness of these heavy oil products.

## **Introduction**

Rapid increase in the demand for petroleum has resulted in a greater potential for oil spills resulting from transportation and consumption of these products. Marine oil spills can have disastrous consequences on the local environment. Among the different cleanup methods available, use of dispersants is growing in popularity as an effective countermeasure. Evidence from spills treated with dispersants shows that dispersion of oil can reduce overall environmental impacts by reducing exposure to water fowl at the sea surface and shoreline. At the same time dispersant use for cleanup of an oil slick on the water may also reduce intrusiveness, duration, and cost of the cleanup.

Dispersants are mainly mixtures of surfactants and other chemicals, and when applied to the oil slick, they cause the dispersion of small oil droplets into the water column (Chandrasekar *et. al.*, 2005). Dispersant effectiveness is a measure of the amount of oil that has been dispersed into the water column compared to the amount that remains on the surface. Numerous factors influence the effectiveness of dispersants, such as amount of dispersant added, temperature, type of surfactants, weathering of the oil, physical properties of the oil, mixing energy, and salinity. The amount of dispersant added is one of the important factors influencing dispersion. In most cases, dispersant effectiveness is directly proportional to the amount of dispersant added. The mixing energy provided by the sea also determines how much dispersion takes place. A rough sea imparts significant energy to promote the mixing of the oil and the dispersant and, hence, results in good dispersion. The physical and chemical properties of the oil also affect its dispersability. Oil undergoes weathering when it is spilled, resulting in an increase in its viscosity, and the higher viscosity in turn reduces dispersability. Lower

water temperature may also have a similar effect on dispersion. The energy requirement for the mixing of the oil and the dispersant increases to account for the increase in the viscosity. Lab-, pilot-, and field-scale research is currently focused on methods to optimize the effectiveness of dispersants.

The Baffled Flask Test (BFT) is being proposed by EPA as the replacement protocol for listing chemical dispersant products on the National Contingency Plan (NCP) Product Schedule. The reason is that research conducted in 2000-2002 demonstrated that the SFT was inadequate as a protocol for testing dispersant effectiveness due to its poor reproducibility and repeatability (Sorial *et al.*, 2004; Sorial *et al.*, 2004; Venosa *et al.*, 2002). The primary reasons for the lack of reproducibility were the inadequate mixing regime within the swirling flask and the substantial human error associated with the conduct of the test. In a related subsequent study, Kaku *et al.* (2004) measured the turbulence in the swirling and the baffled flasks at two different mixing speeds using a hot wire anemometer and found that the energy dissipation rate in the BF was more than 2 orders of magnitude greater than that in the SF. This mixing energy was shown to be more in line with published measurements of sea states conducive to good dispersion (Delvigne and Sweeney, 1988). This study reports the use of the BFT as the primary testing approach to evaluate commercial dispersants under a variety of environmental conditions. Three commercial dispersants (C9500, SD25, and Agma) were tested on heavy refined oils, IFO 180 and IFO 380. The BFT experiments were carried out at three different dispersant-to-oil ratios (DORs), 1:25, 1:50, and 1:100, and at three different mixing speeds, 150, 200, and 250 rpm. This enabled determination of dispersion effectiveness at different mixing energies providing conditions that might mimic low,

intermediate, and high energy sea states and at DORs that might exist when a field trial is attempted. Also, not much has been published on dispersant effectiveness under cold climate conditions, especially with heavier oils. Thus, two temperatures were selected to study temperature effects on dispersant effectiveness, 5 °C and 16 °C. This study aimed to provide a database needed for evaluating commercial dispersants under a variety of environmental conditions.

## **Materials and methods**

### *Flasks*

Modified 150 mL glass baffled trypsinizing flasks with screw caps at the top and Teflon stopcocks placed near the bottom were used in all the experiments (see Figure 1). An orbital shaker (Lab-Line Instruments Inc, Melrose Park, IL) with a variable speed control unit (40-400 rpm) and an orbital diameter of 0.75 inches (2 cm) was used to provide turbulence in the test flasks. The shaker was equipped with a control speed dial to provide an rpm reading on the instrument. The accuracy was found to vary  $\pm 10\%$ . A Brinkmann Eppendorf repeater pipettor (Fisher Scientific, Pittsburgh, PA) capable of dispensing 4  $\mu\text{L}$  of dispersant and 100  $\mu\text{L}$  of oil with an accuracy of 0.3% and a precision of 0.25% was used with 100- $\mu\text{L}$  and 5-mL syringe tip attachments. Glassware consisting of graduated cylinders, 125-mL separatory funnels with Teflon stopcocks, pipettes, 50-mL crimp style amber glass vials, and 50-, 100-, and 1000- $\mu\text{L}$  gas-tight syringes were also used.



**Figure 1. Baffled Flask Test Apparatus**

*Analytical Instruments*

A UV mini-1240 UV-VIS Spectrophotometer (UV-VIS spec) (Shimadzu Scientific Instruments, Inc, Wood Dale, IL) capable of measuring absorbance at 340, 370, and 400 nm was used in all the experiments to measure dispersed oil concentration after extraction.

*Reagents*

The synthetic sea water “Instant Ocean” (Aquarium Systems, Mentor, OH) was used for all the experiments at a concentration (salinity) of 34 ppt, based on an ion

composition shown in Table 1. The properties of the two oil types used in the study are listed in Table 2.

**Table 1. Major Ion Composition of “Instant Ocean” Synthetic Sea Salt**

<b>Major Ion</b>	<b>% Total Weight</b>	<b>Ionic Concentration at 34 ppt salinity, mg/L</b>
Chloride	47.5	18,700
Sodium	26.3	10,400
Sulfate	6.6	2,600
Magnesium	3.2	1,200
Calcium	1.0	400
Potassium	1.0	400
Bicarbonate	0.5	200
Boron	0.015	6
Strontium	0.001	8
Solids Total	86.1	34,000
Water	13.9	
<b>Total</b>	<b>100.0</b>	

<b>Table 2. Properties of the test oils.</b>		
<b>Analyte</b>	<b>IFO 180</b>	<b>IFO 380</b>
Specific gravity at 15 °C	0.983 °C <sup>1</sup>	0.990 °C <sup>1</sup>
API Gravity	12.5 <sup>o1</sup>	11.5 <sup>o1</sup>
Sulfur	2 wgt.% <sup>2</sup>	3-4 wgt.% <sup>2</sup>
Nitrogen	--	--
Vanadium	85 mg/L <sup>2</sup>	100-600 mg/L <sup>3</sup>
Nickel	--	--
Pour Point	4.4-15.6 °C <sup>1</sup>	4.4-15.6 °C <sup>1</sup>
Viscosity at 50 °C	170 cST <sup>2</sup>	380 cST <sup>2</sup>
Viscosity at 100 °C	20 cST <sup>2</sup>	35 cST <sup>4</sup>
Source:		
<sup>1</sup> <a href="http://www.amsa.gov.au/Marine_Environment_Protection/National_Plan/General_Information/Dispersants_Information/Oil-Sea_Temperature_Dispersability_Matrix.asp">http://www.amsa.gov.au/Marine_Environment_Protection/National_Plan/General_Information/Dispersants_Information/Oil-Sea_Temperature_Dispersability_Matrix.asp</a>		
<sup>2</sup> <a href="http://www.emo.ie/bunkering/product_specs/Emo-PS-IFO-180.pdf">http://www.emo.ie/bunkering/product_specs/Emo-PS-IFO-180.pdf</a>		
<sup>3</sup> <a href="http://www.emis.platts.com/thezone/guides/platts/oil/productspecs.html">http://www.emis.platts.com/thezone/guides/platts/oil/productspecs.html</a>		
<sup>4</sup> <a href="http://www.socp.org/projects/completedproj/BunkerFuelOil/images/sample78.doc">http://www.socp.org/projects/completedproj/BunkerFuelOil/images/sample78.doc</a>		



### *Oil standard procedure*

Standard solutions of oil for calibrating the UV-VIS spectrophotometer were prepared with a mixture of the specific reference oils and dispersant used for a particular set of experimental test runs. For control treatments with no dispersant, only oil was used to make the standard solution. Initially, oil alone stock standard was prepared. The density of 2 mL of the specific reference oil with 18 mL DCM added was measured by using a 1-mL gas tight syringe, and the concentration of the oil solution was then determined. Specific volumes of 11, 20, 50, 75, 100, and 125  $\mu\text{L}$  of IFO 180-DCM stock or the IFO 380-DCM stock were added to 30 mL of synthetic seawater in a separatory funnel and extracted three times with 5 mL of DCM. The final DCM volume for the combined extracts was adjusted to 20 mL with DCM. The extracts were transferred to a 20-mL crimp style glass vial with a Teflon/aluminum seal, mixed by inverting many times, and stored in a refrigerator at  $4 \pm 2$  °C until the time of analysis. For oil plus dispersant stock standard, 80  $\mu\text{L}$  of a given dispersant was added to 2 mL of the specific reference oil (resulting in a DOR of 1:25) followed by 18 mL DCM, and the density was measured using a 1 mL gas tight syringe. For a DOR of 1:50, 40  $\mu\text{L}$  of the dispersant was added to 2 ml of the oil, and for a DOR of 1:100, 20  $\mu\text{L}$  of the dispersant was added to 2 ml of the oil following the same procedure. Based on the amount of oil and dispersant added, and the density measured, the concentration of the stock solution was calculated.

### *Dispersant effectiveness procedure*

All experimental samples were conducted in a temperature controlled room at the desired temperature ( $16 \pm 1$  °C or  $5 \pm 2$  °C). For each sample, four replicates were prepared. A volume of 120 mL of synthetic sea water equilibrated at the desired

temperature was added to the test flask (Figure 1), followed by the sequential addition of oil and finally the dispersant. A volume of 100  $\mu\text{L}$  of oil was dispensed directly onto the surface of the synthetic sea water using an Eppendorf repeater pipettor with a 5 mL syringe tip attachment. The dispersant was then dispensed onto the center of the oil slick by using a 100  $\mu\text{L}$  syringe tip attachment that was set to dispense 4  $\mu\text{L}$ . For DORs other than 1:25, the amount of dispersant added was varied appropriately, keeping the amount of oil added fixed. The flask was placed on an orbital shaker and mixed for 10 minutes at the desired rotation speed, at the end of which it was removed from the shaker and allowed to remain stationary on the bench top for another 10 minutes. At the end of the settling time, the first 2 mL of sample was drained from the stopcock and discarded, and then 30 mL of sample was collected in a 50 mL measuring cylinder. The 30 mL sample was then transferred to a 125 mL separatory funnel and extracted three times with 5 mL fresh DCM. The extract was then adjusted to a final volume of 20 mL and transferred to a 20 mL crimp style glass vial with a Teflon/aluminum seal. These vials were stored at  $4 \pm 2$  °C until the time of analysis (maximum of 5 days). The oil standards procedure and test procedures were conducted according to the procedures given by Sorial et al. (2004).

Dispersant effectiveness is defined as the concentration of the dispersed oil in water (which is determined through extraction by DCM as stated above) divided by the total concentration of oil, i.e., based on the total volume of oil added.

### *Sample analysis*

The experimental sample extracts and the standard solutions prepared were removed from the refrigerator and allowed to equilibrate at the laboratory temperature. First, a blank solution (DCM) was introduced. Then the standard solutions were

introduced in the order of increasing concentration, and the absorbance values were noted at wavelengths of 340, 370, and 400 nm. After this, the experimental samples were introduced. For samples that exceeded the highest calibration standard point, dilution was done. The sequence of analyses is thus: (1) solvent blank; (2) six calibration standards for the specific test oil plus dispersant, and (3) experimental samples.

### *Calculation procedure*

The area under the absorbance vs. wavelength curve for the experimental samples between wavelengths 340 and 400 nm was calculated by using the trapezoidal rule according to the following equation:

$$Area = \frac{(Abs_{340} + Abs_{370}) * 30}{2} + \frac{(Abs_{370} + Abs_{400}) * 30}{2} \quad (1)$$

The dispersant effectiveness (i.e., percent of oil dispersed) based on the ratio of oil dispersed in the test system to the total oil added to the system was determined by:

$$Eff \% = \frac{\text{Total oil Dispersed}}{\rho_{oil} * V_{oil}} * 100 \quad (2)$$

where

$\Delta_{oil}$  = density of the specific test oil, g/L,

$V_{oil}$  = Volume (L) of oil added to the test flask ( $100 \mu\text{L} = 10^{-4} \text{ L}$ ).

$$\text{Total oil dispersed, g} = \text{Mass of oil} * \left( \frac{V_{tw}}{V_{ew}} \right) \quad (3)$$

where

$V_{tw}$  = total water volume in the testing flask (120 mL),

$V_{ew}$  = volume of water extracted for dispersed oil content (30 mL).

$$\text{Mass of oil, g} = \text{Concentration of oil} * V_{DCM} \quad (4)$$

where

$$\text{Concentration of oil, g/l} = \left( \frac{\text{Area as determined by equation 1}}{\text{slope of calibration curve}} \right) \quad (5)$$

where,  $V_{DCM}$  = the final volume of the DCM-extract of water sample (0.020 L).

The data were entered into a spreadsheet and all the necessary calculations were performed. The data are attached in the form of tables in Appendix 1.

## **Results and Discussion**

The results for the BFT tests run on the two oils, IFO 180 and IFO 380, are shown in Figures 2 through 5. The three variables studied were DOR, mixing speed, and temperature. For the dispersants, C9500 and SD25, the effectiveness using BFT was studied at three DORs, namely 1:25, 1:50, and 1:100. The effectiveness of Agma was studied at only one DOR, 1:25. The BFT experiments were run at two different temperatures to determine the utility of the dispersants at different sea temperatures. The four figures show the percent effectiveness of the three dispersants at different DORs, mixing speeds and temperatures.

Figure 2 represents dispersant effectiveness for IFO 180 at  $5 \pm 2$  °C. At this temperature, percent dispersant effectiveness increased steadily with DOR and mixing speed. For both C9500 and SD25, there was a good distinction among the different DORs and mixing speeds. The increase in the dispersant effectiveness at 250 rpm is much more

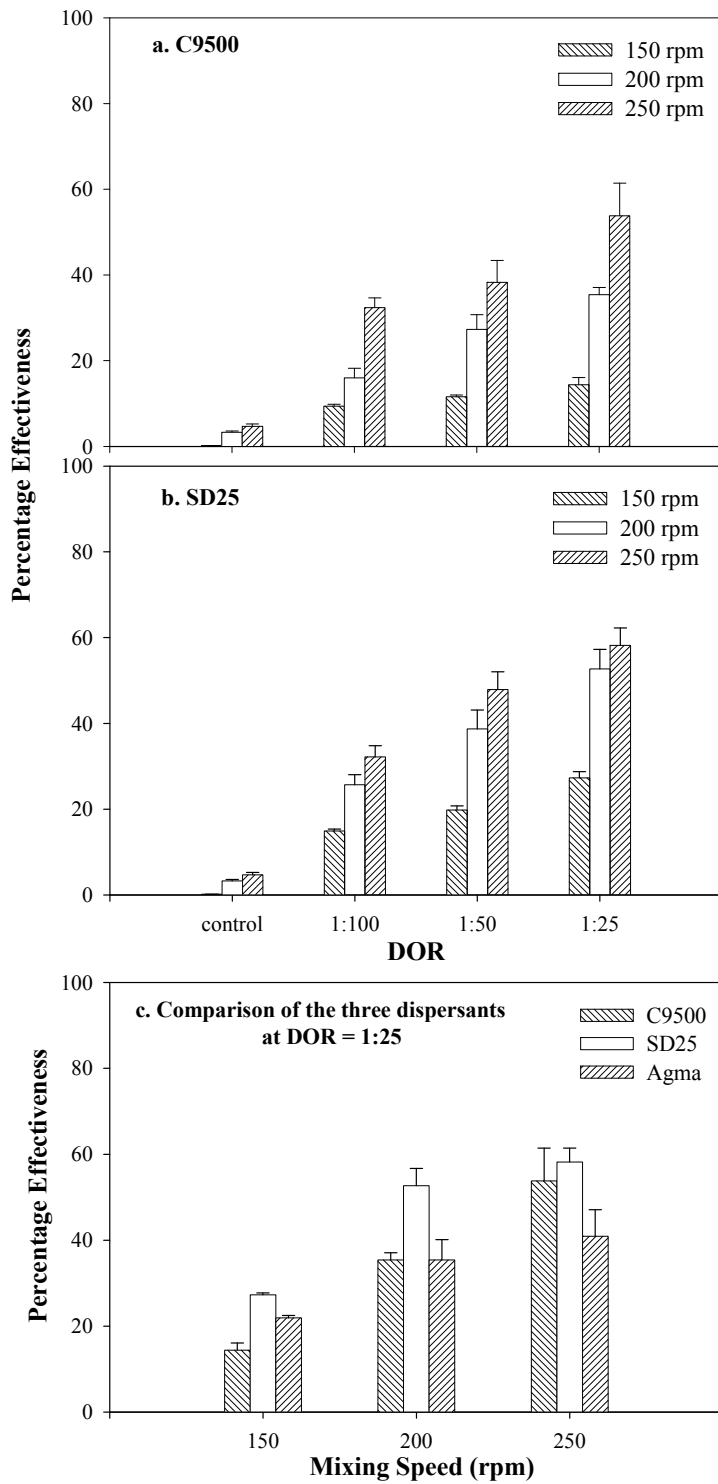
pronounced than at 150 rpm as DOR increased from 1:100 to 1:25. Figures 2a and 2b show that SD25 performed better than C9500 at all DORs and mixing speeds. Figure 2c compares Agma with the other two dispersants at a DOR of 1:25. Although the effectiveness with Agma is comparable to C9500 at the lower mixing speeds, it is much lower at 250 rpm.

Figure 3 represents dispersant effectiveness for IFO 180 at  $16 \pm 1^\circ\text{C}$ . The increase in dispersant effectiveness with increase in DOR is pronounced. However, little distinction exists between performance at mixing speeds of 200 and 250 rpm, especially at higher DORs. The effectiveness of C9500 and SD25 at 200 and 250 rpm is similar. At a DOR of 1:100, a clear difference in dispersant effectiveness is evident at the three mixing speeds. The overall performance of C9500 at this temperature appears to be slightly better than SD25. Effectiveness of Agma (Figure 3c) is lower than the other two dispersants at 150 and 200 rpm but is comparable at 250 rpm.

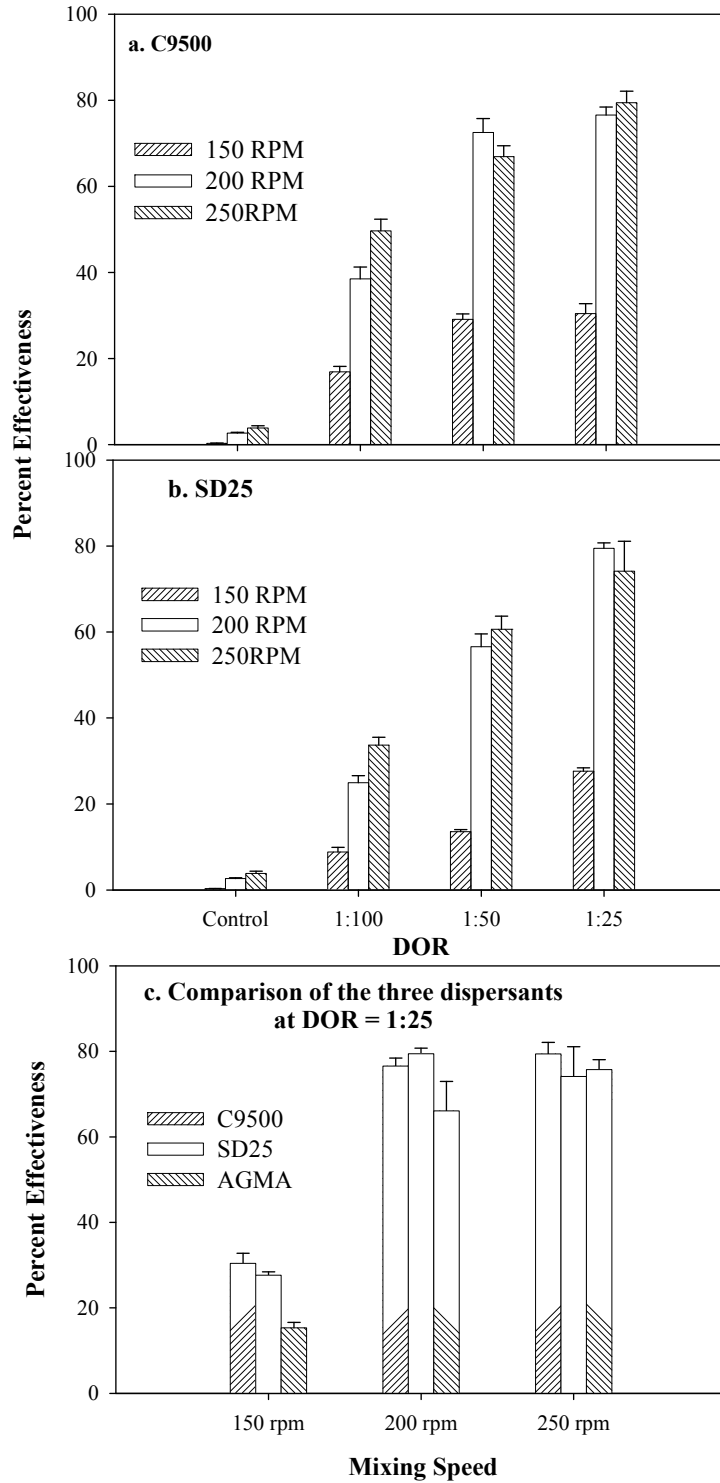
Figure 4 represents dispersant effectiveness for IFO 380 at  $5 \pm 2^\circ\text{C}$ . At this temperature, the percent dispersant effectiveness increased steadily with DORs and mixing speeds, as in the case with IFO 180. For both C9500 and SD25, there was a good distinction between the different DORs and mixing speeds. The overall trend was similar to IFO 180 at the same temperature. However, in the case of the heavier IFO, Figure 4a and 4b show that C9500 performed better than SD25. Figure 4c shows that Agma's performance is comparable to the other two dispersants at a DOR of 1:25.

Figure 5 summarizes effectiveness of the dispersants for IFO 380 at  $16 \pm 1^\circ\text{C}$ . For C9500, the dispersant effectiveness increased with increase in DOR and mixing speed. However at a DOR of 1:25, the dispersant effectiveness at 200 rpm and 250 rpm is

almost the same. Also for the 150 rpm mixing speed, there is not much difference in the dispersant effectiveness when the DOR is increased from 1:50 to 1:25. However, the impact of DOR is more pronounced for SD25, as seen in Figure 5b. C9500 seems to perform marginally better than SD25, except at the DOR-mixing speed combination of 1:25 and 250 rpm. At the DOR of 1:25, Agma has slightly lower effectiveness when compared to C9500 and SD25 at 150 and 200 rpm but is higher at 250 rpm (see Figure 5c).

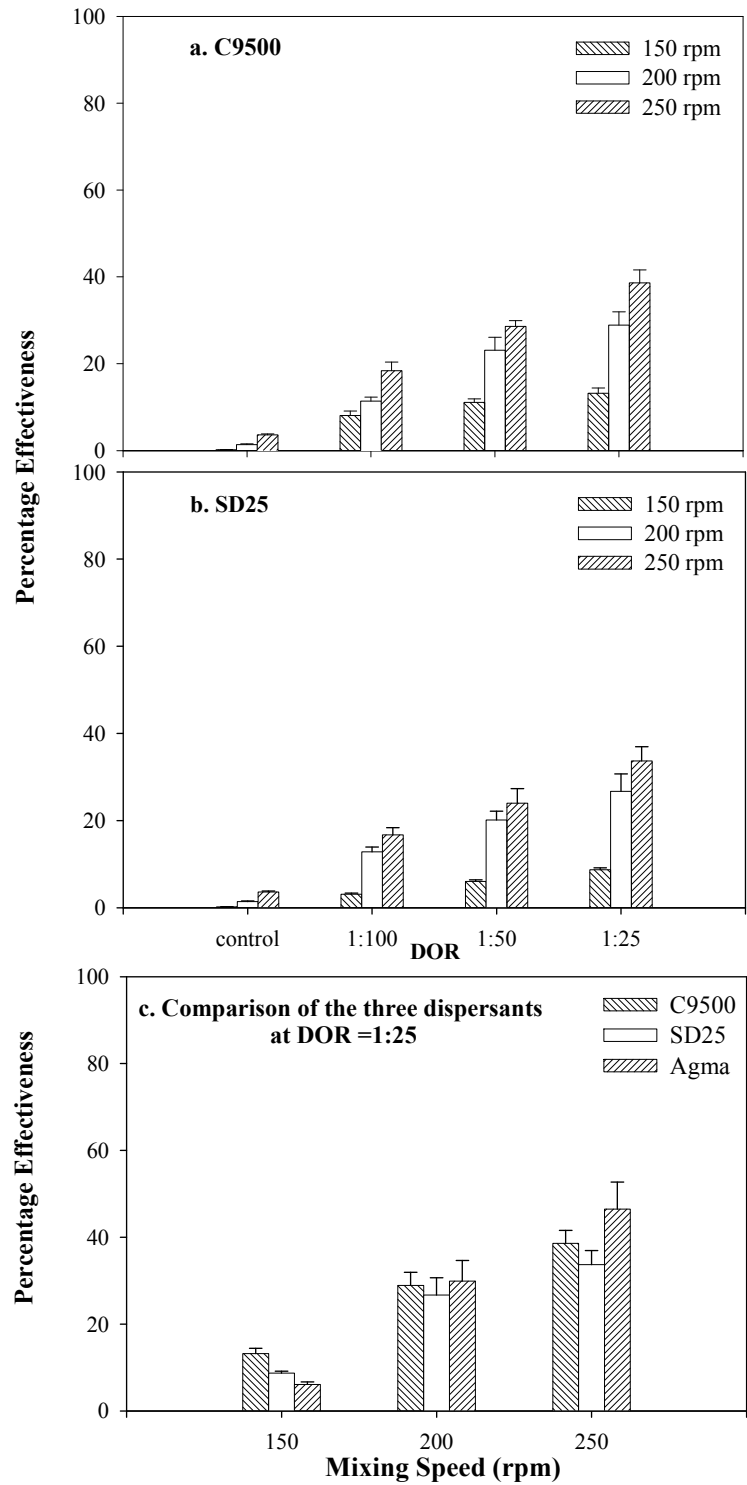


**Figure 2. Dispersant Effectiveness for IFO 180 at 5±2°C**

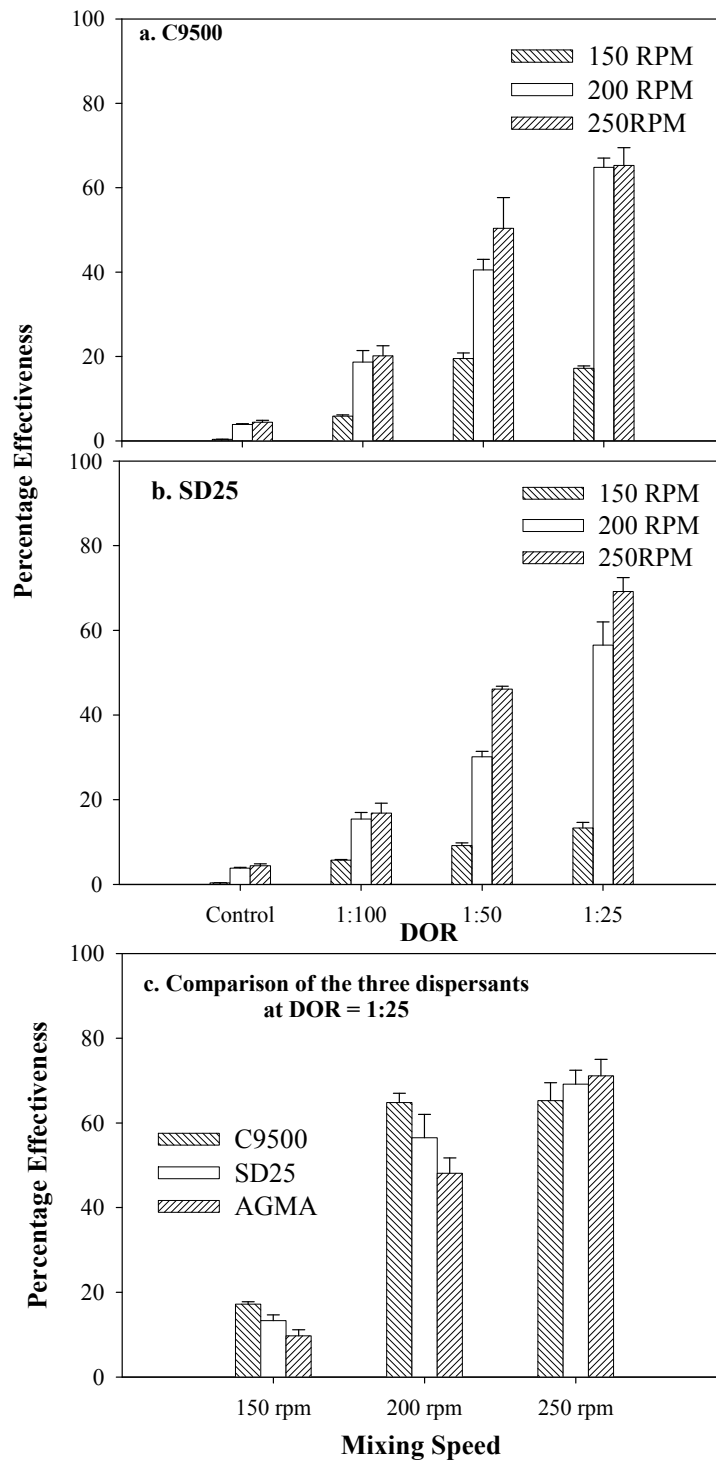


**Figure 3. Dispersant Effectiveness for IFO 180 at 16±1°C**





**Figure 4. Dispersant Effectiveness for IFO 380 at 5±2°C**



**Figure 5. Dispersant Effectiveness for IFO 380 at 16±1°C**

## Conclusion

From the results obtained, we concluded that the dispersant effectiveness for all three dispersants increased with increases in mixing speeds and DORs. For both IFO 180 and IFO 380 at both temperatures, the increase in dispersant effectiveness was more pronounced with the increase in DORs than with the mixing speeds. When the DOR was increased from 1:100 to 1:50 while keeping the mixing speed constant, the dispersant effectiveness doubled in most cases. However, when the DOR was doubled again from 1:50 to 1:25, dispersion effectiveness increased by only about 50%. The DOR is clearly an important factor influencing dispersant effectiveness.

Mixing had a more pronounced effect at lower DORs. In almost all cases, when the DOR was 1:100, dispersant effectiveness increased significantly when the mixing speed was increased from 150 to 200 rpm and less so from 200 to 250 rpm. However, at higher DORs of 1:50 and 1:25, dispersion effectiveness increased significantly when the mixing speed was increased from 150 to 200 rpm, but little increase occurred at 250 rpm. This effect is clearly seen for IFO 180 at 16°C, where in some cases, the dispersant effectiveness at 200 rpm was found to be higher than at 250 rpm. It would be reasonable to say that the effect of mixing speeds was more pronounced at the lower DOR of 1:100.

Temperature was the other important factor covered in this study. As expected, both oils showed better dispersion at the higher temperature. For IFO 180, with all three dispersants, there was a 20% difference between the effectiveness at the two temperatures. This effect was even more significant for IFO 380, in which case, the dispersant effectiveness almost doubled with the increase in temperature. Overall, the higher viscosity IFO 380 was less susceptible to dispersion compared to IFO 180.

## References

1. Devlign, G. A. L, and Sweeney, C. E. (1988). "Natural dispersion of oil." *Oil and Chemical Pollution*, 4, pp. 281-310.
2. Kaku, V.J., M.C. Boufadel, and A.D. Venosa. 2004. "Evaluation of mixing energy in laboratory flasks used for dispersant effectiveness testing." *J. Environmental Eng. ASCE*, in press
3. Sorial, G.A., A.D. Venosa, K.M. Koran, E. Holder, D.W. King. 2004. "Oil spill dispersant effectiveness protocol: I. impact of operational variables." *J. Environmental Eng. ASCE*, 130(10):1073-1084.
4. Sorial, G.A., A.D. Venosa, K.M. Koran, E. Holder, D.W. King. 2004. "Oil spill dispersant effectiveness protocol: II. performance of the revised protocol." *J. Environmental Eng. ASCE*, 130(10):1085-1093.
5. Venosa, A. D., King, D. W., and Sorial, G. A. (2002). "The Baffled Flask Test for Dispersant Effectiveness: A Round Robin Evaluation of Reproducibility and Repeatability." *Spill Sci. & Technol. Bulletin*, 7(5), pp. 299-308.
6. Chandrasekar, S., "Dispersant Effectiveness Data for a Suite of Environmental Conditions", MS Thesis, University of Cincinnati, 2004.
7. Chandrasekar, S., Sorial, G., A. and Weaver, J., W. (2005) "Dispersant Effectiveness on Three Oils under Various Simulated Environmental Conditions", *Environmental Engineering Science*, 22(3): 324-336.

Appendix 1.

**Table 1. Dispersant Effectiveness Test (Oil : IFO 180, Temperature = 5±2°C)**

Dispersant	DOR	Mixing Speed, rpm	% Effectiveness of the replicate samples				Average Effectiveness	Coeff. of variation
			R1	R2	R3	R4		
-	Control	150	0.15	0.14	0.18	0.13	0.15	14.713
		200	3.22	3.62	3.07	3.13	3.27	7.668
		250	4.82	3.88	4.89	5.13	4.68	11.766
C9500	1:25	150	13.33	14.46	16.69	12.99	14.37	11.637
		200	33.05	35.77	35.86	37.05	35.43	4.771
		250	49.46	60.34	60.23	45.24	53.82	14.235
	1:50	150	11.91	11.83	11.55	11.02	11.58	3.469
		200	22.21	28.11	29.13	29.76	27.3	12.685
		250	35.37	35.63	45.93	36.14	38.27	13.375
	1:100	150	10.09	9.48	9.48	9.00	9.52	4.673
		200	18.16	15.67	13.34	18.04	16.30	13.994
		250	34.39	34.38	29.56	33.38	32.93	6.978

**Table 1. Contd.**

Dispersant	DOR	Mixing Speed, rpm	% Effectiveness of the replicate samples				Average Effectiveness	Coeff. of variation
			R1	R2	R3	R4		
SD 25	1:25	150	29.22	25.7	26.91	27.18	27.25	5.36
		200	52.01	48.65	59.22	51.08	52.74	8.62
		250	60.47	56.51	53.31	62.36	58.16	6.96
	1:50	150	20.01	18.48	19.92	20.82	19.81	4.93
		200	37.38	44.49	33.92	39.1	38.72	11.39
		250	49.72	50.21	44.86	41.66	47.86	8.65
	1:100	150	14.59	14.67	15.55	14.81	14.9	2.96
		200	26.33	27.48	26.76	22.25	25.71	9.15
		250	29.91	35.04	30.12	33.83	32.22	8.07
Agma	1:25	150	24.76	24.28	18.73	19.68	21.86	14.17
		200	31.84	39.06	40.69	29.98	35.39	14.9
		250	44.43	41.05	39.97	38.3	40.94	6.32

**Table 2. Dispersant Effectiveness Test (Oil : IFO 180, Temperature = 16±1°C)**

Dispersant	DOR	Mixing Speed, rpm	% Effectiveness of the replicate samples				Average Effectiveness	Coeff. of variation
			R1	R2	R3	R4		
-	Control	150	0.31	0.37	0.29	0.27	0.31	13.96
		200	2.79	2.64	2.44	2.75	2.66	5.91
		250	4.03	4.05	3.10	4.24	3.86	13.28
C9500	1:25	150	30.51	28.15	33.62	29.39	30.42	7.70
		200	77.43	74.57	75.64	78.69	76.58	2.40
		250	80.68	75.60	81.70	79.64	79.41	3.37
	1:50	150	29.65	30.22	29.23	27.28	29.09	4.40
		200	69.86	69.81	76.52	73.77	72.49	4.51
		250	69.26	63.54	66.40	68.36	66.89	3.79
	1:100	150	17.45	18.16	15.19	16.78	16.90	7.51
		200	41.86	35.09	38.68	38.40	38.51	7.18
		250	49.39	53.37	49.07	46.88	49.68	5.45

**Table 2. Contd.**

Dispersant	DOR	Mixing Speed, rpm	% Effectiveness of the replicate samples				Average Effectiveness	Coeff. of variation
			R1	R2	R3	R4		
SD 25	1:25	150	28.16	26.81	28.42	27.14	27.63	2.81
		200	78.21	80.14	80.88	78.60	79.46	1.59
		250	77.43	76.37	78.97	63.87	74.16	9.36
	1:50	150	12.95	13.31	13.92	13.97	13.54	3.63
		200	55.14	53.80	56.86	60.63	56.61	5.23
		250	62.04	57.13	59.22	64.10	60.62	5.07
	1:100	150	10.16	8.56	7.62	9.03	8.84	11.95
		200	26.01	23.39	23.67	26.69	24.94	6.64
		250	31.63	33.70	33.38	36.05	33.69	5.40
Agma	1:25	150	16.22	15.03	16.42	13.71	15.35	8.16
		200	70.90	72.09	57.18	64.18	66.09	10.42
		250	72.88	77.59	74.94	77.68	75.77	3.06



**Table 3. Dispersant Effectiveness Test (Oil : IFO 380, Temperature = 5±2°C)**

Dispersant	DOR	Mixing Speed, rpm	% Effectiveness of the replicate samples				Average Effectiveness	Coeff. of variation
			R1	R2	R3	R4		
-	Control	150	0.17	0.18	0.18	0.23	0.19	14.53
		200	1.50	1.14	1.39	1.37	1.35	11.35
		250	3.52	3.84	3.40	3.80	3.64	5.81
C9500	1:25	150	12.63	15.09	12.58	12.67	13.24	9.29
		200	32.91	28.59	28.73	25.48	28.93	10.54
		250	42.42	36.06	39.66	36.43	38.64	7.75
	1:50	150	11.80	10.56	11.78	10.28	11.11	7.18
		200	20.80	20.58	26.78	24.13	23.08	12.81
		250	28.68	27.52	27.79	30.49	28.62	4.69
	1:100	150	7.17	9.50	7.53	8.26	8.12	12.65
		200	11.10	12.67	10.51	11.46	11.44	7.98
		250	17.92	19.40	15.93	20.45	18.43	10.64

**Table 3. Contd.**

Dispersant	DOR	Mixing Speed, rpm	% Effectiveness of the replicate samples				Average Effectiveness	Coeff. of variation
			R1	R2	R3	R4		
SD 25	1:100	150	3.21	3.14	3.28	2.75	3.09	7.67
		200	14.45	12.12	12.01	12.58	12.79	8.87
		250	18.71	14.83	16.07	17.35	16.74	9.96
	1:50	150	6.00	5.96	6.47	5.55	5.99	6.30
		200	21.62	17.98	18.02	22.06	20.12	10.06
		250	21.06	21.98	24.34	28.47	23.96	13.81
	1:25	150	9.31	8.75	8.46	8.30	8.70	5.10
		200	24.69	28.28	22.27	31.37	26.65	15.00
		250	37.39	30.93	35.33	30.95	33.65	9.63
Agma	1:25	150	5.74	5.72	5.95	6.94	6.09	9.47
		200	33.06	23.77	33.24	29.38	29.86	14.84
		250	45.05	53.47	48.73	38.71	46.49	13.39

**Table 4. Dispersant Effectiveness Test (Oil : IFO 380, Temperature = 16±1°C)**

Dispersant	DOR	Mixing Speed, rpm	% Effectiveness of the replicate samples				Average Effectiveness	Coeff. of variation
			R1	R2	R3	R4		
-	Control	150	0.42	0.40	0.35	0.33	0.37	12.04
		200	4.04	3.76	3.55	4.05	3.85	6.32
		250	5.05	3.98	4.40	4.18	4.40	10.62
C9500	1:25	150	16.38	17.48	17.77	17.07	17.17	3.51
		200	65.65	63.70	67.44	62.44	64.81	3.39
		250	65.47	69.92	65.98	59.69	65.27	6.46
	1:50	150	21.12	17.95	19.88	18.98	19.48	6.90
		200	39.35	37.53	42.77	42.35	40.50	6.18
		250	49.13	43.62	48.05	60.67	50.37	14.43
	1:100	150	5.67	6.15	6.03	5.59	5.86	4.65
		200	17.82	15.61	22.18	19.05	18.66	14.69
		250	22.13	19.00	22.12	17.38	20.16	11.74

**Table 4. Contd.**

Dispersant	DOR	Mixing Speed, rpm	% Effectiveness of the replicate samples				Average Effectiveness	Coeff. of variation
			R1	R2	R3	R4		
SD 25	1:25	150	11.45	13.36	13.66	14.74	13.30	10.30
		200	50.61	60.65	61.81	52.99	56.52	9.82
		250	72.54	70.20	64.72	69.23	69.17	4.74
	1:50	150	9.67	9.48	9.24	8.26	9.16	6.86
		200	30.17	31.91	29.37	29.04	30.12	4.26
		250	46.09	47.11	45.85	45.45	46.13	1.53
	1:100	150	5.76	5.48	5.74	5.93	5.73	3.20
		200	14.61	14.24	17.64	15.39	15.47	9.85
		250	20.15	16.07	14.73	16.39	16.83	13.81
Agma	1:25	150	11.15	10.10	7.79	9.91	9.74	14.46
		200	48.99	51.77	43.05	48.57	48.10	7.59
		250	69.63	76.39	71.27	67.18	71.12	5.48