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Subsea dispersants injection (SSDI), effectiveness of different dispersant injection techniques – An experimental approach

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ABSTRACT

The main objective with this study has been to study injection techniques for subsea dispersant injection (SSDI) to recommend techniques relevant for both laboratory studies and operational response equipment.

The most significant factor was the injection point of the dispersant in relation to the release of the oil. The dispersant should be injected immediately before or after the oil is released. Then the dispersant will mix into the oil and reduce IFT before the oil enters the turbulent zone where initial droplet formation occurs.

All injection techniques tested gave significant reductions in oil droplet sizes. However, due to the rapid oil droplet formation in turbulent jets and possible formation of surfactant aggregates in the oil, premixing of dispersants should not be used for experimental studies of subsea dispersant injection. This could underestimate dispersant effectiveness and produce results that might not be representative for up-scaled field conditions.

1. Introduction

Subsea injection of dispersants was first tested during the blow-out from the MC252 well in the Gulf of Mexico in 2010 (Place et al., 2010). The dispersants were injected directly into the rising flow of oil and gas and after two short test periods in May, dispersant was injected continuously as one of the primary response strategies until the well was capped two months later on July 15, 2010. During that period, several techniques were used to inject dispersant depending on the nature of the oil release and the available technology. Early in the incident, the oil was released from multiple locations on the broken riser, which included kinks and cracks. The dispersant was injected with an “insertion tool” mixing the dispersant into the oil flow a few meters before the release opening. Later, when the riser was cut, and the oil was released directly from the blow-out preventer, dispersant was injected with various types of wands directly into the rising stream of oil, gas and water above the blow-out preventer.

Limited knowledge exists on the effectiveness of different subsurface dispersant injection techniques. Studies have been performed at different scales (Belore, 2014; Zhao et al., 2017), but they have either used premixed dispersants or not quantified the effect of different injection techniques. This paper presents the main findings from a study focusing on the effectiveness of a broad selection of injection techniques. The full dataset can be found in the technical reports (Brandvik et al., 2014a,b). The main objectives for this study were to increase the knowledge regarding subsea injection of dispersant and to recommend injection techniques relevant for both laboratory studies and operational response equipment.

2. Experimental

The experiments described in this paper were performed in two different laboratory facilities at SINTEF, Trondheim, Norway. The larger is called a Tower Basin and consists of a 6 m high and 3 meter wide basin containing 42,000 L of natural sea water. Oil and gas were injected from the base of the basin, and oil droplets and air bubbles were monitored 2 m above the release. The smaller experimental facility is called the MiniTower and consists of a 1 meter high and 0.5 meter wide basin holding 80 L of natural sea water. This smaller facility has a salt water flow-through system (30–100 L/min) to dilute the plume of dispersed oil droplets and facilitate continuous experiments.

The reduction in droplets sizes as a function of dispersant injection (dosage and injection method) was used to quantify the effectiveness of the treatment. The oil droplet sizes were quantified with a laser diffraction instrument (LISST 100X), which provides a volume-based distribution of the diameter of particles (oil droplets and air bubbles) passing through its measurement chamber. The instrument makes 10 measurements every second, covering 32 logarithmic spaced bins in the 2.5–500 μm diameter range, and stores these as an average reading. An

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average over a 30-second period (300 individual droplet size scans) was used in this study to quantify each particle size distribution. Averaging over this period should reduce uncertainties from possible pulsing in oil or dispersant flow rates and inhomogeneity in the rising oil plume.

The representative diameter in each bin was computed as the geometric mean of the lower and upper value in the bin, i.e. $\bar{d} = (d_{n-1}d_n)^{1/2}$, where subscript n denotes the bin number. These diameters are used as labels for each bin in tables and figures presented in this paper. Data near the lower range (the first three bins, $< 4.5\,\mu m$) have been omitted from the results due to background noise, especially when dispersants were used. However, the sizes of oil droplets generated in this study have insignificant volumes in this size range, so omitting these lower bins was assumed to have no influence on the presented results. With an upper detection limit of 500 μm, some of the largest droplets may fall outside the observable range in some cases. For this reason, we have chosen to define the characteristic droplet diameter as the centre of the bin where the peak was observed in the distribution. If the droplet size distribution follows a lognormal distribution, this peak diameter will coincide with the volume median droplet size (VMD) or d_{50} within the uncertainty given by the finite bin size. More details on this issue are given in an earlier paper (Johansen et al., 2013).

The release conditions (nozzle diameters and release rates) for experiments with untreated oil were selected in order to keep the observed maximum peak (or d_{50}) below the upper detection limit. In the upper bins the number of droplets becomes low and experimental uncertainty could cause an increase in the largest droplet bin size (see example in Fig. 2).

The principles of the tower basin, oil release system and the instrumentation are described elsewhere (Brandvik et al., 2013) and in the technical report from this study (Brandvik et al., 2014a). The experimental work presented in this paper focused on the dispersant injection systems. The experiments performed in the larger Tower Basin and in the smaller Mini Tower were all performed with the same oil and dispersant type, see next sections and Table 1. The majority of the work was performed in the Tower basin, only the experiments presented in Fig. 6 and partly in Fig. 8 were performed in the Mini Tower.

2.1. *Oil type*

The oil used was a light paraffinic Norwegian North Sea crude, which has similar composition and properties as the MC252 crude released during the Macondo incident. The properties for the oils were derived from an oil weathering study performed at SINTEF (Daling et al., 2014). A selection of relevant properties for these two oil types is given in Table 2. A simple one-stage distillation was used to simulate evaporation (Stiver and Mackay, 1984). The Oseberg blend was received from the Sture oil terminal in Norway and used as received.

2.2. *Dispersant*

Corexit® 9500 was selected for this study since it was the main dispersant used during the Macondo incident and it is stored worldwide as a part of operational oil spill contingency plans. It was received from Nalco in March 2012 (SINTEF ID: 2012-0062) and was used as received.

Table 1
Experimental conditions for the basin facilities.

Tank type	Tower Basin	Mini Tower
Nozzle size (mm)	1.5	0.5
Oil release rate (L/min)	1.2	0.1
Water temperature (°C)	10	10
Oil injection temperature (°C)	20	20
Tank height (m)	6	1.2
Tank diameter (m)	3	0.5
Tank volume (L)	42,000 (static)	80 (continuous exchange, 30–100 L/min)

Table 2
Properties of Macondo MC252 and Oseberg blend.

	Macondo MC252 (ID 2010-0408)	Oseberg blend (ID 2012-0347)
Density (kg/L)	0.833	0.832
Pour point (°C)	−27	−6
Viscosity (mPas, shear rate $10\,s^{-1}$, 40 °C)	4	5
Asphaltene (wt%)	0.2	0.3
Waxes (wt%)	1.6	3.2
150 °C – evaporative loss (vol%)	27	22
200 °C – evaporative loss (vol%)	39	34
250 °C – evaporative loss (vol%)	50	45

2.3. *Interfacial tension*

To evaluate the effectiveness of the different injections techniques, it was important to know the reduction in interfacial tension (IFT) and the resulting effect on the droplet size distribution. The IFT between water and oil was measured using the spinning drop method (Khelifa and So, 2009). The water samples containing dispersed oil droplets were taken from the oil plume inside the tower basin during the experiment. Oil settled as a layer and was collected for IFT measurements after 24 h. The long settling time was important for collecting the smaller oil droplets in experiments with high dispersant effectiveness. All spinning drop analyses were performed at 13 °C. Measurements of IFT in the spinning drop instrument were taken as soon as the drop elongation was stable, usually within a few minutes. Measurements were done on multiple droplets and standard deviations were typical ± 0.2 for high to medium IFTs values (2–20 mN/m) and ± 0.01 for low IFTs values (0.01–2 mN/m). Further details are given in Brandvik et al. (2013).

2.4. *Dispersant injection techniques*

In these laboratory experiments, scaling from field conditions was done by using the release diameter (D) as a scaling factor. The “distances” referred to in the list below are relative to a nozzle diameter of 1.5 mm. Close to the release opening, in the jet zone of the release, this scaling approach was regarded to be highly relevant. Higher above the release, where a plume behaviour dominates, other scaling approaches could probably be more relevant (Papanicolaou and List, 1988).

Four different injection techniques were tested as a part of this study. Three of these (1–3) were designed to simulate operational methods used during the Macondo incident and the fourth was added to study the effect of premixed dispersant, primarily used for laboratory experiments.

1. Simulated insertion tool (SIT): Dispersant was injected into the oil stream 6 nozzle diameters before the nozzle outlet (see Fig. 1-1). This was meant to simulate the insertion tool that was used in an early phase of the Macondo release in the Gulf of Mexico in 2010. This was a nozzle on the tip of a 2–3 m long tube which was inserted into the broken riser. At the scale of our tests (1.5 mm discharge orifice), it was not practical to make a scaled insertion tube, without significantly disturbing the oil flow. For this reason, the dispersant was injected into the oil stream by a separate line, 6 diameters before the release point (see Fig. 1-1).
2. Injected above nozzle: Dispersant was injected in to the centre of the oil jet or plume at different distances above the nozzle (0–30 nozzle diameters above the nozzle). This was meant to simulate the wand, injecting dispersant into the rising oil, used during the Macondo release. In Fig. 1-2 the injection point is 30 D above the release