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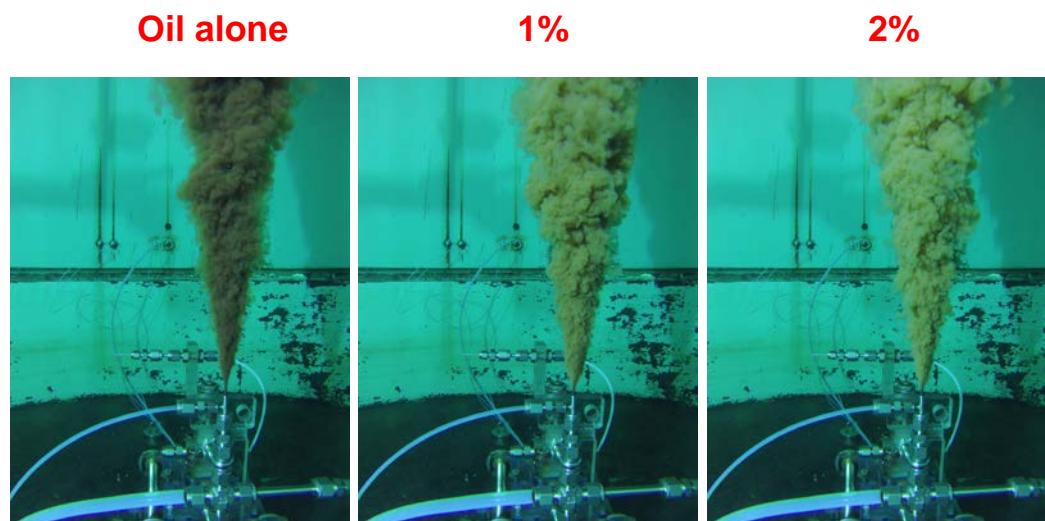
FINAL Report

Subsurface oil releases – Experimental study of droplet size distributions Phase-II

A scaled experimental approach using the SINTEF Tower basin

Authors

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Simulating subsurface releases in the SINTEF Tower basin with dispersant injection of Corexit C9500 and the waxy North Sea crude, Norne.

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ABSTRACT

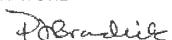
The main objectives with this study are to answer the following questions regarding dispersant injection during a subsea blowout:

1. How does the temperature of the released oil influence the droplet size distribution of the oil, both with and without injection of dispersants?
2. Does the presence of gas (air), released together with oil, influence the droplet size distribution of the oil, both with and without injection of dispersants?
3. How does dispersant effectiveness (measured by shift in droplet size distribution) vary as a function of oil properties (four different oil types), dispersant type (six different products) and dispersant dosage (six different dosages)?

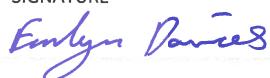
The main answers of these questions are found in Chapter 7, Conclusions and Chapter 8, Recommendations.

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APPENDICES

Appendix A: Summary overview of all Tower Basin experiments.

Appendix B: Experimental data: Numerical distributions of oil and oil/dispersant flow rates.

Appendix C: Droplet formation in turbulent flow.

1 Introduction

This is the second study performed by SINTEF for the American Petroleum Institute (API) on subsea releases of oil and gas and the effectiveness of dispersant injection. SINTEF performed the first study in 2012-13 and the main findings are reported in: "Sub-surface oil releases – Experimental study of droplet distributions and different dispersant injection techniques. A scaled experimental approach using the SINTEF Tower basin" (Brandvik et al., 2014). This study is referred to as "API D3 Phase-I".

This report covers the main findings from the second study and is referred to as "API D3 Phase-II" and was funded by contract 2012-106765 and has later been extended by an amendment (August 2013).

Phase-I mainly focused on more basic studies of droplet formation from subsea releases, effectiveness of dispersant injection and different injection techniques.

Phase-II followed up some of the findings from Phase-I and focused on the effect of different dispersants, oil types, release temperature of the oil, mixed releases and possible coalescence in the highly concentrated plume close to the release point.

2 Objectives

The main objectives with this study are to answer the following questions regarding dispersant injection during a subsea blowout:

1. How does the temperature of the released oil influence the droplet size distribution of the oil, both with and without injection of dispersants?
2. Does the presence of gas (air), released together with oil, influence the droplet size distribution of the oil, both with and without injection of dispersants?
3. How does dispersant effectiveness (measured by shift in droplet size distribution) vary as a function of oil properties (four different oil types), dispersant type (six different products) and dispersant dosage (six different dosages)?

3 Deliveries

The final report from this Phase-I will include at least the following sections:

1. Description of test tank, measurement methods, etc.
2. Summary of the experiment test matrix.
3. Summary of data analysis with special emphasis on effectiveness of the different dispersant injection techniques, Dispersant to oil ratio (DOR), dispersant type and the effect on oil droplet size distribution.
4. Discussion of scaling the results from the Tower basin dispersant injection testing to field scale including an assessment of the confidence limits of such an extrapolation.
5. Summary of further research needs and opportunities.

The main findings from this study will be published in a relevant peer reviewed scientific journal focusing on the effectiveness of the different dispersant injection techniques, the effect of dispersant dosage and different dispersant products and oil types.

4 Experimental

This section contains a description of the experimental methods and the experimental work performed in this project.

4.1 Selection of oil types

The experiments in Phase-I were performed with Oseberg blend, a crude oil with similar properties as the MC252 oil, a light paraffinic crude with high evaporative loss. We have studied different oil types that span out a large variation in possible properties. See Table 4.1 below for comparison of the four selected oil types we have used in this study. The data are from earlier weathering studies at SINTEF.

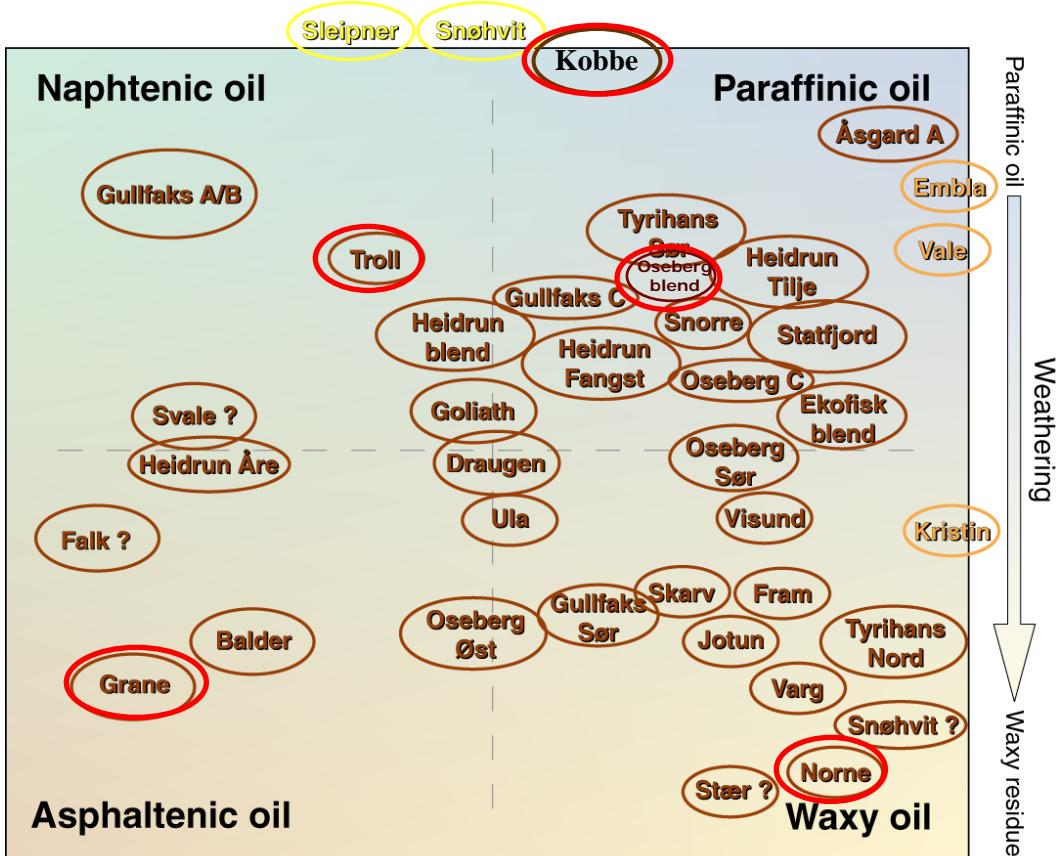


Figure 4.1: An illustration of different crude oil properties, based on weathering studies performed at SINTEF.

Table 4.1: Oil properties for oil types used in this study.

	Oseberg blend 2012-0347	Grane 2006-1060	Kobbe 2006-1061	Norne Blend 2007-0260	Troll B 2007-0287
Specific gravity (kg/l)	0.832	0.941	0.797	0.860	0.900
Pour Point (°C)	-6	-24	-36	21	-36
Viscosity (mPas 13°C, Shear rate 100 s ⁻¹)	44	640	22	89	20
Asphaltene (wt%)	0.3	1.4	0.03	0.3	0.09
Waxes (wt%)	3.2	3.2	3.4	4.2	0.95
150°C – Evap loss (vol%)	22	3	34	9	7.2
200°C – Evap loss (vol%)	34	5	43	18	13.5
250°C – Evap loss (vol%)	45	13	54	28	25.5

The crude oils indicated in the figure above have been chosen from four different crude oil categories. These four oils represent a broad selection of oil types and should be representative for a large number of oils worldwide.

- Paraffinic crude oil (e.g. Oseberg): Rich in paraffins and saturated components.
- Waxy crude oil (e.g. Norne): Rich in waxes (higher saturated components > C₂₀), high pour point.
- Naphthenic crude oil (e.g. Troll): Biodegraded, rich in saturated cyclic components, branched alkanes and often aromatic components.
- Asphaltenic crude oil (e.g. Grane): Rich in polar resins and asphaltenes, high density (or low API gravity).
- Condensate (e.g. Kobbe): Very light hydrocarbon, low in polar resins, asphaltenes and waxes, low density (or high API gravity).

The SINTEF ID for each oil type was tracked during the experimental work in the Tower Basin and each experiment was linked to this ID.

4.2 Selection of dispersants

Three different commercial dispersants were included in this study; Corexit C9500, Finasol OSR 52 and Dasic Slickgone NS. These were supplied by Nalco in the US, Total Fluids in France and Dasic International in the UK. These dispersants were supplied in two versions; The normal commercial version and a concentrated version (approximately double surfactant concentration). All products were given individual IDs upon arrival, which were tracked during the experimental work.

4.3 Temperature controlled oil tanks

Four separate heating tanks were installed to obtain a better temperature control compared to the experiments performed in Phase-I. These tanks are also used to perform experiments with different oil types later in this project.



Figure 4.2: The new system with four 7 L tanks to heat the oil. Heating coils were wrapped around the tanks and covered with aluminium foil. The tanks were also insulated with foam (removed for this picture). The blue objects are pumps for internal circulation.

4.4 Overview SINTEF Tower basin

The tower basin was constructed and built in 2005, but was not assembled or tested before it was used in 2010 after the Macondo release. An outline of the tower showing the scaffolding/railing around the tower basin together with the ventilated hood and oil collecting system is shown in Figure 4.3. and Figure 4.4. An overview of the control system for oil, gas and dispersants is given in Figure 4.5.

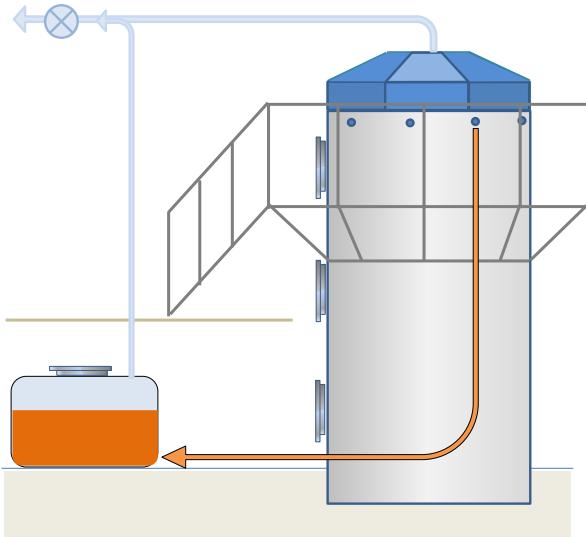


Figure 4.3: Principles for the scaffolding/railing around the tower, ventilated hood and overflow system to collect surface oil from the top of the tower.



Figure 4.4: The Tower basin per March 2012 showing the ventilated hood, scaffolding, staircase and railings to ensure safe working conditions.

Trying to fully simulate a deep water, large-scale oil and gas blow out in a 6-meter high basin is not possible. As such, we have focused on selected important aspects. These are scaled down and simulated in the tower basin. The main objectives have been to study oil droplet size distribution as a function of:

1. Oil release conditions (release diameter and release rates)
2. Different dispersant application techniques
3. Dispersant to oil ratio (DORs)
4. Possible splitting or coalescence of rising oil droplets

The droplets are formed by turbulent droplet splitting immediately after the release nozzle, where the oil/gas/water plume will quickly stabilize with respect to droplet size distribution. The resulting plume will rise mainly due to the buoyancy of gas (air) bubbles and oil droplets. As the plume rises, it also spreads laterally, creating an increasing dilution with respect to distance from the release nozzle. It is in this zone, in the middle of the tank, approximate 3 meters above the release nozzle where the droplet size distribution measurements are performed. For the set of experiments conducted in this study, this distance from the release nozzle has typically achieved sufficient instrument signal coupled with a timely response to changing release conditions.

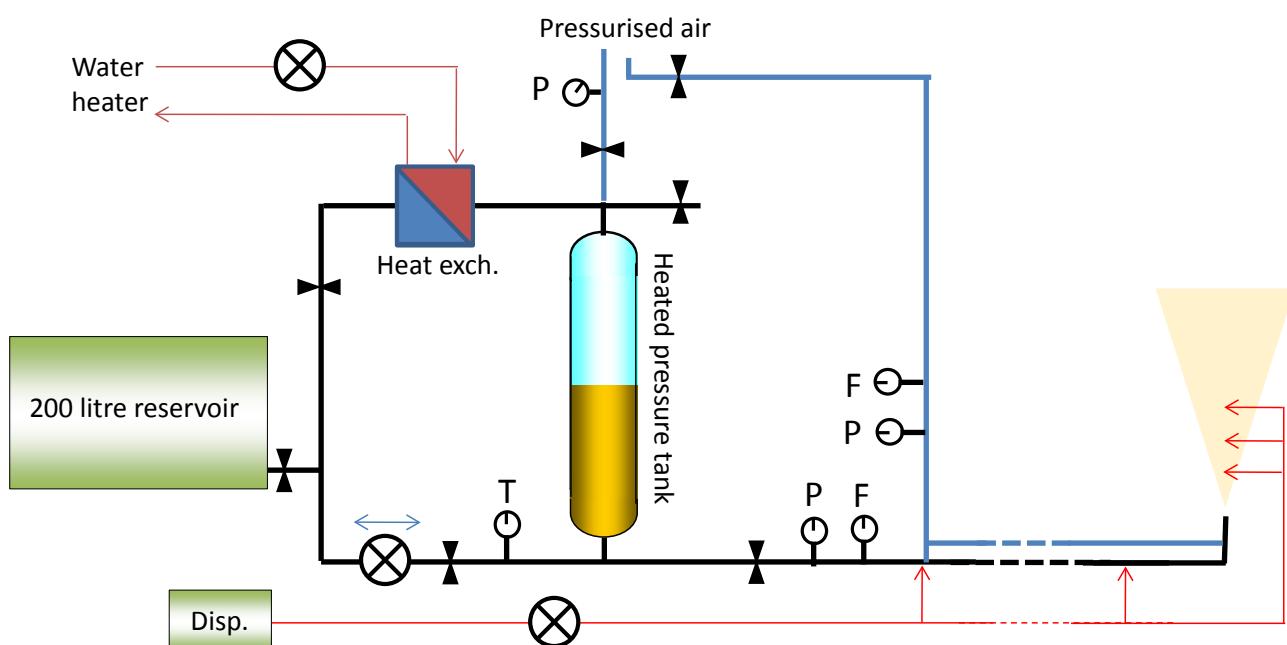


Figure 4.5: Principle overview of the set-up showing how oil, gas and dispersant are released during the experiments. The oil flow is controlled by pressurized air (P) and a mass controller (F). The oil temperature (10-95 °C) is controlled by using 4 heated 7-liter tanks. The dispersant is delivered by a high precision piston pump that is valved to several alternative injection pints. Gas flow is controlled by pressure (P) and a mass controller (F).

A more detailed description of the SINTEF Tower basin is available from the API Phase-I report (Brandvik et al., 2014) and Brandvik et al., 2013a, Brandvik et al., 2013b and Johansen et al., 2013.

4.5 Dispersant injection

The dispersant application techniques used in this study are:

- Upstream injection also called premixed. Dispersant is injected into the oil line 2000 release diameters before the release nozzle.
- Simulated insertion tool (injected 6 nozzle diameters before the nozzle outlet). See Figure 4.6-A1.
- Injected above nozzle in the centre of the jet/plume – simulated "Wand" (different distances above nozzle), See Figure 4.6-A2

In these down-scaled laboratory experiments, scaling from field conditions was done by using the release diameter as a scaling factor. The "distances" referred to in the bulleted list above (b and c) are relative to nozzle diameter of 1.5 mm.

With upstream injection, the dispersant was injected into a 4 mm oil line 3 meters (or 2000 release diameters) before the nozzle (see Figure 4.5). With an oil rate of 1.2-1.5 L/min, the residence time of the oil/dispersant blend from the injection point to the nozzle is in the range of 1.5 to 1.9 seconds. The dispersant is injected into a t-section (or restriction in the oil line) with a 0.5-mm dispersant line and a 1.5-mm oil line. The restrictions made by this t-section ensure turbulent flow (Reynolds number 3000-4000). This ensure sufficient mixing of the oil/dispersant before oil was released through the nozzle (premixed). Ideally the dispersant should have been blended into the oil in the pressure tank before injection, but this would demand thorough cleaning between experiments and probably introduce other uncertainties. However, this "premixed mode" could also be regarded as a "deep down-hole or upstream injection".

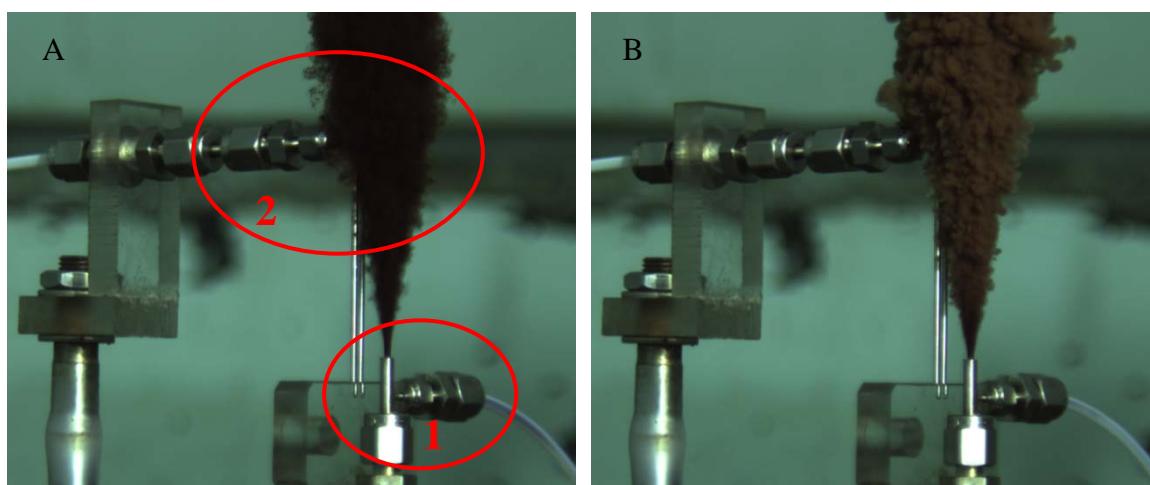


Figure 4.6: Release arrangement (1.5 mm nozzle) with options for injection of dispersant by the "Simulated insertion tool" (1) and "injection in the oil above the nozzle" (2). A: Oil released alone, no dispersant, and B: Dispersant injected with the "Simulated Insertion tool" (DOR: 1:25).

4.5.1 Spinning drop method

In spinning drop method [SDM], two immiscible fluids are placed in a capillary tube, which is rotated, as shown in Figure 4.7. Fluid A (oil droplet) is the less dense fluid, while fluid B (sea-water) is the more dense fluid. The centrifugal field generated by rotation forces keeps the less dense fluid in the centre of the capillary tube, forming an elongated drop. The configuration of the drop is determined by the balance of the centrifugal force and interfacial tension force (IFT). The

centrifugal force elongates the drop, while the IFT suppresses this elongation to minimize the interfacial area. In pendant drop method, gravity forces are applied for drop deformation, while SDM employs centrifugal forces (Liu, 2007). Determination of interfacial tension is related only to the diameter and does not require measurement of the drop volume.

This method is perfectly suitable for measurement of ultra-low tensions and the measurable values of IFT may range from 0.0005 to 0.5 mN/m (Zhang et al., 2001). Oil/sea-water/surfactant interfaces for ultra-low IFTs values are commonly measured by spinning drop technique (Khelifa and So., 2011), (Zhu et al., 2008) and (Standness and Austad., 2000).

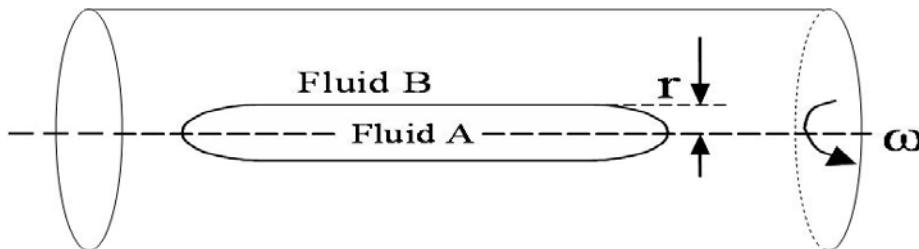


Figure 4.7: Schematic of the spinning drop method

For the interfacial tensions measurements by spinning drop method, the Dataphysics Spinning Drop Tensiometer SVT-20N with control and calculation software SVTS 20 IFT was used (Figure 4.8). The Julabo F12-ED Refrigerated and Heating Circulator were used for temperature control. Disposable 1ml plastic syringes were used to inject the oil sample into the SVT 20N capillary tube.

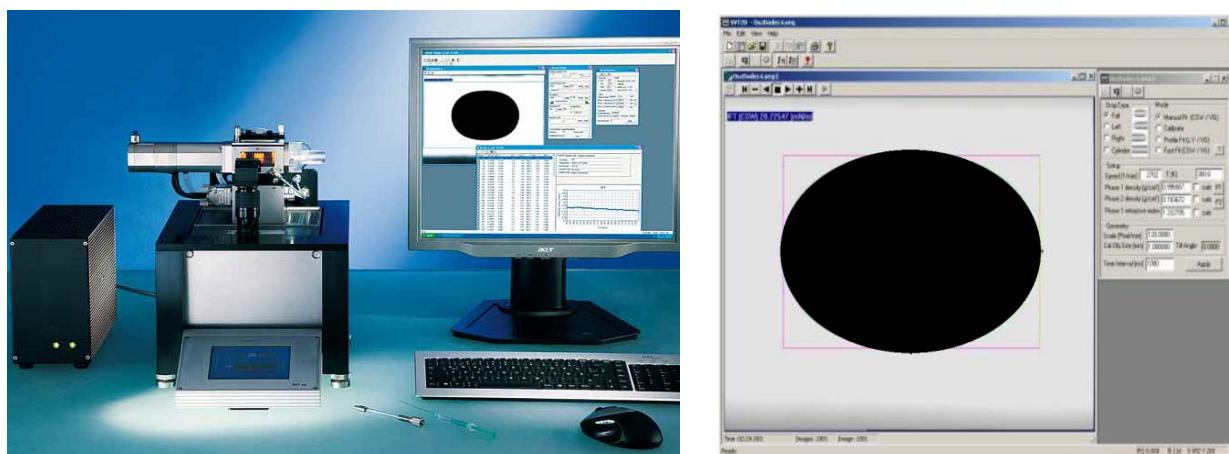


Figure 4.8: The Dataphysics Spinning Drop Tensiometer SVT-20N and its software used to measure ultra-low interfacial tension values of oil/water/dispersant interfaces.

Prior to each measurement, the capillary tube was rinsed three times with dichloromethane (DCM), acetone and deionized water, dried with nitrogen gas, and then rinsed three times with the sea-water. The capillary was carefully filled with the sea-water (outer phase liquid) to ensure the absence of air bubbles. The injection of a drop of the oil sample (inner phase) into the filled capillary was done by use of a 1 ml syringe with a long needle. Depending on the oil sample, the capillary may be stationary or rotating (varied as needed) when the drop of oil is injected.

Measurements of IFT were taken as soon as the drop elongation was stable. Depending on the interfacial tension, different oil samples have different volumes of droplet. Parent oil and their mixture with low DOR formed relatively big droplets while oil with high DOR formed very small

droplets, Figure 4.9A, B, C and D. Each measurement was run for 30-60 minutes and repeated at least two times. The reported IFT values were the mean IFT of different droplets measured during first 50-150 seconds.

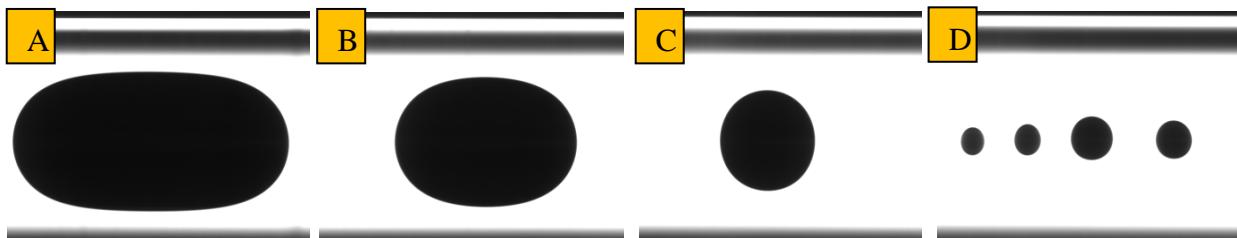


Figure 4.9: Oil droplets with different DOR; A) Oil alone, B) DOR: 1:500, C) 1:250, D) 1:50

4.5.2 Oil sampling for IFT measurements

During different injection sequences of dispersants into the oil, oil/water samples were taken from 0.8 meters above the nozzle after 60 seconds of each dispersant injection. Oil/water samples were collected in 1 litre long necked measuring flasks. Upon collection, oil appeared as droplets in seawater, with droplet sizes dependant on DOR and method of application. Oil settled as a layer in the narrow neck of the bottle and was collected for IFT measurements after 24 hours. The settling time was important for collecting the smaller droplets in experiments with high dispersant effectiveness. The collected oil samples were stored in a dry and cool place overnight. No homogenization or heating was done before the IFT measurements.

5 Results

5.1 Overview of experiments

The Tower Basin experiments reported from this study were performed from December 2012 to July 2013. Totally, 26 experiments were performed in this period. Each experiment usually takes a week, consisting of two days of preparation, one day for performing the experiment and another two days for cleaning and post processing of data. A summary overview of the experiments is given in Appendix A and the experiment numbers given below refers to this appendix.

The experiments in this study were divided into the following groups or phases.

1. **Extended warm oil experiments** (Experiment 1, 8 and 14, 15, 17, 18). Experiments with oil temperature ranging from 10 to 100 °C, with two different oil types (Oseberg and Troll B) and two different dispersants (C9500 and Dasic NS).
2. **DOR testing of new dispersants** (Experiment 3, 4, 5, 7, 10, 20 and 21). Experiments with new dispersants (Dasic Slickgone NS and Finasol OSR 52) in both normal and concentrated versions.
3. **Extended range of oil types** (Experiment 13, 19, 23 and 24). Experiments with three dispersants (C9500, Dasic NS and Finasol 52) and four different oil types (Oseberg, Grane, Kobbe and Norne).
4. **Mixed releases of oil and gas** (Experiment 25, 27). Experiments to study the effect of mixed releases. Try to generate different droplet sizes of oil and gas, since the LISST can't distinguish between oil droplets and gas bubbles.
5. **Coalescence study:** (Experiment 19 and 25): Experiments with Twin LISST configuration (2 and 5 m above nozzle) to monitor any changes in droplets size distribution. Two dispersants (C9500/Finasol 52) and the four different oil types.

The background or basic theory for the experimental plan (release rates and turbulence levels) is based on earlier tank experiments described in Appendix C, Figure C.3. This figure presents the release conditions based on Ohnesorge vs. Reynolds number and has been used to find a suitable starting point for the initial testing and to determine the total design of this study. For further detail see Appendix C and Johansen et al., 2013.

5.2 Calibration and documentation of uncertainty

Calibration and uncertainty of the system including quantification of droplets (laser scattering), flow rates of oil (pressurized tank controlled by mass regulator) and injection rate of dispersants (piston pump) are discussed and documented in Brandvik et al., 2013.

A particle standard (80 and 346 micron) is injected in front of the LISST instrument before Tower basin experiments are initiated as a part of the general quality assurance procedure.

5.2.1 Presentation of droplet size distributions

Since the LISST often detects noise or "non-oil" particles in the water in the three smallest size bins (2.7, 3.2 and 3.8 microns), these bins are excluded from the relative distributions. As, including this noise would have introduced a systematic shift in the calibrating data set towards smaller volume median droplet sizes (VMD) or d_{50} .

The histograms from the droplet size distributions in this study are presented as graphs in this report. This is not strictly correct since the data are discrete and not continuous. However, graphs were used since projecting several histograms on top of each other is visually difficult to interpret.

The graphs presenting the droplets size distributions are usually averages of 30 individual LISST measurements measured over 30 seconds. For the smallest droplets, each bins represents thousands of droplets, several hundred for the medium sized and a few tens for the largest droplets.

The volume median droplet sizes (VMD) or d_{50} were calculated from the relative volume distributions using the maximum peak as an estimate. If the assumption that the data can be approximated with a log normal distribution is valid, the difference between these two measures of d_{50} should be very small. A cumulative distribution could also been used, but for high d_{50} the distributions will contain a significant amount of droplets larger than 500 μm and the total droplet range is not covered by LISST. For such distributions the cumulative d_{50} will be underestimated (Davies et al., 2012). In such cases will the maximum peak still offer a good estimate of VMD or d_{50} and this is the reason for using this approach in this study.

5.2.2 Reproducibility between experiments

Comparison of droplet size distributions from several experiments is used to document the stability and reproducibility of the system. Data from three different experiments (21 March, 30 April and 31 May 2013) are used for this purpose. The distributions for four different oil types (without dispersant injection) are given in Figure 5.24, Figure 5.25, Figure 5.26 and

Figure 5.27.

In the DOR experiment described in Chapter 5.4, droplet size distribution of untreated oil is monitored both in the beginning and at the end of the experiments. These replicate measurements are presented in Figure 5.15, Figure 5.16 and Figure 5.17.

5.2.3 Reproducibility within an experiment

In the experiment performed on 01.02.13, the dispersant valve did not open and the experiment can be used to document the stability of the droplet distribution as a function of time. This is shown in Figure 5.1.

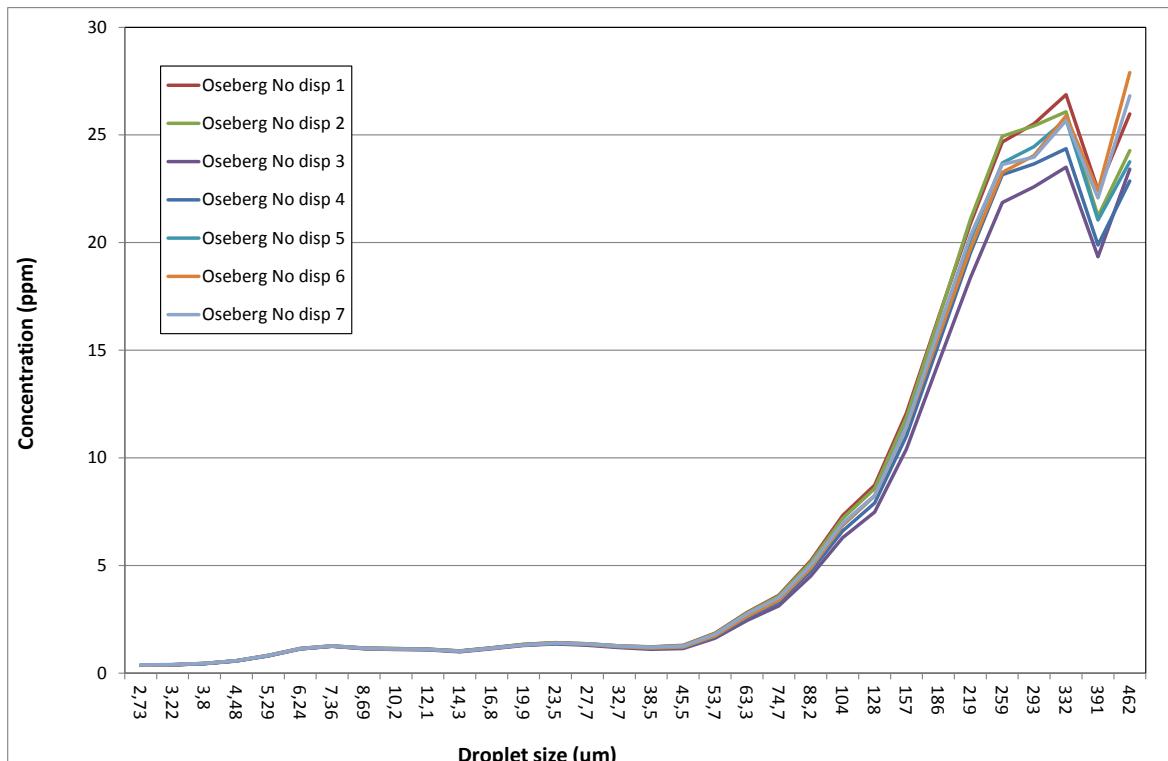


Figure 5.1: Variation within one Tower basin experiment (01. February 2013). Relative droplet size distribution (volume %) for 7 individual experiments with the same experimental condition (1.5 mm nozzle and 1.2 L/min) measured with LISST instrumentation.

5.3 Dispersant effectiveness as a function of oil release temperature

This section contains data describing the relationship between oil droplet size distribution, the temperature of the released oil and dispersant injection. Some of the data are reported earlier as a part of Phase-I (Tower Basin experiment from 20. June 2012) and new data are generated as a part of Phase-II (TB experiment from 19. December 2012 and 7. February 2013).

The warm oil experiments are performed in the following manner.

1. Correct flow and temperature of the released oil are established in the Tower Basin
2. A reference experiment with oil alone is performed, then
3. Dispersant is injected (simulated insertion tool) at two different dosages (1:100 & 1:50).

This (1-3) is repeated for each temperature (13, 25, 35, 50, 66, 75 and 100°C). The oil is delivered from the four individually temperature-controlled tanks. Between 2 and 4 temperatures are tested in each Tower basin experiment. The nozzle and flow rate used for all experiments are 1.5 mm and 1.2 L/min, respectively.

Typical flow rate stability was ± 0.02 L/min during the monitoring period. The first experiment (June 2012) was performed with an external heater (hot water heat exchanger) in the oil line. To obtain a more controllable and quicker temperature control four separately heated steel tanks (external electric heating) were used for the two last experiments (Dec. 2012 and Febr. 2013). The control, precision and documentation of the oil temperature at the release nozzle were improved for the two last experiments. Typically, temperature stability is $\pm 0.5^\circ\text{C}$ during the monitoring period. Both flow rate and release temperature are logged continuously during the experiments.

The results are presented in the following figures; Figure 5.2, Figure 5.3, Figure 5.4, Figure 5.5 and Table 5.1. Interfacial tension (IFT) values for dispersant premixed into Oseberg blend in the laboratory are presented in Figure 5.6.

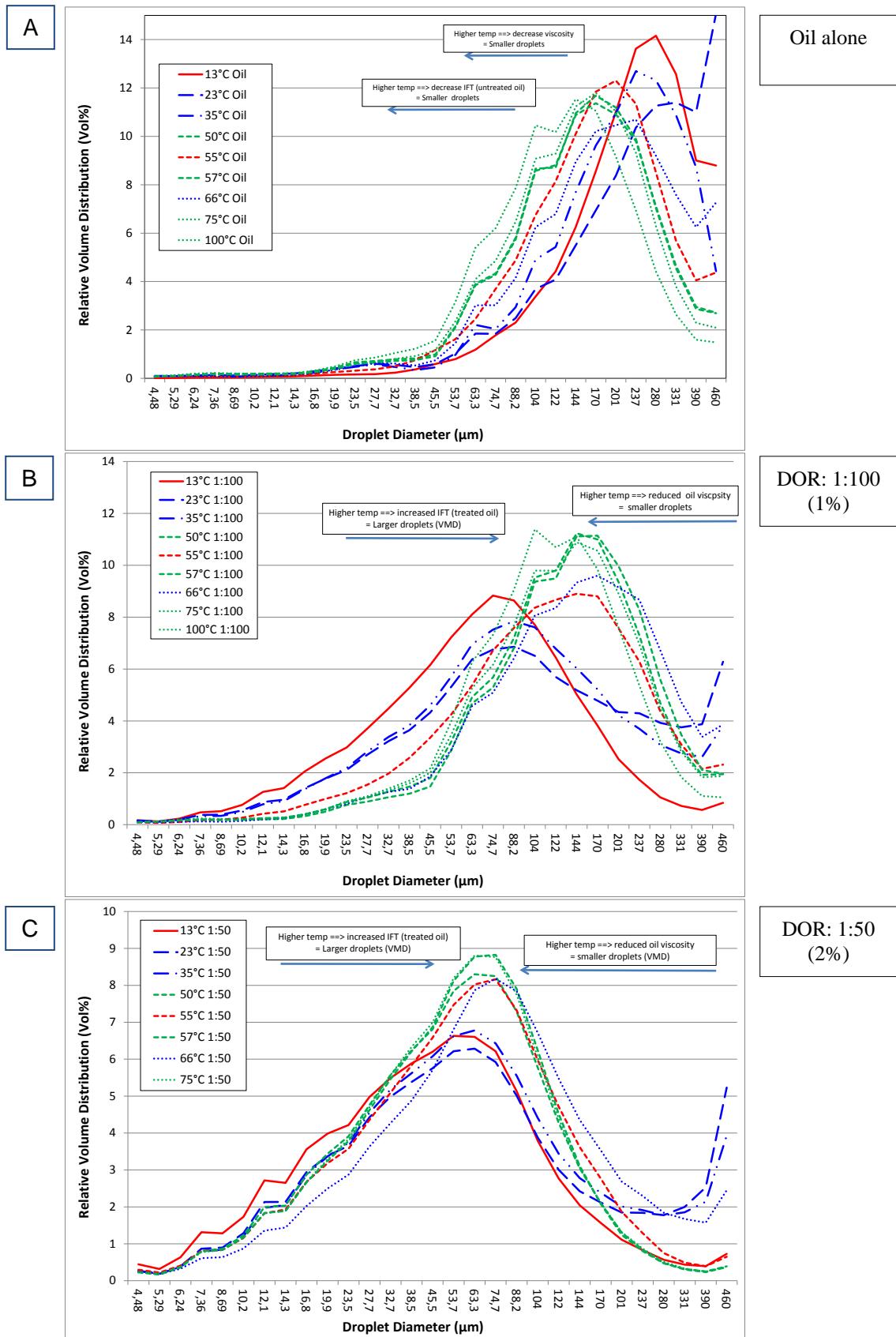


Figure 5.2: Combined results from the three different Tower basin experiments as a function of temperature (13-100°C). A: oil alone, B: DOR: 1:100 and C: DOR: 1:50.

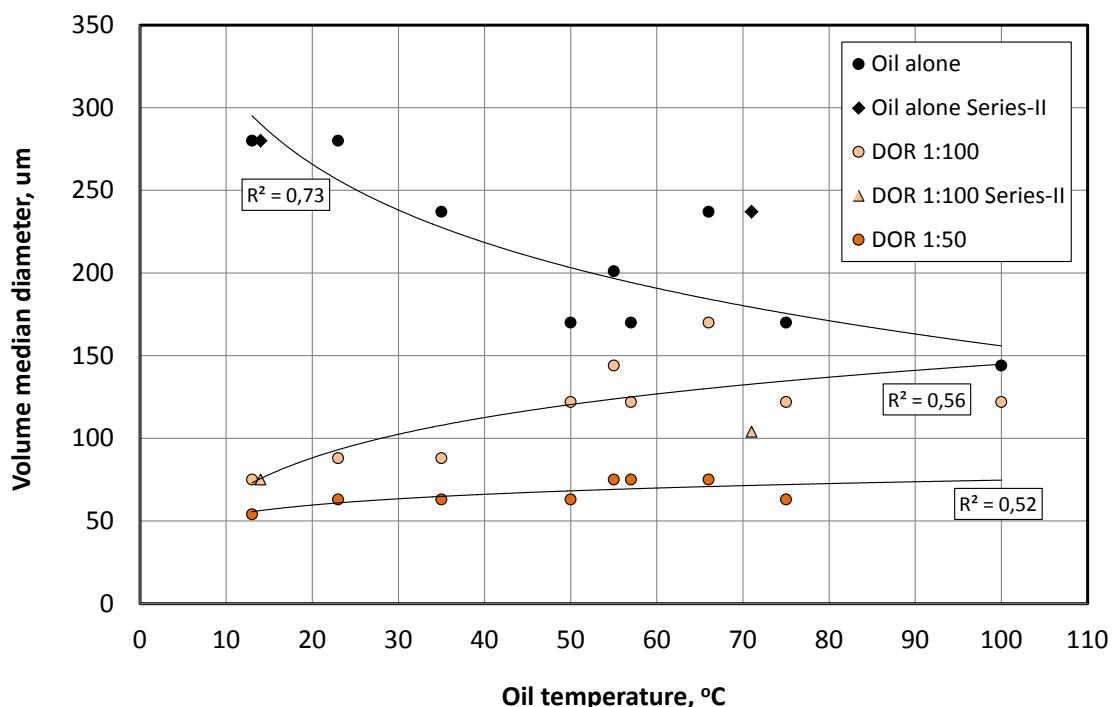


Figure 5.3: Volume Median Diameter (VMD) as a function of temperature of released oil (13–100°C) and dispersant injection (DOR). Trend lines are second order polynomials. Release conditions: 1.5 mm and 1.2 L/min. Raw peak data from Table 1. Data from the second series of temperature experiments (Figure 5.7) are included as (diamonds and triangles).

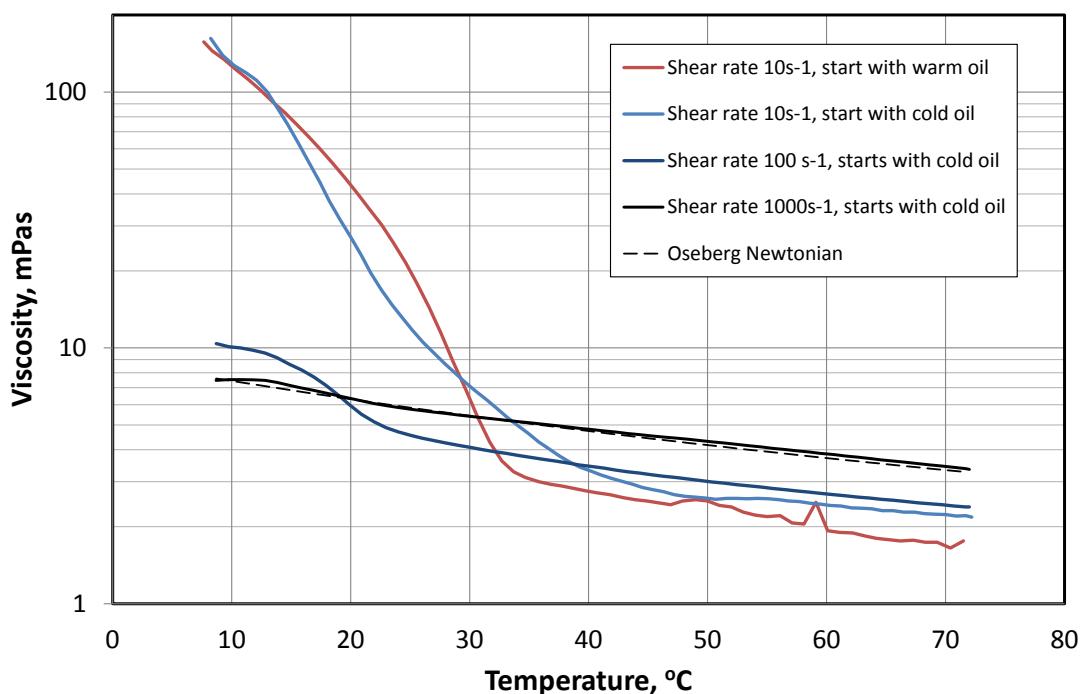


Figure 5.3b: Viscosity of Oseberg blend (2012-0347) as a function of shear rate (10, 100 and 1000) and temperature. At low shear rate the temperature program is run both ways (high to low and opposite).

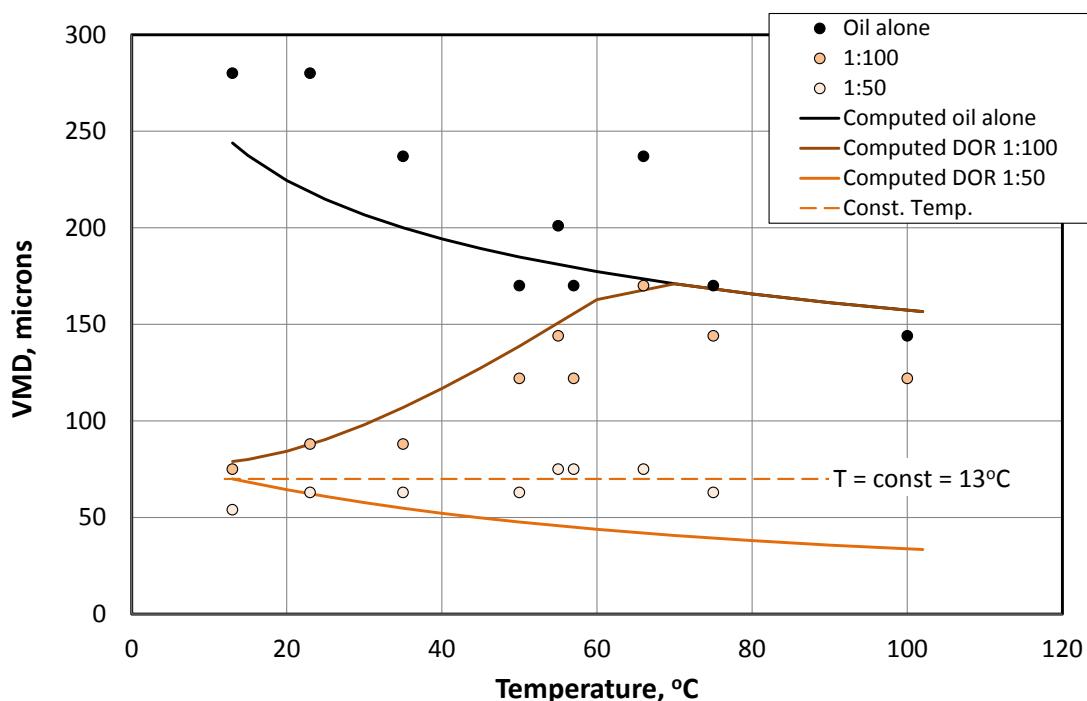


Figure 5.4: Computed trend lines with the new modified Weber scaling (Johansen et al., 2013) based on measured oil viscosity and IFT versus temperature. For the DOR 1:100 case, IFT is assumed to coincide with IFT for untreated oil at temperatures above 70 °C. The dashed line represents VMD for a constant temperature of 13 °C. Release conditions: 1.5 mm and 1.2 L/min.

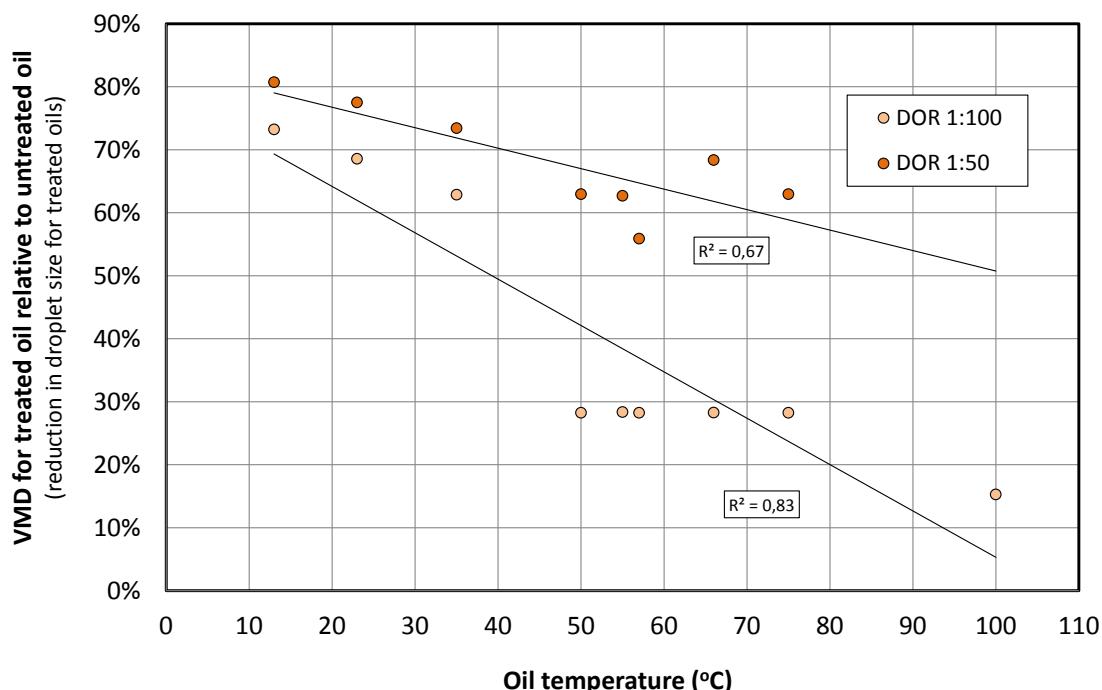


Figure 5.5: Relative Effect of dispersant treatment expressed as VMD for treated oils relative to untreated (%) as a function of temperature (13-100°C) and dispersant injection (DOR). Release conditions: 1.5 mm and 1.2 L/min. Raw peak data are from Table 5.1.

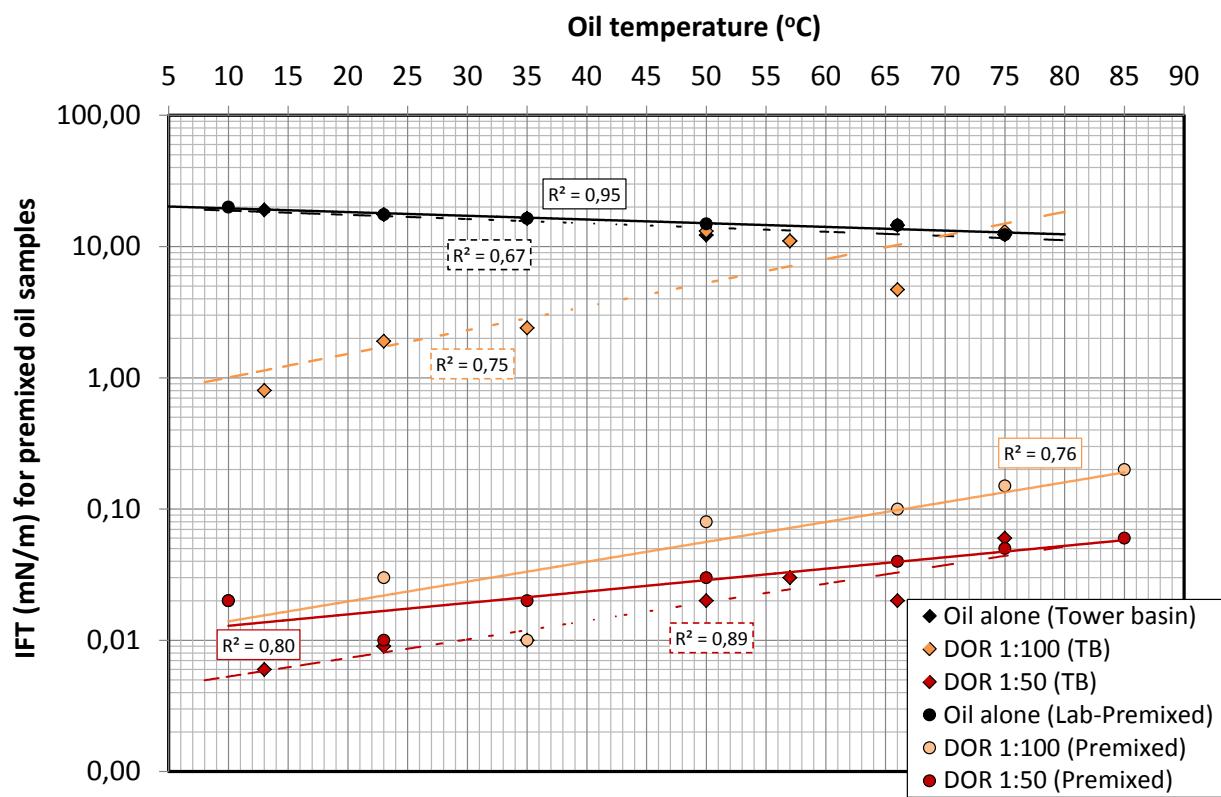


Figure 5.6: Inter Facial Tension (mN/m) as a function of temperature (13-100°C) and dispersant dosage (DOR: 1:100, 50) with Oseberg blend. Data are compared for both premixed samples, prepared separately in the laboratory, and samples taken from the Tower basin during the experiments.

Table 5.1: VMD (or D_{50}) as a function of temperature (13-100°C) at DOR: 1:100, 50 and 25 with Oseberg oil. Dispersant injected with simulated insertion tool in SINTEF Tower Basin. VMDs are determined both by the maximum peak (Peak) and by the

cumulative distribution ($\text{Cum}_{50\%}$). Release conditions 1.5 mm and 1.2 L/min. Relative reduction in VMD, compared to untreated oil, and IFT for in-situ samples (tower basin) are given for each experiment.

Temp (°C)	Conditions (oil alone or DOR)	VMD (μm)		Relative Reduction in VMD		Viscosity* of oil (mPas)	IFT (mN/ m)
		Peak	Cum _{50%}	Peak	Cum _{50%}		
100	Oil alone	144	122			2.0/2.0/2.5	ND ¹⁾
100	1:100	122	104	0,85	0,85		
75	Oil alone	170	122			2.2/2.4/2.8	12.3
75	1:100	122	104	0,72	0,85		13.0
75	1:50	63	46	0,37	0,38		0.06
66	Oil alone	237	170			2.3/2.5/3.5	14.5
66	1:100	170	122	0,72	0,72		4.7
66	1:50	75	63	0,32	0,37		0.02
57	Oil alone	170	144				11.0
57	1:100	122	122	0,72	0,85		11.0
57	1:50	75	54	0,44	0,38		0.03
55	Oil alone	201	201			2.6/2.8/3.9	ND ²⁾
55	1:100	144	144	0,72	0,61		
55	1:50	75	75	0,37	0,32		
55	1:25	32	32	0,22	0,27		
50	Oil alone	170	144			2.7/3.0/4.1	12.2
50	1:100	122	122	0,72	0,85		13.1
50	1:50	63	46	0,37	0,32		0.02
35	Oil alone	237	201			4.6/3.7/5.0	16.4
35	1:100	88	75	0,37	0,37		2.4
35	1:50	63	46	0,27	0,23		0.01
23	Oil alone	280	280			23/4.9/6.0	17.5
23	1:100	88	88	0,31	0,31		1.9
23	1:50	63	46	0,23	0,16		0.009
13	Oil alone	280	280			110/9.6/7.1	17.0 ³⁾
13	1:100	75	63	0,27	0,23		0.8
13	1:50	54	39	0,19	0,14		0.006
13	1:25	28	24	0,37	0,38		

¹⁾ No data available (ND), the upper limit for the spinning drop instrument is 85°C.

²⁾ No data available. No oil samples for IFT analysis were taken during the June 2012 experiment (13 and 55 °C).

³⁾ IFT values are from another Tower basin experiment at 13°C 21. March 2013).

* Viscosity is measured at shear rates of 10, 100 and 1000 s⁻¹ (presented in this order). Values are from measurement presented in figure 5.3b.

5.3.1 Additional warm oil experiments

To study the effect of oil temperature on droplet sizes and the effect of dispersant injection, the API D3 management team decided to perform a series of additional experiments including an additional oil type, dispersant and several injection techniques. As an amendment to the original contract, the following additional experiments were performed to study the effect of oil temperature on dispersant injection effectiveness in more detail. The following parameters were used to define the design for these experiments:

- ✓ Oil temperature: 2 - Low/High (approx. 13 and 75°C)
- ✓ Dispersant temperature: 1 - injected at ambient sea water temperature (10°C).
- ✓ Oil type: 2 - Oseberg Blend or OB (paraffinic) and Troll B (naphtenic)
- ✓ Injection technique: 3 - Simulated injection tool (SIT), premixed and injection above nozzle.
- ✓ Dispersant: 2 - C9500 and Dasic NS.

	Oil type	Injection method	Dispersant type	Temperature (°C)	DOR
1	Oseberg blend	Oil alone + SIT, Premixed and Injection above nozzle. Performed on 22. April 2013 (220413)	C9500	13 & 75	1:100
2	Oseberg blend	As above (080413)	Dasic NS	As above	As above
3	Troll B	As above (170413)	C9500	As above	As above
4	Troll B	As above (120413)	Dasic NS	As above	As above

To be able to do these experiments more efficiently and cost effectively, SINTEF installed four smaller pressurized oil tanks (7 liters) in our experimental set-up for the Tower basin (see Figure 4.2).

The number of experiments we can do with the same volume of sea water in the Tower basin is limited. In Phase-I, we have mostly done a series of dosage experiments, a few injection methods or flow rate experiments with one oil type before the Tower basin becomes over-concentrated with oil droplets. This usually involves releases of 8-12 liters of oil. With the new and smaller oil tanks, experiments with both oil types, one dispersant (three injection methods) and both temperatures could be performed in the same volume of water.

The results from these experiments are presented in the figures on the following pages.

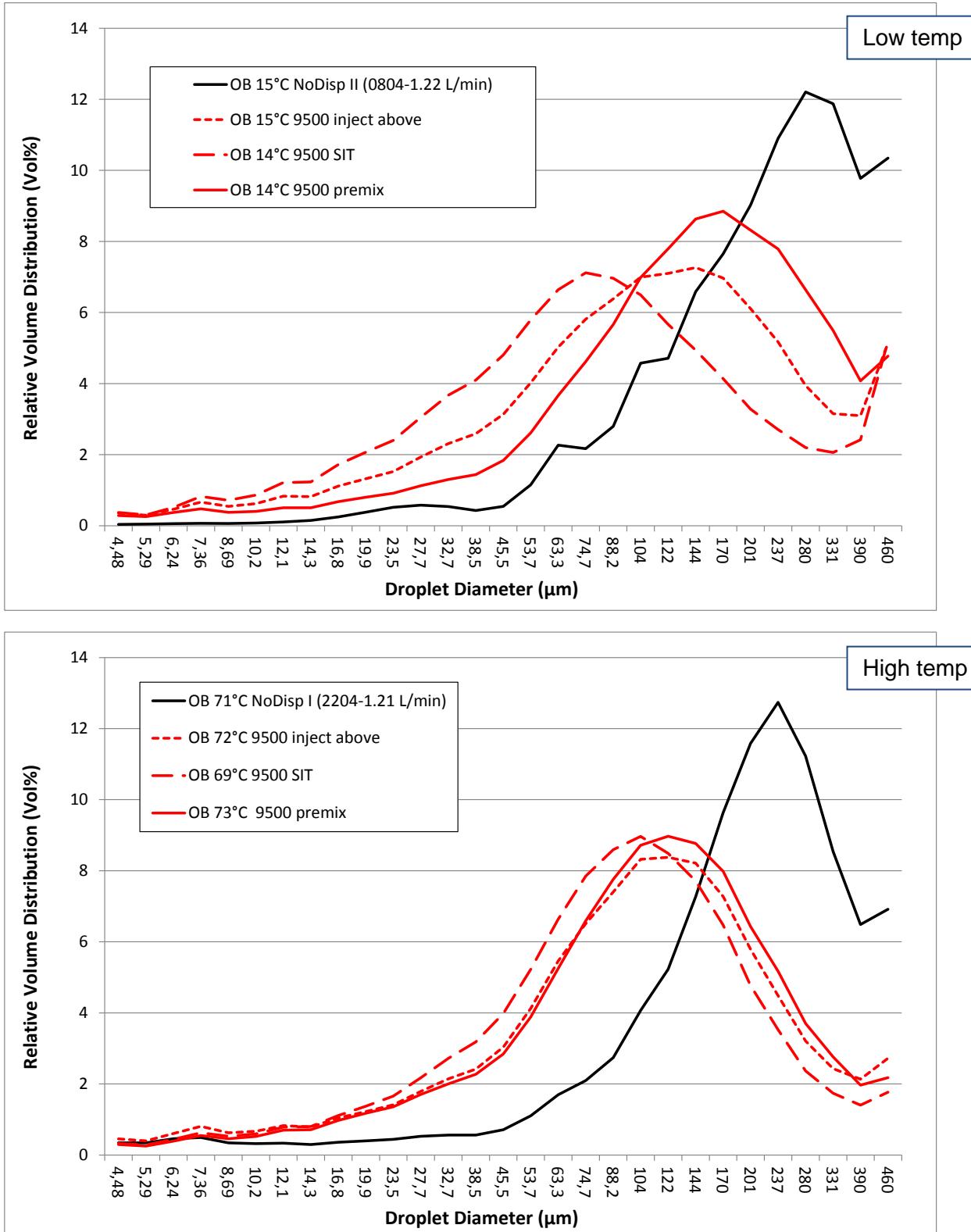


Figure 5.7: Oseberg-C9500: Relative droplet size distribution (volume %) as a function of oil temperature (LOW/HIGH or approximate 13/75 °C) and injection method (Simulated injection tool-SIT, injection above and upstream injection/premixed) with Oseberg oil. Release conditions 1,5 mm and 1,2 L/min. Dispersant used is C9500 and 1%.

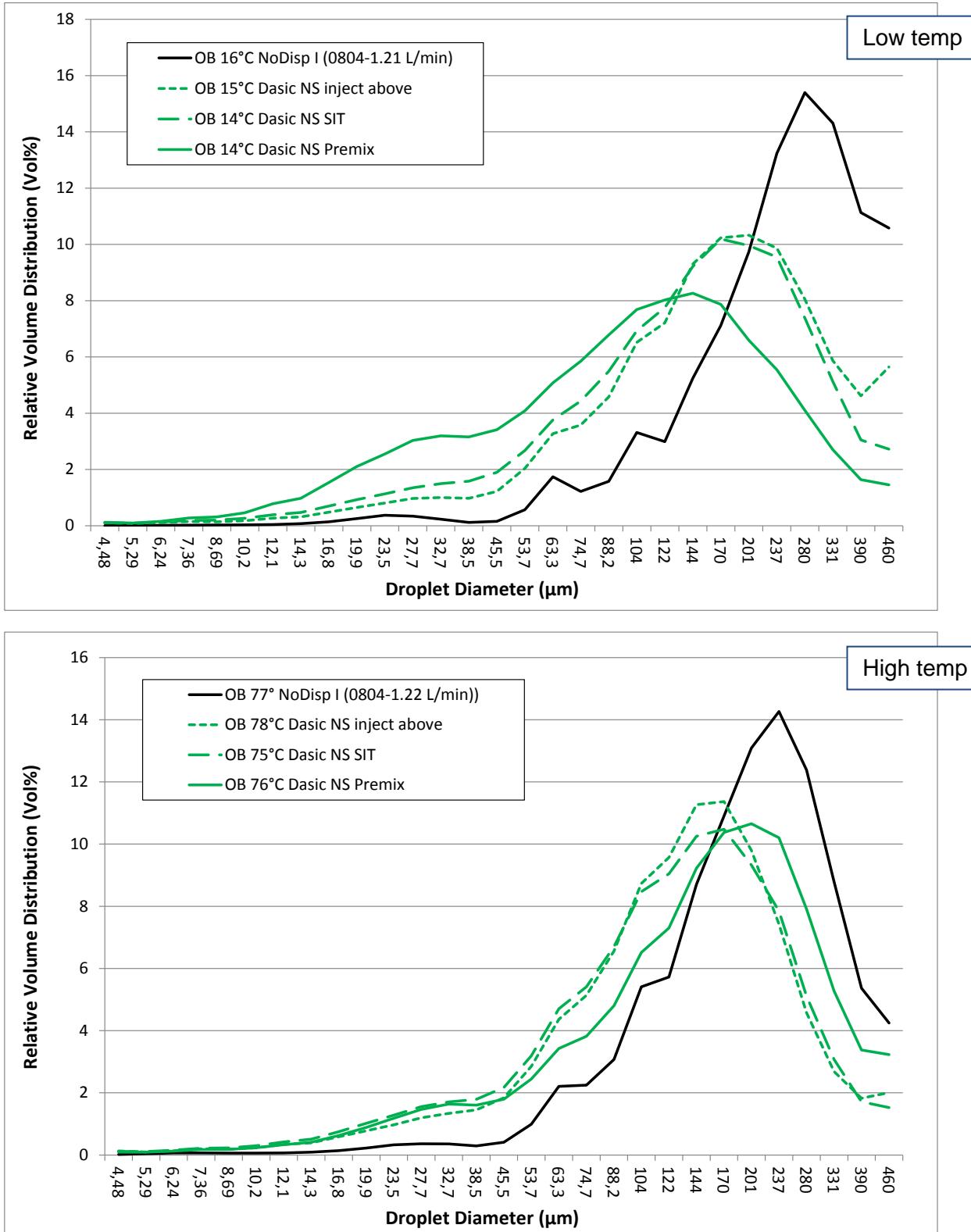


Figure 5.8: Oseberg-Dasic NS: Relative droplet size distribution (volume %) as a function of oil temperature (LOW/HIGH or approximate 13/75 °C) and injection method (Simulated injection tool-SIT, injection above and upstream injection/premixed) with Oseberg oil. Release conditions 1.5 mm and 1.2 L/min. Dispersant used is Dasic NS and 1%.

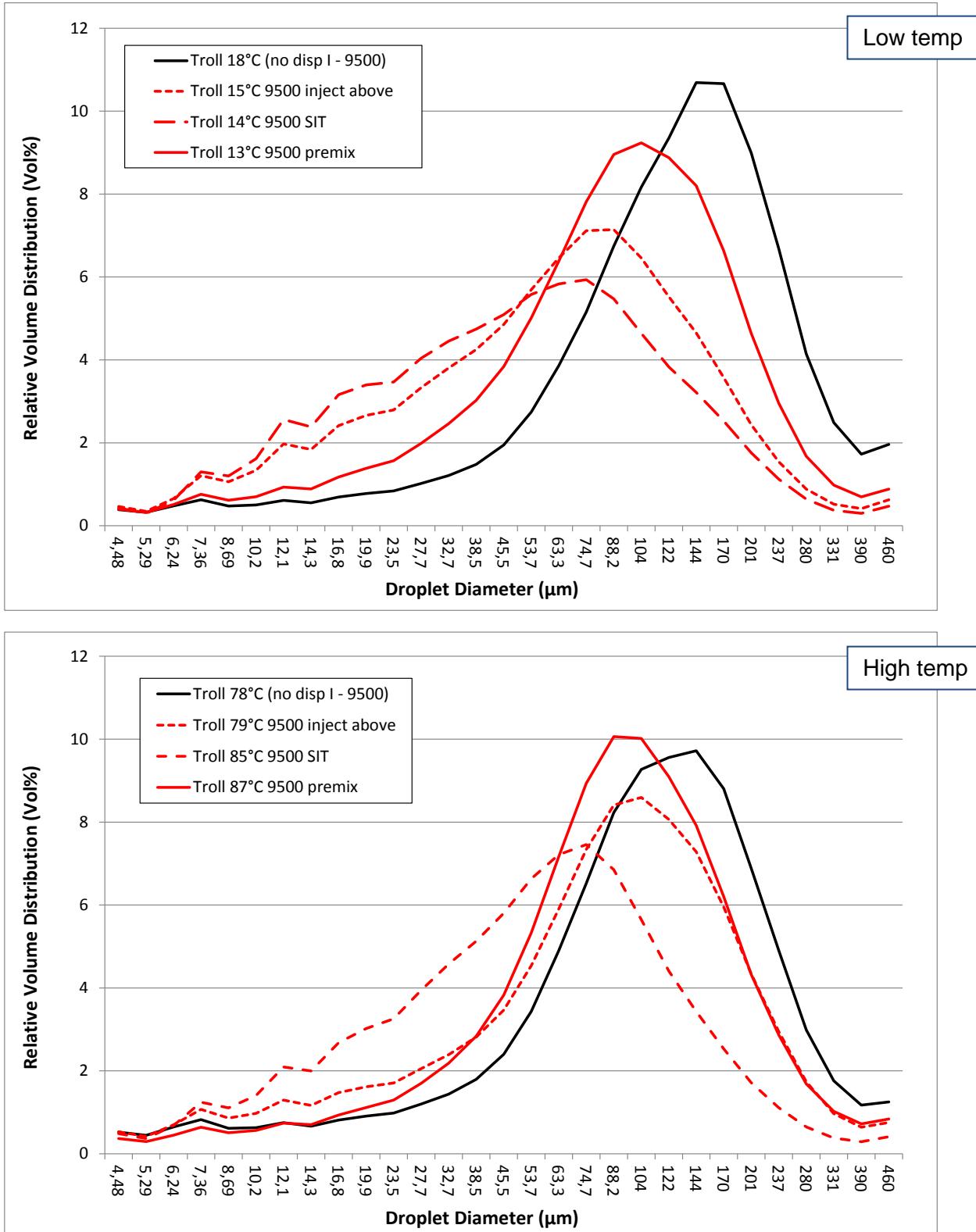


Figure 5.9: Troll-C9500: Relative droplet size distribution (volume %) as a function of oil temperature (LOW/HIGH or approximate 13/75 °C) and injection method (Simulated injection tool-SIT, injection above and upstream injection/premixed) with Troll oil. Release conditions 1,5 mm and 1,2 L/min. Dispersant used is C9500 and 1%.

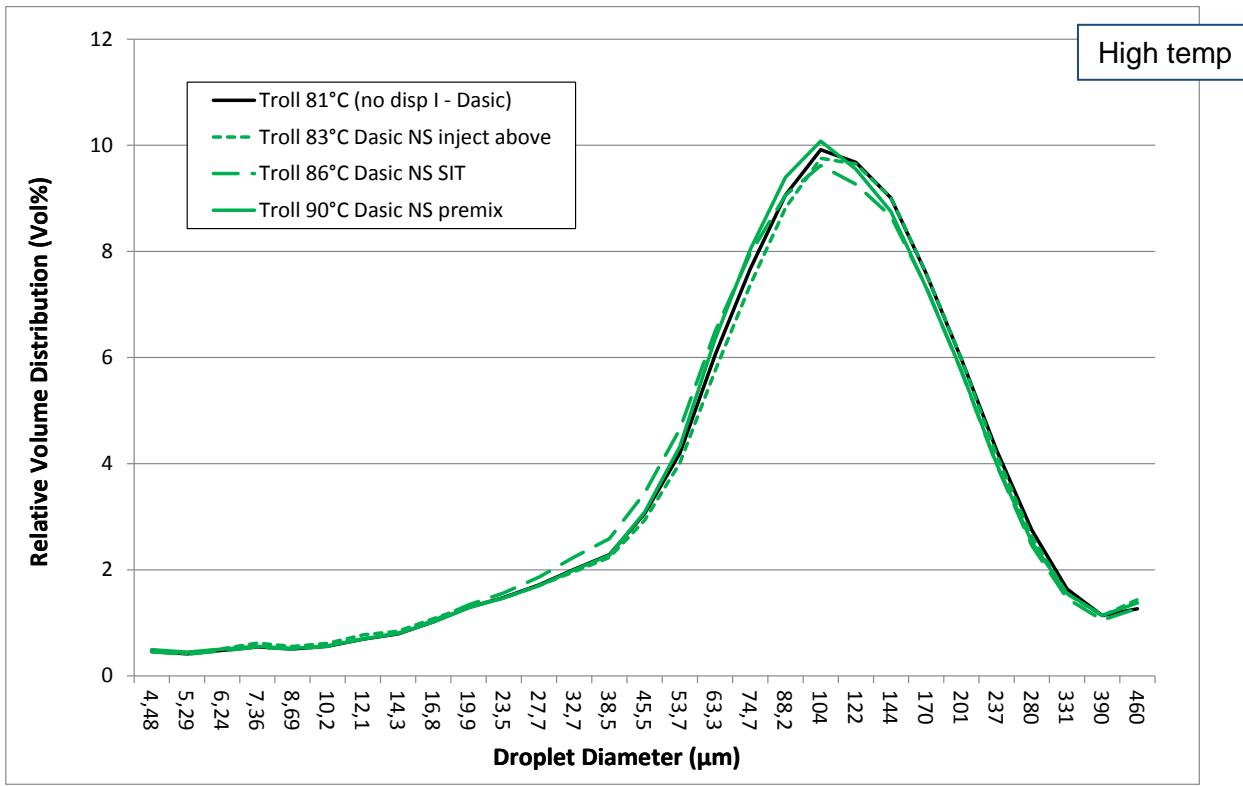
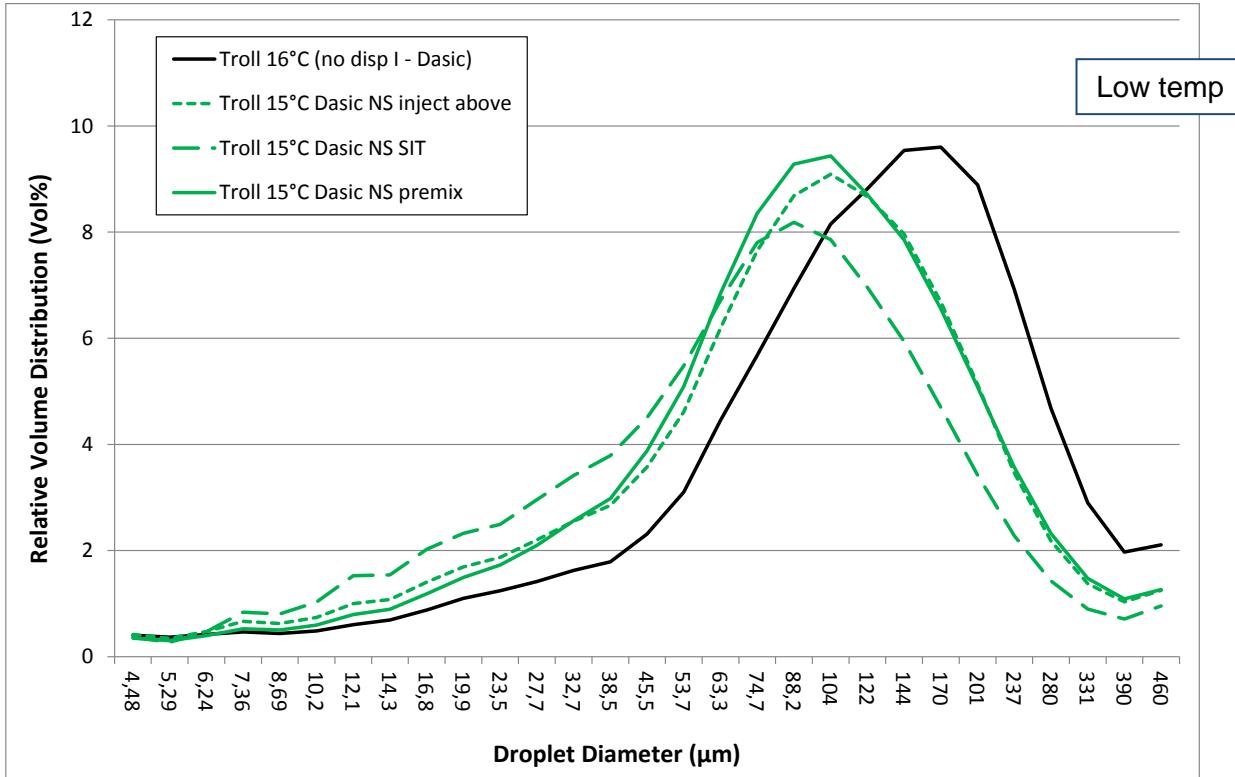


Figure 5.10: Troll-Dasic NS: Relative droplet size distribution (volume %) as a function of oil temperature (LOW/HIGH W or approximate 13/75 °C) and injection method (Simulated injection tool-SIT, injection above and upstream injection/premixed) with Troll oil. Release conditions 1,5 mm and 1,2 L/min. Dispersant used is Dasic NS and 1%.

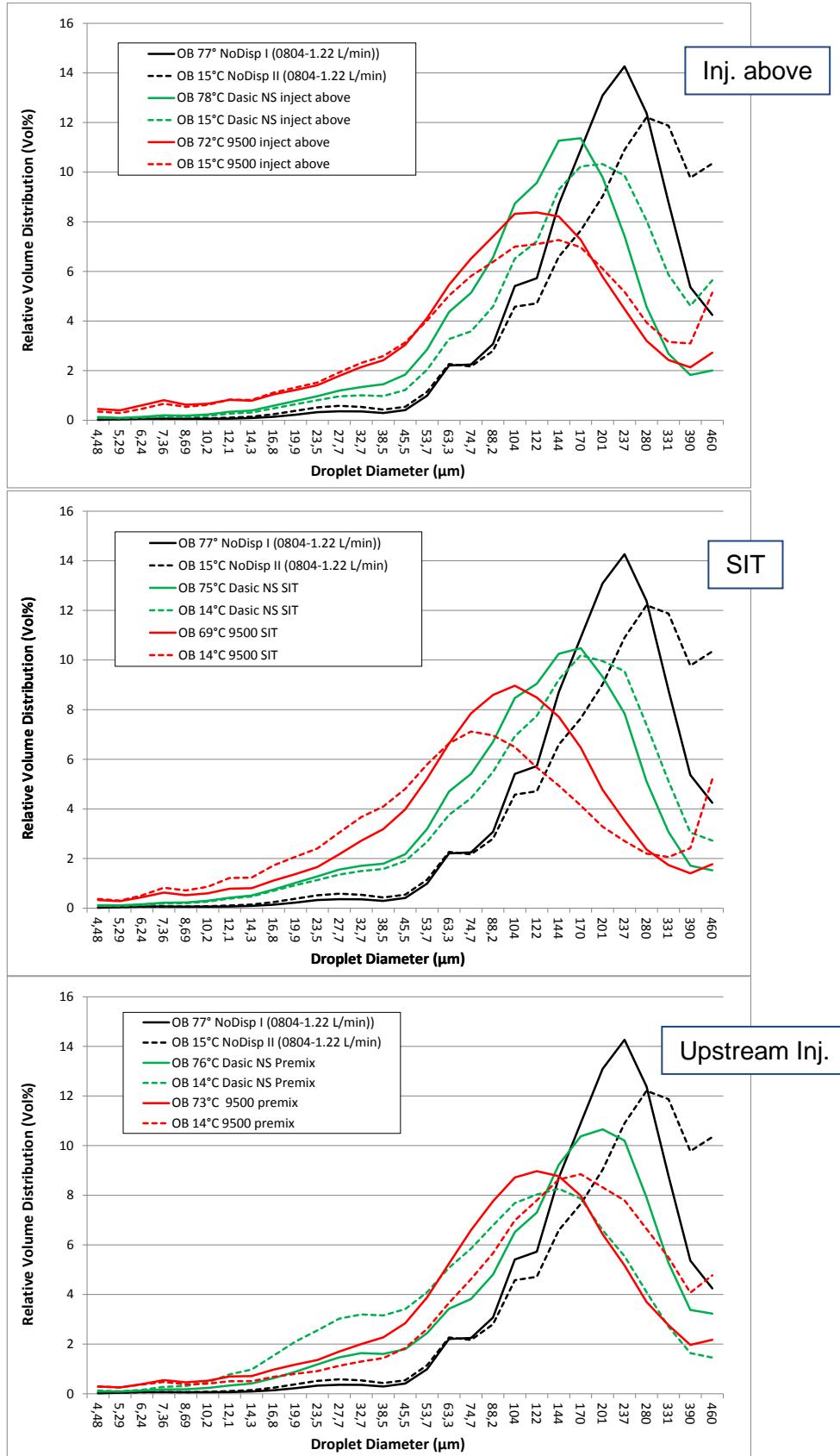


Figure 5.11: Oseberg – All inj. methods: Relative droplet size distribution (volume %) as a function of oil temperature (LOW/HIGH or approx. 13/75 °C) with Simulated injection tool. Release conditions 1,5 mm /1,2 L/min. Dispersants; C9500 and Dasic NS and 1%.

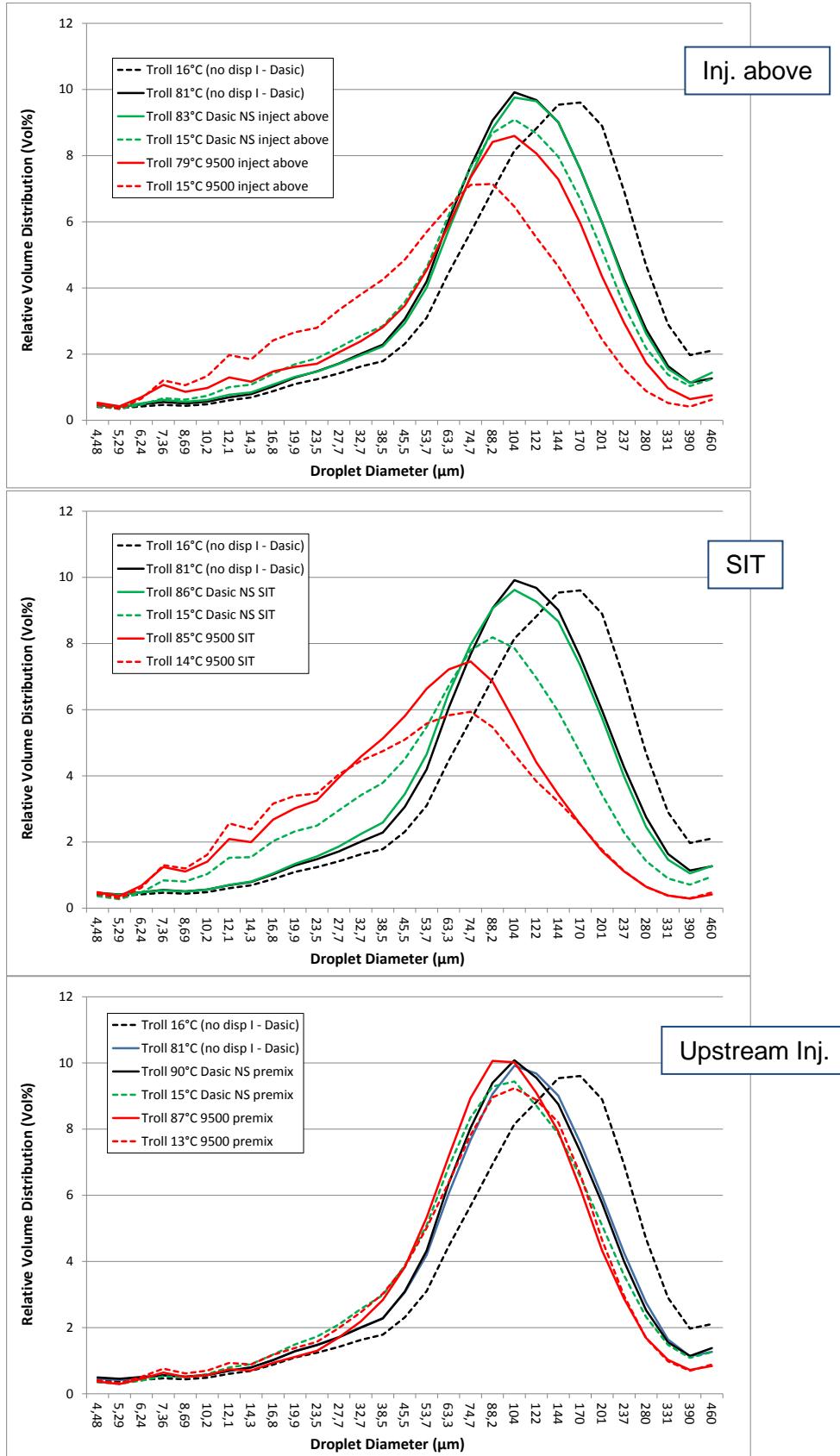


Figure 5.12: Troll – All inj. methods: Relative droplet size distribution (volume %) as a function of oil temperature (LOW/HIGH or approx. 13/75 °C) with Simulated injection tool.
Release conditions 1,5 mm /1,2 L/min. Dispersants; C9500 and Dasic NS and 1%.

Table 5.2: IFT for in-situ samples taken from the oil plume in the tower basin for all temperature experiments (Two oil types, three injection techniques and two dispersants.). DOR for all experiments is 1:100.

	COREXIT C9500		DASIC NS	
	13°C	75°C	13°C	75°C
Oseberg Blend-I	13.4±0.2	13.4±0.3	16.0±0.2	15.5±0.3
Premixed	2.1±0.5	2.7±0.7	2.4±1.2	3.2±0.6
Sim. Inj. Tool	2.3±0.3	6.8±0.6	1.6±0.2	3.1±0.2
Inj. above nozzle	11.1±0.3	11.2±0.7	6.8±0.8	12.6±0.4
Oseberg Blend-II	13.5±0.3	13.5±0.3	11.6±0.3	15.2±0.4

	COREXIT C9500		DASIC NS	
	13°C	80°C	13°C	75°C
Troll B-I	10.0±0.5	10.7±0.1	10.7±0.3	11.5
Premixed	2.5±0.3	0.4±0.3*	2.1±0.5	2.1±0.1
Sim. Inj. Tool	3.5±0.3	3.7±0.3	3.8±0.5	10.2±0.4
Inj. above nozzle	7.9	9.7±0.4	5.4±0.4	6.2±0.4
Troll B-II	9.6±0.2	11.1±0.3	10.7±0.2	11.0±0.3

*Experiment performed on 17.04.13

5.4 Dispersant effectiveness as a function of oil type and dispersant dosage

Earlier dispersant experiments have mainly been performed with Corexit C9500 and Oseberg blend (Brandvik et al., 2014). In this section, three different dispersants are compared (C9500, Finasol OSR 52 and Dasic Slickgone NS) with Oseberg blend at different dosage rates (1:1000 to 1:25). The dispersants are tested in two different versions, the commercial version and a concentrated version where the content of active material is doubled due to removal of solvent. All products were used as received by the suppliers.

To be able to evaluate the effectiveness of dispersant dosage it is important to know the reduction in interfacial tension (IFT) and the resulting effect on droplet size at different DORs. These experiments were performed with premixed or upstream injection.

The experimental conditions for these experiments are given in the table below.

Table 5.3: Experimental conditions for the Oil type experiments

Nozzle diameter:	One - 1.5 mm
Flow rate:	One - 1.2 L/min
Number of replicate experiments:	None
Dispersant application technique:	Upstream injection (premixed)
Dispersant:	Three + concentrated versions
Gas-oil-ratio:	Only oil
DORs	1:25, 50, 100, 250, 500 and 1000
Oil type:	One - Oseberg

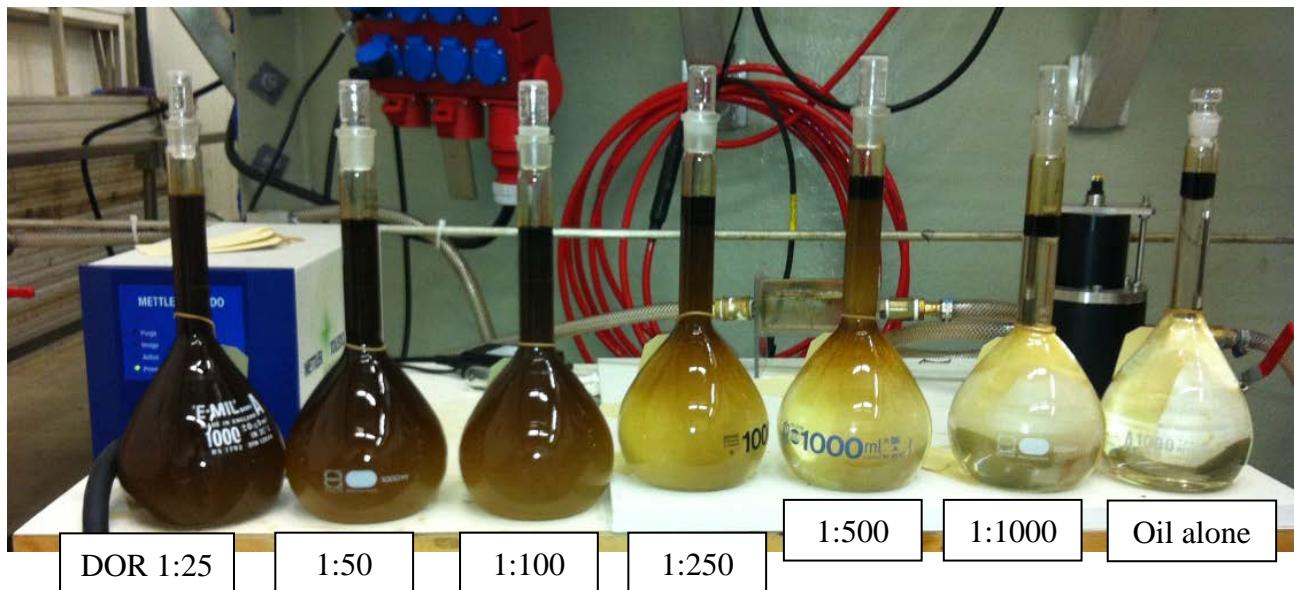


Figure 5.13: Example of oil and water samples taken from the Tower basin for IFT measurements. The picture is taken after approximately 15 minutes of settling. The large droplets have already risen and formed a surface layer in the neck of the bottles. The colour of the samples reflects the concentration and droplet sizes of the remaining dispersed oil. The labels give the used DORs.

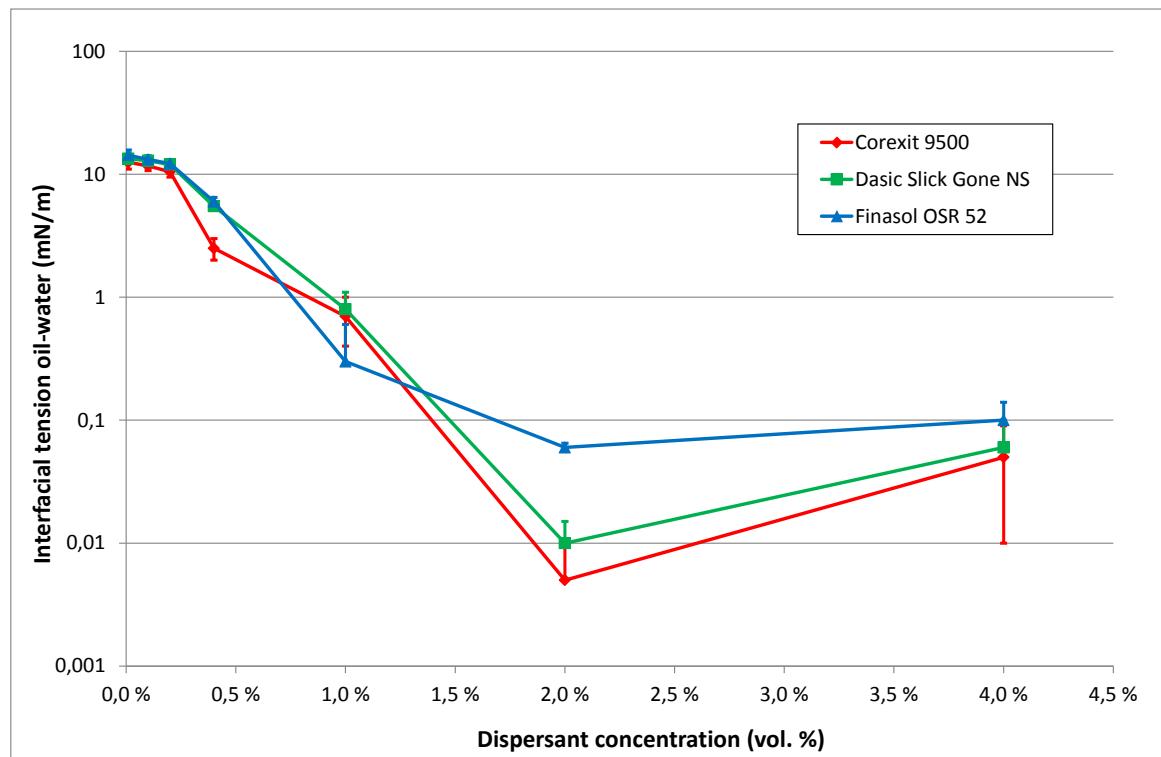


Figure 5.14: IFT as a function of dispersant type and dosage measured on samples taken in-situ in the Tower basin during effectiveness testing of the three dispersants. Dispersant effectiveness results of the individual dispersants are given on the next pages. Error bars indicate the general standard deviation for the spinning drop instrument.

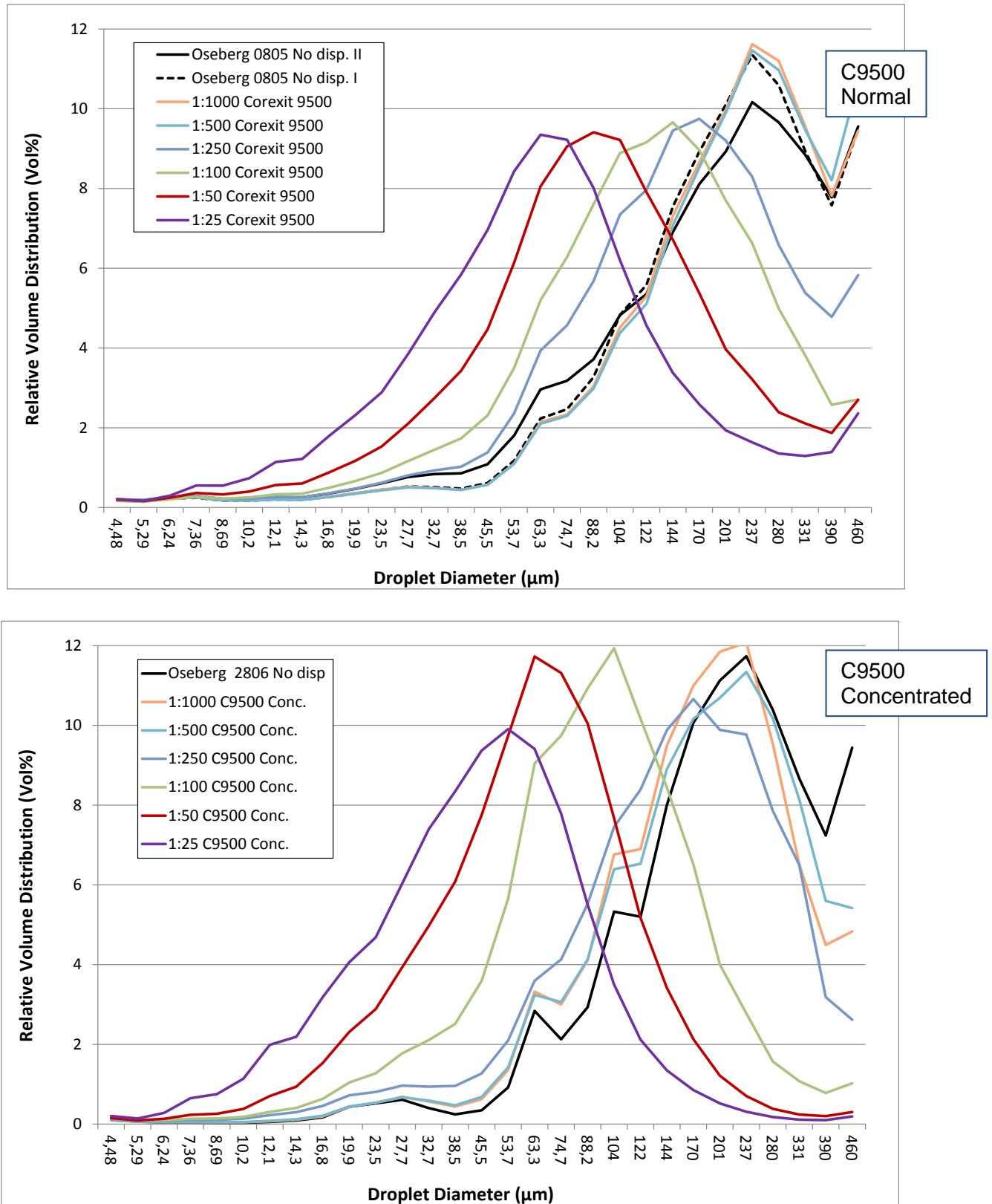


Figure 5.15: Relative droplet size distribution (volume %) as a function of Dispersant to Oil Ratio (DOR) with the Oseberg oil. Release conditions 1,5 mm and 1,2. Dispersant C9500 normal and concentrated version.

Table 5.4: Corexit C9500 DOR experiment: VMD as a function of Dispersant to oil ratio (DOR) for premixed dispersant. Nozzle size 1.5 mm and flow rate 1.5 L/min for the Oseberg oil measured with LISST instrumentation. Interfacial tension measured on oil samples collected in-situ from the oil plume in the Tower basin.

DOR	Maximum peak VMD (μm)	Relative shift in VMD	Cumulative 50% VMD (μm)	Relative shift in VMD	Interfacial tension – Initial (mN/m)
No disp I	237	1,00	170	1,00	12.5
No disp II	237	1,00	170	1,00	11.7±1
1000	237	1,00	201	1,18	10.5±1
500	237	1,00	201	1,18	2.5
250	170	0,72	144	0,85	0.7±0.3
100	144	0,61	104	0,61	0.006±0.005
50	88	0,37	75	0,44	0.05±0.04
25	63	0,27	54	0,32	-----

Table 5.5: Corexit C9500 (concentrated version) DOR experiment: VMD as a function of Dispersant to oil ratio (DOR) for premixed dispersant. Nozzle size 1.5 mm and flow rate 1.2 L/min for the Oseberg oil measured with LISST instrumentation. Interfacial tension measured on oil samples collected from the oil plume in the Tower basin.

DOR	Maximum peak VMD (μm)	Relative shift in VMD	Cumulative 50% VMD (μm)	Relative shift in VMD	Interfacial tension - Initial (mN/m) *
No disp I	237	1,00	170	1,00	18,1
No disp II					
1000	237	1,00	144	0,85	7,5
500	237	1,00	170	1,00	2,4
250	170	0,72	144	0,85	0,7
100	104	0,44	75	0,44	0,09
50	63	0,27	53	0,31	0,07
25	54	0,23	39	0,23	0,05

* IFT values are from API Phase-I Report (Brandvik et al., 2014)

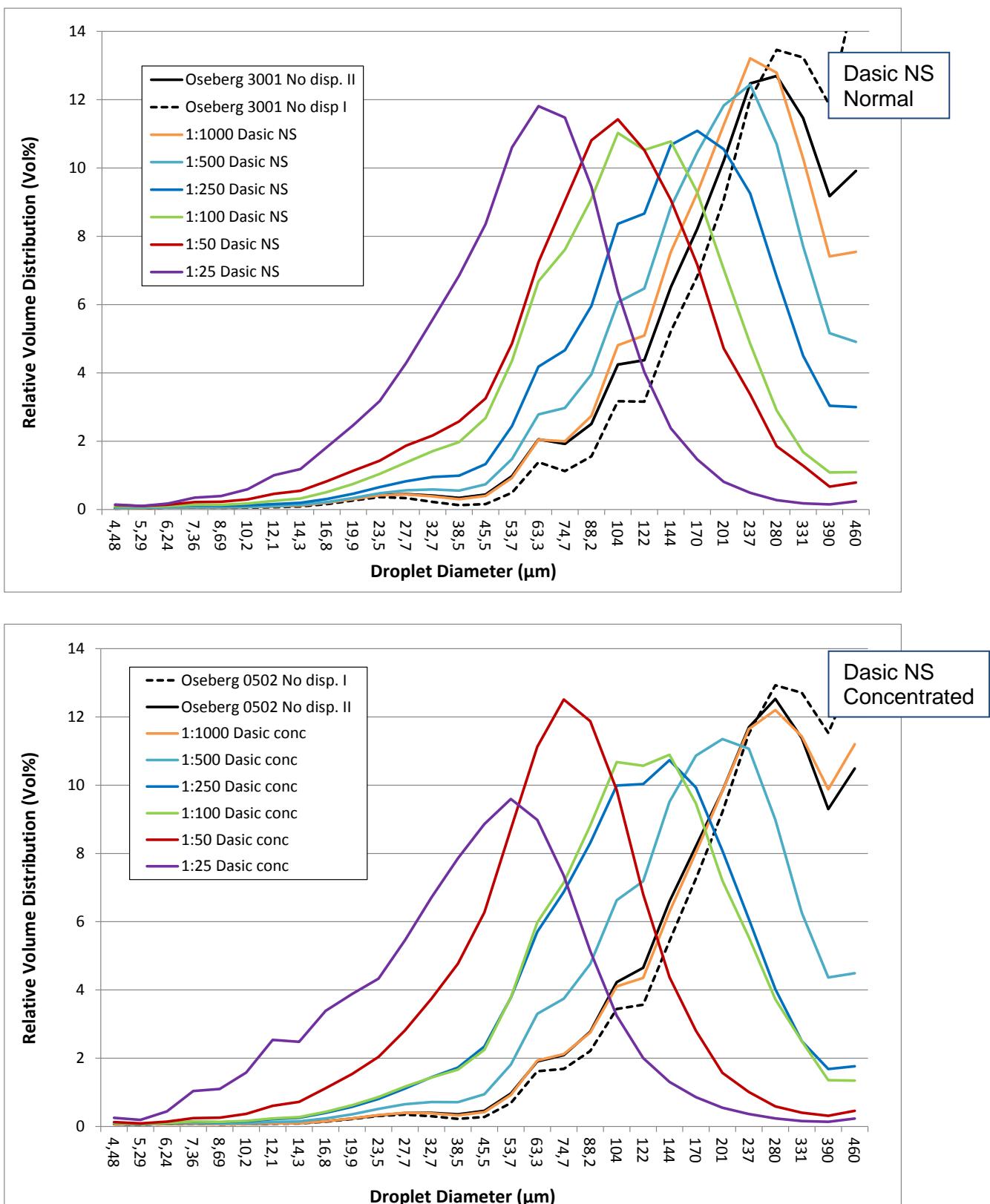


Figure 5.16: Relative droplet size distribution (volume %) as a function of Dispersant to Oil Ratio (DOR) with the Oseberg oil. Release conditions 1,5 mm and 1,2. Dispersant Basic NS Slickgone normal and concentrated version.

Table 5.6: Basic Slickgone NS DOR experiment: VMD as a function of Dispersant to oil ratio (DOR) for premixed dispersant. Nozzle size 1.5 mm and flow rate 1.5 L/min for the Oseberg oil measured with LISST instrumentation. Interfacial tension measured on oil samples collected in-situ from the oil plume in the Tower basin.

DOR	Maximum peak VMD (µm)	Relative shift in VMD	Cumulative 50% VMD (µm)	Relative shift in VMD	Interfacial tension – Initial (mN/m)
No disp I	280	1,00	237	1,0	11.6±0.6
No disp II	280	1,00	237	1,0	13.4±0.8
1000	237	0,85	201	0,85	12.9
500	237	0,85	170	0,72	12±0.7
250	170	0,61	122	0,51	5.5±1.3
100	104	0,37	88	0,37	1.7.....0.3
50	104	0,37	88	0,37	0.02....0.001
25	63	0,23	54	0,23	0.06±0.04

Table 5.7: Basic Slickgone NS (concentrated version) DOR experiment: VMD as a function of Dispersant to oil ratio (DOR) for premixed dispersant. Nozzle size 1.5 mm and flow rate 1.5 L/min for the Oseberg oil measured with LISST instrumentation. Interfacial tension measured on oil samples collected in-situ from the oil plume in the Tower basin.

DOR	Maximum peak VMD (µm)	Relative shift in VMD	Cumulative 50% VMD (µm)	Relative shift in VMD	Interfacial tension - Initial (mN/m)
No disp I	280	1,00	237	1,00	14.9
No disp II	280	1,00	201	0,85	14.3
1000	280	1,00	201	0,85	14.7
500	201	0,72	144	0,61	12.0
250	144	0,51	104	0,44	3.0±0.9
100	144	0,51	104	0,44	0.4±0.1
50	75	0,27	63	0,27	0.3---0.02
25	54	0,19	39	0,16	0.07±0.03

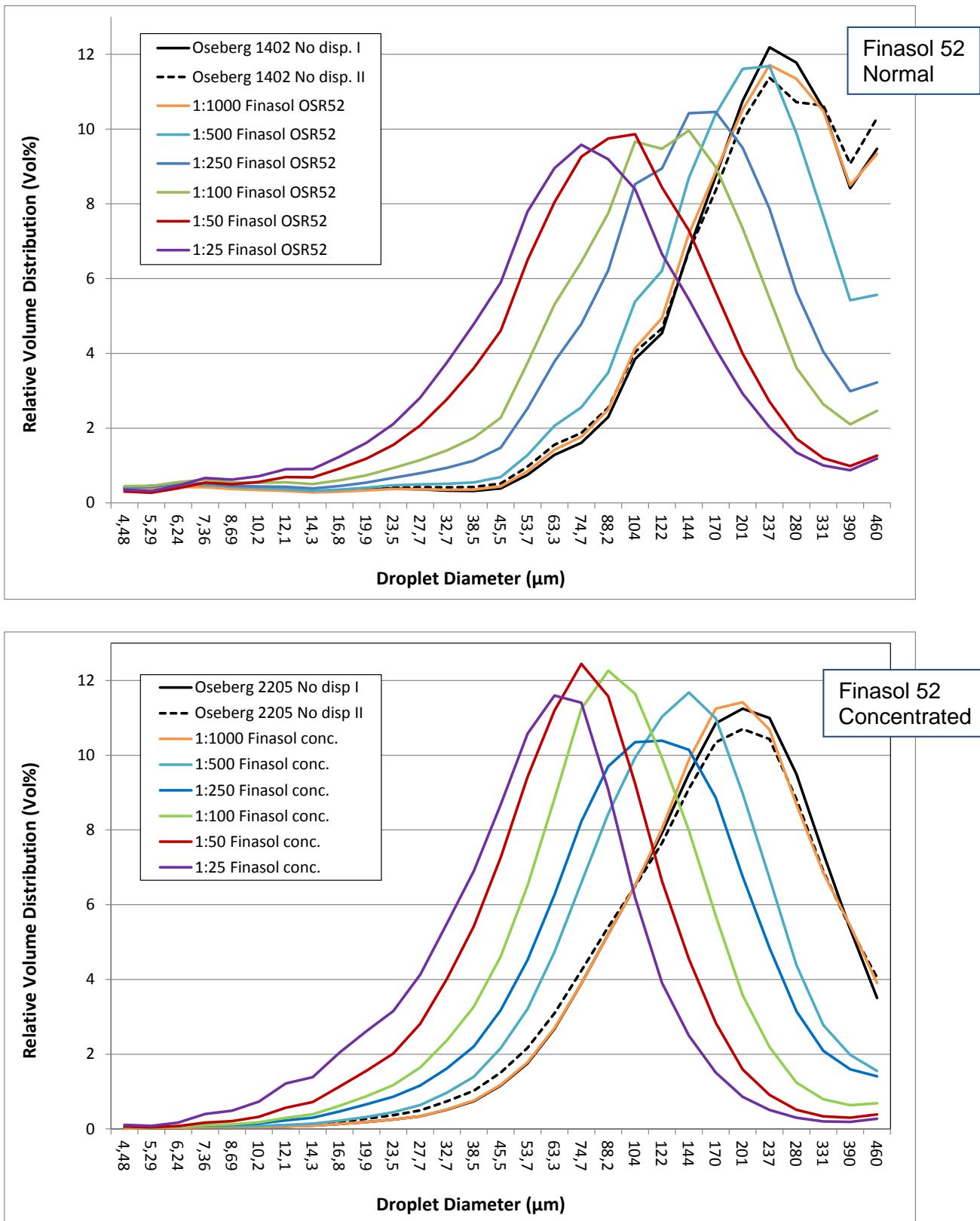


Figure 5.17: Relative droplet size distribution (volume %) as a function of Dispersant to Oil Ratio (DOR) with the Oseberg oil. Release conditions 1,5 mm and 1,2. Dispersant Finasol 52 normal and concentrated version.

Table 5.8: Finasol OSR 52 DOR experiment: VMD as a function of Dispersant to oil ratio (DOR) for premixed dispersant. Nozzle size 1.5 mm and flow rate 1.5 L/min for the Oseberg oil measured with LISST instrumentation. Interfacial tension measured on oil samples collected in-situ from the oil plume in the Tower basin.

DOR	Maximum peak VMD (μm)	Relative shift in VMD	Cumulative 50% VMD (μm)	Relative shift in VMD	Interfacial tension – Initial (mN/m)
No disp I	237	1,00	201	1,00	14.3 \pm 0.3
No disp II	237	1,00	201	1,00	8.7 \pm 0.1
1000	237	1,00	201	1,00	13.2 \pm 0.8
500	237	1,00	170	0,85	12.2 \pm 0.3
250	170	0,72	122	0,61	6.0 \pm 2
100	144	0,61	104	0,52	1.0----0.07
50	104	0,44	75	0,37	0.06 \pm 0.04
25	75	0,32	63	1,00	0.3.....0.02

Table 5.9: Finasol OSR 52 (concentrated version) DOR experiment: VMD as a function of Dispersant to oil ratio (DOR) for premixed dispersant. Nozzle size 1.5 mm and flow rate 1.5 L/min for the Oseberg oil measured with LISST instrumentation. Interfacial tension measured on oil samples collected in-situ from the oil plume in the Tower basin.

DOR	Maximum peak VMD (μm)	Relative shift in VMD	Cumulative 50% VMD (μm)	Relative shift in VMD	Interfacial tension - Initial (mN/m)
No disp I	201	1,00	144	1,00	11.6 \pm 0.6
No disp II	201	1,00	144	1,00	9.6 \pm 0.7
1000	201	1,00	144	1,00	14.3 \pm 0.6
500	144	0,85	104	0,72	12.0 \pm 0.3
250	122	0,61	88	0,61	4.7 \pm 0.6
100	88	0,52	75	0,52	0.02 \pm 0.01
50	75	0,37	63	0,44	0.3----0.04
25	63	0,31	54	0,38	0.2----0.06

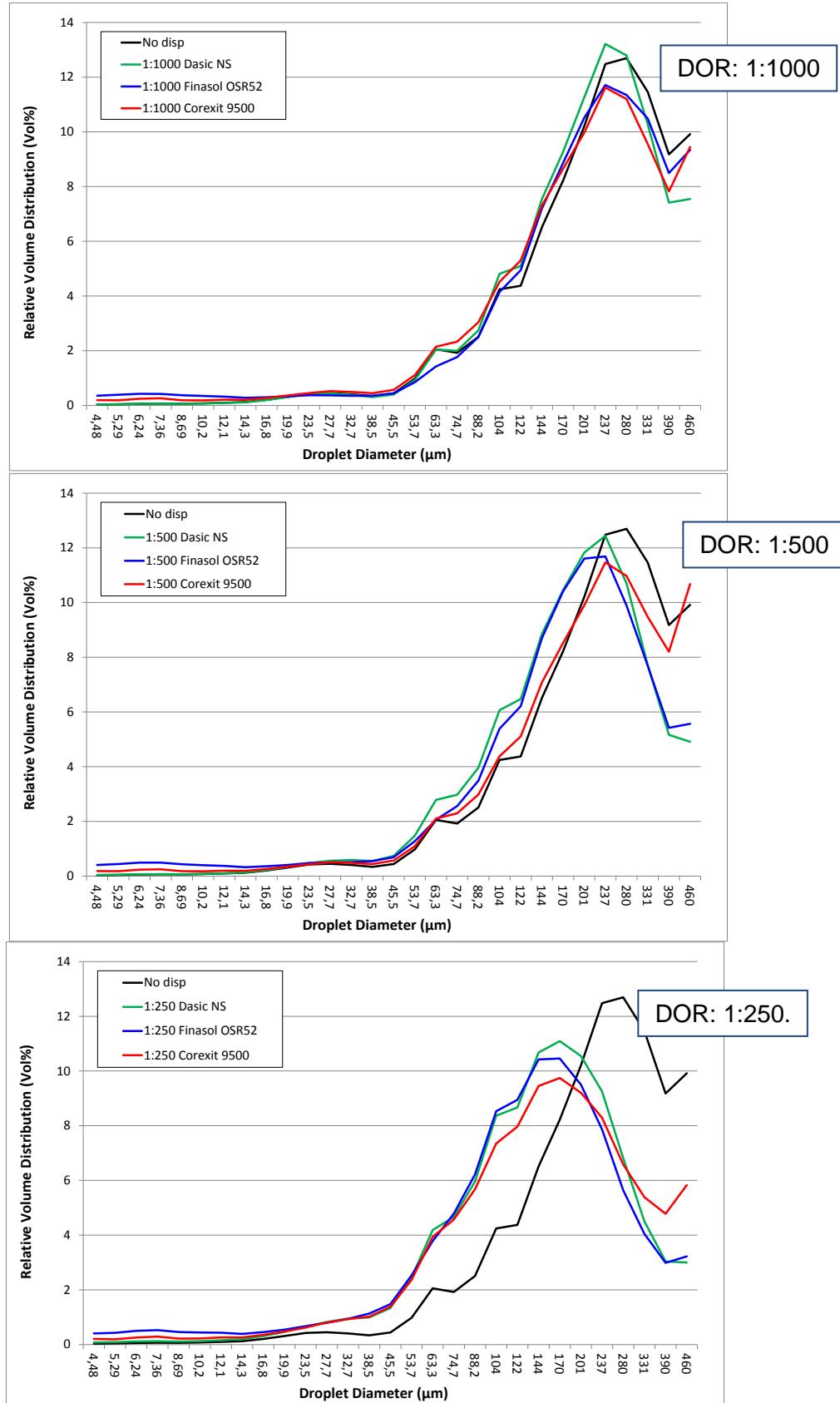


Figure 5.18: All dispersants at low DORs: Relative droplet size distribution (volume %) as a function of different DORs with upstream injection. Release conditions 1,5 mm /1,2 L/min. Dispersants; C9500, Finasol 52 and Dasic NS.

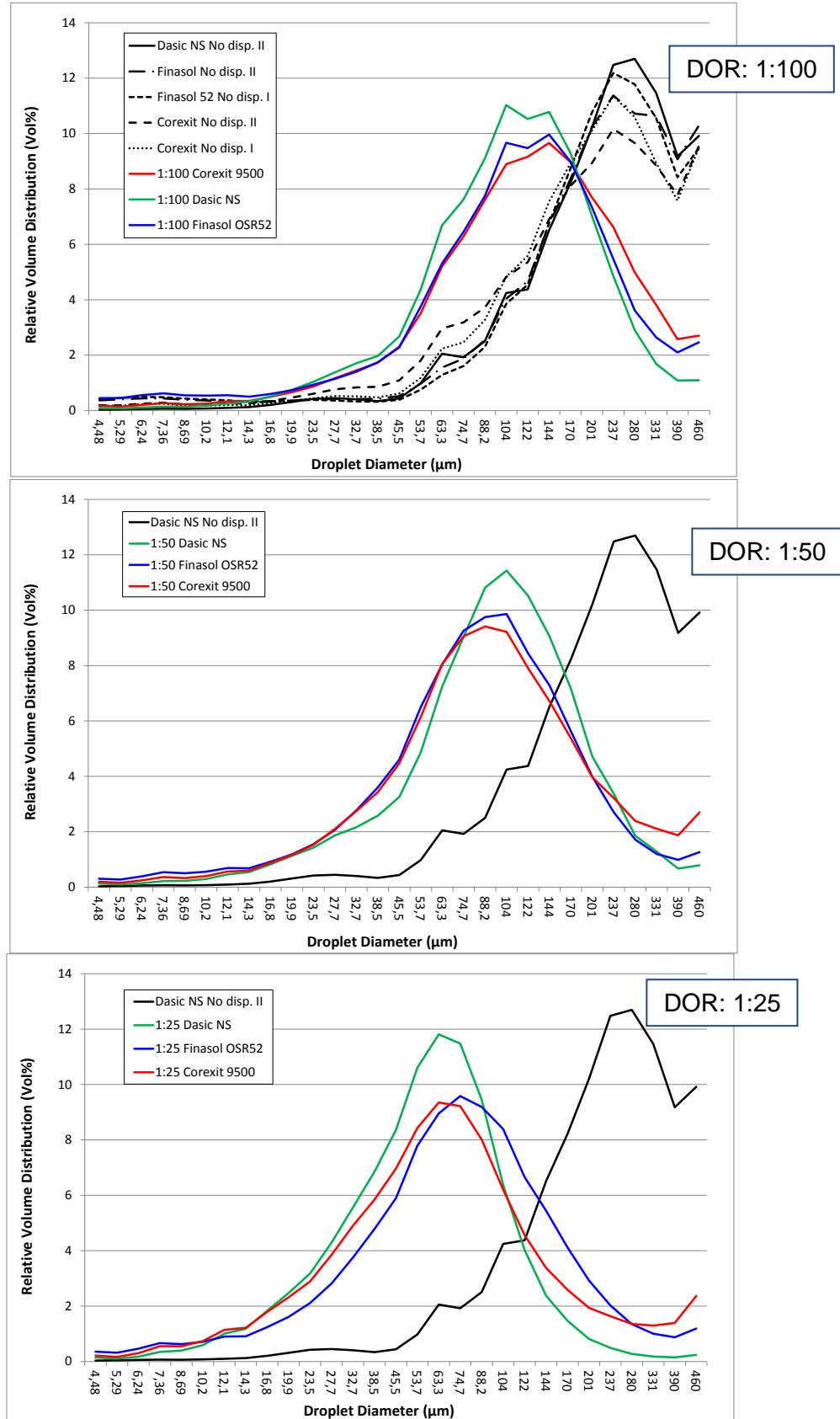


Figure 5.19: All dispersants at high DORs: Relative droplet size distribution (volume %) as a function of DORs with upstream injection. Release conditions 1,5 mm /1,2 L/min. Dispersants; C9500, Finasol 52 and Dasic NS.

5.5 Dispersant effectiveness as a function of dispersant and oil type

Earlier experiments in Phase I have mainly been performed with Oseberg blend and Corexit C9500 (Brandvik et al., 2014). In this section, experiments with four different oil types and three different dispersants are presented, see table below. All these experiments have been performed with simulated insertion tool (see Figure 4.6), and two different dispersant dosages (1:100 or 1:50).

Table 5.10: Experimental conditions for the new dispersant experiments

Nozzle diameter:	One – 1,5 mm
Flow rate:	One – 1,2 L/min
Gas-oil-ratio:	Oil alone
Water temperature:	8-10 °C
Oil injection temperature:	13-15 °C
Number of replicate experiments:	None
Dispersant application technique:	One - Simulated injection tool
Dispersant:	Three: C9500, Dasic NS and Finasol 52
Oil type:	Four: Oseberg, Grane, Norne and Kobbe
DORs	Two: 1:50 and 1:100

The testing with each dispersant was performed as separate Tower basin experiments with the four oil types utilizing the new separate oil tanks (Figure 4.2). With these new and smaller oil tanks, experiments with all four oil types (4 x 7 L), one dispersant (two dosages) can be performed in the same volume of water.

Data and images from the following experiments are presented on the figures on the next pages.

Exp no	ID in figures (date)	Dispersant
13	21.03	Dasic NS
19	30.04	C9500
24	31.05	Finasol 52
23	24.05	C9500 (additional Grane experiments to verify flow rate)

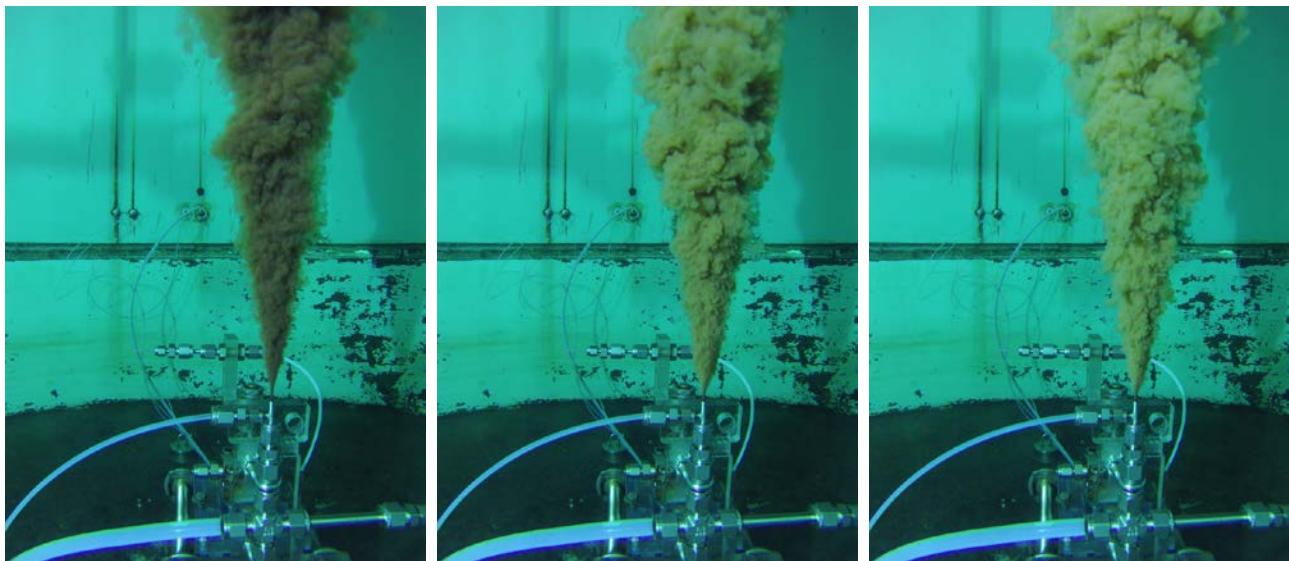
Oil alone**1%****2%**

Figure 5.20: Norne: Oil alone and dispersant injection at DOR 1:100 (1%) and 1:50 (2%), with 1.5 mm nozzle, 1.2 L/min and Simulated insertion tool. Dispersant: C9500.

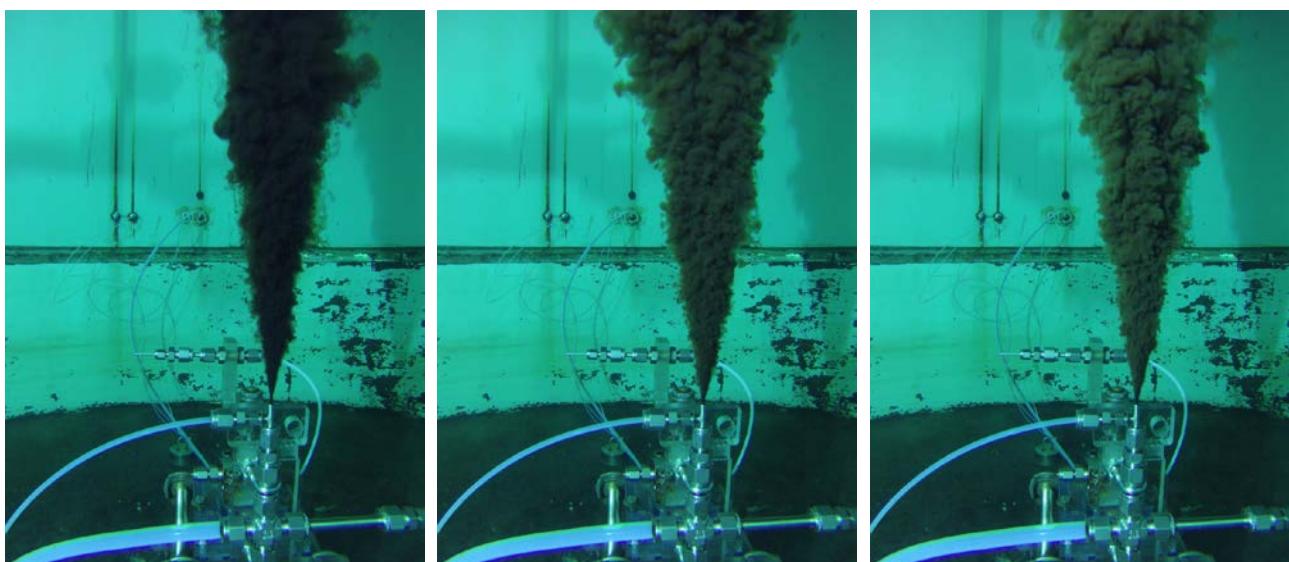
Oil alone**1%****2%**

Figure 5.21: Oseberg: Oil alone and dispersant injection at DOR 1:100 (1%) and 1:50 (2%), with 1.5 mm nozzle, 1.2 L/min and Simulated insertion tool. Dispersant: C9500.

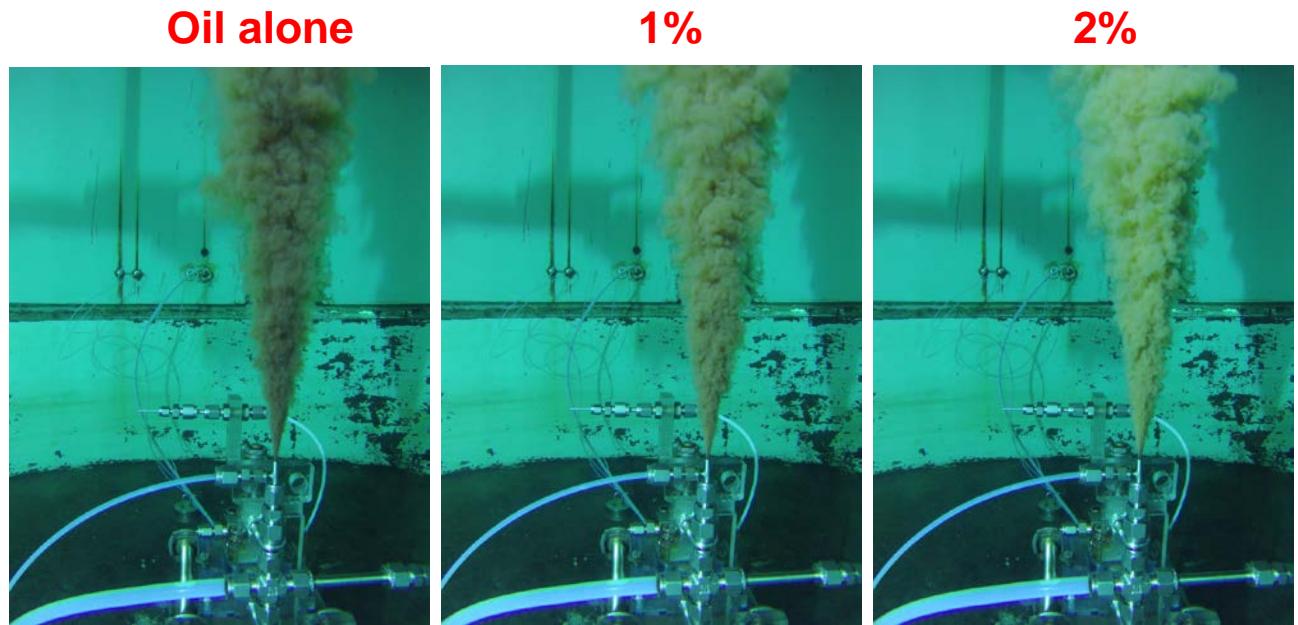


Figure 5.22: Kobbe: Oil alone and dispersant injection at DOR 1:100 (1%) and 1:50 (2%), with 1.5 mm nozzle, 1.2 L/min and Simulated insertion tool. Dispersant: C9500.

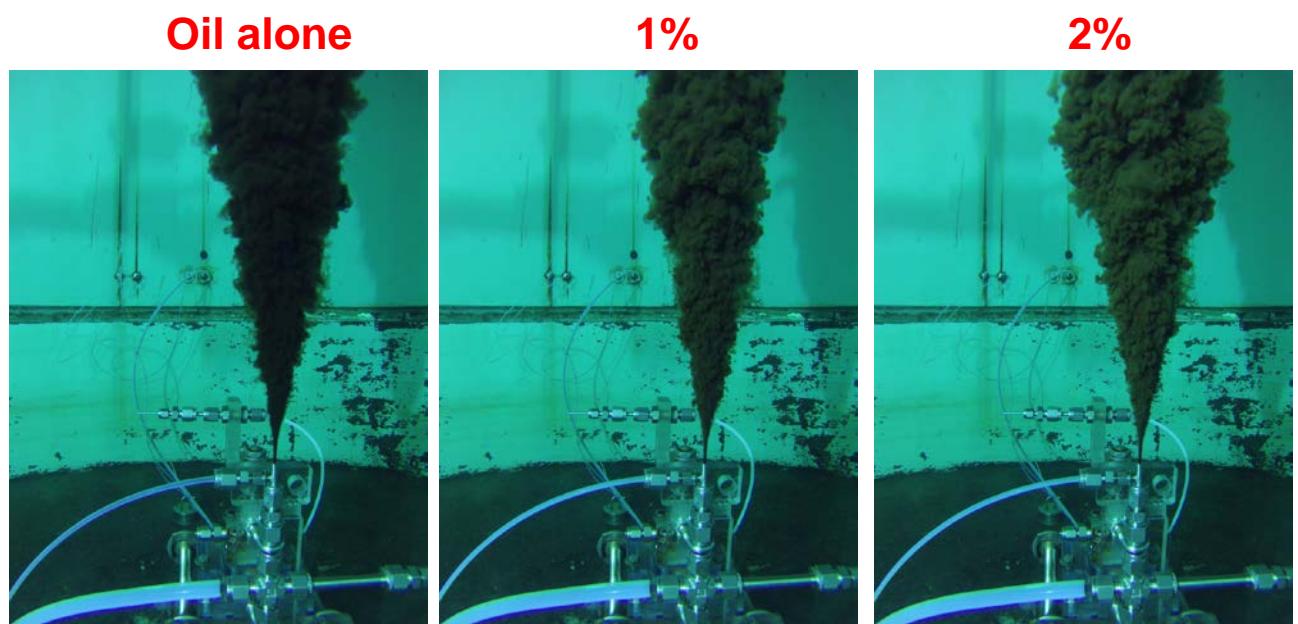


Figure 5.23: Grane: Oil alone and dispersant injection at DOR 1:100 (1%) and 1:50 (2%), with 1.5 mm nozzle, 1.2 L/min and Simulated insertion tool. Dispersant: C9500.

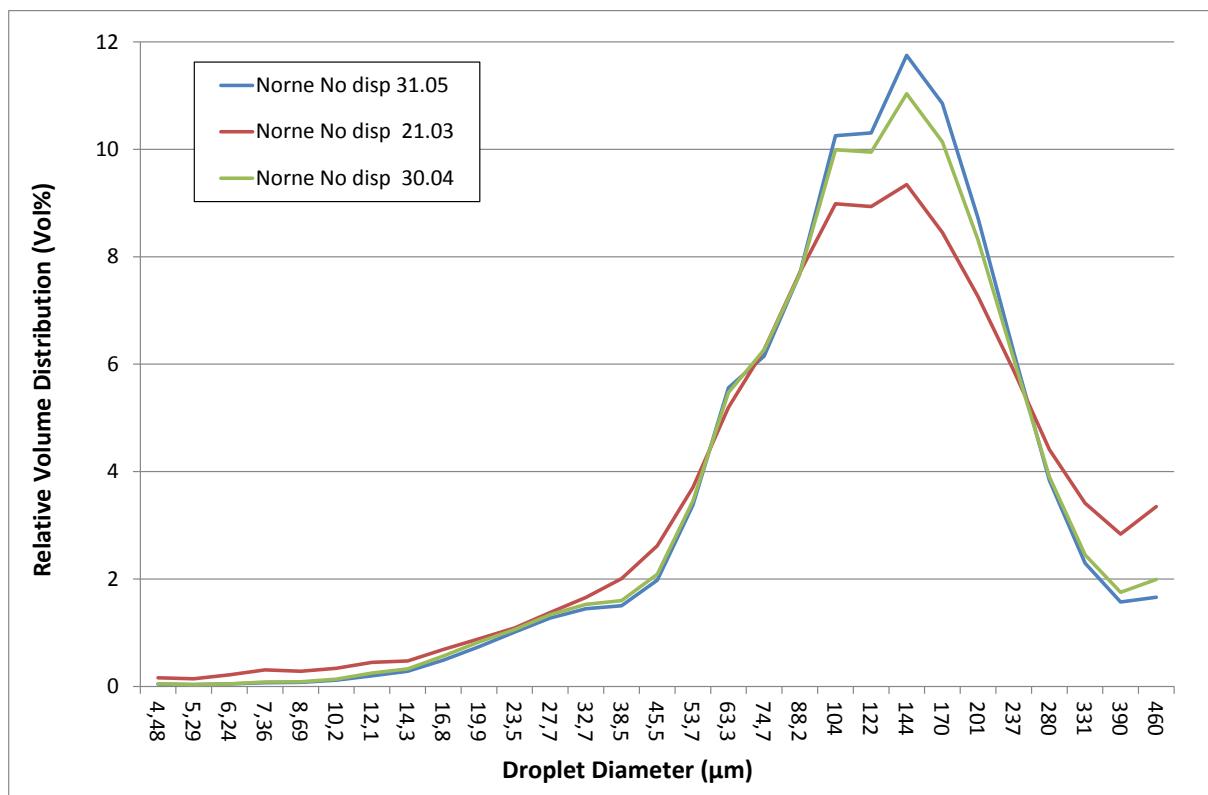


Figure 5.24: **Norne no dispersant:** Droplet size distribution (volume %) for the three experiments used to test the three dispersants. Release conditions 1,5 mm and 1,2 L/min.

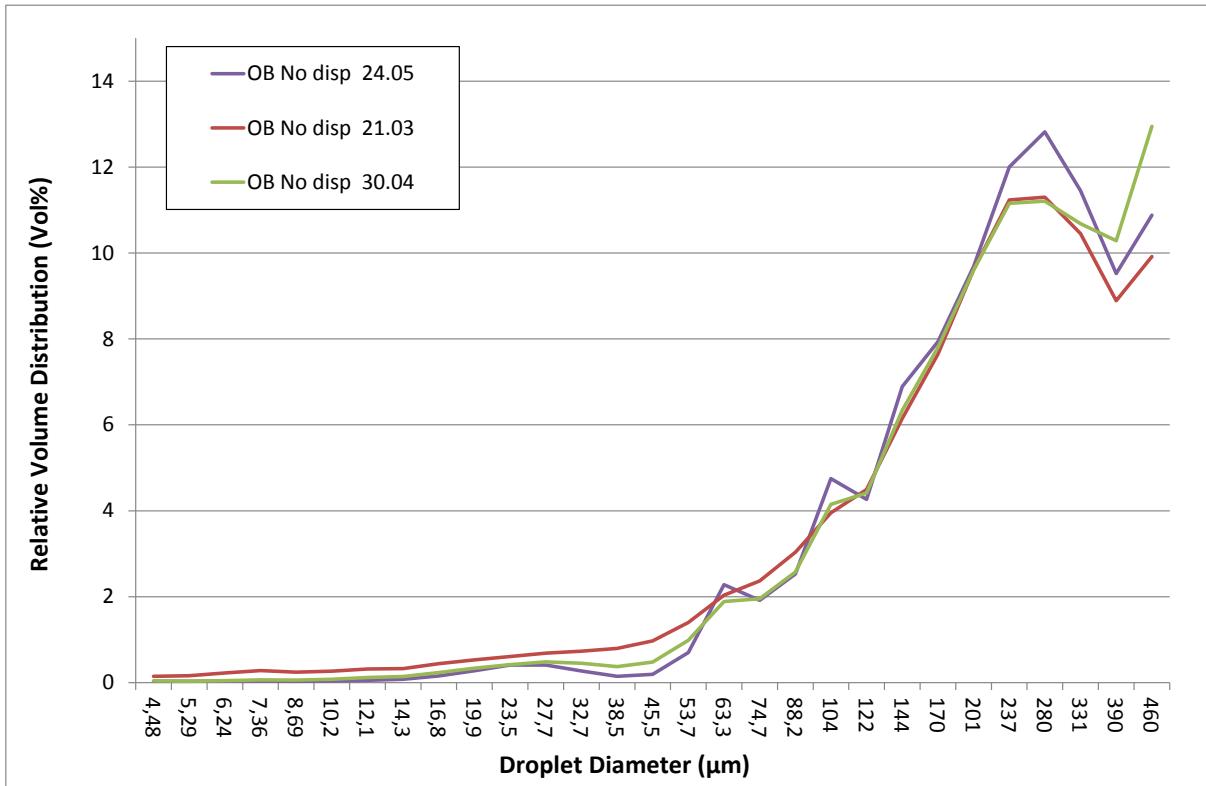


Figure 5.25: **Oseberg no dispersant:** Droplet size distribution (volume %) for the three experiments used to test the three dispersants. Release conditions 1,5 mm and 1,2 L/min.

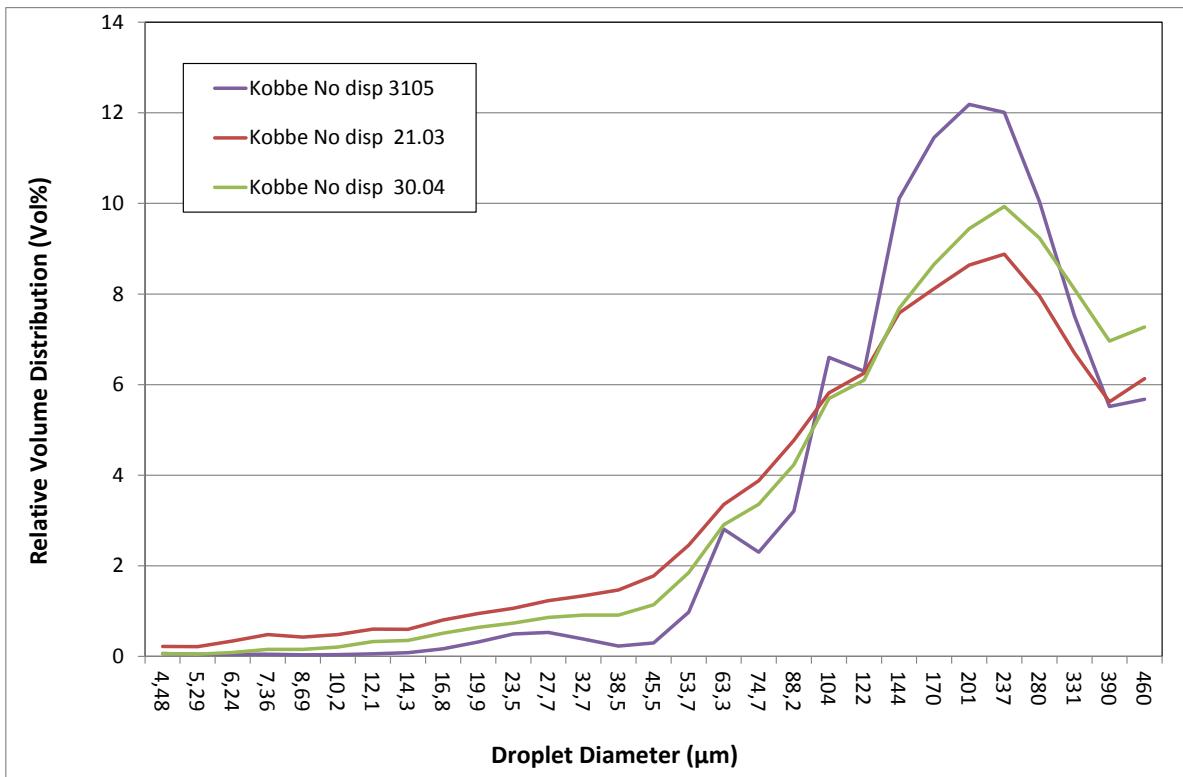


Figure 5.26: **Kobbe no dispersant:** Droplet size distribution (volume %) for the three experiments used to test the three dispersants. Release conditions 1,5 mm and 1,2 L/min.

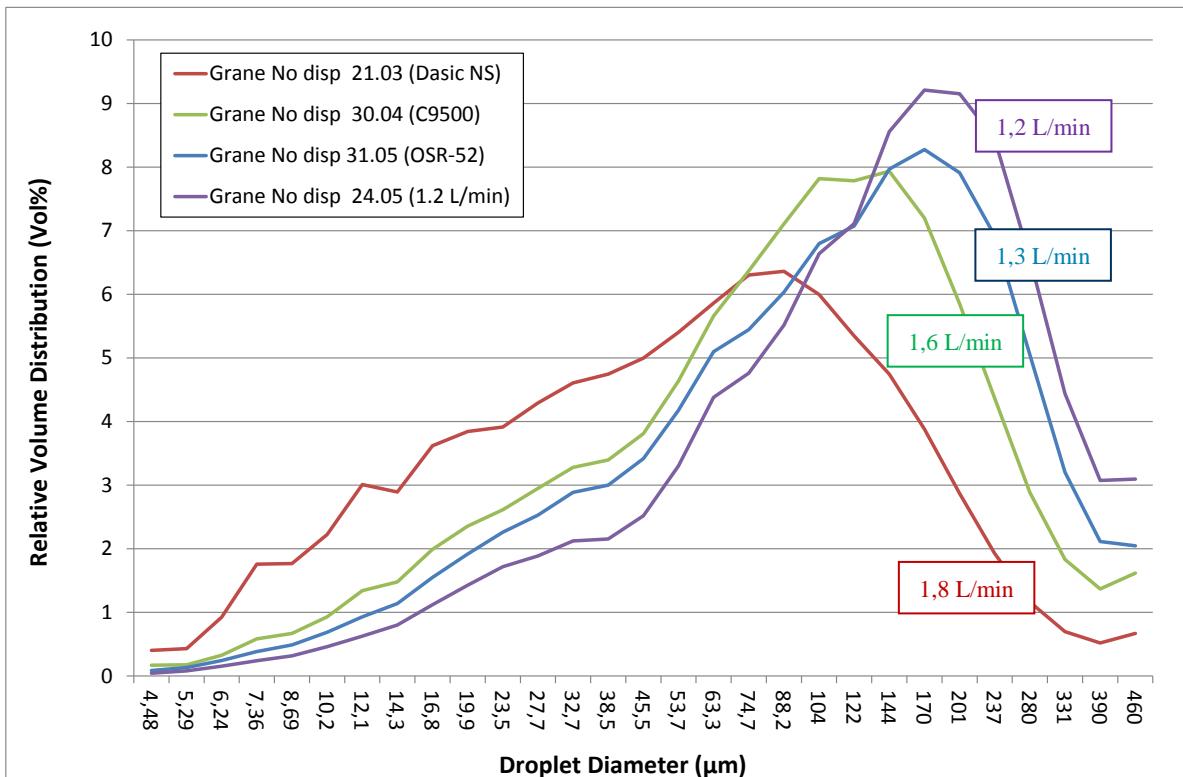


Figure 5.27: **Grane no dispersant:** Droplet size distribution (volume %) for the 3+1 experiments used to test the three dispersants. Release conditions 1,5 mm and 1,8 - 1,2 L/min.

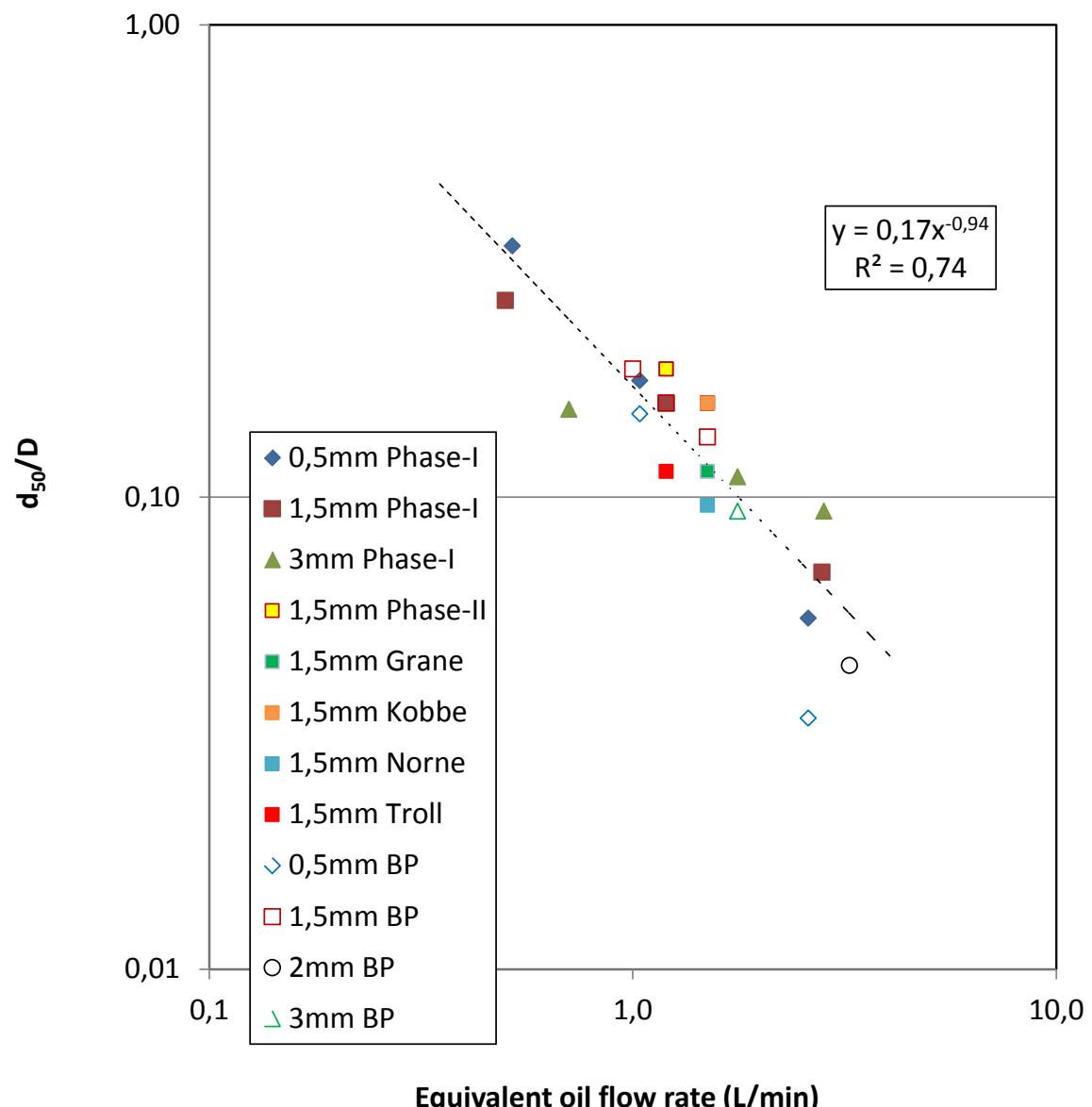


Figure 5.27b: Comparison of VMD (d_{50}) versus flow rate and release diameter from several Tower Basin studies. Results from flow rate experiments presented in a scaled form from an earlier BP study (Brandvik et al., 2013a), API Phase-I (Brandvik et al., 2014) and Phase-II (Tables: 5.1, 5.4, 5.11, 5.13, 5.14 and Figure 5.7). The relative peak diameter d_p/D is plotted vs. equivalent oil flow rates (Q_a). The equivalent oil flow rate refers to an apparent fixed nozzle diameter of 1.5 mm (see equation 2 in Brandvik et al., 2013a).

Most of the data presented in figure 5.27b are with Oseberg blend and only a limited number of experiments are performed with other oils (Troll, Norne, Kobbe and Grane). The oils have different chemical composition, IFT and viscosity.

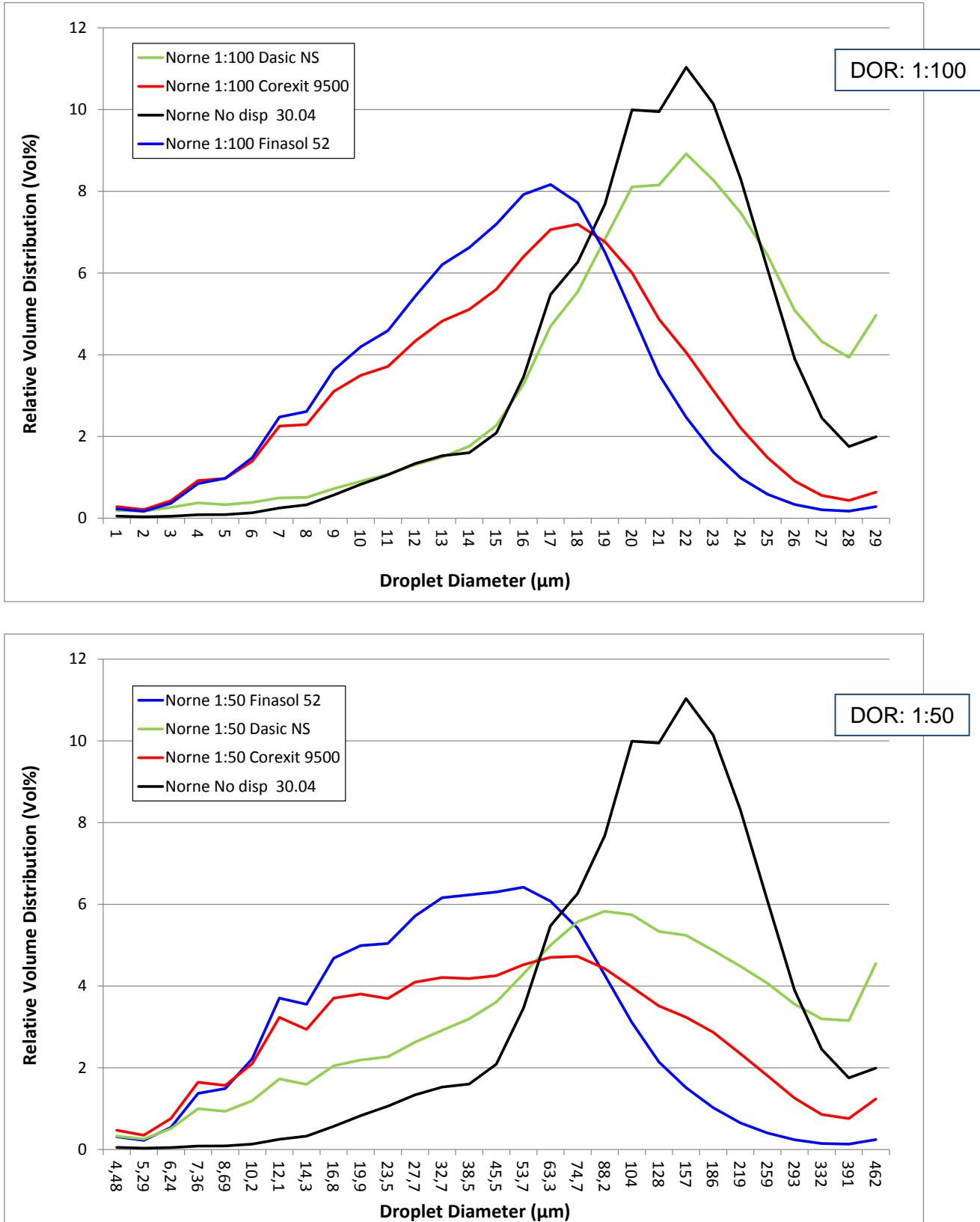


Figure 5.28: Norne: Relative droplet size distribution (volume %) as a function of Dispersant type at two Dispersant to Oil Ratios (1:100 and 1:50). Release conditions 1,5 mm and 1,2 L/min.

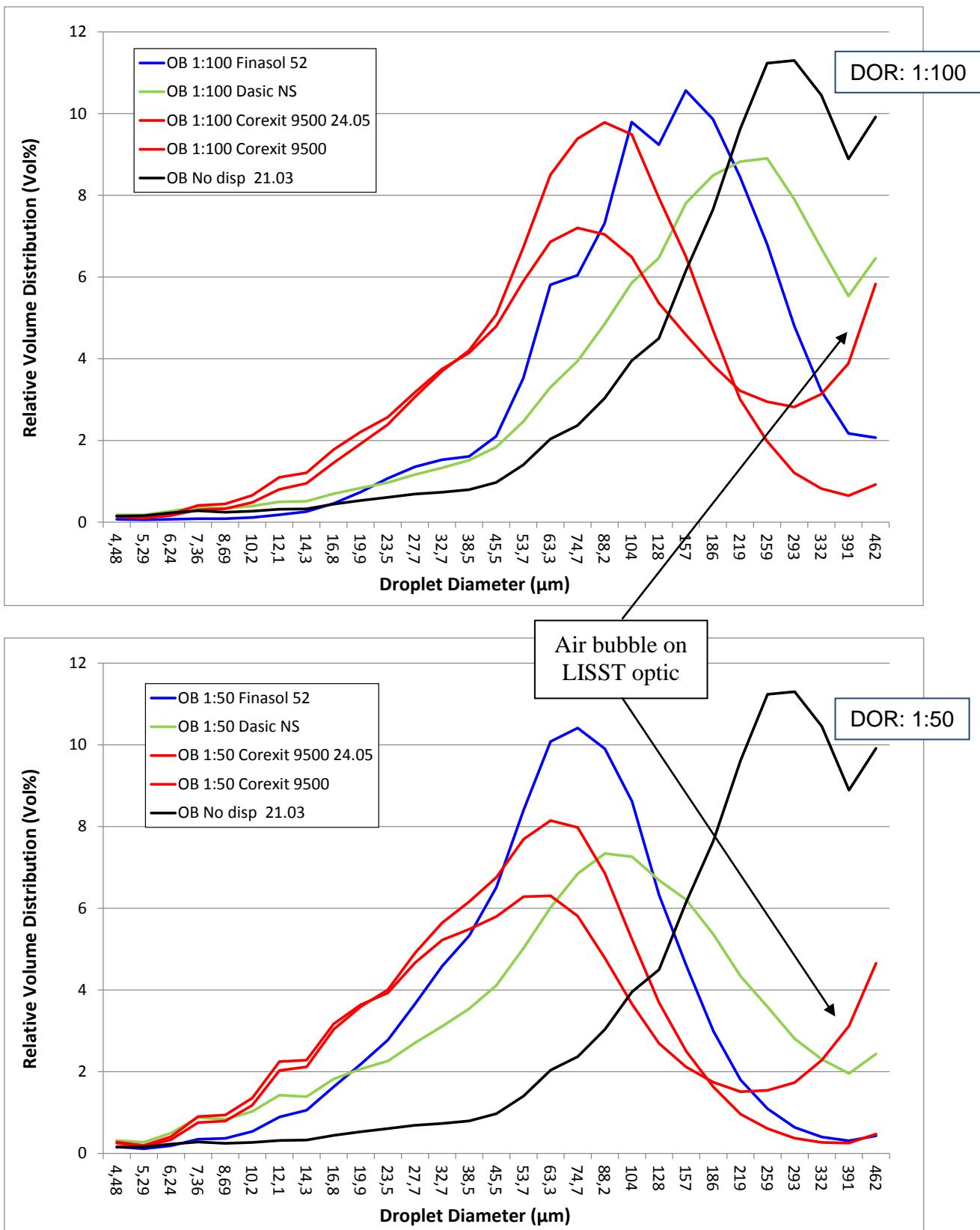


Figure 5.29: Oseberg: Relative droplet size distribution (volume %) as a function of Dispersant type at two Dispersant to Oil Ratios (1:100 and 1:50). Release conditions 1,5 mm and 1,2 L/min.

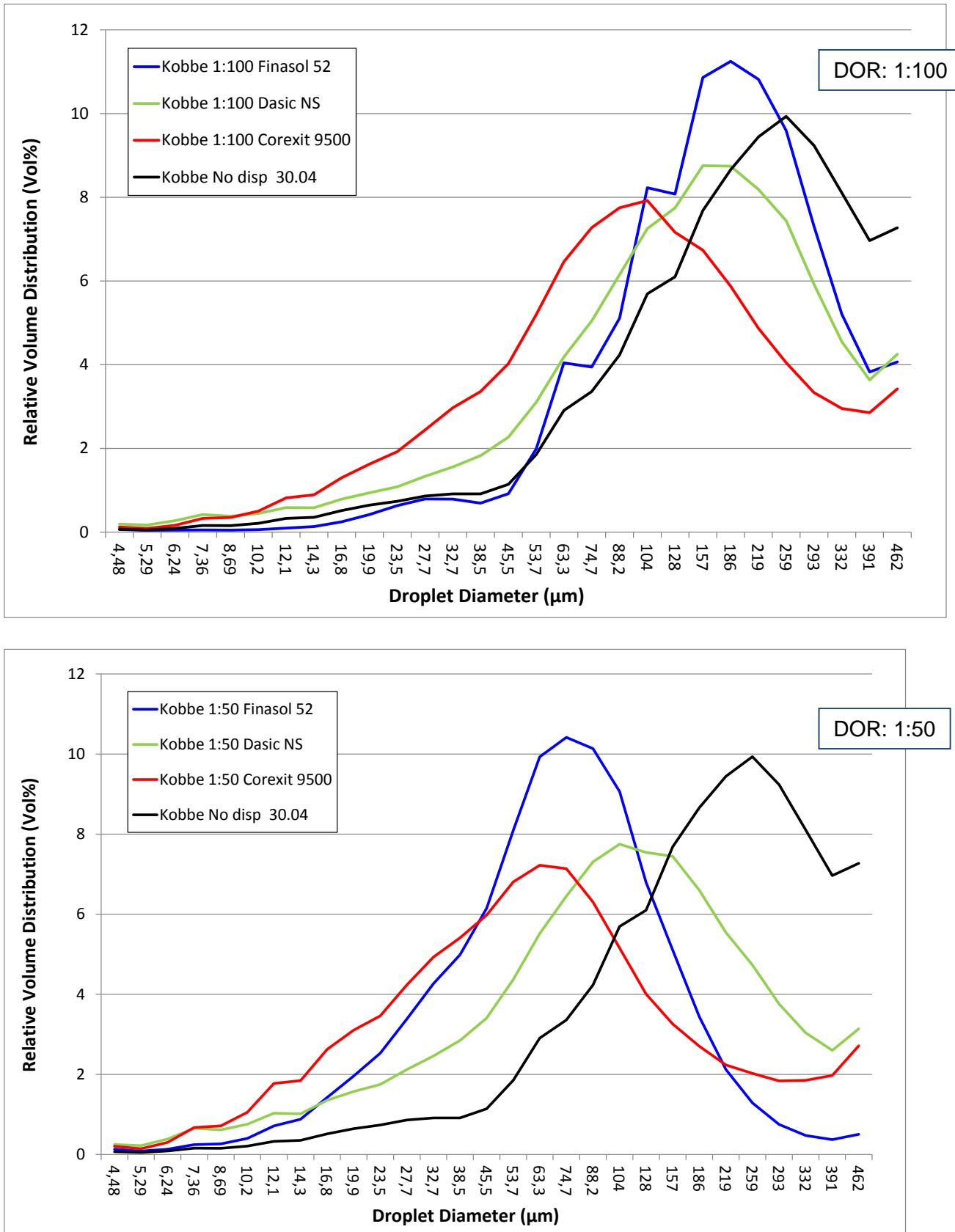


Figure 5.30: Kobbe: Relative droplet size distribution (volume %) as a function of Dispersant type at two Dispersant to Oil Ratios (1:100 and 1:50). Release conditions 1,5 mm and 1,2 L/min.

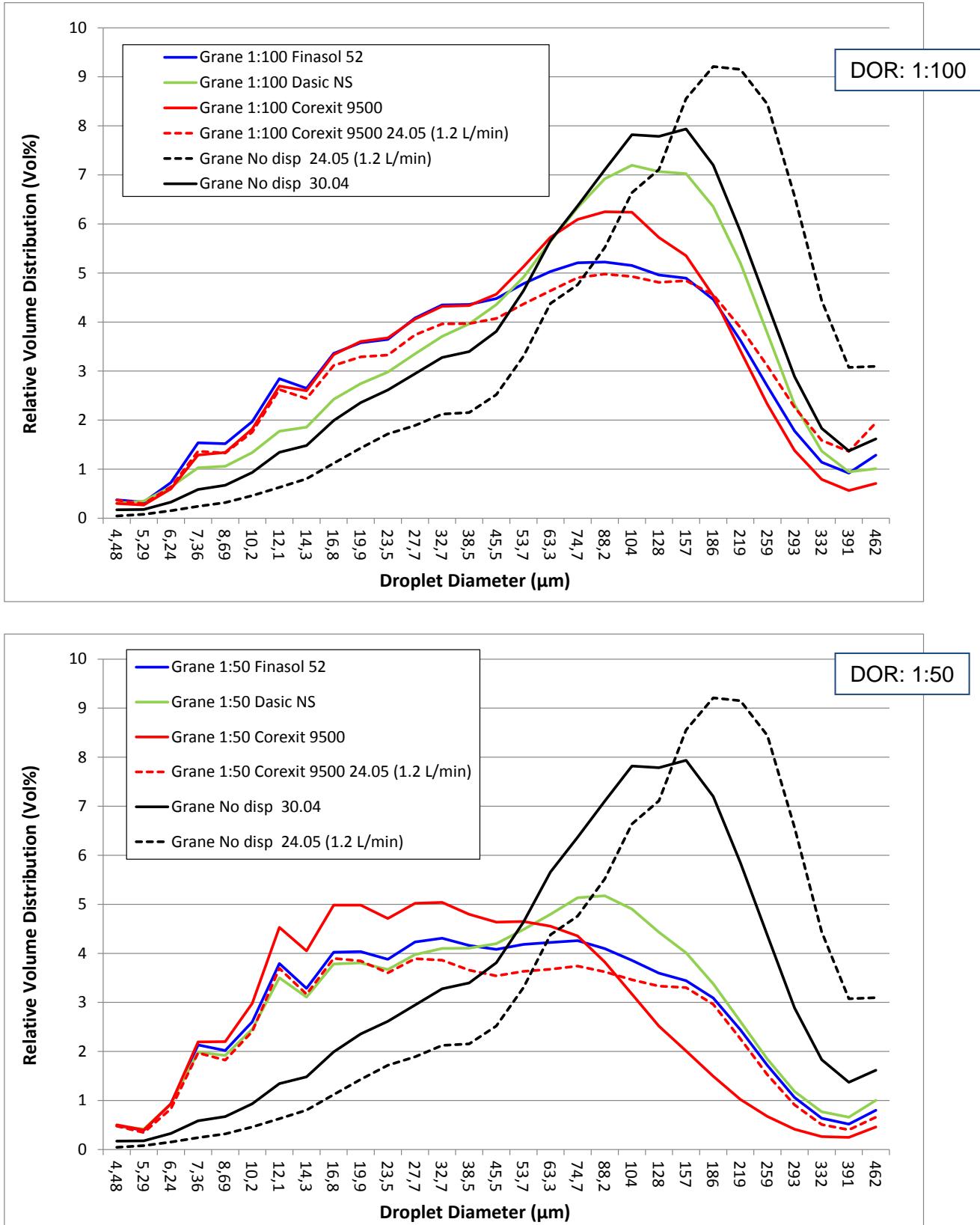


Figure 5.31: Grane: Relative droplet size distribution (volume %) as a function of Dispersant type at two Dispersant to Oil Ratios (1:100 and 1:50). Release conditions 1,5 mm and 1,2 L/min.

Table 5.11: **Norne:** VMD for three different dispersants at two different dosages (DOR 1:100 and 1:50). Dispersant injected with simulated insertion tool (SIT). Nozzle size 1.5 mm and flow rate 1.5 L/min, droplet sizes measured with LISST instrumentation in SINTEF Tower Basin. Interfacial tension measured on oil samples from the oil plume in the Tower basin.

oil/ dispersant/ dosage	Maximum peak VMD (μm)	Relative shift in VMD	Cumulative 50% VMD (μm)	Relative shift in VMD	Interfacial tension - Initial (mN/m)
Norne alone	144/144/144		104/104/104		21.0/20.4/18.2
C9500 1%	75	0,48	46	0,44	2.8±0.3*
Dasic NS 1%	157	1,00	104	1,00	17.0±2.6*
Finasol 52 1%	63	0,40	39	0,38	20.4±0.5*
C9500 2%	75	0,48	39	0,38	0.1±0.5
Dasic NS 2%	88	0,56	75	0,72	1.3±0.4
Finasol 52 2%	54	0,34	33	0,32	0.01±0.05

Table 5.12: **Oseberg:** VMD for three different dispersants at two different dosages (DOR 1:100 and 1:50). Dispersant injected with simulated insertion tool (SIT). Nozzle size 1.5 mm and flow rate 1.5 L/min, droplet sizes measured with LISST instrumentation in SINTEF Tower Basin. Interfacial tension measured on oil samples from the oil plume in the Tower basin.

oil/ dispersant/ dosage	Maximum peak VMD (μm)	Relative shift in VMD	Cumulative 50% VMD (μm)	Relative shift in VMD	Interfacial tension - Initial (mN/m)
Oseberg alone	280/331/280		201/219/219		16.8/17.0/16.2
C9500 1%	75	0,27	75	0,34	15.0±1*
Dasic NS 1%	237	0,85	??	??	16.5±0.3*
Finasol 52 1%	157	0,56	104	0,47	8.7±0.3*
C9500 2%	63	0,23	46	0,21	0.4±0.4
Dasic NS 2%	88	0,31	75	0,34	0.01±0.03
Finasol 52 2%	75	0,27	54	0,25	0.4±0.3

* **NB!** These oil samples taken from the Tower basin during the experiments are probably taken too early after dispersant injection has started. The plume of treated oil has probably not risen to the sampling point above the nozzle. The measured IFT values do not reflect the low values expected for a 1% treated sample and the observed reduction in droplet sizes.

Table 5.13: **Kobbe Condensate:** VMD for three different dispersants at two different dosages (DOR 1:100 and 1:50). Dispersant injected with simulated insertion tool (SIT). Nozzle size 1.5 mm and flow rate 1.5 L/min, droplet sizes measured with LISST instrumentation in SINTEF Tower Basin. Interfacial tension measured on oil samples from the oil plume in the Tower basin.

oil/ dispersant/ dosage	Maximum peak VMD (μm)	Rel shift in VMD	Cumulative 50% VMD (μm)	Rel shift in VMD	Interfacial tension - Initial (mN/m)
Kobbe alone	201/237/237		170/157/186		13.6/16.0/9.5
C9500 1%	104	0,40	88	0,52	16.7±0.6*
Dasic NS 1%	157	0,61	128	0,75	19.0±1*
Finasol 52 1%	170	0,66	144	0,85	5.8*
C9500 2%	63	0,24	54	0,32	0.06±0.05
Dasic NS 2%	104	0,40	88	0,52	0.05±0.03
Finasol 52 2%	75	0,29	63	0,37	0.7±0.2

Table 5.14: **Grane:** VMD for three different dispersants at two different dosages (DOR 1:100 and 1:50). Dispersant injected with simulated insertion tool (SIT). Nozzle size 1.5 mm and flow rate 1.5 L/min, droplet sizes measured with LISST instrumentation in SINTEF Tower Basin. Interfacial tension measured on oil samples from the oil plume in the Tower basin.

oil/ dispersant/ dosage	Maximum peak VMD (μm)	Rel shift in VMD	Cumulative 50% VMD (μm)	Rel shift in VMD	Interfacial tension - Initial (mN/m)
Grane alone	186/188/157		104/46/75		10.2/10.6/10.8
C9500 1%	88	0,47	54	0,72	8.3*
Dasic NS 1%	104	0,56	75	1,00	8.9*
Finasol 52 1%	88	0,47	??	??	9.8*
C9500 2%	33	0,18	28	0,37	4.0±1.4
Dasic NS 2%	88	0,47	46	0,61	5.2±0.3
Finasol 52 2%	33	0,18	38	0,51	4.1±0.3

* **NB!** These oil samples taken from the Tower basin during the experiments are probably taken too early after dispersant injection has started. The plume of treated oil has probably not risen to the sampling point 1.5 m above the nozzle. The measured IFT values do not reflect the low values expected for a 1% treated sample and the observed reduction in droplet sizes.

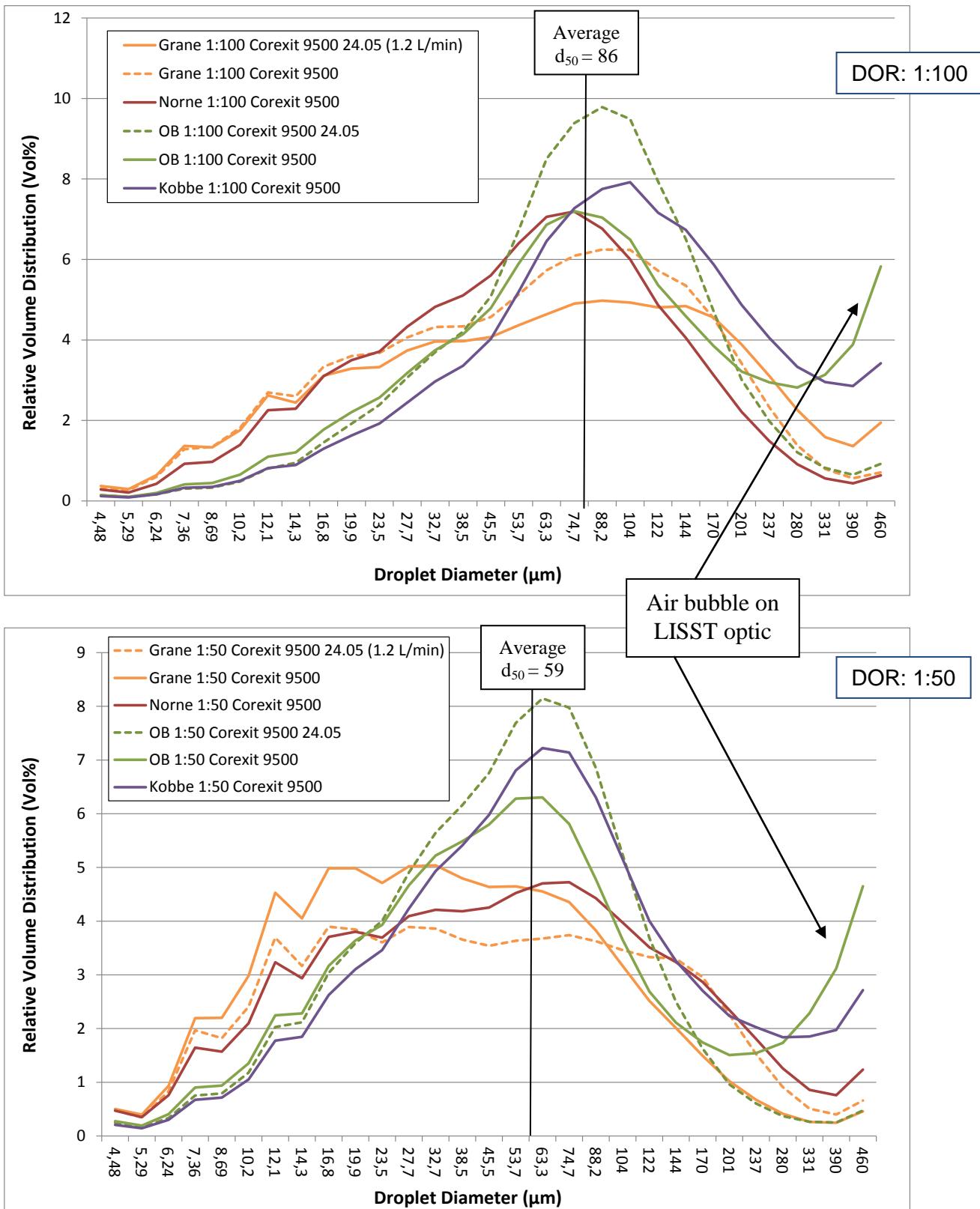


Figure 5.32: Corexit C9500 with all four oil types: Relative droplet size distribution (volume %) as a function of Dispersant type at two Dispersant to Oil Ratios (1:100 and 1:50). Release conditions 1,5 mm and 1,2 L/min.

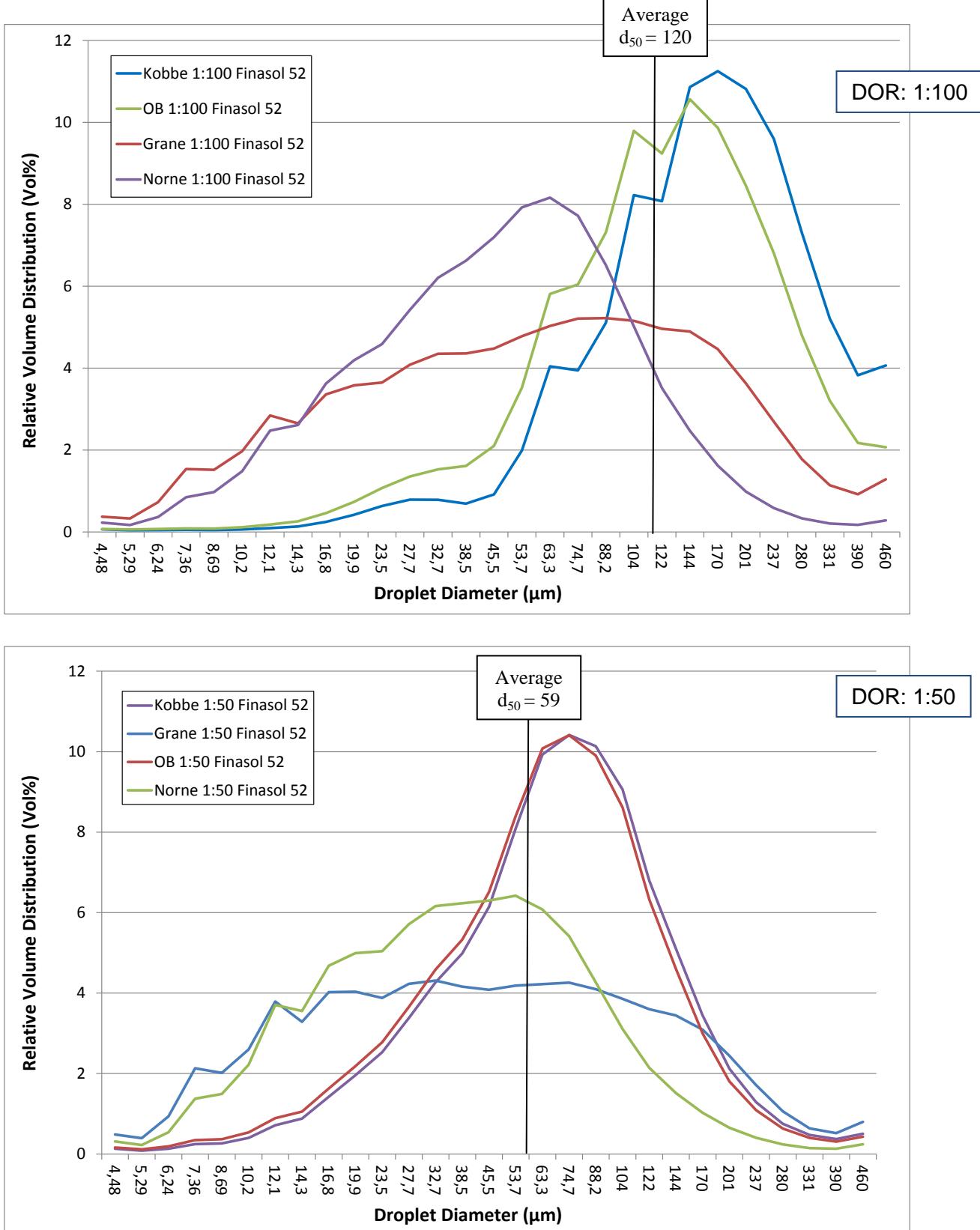


Figure 5.33: Finasol OSR 52 with all four oil types: Relative droplet size distribution (volume %) as a function of Dispersant type at two Dispersant to Oil Ratios (1:100 and 1:50). Release conditions 1,5 mm and 1,2 L/min..

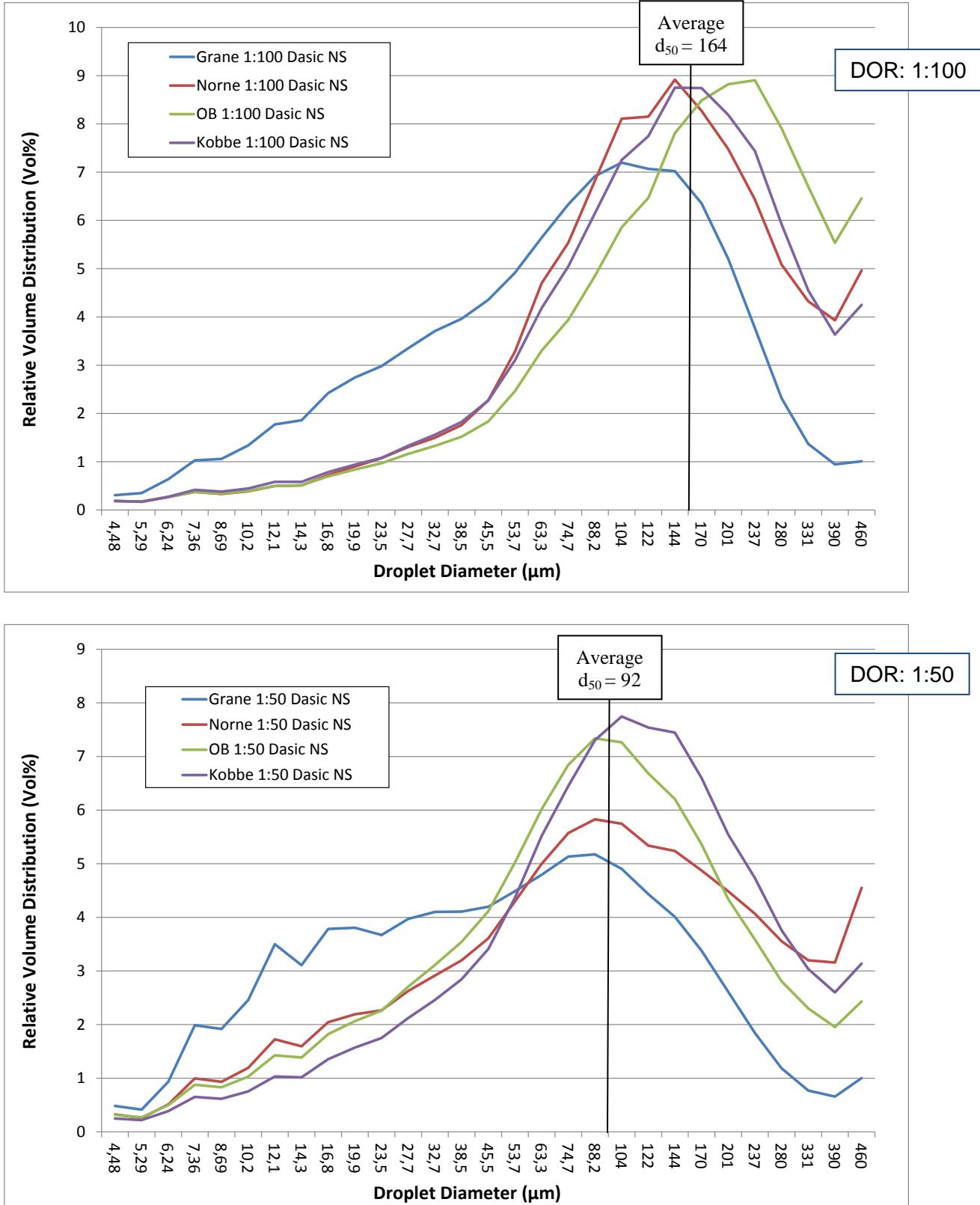


Figure 5.34: Basic Slicigone NS with all four oil types: Relative droplet size distribution (volume %) as a function of Dispersant type at two Dispersant to Oil Ratios (1:100 and 1:50). Release conditions 1,5 mm and 1,2 L/min.

5.6 Mixed releases of oil and gas

Only limited experiments with combined releases with oil, gas and dispersant were performed as a part of Phase I (Brandvik et al., 2014) and no clear conclusions could be drawn from these data. For this reason additional test were done in Phase-II with an intention to answer the following questions:

1. Does the presence of gas (air), released together with oil, influence the droplet size distribution differently than described by available theory (see report from Phase-I)?
2. Does the presence of gas (air), released together with oil, influence the dispersant ability to reduce oil droplet sizes?

In Phase-I of this study most of the experiments were done with oil alone, since both the Laser diffraction instruments (LISST) and in-situ cameras can't differentiate between oil droplets and gas bubbles. For this reason the presence of gas bubbles will complicate or obscure the measurements of the oil droplet size distributions. However, we have performed the following experiments to investigate further how such combined releases influence the droplet size distribution:

- a. Experiments with oil and gas where we keep the oil rate constant and vary the rate of gas added. By designing these experiments carefully we hoped to generate different particle size distributions of oil and gas, so the effect of varying amount of gas on the oil droplet distribution could be studied.
- b. Similar as (a), but with injection of dispersant.
- c. The gas bubble distributions generated in (a) and (b) were studied alone by performing similar experiments using water to simulate oil (same momentum generated with water as with oil in earlier experiments).
- d. The corresponding droplet size distribution of oil-dispersant (no gas) was generated by experiments without gas (and can also be found in previous experiments from Phase-I).

Table 5.15: Experimental conditions for the new dispersant experiments

Nozzle diameter:	One – for example 1.5 mm
Flow rate:	One – for example 1.2 L/min
Water temperature:	8-10 °C
Oil injection temperature:	13-15 °C
Gas-oil-ratio:	Oil alone and varying GOR
Number of replicate experiments:	None
Dispersant application technique:	One - Simulated injection tool or Upstream injection
Dispersant:	One - Corexit 9500
Oil type:	One - Oseberg
GOR:	One - 1:50

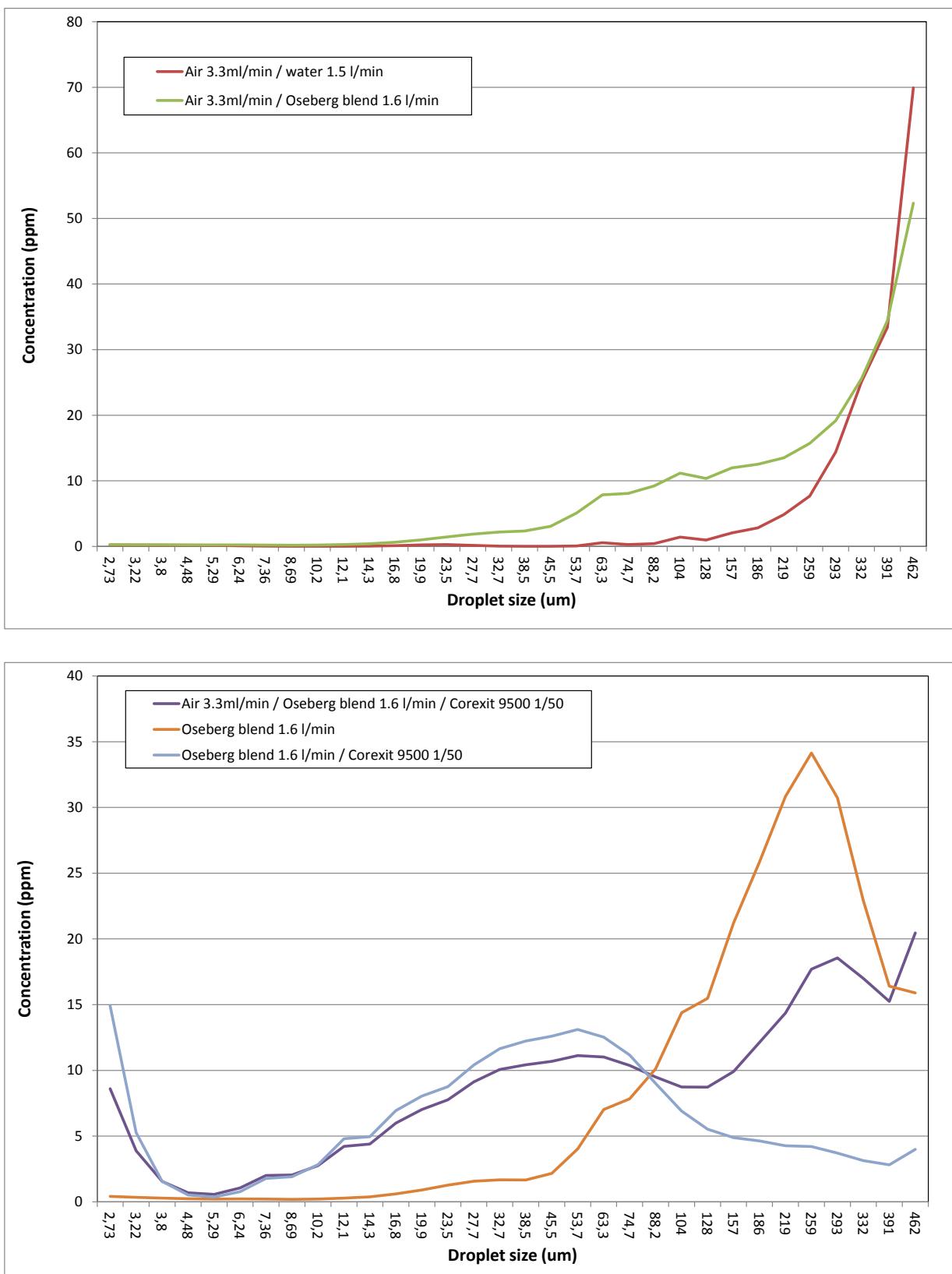


Figure 5.35: Combined experiments with gas (air), Oseberg blend and dispersant (C9500) showing relative droplet size distribution (volume %). DOR 1:50. Experiments in SINTEF Tower Basin. Release conditions 1,5 mm nozzle and 1,5 L/min (water) and 1,6 L/min (oil).

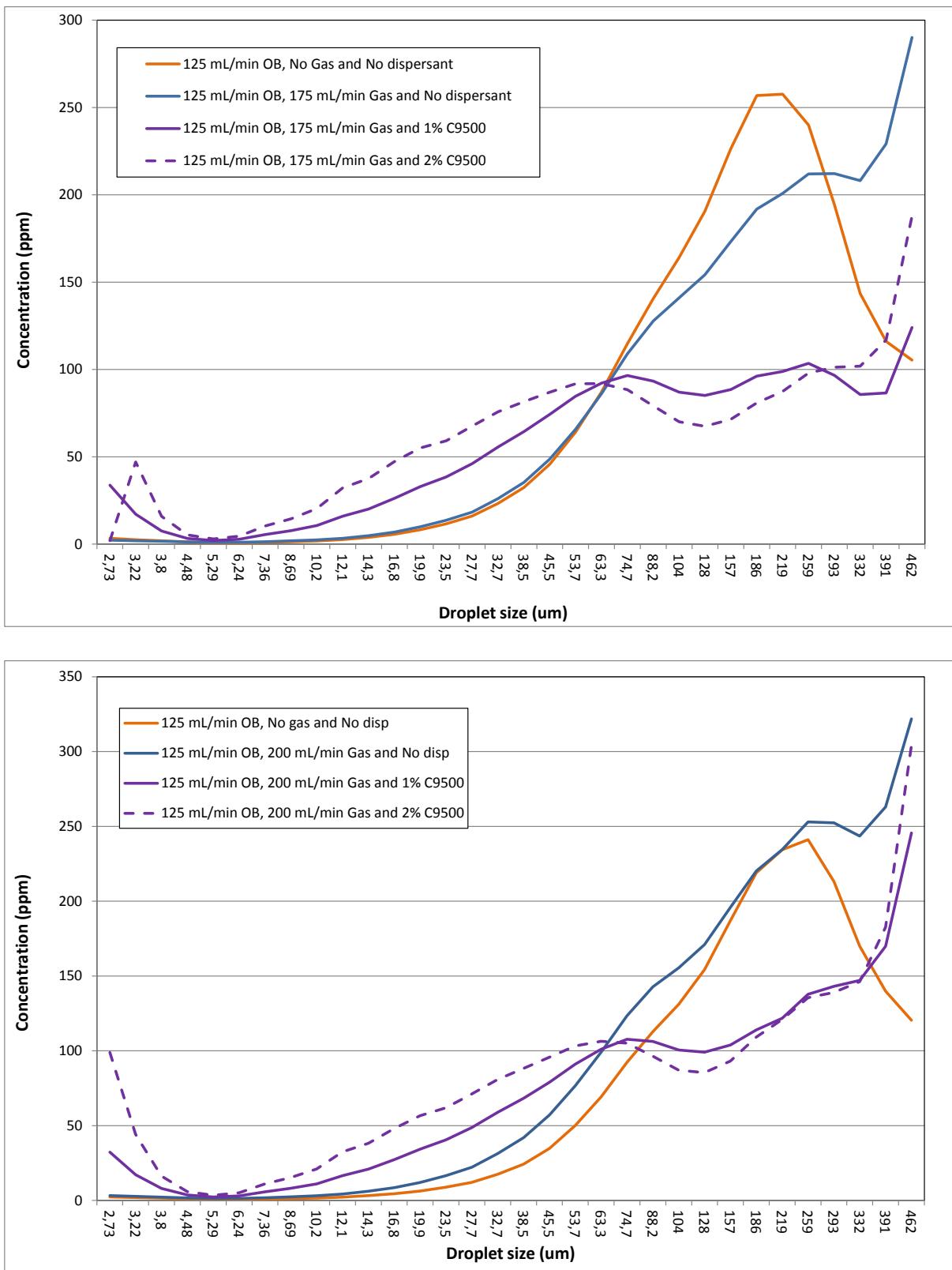


Figure 5.36: Combined experiments with Oil, Gas (air) and dispersant using Oseberg blend (OB) and C9500 showing droplet and bubble concentrations (ppm) from SINTEF MiniTower experiments. Release conditions 0,5 mm nozzle, all rates are ml/min.

5.7 Studies of possible coalescence and droplet splitting

Secondary droplet splitting might occur as the oil droplets from a subsea release rise towards the surface. However, the maximum stable droplet diameters of freely rising droplets in stagnant water (Hu and Kintner 1955) show that the range of droplet diameters in the Tower basin (10 – 500 µm) should fall well below this limit both for untreated oil (about 8 mm) and for oil treated with dispersants (about 1 mm). However, newer research indicate that treated oil droplets could shed streams of smaller droplets (tip-streaming), caused by locally ultra-low interfacial tensions due to uneven distribution of surfactants on the interface (Gopalan and Katz, 2010).

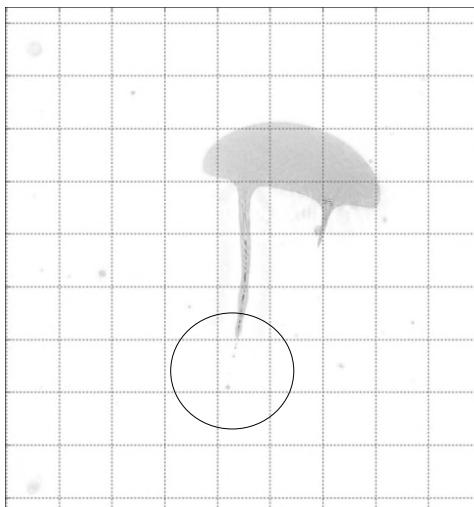


Figure 5.37: Holographic images (LISST HOLO) from tip-streaming studies in SINTEF Tower basin as a part of the DROPPS GOMRI project. Grid size is 500 µm. Images are obtained 5 meters above a low turbulent release like type C in Figure C.1. Oil type is Oseberg with 2% C9500 (upstream injection).

Figure 5.37 is showing formation of micro droplets (see circle) due to turbulent shearing and ultra-low interfacial tension at the edges of large freely rising treated oil droplets. This is in accordance with earlier studies by Joe Katz and his group at Johns Hopkins University (Gopalan and Katz, 2010).

Coalescence is the other process that could change the droplet distribution in a rising oil plume. The probability of droplet collisions and formation of larger droplets is strongly correlated with distance between the rising droplets (concentration and droplet size). This distance will increase as a function of distance from the release point due to plume dilution. This can be illustrated with statistical simulations. The relative difference in rising velocity for different size classes, e.g. larger droplets colliding with smaller droplets due to higher rising velocity, is also contributing to droplet coalescence. Coalescence is probably also affected by the presence of surfactants from the dispersants treatment. The surfactants located on the oil-water interphase will create both a charge and a steric hindrance which should reduce droplet collisions and coalescence.

To study possible droplet splitting and coalescence in the SINTEF Tower basin and collect experimental data to describe this phenomenon a second LISST instrument was located 3 meters above the standard LISST instrumentation. Two experiments were performed with this twin LISST configuration (30. April 2013 and 31. May 2013). These experiments consisted of dispersant testing (C9500 & Finasol 52) with four oil types (Grane, Norne, Oseberg and Kobbe) and two different

dispersant dosages (DOR 1:100 & 1:50). The data from these experiments are presented in Figure 5.38 and Figure 5.39.

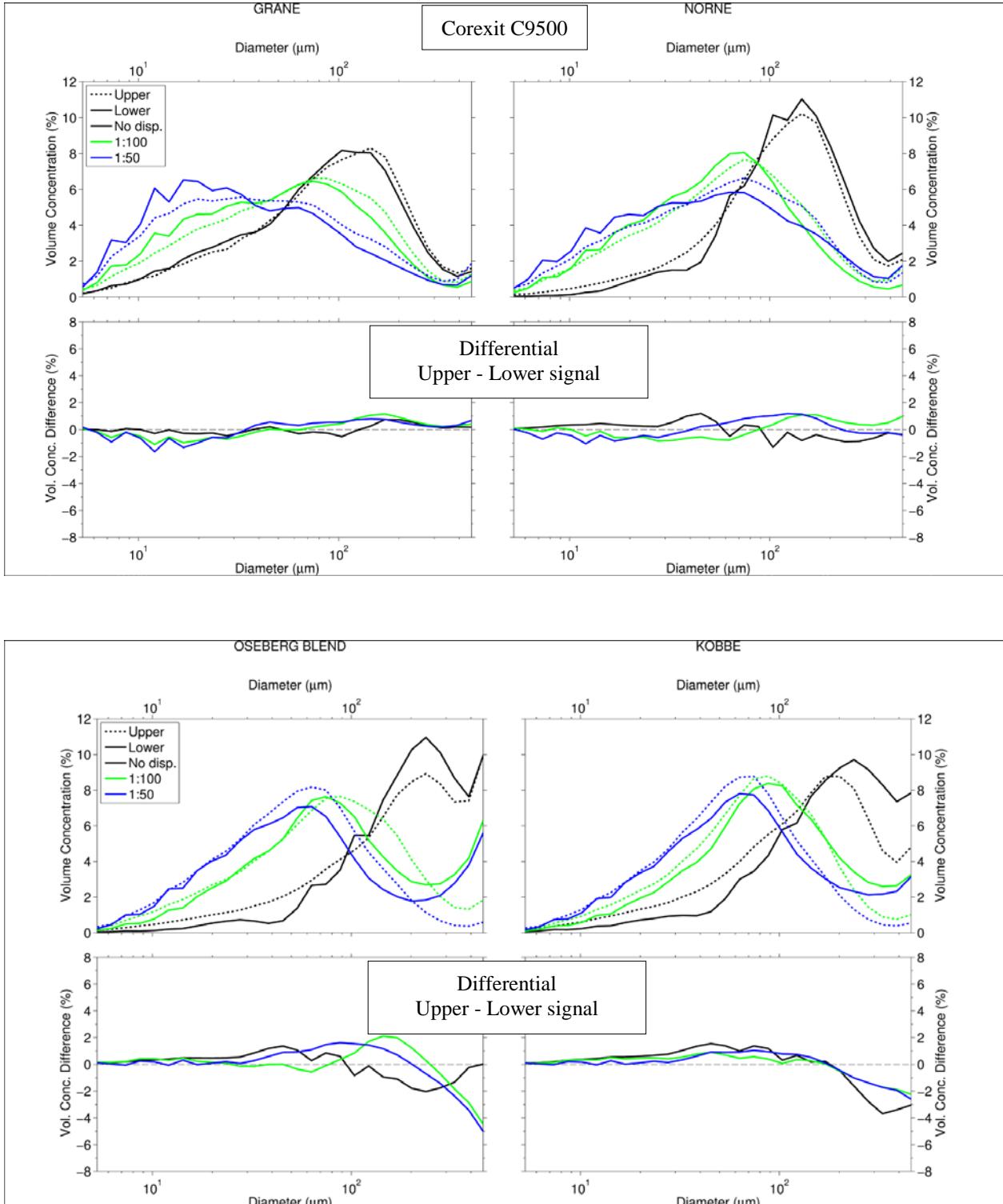


Figure 5.38: Relative droplet size distribution (volume %) as a function of distance from the initial droplet formation (release). "Lower" = 2 meter and "Upper" is 5 meter. Lower figures present the difference between the two LISST instruments. Dispersant Corexit C9500, dispersant to Oil Ratios (1:100 and 1:50) with four different oil types. Release conditions 1,5 mm and 1,2 L/min.

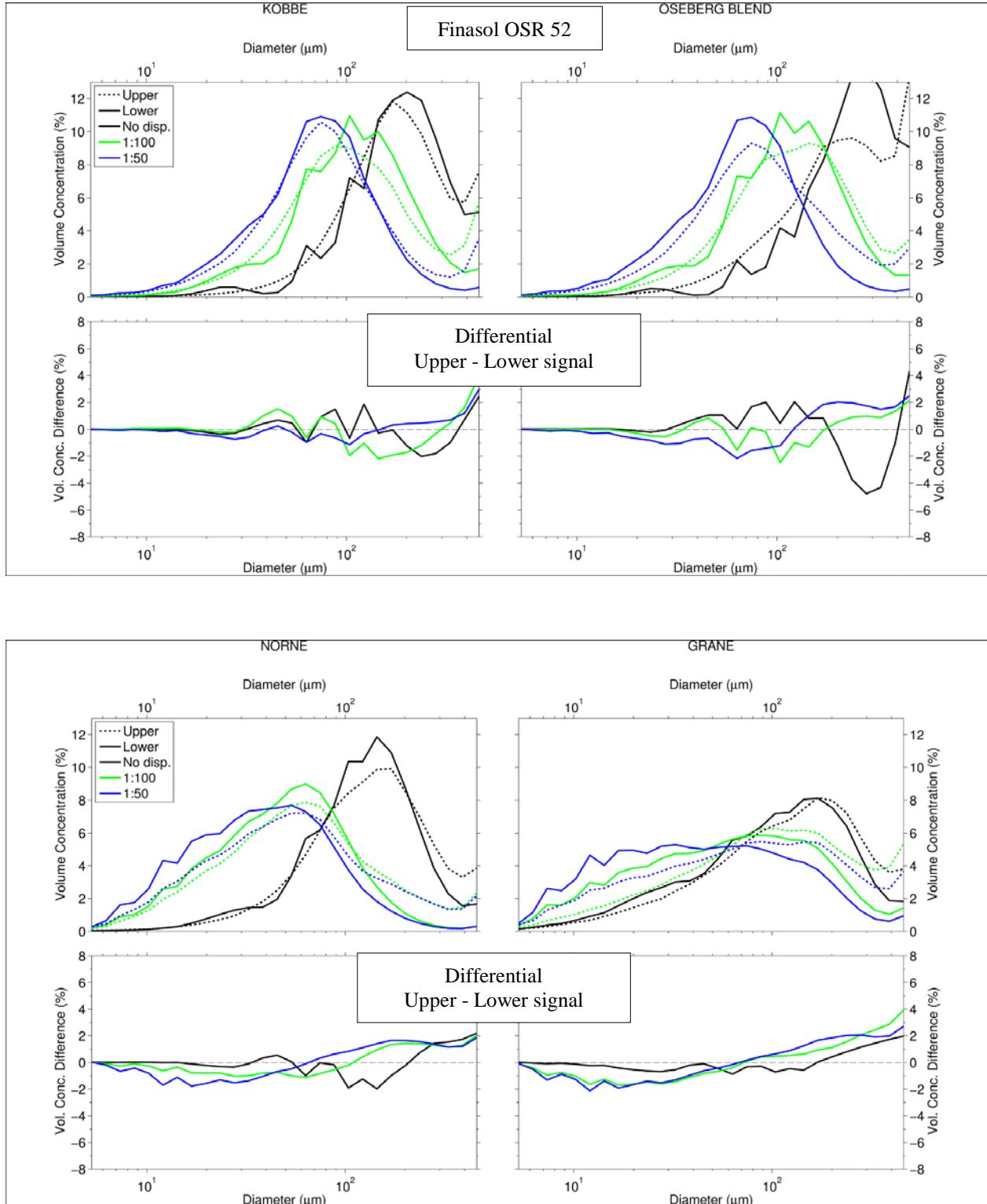


Figure 5.39: Relative droplet size distribution (volume %) as a function of distance from the initial droplet formation (release). "Lower" = 2 meter and "Upper" is 5 meter. Lower figures present the difference between the two LISST instruments. Dispersant is Finasol 52, dispersant to Oil Ratios (1:100 and 1:50) with four different oil types. Release conditions 1,5 mm and 1,2 L/min.

6 Discussions

This chapter contains the discussion of the results presented in Chapter 5.

6.1 Initial experiments

6.1.1 Verification of droplet distributions measured with the LISST instrument

Droplet size distributions measured with the LISST instruments on mono-disperse particle standards are documented in Brandvik et al., 2013a. They show a very good fit between the standard particles and the distribution from the LISST instruments.

6.1.2 Reproducibility within and between experiments

Figure 5.1 shows the droplet distributions for Oseberg oil alone at 7 different experimental periods (90 seconds) within a Tower basin experiment releasing only oil. This shows very little variation of droplet size distributions within one experiment.

In the DOR experiment described in Chapter 5.4, droplet size distribution of untreated oil is monitored both in the beginning and at the end of each experiment. These replicate measurements are presented in Figure 5.15, Figure 5.16 and Figure 5.17. These figures show good correspondence in droplet sizes at the start and end of the DOR experiments (14 minutes apart).

The ability of the control and monitoring system in the Tower basin to reproduce droplet size distributions at the most frequently used conditions (1.5 mm nozzle and oil rate 1.2 L/min) is documented in Figure 5.24, Figure 5.25 and Figure 5.26 for Norne, Oseberg and Kobbe, respectively. The oil alone reference experiments with Grane does not show the same reproducibility due to differences in oil temperature, viscosity and flow rate.

6.2 Dispersant effectiveness as a function of oil release temperature

Figure 5.2 presents the merged droplet size distributions for the three different experiments with release of warm oil. The colour codes used in the figures represents the three different series with Tower Basin experiments: June 2012 (Phase-I): Red, Dec 2012: Blue and Feb 2013: Green.

It is not straight forward to interpret these rather complex figures. Several phenomena are probably influencing simultaneously the droplet sizes with temperature, when the temperature of the released oil is increased:

1. The IFT of the reference oils are reduced (see Figure 5.6), this will reduce the droplet sizes for the untreated oils.
2. The viscosity of the released oils is reduced and this will reduce the VMDs.
3. The IFTs for the dispersant treated oils are increasing. This can be observed for IFT measured on the oil samples taken in-situ during the Tower basin experiments (see Table 5.1) and on premixed samples (see Figure 5.6). This will produce larger droplet sizes for the treated oils.

To better visualize the effect of the temperature on both the non-treated and treated oils, the VMDs for both groups are plotted as a function of temperature in Figure 5.3 and Figure 5.5. The first figure shows how the VMDs for the non-treated oils drop as the temperature increases, probably due to the reduced viscosity and IFT (see Table 5.1 and Figure 5.6). While the treated oils, and especially at

low dosage (DOR 1:100) show increased VMDs as the temperature increases. This increase is probably due to the significant increase in IFT measured on the samples collected in-situ (0.8 to 13 mN/m), see Table 5.1, but probably also due to the smaller increase in IFT measured in the premixed oil samples (0.02 to 0.2 mN/m), see Figure 5.6.

The most important trend in Figure 5.3 is that the difference between non-treated and treated oil, expressed as VMD, is significantly reduced as the temperature of the released oil increase. A shift in VMD from 280 to 63 microns (87%) at 13°C is reduced to a shift from 122 to 104 (15%) at 100°C. This indicates that the effect of injected dispersant could be significantly reduced at elevated oil temperatures.

This reduction in the effect of dispersant treatment (shift in VMD) as a function of temperature is presented in Figure 5.5. For both treatment ratios (1:100 and 1:50) a significant reduction in the effect of the injected dispersant is observed.

One possible reason for the increase in IFT and reduction in dispersant effectiveness at increased temperatures could be that the structure and properties of especially the non-ionic surfactants change as a function of temperature. Figure 6.1 shows the structure of two types of non-ionic surfactants widely used in commercial dispersants (Span/Tween).

The solubility, surface activity, and consequently the hydrophilic-to-lipophilic balance (HLB) of these non-ionic surfactants are highly dependent on the temperature because the interaction between water and hydrophilic group or between oil and lipophilic group changes with temperature. This causes changes in the solubility, micellization of the surfactant in the water or oil phase and/or in the state of orientation of a surfactant at the oil-water interface (Mohajeri and Noudeh 2012). It also changes the steric relationship between the surfactants and their packing on the oil-water interphase (Holmberg et al., 2002). An informative review article regarding surfactants structure, properties and emulsions is written by Israelachvili in 1993.

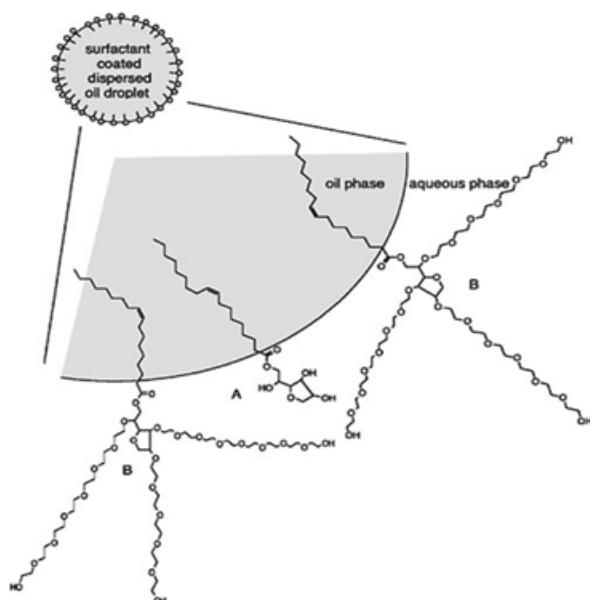


Figure 6.1: Possible orientation of non-ionic surfactants at oil-water interface in dispersed oil droplets. Surfactant A is sorbitan monooleate (e.g. Span 80) and surfactant B is ethoxylate sorbitan monooleate (e.g. Tween-80).

The steric repulsion between the ethoxylated hydrophilic headgroups (see Figure 6.1) usually decreases with increasing temperature. This influences both their internal interaction and their interaction with other surface active components (surfactants) from the dispersant or naturally present in the oil.

The structure or shape of a surfactant molecule can also be described by its critical packing parameter, CPP. The packing parameter takes into account the volume of the hydrophobic tail (V_t), the cross sectional area of the hydrophilic head (a), and the length of the hydrophobic tail (l_t).

$$CPP = V_t / l_t a$$

However, the packing parameter for a specific surfactant is not a constant. It is dependent on the properties of the solvent, the temperature, and the ionic strength of the solvent.

The extent of reduction in the IFT is directly related to the amount of surfactant that can be adsorbed or packed on a given interfacial area which is directly dependent on the CPP of the surfactant. The concentration of a surfactant in the interfacial area relative to its concentration in the bulk phase should, therefore, serve as an indicator of the adsorption efficiency of a given surfactant. The maximum number of surfactant molecules that could be fitted into the interfacial area depends on the area occupied by each molecule. That area will be determined by either the cross-sectional area of the lipophilic chain or the area required for the closest packing of the hydrophilic head groups, whichever is greater. Any changes in the properties of the hydrophilic head groups (e.g. ethoxylated chains, see Figure 6.1) caused by increased temperature, will influence surfactant packing at the interphase and hence reduction in IFT.

The measured viscosity shows a significant temperature dependency when measured at shear rate 10 s^{-1} , resulting in high viscosities at low temperature (see Table 5.1 and Figure 5.3b). The wax content in the Oseberg blend makes the viscosity very sensitive to shear forces and this temperature effect is not observed at shear rate 100 (see Table 5.1 and Figure 5.3b). The shear rate at the release conditions in the tower basin is calculated to be approximately 8000. The influence of viscosity on the droplet sizes is for this reason observed to be lower than expected by the span in viscosity measured at shear rate 10 s^{-1} .

Both the temperature dependant viscosities and IFTs from Table 5.1 are used in the new algorithm for initial droplet formation (Johansen et al., 2013) to predict droplet sizes as a function of temperature and dispersant injection in Figure 5.4. The figure shows that the new algorithm is able to describe the droplets sizes as a function of viscosity and IFT that correlates well with the measured data.

6.2.1 Extended warm oil experiments

To study the effect of oil temperature on dispersant injection effectiveness a series of experiments were performed with two different oil types: Oseberg blend (paraffinic) and Troll B (naphthenic), two different dispersants (C9500/Dasic NS) and three different injection techniques (upstream, SIT and Above Nozzle). The results are presented Figure 5.7 to Figure 5.12.

The first series of figures presents the shift in droplet size distribution as a function of the three injection techniques for LOW/HIGH temp for each oil-dispersant combination (Figure 5.7 to Figure 5.10). The second series of figures compare the three dispersants for each injection technique and oil type (Figure 5.11 and Figure 5.12). The main difference between the three injection techniques is the contact time between the dispersant (10°C) and the oil (10 or 70°C). It ranges from 1.9 seconds (Upstream), some milliseconds (SIT) to a few milliseconds after release (injection above).

Injection method:

For both dispersants there are differences between the injection methods. C9500 shows, as in previous experiments, the best results (largest shift in VMD) with SIT and significantly lower with upstream injection. Dasic NS has generally less difference between the injection methods, but does not show the significantly lower effectiveness for upstream injection. These smaller differences for Dasic NS could also be explained with a generally lower effectiveness compared to C9500 (more in next chapters).

Oil temperature:

Generally, the differences between the three injection techniques are reduced with the warm oil experiments. This indicates that the effect of the increased temperature is larger than the effect of the varying contact time for the different injection techniques. The general trend for most of the oil-dispersant-injection combinations is that the increased temperature reduces the shift in VMD from the untreated oil.

For the warm oil it seems like the longer mixing time (upstream injection, SIT and injection above) lowers the effectiveness of the dispersant injection (larger droplets). This can be explained with the longer mixing/contact time (seconds versus milliseconds), but also that the oil could cool down before injection when dispersant is injected above the nozzle.

However, as seen in Phase-I, SIT is the most effective injection method. Even if injecting the dispersant above the nozzle is less sensitive for increased oil temperatures, it seems that the SIT is also the preferred injection method with warm oils.

Oil type:

From the experiments with the paraffinic Oseberg blend and the naphthenic Troll B it seems like there also could be a difference between the two oil types. The temperature effect seems to be lower for Troll B than for Oseberg (see SIT data on Figure 5.11 and Figure 5.12) indicating a possible influence of oil chemistry.

6.3 Dispersant effectiveness as a function of dispersant dosage

To study the effectiveness of different dispersants as a function of dosage, experiments with monitoring of droplet size distributions and interfacial tensions were performed over a wide range of DORs (1:1000 to 1:25). The three dispersants tested are Corexit C9500, Finasol OSR 52 and Dasic Slickgone NS. They are all tested with Oseberg blend. The dispersants are tested in two different versions, the commercial version and a concentrated version where the content of active material is doubled due to removal of solvent. All products were used as received by the suppliers.

The shifts in droplet size distribution as a function of dispersant dosage (normal and concentrated versions) for the three products are presented in Figure 5.15, Figure 5.16 and Figure 5.17. The maximum peaks (VMD or d_{50}) are given in Table 5.4 to Table 5.9.

IFTs were measured by the spinning drop method on oil samples collected from the Tower basin during the experiments. Measurements as a function of DORs are presented in Figure 5.14. The figure shows a significant drop in IFT for all three dispersants from DOR 1:500 (10-12 mN/m), via 1:250 (2-6 mN/m) to 1:100 (0.3-0.8 mN/m) and C9500 is generally giving a lower IFT than the other two products.

The figures presenting the shifts in droplet sizes (Figure 5.15, Figure 5.16 and Figure 5.17) as a function of dosage for the three different dispersants (C9500, Dasic NS and Finasol 52) show the same trend for all three products and this is especially visualized in Figure 5.19, presenting all dispersants at high DORs (1, 2 and 4%). The products show similar performance and alternates being slightly better than the others, but these differences are small and probably not significant. However, previously we have seen significant differences in effectiveness between different injection techniques (Phase-I report and also previous chapter), so using another injection technique might reveal a difference in performance between the products. This is observed in the next chapter where SIT is used to test the three dispersants on different oil types.

The concentrated products all show an increased shift towards smaller droplets which corresponds to the estimated double concentration of active material. This means that the 1:100 of the concentrates give similar shifts like the 1:50 for the normal version of the products.

The lack of shift in droplet size distribution for the lowest dosages of dispersant (1:1000 and 1:500) is reflecting the minor reduction in Interfacial tension. The relatively large bin sizes could also mask small shifts in droplet size distribution. Insufficient mixing of the dispersant into the oil should not be a factor. A high Re (3000-4000) at the dispersant injection point into the oil line 2000 release diameters before the nozzle, should ensure sufficient mixing of the dispersants into the oil.

6.4 Dispersant effectiveness as a function of dispersant and oil type

The three dispersants (C9500, Dasic NS and Finasol 52) were tested with the four oil types (Oseberg, Norne, Grane and Kobbe). The testing was performed with SIT as injection techniques and with two different dispersant dosages (1 and 2%).

Figure 5.21 to Figure 5.23 give a visual impression of the oil plume without and with 1 and 2% dispersant. The paraffinic Oseberg and the asphaltenic Grane both have generally dark oil plumes, while the waxy Norne and the condensate Kobbe have lighter oil plumes. The colour of the plume likely reflects both the difference in oil components on the oil-water interphase (asphaltenes versus waxes), but also differences in droplet sizes.

The first four figures (Figure 5.24 to Figure 5.27) show the droplet sizes for the experiments with oil alone. These tests are performed by testing the four oil types (four oil tanks) with the same dispersant (one dispersant injection pump). When comparing the performance of the dispersant across the experiments it is important to ensure that the experiments are comparable. This is done by comparing the oil alone experiments in these figure.

The only significant deviation is seen for the Grane oil (Figure 5.27) where we had problems adjusting the correct flow rate due to high oil viscosity. The viscous Grane was slightly heated (40°C) to reduce the viscosity and increase flow rate. However, the flow meter was more sensitive to viscosity than expected and this resulted in slightly higher flow rates for Grane in the first experiments (21.03 with Dasic and 30.04 with C9500). The forth experiment with Grane (24.05) was performed to verify the correct flow rate (1.2 L/min).

Figure 5.27b compares VMD (d_{50}) versus flow rate and release diameter from several Tower Basin studies. Results from flow rate experiments presented in a scaled form from an earlier BP study (Brandvik et al., 2013a), API Phase-I (Brandvik et al., 2014) and Phase-II (Tables: 5.1, 5.4, 5.11, 5.13, 5.14 and Figure 5.7). The relative peak diameter d_p/D is plotted vs. equivalent oil flow rates (Q_a). The equivalent oil flow rate refers to an apparent fixed nozzle diameter of 1.5 mm (see equation 2 in Brandvik et al., 2013a). Most of the data are with Oseberg blend and only a limited number of experiments are performed with other oils (Troll, Norne, Kobbe and Grane). The oils have different chemical composition, IFT and viscosity. The scaled data indicate, even without taking IFT and viscosity into account, that d_{50} is following an underlying Weber scaling across several very different oil types. Using the modified weber scaling (Johansen et al., 2013), including IFT & oil viscosity, should give a better agreement between the main body of data (Oseberg) and the oils tested in Phase-II; Troll, Norne, Kobbe and Grane.

The ranking of the dispersants are to some degree dependant on oil type, with C9500 offering a high effectiveness on paraffinic oils and Finasol 52 on waxy oils. However, the results follow a general trend with C9500 as generally the most effective dispersant, then Finasol 52 and Dasic NS. The figures presenting the distributions of all oil types for each dispersant in Figure 5.32, Figure 5.33 and Figure 5.34 also show an average d_{50} for the three dispersants (DOR: 1:100 and 1:50) of C9500 (86 and 59 µm), Finasol 52 (120 and 59 µm) and Dasic NS (164 and 92 µm).

A ranking of the dispersant based on the relative shift in droplet sizes (Table 5.11 to Table 5.14) for two dosages and four oil types gives C9500 the best scores (6 first, 2 seconds), Finasol 52 next best (4 first, 3 seconds and one third) and then Dasic NS (three seconds and five thirds).

6.5 Mixed releases of oil and gas

The main objectives with the mixed experiments in Phase-II was to study if presence of gas (air), released together with oil, influence the droplet size distribution differently than described by available theory (increased momentum from gas will decrease droplet sizes). Another important issue in this study was to evaluate if the presence of gas (air) influences the dispersant ability to reduce oil droplet sizes.

This is difficult to study since both the Laser diffraction instruments (LISST) and in-situ cameras can't differentiate between oil droplets and gas bubbles. However, we have performed a set of experiments where we have tried to generate distributions of bubble and oil droplets with different peak values. This will give indications of the influence of gas on the droplet sizes following in mixed release.

The distributions of the air bubbles, when release alone, could easily be dominated by a few large droplets that cause a peak outside the 5-500 µm range of the LISST instruments.

When we compare the distributions for the combined experiments in (Figure 5.35) we see a well-defined peak for the oil alone experiment at 280 µm shifting down to around 55 µm when dispersant is injected (C9500, 1:50). When we compare this with the distribution of a combined gas (air), oil and dispersants release we notice a bimodal distribution with well-defined peaks at approximately 280 and 55 µm. This is an indication that the presence of gas does not significantly influence the shift in droplet distribution for the oil when dispersant is injected. This trend is also observed with data both from the Tower basin and the MiniTower (Figure 5.36).

Further work will be done with combined releases of oil and gas in Phase-V in the API D3 JITs both at SINTEF and at Southwest Research Institute in San Antonio, Texas (spring & fall 2015).

6.6 Coalescence studies

The experiments with the twin LISST configuration (30. April 2013 and 31. May 2013) were performed to study possible coalescence or droplet splitting as the oil plume rises inside the Tower Basin. The data from these two experiments are presented in Figure 5.38 and Figure 5.39 and contains distributions for dispersant testing (C9500 & Finasol 52) with four oil types (Grane, Norne, Oseberg and Kobbe) and two different dispersant dosages (DOR 1:100 & 1:50).

Both dispersants, the four oil types and the two dosages show no significant differences in droplet size distributions between the upper and lower LISST instrument. If coalescence was a dominant process in this early phase of the plume we would expect a systematic shift towards larger droplets.

7 Conclusions

The major findings from the discussions are summarized in this chapter.

The projects performed so far in the SINTEF Tower Basin have been focusing on the initial droplet formation from mixed release of oil and gas under turbulent jet conditions. Other processes like secondary droplet splitting could change the droplet size distributions after the initial formation as the droplets rise through the water column. These processes are currently not well described in operational models for deep water releases and could lead to overestimation of oil droplet sizes.

However, further research is being performed at SINTEF and at University of Hawaii (API D3 JITS Phase-IV) to increase our knowledge regarding the behaviour of oil droplets after the initial formation. This experimental work is performed from May 2014 to January 2015 and a final report is expected in June 2015.

7.1 Dispersant effectiveness as a function of oil release temperature

- For oil treated with dispersants, IFT increases with temperature, however to a degree depending on DOR.
- For oil alone, IFT decreases with increasing oil temperature.
- For lower DOR (1:100), IFT approaches values for untreated oil at oil temperatures above 50°C. This implies that dispersant application with low DOR will reduce dispersant effectiveness above that temperature.
- This reduction in dispersant effectiveness could be explained by changes in structure and properties of especially the non-ionic surfactants at high temperatures.
- This reduced effectiveness is dependent on both type of dispersant and combination of oil and dispersant.
- A possible operational consequence of these findings could be that at elevated oil release temperatures higher treatment rates (>1%) of dispersant or products with higher concentrations of surfactants should be used to avoid reduction in effectiveness.
- For higher DOR (1:50), IFT is kept at low values ($\text{IFT} \ll 1$) with increasing temperature
 - Due to this, oil viscosity will be the dominating property (Reynolds number scaling)
 - The formation of small droplets may cause a more rapid cooling of the oil to the ambient water temperature.
 - This implies that for higher DOR, dispersant efficiency is more independent of oil temperature.
- Oil viscosity decreases with decreasing oil temperature. However, this temperature effect depends strongly on shear rate and the rheology of the oil. Some oils are shear thinning due to wax or asphaltene structures in the oil and the measured viscosity is very dependent on shear rate. Shear rates relevant for subsurface releases ($1000 - 10\,000 \text{ s}^{-1}$) are very different than surface releases ($10-100 \text{ s}^{-1}$). Viscosity measurements relevant for subsea release applications should be measured at high shear rate (1000 s^{-1} or higher if possible).
- Using traditional viscosity data for shear thinning oils (shear rate 10 s^{-1} /13°C) and extrapolating this to 100°C, could overestimate both viscosity and oil droplet sizes. This will especially be the case for treated oils since viscosity could be the dominating property (Reynolds number scaling) according to modified Weber scaling (Johansen et al., 2013).
- For oils with high wax content it is important that the viscosity is measured well above the pour point for the oil, in addition to at high shear rate.

7.2 Dispersant effectiveness as a function of dispersant dosage

- Of the three products tested (C9500, Dasic NS and Finasol 52), C9500 shows the lowest IFTs as a function of dosage for samples taken from the Tower basin.
- Regarding reduction in droplet sizes as a function of dosage, all three products show similar performance and alternates being slightly better than the others, but these differences are probably not significant.
- However, since we earlier have seen significant differences in effectiveness between different injection techniques (Phase-I report and also previous chapter), using another injection technique might reveal a difference in performance between the products.
- The concentrated products all show an increased shift in droplets sizes (VMD) which correspond to the estimated double concentration of active material. This means that the 1:100 treatment using the concentrates give similar shifts like the 1:50 for the normal version of the products.

7.3 Dispersant effectiveness as a function of dispersant and oil type

- The ranking of the dispersants are to some degree dependant on oil type, but follows a general trend with C9500 as the generally best dispersant, then Finasol 52 and Dasic NS.
- This trend is seen both when comparing the absolute droplets sizes for all treated oils and for the relative shift in droplet size compared to the untreated oils.

7.4 Mixed releases of oil and gas

- The size of oil droplets and the effect of injecting dispersants do not appear to be substantially altered by the addition of gas.
- The peak distribution for the individual experiments with both gas and oil/dispersants can be identified in the mixed release indicating a bimodal distribution for the mixed release.

7.5 Coalescence studies

- No systematic differences in droplet sizes were observed between 2 and 5 m above the release for any of the tested oils and dispersant combinations, indicating that coalescence was not an influential factor within these conditions.

8 Recommendations

8.1 Dispersant effectiveness as a function of oil release temperature

- Needs better and more detailed knowledge regarding internal surfactant interactions (at the oil-water interphase) versus oil properties and temperature.
 - o A more empirical approach could be to study subsurface dispersant effectiveness (d_{50} – SINTEF MiniTower) with varying surfactant composition as a function of temperature (using a model dispersant).
 - o A more basic research approach would be to study surfactant structures and interactions (in oil, water and at the interphase) as a function of temperature for relevant surfactant systems.
- Needs more knowledge on temperature effect on IFT for untreated oils for a broader variety of oil properties.
- SINTEF Materials and Chemistry shear R&D facilities and has close project cooperation with the Surface Chemistry group (Ugelstad laboratory) at the Norwegian University of Science and Technology - NTNU. Staff from this group would be an essential resource in such project as listed above.

8.2 Mixed releases of oil and gas

- Experiments should be supplemented with experiments with only gas and dispersant to verify dispersant effect on gas bubble sizes.
- Detection techniques should be improved and refined to better separate between gas bubbles and oil droplets. A newly designed "Silhouette camera" developed at SINTEF could offer new capabilities.
- Experiments should be performed (ambient conditions) with natural gas to study
 - o differences between using air/nitrogen as a proxy and using natural gas
 - o gas bubble size versus dispersant dosage
 - o possible surfactant scavenging
- Experiments should be performed (high pressure conditions) with natural gas to study
 - o effect of live gas
 - o effect of combined oil & gas releases
 - o use of high pressure chambers increase the need for better gas/bubble detection

9 References (also cited in Appendix C)

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A Appendix A: Summary overview of all Tower Basin experiments.

API D3 Phase II - Tower basin experiments – Summary log for all experiments (Dec. 2012 – July 2013)

Exp. no	Date	Nozzle size (mm)	Type of experiment						Comments
			Rate (L/min)	Oil (type and SINTEF-ID)	Gas (Y/N)	Type experi- ment	Disp GOR Injection		
1	19.12.12	1,5	1,2	Oseberg blend (2012-0347)	N	TEMP-I	C9500 SIT	Experiments with new heated oil tanks 10, 25, 35, 50 and 66. Good results!	
2	09.01.13	1,5	1,5	Oseberg blend (2012-0347)	N	DOR	Corexit 9500 Upstream + Sim.inj	DOR: Oil, 1:1000, 500, 250, 100, 50, 25 + sim inj. Tool (1:100) Generally too small droplets, a restriction (particle?) in the nozzle..? Redo.	
3	18.01.13	1,5	1,5	Oseberg blend (2012-0347)	N	DOR	Dasic NS (Normal) Upstream + Sim.inj	DOR: Oil, 1:1000, 500, 250, 100, 50, 25, sim inj. Tool – SIT (1:100). Strange size distribution. Oil and 1:1000 has smaller droplets and lower IFT than 1:500 – Dispersant residues in the nozzle/line..?	
4	24.01.13	1,5	1,5	Oseberg blend (2012-0347)	N	DOR	Dasic NS (concentrated) Upstream + Sim.inj	DOR: Oil, 1:1000, 500, 250, 100, 50, 25, sim inj. Tool (1:100). Strange size distribution. Oil and 1:1000 has smaller droplets and lower IFT than 1:500 – Same as above, nozzle needs cleaning!	
5	30.01.13	1,5	1,5	Oseberg blend (2012-0347)	N	DOR	Dasic NS (normal) Upstream	DOR: Oil, 1:1000, 500, 250, 100, 50, 25, oil New test with Dasic NS (normal). Lots of effort in cleaning the tower basin and the lines before oil release. This work, and values are "normal" (in comparison with the one 18.01.13).	
6	01.02.13	1,5	1,5	Oseberg blend (2012-0347)	N	DOR	Dasic NS (concentrated) Upstream	Dispersant valve did not open. Only last part of the exp. Was with 1:25. New test with Dasic NS (concentrated)	
7	05.02.13	1,5	1,5	Oseberg blend (2012-0347)	N	DOR	Dasic NS (concentrated) Upstream	DOR: Oil, 1:1000, 500, 250, 100, 50, 25, oil. New test with Dasic NS (concentrated). Normal values.	

8	07.02.13	1,5	1,2	Oseberg blend (2012-0347)	N	Temp-I	Corexit 9500 Sim.injection tool	GOR: Oil, 1:100 and 1:50. 4 different temperatures: 100, 75, 57 and 50°C. No IFT water sample on 1:50 on 100°C, too long time before stabilizing pressure.
9	14.02.13	1,5	1,5 ++	No oil – water only	Y	Gas/ water	No disp.	Test with air and water, no oil. Problems with coalescing of air bubbles on the LISST instruments.
10	14.02.13	1,5	1,5	Oseberg blend (2012-0347)	N	DOR	Finasol 52	Oil alone, 1:1000, 500, 250, 100, 50, 25 and oil alone. Some background due to air bubbles from previous test.
11	20.02.13	1,5	1,5	Kobbe, OB, Norne blend, Grane	N	Oil exp.	Finasol 52	Oil exp. Oil alone, 1:100/50. Only data at Kobbe and OB. Norne was leaking and Grane blew the gaskets in the oil tank (high visc. needed 30 bar). Need to fix the oil tank & gaskets before next exp.
12	190313	1,5	1,2	Kobbe, OB, Norne blend, Grane	N	Oil exp.	Finasol 52	Heating on Grane (50C) and reduced rate to 1.2 L/min. Problems with bimodal distributions? Experiment repeated (31.05.)
13	210313	1,5	1,2	Kobbe, OB, Norne blend, Grane	N	Oil exp	Dasic NS	
14	080413	1,5	1,2	OB	N	Temp-II	Dasic NS	Calibrated flowmeters for temp and viscosity differences
15	120413	1,5	1,2	Troll B	N	Temp-II	Dasic NS	
16	160413	1,5	1,2	Troll B	N	Temp-II	C9500	Oil/Gas leakage, fixed and rerun the day after!
17	170413	1,5	1,2	Troll B	N	Temp-II	C9500	
18	220413	1,5	1,2	OB	N	Temp-II	C9500	
19	300413	1,5	1,2	Kobbe, OB, Norne blend, Grane	N	Oil exp	C9500	2 x LISST 100X 3 & 5 meter (very good results)
20	080513	1,5	1,5	OB	N	DOR	C9500	Replicate of 090113. Testing of LISST DEEP and LISST 100X
21	220513	1,5	1,5	OB	N	DOR	Finasol 52 concentrated	Testing of LISST Deep together with LISST 100X

23	240513	1.5	1.2	Only OB+Grane	N	Oil exp	C9500	Replication of earlier experiments to increase quality (Correct flow rate on Grane 1.2 L/min)
24	310513	1.5	1.2	Kobbe, OB, Norne blend, Grane	N	Oil exp	Finasol 52	Replication of earlier experiments (19.03) to increase quality. 2 x LISST 100X 3 & 5 meter (very good results)
25	250613	1.5	1.2?	Oseberg	Y	Oil GAS	C9500	Experiments with Oil and Gas combined with DROPPS experiment
26	370613	1.5	1.5	Troll B	N	DOR	C9500	Combined DROPPS experiment
27	010713	1.5	1.2?	Oseberg	Y	Oil GAS	C9500	Replicate of 250613 with correct dispersant dosage.

NB! Date (DDMMYY) is used to identify experiments both in Appendix 2 (raw data) and in the report.

Red: Not successful experiment

Yellow: Partly successful experiment

Green: Completely successful experiment

Type of experiment:

DOR – 6 different dispersants and 7 DORs, one oil used in all experiments (Oseberg blend)

Temp I – One oil (Oseberg blend), one dispersant (Corexit 9500), different temperature

Temp II – Two oils (Oseberg blend and Troll), two dispersants (Corexit 9500/basic NS), different temperatures

Oil exp. – 4 different oils, 6 different dispersants and 3 DORs (oil, 1:100 and 1:50).

B Appendix B: Experimental data: Numerical distributions of oil and experimental conditions.

2307-2012

Date 2307-2012

Date: DDMM-YYYY of experiment – Used to identify each experiments in the report and in this appendix

Conditions
Comments
Nozzle size

 Warm oil experiments (50-100C)
 SIT injection, DOR:100-25 & C9500
 1,5 mm, 1,2 L/min

This field is used to define the experimental conditions and the purpose or type of experiment

Name 57°C 1:100
Average start 1250 15:02:31
Average stop 1280 15:03:01
Number of records 30

oil temp
flow
 Average 57,3
 STDev 0,29
 1,2 0,03

For some types of experiments (e.g. warm oil) average & StDev for oil flow rate and oil temperature over the averaged intervals are given

Bins 2,73 3,22 3,8 4,48 5,29 6,24 7,36 8,69
 63,3 74,7 88,2 104 122 144 170 201

Average conc 5,28 2,17 0,72 0,22 0,11 0,12 0,16
 6,46 8,75 12,05 15,10 17,90 20,00 21,71 21,60

Stdev conc 0,74 0,31 0,11 0,04 0,02 0,03 0,05
 2,27 3,90 4,75 5,59 6,30 7,08 7,36

One experiments contains many runs with different flow rates, injection techniques and/or dispersant to oil ratios (DORs). This section identifies each run or data segment.
Name: Used as identifier (legends) in many of the figures in the report.
Start/Stop and Number of records identifies the data records averaged and used to represent this run or data segment.

Bins: Midpoint in microns for each of the 32 log distributed bins. These are not given for each of the data sets.

Average conc: Averaged concentration in ppm (10 measurements per second/record, usually 300 measurements) for all droplets within each bin.
Stdev conc: Standard deviation in concentration for all droplets within each bin. Reflects both experimental variation and the size variation within each bin.

Date 2006-2012

Conditions Sim.Inj.Tool, DOR 1:100/50/25

Comments Warm Vs Cool, 1st experiments

Nozzle size 1,5mm, 1,2L/min

Bins	2,73	3,22	3,8	4,48	5,29	6,24	7,36	8,69	10,2	12,1	14,3	16,8	19,9	23,5	27,7	32,7	38,5	45,5	53,7
	63,3	74,7	88,2	104	122	144	170	201	237	280	331	390	460						

Name 13°C 1:100

Average start 300 15:43:31

Average stop 330 15:44:1

Number of records 30

average	5,02	2,10	0,76	0,30	0,22	0,40	0,81	0,90	1,31	2,17	2,42	3,53	4,39	5,12	6,38	7,69	9,07	10,58	
	12,42	13,94	15,18	14,86	13,25	11,07	8,64	6,56	4,35	2,97	1,81	1,24	0,98	1,45					
stdev	3,43	1,26	0,38	0,12	0,08	0,17	0,40	0,43	0,65	1,12	1,18	1,70	2,05	2,31	2,86	3,33	3,76	4,22	4,90
	5,30	5,55	5,32	4,60	3,88	3,18	2,67	2,01	1,50	1,01	0,81	0,76	1,36						

Name 13°C 1:50

Average start 461 15:46:12

Average stop 471 15:46:22

Number of records 10

average	16,06	6,15	1,96	0,68	0,49	0,98	2,02	1,97	2,66	4,17	4,07	5,46	6,11	6,47	7,64	8,42	9,03	9,51	
	10,17	10,13	9,53	7,87	5,82	4,25	3,13	2,40	1,70	1,27	0,87	0,67	0,60	1,12					
stdev	3,81	1,48	0,50	0,18	0,12	0,20	0,34	0,31	0,40	0,62	0,61	0,83	0,91	0,98	1,14	1,17	1,16	1,11	1,11
	1,10	1,13	1,05	0,86	0,72	0,57	0,48	0,46	0,48	0,45	0,40	0,38	0,84						

Name 13°C 1:25

Average start 548 15:47:39

Average stop 558 15:47:49

Number of records 10

average	27,49	9,60	2,70	0,84	0,55	1,08	2,24	2,07	2,73	4,28	3,97	5,11	5,37	5,26	5,83	5,74	5,54	5,19	
	4,87	4,22	3,47	2,60	1,80	1,33	1,02	0,87	0,70	0,60	0,41	0,26	0,20	0,32					
stdev	21,08	6,27	1,32	0,25	0,11	0,29	0,85	0,80	1,17	2,09	1,90	2,53	2,58	2,43	2,68	2,61	2,54	2,33	2,08
	1,52	1,06	0,71	0,44	0,27	0,19	0,12	0,05	0,05	0,08	0,09	0,09	0,11						

Name 55°C 1:100

Average start 1005 15:55:16

Average stop 1035 15:55:45

Number of records 30

average	1,29	0,64	0,30	0,15	0,12	0,18	0,30	0,32	0,45	0,72	0,87	1,30	1,69	2,07	2,62	3,35	4,38	5,70	
	7,21	9,12	11,41	12,88	14,21	14,73	15,12	14,95	12,86	10,68	7,42	5,25	3,66	3,93					
stdev	1,52	0,65	0,24	0,09	0,06	0,11	0,22	0,25	0,37	0,63	0,73	1,08	1,39	1,67	2,14	2,66	3,25	3,89	4,74
	5,47	6,14	6,24	5,73	5,40	5,61	6,39	6,26	5,63	4,35	3,57	2,87	3,23						

Name 55°C 1:50

Average start 1060 15:56:10

Average stop 1090 15:56:40

Number of records 30

average	6,70	2,83	1,03	0,41	0,30	0,56	1,10	1,15	1,59	2,51	2,64	3,67	4,36	4,90	5,98	6,99	8,00	9,02	
	10,24	11,00	11,20	10,04	8,20	6,47	4,96	3,80	2,56	1,76	1,03	0,67	0,54	0,89					
stdev	4,27	1,64	0,53	0,19	0,13	0,25	0,54	0,56	0,79	1,27	1,29	1,77	2,05	2,24	2,70	3,05	3,32	3,52	3,82
	3,82	3,61	2,99	2,18	1,72	1,50	1,36	1,04	0,75	0,43	0,37	0,42	0,89						

Name 55°C 1:25

Average start 1136 15:57:26

Average stop 1160 15:57:50

Number of records 24

average	16,00	5,84	1,75	0,58	0,41	0,83	1,76	1,70	2,29	3,59	3,39	4,39	4,68	4,70	5,27	5,41	5,31	5,06	
	4,83	4,29	3,61	2,73	1,91	1,37	1,06	0,87	0,63	0,44	0,28	0,18	0,17	0,34					
stdev	16,58	5,59	1,54	0,48	0,33	0,68	1,47	1,41	1,92	3,06	2,86	3,71	3,92	3,89	4,34	4,42	4,31	4,07	3,88
	3,44	2,90	2,20	1,55	1,12	0,87	0,72	0,53	0,40	0,27	0,19	0,19	0,48						

Name 13°C Oil

Average start 194 15:41:45

Average stop 224 15:42:15

Number of records 30

average	0,00	0,00	0,01	0,01	0,03	0,04	0,05	0,06	0,07	0,09	0,11	0,15	0,18	0,21	0,22	0,30	0,47	0,75	
	1,01	1,50	2,26	2,92	4,29	5,60	7,93	10,85	13,96	17,27	17,95	15,94	11,41	11,15					
stdev	0,00	0,01	0,01	0,01	0,02	0,03	0,04	0,04	0,04	0,04	0,05	0,06	0,08	0,09	0,10	0,13	0,20	0,33	0,46
	0,72	1,08	1,41	1,91	2,37	3,41	4,73	6,44	8,53	10,04	10,83	9,11	10,94						

Name 55°C Oil

Average start 937 15:54:8

Average stop 967 15:54:38

Number of records 30

average	0,07	0,06	0,05	0,06	0,06	0,08	0,09	0,09	0,11	0,15	0,19	0,29	0,39	0,47	0,55	0,73	1,11	1,72	
	2,39	3,63	5,45	7,20	9,97	12,02	14,91	17,49	18,16	16,75	12,55	8,40	5,98	6,46					
stdev	0,02	0,01	0,02	0,02	0,03	0,03	0,03	0,03	0,04	0,04	0,05	0,07	0,11	0,15	0,18	0,27	0,43	0,70	1,02
	1,55	2,37	3,24	4,57	5,63	6,98	7,93	8,24	8,10	6,75	5,29	4,85	6,06						

Date 1912-2012

Conditions Sim.Inj.Tool, DOR 1:100/50
 Comments Warm oil: Droplet formation vs. Oil temperature and disp injection
 Nozzle size 1.5mm, 1.2L/min

Name 66°C Oil

Average start 430 15:07:00

Average stop 460 15:07:30

Number of records 30

	0,21	0,17	0,15	0,13	0,13	0,14	0,13	0,11	0,13	0,16	0,20	0,33	0,52	0,72	0,92	0,89	0,79	1,10	
average	2,14	4,44	4,45	6,12	9,20	10,00	13,17	15,04	15,41	15,75	13,54	11,17	9,21	10,70					
stdev	0,04	0,03	0,03	0,03	0,04	0,04	0,05	0,04	0,05	0,06	0,08	0,12	0,17	0,24	0,35	0,47	0,55	0,79	1,28
	2,09	2,65	3,57	4,73	5,44	6,72	7,46	7,36	6,75	5,25	3,82	3,26	4,49						

Name 66°C 1:100

Average start 550 15:09:00

Average stop 570 15:09:20

Number of records 20

	0,64	0,42	0,28	0,19	0,17	0,21	0,24	0,22	0,28	0,39	0,48	0,76	1,14	1,55	2,09	2,45	2,67	3,61	
average	5,57	8,87	9,86	12,42	15,62	16,19	18,08	18,60	17,73	16,80	13,02	9,16	6,56	7,48					
stdev	0,37	0,20	0,10	0,05	0,04	0,05	0,08	0,09	0,12	0,19	0,23	0,36	0,49	0,63	0,87	1,17	1,50	1,95	2,54
	3,13	3,88	4,31	4,35	4,34	4,52	5,22	6,42	7,55	6,62	4,31	2,97	3,53						

Name 66°C 1:50

Average start 580 15:09:30

Average stop 610 15:10:00

Number of records 30

average	7,21	3,18	1,24	0,53	0,41	0,73	1,38	1,44	1,97	3,06	3,25	4,57	5,64	6,49	8,21	9,65	11,03	12,88	
	15,37	17,77	18,48	17,71	15,18	12,37	9,84	7,99	6,07	5,18	4,16	3,78	3,55	5,54					
stdev	5,16	1,93	0,60	0,20	0,14	0,27	0,61	0,66	0,96	1,61	1,67	2,34	2,78	3,08	3,85	4,55	5,26	5,94	6,85
	7,56	8,25	8,09	7,11	5,97	4,64	3,53	2,38	1,68	1,01	0,70	0,78	1,85						

Name 50°C Oil

Average start 735 15:12:05

Average stop 765 15:12:35

Number of records 30

average	0,21	0,16	0,13	0,11	0,10	0,11	0,10	0,07	0,08	0,11	0,14	0,23	0,39	0,53	0,61	0,46	0,31	0,42
	0,96	2,42	2,10	3,10	5,32	5,57	7,84	9,84	11,50	14,22	14,11	12,53	10,17	11,66				
stdev	0,04	0,02	0,01	0,02	0,03	0,03	0,02	0,02	0,02	0,03	0,05	0,07	0,11	0,15	0,19	0,18	0,25	0,48
	0,91	1,02	1,44	2,22	2,62	3,77	4,87	5,98	6,91	6,31	5,19	4,12	4,65					

Name 50°C 1:100

Average start 826 15:13:36

Average stop 856 15:14:06

Number of records 30

average	2,98	1,44	0,63	0,29	0,23	0,37	0,63	0,65	0,90	1,43	1,62	2,44	3,22	3,93	5,11	6,12	6,93	8,40	
	10,49	12,96	13,84	14,12	13,15	11,06	9,24	7,59	5,91	5,03	4,18	3,83	3,78	6,04					
stdev	1,98	0,86	0,32	0,13	0,09	0,16	0,32	0,35	0,51	0,84	0,95	1,39	1,76	2,09	2,71	3,38	4,03	4,78	5,66
	6,47	7,34	7,45	6,72	5,75	4,66	3,64	2,49	1,68	0,96	0,65	0,88	2,24						

Name 50°C 1:50 (-)

Average start 879 15:14:29

Average stop 909 15:14:59

Number of records 30

average	0,39	0,28	0,20	0,16	0,14	0,17	0,18	0,15	0,18	0,24	0,29	0,48	0,73	0,98	1,25	1,28	1,19	1,60
	2,77	5,11	5,42	7,36	10,52	11,33	13,99	15,82	16,28	16,51	14,30	11,45	9,19	11,04				
stdev	0,08	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,05	0,06	0,09	0,13	0,17	0,24	0,30	0,35	0,46	0,69
	1,09	1,43	2,02	2,90	3,42	4,61	5,67	6,22	6,51	5,70	4,37	3,41	4,31					

Name 35°C Oil

Average start 987 15:16:17

Average stop 1017 15:16:47

Number of records 30

average	0,25	0,19	0,15	0,12	0,11	0,13	0,13	0,10	0,12	0,15	0,18	0,29	0,46	0,60	0,71	0,59	0,43	0,57
	1,22	2,77	2,56	3,69	6,17	6,81	9,65	12,07	13,73	15,93	15,45	13,65	10,95	5,56				
stdev	0,06	0,03	0,01	0,02	0,02	0,02	0,02	0,02	0,02	0,03	0,04	0,06	0,09	0,13	0,16	0,16	0,22	0,41
	0,83	0,95	1,37	2,11	2,44	3,33	4,06	4,78	5,53	5,36	5,12	4,97	4,43					

Name 35°C 1:100

Average start 1075 15:17:45

Average stop 1105 15:18:15

Number of records 30

average	3,76	1,75	0,73	0,33	0,25	0,41	0,71	0,74	1,06	1,72	1,98	2,97	3,90	4,76	6,14	7,35	8,35	10,01
	12,42	15,13	16,36	17,07	16,55	14,75	13,13	11,34	9,18	8,04	6,69	5,98	5,68	8,31				
stdev	2,51	0,98	0,31	0,10	0,07	0,14	0,32	0,36	0,54	0,92	1,01	1,49	1,85	2,15	2,72	3,30	3,85	4,37
	5,40	5,86	5,63	4,83	4,08	3,26	2,73	2,21	1,87	1,40	1,09	1,31	2,85					
%stdev	66,64	56,22	42,79	30,48	26,22	34,29	45,39	48,09	50,68	53,77	51,29	50,14	47,33	45,16	44,32	44,87	46,18	43,60
																	40,31	

Name 35°C 1:50

Average start 1133 15:18:43

Average stop 1163 15:19:13

Number of records 30

	13,41	5,20	1,70	0,61	0,44	0,86	1,82	1,92	2,76	4,52	4,69	6,54	7,70	8,53	10,40	11,85	12,85	13,89
average	15,14	15,50	14,70	12,69	10,09	7,87	6,36	5,45	4,60	4,37	4,05	4,24	4,89	8,99				
stdev	7,74	2,71	0,76	0,23	0,14	0,30	0,73	0,79	1,16	1,99	2,00	2,73	3,06	3,22	3,80	4,22	4,55	4,67
	4,68	4,46	3,72	2,83	2,15	1,59	1,19	0,81	0,61	0,45	0,55	1,03	2,57					

Name 23°C Oil

Average start 1283 15:21:13

Average stop 1313 15:21:43

Number of records 30

	0,47	0,33	0,22	0,17	0,16	0,21	0,23	0,20	0,24	0,31	0,34	0,50	0,69	0,86	1,01	0,94	0,79	0,99
average	1,73	3,13	3,11	4,21	6,25	6,90	9,30	11,74	14,16	17,53	19,05	19,28	18,60	25,49				
stdev	0,12	0,06	0,02	0,02	0,03	0,03	0,02	0,02	0,03	0,03	0,04	0,04	0,04	0,05	0,07	0,09	0,09	0,12
	0,56	0,62	0,99	1,76	2,17	3,40	4,81	6,44	8,40	9,00	8,60	8,72	14,01					

Name 23°C 1:100

Average start 1363 15:22:33

Average stop 1393 15:23:03

Number of records 30

	4,31	1,91	0,75	0,33	0,25	0,44	0,80	0,83	1,17	1,87	2,05	3,00	3,80	4,51	5,77	6,87	7,78	9,24
average	11,35	13,61	14,42	14,64	13,91	12,16	11,07	10,21	9,27	9,17	8,38	8,02	8,28	13,42				
stdev	3,26	1,25	0,40	0,13	0,08	0,18	0,43	0,47	0,70	1,20	1,30	1,89	2,32	2,68	3,41	4,16	4,89	5,63
	6,91	7,43	6,85	5,31	3,94	2,53	2,14	2,64	3,42	3,39	2,59	2,27	4,17					

Name 23°C 1:50

Average start 1439 15:23:49

Average stop 1469 15:24:19

Number of records 30

average	21,40	7,66	2,26	0,73	0,51	1,08	2,42	2,50	3,59	5,95	5,96	8,21	9,43	10,19	12,35	13,91	15,01	16,05	
	17,34	17,52	16,52	13,98	10,83	8,39	6,76	5,92	5,16	5,13	4,96	5,57	7,06	14,59					
stdev	9,23	2,76	0,63	0,15	0,09	0,20	0,57	0,60	0,91	1,67	1,61	2,23	2,43	2,46	2,89	3,13	3,28	3,32	3,48
	3,34	3,13	2,58	1,93	1,44	1,07	0,85	0,70	0,67	0,61	0,68	1,25	3,53						

Date 0702-2013
 Conditions Sim.Inj.Tool, DOR 1:100/50/25
 Comments Warm oil: 100, 75, 57 and 50C
 Nozzle size 1,5mm, 1,2L/min

Name 100°C Oil															Average		STDev		
Average start		749	14:54:10			oil temp			97,5			0,47							
Average stop		779	14:54:40			flow			1,28			0,05							
Number of records															30				
average	0,07	0,07	0,08	0,11	0,17	0,26	0,29	0,26	0,26	0,27	0,29	0,42	0,65	0,98	1,12	1,37	1,60	2,04	
	4,12	7,05	8,10	10,25	13,64	13,27	15,05	14,42	11,95	9,05	5,76	3,44	2,08	1,94					
stdev	0,06	0,05	0,05	0,06	0,07	0,08	0,08	0,07	0,08	0,10	0,12	0,18	0,26	0,37	0,51	0,72	0,97	1,33	2,11
	2,96	3,86	4,85	5,87	6,32	6,91	6,57	5,41	4,13	2,75	1,73	1,17	1,23						
Name 100°C 1:100															Average		STDev		
Average start		810	14:55:11			oil temp			98,7			0,58							
Average stop		840	14:55:41			flow			1,29			0,06							
Number of records															30				
average	0,15	0,12	0,12	0,13	0,18	0,27	0,32	0,30	0,31	0,34	0,36	0,54	0,81	1,22	1,47	1,86	2,27	2,90	
	5,29	8,35	9,71	11,98	15,06	14,10	14,57	12,87	9,93	7,02	4,20	2,40	1,45	1,39					
stdev	0,22	0,15	0,10	0,07	0,06	0,08	0,11	0,11	0,14	0,19	0,22	0,34	0,48	0,67	0,94	1,34	1,79	2,36	3,41
	4,43	5,58	6,60	7,43	7,72	7,93	7,30	5,82	4,10	2,40	1,38	0,94	0,94						

Name 100°C 1:50												Average		STDev					
Average start		870	14:56:11		oil temp				100,2	0,78									
Average stop		880	14:56:21		flow				1,21	0,11									
Number of records																			
average	0,51	0,34	0,23	0,17	0,19	0,30	0,40	0,33	0,32	0,34	0,30	0,39	0,49	0,59	0,59	0,56	0,52	0,57	
	1,05	1,64	1,52	1,58	1,80	1,45	1,53	1,52	1,49	1,62	1,70	1,88	2,06	3,78					
stdev	0,13	0,08	0,05	0,03	0,03	0,05	0,07	0,06	0,06	0,08	0,09	0,12	0,18	0,25	0,32	0,39	0,42	0,47	0,69
	0,79	0,74	0,66	0,54	0,42	0,34	0,31	0,43	0,71	1,00	1,32	1,61	3,69						
Name 75°C Oil												Average		STDev					
Average start		939	14:57:20		oil temp				73,7	0,14									
Average stop		969	14:57:50		flow				1,20	0,01									
Number of records																			
average	0,09	0,09	0,09	0,11	0,16	0,24	0,28	0,26	0,27	0,28	0,30	0,44	0,68	1,03	1,19	1,42	1,63	2,06	
	4,17	7,25	8,59	11,45	16,06	16,42	19,87	20,87	19,51	16,49	11,12	6,70	4,06	3,70					
stdev	0,07	0,06	0,05	0,04	0,04	0,05	0,06	0,06	0,07	0,09	0,11	0,17	0,24	0,33	0,46	0,64	0,85	1,13	1,83
	2,71	3,68	4,85	6,14	6,84	7,89	8,07	7,62	6,58	4,66	3,01	2,08	2,14						
Name 75°C 1:100												Average		STDev					
Average start		1000	14:58:21		oil temp				74,5	0,07									
Average stop		1030	14:58:51		flow				1,20	0,01									
Number of records																			
average	0,39	0,27	0,20	0,17	0,19	0,27	0,36	0,35	0,41	0,50	0,55	0,83	1,21	1,76	2,18	2,78	3,38	4,18	
	6,81	9,87	11,43	13,82	16,79	16,33	17,20	15,94	12,75	9,68	6,16	3,91	2,59	2,73					
stdev	0,43	0,24	0,12	0,06	0,04	0,06	0,12	0,13	0,19	0,29	0,33	0,50	0,68	0,90	1,22	1,64	2,10	2,60	3,39
	4,06	4,98	5,58	5,69	5,69	5,51	5,32	4,63	3,75	2,59	1,84	1,41	1,74						

Name 75°C 1:50												Average		STDev					
Average start		1080	14:59:41	oil temp				75,2	0,06										
Average stop		1110	15:00:11	flow				1,20	0,01										
Number of records																			
average	8,73	3,41	1,17	0,46	0,36	0,74	1,60	1,70	2,37	3,74	3,84	5,46	6,67	7,76	9,52	11,26	12,77	14,08	
	16,54	17,77	17,59	15,47	12,04	8,66	5,97	4,06	2,49	1,62	0,95	0,63	0,50	0,78					
stdev	8,33	2,78	0,75	0,22	0,15	0,35	0,92	1,01	1,53	2,65	2,67	3,77	4,38	4,78	5,83	6,77	7,52	8,11	8,83
	8,96	8,92	7,73	5,85	4,36	3,04	2,14	1,36	0,90	0,53	0,36	0,31	0,55						
Name 57°C Oil												Average		STDev					
Average start		1165	15:01:06	oil temp				56,6	0,17										
Average stop		1195	15:01:36	flow				1,20	0,01										
Number of records																			
average	0,06	0,06	0,07	0,08	0,12	0,19	0,23	0,21	0,21	0,21	0,22	0,32	0,50	0,77	0,82	0,91	0,95	1,16	
	2,67	4,94	5,47	7,34	10,95	11,01	13,84	14,76	14,15	12,51	8,88	5,74	3,62	3,40					
stdev	0,02	0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,04	0,05	0,08	0,11	0,15	0,22	0,30	0,37	0,48	0,88	
	1,38	1,81	2,44	3,36	3,75	4,56	4,99	5,03	4,56	3,46	2,58	2,08	2,39						
Name 57°C 1:100												Average		STDev					
Average start		1250	15:02:31	oil temp				57,3	0,09										
Average stop		1280	15:03:01	flow				1,20	0,01										
Number of records																			
average	0,55	0,36	0,24	0,18	0,19	0,27	0,38	0,38	0,44	0,56	0,62	0,92	1,32	1,87	2,32	2,89	3,45	4,21	
	6,68	9,48	10,91	13,09	15,81	15,56	16,23	14,73	11,62	8,74	5,44	3,33	2,07	2,10					
stdev	0,56	0,30	0,14	0,06	0,04	0,07	0,14	0,16	0,23	0,35	0,41	0,60	0,81	1,03	1,36	1,78	2,26	2,77	3,52
	4,12	5,03	5,48	5,23	4,97	4,27	3,73	3,32	2,94	2,02	1,16	0,77	0,94						

Name	57°C 1:50										Average	STDev							
Average start	1335 15:03:56										oil temp	57,4							
Average stop	1365 15:04:26										flow	1,20							
Number of records	30																		
average	5,61	2,42	0,92	0,39	0,31	0,61	1,23	1,30	1,76	2,68	2,78	3,94	4,90	5,81	7,13	8,50	9,72	10,82	
	13,01	14,22	14,32	12,90	10,35	7,56	5,29	3,61	2,20	1,45	0,87	0,60	0,48	0,80					
stdev	3,87	1,42	0,43	0,14	0,10	0,21	0,51	0,55	0,81	1,35	1,39	1,97	2,33	2,62	3,24	3,86	4,41	4,85	5,44
	5,66	5,81	5,16	3,95	2,91	1,97	1,36	0,86	0,61	0,40	0,31	0,30	0,56						
Name	50°C Oil	Average	STDev																
Average start	1430 15:05:31	oil temp	49,3																
Average stop	1460 15:06:01	flow	1,20																
Number of records	30																		
average	0,09	0,08	0,08	0,09	0,13	0,20	0,24	0,23	0,23	0,24	0,24	0,36	0,55	0,82	0,89	0,97	1,02	1,22	
	2,65	4,75	5,28	7,08	10,58	10,86	13,42	14,03	13,46	12,09	8,77	5,73	3,64	3,35					
stdev	0,02	0,02	0,02	0,02	0,03	0,04	0,03	0,03	0,03	0,04	0,07	0,11	0,15	0,21	0,30	0,38	0,50	0,89	
	1,46	1,89	2,66	3,94	4,51	5,92	6,76	6,86	6,28	4,77	3,36	2,32	2,21						
Name	50°C 1:100	Average	STDev																
Average start	1515 15:06:56	oil temp	50,6																
Average stop	1545 15:07:26	flow	1,20																
Number of records	30																		
average	0,88	0,51	0,29	0,19	0,19	0,29	0,44	0,44	0,54	0,72	0,80	1,19	1,69	2,31	2,88	3,58	4,26	5,12	
	7,75	10,62	12,28	14,43	16,76	16,17	16,26	14,47	11,21	8,20	5,05	3,10	2,02	2,05					
stdev	1,16	0,53	0,21	0,08	0,05	0,09	0,20	0,23	0,34	0,55	0,63	0,94	1,24	1,54	2,00	2,55	3,11	3,66	4,42
	4,99	5,87	6,06	5,45	4,97	4,32	4,06	3,68	3,13	2,25	1,68	1,31	1,32						

Name	50°C 1:50										Average	STDev							
Average start	1600	15:08:21	oil temp					50,6	0,68										
Average stop	1630	15:08:51	flow					1,20	0,01										
Number of records	30																		
average	10,68	4,11	1,36	0,50	0,38	0,78	1,70	1,81	2,56	4,06	4,18	5,90	7,13	8,21	10,00	11,78	13,27	14,58	
	17,02	18,17	18,15	16,13	12,84	9,47	6,73	4,67	2,91	1,88	1,09	0,69	0,52	0,76					
stdev	7,85	2,58	0,67	0,19	0,12	0,27	0,74	0,81	1,24	2,18	2,18	3,06	3,51	3,78	4,58	5,26	5,79	6,20	6,72
	6,76	6,62	5,59	4,10	2,97	2,03	1,44	0,91	0,60	0,37	0,27	0,23	0,38						

Date 0804-2013

Conditions Warm oil experiments: Method: Inject above, SIT, Premix. DOR: 1/100, Temp: 75°C + 10°C

Dispersion Basic NS

Nozzle size 1,5mm, 1,2L/min

OSEBERG BLEND 75°C - BASIC

Name OB 77° NoDisp I (0804-1.22 L/min))

											average	stddev		
Average start	1448	15:54:55	oil temp					77,7	0,13					
Average stop	1478	15:55:25	flow					1,22	0,01					
Number of records										30				

average	0,00	0,00	0,01	0,03	0,08	0,12	0,12	0,11	0,11	0,12	0,16	0,26	0,41	0,60	0,65	0,64	0,53	0,74	
	1,79	4,00	4,07	5,57	9,80	10,36	15,76	19,76	23,71	25,83	22,43	15,91	9,72	7,69					
stdev	0,00	0,00	0,01	0,02	0,05	0,07	0,06	0,05	0,04	0,04	0,05	0,07	0,09	0,13	0,18	0,23	0,25	0,36	0,67
	1,11	1,44	2,01	3,08	3,80	5,50	6,89	8,14	9,34	8,97	7,03	4,82	4,41						

Name OB 78°C Basic NS inject above

											average	stddev		
Average start	1500	15:55:47	oil temp					78,4	0,1					
Average stop	1530	15:56:17	flow					1,20	0,01					
Number of records										30				

average	1,52	0,77	0,36	0,17	0,13	0,18	0,27	0,25	0,31	0,46	0,53	0,79	1,05	1,31	1,61	1,81	1,96	2,48	
	3,84	5,88	6,93	8,85	11,78	12,90	15,19	15,33	13,21	10,01	6,17	3,62	2,46	2,71					
stdev	1,40	0,65	0,26	0,11	0,08	0,12	0,19	0,18	0,23	0,34	0,36	0,51	0,63	0,75	0,98	1,23	1,50	1,89	2,52

Name	OB 75°C Basic NS SIT										average		stddev						
Average start	1655	15:58:22	oil temp					75,0	0,38										
Average stop	1685	15:58:52	flow					1,21	0,01										
Number of records										30									
average	0,51	0,34	0,22	0,15	0,14	0,21	0,29	0,30	0,39	0,55	0,67	0,99	1,34	1,69	2,05	2,25	2,37	2,87	
	4,21	6,21	7,14	8,85	11,19	11,95	13,54	13,84	12,31	10,36	6,75	4,06	2,26	2,02					
stdev	0,38	0,24	0,14	0,09	0,07	0,10	0,15	0,15	0,20	0,28	0,34	0,49	0,63	0,78	0,99	1,19	1,40	1,68	2,15
	2,79	3,62	4,55	5,33	6,00	6,37	6,57	5,75	4,94	3,40	2,31	1,39	1,36						
Name OB 76°C Basic NS Premix										average		stddev							
Average start	1723	15:59:30	oil temp					76,2	0,102										
Average stop	1753	16:00:00	flow					1,22	0,012										
Number of records										30									
average	0,44	0,30	0,20	0,15	0,14	0,20	0,27	0,29	0,37	0,52	0,65	0,99	1,40	1,86	2,31	2,58	2,52	2,83	
	3,84	5,39	6,01	7,55	10,25	11,48	14,51	16,32	16,75	16,05	12,44	8,29	5,31	5,08					
stdev	0,39	0,23	0,12	0,07	0,05	0,07	0,12	0,13	0,17	0,26	0,30	0,44	0,60	0,76	0,97	1,12	1,16	1,18	1,20
	1,29	1,65	2,09	2,56	3,05	3,58	4,02	4,20	4,47	4,24	3,72	2,93	3,58						
Name OB 77°C NoDisp II (0804-1.22 L/min)										average		stddev							
Average start	1840	16:01:26	oil temp					77,3	0,25										
Average stop	1870	16:01:56	flow					1,20	0,06										
Number of records										30									
average	0,00	0,00	0,01	0,02	0,05	0,09	0,09	0,09	0,10	0,12	0,17	0,26	0,41	0,58	0,60	0,57	0,43	0,58	
	1,44	3,23	3,09	4,20	7,56	7,88	12,02	15,14	18,43	20,56	18,20	12,55	7,49	5,74					
stdev	0,00	0,00	0,01	0,02	0,04	0,06	0,05	0,04	0,04	0,04	0,05	0,07	0,10	0,13	0,17	0,20	0,27	0,55	
	1,04	1,26	1,79	2,91	3,31	4,82	6,23	7,67	8,59	7,90	6,07	4,21	3,84						

OSEBERG BLEND 10°C - BASIC

Name: OB 16°C NoDisp I (0804-1.21 L/min)												average		stddev							
Average start 1995 16:04:01				oil temp				16,4		0,17											
Average stop 2025 16:04:31				flow				1,21		0,01											
Number of records 30																					
average	0,00	0,00	0,00	0,00	0,01	0,02	0,02	0,03	0,04	0,05	0,09	0,17	0,30	0,44	0,40	0,27	0,14	0,18			
	0,67	2,05	1,44	1,85	3,90	3,52	6,16	8,37	11,45	15,56	18,10	16,83	13,09	12,44							
stdev	0,00	0,00	0,00	0,00	0,01	0,02	0,02	0,02	0,02	0,03	0,04	0,06	0,07	0,08	0,09	0,07	0,10	0,25			
	0,50	0,56	0,78	1,49	1,62	2,60	3,54	4,93	6,52	7,40	7,62	7,33	8,06								
Name OB 15°C Basic NS inject above												average		stddev							
Average start 2174 16:07:00				oil temp				15,3		0,30											
Average stop 2204 16:07:30				flow				1,20		0,02											
Number of records 30																					
average	0,94	0,51	0,25	0,13	0,09	0,12	0,17	0,16	0,21	0,31	0,37	0,56	0,76	0,95	1,13	1,17	1,14	1,43			
	2,38	3,82	4,19	5,35	7,62	8,43	10,87	11,96	12,07	11,53	9,41	6,86	5,40	6,59							
stdev	0,33	0,16	0,08	0,04	0,03	0,03	0,04	0,04	0,05	0,08	0,08	0,12	0,14	0,16	0,21	0,26	0,31	0,38	0,51		
	0,68	0,94	1,30	1,85	2,41	3,39	4,18	4,51	4,68	4,32	3,89	3,85	5,66								
Name OB 14°C Basic NS SIT												average		stddev							
Average start 2284 16:08:50				oil temp				14,4		0,01											
Average stop 2314 16:09:20				flow				1,21		0,01											
Number of records 30																					
average	0,93	0,58	0,34	0,22	0,19	0,27	0,40	0,42	0,56	0,82	1,00	1,49	1,98	2,42	2,88	3,18	3,37	4,04			
	5,70	8,02	9,45	11,70	14,77	16,53	19,64	21,72	21,23	20,36	15,74	10,92	6,49	5,81							
stdev	0,40	0,21	0,10	0,05	0,04	0,06	0,10	0,11	0,15	0,23	0,27	0,39	0,50	0,59	0,73	0,86	0,98	1,18	1,51		
	1,95	2,49	3,13	3,85	4,73	5,69	6,48	6,31	6,32	5,13	4,01	2,81	3,09								

Name	OB 14°C Basic NS Premix										average	stddev							
Average start	2396 16:10:42										oil temp	14,5							
Average stop	2426 16:11:12										flow	1,21							
Number of records	30																		
average	2,23	1,09	0,48	0,22	0,17	0,27	0,49	0,55	0,81	1,37	1,72	2,70	3,71	4,49	5,33	5,63	5,56	6,00	
	7,20	8,94	10,29	11,94	13,53	14,13	14,54	13,85	11,60	9,76	7,22	4,76	2,88	2,56					
stdev	0,99	0,44	0,17	0,07	0,05	0,08	0,15	0,17	0,24	0,42	0,51	0,79	1,06	1,20	1,43	1,46	1,52	1,62	1,82
	2,17	2,66	3,18	3,61	4,17	4,38	4,53	3,87	3,61	2,86	2,08	1,43	1,50						
Name	OB 15°C NoDisp II (0804-1.22 L/min)										average	stddev							
Average start	2502 16:12:28										oil temp	14,6							
Average stop	2532 16:12:58										flow	1,22							
Number of records	30																		
average	0,06	0,05	0,05	0,05	0,07	0,08	0,09	0,09	0,11	0,15	0,21	0,34	0,53	0,72	0,80	0,75	0,60	0,75	
	1,59	3,14	3,00	3,87	6,33	6,52	9,12	10,59	12,49	15,09	16,90	16,44	13,53	14,32					
stdev	0,05	0,03	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,03	0,04	0,05	0,07	0,08	0,10	0,10	0,14	0,32	
	0,65	0,71	1,00	1,72	1,97	3,13	4,37	6,18	8,20	9,59	9,62	8,55	10,27						

Date 1204-2013

Conditions Warm oil experiments: Method: Inject above, SIT, Premix. DOR: 1/100, Temp: 75°C + 13°C
 Comments Dasic NS
 Nozzle size 1,5mm, 1,2L/min

Name Troll 81°C (no disp I - Dasic)															average	stddev			
Average start	783	15:32:09	oil temp				81,2	0,44											
Average stop	813	15:32:39	flow				1,21	0,01											
Number of records															30				
average	1,99	1,50	1,11	0,84	0,76	0,89	1,01	0,93	1,03	1,28	1,45	1,88	2,37	2,72	3,15	3,69	4,20	5,62	
	7,71	11,11	14,09	16,65	18,22	17,78	16,55	13,93	10,97	7,81	5,05	3,01	2,09	2,33					
stdev	0,57	0,34	0,18	0,09	0,06	0,11	0,17	0,17	0,21	0,30	0,33	0,47	0,61	0,77	1,02	1,34	1,69	2,33	3,21
	4,45	5,76	6,92	7,63	7,54	7,01	5,63	3,96	2,51	1,46	0,94	0,80	1,03						
Name Troll 83°C Dasic NS inject above															average	stddev			
Average start	906	15:34:12	oil temp				83,2	0,05											
Average stop	936	15:34:42	flow				1,213	0,01											
Number of records															30				
average	3,33	2,20	1,40	0,93	0,80	0,98	1,18	1,06	1,17	1,47	1,60	2,05	2,50	2,79	3,24	3,74	4,25	5,58	
	7,63	10,94	14,03	16,79	18,57	18,36	17,15	14,44	11,36	7,94	4,99	2,95	2,15	2,74					
stdev	1,64	0,81	0,31	0,09	0,06	0,12	0,22	0,19	0,24	0,35	0,34	0,48	0,57	0,68	0,91	1,16	1,45	1,92	2,62
	3,60	4,75	5,77	6,40	6,43	6,04	4,94	3,53	2,33	1,46	1,01	0,95	1,50						

Name Troll 86°C Basic NS SIT												average		stddev					
Average start		1045	15:36:31	oil temp				85,7	0,86										
Average stop		1075	15:37:01	flow				1,22	0,01										
Number of records																			
average	2,07	1,56	1,16	0,88	0,80	0,92	1,05	0,98	1,09	1,36	1,57	2,04	2,60	3,04	3,62	4,36	5,03	6,70	
	9,04	12,62	15,48	17,61	18,70	18,01	16,84	14,26	11,16	7,73	4,78	2,84	2,05	2,48					
stdev	0,43	0,24	0,11	0,05	0,04	0,07	0,12	0,12	0,15	0,22	0,25	0,36	0,48	0,60	0,80	1,06	1,33	1,78	2,35
	3,09	3,83	4,35	4,52	4,30	3,92	3,22	2,46	1,80	1,22	0,88	0,82	1,25						
Name Troll 90°C Basic NS premix												average		stddev					
Average start		1150	15:38:16	oil temp				89,62	0,20										
Average stop		1180	15:38:46	flow				1,21	0,01										
Number of records																			
average	1,74	1,37	1,07	0,85	0,77	0,87	0,96	0,89	0,98	1,19	1,37	1,75	2,21	2,52	2,93	3,44	3,91	5,31	
	7,43	10,91	13,81	16,15	17,32	16,41	15,04	12,58	9,89	6,87	4,34	2,67	1,96	2,37					
stdev	0,53	0,29	0,14	0,06	0,05	0,09	0,16	0,15	0,19	0,27	0,31	0,43	0,57	0,72	0,96	1,30	1,65	2,30	3,18
	4,40	5,61	6,48	6,70	6,22	5,64	4,63	3,49	2,42	1,46	0,91	0,82	1,16						
Name Troll 91°C (no disp II - Basic)												average		stddev					
Average start		1200	15:39:06	oil temp				91,19	0,28										
Average stop		1230	15:39:36	flow				1,21	0,01										
Number of records																			
average	1,67	1,33	1,06	0,85	0,78	0,87	0,95	0,88	0,95	1,16	1,33	1,69	2,12	2,41	2,77	3,21	3,60	4,82	
	6,72	9,92	12,67	15,15	16,95	17,04	16,67	14,77	12,13	8,60	5,41	3,18	2,15	2,39					
stdev	0,38	0,25	0,15	0,09	0,07	0,11	0,16	0,15	0,18	0,24	0,27	0,38	0,51	0,65	0,87	1,15	1,45	2,03	2,85
	4,10	5,37	6,61	7,59	7,87	8,00	7,23	5,82	4,15	2,71	1,73	1,25	1,40						

Troll B 13°C - DASIC

Name Troll 16°C (no disp I - Dasic)												average		stddev					
Average start 1406 15:42:32												oil temp		16,18					
Average stop 1436 15:43:02												flow		0,14					
Number of records 30												1,18		0,01					
average	1,88	1,47	1,14	0,89	0,82	0,93	1,04	0,97	1,08	1,34	1,53	1,95	2,44	2,76	3,15	3,61	3,97	5,13	
	6,89	9,90	12,62	15,42	18,11	19,60	21,20	21,34	19,76	15,39	10,40	6,44	4,38	4,68					
stdev	0,35	0,21	0,11	0,06	0,04	0,08	0,12	0,12	0,15	0,21	0,23	0,32	0,41	0,50	0,64	0,83	1,01	1,35	1,80
	2,45	3,13	3,80	4,41	4,80	5,23	5,27	4,93	4,31	3,19	2,16	1,73	2,53						
Name Troll 15°C Dasic NS inject above												average		stddev					
Average start 1528 15:44:34												oil temp		15,386		0,04			
Average stop 1558 15:45:04												flow		1,19		0,013			
Number of records 30																			
average	4,73	2,69	1,43	0,82	0,67	0,93	1,30	1,22	1,45	1,96	2,11	2,75	3,31	3,66	4,30	4,99	5,57	6,98	
	9,02	12,11	14,96	16,98	17,77	16,95	15,57	13,07	10,03	6,78	4,26	2,69	2,02	2,44					
stdev	2,58	1,06	0,32	0,07	0,03	0,11	0,31	0,32	0,45	0,73	0,76	1,05	1,23	1,38	1,73	2,13	2,50	3,07	3,86
	4,83	5,99	6,73	6,78	6,20	5,32	4,09	2,83	1,90	1,33	1,02	0,96	1,34						
Name Troll 15°C Dasic NS SIT												average		stddev					
Average start 1663 15:46:49												oil temp		14,69		0,01			
Average stop 1693 15:47:19												flow		1,17		0,01			
Number of records 30																			
average	12,10	5,31	2,03	0,85	0,64	1,09	1,96	1,88	2,41	3,56	3,60	4,73	5,43	5,82	6,91	7,98	8,85	10,52	
	12,80	15,68	18,22	19,12	18,36	16,25	13,87	10,97	7,99	5,33	3,33	2,10	1,66	2,23					
stdev	4,82	1,61	0,38	0,08	0,04	0,10	0,34	0,36	0,55	0,96	0,93	1,27	1,40	1,46	1,78	2,07	2,34	2,67	3,15
	3,61	4,22	4,47	4,28	3,75	3,11	2,33	1,57	1,04	0,69	0,53	0,56	0,99						

Name	Troll 15°C Basic NS premix										average	stddev							
Average start	1784	15:48:50										oil temp	14,65	0,013					
Average stop	1814	15:49:20										flow	1,17	0,01					
Number of records	30																		
average	3,60	2,31	1,41	0,91	0,78	1,04	1,37	1,32	1,55	2,07	2,33	3,09	3,89	4,51	5,47	6,68	7,78	10,12	
	13,28	17,87	21,80	24,23	24,63	22,72	20,50	17,11	13,26	9,32	6,06	3,85	2,84	3,30					
stdev	1,08	0,49	0,17	0,05	0,03	0,08	0,20	0,21	0,29	0,46	0,50	0,71	0,88	1,04	1,34	1,71	2,06	2,59	3,24
	4,03	4,91	5,43	5,58	5,35	4,84	3,93	2,93	2,10	1,45	1,03	0,98	1,62						

Date 1704-2013

Conditions warm oil Experiments: Method: Inject above, SIT, Premix. DOR: 1/100, Temp: 75°C + 13°C

Comments 9500

Nozzle size 1,5mm, 1,2L/min

Troll B 75°C - C9500

Name Troll 78°C (no disp I - 9500)

											average	stddev							
Average start	710 15:06:39										oil temp	77,96	0,61						
Average stop	730 15:06:59										flow	1,23	0,012						
Number of records	20 0																		
average	5,48	3,07	1,59	0,89	0,76	1,10	1,40	1,04	1,07	1,28	1,13	1,38	1,54	1,67	2,04	2,44	3,05	4,07	
	5,83	8,33	11,08	13,98	15,75	16,24	16,51	14,96	11,70	8,33	5,08	2,99	2,00	2,13					
stdev	0,76	0,39	0,18	0,09	0,07	0,10	0,15	0,13	0,16	0,22	0,23	0,32	0,41	0,50	0,68	0,91	1,20	1,65	2,35
	3,31	4,44	5,62	6,42	6,72	6,83	6,11	4,62	3,06	1,78	1,14	0,91	1,16						

Name Troll 79°C 9500 inject above

											average	stddev							
Average start	911 15:10:00										oil temp	79,48	4,62						
Average stop	941 15:10:30										flow	1,17	0,11						
Number of records	30																		
average	10,24	4,75	1,96	0,90	0,71	1,18	1,82	1,46	1,65	2,20	1,98	2,50	2,74	2,90	3,48	4,06	4,77	5,88	
	7,69	10,01	12,45	14,27	14,58	13,68	12,35	10,10	7,35	5,00	2,94	1,64	1,09	1,28					
stdev	4,43	1,62	0,45	0,12	0,06	0,16	0,43	0,42	0,58	0,92	0,88	1,19	1,35	1,47	1,83	2,18	2,54	3,02	3,75
	4,67	5,85	6,76	7,04	6,73	6,00	4,80	3,43	2,29	1,33	0,77	0,61	0,85						

Name	Troll 85°C 9500 SIT										Average		STDdev						
Average start	1066	15:12:35	oil temp					84,88	0,608										
Average stop	1096	15:13:05	flow					1,22	0,01										
Number of records	30																		
average	19,09	7,74	2,71	1,06	0,80	1,49	2,72	2,42	3,07	4,58	4,37	5,86	6,61	7,12	8,64	10,02	11,22	12,70	
	14,52	15,79	16,32	15,00	12,36	9,65	7,51	5,54	3,76	2,43	1,42	0,83	0,63	0,90					
stdev	10,26	3,42	0,95	0,32	0,23	0,44	0,98	0,94	1,32	2,19	2,10	2,90	3,26	3,50	4,30	5,04	5,67	6,42	7,37
	7,94	8,19	7,46	6,10	4,64	3,46	2,40	1,51	0,93	0,55	0,36	0,33	0,57						
Name	Troll 87°C 9500 premix										Average		STDev						
Average start	1164	15:14:13	oil temp					86,9	0,26										
Average stop	1194	15:14:43	flow					1,21	0,01										
Number of records	30																		
average	8,94	4,50	2,05	1,01	0,80	1,23	1,75	1,39	1,54	2,02	1,93	2,56	3,05	3,55	4,65	5,99	7,76	10,48	
	14,58	19,62	24,47	27,55	27,43	24,90	21,69	16,99	11,84	7,85	4,62	2,80	1,98	2,29					
stdev	1,95	0,75	0,23	0,06	0,04	0,07	0,18	0,18	0,25	0,41	0,43	0,63	0,79	0,97	1,32	1,76	2,28	2,98	3,94
	4,95	5,93	6,35	6,23	5,82	5,44	4,84	3,91	2,92	1,86	1,18	0,91	1,16						
Name	Troll 87°C (no disp II - 9500)										Average		STDev						
Average start	1193	15:14:42	oil temp					87,0	0,40										
Average stop	1208	15:14:57	flow					1,22	0,01										
Number of records	15																		
average	6,71	3,61	1,77	0,95	0,79	1,17	1,54	1,17	1,23	1,52	1,39	1,77	2,04	2,29	2,91	3,63	4,64	6,30	
	8,99	12,62	16,44	19,89	21,66	21,74	21,37	18,96	14,88	10,81	6,63	3,95	2,72	3,13					
stdev	1,01	0,45	0,17	0,07	0,04	0,07	0,13	0,13	0,16	0,24	0,25	0,37	0,47	0,58	0,80	1,06	1,37	1,83	2,48
	3,25	4,09	4,76	5,23	5,64	6,31	6,47	5,56	4,16	2,63	1,63	1,23	1,56						

Troll B 13°C - C9500

Name Troll 18°C (no disp I - 9500)

Average start 1330 15:16:59

Average stop 1360 15:17:29

Number of records 30

average	6,30	3,45	1,73	0,94	0,80	1,17	1,53	1,16	1,22	1,49	1,35	1,69	1,90	2,05	2,49	2,96	3,62	4,75	
	6,69	9,43	12,59	16,47	19,94	22,82	26,09	26,03	21,95	16,31	10,12	6,08	4,22	4,79					
stdev	1,00	0,46	0,18	0,07	0,05	0,09	0,16	0,15	0,19	0,28	0,28	0,39	0,49	0,59	0,79	1,02	1,31	1,72	2,34
	3,16	4,17	5,18	5,95	6,47	6,81	6,52	5,48	4,12	2,62	1,78	1,65	2,56						

Name Troll 15°C 9500 inject above

Average start 1485 15:19:34

Average stop 1515 15:20:04

Number of records 30

average	16,60	6,61	2,24	0,85	0,63	1,19	2,20	1,93	2,43	3,60	3,35	4,40	4,85	5,09	6,07	6,93	7,75	8,85	
	10,38	11,77	12,97	13,02	11,77	10,07	8,48	6,52	4,44	2,81	1,61	0,95	0,75	1,14					
stdev	9,95	3,57	1,09	0,39	0,29	0,54	1,06	0,96	1,27	1,97	1,85	2,47	2,70	2,81	3,34	3,80	4,20	4,74	5,51
	6,18	6,78	6,72	5,99	5,01	4,11	3,12	2,13	1,38	0,82	0,51	0,43	0,69						

Name Troll 14°C 9500 SIT

Average start 1571 15:21:00

Average stop 1601 15:21:30

Number of records 30

average	29,62	10,39	2,98	0,95	0,66	1,36	2,86	2,64	3,56	5,64	5,25	6,95	7,48	7,63	8,90	9,80	10,44	11,21	
	12,28	12,83	13,06	12,05	10,21	8,43	7,08	5,56	3,88	2,47	1,41	0,82	0,65	1,04					
stdev	13,17	4,20	1,10	0,34	0,24	0,47	1,02	0,97	1,36	2,26	2,11	2,84	3,04	3,07	3,59	3,95	4,23	4,57	5,08
	5,40	5,62	5,25	4,49	3,66	2,97	2,27	1,56	1,00	0,58	0,35	0,30	0,54						

Name	Troll 13°C 9500 premix										Average		STDev								
Average start	1661	15:22:30	oil temp					13,4	0,01												
Average stop	1691	15:23:00	flow					1,20	0,01												
Number of records										30											
average	9,14	4,51	1,99	0,96	0,77	1,23	1,82	1,48	1,68	2,24	2,13	2,83	3,33	3,77	4,79	5,93	7,28	9,24			
	12,06	15,36	18,81	21,56	22,23	21,37	19,74	15,96	11,17	7,11	4,03	2,36	1,67	2,13							
stdev	1,57	0,65	0,22	0,08	0,05	0,09	0,19	0,19	0,27	0,42	0,44	0,63	0,78	0,93	1,23	1,59	2,00	2,53	3,18		
	3,82	4,48	4,86	4,85	4,70	4,40	3,62	2,57	1,65	0,98	0,65	0,58	0,86								
Name Troll 13°C (no disp II - 9500)										Average		STDev									
Average start	1800	15:24:49	oil temp					12,9	#N/A												
Average stop	1830	15:25:19	flow					1,10	0,18												
Number of records										30											
average	6,02	3,22	1,57	0,84	0,71	1,08	1,45	1,10	1,15	1,41	1,24	1,52	1,67	1,76	2,07	2,37	2,78	3,50			
	4,72	6,37	8,19	10,21	11,59	12,59	13,64	12,69	10,17	7,39	4,35	2,18	1,22	1,34							
stdev	0,88	0,42	0,17	0,07	0,05	0,09	0,16	0,15	0,19	0,27	0,27	0,38	0,47	0,56	0,73	0,94	1,18	1,53	2,03		
	2,68	3,46	4,24	4,73	4,92	4,90	4,32	3,43	2,59	1,79	1,20	0,95	1,28								

Date 2204-2013

Conditions Warm oil experiments Method: Inject above, SIT, Premix. DOR: 1/100, Temp: 75°C + 13°C

Comments 9500

Nozzle size 1,5mm, 1,2L/min

OSEBERG BLEND 75°C - C9500

Name OB 71°C NoDisp I (2204-1.21 L/min)												Average		STDev					
Average start		750	14:24:04		oil temp		70,6		0,22										
Average stop		780	14:24:34		flow		1,21		0,01										
Number of records																			
average	1,61	1,10	0,73	0,54	0,54	0,72	0,78	0,54	0,50	0,53	0,47	0,57	0,63	0,70	0,83	0,89	0,89	1,12	
	1,74	2,68	3,30	4,32	6,42	8,25	11,46	15,20	18,27	20,09	17,70	13,47	10,23	10,91					
stdev	0,09	0,09	0,09	0,09	0,09	0,11	0,11	0,08	0,08	0,08	0,07	0,10	0,13	0,17	0,24	0,32	0,39	0,53	0,85
	1,34	1,81	2,48	3,61	4,61	6,19	7,76	9,04	10,05	9,66	8,38	7,09	7,69						

Name OB 72°C 9500 inject above

Name OB 72°C 9500 inject above												Average		STDev					
Average start		860	14:25:54		oil temp		71,9		0,07										
Average stop		890	14:26:24		flow		1,20		0,01										
Number of records																			
average	3,55	1,95	0,99	0,56	0,49	0,74	0,99	0,77	0,82	1,01	0,97	1,28	1,50	1,73	2,19	2,63	2,96	3,72	
	5,05	6,69	7,98	9,06	10,19	10,26	10,06	8,91	7,09	5,49	3,93	2,98	2,61	3,34					
stdev	1,52	0,67	0,24	0,09	0,06	0,10	0,21	0,20	0,26	0,39	0,39	0,54	0,65	0,77	1,01	1,29	1,56	1,94	2,49
	3,07	3,74	4,19	4,34	4,18	3,79	3,11	2,27	1,65	1,15	0,94	1,06	1,92						

Name OB 69°C 9500 SIT												Average		STDev					
Average start		957	14:27:31		oil temp				69,2	0,76									
Average stop		987	14:28:01		flow				1,20	0,01									
Number of records																			
average	4,33	2,36	1,19	0,66	0,57	0,89	1,27	1,06	1,21	1,59	1,62	2,25	2,77	3,35	4,39	5,50	6,44	8,05	
	10,56	13,42	15,87	17,38	18,13	17,17	15,59	13,09	9,64	7,13	4,79	3,51	2,84	3,58					
stdev	1,26	0,58	0,23	0,09	0,06	0,10	0,20	0,20	0,27	0,42	0,46	0,66	0,85	1,05	1,40	1,81	2,22	2,75	3,49
	4,24	5,05	5,43	5,41	5,12	4,59	3,88	2,81	2,06	1,34	1,01	0,88	1,33						
Name OB 73°C 9500 premix												Average		STDev					
Average start		1063	14:29:16		oil temp				72,6	0,16									
Average stop		1093	14:29:46		flow				1,20	0,01									
Number of records																			
average	4,46	2,40	1,19	0,65	0,55	0,85	1,20	1,00	1,15	1,53	1,56	2,13	2,57	2,98	3,73	4,39	4,98	6,23	
	8,51	11,51	14,45	17,01	19,11	19,66	19,22	17,49	14,10	11,33	8,12	6,06	4,31	4,77					
stdev	2,01	0,91	0,35	0,13	0,08	0,13	0,28	0,29	0,38	0,59	0,63	0,90	1,13	1,33	1,73	2,12	2,60	3,31	4,51
	6,00	7,81	9,36	10,31	10,85	10,52	9,48	7,20	5,44	3,45	2,46	1,78	2,57						
Name OB 74°C NoDisp II (2208-1.21 L/min)												Average		STDev					
Average start		1160	14:30:53		oil temp				73,8	0,08									
Average stop		1190	14:31:23		flow				1,21	0,01									
Number of records																			
average	1,61	1,09	0,72	0,52	0,51	0,69	0,74	0,50	0,47	0,50	0,44	0,54	0,60	0,66	0,77	0,81	0,79	0,97	
	1,48	2,25	2,71	3,44	5,01	6,38	8,70	11,17	13,02	14,14	12,61	10,51	9,30	11,47					
stdev	0,04	0,05	0,05	0,05	0,05	0,05	0,05	0,04	0,04	0,05	0,05	0,07	0,09	0,11	0,14	0,18	0,20	0,27	0,42
	0,64	0,81	1,06	1,49	1,83	2,48	3,34	4,41	5,36	5,02	3,91	3,35	5,44						

OSEBERG BLEND 13°C - C9500

Name OB 22°C NoDisp I (2204-1.21 L/min)												Average		STDev					
Average start		1315	14:33:28	oil temp				16,0	0,16										
Average stop		1345	14:33:58	flow				1,21	0,01										
Number of records				30															
average	1,65	1,11	0,71	0,51	0,49	0,66	0,71	0,49	0,47	0,50	0,45	0,57	0,65	0,71	0,83	0,85	0,81	1,00	
	1,51	2,25	2,60	3,22	4,69	6,00	8,50	11,57	14,88	18,07	18,53	18,27	18,93	27,77					
stdev	0,06	0,06	0,06	0,05	0,05	0,05	0,04	0,03	0,03	0,04	0,04	0,05	0,07	0,09	0,13	0,16	0,18	0,25	0,40
	0,65	0,85	1,16	1,75	2,29	3,33	4,60	5,90	7,12	7,59	7,33	7,45	12,81						
Name OB 15°C 9500 inject above												Average		STDev					
Average start		1410	14:35:03	oil temp				15,22	0,03										
Average stop		1440	14:35:33	flow				1,21	0,01										
Number of records				30															
average	5,36	2,66	1,21	0,62	0,52	0,81	1,16	0,95	1,09	1,46	1,43	1,95	2,31	2,66	3,38	4,04	4,53	5,48	
	7,03	8,79	10,16	11,16	12,23	12,42	12,70	12,18	10,68	9,04	6,90	5,52	5,42	8,99					
stdev	3,98	1,55	0,47	0,14	0,08	0,17	0,43	0,44	0,62	0,98	1,00	1,40	1,66	1,87	2,36	2,83	3,24	3,72	4,31
	4,77	5,29	5,37	5,19	5,06	5,19	5,39	5,37	4,98	3,76	2,53	1,91	3,06						
Name OB 14°C 9500 SIT												Average		STDev					
Average start		1558	14:37:31	oil temp				14,3	0,01										
Average stop		1588	14:38:01	flow				1,20	0,01										
Number of records				30															
average	6,61	3,14	1,34	0,63	0,52	0,88	1,40	1,21	1,47	2,07	2,09	2,93	3,52	4,08	5,18	6,24	6,96	8,17	
	9,84	11,29	12,10	11,83	11,04	9,63	8,39	7,03	5,58	4,60	3,74	3,50	4,11	8,83					
stdev	2,94	1,11	0,34	0,10	0,06	0,13	0,33	0,35	0,50	0,81	0,84	1,19	1,42	1,61	2,02	2,45	2,81	3,21	3,69
	4,01	4,37	4,40	4,21	3,89	3,58	3,11	2,50	1,94	1,32	0,96	1,03	3,11						

Name	OB 14°C 9500 premix										Average		STDev								
Average start	1648	14:39:01	oil temp					14,2	0,02												
Average stop	1678	14:39:31	flow					1,20	0,01												
Number of records										30											
average	3,11	1,83	1,01	0,61	0,54	0,79	1,01	0,79	0,85	1,07	1,07	1,44	1,70	1,93	2,38	2,75	3,04	3,89			
	5,52	7,75	9,77	11,97	14,77	16,47	18,25	18,71	17,59	16,47	14,04	11,62	8,62	10,09							
stdev	0,75	0,38	0,17	0,08	0,05	0,08	0,13	0,12	0,14	0,21	0,22	0,31	0,39	0,48	0,66	0,85	1,08	1,45	2,10		
	2,97	4,04	5,23	6,47	7,55	8,62	9,06	8,44	7,69	6,05	4,81	3,27	5,01								
Name OB 14°C NoDisp II (2204-1.20 L/min)										Average		STDev									
Average start	1720	14:40:13	oil temp					14,2	#N/A												
Average stop	1750	14:40:43	flow					1,20	0,01												
Number of records										30											
average	2,00	1,28	0,78	0,52	0,49	0,68	0,78	0,56	0,55	0,63	0,59	0,78	0,90	1,03	1,26	1,39	1,43	1,79			
	2,59	3,67	4,29	5,14	6,79	8,07	10,52	13,15	15,56	17,57	17,08	15,67	15,44	23,37							
stdev	0,07	0,04	0,03	0,03	0,03	0,03	0,03	0,02	0,03	0,04	0,04	0,06	0,07	0,08	0,10	0,12	0,13	0,18	0,27		
	0,43	0,58	0,80	1,23	1,73	2,69	3,83	5,03	6,29	6,68	6,28	6,33	10,11								

Date 3001-2013

Conditions Upstream, DOR Oil - 1:1000 - 1:25 - oil

Comments DOR Basic NS/Oseberg blend

Nozzle size 1.5mm, 1.5L/min

Name Oseberg 3001 No disp I

Average start 300 15:16:00

oil temp

average

stddev

Average stop 330 15:16:30

flow

1,51

0,03

Number of records 30

	0,03	0,03	0,03	0,05	0,07	0,09	0,09	0,08	0,08	0,10	0,14	0,24	0,40	0,55	0,51	0,34	0,19	0,24	
average	0,03	0,03	0,03	0,05	0,07	0,09	0,09	0,08	0,08	0,10	0,14	0,24	0,40	0,55	0,51	0,34	0,19	0,24	
	0,75	2,11	1,71	2,37	4,83	4,81	7,95	10,40	13,82	18,29	20,49	20,16	18,03	23,27					
stdev	0,02	0,01	0,01	0,02	0,03	0,03	0,03	0,02	0,02	0,03	0,03	0,05	0,08	0,11	0,14	0,16	0,13	0,18	0,40
	0,81	0,89	1,23	2,02	2,28	3,42	4,40	5,62	7,11	7,97	7,76	7,20	11,86						

Name 1:1000 Basic NS

Average start 390 15:17:30

oil temp

average

stddev

Average stop 420 15:18:00

flow

1,51

0,02

Number of records 20

	0,05	0,04	0,05	0,06	0,08	0,10	0,11	0,10	0,12	0,15	0,20	0,34	0,53	0,72	0,76	0,66	0,52	0,68
average	0,05	0,04	0,05	0,06	0,08	0,10	0,11	0,10	0,12	0,15	0,20	0,34	0,53	0,72	0,76	0,66	0,52	0,68
	1,59	3,52	3,43	4,72	8,28	8,76	12,97	15,94	19,37	22,72	22,00	17,68	12,75	12,97				
stdev	0,03	0,02	0,02	0,02	0,03	0,04	0,04	0,04	0,05	0,07	0,10	0,15	0,21	0,27	0,33	0,34	0,46	0,85
	1,44	1,75	2,37	3,52	4,05	5,66	7,20	8,80	10,24	10,13	8,42	6,70	7,90					

												average	stddev												
						oil temp			flow																
Name		1:500 Basic NS																							
Average start		466				15:18:46							13,52			0,02									
Average stop		496				15:19:16							1,51			0,02									
Number of records		30																							
average	0,09	0,08	0,08	0,09	0,11	0,14	0,15	0,14	0,17	0,22	0,29	0,46	0,71	1,00	1,18	1,24	1,16	1,55							
	3,12	5,87	6,26	8,33	12,78	13,64	18,65	22,04	24,92	26,21	22,54	16,24	10,87	10,35											
stdev	0,04	0,03	0,03	0,04	0,04	0,05	0,05	0,04	0,05	0,06	0,08	0,12	0,17	0,24	0,33	0,43	0,51	0,69	1,09						
	1,68	2,16	2,89	3,92	4,57	5,85	6,96	8,14	8,90	7,82	5,90	4,55	5,28												
average	0,17	0,14	0,13	0,13	0,15	0,19	0,21	0,19	0,21	0,27	0,33	0,52	0,79	1,12	1,41	1,62	1,69	2,28							
	4,18	7,14	7,97	10,18	14,28	14,80	18,23	18,94	18,02	15,81	11,64	7,69	5,19	5,13											
stdev	0,11	0,08	0,06	0,06	0,07	0,09	0,10	0,09	0,09	0,11	0,13	0,20	0,28	0,39	0,55	0,78	0,99	1,34	2,01						
	2,76	3,59	4,45	5,42	6,09	7,09	7,71	8,18	8,36	7,23	5,54	4,29	4,79												
average	0,45	0,30	0,20	0,14	0,13	0,17	0,22	0,21	0,27	0,39	0,49	0,78	1,15	1,60	2,11	2,61	3,02	4,10							
	6,66	10,23	11,64	13,92	16,87	16,10	16,49	14,21	10,76	7,43	4,44	2,57	1,66	1,67											
stdev	0,21	0,13	0,08	0,06	0,05	0,06	0,08	0,08	0,11	0,16	0,20	0,30	0,42	0,56	0,79	1,11	1,47	1,99	2,78						
	3,64	4,60	5,45	6,01	6,16	6,32	5,83	4,76	3,52	2,28	1,47	1,07	1,12												

Name	1:50 Basic NS										average		stddev						
Average start	721	15:23:01									oil temp		13,83	0,02					
Average stop	751	15:23:31									flow		1,51	0,02					
Number of records																			
average	2,29	1,23	0,61	0,31	0,24	0,33	0,51	0,53	0,69	1,07	1,27	1,92	2,64	3,32	4,34	5,03	5,99	7,56	
	11,29	16,83	21,00	25,11	26,53	24,44	21,05	16,65	10,95	7,83	4,31	2,98	1,55	1,84					
stdev	0,92	0,41	0,16	0,06	0,04	0,06	0,12	0,13	0,18	0,31	0,36	0,55	0,76	0,98	1,30	1,65	2,07	2,67	3,85
	5,28	6,72	7,40	7,03	6,40	5,38	4,29	2,82	2,14	1,21	0,90	0,58	0,83						
Name	1:25 Basic NS										average		stddev						
Average start	813	15:24:33									oil temp		14,03	0,02					
Average stop	843	15:25:03									flow		1,51	0,02					
Number of records																			
average	5,48	2,30	0,85	0,33	0,23	0,40	0,80	0,90	1,35	2,29	2,71	4,18	5,64	7,25	9,80	12,70	15,65	19,08	
	24,22	26,98	26,21	21,59	14,56	9,20	5,43	3,35	1,86	1,12	0,63	0,41	0,34	0,55					
stdev	3,86	1,45	0,46	0,16	0,10	0,18	0,40	0,47	0,74	1,34	1,55	2,39	3,12	3,80	4,91	6,15	7,50	8,75	10,28
	10,66	10,23	8,26	5,31	3,41	2,01	1,24	0,70	0,43	0,25	0,17	0,15	0,29						
Name	Oseberg 3001 No disp. II										average		stddev						
Average start	903	15:26:03									oil temp		14,03	0,03					
Average stop	933	15:26:33									flow		1,511	0,02					
Number of records																			
average	0,07	0,06	0,05	0,06	0,08	0,10	0,12	0,11	0,13	0,17	0,22	0,35	0,54	0,73	0,77	0,70	0,58	0,75	
	1,68	3,53	3,30	4,30	7,29	7,52	11,19	14,12	17,54	21,44	21,81	19,69	15,77	17,04					
stdev	0,08	0,05	0,03	0,02	0,03	0,04	0,04	0,04	0,05	0,06	0,08	0,11	0,15	0,20	0,29	0,39	0,44	0,58	1,00
	1,52	1,68	2,17	3,40	3,96	5,96	7,86	10,22	12,69	13,23	12,06	10,23	11,20						

Date 0502-2013

Conditions Upstream, DOR Oil - 1:1000 - 1:25 - oil

Comments DOR Basic NS Concentrated/Oseberg blend

Nozzle size 1.5mm, 1.5L/min

Name Oseberg 0502 No disp. I												average		stddev					
Average start		300	12:45:15	oil temp				12143	40,27										
Average stop		330	12:45:45	flow				1,52	0,04										
Number of records 30																			
average	0,34	0,24	0,16	0,12	0,11	0,13	0,15	0,12	0,12	0,14	0,16	0,25	0,38	0,54	0,61	0,53	0,39	0,49	
	1,21	2,84	2,95	3,87	6,03	6,24	9,52	12,71	16,12	20,15	22,62	22,24	20,18	23,34					
stdev	0,05	0,02	0,02	0,02	0,03	0,03	0,03	0,03	0,03	0,03	0,04	0,06	0,08	0,12	0,14	0,14	0,18	0,35	
	0,63	0,77	1,09	1,69	1,92	2,82	3,84	4,96	6,35	7,26	7,62	8,60	11,84						
Name 1:1000 Basic conc												average		stddev					
Average start		375	12:46:30	oil temp				12243	14,81										
Average stop		405	12:47:00	flow				1,50	0,01										
Number of records 30																			
average	0,35	0,25	0,18	0,14	0,13	0,15	0,17	0,14	0,14	0,17	0,20	0,30	0,46	0,65	0,78	0,75	0,63	0,81	
	1,79	3,75	4,11	5,34	7,96	8,44	12,21	15,57	19,06	22,59	23,66	22,16	19,15	21,72					
stdev	0,04	0,02	0,03	0,03	0,03	0,04	0,04	0,03	0,03	0,04	0,06	0,09	0,13	0,17	0,22	0,24	0,31	0,57	
	0,92	1,15	1,55	2,29	2,70	3,81	4,93	6,27	7,79	8,30	7,92	7,80	10,30						
Name 1:500 Basic conc												average		stddev					
Average start		465	12:48:00	oil temp				12336	13,98										
Average stop		495	12:48:30	flow				1,51	0,02										
Number of records 30																			
average	0,50	0,34	0,22	0,15	0,13	0,16	0,18	0,15	0,16	0,21	0,24	0,38	0,58	0,83	1,05	1,15	1,15	1,52	
	2,90	5,29	6,00	7,63	10,62	11,51	15,24	17,41	18,18	17,73	14,39	10,03	6,99	7,19					
stdev	0,11	0,07	0,05	0,04	0,04	0,04	0,05	0,05	0,06	0,08	0,09	0,14	0,21	0,30	0,43	0,58	0,71	0,96	1,51
	2,20	2,83	3,62	4,64	5,42	6,84	7,77	7,81	6,93	4,79	3,12	2,73	4,00						

Name	1:250 Basic conc												average	stddev					
Average start	555 12:49:30												oil temp	12418	18,40				
Average stop	585 12:50:00												flow	1,50	0,01				
Number of records	30																		
average	1,04	0,60	0,33	0,19	0,16	0,21	0,28	0,26	0,32	0,45	0,53	0,82	1,19	1,67	2,29	2,97	3,55	4,82	
	7,76	11,74	14,14	17,09	20,55	20,65	22,08	20,43	16,63	12,50	8,27	5,14	3,47	3,63					
stdev	0,32	0,17	0,09	0,05	0,04	0,06	0,08	0,08	0,10	0,15	0,18	0,28	0,39	0,54	0,76	1,08	1,43	1,94	2,73
	3,62	4,68	5,55	6,14	6,24	6,22	5,83	4,98	3,90	2,73	1,93	1,56	1,86						
Name	1:100 Basic conc												average	stddev					
Average start	645 12:51:00												oil temp	12532	19,76				
Average stop	675 12:51:30												flow	1,51	0,02				
Number of records	30																		
average	1,14	0,62	0,31	0,16	0,12	0,16	0,23	0,21	0,26	0,37	0,43	0,68	0,98	1,36	1,84	2,25	2,62	3,53	
	5,94	9,39	11,22	13,84	16,76	16,59	17,09	14,85	11,30	8,70	5,85	3,92	2,13	2,11					
stdev	0,65	0,30	0,12	0,05	0,03	0,05	0,08	0,08	0,12	0,19	0,23	0,37	0,52	0,71	1,01	1,39	1,83	2,42	3,51
	4,77	6,17	7,53	8,39	8,49	8,30	7,16	5,54	4,44	2,83	1,97	1,05	1,27						
Name	1:50 Basic conc												average	stddev					
Average start	735 12:52:30												oil temp	12655	17,03				
Average stop	765 12:53:00												flow	1,50	0,01				
Number of records	30 0																		
average	3,06	1,41	0,58	0,24	0,17	0,27	0,46	0,48	0,69	1,13	1,35	2,09	2,87	3,80	5,25	6,98	8,89	11,70	
	16,26	20,76	23,33	22,15	18,39	12,70	8,16	5,23	2,93	1,88	1,10	0,76	0,58	0,86					
stdev	1,46	0,59	0,20	0,07	0,05	0,08	0,16	0,18	0,28	0,50	0,60	0,93	1,24	1,57	2,17	2,93	3,76	4,74	5,90
	6,59	7,41	6,82	5,07	3,63	2,27	1,45	0,88	0,59	0,38	0,28	0,27	0,48						

Name	1:25 Basic conc												average	stddev					
Average start	825 12:54:00												oil temp	12739 14,33					
Average stop	855 12:54:30												flow	1,51 0,02					
Number of records	30																		
average	12,87	4,66	1,43	0,50	0,38	0,87	2,04	2,15	3,09	4,96	4,85	6,62	7,59	8,47	10,67	13,12	15,36	17,32	
	18,75	17,55	14,37	10,05	6,34	3,92	2,55	1,68	1,08	0,72	0,46	0,31	0,27	0,46					
stdev	11,34	3,83	1,07	0,35	0,26	0,60	1,51	1,60	2,34	3,84	3,69	4,98	5,58	6,06	7,54	9,12	10,52	11,65	12,33
	11,33	9,24	6,41	4,01	2,46	1,58	1,03	0,66	0,44	0,28	0,19	0,17	0,33						
Name	Oseberg 0502 No disp. II	average	stddev																
Average start	930 12:55:45	oil temp	12711 14,53																
Average stop	960 12:56:15	flow	1,51 0,01																
Number of records	30																		
average	0,38	0,28	0,21	0,16	0,15	0,18	0,19	0,16	0,17	0,21	0,24	0,36	0,54	0,75	0,91	0,92	0,82	1,06	
	2,22	4,38	4,79	6,37	9,70	10,67	15,13	18,84	22,56	26,84	28,74	26,10	21,33	24,06					
stdev	0,04	0,03	0,03	0,04	0,04	0,05	0,05	0,04	0,04	0,05	0,06	0,08	0,11	0,17	0,22	0,28	0,32	0,42	0,73
	1,23	1,59	2,19	3,24	3,92	5,67	7,43	9,32	11,07	11,39	10,47	9,63	12,49						

Date 1402-2013

Conditions Upstream, DOR Oil - 1:1000 - 1:25 - oil

Comments DOR Finasol 52/Oseberg blend

Nozzle size 1.5mm, 1.5L/min

Name Oseberg 1402 No disp. I

Average start	738	15:07:29	oil temp	11,6	stddev	0,02
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Average stop	768	15:07:59	temp	1,50	stddev	0,01
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Number of records	30
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average	0,60	0,60	0,63	0,67	0,74	0,80	0,78	0,70	0,65	0,60	0,51	0,54	0,59	0,62	0,59	0,53	0,52	0,63	
	1,22	2,08	2,60	3,72	6,23	7,35	10,96	14,15	17,40	19,72	19,06	17,07	13,63	15,33					
stdev	0,04	0,04	0,06	0,09	0,11	0,11	0,09	0,08	0,08	0,08	0,09	0,12	0,16	0,21	0,25	0,28	0,31	0,40	0,77
	1,30	1,65	2,29	3,55	4,14	6,08	8,15	10,31	12,17	12,28	11,31	9,50	10,69						

Name 1:1000 Finasol OSR52

Average start	830	15:09:01	oil temp	11,8	stddev	0,02
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Average stop	860	15:09:31	temp	1,51	stddev	0,01
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Number of records	30
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average	0,64	0,64	0,66	0,70	0,77	0,84	0,83	0,74	0,68	0,63	0,55	0,60	0,66	0,74	0,72	0,69	0,71	0,87	
	1,67	2,81	3,49	4,93	8,18	9,77	14,21	17,50	20,77	23,12	22,40	20,70	16,77	18,44					
stdev	0,08	0,07	0,07	0,08	0,09	0,10	0,10	0,08	0,08	0,09	0,09	0,12	0,17	0,23	0,28	0,32	0,37	0,49	0,88
	1,42	1,80	2,43	3,71	4,47	6,31	7,74	9,12	10,21	10,32	10,47	9,54	11,61						

Name 1:500 Finasol OSR52												average		stddev					
Average start 919 15:10:30						oil temp			11,7		0,01								
Average stop 949 15:11:00						temp			1,50		0,01								
Number of records 30																			
average	0,71	0,68	0,68	0,70	0,76	0,85	0,85	0,75	0,69	0,64	0,56	0,62	0,70	0,82	0,86	0,88	0,95	1,19	
	2,21	3,55	4,41	6,01	9,28	10,70	14,99	17,95	20,01	20,14	17,05	13,25	9,35	9,60					
stdev	0,10	0,08	0,07	0,07	0,08	0,10	0,10	0,08	0,08	0,09	0,09	0,13	0,17	0,24	0,31	0,39	0,47	0,62	1,07
	1,65	2,08	2,72	3,84	4,41	5,96	7,39	8,85	10,23	9,82	7,92	6,05	6,64						
Name 1:250 Finasol OSR52												average		stddev					
Average start 1009 15:12:00						oil temp			11,8		0,01								
Average stop 1039 15:12:30						temp			1,50		0,01								
Number of records 30																			
average	1,01	0,88	0,80	0,75	0,79	0,92	0,97	0,84	0,81	0,80	0,72	0,83	1,00	1,23	1,46	1,72	2,08	2,71	
	4,65	6,94	8,79	11,42	15,66	16,43	19,14	19,20	17,45	14,45	10,36	7,43	5,48	5,92					
stdev	0,32	0,22	0,14	0,10	0,09	0,12	0,17	0,14	0,15	0,18	0,19	0,26	0,34	0,46	0,63	0,86	1,14	1,52	2,33
	3,20	4,10	4,96	5,99	6,41	7,17	7,25	6,78	5,94	4,47	3,16	2,44	2,94						
Name 1:100 Finasol OSR52												average		stddev					
Average start 1099 15:13:30						oil temp			11,8		0,02								
Average stop 1129 15:14:00						temp			1,50		0,01								
Number of records 30																			
average	1,18	0,96	0,78	0,68	0,68	0,84	0,94	0,83	0,81	0,83	0,76	0,91	1,11	1,41	1,72	2,11	2,62	3,43	
	5,64	7,98	9,70	11,65	14,54	14,25	14,99	13,51	11,05	8,23	5,44	3,97	3,16	3,71					
stdev	0,30	0,19	0,11	0,06	0,05	0,07	0,11	0,10	0,12	0,16	0,17	0,24	0,33	0,45	0,62	0,85	1,13	1,50	2,24
	2,96	3,68	4,27	4,86	4,88	4,93	4,29	3,27	2,34	1,52	1,02	0,86	1,17						

Name	1:50 Finasol OSR52												average	stddev					
Average start	1188 15:14:59												oil temp	11,9	0,03				
Average stop	1218 15:15:29												temp	1,50	0,01				
Number of records	30																		
average	3,40	2,04	1,19	0,75	0,67	0,96	1,34	1,23	1,38	1,70	1,68	2,26	2,91	3,82	5,09	6,82	8,86	11,32	
	15,97	19,77	22,76	23,96	24,24	20,74	17,92	13,84	9,81	6,65	4,23	2,94	2,42	3,11					
stdev	1,77	0,82	0,30	0,09	0,04	0,10	0,28	0,29	0,41	0,64	0,68	1,00	1,30	1,69	2,32	3,18	4,14	5,18	6,67
	7,78	9,02	9,10	8,27	6,85	5,41	3,93	2,55	1,65	1,04	0,77	0,77	1,20						
Name	1:25 Finasol OSR52												average	stddev					
Average start	1279 15:16:30												oil temp	11,9	0,01				
Average stop	1309 15:17:00												temp	1,50	0,01				
Number of records	30																		
average	3,74	2,18	1,23	0,75	0,67	0,99	1,42	1,33	1,52	1,92	1,93	2,63	3,42	4,49	5,98	7,99	10,17	12,53	
	16,57	19,04	20,37	19,54	17,85	14,16	11,57	8,75	6,22	4,30	2,87	2,13	1,86	2,52					
stdev	2,07	0,84	0,26	0,08	0,05	0,09	0,29	0,31	0,46	0,75	0,79	1,16	1,49	1,88	2,52	3,35	4,16	4,95	5,89
	6,27	6,56	5,87	4,73	3,58	2,68	1,95	1,28	0,82	0,55	0,48	0,50	0,86						
Name	Oseberg 1402 No disp. II												average	stddev					
Average start	1346 15:17:37												oil temp	11,9	0,01				
Average stop	1370 15:18:01												temp	1,50	0,01				
Number of records	24																		
average	0,65	0,64	0,66	0,70	0,77	0,84	0,83	0,74	0,69	0,65	0,56	0,61	0,69	0,78	0,80	0,79	0,81	0,99	
	1,85	2,96	3,56	4,85	7,70	8,89	12,82	15,93	19,50	21,67	20,42	20,26	17,29	19,61					
stdev	0,04	0,04	0,04	0,05	0,07	0,07	0,07	0,06	0,06	0,06	0,07	0,08	0,10	0,14	0,16	0,20	0,22	0,29	0,52
	0,82	1,04	1,40	2,14	2,54	3,77	5,05	6,82	8,45	8,55	8,61	7,92	10,52						

Date 0805-2013

Conditions Upstream, DOR Oil - 1:1000 - 1:25 - oil (new run with corexit)

Comments DOR Corexit 9500/Oseberg blend

Nozzle size 1.5mm, 1.5L/min

Name Oseberg 0805 No disp. I

Average start 2700 15:17:17

oil temp

14,2

average

stddev

Average stop 2730 15:17:47

flow

1,50

0,01

Number of records 30

average	1,02	0,71	0,49	0,36	0,35	0,45	0,48	0,34	0,34	0,39	0,39	0,52	0,69	0,87	1,03	1,00	0,92	1,20	
	2,29	4,36	4,81	6,38	9,42	10,89	14,71	17,40	19,70	22,14	20,65	17,43	14,78	18,51					
stdev	0,07	0,05	0,05	0,04	0,04	0,04	0,04	0,03	0,04	0,04	0,05	0,07	0,10	0,14	0,20	0,25	0,28	0,40	0,68
	1,15	1,44	1,93	2,71	3,25	4,44	5,47	6,31	7,09	6,66	5,51	5,13	6,98						

Name 1:1000 Corexit 9500

Average start 2744 15:18:01

oil temp

14,2

average

stddev

Average stop 2774 15:18:31

flow

1,51

0,01

Number of records 30

average	0,98	0,68	0,47	0,35	0,34	0,44	0,47	0,34	0,33	0,38	0,37	0,49	0,65	0,81	0,94	0,88	0,79	1,02	
	1,98	3,84	4,16	5,43	8,08	9,48	13,07	15,48	17,84	20,78	20,03	17,09	13,99	16,90					
stdev	0,07	0,06	0,05	0,05	0,05	0,05	0,05	0,05	0,06	0,06	0,06	0,09	0,13	0,19	0,27	0,34	0,37	0,50	0,86
	1,46	1,80	2,44	3,48	4,20	5,84	7,25	8,44	9,06	7,77	5,97	4,93	6,11						

Name	1:500 Corexit 9500												average	stddev					
Average start	2833 15:19:30												oil temp	14,4	0,03				
Average stop	2863 15:20:00												flow	1,50	0,01				
Number of records	30																		
average	0,99	0,69	0,48	0,35	0,35	0,45	0,48	0,34	0,34	0,38	0,37	0,51	0,68	0,84	0,98	0,94	0,86	1,11	
	2,13	4,08	4,46	5,79	8,51	9,92	13,75	16,56	19,22	22,27	21,30	18,40	15,93	20,73					
stdev	0,06	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,06	0,06	0,08	0,11	0,16	0,22	0,29	0,32	0,43	0,73	
	1,22	1,56	2,18	3,20	3,82	5,14	6,57	7,91	8,02	6,70	5,89	6,17	10,45						
Name	1:250 Corexit 9500												average	stddev					
Average start	2923 15:21:00												oil temp	14,4	0,03				
Average stop	2953 15:21:30												flow	1,50	0,01				
Number of records	30																		
average	1,31	0,88	0,58	0,42	0,40	0,53	0,59	0,44	0,45	0,53	0,53	0,73	0,97	1,27	1,64	1,90	2,09	2,81	
	4,81	8,03	9,32	11,58	14,99	16,25	19,28	19,88	18,77	16,92	13,43	10,98	9,75	11,89					
stdev	0,25	0,16	0,11	0,07	0,07	0,09	0,11	0,10	0,11	0,13	0,14	0,21	0,28	0,39	0,56	0,76	0,97	1,32	1,97
	2,84	3,68	4,65	5,69	6,36	7,26	7,41	6,82	5,73	4,26	3,39	3,30	4,42						
Name	1:100 Corexit 9500												average	stddev					
Average start	2999 15:22:16												oil temp	14,5	0,05				
Average stop	3029 15:22:46												flow	1,50	0,01				
Number of records	30																		
average	2,48	1,44	0,79	0,46	0,40	0,57	0,75	0,63	0,71	0,92	0,97	1,38	1,85	2,42	3,25	4,03	4,82	6,43	
	9,74	14,47	17,48	21,16	24,74	25,48	26,88	24,95	21,43	18,44	13,88	10,62	7,17	7,53					
stdev	0,67	0,32	0,14	0,06	0,04	0,05	0,10	0,10	0,14	0,22	0,25	0,37	0,50	0,65	0,92	1,26	1,63	2,14	2,91
	3,82	4,89	5,87	6,46	6,73	6,74	6,10	4,92	3,88	2,67	2,07	1,54	2,00						

												average	stddev							
						oil temp			flow											
Name 1:50 Corexit 9500																				
Average start 3074 15:23:31																				
Number of records	30																			
average	3,65	1,90	0,92	0,48	0,39	0,60	0,89	0,80	0,97	1,37	1,46	2,13	2,84	3,71	5,10	6,67	8,32	10,83		
	14,88	19,52	21,95	22,81	22,34	19,16	16,29	13,03	9,61	7,79	5,79	5,11	4,54	6,55						
stdev	1,64	0,67	0,22	0,07	0,04	0,09	0,22	0,24	0,34	0,56	0,61	0,93	1,21	1,54	2,15	2,89	3,70	4,66	5,79	
	6,74	7,90	8,02	7,26	6,11	4,65	3,37	2,15	1,33	0,84	0,93	1,19	2,26							
Name 1:25 Corexit 9500															average	stddev				
Average start 3164 15:25:01															14,6	0,03				
Average stop 3194 15:25:31															1,50	0,01				
Number of records	30																			
average	8,08	3,52	1,35	0,57	0,44	0,80	1,48	1,47	1,97	3,05	3,26	4,79	6,20	7,73	10,30	13,12	15,63	18,63		
	22,55	25,01	24,67	21,44	16,59	12,21	9,04	6,92	5,18	4,37	3,63	3,46	3,72	6,32						
stdev	3,78	1,39	0,41	0,13	0,08	0,15	0,39	0,44	0,68	1,19	1,29	1,90	2,35	2,77	3,56	4,43	5,27	6,03	6,82	
	7,05	6,96	5,88	4,28	3,01	2,03	1,41	0,95	0,77	0,68	0,75	1,14	2,51							
Name Oseberg 0805 No disp. II															average	stddev				
Average start 3225 15:26:02															14,5	0,04				
Average stop 3255 15:26:32															1,50	0,02				
Number of records	30																			
average	1,25	0,82	0,53	0,37	0,36	0,48	0,55	0,41	0,42	0,50	0,49	0,67	0,90	1,16	1,46	1,60	1,64	2,08		
	3,44	5,66	6,08	7,10	9,22	10,23	13,20	15,50	17,06	19,42	18,46	16,90	14,87	18,26						
stdev	0,28	0,16	0,08	0,05	0,05	0,07	0,09	0,08	0,10	0,13	0,14	0,20	0,28	0,39	0,56	0,77	0,94	1,19	1,63	
	2,06	2,56	3,06	3,70	4,26	5,34	6,63	7,74	8,87	8,69	7,52	6,28	7,56							

Date 2806-2012

Conditions Upstream, DOR Oil - 1:1000 - 1:25 - oil ("old" experiment - phase I)

Comments DOR Corexit 9500 Concentrated/Oseberg blend

Nozzle size 1.5mm, 1.5L/min

Name 1:1000 C9500 Conc.

Average start 1802 14:29:19

Average stop 1832 14:29:49

Number of records 30

average	0,36	0,28	0,21	0,13	0,08	0,06	0,06	0,05	0,05	0,08	0,12	0,22	0,50	0,62	0,79	0,65	0,51	0,72
	1,56	3,82	3,45	4,72	7,78	7,94	10,92	12,65	13,63	13,90	10,98	7,49	5,17	5,56				
stdev	0,07	0,05	0,05	0,05	0,05	0,04	0,04	0,04	0,05	0,07	0,12	0,19	0,26	0,40	0,50	0,53	0,75	1,25
	2,08	2,54	3,34	4,40	4,86	6,37	8,02	9,86	11,14	9,19	6,19	4,27	4,43					

Name 1:500 C9500 Conc.

Average start 1883 14:30:40

Average stop 1913 14:31:10

Number of records 30

average	0,40	0,30	0,22	0,14	0,09	0,07	0,07	0,07	0,08	0,12	0,18	0,31	0,64	0,78	0,98	0,86	0,69	1,00
	2,08	4,74	4,48	6,04	9,36	9,56	13,03	14,87	15,64	16,59	14,90	11,92	8,19	7,93				
stdev	0,07	0,04	0,03	0,02	0,02	0,02	0,03	0,02	0,03	0,05	0,06	0,10	0,14	0,18	0,23	0,28	0,29	0,41
	1,01	1,29	1,79	2,50	3,00	4,16	5,00	5,58	6,33	6,20	5,70	5,06	7,74					

Name 1:250 C9500 Conc.

Average start 1962 14:31:59

Average stop 1992 14:32:29

Number of records 30

average	1,33	0,81	0,45	0,24	0,15	0,16	0,22	0,23	0,29	0,48	0,64	0,98	1,54	1,72	2,06	2,00	2,04	2,70	
	4,47	7,65	8,79	11,75	15,86	17,86	21,03	22,70	21,05	20,80	16,73	13,84	6,78	5,57					
stdev	0,50	0,25	0,12	0,06	0,04	0,05	0,06	0,06	0,08	0,13	0,15	0,24	0,35	0,47	0,66	0,80	0,97	1,30	1,99
	2,94	3,71	5,01	6,45	7,60	8,30	8,77	8,38	8,88	7,29	7,23	4,48	4,73						

Name 1:100 C9500 Conc.

Average start 2052 14:33:29

Average stop 2082 14:33:59

Number of records 30

average	1,16	0,67	0,35	0,17	0,11	0,11	0,15	0,16	0,21	0,35	0,47	0,73	1,21	1,48	2,05	2,44	2,91	4,16	
	6,54	10,46	11,27	12,63	13,80	11,76	9,76	7,54	4,63	3,21	1,82	1,25	0,90	1,19					
stdev	0,54	0,26	0,11	0,05	0,03	0,04	0,07	0,08	0,11	0,18	0,23	0,35	0,50	0,68	1,02	1,42	1,88	2,59	3,60
	4,68	5,86	6,40	6,16	5,68	4,63	3,94	2,58	1,75	1,06	0,78	0,75	1,57						

Name 1:50 C9500 Conc.

Average start 2143 14:35:0

Average stop 2173 14:35:30

Number of records 30

average	3,33	1,53	0,61	0,24	0,15	0,22	0,38	0,42	0,62	1,14	1,52	2,49	3,75	4,68	6,38	8,06	9,87	12,58	
	15,81	19,03	18,36	16,31	12,45	8,39	5,54	3,46	1,97	1,14	0,62	0,39	0,32	0,49					
stdev	1,74	0,70	0,24	0,09	0,05	0,08	0,17	0,20	0,32	0,60	0,76	1,19	1,58	1,95	2,59	3,38	4,27	5,23	6,13
	6,66	6,76	5,82	4,26	2,93	1,92	1,26	0,76	0,45	0,28	0,22	0,22	0,38						

Name 1:25 C9500 Conc.

Average start 2228 14:36:25

Average stop 2258 14:36:55

Number of records 30

average	11,36	4,22	1,32	0,45	0,31	0,61	1,42	1,64	2,48	4,33	4,78	6,95	8,85	10,22	13,16	16,12	18,21	20,44	
	21,61	20,52	16,99	12,01	7,64	4,62	2,94	1,87	1,13	0,68	0,39	0,25	0,22	0,42					
stdev	7,82	2,48	0,62	0,17	0,11	0,25	0,67	0,77	1,26	2,35	2,51	3,66	4,33	4,78	5,91	6,98	7,62	8,07	8,14
	7,32	6,14	4,34	2,79	1,82	1,30	0,95	0,64	0,42	0,26	0,19	0,18	0,42						

Name Oseberg 2806 No disp

Average start 1596 14:25:54

Average stop 1626 14:26:24

Number of records 30

average	0,32	0,25	0,17	0,10	0,06	0,04	0,04	0,03	0,03	0,05	0,08	0,16	0,40	0,49	0,57	0,37	0,23	0,32	
	0,86	2,65	1,98	2,73	4,97	4,85	7,46	9,38	10,37	10,94	9,69	8,08	6,75	8,80					
stdev	0,04	0,02	0,02	0,03	0,03	0,02	0,02	0,02	0,02	0,03	0,04	0,07	0,11	0,16	0,24	0,26	0,21	0,30	0,61
	1,26	1,38	1,93	2,95	3,09	4,32	5,62	6,95	8,58	9,64	9,80	9,08	12,92						

Date 2205-2013

Conditions Upstream, DOR Oil - 1:1000 - 1:25 - oil
 Comments DOR Finasol 52 concentrated/Oseberg blend
 Nozzle size 1.5mm, 1.5 L/min

Name	Oseberg 2205 No disp I												average	stddev
Average start	472	14:07:48	oil temp						15,1	0,01				
Average stop	502	14:08:17	flow						1,50	0,01				
Number of records												30		
average	0,01	0,01	0,02	0,02	0,03	0,05	0,06	0,07	0,09	0,11	0,15	0,22	0,31	0,42
	2,94	4,48	6,51	8,71	10,90	13,25	15,90	18,16	18,82	18,40	15,89	12,34	8,96	5,87
stdev	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02	0,03	0,03	0,04	0,05	0,06	0,08
	0,61	0,87	1,15	1,47	1,87	2,28	2,74	3,28	3,79	3,84	3,53	2,96	2,58	0,11
Name	1:1000 Finasol conc.												average	stddev
Average start	550	14:09:05	oil temp						15,2	0,01				
Average stop	580	14:09:35	flow						1,50	0,01				
Number of records												30		
average	0,01	0,01	0,02	0,02	0,03	0,05	0,06	0,07	0,08	0,10	0,14	0,21	0,29	0,39
	2,79	4,22	6,08	8,14	10,18	12,56	15,44	17,58	17,85	16,70	13,58	10,71	8,51	6,11
stdev	0,01	0,01	0,01	0,01	0,02	0,03	0,03	0,02	0,02	0,03	0,05	0,06	0,07	0,10
	0,66	1,04	1,43	1,80	2,34	2,97	3,37	3,59	3,44	2,99	3,16	3,23	3,38	0,15

Name	1:500 Finasol conc.												average	stddev				
Average start	630 14:10:25												oil temp	15,3	0,03			
Average stop	660 14:10:55												flow	1,50	0,01			
Number of records	30																	
average	0,15	0,12	0,11	0,10	0,10	0,13	0,15	0,13	0,15	0,20	0,26	0,41	0,60	0,84	1,19	1,81	2,61	4,04
	6,00	8,83	12,30	15,75	18,55	20,60	21,81	20,51	16,77	12,53	8,19	5,19	3,70	2,90				
stdev	0,04	0,03	0,03	0,03	0,04	0,04	0,04	0,03	0,03	0,05	0,07	0,09	0,12	0,17	0,25	0,35	0,52	0,77
	1,10	1,57	2,00	2,39	2,81	3,39	3,82	3,63	3,24	2,67	2,11	1,67	1,21					
Name	1:250 Finasol conc.												average	stddev				
Average start	721 14:11:56												oil temp	15,4	0,03			
Average stop	751 14:12:26												flow	1,50	0,01			
Number of records	30																	
average	0,49	0,29	0,17	0,10	0,09	0,13	0,19	0,21	0,29	0,45	0,59	0,92	1,29	1,69	2,27	3,17	4,31	6,21
	8,83	12,23	16,06	18,95	20,21	20,29	19,81	17,31	13,19	9,46	6,15	4,08	3,12	2,75				
stdev	0,17	0,09	0,04	0,02	0,02	0,02	0,04	0,05	0,07	0,12	0,16	0,24	0,33	0,40	0,50	0,61	0,73	0,93
	1,65	2,12	2,42	2,60	2,68	3,04	3,23	2,99	2,65	2,06	1,57	1,27	1,22					
Name	1:100 Finasol conc.												average	stddev				
Average start	816 14:13:31												oil temp	15,5	0,2			
Average stop	846 14:14:01												flow	1,51	0,01			
Number of records	30																	
average	1,24	0,61	0,27	0,12	0,09	0,13	0,23	0,27	0,40	0,67	0,88	1,39	1,96	2,63	3,69	5,32	7,34	10,35
	14,62	19,82	25,21	27,51	26,12	22,28	17,91	12,79	8,03	4,92	2,79	1,79	1,43	1,54				
stdev	0,21	0,09	0,03	0,01	0,01	0,01	0,02	0,03	0,04	0,07	0,09	0,14	0,21	0,27	0,38	0,54	0,70	0,97
	1,85	2,32	2,51	2,44	2,25	2,08	1,97	1,65	1,30	0,89	0,71	0,68	0,77					

Name	1:50 Finasol conc.										average	stddev							
Average start	896 14:14:51										oil temp	15,6	0,03						
Average stop	926 14:15:21										flow	1,50	0,01						
Number of records	30																		
average	2,50	1,06	0,40	0,16	0,11	0,19	0,40	0,50	0,78	1,36	1,72	2,72	3,73	4,84	6,75	9,63	13,00	17,42	
	22,60	26,85	29,85	27,77	22,16	15,90	10,91	6,81	3,82	2,19	1,23	0,80	0,72	0,93					
stdev	0,73	0,27	0,08	0,02	0,01	0,03	0,08	0,10	0,16	0,30	0,37	0,58	0,76	0,93	1,26	1,72	2,23	2,84	3,53
	4,04	4,51	4,19	3,33	2,40	1,69	1,15	0,78	0,61	0,43	0,32	0,31	0,44						
Name	1:25 Finasol conc.										average	stddev							
Average start	985 14:16:20										oil temp	15,8	0,41						
Average stop	1015 14:16:50										flow	1,51	0,01						
Number of records	30																		
average	4,92	1,93	0,66	0,25	0,18	0,38	0,91	1,11	1,65	2,76	3,14	4,63	5,94	7,15	9,36	12,47	15,65	19,68	
	23,98	26,30	25,87	20,60	14,04	8,86	5,66	3,42	1,95	1,15	0,68	0,46	0,43	0,62					
stdev	2,17	0,74	0,20	0,06	0,04	0,10	0,30	0,38	0,57	0,99	1,07	1,53	1,86	2,12	2,71	3,47	4,18	4,99	5,92
	6,24	5,91	4,45	2,77	1,59	0,97	0,63	0,43	0,33	0,25	0,24	0,29	0,42						
Name	Oseberg 2205 No disp II										average	stddev							
Average start	1060 14:17:35										oil temp	15,7	0,02						
Average stop	1090 14:18:05										flow	1,52	0,01						
Number of records	30																		
average	0,08	0,06	0,06	0,06	0,06	0,09	0,11	0,12	0,15	0,21	0,28	0,42	0,58	0,77	1,04	1,55	2,15	3,17	
	4,55	6,49	8,88	11,32	13,61	16,04	19,08	21,68	22,43	21,87	18,50	14,46	11,27	8,49					
stdev	0,05	0,03	0,02	0,02	0,02	0,03	0,03	0,03	0,05	0,06	0,07	0,09	0,11	0,17	0,23	0,32	0,42	0,50	0,64
	0,83	1,25	1,85	2,53	3,21	3,97	4,83	5,35	5,74	5,48	4,76	4,45	4,75						

Date 31052013

Conditions SIT, DOR Oil - 1:100/50

Comments DOR Finasol 52 - Oil exp.

Nozzle size 1,5mm, 1,2L/min

Name Kobbe No dispersant 3105

Average start 314 13:16:31

oil temp

average

stddev

Average stop 344 13:17:01

flow

1,21

0,07

Number of records 30

average	0,21	0,15	0,10	0,07	0,05	0,05	0,05	0,04	0,04	0,06	0,09	0,18	0,33	0,51	0,55	0,40	0,24	0,31	
1,01	2,90	2,38	3,31	6,82	6,50	10,44	11,83	12,59	12,41	10,38	7,76	5,70	5,86						
stdev	0,11	0,07	0,05	0,04	0,03	0,03	0,03	0,02	0,02	0,03	0,04	0,05	0,06	0,10	0,17	0,20	0,16	0,21	0,53
0,92	1,09	1,49	2,35	2,79	4,05	4,99	5,70	6,08	5,68	4,49	3,48	3,72							

Name Kobbe 1:100 Finasol 52

Average start 394 13:17:51

oil temp

average

stddev

Average stop 424 13:18:21

flow

1,21

0,01

Number of records 30

average	0,43	0,25	0,14	0,08	0,05	0,06	0,06	0,06	0,07	0,11	0,16	0,30	0,51	0,78	0,97	0,96	0,85	1,12
2,44	4,96	4,84	6,27	10,09	9,91	13,32	13,80	13,27	11,77	8,96	6,39	4,69	4,99					
stdev	0,31	0,15	0,07	0,04	0,03	0,03	0,03	0,04	0,07	0,09	0,15	0,22	0,33	0,50	0,69	0,79	1,05	1,73
2,43	3,06	3,73	4,47	4,83	5,65	6,09	6,23	6,03	4,99	3,80	2,95	3,38						

Name Kobbe 1:50 Finasol 52												average		stddev					
Average start 492 13:19:29						oil temp			15,2		0,03								
Average stop 522 13:19:59						flow			1,21		0,01								
Number of records 30																			
average	3,87	1,58	0,55	0,20	0,13	0,20	0,37	0,40	0,61	1,08	1,33	2,15	2,96	3,82	5,11	6,44	7,52	9,27	
	12,21	14,98	15,72	15,29	13,68	10,25	7,70	5,19	3,20	1,95	1,13	0,72	0,56	0,76					
stdev	3,13	1,11	0,32	0,09	0,05	0,10	0,21	0,24	0,38	0,73	0,86	1,36	1,76	2,14	2,85	3,69	4,50	5,42	6,38
	7,00	7,86	7,58	6,43	5,07	3,76	2,61	1,65	1,03	0,63	0,40	0,32	0,45						
Name OB No disp 31.05												average		stddev					
Average start 593 13:21:10						oil temp			15,1		0,10								
Average stop 623 13:21:40						flow			1,21		0,01								
Number of records 30																			
average	0,00	0,00	0,01	0,01	0,02	0,03	0,03	0,03	0,04	0,05	0,09	0,18	0,35	0,51	0,45	0,26	0,11	0,14	
	0,63	2,33	1,50	2,02	4,79	4,16	7,45	9,31	12,00	15,21	16,66	15,49	12,11	12,14					
stdev	0,00	0,00	0,01	0,01	0,02	0,02	0,01	0,01	0,02	0,02	0,04	0,05	0,08	0,10	0,10	0,06	0,08	0,23	
	0,52	0,51	0,72	1,33	1,41	2,25	2,92	3,98	5,49	6,84	7,35	6,99	9,44						
Name OB 1:100 Finasol 52												average		stddev					
Average start 673 13:22:30						oil temp			15,2		0,08								
Average stop 703 13:23:00						flow			1,21		0,01								
Number of records 30																			
average	0,32	0,20	0,13	0,08	0,07	0,08	0,10	0,10	0,13	0,21	0,30	0,53	0,85	1,24	1,57	1,77	1,86	2,43	
	4,07	6,72	6,99	8,46	11,33	10,69	12,22	11,41	9,78	7,87	5,56	3,71	2,51	2,39					
stdev	0,43	0,23	0,11	0,06	0,04	0,05	0,08	0,09	0,13	0,21	0,27	0,43	0,61	0,82	1,18	1,58	1,89	2,44	3,47
	4,51	5,50	6,35	6,80	6,74	6,42	5,68	4,57	3,52	2,64	2,16	1,74	1,74						

Name OB 1:50 Finasol 52												average		stddev					
Average start 773 13:24:10						oil temp			15,2		0,02								
Average stop 803 13:24:40						flow			1,21		0,02								
Number of records 30																			
average	3,24	1,44	0,56	0,23	0,16	0,27	0,49	0,53	0,77	1,27	1,51	2,33	3,12	3,97	5,23	6,55	7,62	9,31	
	12,00	14,40	14,88	14,15	12,31	9,04	6,58	4,28	2,57	1,56	0,91	0,57	0,44	0,61					
stdev	1,89	0,75	0,25	0,09	0,06	0,10	0,22	0,24	0,36	0,62	0,71	1,06	1,34	1,62	2,14	2,76	3,36	4,02	4,70
	5,10	5,64	5,33	4,42	3,45	2,55	1,75	1,11	0,70	0,42	0,27	0,21	0,30						
Name Norne No disp 31.05												average		stddev					
Average start 1003 13:28:00						oil temp			15,7		0,02								
Average stop 1033 13:28:30						flow			1,20		0,01								
Number of records 30																			
average	0,36	0,21	0,12	0,07	0,05	0,07	0,11	0,12	0,18	0,31	0,44	0,76	1,15	1,58	1,98	2,25	2,34	3,08	
	5,26	8,65	9,57	11,97	15,96	16,04	18,29	16,90	13,57	9,69	5,97	3,57	2,45	2,59					
stdev	0,19	0,09	0,04	0,02	0,01	0,02	0,03	0,04	0,06	0,10	0,14	0,23	0,32	0,41	0,55	0,73	0,91	1,19	1,68
	2,25	2,97	3,71	4,40	4,81	5,35	5,30	4,54	3,41	2,24	1,49	1,16	1,35						
Name Norne 1:100 Finasol 52												average		stddev					
Average start 1124 13:30:01						oil temp			15,7		0,01								
Average stop 1154 13:30:31						flow			1,20		0,01								
Number of records 30																			
average	8,02	3,07	1,00	0,37	0,27	0,59	1,37	1,57	2,39	3,99	4,21	5,84	6,76	7,40	8,75	10,01	10,68	11,60	
	12,78	13,16	12,45	10,50	8,09	5,67	3,98	2,61	1,59	0,94	0,54	0,33	0,28	0,46					
stdev	4,57	1,56	0,44	0,14	0,10	0,21	0,55	0,63	0,98	1,70	1,70	2,27	2,46	2,52	2,90	3,26	3,45	3,59	3,67
	3,57	3,50	2,96	2,26	1,66	1,20	0,82	0,55	0,37	0,24	0,17	0,15	0,26						

Name	Norne 1:50 Finasol 52										average	stddev							
Average start	1183 13:31:00										oil temp	15,7							
Average stop	1213 13:31:30										flow	1,20							
Number of records	30																		
average	22,78	7,59	2,07	0,64	0,47	1,12	2,84	3,08	4,59	7,66	7,35	9,68	10,32	10,42	11,82	12,75	12,89	13,03	
	13,28	12,57	11,20	8,82	6,43	4,43	3,13	2,12	1,35	0,83	0,49	0,30	0,27	0,50					
stdev	13,28	3,81	0,85	0,22	0,14	0,36	1,04	1,13	1,76	3,14	2,88	3,73	3,78	3,59	3,97	4,13	4,09	4,00	3,95
	3,62	3,20	2,48	1,78	1,25	0,91	0,66	0,46	0,30	0,18	0,11	0,11	0,24						
Name	Grane No disp 31.05										average	stddev							
Average start	1437 13:35:14										oil temp	43,5							
Average stop	1467 13:35:44										flow	0,81							
Number of records	30																		
average	0,14	0,12	0,12	0,15	0,22	0,41	0,64	0,82	1,16	1,56	1,91	2,60	3,22	3,79	4,24	4,84	5,03	5,73	
	7,00	8,55	9,13	10,11	11,40	11,86	13,36	13,87	13,26	11,61	8,47	5,37	3,54	3,43					
stdev	0,07	0,06	0,05	0,06	0,10	0,21	0,35	0,45	0,63	0,83	0,98	1,27	1,47	1,64	1,80	2,14	2,35	2,63	2,86
	3,14	3,69	4,18	4,66	5,31	6,23	6,99	7,17	6,70	5,25	3,62	2,67	2,97						
Name	Grane 1:100 Finasol 52										average	stddev							
Average start	1554 13:37:11										oil temp	44,9							
Average stop	1584 13:37:41										flow	0,80							
Number of records	30																		
average	10,73	4,44	1,62	0,69	0,61	1,35	2,85	2,82	3,65	5,28	4,92	6,23	6,64	6,77	7,57	8,07	8,09	8,31	
	8,87	9,33	9,66	9,69	9,56	9,21	9,08	8,28	6,73	4,99	3,30	2,12	1,71	2,39					
stdev	7,15	2,56	0,76	0,26	0,20	0,51	1,25	1,22	1,61	2,41	2,07	2,53	2,51	2,37	2,60	2,70	2,66	2,59	2,55
	2,47	2,57	2,51	2,38	2,32	2,24	2,12	1,83	1,55	1,24	0,98	0,97	1,61						

Name	Grane 1:50 Finasol 52										average	stddev							
Average start	1637	13:38:34										oil temp	45,0	2,61					
Average stop	1667	13:39:04										flow	0,79	0,01					
Number of records	30																		
average	19,57	7,19	2,21	0,79	0,64	1,53	3,49	3,30	4,25	6,20	5,37	6,58	6,60	6,34	6,92	7,05	6,80	6,67	
	6,84	6,91	6,96	6,70	6,31	5,88	5,63	5,05	3,99	2,80	1,73	1,04	0,85	1,31					
stdev	10,53	3,71	1,10	0,38	0,30	0,72	1,66	1,57	2,04	3,01	2,59	3,15	3,13	2,98	3,24	3,28	3,16	3,09	3,16
	3,19	3,22	3,09	2,91	2,74	2,70	2,57	2,19	1,63	1,06	0,66	0,53	0,85						

Date 2103-2013

Conditions SIT, DOR Oil - 1:100/50
 Comments DOR Basic NS - Oil exp.
 Nozzle size 1,5mm, 1,2L/min

Name Grane No disp 21.03

Average start 1941 14:43:21

Average stop 1971 14:43:51

Number of records 30

average	7,93	4,12	2,02	1,18	1,26	2,70	5,13	5,15	6,49	8,78	8,44	10,56	11,22	11,42	12,52	13,44	13,84	14,58	
	15,76	17,10	18,39	18,56	17,49	15,60	13,84	11,32	8,37	5,62	3,40	2,03	1,52	1,95					
stdev	3,65	1,59	0,61	0,27	0,26	0,68	1,57	1,55	1,98	2,75	2,41	2,91	2,90	2,78	3,00	3,14	3,13	3,18	3,33
	3,47	3,67	3,54	3,21	2,83	2,51	2,11	1,61	1,15	0,75	0,53	0,53	0,84						

Name Grane 1:100 Basic NS

Average start 2034 14:44:54

Average stop 2064 14:45:24

Number of records 30

average	2,11	1,36	0,87	0,65	0,74	1,34	2,16	2,22	2,81	3,72	3,90	5,09	5,76	6,26	7,04	7,78	8,32	9,14	
	10,32	11,85	13,29	14,53	15,11	14,84	14,74	13,34	10,93	7,91	4,86	2,87	1,98	2,12					
stdev	1,07	0,59	0,31	0,18	0,19	0,42	0,82	0,87	1,13	1,56	1,56	1,99	2,17	2,28	2,57	2,89	3,08	3,31	3,57
	3,89	4,35	4,59	4,59	4,51	4,41	4,02	3,33	2,51	1,59	1,02	0,92	1,29						

Name Grane 1:50 Basic NS

Average start 2097 14:45:57

Average stop 2127 14:46:27

Number of records 30

average	12,76	5,06	1,75	0,72	0,62	1,39	2,95	2,85	3,65	5,20	4,62	5,62	5,65	5,45	5,90	6,09	6,10	6,24	
	6,67	7,12	7,63	7,69	7,29	6,59	5,96	5,02	3,88	2,74	1,76	1,15	0,98	1,49					
stdev	11,29	4,21	1,38	0,56	0,48	1,05	2,25	2,17	2,79	4,02	3,53	4,28	4,27	4,09	4,41	4,54	4,52	4,60	4,91
	5,24	5,61	5,64	5,34	4,82	4,36	3,68	2,85	2,01	1,30	0,87	0,77	1,29						

Name Norne No disp 21.03

Average start 2309 14:49:29

Average stop 2339 14:49:59

Number of records 30

average	1,51	0,88	0,49	0,29	0,26	0,39	0,56	0,52	0,61	0,81	0,87	1,25	1,62	1,98	2,51	3,02	3,66	4,77	
	6,75	9,46	11,42	14,03	16,37	16,28	17,03	15,40	13,23	10,71	8,03	6,22	5,17	6,10					
stdev	0,40	0,19	0,08	0,03	0,02	0,03	0,06	0,07	0,10	0,17	0,20	0,30	0,38	0,49	0,65	0,86	1,11	1,45	1,96
	2,65	3,44	4,22	4,87	5,11	5,29	4,69	3,75	2,96	2,20	1,63	1,67	2,47						

Name Norne 1:100 Basic NS

Average start 2392 14:50:52

Average stop 2422 14:51:22

Number of records 30

average	1,26	0,74	0,42	0,26	0,24	0,37	0,52	0,46	0,54	0,69	0,71	1,00	1,25	1,49	1,81	2,08	2,44	3,15	
	4,55	6,51	7,68	9,46	11,24	11,31	12,37	11,47	10,37	8,92	7,05	5,99	5,45	6,88					
stdev	0,52	0,24	0,09	0,04	0,02	0,03	0,08	0,09	0,13	0,21	0,23	0,33	0,42	0,51	0,67	0,85	1,07	1,36	1,79
	2,34	2,98	3,56	3,90	3,91	4,06	3,96	3,60	2,91	2,00	1,46	1,61	3,09						

Name Norne 1:50 Basic NS

Average start 2467 14:52:07

Average stop 2497 14:52:37

Number of records 30

average	8,87	3,64	1,29	0,52	0,41	0,81	1,58	1,48	1,89	2,74	2,53	3,24	3,47	3,60	4,16	4,62	5,07	5,72	
	6,81	7,92	8,84	9,25	9,11	8,46	8,31	7,73	7,11	6,45	5,64	5,07	5,01	7,22					
stdev	3,68	1,26	0,35	0,11	0,07	0,14	0,34	0,34	0,47	0,76	0,68	0,86	0,88	0,86	1,01	1,14	1,26	1,39	1,60
	1,75	1,99	2,04	1,97	1,83	1,72	1,62	1,49	1,28	1,06	0,90	1,20	2,41						

Name OB No disp 21.03

Average start 2578 14:53:58

Average stop 2608 14:54:28

Number of records 30

average	0,79	0,58	0,43	0,35	0,37	0,53	0,66	0,57	0,63	0,74	0,76	1,03	1,24	1,42	1,61	1,71	1,86	2,27	
	3,27	4,75	5,52	7,08	9,23	10,49	14,35	17,85	22,43	26,22	26,37	24,39	20,75	23,14					
stdev	0,08	0,03	0,03	0,04	0,05	0,05	0,03	0,02	0,02	0,04	0,04	0,05	0,05	0,07	0,11	0,16	0,22	0,34	0,63
	1,12	1,46	2,14	3,19	3,86	5,57	7,44	9,98	12,15	12,67	12,00	10,41	12,70						

Name OB 1:100 Basic NS

Average start 2662 14:55:22

Average stop 2692 14:55:52

Number of records 30

average	1,60	0,99	0,60	0,41	0,40	0,61	0,85	0,77	0,89	1,13	1,16	1,58	1,90	2,20	2,64	3,01	3,44	4,16	
	5,58	7,48	8,94	11,00	13,28	14,66	17,70	19,24	20,00	20,19	17,92	15,19	12,55	14,64					
stdev	0,96	0,48	0,21	0,09	0,06	0,11	0,22	0,23	0,29	0,43	0,45	0,61	0,74	0,88	1,14	1,44	1,77	2,16	2,76
	3,49	4,44	5,39	6,24	6,81	7,38	7,59	7,72	8,62	9,31	9,61	9,93	14,30						

Name OB 1:50 Basic NS

Average start 2760 14:57:00

Average stop 2790 14:57:30

Number of records 30

average	6,37	2,99	1,27	0,61	0,52	0,95	1,67	1,59	1,96	2,72	2,64	3,47	3,94	4,31	5,16	5,93	6,76	7,84	
	9,58	11,47	13,05	14,00	13,85	12,75	11,84	10,23	8,28	6,84	5,35	4,39	3,73	4,64					
stdev	3,91	1,54	0,50	0,17	0,11	0,23	0,53	0,53	0,71	1,09	1,03	1,35	1,49	1,60	1,96	2,30	2,67	3,10	3,75
	4,43	5,20	5,49	5,27	4,84	4,28	3,52	2,44	1,58	0,91	0,63	0,67	1,21						

Name Kobbe No disp 21.03

Average start 2881 14:59:01

Average stop 2911 14:59:31

Number of records 30

average	1,36	0,83	0,49	0,32	0,31	0,50	0,70	0,62	0,70	0,88	0,87	1,18	1,38	1,55	1,80	1,95	2,14	2,59	
	3,57	4,88	5,65	6,95	8,47	9,10	11,04	11,82	12,58	12,93	11,59	9,75	8,19	8,93					
stdev	0,20	0,13	0,08	0,05	0,04	0,04	0,04	0,03	0,03	0,04	0,04	0,05	0,05	0,07	0,10	0,15	0,22	0,34	0,63
	1,05	1,45	2,08	2,97	3,59	4,90	5,97	7,05	7,51	6,52	5,29	4,86	5,83						

Name Kobbe 1:100 Basic NS

Average start 2970 15:00:30

Average stop 3000 15:01:00

Number of records 30

average	2,62	1,43	0,73	0,41	0,36	0,59	0,90	0,82	0,96	1,26	1,26	1,70	2,02	2,33	2,87	3,36	3,94	4,90	
	6,69	9,02	10,89	13,27	15,65	16,71	18,88	18,86	17,66	16,05	12,78	9,81	7,84	9,17					
stdev	0,84	0,39	0,15	0,06	0,04	0,06	0,13	0,12	0,16	0,24	0,24	0,33	0,41	0,49	0,65	0,84	1,05	1,33	1,79
	2,36	3,01	3,70	4,35	4,81	5,45	5,70	5,38	4,90	3,93	3,06	2,59	3,79						

Name Kobbe 1:50 Basic NS

Average start 3025 15:01:25

Average stop 3055 15:01:55

Number of records 30

average	3,89	1,91	0,87	0,44	0,39	0,68	1,15	1,08	1,33	1,82	1,79	2,39	2,77	3,08	3,74	4,34	5,02	6,01	
	7,70	9,73	11,37	12,88	13,66	13,29	13,13	11,63	9,77	8,34	6,63	5,35	4,58	5,53					
stdev	2,62	1,05	0,34	0,11	0,07	0,14	0,34	0,35	0,49	0,77	0,76	1,03	1,19	1,34	1,69	2,06	2,47	2,95	3,66
	4,50	5,59	6,46	6,90	7,01	6,71	5,82	4,33	3,09	2,05	1,58	1,62	2,59						

3004-2013

Conditions SIT, DOR Oil - 1:100/50
 Comments DOR Corexit 9500 - Oil exp.
 Nozzle size 1,5mm, 1,2L/min

Name	Grane	No disp	30.04															Average	STDev
Average start	870		15:09:11															62,6	0,63
Average stop	900		15:09:41															1,21	0,01
Number of records		30																	
average	1,09	0,64	0,37	0,24	0,25	0,46	0,83	0,95	1,32	1,90	2,09	2,81	3,33	3,69	4,16	4,63	4,80	5,38	
	6,54	7,99	8,99	10,03	11,04	10,99	11,20	10,16	8,26	6,17	4,08	2,59	1,93	2,28					
stdev	0,26	0,17	0,12	0,09	0,09	0,17	0,29	0,34	0,45	0,62	0,68	0,87	0,98	1,06	1,19	1,39	1,54	1,73	1,93
	2,18	2,60	2,91	3,11	3,25	3,28	2,99	2,48	2,03	1,46	0,95	0,85	1,36						
Name	Grane	1:100	Corexit 9500															Average	STDev
Average start	947		15:10:27															66,6	0,30
Average stop	977		15:10:57															1,21	0,01
Number of records		30																	
average	6,29	2,63	0,98	0,43	0,38	0,85	1,83	1,91	2,59	3,84	3,70	4,75	5,13	5,23	5,78	6,15	6,17	6,50	
	7,30	8,15	8,67	8,89	8,88	8,14	7,62	6,45	4,86	3,31	1,97	1,13	0,80	1,01					
stdev	5,87	2,27	0,74	0,27	0,22	0,54	1,27	1,28	1,71	2,55	2,27	2,77	2,75	2,57	2,76	2,84	2,83	2,78	2,70
	2,57	2,72	2,70	2,71	2,76	2,85	2,67	2,15	1,55	0,89	0,49	0,38	0,57						

Name	Grane 1:50 Corexit 9500										Average		STDev						
Average start	989	15:11:09						oil temp		67,6	0,17								
Average stop	1010	15:11:30						flow		1,22	0,01								
Number of records	21																		
average	7,51	2,72	0,84	0,30	0,24	0,56	1,32	1,32	1,79	2,73	2,44	3,00	3,00	2,84	3,02	3,03	2,89	2,79	
	2,80	2,74	2,62	2,30	1,91	1,52	1,21	0,90	0,62	0,41	0,25	0,16	0,15	0,28					
stdev	12,06	4,30	1,35	0,51	0,40	0,87	2,03	2,04	2,76	4,21	3,75	4,60	4,59	4,33	4,61	4,62	4,40	4,25	4,25
	4,16	3,98	3,50	2,91	2,33	1,88	1,41	0,98	0,66	0,40	0,26	0,24	0,45						
Name	Norne No disp 30.04										Average		STDev						
Average start	1148	15:13:48						oil temp		18,8	0,22								
Average stop	1178	15:14:18						flow		1,21	0,02								
Number of records	30																		
average	1,21	0,50	0,18	0,07	0,04	0,06	0,10	0,11	0,17	0,32	0,41	0,72	1,05	1,34	1,69	1,93	2,03	2,64	
	4,37	6,93	7,93	9,72	12,65	12,59	13,97	12,83	10,52	7,72	4,94	3,10	2,22	2,52					
stdev	0,18	0,09	0,04	0,02	0,01	0,02	0,03	0,03	0,05	0,08	0,11	0,18	0,26	0,34	0,46	0,62	0,75	0,98	1,41
	1,94	2,50	3,08	3,74	4,07	4,47	4,30	3,66	2,87	2,06	1,47	1,27	1,65						
Name	Norne 1:100 Corexit 9500										Average		STDev						
Average start	1235	15:15:15						oil temp		17,8	0,04								
Average stop	1265	15:15:45						flow		1,21	0,01								
Number of records	30																		
average	9,21	3,56	1,16	0,42	0,31	0,63	1,37	1,44	2,07	3,35	3,40	4,60	5,19	5,51	6,43	7,16	7,58	8,32	
	9,50	10,48	10,68	10,04	8,91	7,23	6,02	4,64	3,29	2,20	1,35	0,83	0,65	0,94					
stdev	7,31	2,62	0,77	0,25	0,18	0,39	0,90	0,94	1,36	2,22	2,17	2,85	3,07	3,11	3,59	3,95	4,20	4,45	4,65
	4,65	4,74	4,25	3,32	2,62	1,91	1,36	0,88	0,61	0,41	0,30	0,30	0,54						

Name	Norne 1:50 Corexit 9500										Average		STDev						
Average start	1315	15:16:35	oil temp					17,5	0,09										
Average stop	1345	15:17:05	flow					1,22	0,01										
Number of records																			
average	16,14	5,81	1,74	0,60	0,44	0,96	2,08	1,98	2,65	4,09	3,71	4,68	4,81	4,67	5,17	5,32	5,29	5,37	
	5,72	5,94	5,97	5,60	5,02	4,44	4,09	3,62	2,96	2,28	1,59	1,09	0,96	1,56					
stdev	15,99	5,36	1,48	0,48	0,34	0,75	1,68	1,61	2,18	3,44	3,10	3,90	3,95	3,78	4,18	4,28	4,24	4,29	4,53
	4,69	4,75	4,46	3,99	3,53	3,25	2,86	2,32	1,76	1,23	0,84	0,77	1,30						
Name	OB No disp 30.04										Average		STDev						
Average start	1449	15:18:49	oil temp					15,2	0,02										
Average stop	1479	15:19:19	flow					1,21	0,01										
Number of records																			
average	0,69	0,36	0,17	0,08	0,06	0,08	0,12	0,11	0,14	0,23	0,27	0,44	0,63	0,79	0,91	0,85	0,71	0,90	
	1,85	3,55	3,67	4,84	7,80	8,29	11,92	14,66	18,05	20,97	21,06	20,08	19,33	24,33					
stdev	0,06	0,03	0,03	0,02	0,02	0,02	0,03	0,02	0,03	0,04	0,04	0,06	0,07	0,10	0,14	0,18	0,19	0,25	0,45
	0,75	0,91	1,21	1,85	2,18	3,24	4,14	5,11	6,18	6,63	6,83	7,69	11,02						
Name	OB 1:100 Corexit 9500										Average		STDev						
Average start	1536	15:20:16	oil temp					15,1	0,01										
Average stop	1566	15:20:46	flow					1,20	0,01										
Number of records																			
average	4,53	1,82	0,63	0,24	0,17	0,33	0,68	0,74	1,09	1,82	2,00	2,94	3,66	4,26	5,27	6,21	6,87	7,94	
	9,77	11,38	11,93	11,67	10,76	8,89	7,61	6,38	5,33	4,89	4,67	5,20	6,44	9,66					
stdev	3,20	1,17	0,36	0,12	0,08	0,16	0,38	0,42	0,64	1,10	1,19	1,72	2,07	2,34	2,92	3,53	4,05	4,58	5,17
	5,48	5,83	5,45	4,50	3,58	2,70	2,03	1,44	1,26	1,30	1,53	2,20	3,47						

Name	OB 1:50 Corexit 9500										Average		STDev						
Average start	1616	15:21:36						oil temp		15,1	0,01								
Average stop	1646	15:22:06						flow		1,22	0,01								
Number of records										30									
average	11,02	3,99	1,20	0,40	0,28	0,58	1,30	1,35	1,95	3,23	3,28	4,56	5,23	5,65	6,71	7,51	7,89	8,34	
	9,03	9,06	8,35	6,87	5,25	3,87	3,04	2,50	2,17	2,22	2,49	3,29	4,49	6,69					
stdev	9,10	2,99	0,78	0,22	0,14	0,28	0,67	0,70	1,04	1,81	1,81	2,48	2,75	2,87	3,38	3,72	3,91	4,01	4,17
	4,00	3,68	2,95	2,15	1,54	1,15	0,92	0,76	0,72	0,75	1,05	1,59	2,57						
Name	Kobbe No disp 30.04										Average		STDev						
Average start	1746	15:23:46						oil temp		17,0	0,03								
Average stop	1776	15:24:16						flow		1,21	0,01								
Number of records										30									
average	1,59	0,72	0,28	0,12	0,09	0,16	0,28	0,28	0,38	0,59	0,63	0,92	1,15	1,32	1,54	1,64	1,63	2,04	
	3,32	5,21	6,03	7,59	10,21	10,94	13,78	15,53	16,93	17,81	16,57	14,54	12,49	13,04					
stdev	0,19	0,09	0,04	0,02	0,01	0,02	0,04	0,05	0,06	0,10	0,09	0,12	0,12	0,14	0,21	0,29	0,37	0,53	0,90
	1,49	1,88	2,50	3,59	4,28	5,86	7,01	7,73	7,65	6,00	4,01	3,14	4,74						
Name	Kobbe 1:100 Corexit 9500										Average		STDev						
Average start	1836	15:25:16						oil temp		16,9	0,06								
Average stop	1866	15:25:46						flow		1,20	0,01								
Number of records										30									
average	3,96	1,65	0,59	0,23	0,17	0,31	0,62	0,66	0,95	1,56	1,70	2,48	3,10	3,67	4,66	5,66	6,41	7,68	
	9,91	12,32	13,87	14,78	15,11	13,66	12,85	11,20	9,29	7,72	6,36	5,63	5,45	6,53					
stdev	1,37	0,51	0,16	0,06	0,04	0,06	0,13	0,15	0,22	0,40	0,46	0,70	0,90	1,10	1,45	1,86	2,21	2,60	3,08
	3,49	3,95	4,01	3,81	3,49	3,33	3,06	2,72	2,43	2,05	1,72	1,70	2,53						

Name	Kobbe 1:50 Corexit 9500										Average	STDev							
Average start	1921 15:26:41										oil temp	16,5							
Average stop	1951 15:27:11										flow	1,20							
Number of records	30											0,02							
average	11,71	4,27	1,29	0,43	0,30	0,63	1,40	1,49	2,19	3,69	3,84	5,46	6,46	7,20	8,81	10,26	11,25	12,43	
	14,16	15,03	14,85	13,12	10,72	8,33	6,78	5,63	4,65	4,21	3,83	3,86	4,11	5,65					
stdev	5,14	1,70	0,44	0,12	0,07	0,15	0,37	0,41	0,64	1,17	1,23	1,78	2,11	2,34	2,89	3,39	3,79	4,10	4,46
	4,46	4,28	3,45	2,42	1,68	1,12	0,80	0,51	0,38	0,34	0,45	0,86	1,82						

Date 2405-2013

Conditions SIT, DOR Oil - 1:100/50
 Comments DOR Corexit 9500 - Oil exp.
 Nozzle size 1,5mm, 1,2L/min

Name	OB	No disp	24.05											Average	STDev				
Average start	457	14:44:18												15,5	0,01				
Average stop	487	14:44:48												1,21	0,01				
Number of records	30																		
average	0,09	0,07	0,05	0,05	0,04	0,05	0,05	0,04	0,05	0,07	0,10	0,20	0,36	0,53	0,53	0,35	0,19	0,25	
	0,91	2,96	2,49	3,28	6,16	5,53	8,93	10,29	12,56	15,56	16,62	14,85	12,34	14,10					
stdev	0,03	0,01	0,01	0,02	0,02	0,02	0,02	0,02	0,02	0,03	0,04	0,06	0,10	0,13	0,14	0,11	0,15	0,35	
	0,66	0,75	1,02	1,67	1,97	3,06	3,90	5,20	6,62	7,17	6,84	6,41	9,46						
Name	OB	1:100	Corexit	9500	24.05														
Average start	575	14:46:16												15,5	0,01				
Average stop	605	14:46:46												1,21	0,01				
Number of records	30																		
average	3,08	1,35	0,52	0,21	0,15	0,25	0,46	0,49	0,72	1,21	1,42	2,18	2,88	3,58	4,60	5,55	6,31	7,62	
	10,09	12,76	14,09	14,69	14,24	11,92	9,76	7,07	4,52	2,97	1,81	1,23	0,97	1,38					
stdev	1,80	0,70	0,23	0,08	0,05	0,10	0,21	0,23	0,34	0,59	0,67	0,99	1,24	1,46	1,88	2,35	2,80	3,25	3,77
	4,11	4,69	4,67	4,10	3,67	3,01	2,45	1,69	1,20	0,77	0,55	0,45	0,72						

Name	OB 1:50 Corexit 9500 24.05										Average		STDev						
Average start	670	14:47:51	oil temp					15,6	0,02										
Average stop	700	14:48:21	flow					1,2	0,01										
Number of records										30									
average	14,94	5,19	1,48	0,46	0,31	0,62	1,40	1,47	2,19	3,77	3,93	5,64	6,67	7,44	9,11	10,49	11,44	12,56	
	14,28	15,13	14,82	12,73	9,73	6,85	4,65	3,02	1,78	1,13	0,69	0,50	0,47	0,88					
stdev	8,85	2,66	0,63	0,17	0,10	0,22	0,56	0,60	0,94	1,73	1,74	2,48	2,79	2,95	3,55	4,04	4,40	4,65	4,97
	4,95	4,91	4,21	3,18	2,34	1,63	1,14	0,73	0,50	0,34	0,26	0,27	0,55						
Name	Grane No disp 24.05 (1.2 L/min)										Average		STDev						
Average start	989	14:53:10	oil temp					49,2	0,34										
Average stop	1019	14:53:40	flow					0,80	0,01										
Number of records										30									
average	0,04	0,04	0,05	0,07	0,13	0,25	0,38	0,50	0,73	1,00	1,27	1,78	2,27	2,73	3,00	3,37	3,41	3,99	
	5,23	6,94	7,55	8,75	10,53	11,27	13,57	14,61	14,51	13,39	10,41	7,04	4,87	4,91					
stdev	0,02	0,02	0,02	0,03	0,05	0,09	0,15	0,20	0,28	0,38	0,47	0,62	0,74	0,85	0,97	1,20	1,35	1,57	1,78
	2,02	2,38	2,69	2,99	3,48	4,31	5,16	5,41	5,10	4,08	3,07	2,66	3,77						
Name	Grane 1:100 Corexit 9500 24.05 (1.2 L/min)										Average		STDev						
Average start	1115	14:55:16	oil temp					50,3	0,06										
Average stop	1129	14:55:30	flow					0,75	0,01										
Number of records										14									
average	14,17	5,52	1,83	0,69	0,55	1,19	2,55	2,48	3,27	4,89	4,55	5,80	6,13	6,20	6,97	7,39	7,40	7,59	
	8,14	8,64	9,14	9,28	9,19	8,96	9,02	8,49	7,25	5,79	4,22	2,96	2,54	3,62					
stdev	3,91	1,29	0,33	0,10	0,06	0,15	0,41	0,41	0,58	0,93	0,82	1,01	1,00	0,95	1,07	1,14	1,15	1,16	1,19
	1,20	1,31	1,36	1,39	1,39	1,38	1,32	1,29	1,37	1,44	1,23	1,12	1,84						

Name Grane 1:50 Corexit 9500 24.05 (1.2 L/min)										Average		STDev							
Average start	1230	14:57:11					oil temp	49,6		0,09									
Average stop	1231	14:57:12					flow	0,73		0,00									
Number of records	1																		
average	32,23	10,71	2,87	0,88	0,63	1,53	3,61	3,34	4,41	6,77	5,80	7,14	7,05	6,61	7,13	7,08	6,70	6,49	
	6,66	6,74	6,86	6,64	6,34	6,11	6,05	5,43	4,14	2,80	1,67	0,93	0,73	1,21					
stdev	0,21	0,06	0,01	0,00	0,01	0,06	0,16	0,15	0,20	0,28	0,18	0,16	0,13	0,11	0,12	0,16	0,14	0,11	0,03
	0,14	0,31	0,49	0,55	0,58	0,61	0,45	0,04	0,33	0,43	0,27	0,12	0,04						

C Appendix C: Droplet formation in turbulent flow

The size distribution of oil droplets formed in deep water oil and gas blowouts is known to have strong impact on the subsequent fate of the oil in the environment. Large droplets will rise relatively rapidly and come to the surface relatively close to the discharge location, while small droplets will rise more slowly and can be transported long distances from the discharge location with ambient currents before reaching the sea surface. The smallest droplets may even be kept suspended in the water masses for prolonged periods by vertical oceanic turbulent mixing, and this mechanism is the main rational for application of chemical dispersants. Releases which are predominantly producing large oil droplets (in the millimetre size range) may thus result in relatively thick surface oil slicks, while thin surface films may be expected from releases producing small droplets (micrometre range). Thin oil films are more susceptible to natural dispersion and will have distinctly shorter persistence on the sea surface than thicker oil slicks, and the possibility of oiling of adjacent shorelines may thus be strongly reduced.

Reliable predictions of the droplet size distribution in deep water blowouts will thus improve our ability to forecast the fate of oil in the environment, provide guidance for oil spill response operations and relevant information to the public. The present study was initiated to get a better understanding of the mechanisms that governs droplet break up in deep water blowouts, with and without application of chemical dispersants. In order to achieve this, we need to understand the basic mechanisms that govern droplet breakup, and empirical data to support the theoretical understanding. This chapter deals with the theoretical aspects, while the empirical findings will be presented in the subsequent chapters.

C.1 Break up regimes

Droplet breakup may be caused by different mechanisms depending on the properties of the fluid and outlet conditions, ranging from pendant droplets that separate from the nozzle when the buoyant forces outrange the interfacial tension forces, through various axial or transverse instabilities of the jet, to full atomization where droplets of a wide size range are generated almost instantaneously at the jet exit.

The full range of breakup regimes of oil jets in water were investigated in laboratory experiments reported by Masutani and Adams (2000) and Tang and Masutani (2003). Examples of the various breakup regimes of oil jets are shown in Figure C.1. As previously observed from breakup experiments with liquid jets in air, Masutani et al. found that the breakup regimes of oil jets in water could be delimited in a Reynolds number (re) vs Ohnesorge number (Z or Oh) diagram (Figure C.2). The two non-dimensional numbers are defined as $Re = \rho U D / \mu$ and $Oh = \mu / (\rho \sigma D)^{1/2}$, where U is the exit velocity, D the orifice diameter, and ρ and μ are the density and dynamic viscosity of the jet fluid. The Ohnesorge number can also be expressed as a combination of the Reynolds number and the Weber number, i.e. $Oh = We^{1/2}/Re$, where $We = \rho U^2 D / \sigma$. The two boundaries which are shown in the diagram were derived from visual inspection of the breakup conditions. The broken line shows the boundary between laminar and transitional breakup, while the dashed dotted line shows the boundary between the transitional and turbulent (atomization) break regimes. Both lines were found to represent linear relationships of the form $Oh = c Re^{-1}$, where c is a constant of proportionality. From the definition of Ohnesorge number mentioned above, this relationship implies that both boundaries are lines for constant Weber number, with $We = c^2$, or $We = 18 \times 18 = 324$ for the boundary between the transitional and turbulent breakup regime.

In the present study, where the main focus will be on turbulent break up, these findings are useful as a basis for limiting the experimental conditions for the breakup experiments. Figure C.3 shows how the Ohnesorge vs. Reynolds number diagram can be used to delimit the range of discharge conditions. The parallelogram formed grid in the diagram depicts a range of possible orifice diameters and oil flow rates that might be used in the tower tank experiments. The orifice diameters are here limited to the range from 0.5 to 20 mm, with oil flow rates in the range from 0.1 to 20 L/minute. The thick solid line drawn in the diagram shows the boundary between the transition regime and the turbulent breakup (or atomization) regime.

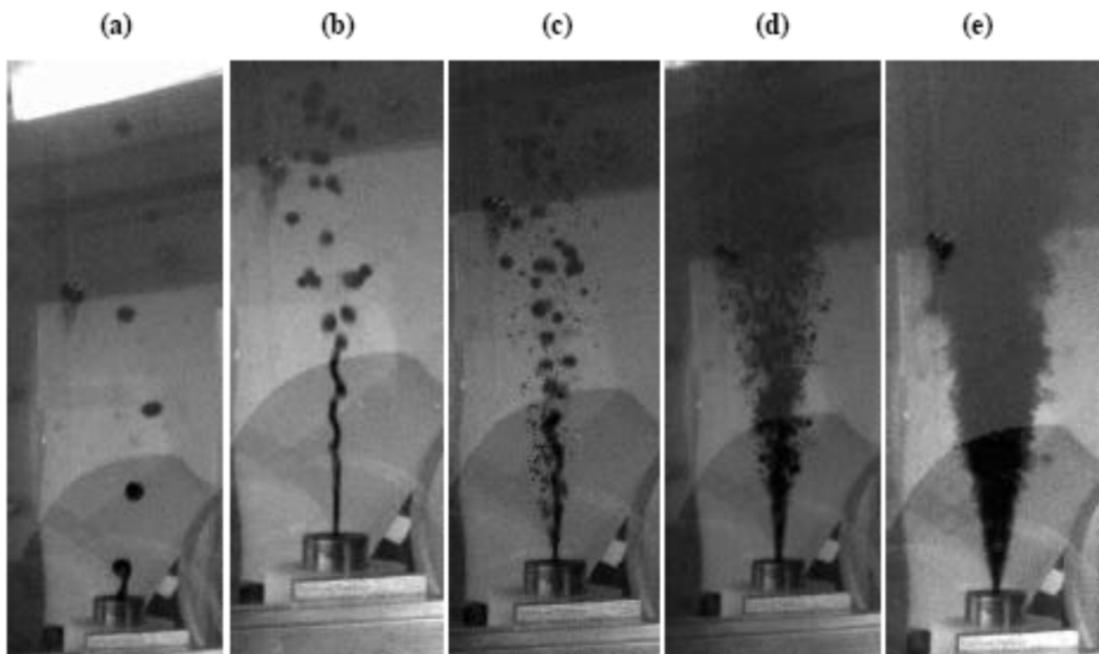


Figure C.1: Illustration of oil jet breakup regimes from Tang and Masutani (2003). At low velocities, Rayleigh instability dominates, producing a near mono-dispersion of droplets larger than the orifice (a). As velocity is increased, the breakup location moves away from the nozzle and at some point the instability changes to a sinuous mode (b). At higher velocities, two instability mechanisms appear to operate in parallel: the surface of the jet becomes unstable to short wavelength disturbances and disintegrates close to the nozzle into fine droplets, while the core of the jet persists as a continuous fluid filament that breaks up further downstream into large droplets (c). Raising the velocity moves the breakup location of the jet core filament closer to the nozzle and also increases the fraction of fine droplets (d). Finally, atomization is attained (e).

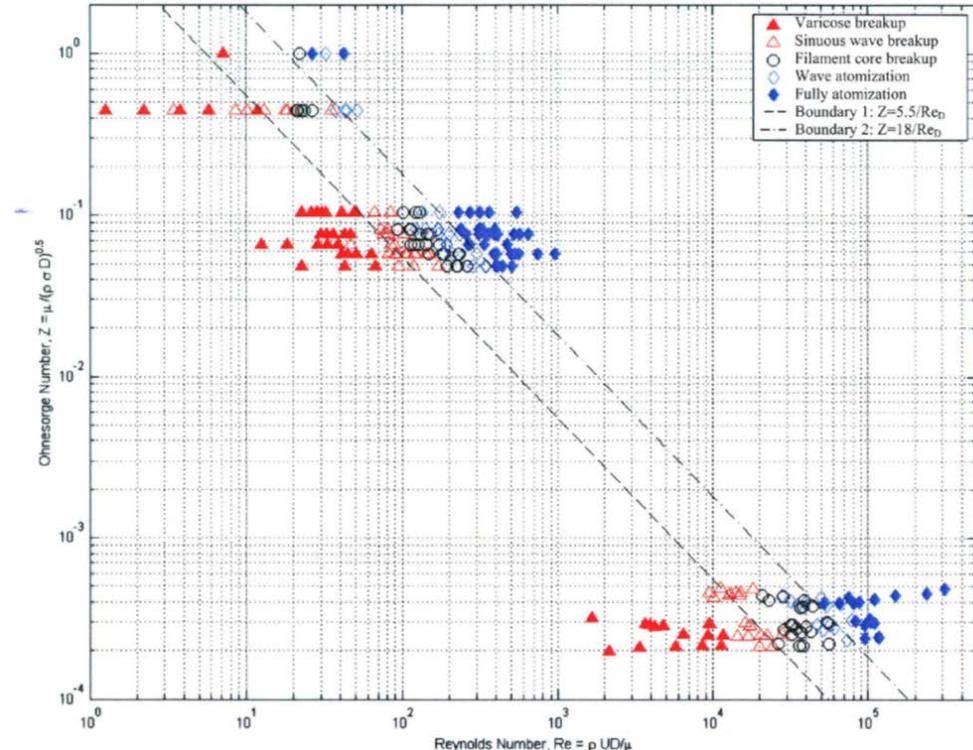


Figure C.2: Liquid-liquid jet breakup regimes based on experiments with oil and silicone injection tests (upper two sets) and liquid CO₂ injection tests (lower right hand corner). After Tang and Masutani (2003).

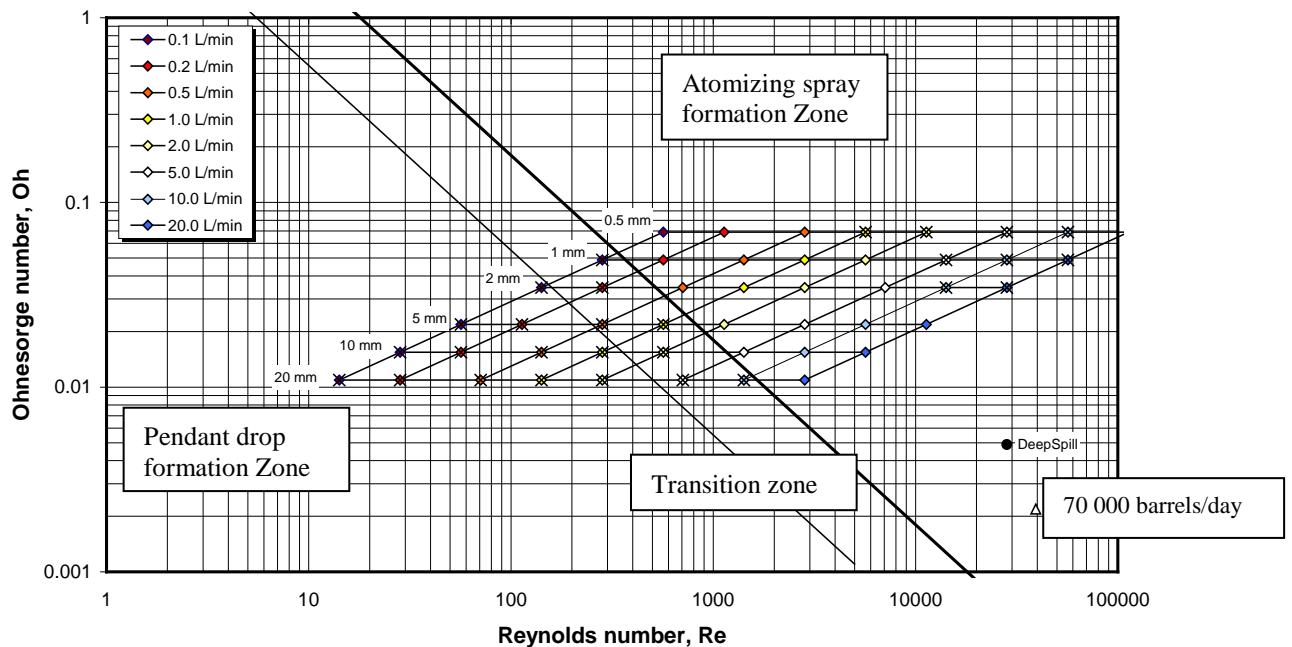


Figure C.3: Possible experimental conditions plotted in an Ohnesorge vs. Reynolds number diagram. Injection rate varied from 0.1 to 20 L/min, with nozzle diameters varied from 0.5 to 20 mm. Oil viscosity is presumed to be 5 cP. Approximate location of the DeepSpill experiment and the Deepwater Horizon incident are shown for comparison (70 000 barrels/day).

The preferred range of experimental conditions are depicted with open markers, while the cases that falls outside the turbulent regime are shown with crossed markers. Some of the cases in the turbulent breakup regime that will produce high outlet velocities (> 40 m/s) are also crossed out. These cases may be difficult to realize due to high pressure drops. The range of experimental conditions are also limited due to the size of the tank, however, nozzle sizes up to 15 mm and rates up to 100 L/min can be tested. The duration of such experiments will be limited 10-30 seconds.

C.2 Weber number scaling

The classical theory of droplet splitting in turbulence predicts a maximum stable droplet size $d_{max} = C(\sigma/\rho)^{3/5} \epsilon^{-2/5}$, where C is a constant of proportionality, σ is the interfacial tension (oil-water), ρ is the density of the continuous phase (water), and ϵ is the stationary turbulent dissipation rate (Hinze 1955). However, in an oil jet emitted into water from a nozzle, the droplets will be carried downstream in the jet during the splitting process. Consequently, in a Lagrangian framework, the turbulent dissipation rate will diminish rapidly with time, and the assumption of stationary turbulence will not be applicable.

However, this theoretical model may still serve as a starting point for experimental design and development of more practical empirical equations. For example, by taking into account that the exit turbulent dissipation rate in a jet scales with the exit velocity U and diameter D , $\epsilon \sim U^3/D$, the equation given above for d_{max} can be expressed in non-dimensional form: $d_{max}/D = A \text{ We}^{-3/5}$, where A is a factor of proportionality, while the exit Weber number $\text{We} = \rho U^2 D / \sigma$. The factor of proportionality will depend on the flow conditions in the break up zone, and have to be determined empirically.

This scaling law is supposed to be valid when the breakup is limited by the interfacial tension of the jet liquid. However, as Hinze (1955) also pointed out, internal viscous stresses in the fluid droplets may also influence the breakup. Hinze introduced a dimensionless viscosity group N_{Vi} to account for this effect. Hinze's viscosity group is actually identical to the Ohnesorge number defined above. More recently, Wang and Calabrese (1986), proposed to replace Hinze's viscosity group by the viscosity number $Vi = \mu U / \sigma$ to account for the effect of viscous stresses. This dimensionless number is also defined as the ratio between the Weber number and the Reynolds number, i.e. $Vi = \text{We}/\text{Re}$.

Wang and Calabrese (1986) found that droplet breakup was governed by the Weber number scaling for small viscosity numbers ($Vi \rightarrow 0$), but that a Reynolds number scaling would apply for large viscosity number ($d_{max}/D = C \text{ Re}^{-3/4}$, $Vi \rightarrow \infty$). For intermediate values of Vi , a combination of the two scaling laws might be applied. We will return to this relationship in the discussion of the experimental results, but it should be pointed out here that the viscosity numbers usually are small in conjunction with oil jet breakup, but large numbers may result in conjunction with application of chemical dispersant, since this can result in reductions in the interfacial tension by several orders of magnitude.

C.3 Bubbly jets

Most oil jet breakup experiments are conducted with a single fluid into water (crude oil or silicone fluid). In subsea blowouts, however, gas is in general discharged together with the oil, and the oil is quite often mixed with certain amounts of formation water. Different flow conditions can occur in such multiphase flows, from bubbly flow with oil as the continuous phase, via slug flow where plugs of oil and gas occupy sequential sections of the pipe, to mist flow where oil droplets are

suspended in the gas flow, and some of the oil might flows along the surface of the pipe (annular flow). Bubbly flow in vertical pipes are normally associated with low to moderate gas void fractions ($0 < n < 60\%$), while mist flow is limited to very high void fractions ($n > 95\%$). However, the actual flow conditions are also influenced by the velocity of the flow, often defined by the superficial velocities of the two fluids. In the present context, we will only consider the bubbly flow condition, which in this study is of most interest because of concerns about high flow rate oil blowouts.

The main issue here is how to account for the presence of gas in the normalized variables defined above (i.e. the Reynolds, Weber and Ohnesorge numbers). For example, Neto et al. (2008) defined the nozzle Reynolds number in a series of bubbly water jet experiments in terms of the superficial water velocity $U_w = Q_w/A$ where Q_w is the volume flow of water and A is the nozzle cross section $A = \pi D^2/4$ corresponding to a nozzle diameter D , i.e. $Re_w = U_w D/\nu_w$ where ν_w is the kinematic viscosity of water.

However, this definition will not discriminate between a pure water jet and a bubbly jet with the same water flow. In order to account for this, the "water only" velocity may be substituted with an "effective" water velocity U_E derived from the principle of conservation of momentum flux. In the following, M is the exit momentum flux of the bubbly water jet, while M_E is the momentum flux of an "equivalent" pure water jet. The effective water velocity is then defined as the velocity of a pure water jet producing the same momentum flux as the bubbly water jet:

$$M = (\rho_w Q_w + \rho_g Q_g) U_{w+g},$$

$$M_E = \rho_w Q_E U_E, \text{ where } Q_E = A U_E$$

If we neglect the contribution of the gas to the momentum flux (due to the much smaller density of the gas), $M_E = M$ will imply $U_E = U_w/(1 - n)^{1/2}$.

Since we now have defined the Reynolds number is in terms of the continuous phase, it is reasonable to do the same for the Weber and the Ohnesorge numbers. We then get the following definitions of the non-dimensional variables:

$$Re = \rho U_E D/\mu, \quad We = \rho U_E D^2/\sigma \quad \text{and} \quad Oh = \mu/(\rho \sigma D)^{1/2}$$

In the following, when we consider a system with oil and gas (instead of water and gas), oil properties will be substituted for water properties, and the subscripts will be dropped in the density and viscosity terms (implicitly implying oil).

Figure C.4 shows a Re vs. Oh plot based on these definitions with results from the bubbly water jet experiments reported by Neto et al. (2008), covering gas volume fractions in the range from approximately 5 to 80 %. Experiments where atomization is observed are represented by filled markers, while open markers represent the transition regime. The thick red line depicts the transition to full atomization based on the liquid only experiments of Tang and Masutani 2003 (with oil or liquid CO_2).

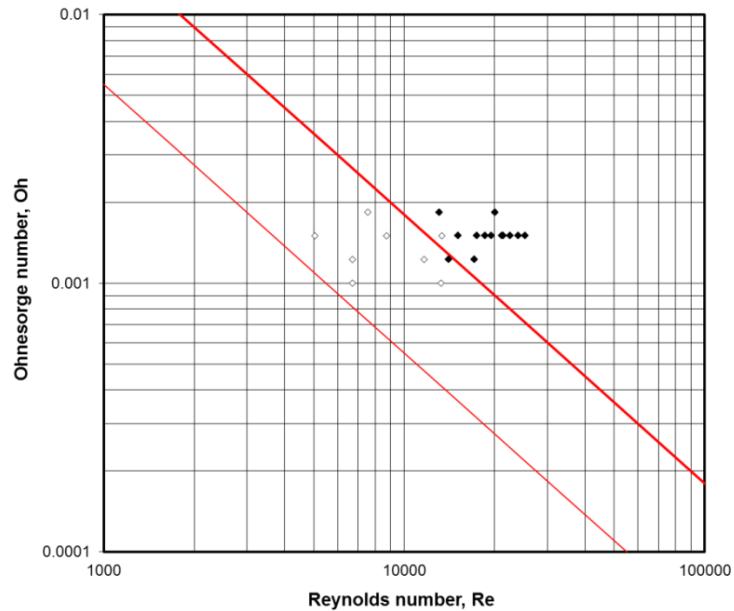


Figure C.4: Ohnesorge – Reynolds number plot of data from bubbly water jet experiments reported by Neto et al. 2008. Filled diamonds represent cases with atomization, while the open diamonds are cases in the transition regime. The thick red line depicts the transition to full atomization based on liquid only experiments of Tang and Masutani 2003.

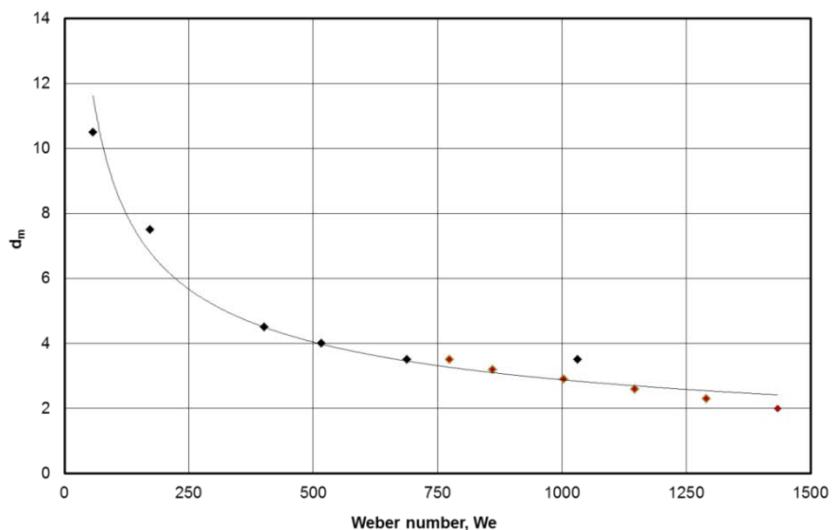


Figure C.5: Volumetric mean bubble diameter plotted as a function of the Weber number computed from the equivalent liquid velocity U_{LE} defined above. The results shown here were obtained by Neto et al. 2008 with a 6 mm nozzle, with water only velocities in the range from about 0.5 to 3 m/s and gas volume fractions in the range from 7 to 80%. The red markers represent experiments with a fixed water only velocity ($U_{LO} = 2.95$ m/s), but with gas volume fraction varied from 7 to 50 %.

Figure C.5 shows a plot of the mean bubble diameter reported by Neto et al. for a set of experiments with a 6 mm nozzle. The gas volume fractions varies in a range from about 7 up to about 80 %, while the water only velocities are in the range from about 0.5 to 3 m/s. It is promising that the transition line derived from single liquid flows also applies to bubbly jets when we use the

definitions given above of the non-dimensional numbers. The same can be said for the quite systematic variation observed in Figure 2 of the mean bubble size with our definition of the Weber number.

In conjunction with the planned oil experiments, these findings seem to imply that a situation with an a gas volume fraction n and an oil volume flow $Q^{(n)}$ might be represented by an oil only experiment with an adjusted oil volume flow $Q = Q^{(n)}/(1-n)^{1/2}$.

C.4 Buoyant jets

The gas fraction in a bubbly jet will also contribute to the buoyancy flux of the discharge. The buoyancy flux is defined as $B = g' Q$, where Q is the total exit volume flow and $g' = g (\rho_w - \rho)/\rho_w$ is the reduced gravity, where g is the acceleration of gravity, ρ_w is the density of water, and ρ is the density of the mixture of liquid and gas. Papanicolaou and List (1988) made an experimental investigation of the dynamics of round vertical buoyant jets, and found that buoyant jets differs from momentum jets in many aspects. While most experiments of droplet breakup in oil jets are made with jet-like outlet flow conditions due to restriction in volumetric flow rates and nozzle diameters, the conditions in deep water blowouts with large volume flows and large outlet diameters may tend to be more plume-like.

Papanicolaou and List (1988) found that the transition from jet-like to plume-like behavior in buoyant plumes is defined by a characteristic length $l_M = M^{3/4}/B^{1/2}$. They conducted experimental studies with buoyant plumes and showed that the flow behaves like a jet at distances $z < l_M$, and like a plume for $z > 5 l_M$. The relative distance l_M/D may indicate whether droplet splitting will take place in the jet-like or plume-like section of the buoyant plume. By insertion of the expressions for Q , B and M in this equation, this ratio is found to correspond to the exit Froude number, $Fr = U/(g'D)^{1/2}$. Exit conditions (defined by the exit velocity and the orifice diameter) that gives high exit Froude numbers will thus imply that droplet splitting will occur in jet-like flow, while low exit Froude number implies buoyant plume flow in the breakup zone.

The authors also showed that in jet-like flow, the centerline velocity w_c at a distance z downstream from the exit will scale with the exit velocity, i.e. $w_c \sim U z/D$. In plume-like flow, the buoyancy flux will be the primary factor that determines the velocity development, i.e. $w_c \sim (B/z)^{1/3}$. This implies that in plume-like conditions, the exit velocity will not be a characteristic velocity for droplet breakup. From the scaling law for plume like flow, we find that at a distance $z = 5 l_M$ where the flow shifts to plume-like behavior, the centerline velocity will be $w_c \sim (g'D)^{1/2}$. Thus, we may define a modified characteristic velocity $U' = U (1 + b Fr^{-1})$, where b is a factor of proportionality in the order of 1, to account for both jet-like and plume-like breakup conditions. The last term will vanish for large exit Froude numbers (i.e. $U' \approx U$ for jet-like flow), while for small Froude numbers (plume-like flow), the modified velocity will approach $U' = b Fr^{-1} = b (g'D)^{1/2}$, corresponding to the velocity at the transition to plume-like behavior. The factor of proportionality b should be determined from droplet breakup studies with buoyant flow conditions, but $b = 1$ could be used as a provisional estimate.

C.5 Droplet size distributions

In the previous section, we have focused on models for prediction of the characteristic droplet size, e.g. defined as the volume median droplet diameter, d_{50} . However, we also need to consider the statistical distribution of the droplet sizes around the characteristic diameter. Of the many available options, two distribution functions are most commonly found in the literature on droplet breakup; the lognormal distribution and the Rosin-Rammler distribution (Lefebvre 1989).

The former can be understood as a normal distribution of the logarithms of the droplet sizes, i.e. a normal distribution of $x = \ln(d)$, with a mean value $M = \langle x \rangle$, and a standard deviation σ_x based on x . The mean value M is also equal to the logarithm of the median droplet diameter, $M = \ln(d_{50})$. Thus, the lognormal distribution is defined by two parameters, M and σ_x .

The Rosin-Rammler distribution is also a two-parameter distribution function, defined in terms of a characteristic diameter d_i corresponding to a certain cumulative volume fraction V_i (e.g. 50%), and a spreading parameter n . The cumulative volume distribution function is given as

$$V(d) = 1 - \exp[-k_i (d/d_i)^n], \text{ where } k_i = -\ln(1-V_i)$$

For $V_i = 50\%$, d_i is the median diameter, and $k_i = -\ln(0.5) = 0.693$.

A third option is the Upper Limit lognormal distribution (UL), which is based on the lognormal distribution, but truncated at an upper limit diameter d_{max} . The cumulative probability function for the Upper Limit lognormal distribution is simply $V_U(d) = V(d)/V(d_{max})$ for $d < d_{max}$ and $V_U(d) = 1$ elsewhere, where $V_U(d)$ corresponds to the upper limit distribution and $V(d)$ corresponds to the lognormal distribution. This distribution function will also be skewed, as shown in Figure C.6.

Figure C.6 shows examples of distributions for the three distribution functions, with cumulative distributions shown in the top graph and frequency distributions in the bottom graph. Both graphs are presented in terms of relative droplet diameters d/d_{50} . The spreading parameter $n = 1.8$ in the Rosin-Rammler distribution is chosen to give an approximate fit to the lognormal distribution with the chosen standard deviation (here $\sigma_x = 0.78$ in natural logarithmic units). The UL distribution has the same nominal median and standard deviation, but is truncated at $d/d_{50} = 3$. The top graph shows that the lognormal distribution is symmetric on a logarithmic x-axis, while both the Rosin-Rammler distribution and the UL distribution are skewed with a shortened high-end tail ($d/d_{50} > 1$). However, at the low-end ($d/d_{50} < 1$), the three distributions have almost the same shape.

The same tendency is found in the bottom graph. This graph is made by binning the diameters in equal logarithmic intervals, corresponding to the data obtained from the LISST instrument. In the output from that instrument, the top value of each bin d_n is 1.18 times the top value of the previous bin d_{n-1} , and the same increment is used here, i.e. $d_n = 1.18 d_{n-1}$. The values given on the x-axis in the bottom frame are median diameters in each bin, i.e. $d_M = (d_{n-1} d_n)^{1/2}$. The height of the columns represent the volume fraction contained in each bin, i.e. $\Delta V = V_n - V_{n-1}$. A close inspection of the bottom chart shows that the maximum bin volume fraction falls in the bin centered near $d/d_{50} = 1$ for all distributions, but with a slightly higher value for the Rosin-Rammler distribution ($d/d_{50} = 1.3$). However, for larger values of the spreading parameter, the peak diameter of the Rosin-Rammler distribution is found to approach the median diameter: with $n = 2.5$, the peak diameter is found to fall in the bin centered at $d/d_{50} = 1.1$.

While the arithmetic mean for a normal distribution is known to coincide with the median value, for a lognormal distribution, the arithmetic mean is given as $E = \exp(M + \sigma_x^2/2)$, where M is the logarithmic mean and σ_x is the logarithmic standard deviation. With the given parameters, $M = 0$ and $\sigma_x = 0.78$, this gives $E = 1.36$. We have estimated the arithmetic mean value for the Rosin-Rammler distribution from the binned distribution as $E = \sum d_i \Delta V_i$, summarized over all bins. With $n = 1.8$, the arithmetic mean diameter was found to be $d/d_{50} = 1.09$, while for larger values of n , the arithmetic diameter was found to be closer to $d/d_{50} = 1$: with $n = 2.5$, the arithmetic mean was found at $d/d_{50} = 1.03$. The same method gave an arithmetic mean at $d/d_{50} = 1.34$ for the lognormal distribution, which is close to the theoretical value given above.

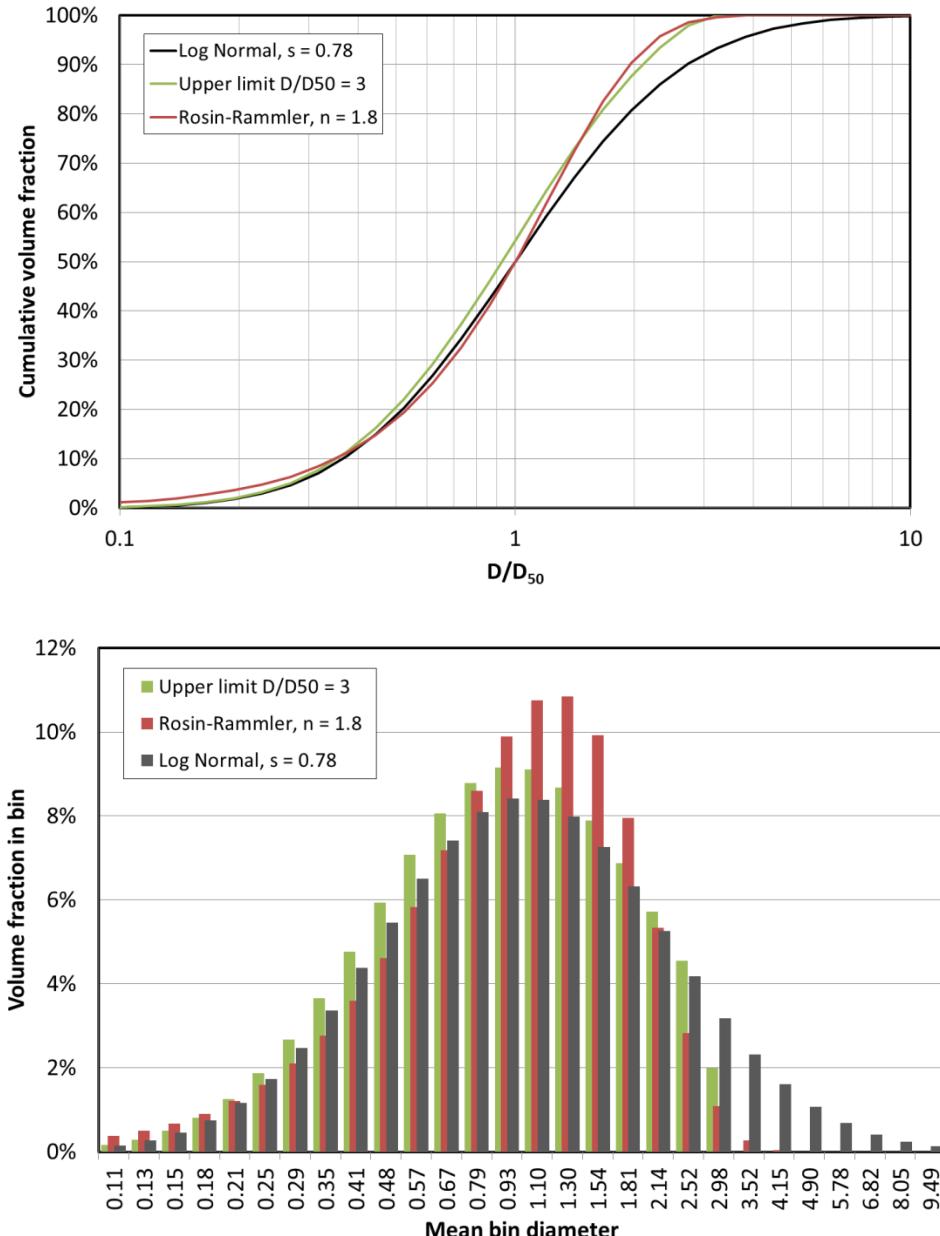


Figure C.6: Comparison of lognormal and Rosin-Rammler distributions (bins in mm). Top: Cumulative distributions, bottom: Frequency distributions. The latter is based on data binned in equal logarithmic intervals, comparable to results from the LISST-instrument (see text).

The lognormal distribution may be linearized by plotting the number of standard deviations S that corresponds to a given cumulative probability V against $x = \ln(d)$ (see Figure C.7, upper graph). The value of $S(d)$ is computed from the given cumulative probability $V(d)$, presuming that the distribution follows a lognormal distribution. In algorithmic notation, this can be expressed as $S(x) = \text{Norm.Inv}(V(x), 0, 1)$, where Norm.Inv represents a function that returns the inverse of a normal distribution with a mean value $M = 0$ and standard deviation $\sigma_x = 1$. If the data are from a true lognormal distribution, the data points will then fall on a straight line $y = a x$, where the coefficient

of proportionality will be $a = 1/\sigma_x$. By plotting an observed distribution in this way, we may thus assess whether the data follows a lognormal distribution, and if that is the case, determine the standard deviation of the distribution from the slope of the line.

The Rosin-Rammler distribution can be linearized in a similar way by plotting the variable $-\ln[1 - V(d)]$ versus the diameter (see bottom graph in Figure C.7). If the data follows a Rosin-Rammler distribution, the data will follow a power law function $y = b d^p$, where the exponent $p = n$ and the coefficient $b = k/d_{50}^n$. This implies that by plotting an observed distribution in this way, we may assess whether the data follows a Rosin-Rammler distribution, and if that is the case, determine the median diameter d_{50} and the spreading parameter n of the distribution.

The examples shown in Figure C.7 demonstrate the point, but also show that the Upper Limit distribution may look like a lognormal distribution at the lower end ($d/d_{50} < 1$), and as a Rosin-Rammler distribution at the upper end ($d/d_{50} > 1$).

We may also conclude that the peak diameter of the logarithmic binned distributions will coincide closely with the median diameter when the data fits a lognormal distribution. The same assumption may be made when the data fits a Rosin-Rammler distribution, but in that case, the median diameter may be slightly overestimated.

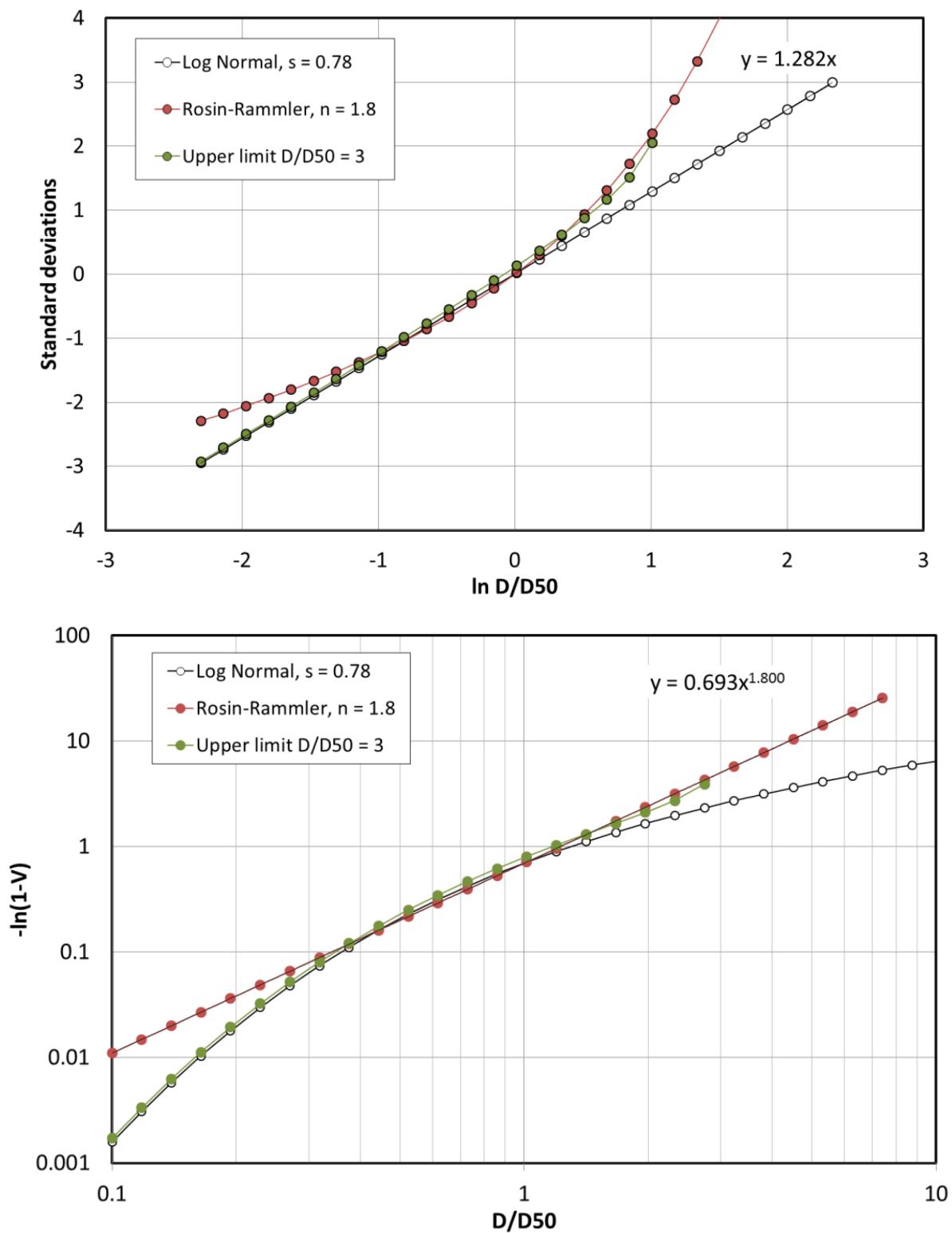


Figure C.7: Linearization of lognormal and Rossin-Rammler distributions. Top: Log normal linearization. Bottom: Rosin-Rammler linearization.



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