Controlling and documenting dispersant effectiveness during subsea dispersant injection (SSDI) - A novel system for dispersant dosage and in-situ monitoring of oil droplet and gas bubble sizes

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Abstract

Subsea dispersant injection (SSDI) has been implemented as a response method since it was first used in large-scale during the Macondo subsea blow-out in the Gulf of Mexico in 2010. Oil and gas operators have access to SSDI equipment through multiple suppliers of response equipment. This equipment is a crucial part of the capping and containment package offered in the event of a subsea blow-out. The concept is used to ensure access to the spill site (remove surface oil), improve working conditions (reduce exposure to volatile oil components) and finally be used as a response option to reduce environmental impact form the spill (reduce surfacing & stranding of oil and increase natural biodegradation of dispersed oil as small droplets).

However, a subsea blow-out of 12 000 m^3/day, would require 800-1600 m^3 of dispersant for the first week with a dosage of 1-2%. Controlling the dispersant dosage could be critical, especially, since the initial volume of available dispersants could be limited.

This paper presents a new system for automatic dispersant dosage control. The system monitors the size distribution of the released oil droplets and gas bubbles. The injected dosage of dispersant is then automatically adjusted to obtain a desired oil droplet size. The dispersant dosage from a hydraulically operated valve is adjusted based on a real-time signal from a silhouette camera (SilCam) positioned in the rising oil & gas plume. The SilCam is used to quantify oil droplet and gas bubble distributions. The SilCam can be held in place by a Remote operated Vehicle (ROV) and all signals are brought to the operator onboard the supply vessel via

the ROV's umbilical cord. The concept is tested by down-scaled experiments at SINTEF and verified in full-scale by Oceaneering in a large ROV test pool.

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1 Introduction

The oil and gas operators have access to subsea dispersant injection (SSDI) equipment through multiple sources; Oil Spill Response Ltd. (OSRL), Wild Well Control (WWC) and Australian Marine Oil Spill Centre Pty Ltd. (AMOSC). This equipment is a crucial part of the capping and containment package offered in the event of a subsea well blowout and could both be used to ensure access to the spill site (remove surface oil), improve working conditions (reduce exposure to volatile oil components) and finally be used as a response option to reduce environmental impact form the spill (reduce surfacing & stranding of oil and increase natural biodegradation of dispersed oil due to smaller oil droplets). The basic concept of this response option consists of a dispersant supply (from a surface vessel), a system to inject the dispersant into the oil (wands), a system to quantify treatment effectiveness (oil droplet sizes) and a system to control the dispersant dosage.

The amount of oil released during the Macondo 84 day blow out is uncertain and estimates range from 6 000 – 12 000 m^3/day (Ryerson et al., 2012). The total amount of dispersant injected was significant and is estimated to 2900 m^3 (Kujawinsli et al., 2011). After initial testing, dispersant was injected continuously from May 15th until the well was plugged 62 days later on July 16th. During that period, several techniques were used subsea to inject dispersant depending on the nature of the oil release and the available technology. Early in this period, while the oil was released from multiple locations or "kinks and cracks" along the broken riser, dispersant was injected with an "insertion tool" injecting the dispersant into the oil flow a few meters before the release opening. Later, when the riser was cut and all 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.

During the release, no direct measurements were conducted in the rising oil plume that could be used to estimate the effectiveness of the dispersant treatment. Measurements of oil droplet sizes before and after dispersant injection would have been helpful to evaluate the different injection techniques and adjust the dosage of dispersants. Extensive video footage is available, but estimating changes in oil droplet sizes from video obtained during the release is not straight forward. The lack of documentation of the initial oil droplet size, dosage of dispersant and the effectiveness of the treatment has led to questioning of the justification for SSDI (Paris et al., 2012).

Sufficient dispersant supply and logistics are important during a SSDI operation. A subsea blow-out of 12 000 m^3/day, would require 800-1600 m^3 of dispersant for the first week with a dosage of 1-2%. Optimizing the dispersant dosage could be critical, especially in the early phase, when dispersant availability could be limited.

This paper presents a new system for automatic dispersant control. The system monitors the size distribution of the released oil droplets and adjusts the dispersant dosage to obtain a desired oil droplet size. The dispersant dosage is adjusted based on a real-time signal from a silhouette camera (SilCam) held in place in the oil and gas plume by a Remotely Operated Vehicle (ROV). The paper describes down-scaled concept testing at SINTEF and full-scale verification in a large ROV test pool at Oceaneering. It presents a summary from a larger study and the details can be found in the technical report (Nordmark et al., 2018).

2 Development of the particle sensor – SilCam

The silhouette camera (SilCam) was earlier developed at SINTEF in the period of 2015-17 (Davies et al., 2017) mainly to measure oil droplets and gas bubbles (20 – 12 000 microns). It has been tested and developed through a series of projects for example for API (Brandvik et al., 2016, Nedwed 2017) and BSEE (Ahnell et al., 2018) and is now routinely used to monitor a wide variety of particles in the marine environment, for example oil droplets, gas bubbles, sediments, plankton, flocks, marine snow and salmon lice (Davies and Nepstad, 2017, Fossum et al., 2019 and Fragoso et al., 2019).

The SINTEF SilCam has been tested in several large-scale laboratory oil releases (50 mm nozzles and 400 l/min) and has proved to be an excellent instrument to monitor oil & gas particle sizes both for untreated oil (multi millimeter droplets) and for oil treated with dispersant (< 0.5 mm) to quantify SSDI effectiveness (Brandvik et al., 2018). The SINTEF SilCam also exists in a high pressure version (300 bar) and has been used for studies in a large-scale hyperbaric chamber at Southwest Research Institute in the USA (Brandvik et al., 2019ab).

In this project the focus has been on operationalization of the SilCam to work with a standard offshore ROV (hardware/software adaption) and improving the real-time data handling to produce full-resolution particle size distributions on oil droplets and gas bubbles.

3 Development of the variable dispersant injector

With the existing equipment available for SSDI, dispersant dosage is controlled mechanically by the ROV using a mechanical arm opening/closing a valve located on the dispersant wand handle. This makes both targeting a specific dispersant treatment rate and post-spill documentation challenging.

As a part of this study, a pressure operated control valve was developed and used to regulate the dispersant flow (see Figure 1). The regulator is controlled by an external hydraulic pressure line from the ROV and operates in the 10 – 120 L/min range. This range covers subsea releases up to 12 000 m^3/day (1% dispersant dosage). The dispersant dosage is remotely controlled by the ROV operator onboard the supply vessel, through a remote control unit (RCU).

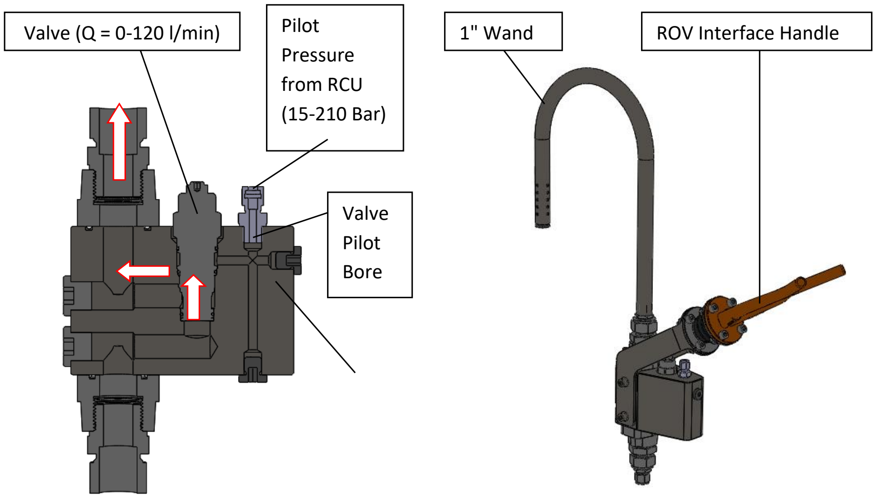

Figure 1: A: Dispersant flow regulator valve, the arrows show the dispersant flow direction through the valve. B: The regulating valve mounted on one of the wands together with the ROV interface handle.

4 Small-scale testing

Down-scaled wands were tested with different release scenarios in SINTEFs tower basin. This facility is three meter in diameter and six meter tall and contains 42 000 m^3 of natural sea water. A light paraffinic crude, Oseberg blend (0.863 kg/L) was used for these experiments, (see Brandvik et al., 2013 for further details).

Oil released from a straight pipe (25 mm), a ruptured pipe line or directly from coarse sediments at the sea bottom, were simulated. An example, where oil was released directly from an open pipe and dispersant was injected into the pipe opening with a wand (insertion tool) is shown in Figure 2. The figure shows untreated oil with large droplets (d_{50} = 1.7 mm) in the photo on the left and size distributions for different flow rates (50-120 L/min) quantified with the SilCam in the graph on the right. Both oil droplet size distributions for experiments with untreated oil (d_{50}: 4.5 – 1.7 mm, solid lines) and distributions for experiments with dispersant injection

(d_{50}: 0.35 – 0.21 mm, dotted lines) are shown in Figure 2. Further details on the dispersant injection technique (insertion tool) are given elsewhere (Brandvik et al., 2018).

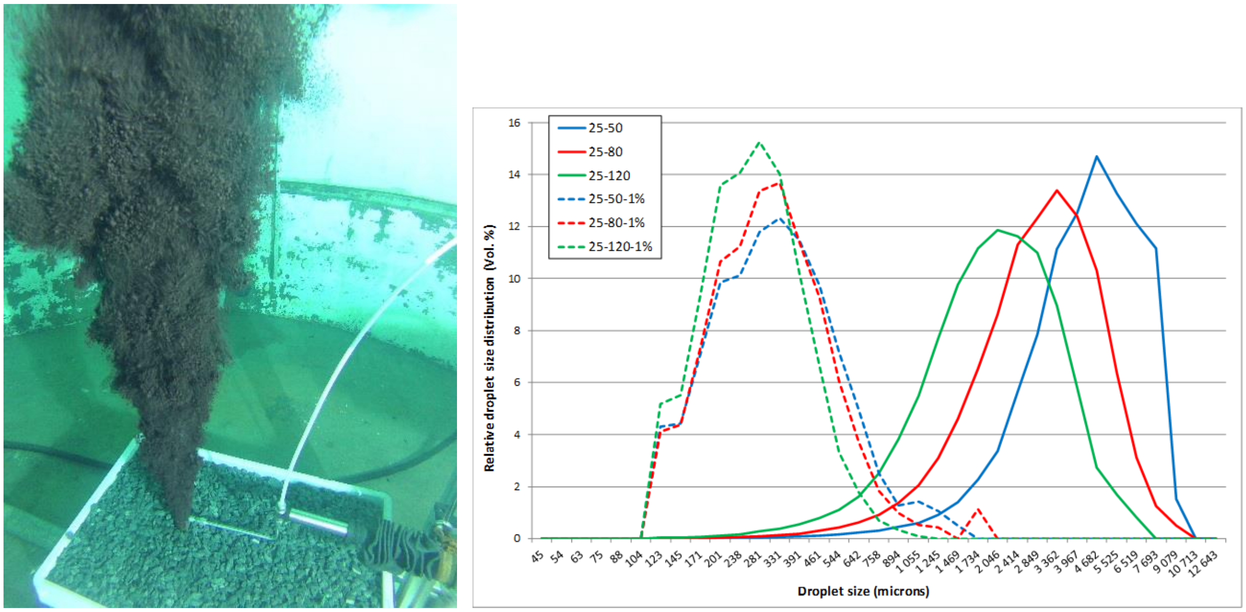

Figure 2: A: Untreated Oseberg blend released from the 25 mm nozzle at 120 L/min. B: Droplet size distributions for 3 different flow rates, 50, 80 and 120 L/min (d_{50}: 4.5 – 1.7 mm, solid lines) and treated with 1% Dasic Slickgone NS (d_{50}: 0.35 – 0.21 mm, dotted lines).

To test the concept of using automatic dispersant control, a down-scaled version of the complete system was tested in the Tower Basin. The signal from the SilCam (d_{50}) was sent to the remote control unit (RCU) and used together with the user input to control the dispersant regulator. The following components were a part of this concept testing:

Oil release: To release oil over a period of 10-15 minutes, without saturating the tank, the release nozzle was reduced to 10 mm nozzle with a flow rate of 6 L/min. These settings gave droplet sizes in the 4000 µm range for untreated oil.

Dispersant injection: The dispersant (Dasic Slickgone NS) was injected directly into the oil nozzle by an insertion tool.

SilCam: The SilCam monitored the droplet sizes 4.5 meters above the release and the mean volume droplet diameter (d_{50}) was used to the droplet sizes. The d_{50} was sent to the RCU with a frequency of 10-15 Hz.

RCU: The control unit received the d_{50} from the SilCam and communicated with the Dispersant regulator to adjust the dispersant dosage. The dosage was regulated to obtain the droplet sizes (d_{50}) set by the operator in the RCU. The RCU operation was simulated with a LabView code.

Dispersant regulator: A programmable pump (5 – 500 mL/min) was used to simulate the dispersant regulator. The dispersant injection rate was regulated based on signals from the control unit.

Two separate experiments were performed using the following procedure:

1. Initiate oil flow (dispersant injection off).
2. Measure untreated oil droplet sizes (approximate 4 mm).
3. Set "target droplet size" in the Controller to 0.5 mm and start "automatic dispersant control".
4. Monitor changes in droplet size (d_{50}) as a function of increase in dispersant injection (mL/min).
5. Stop experiments when d_{50} stabilize at "target droplet size".

Both experiments were very successfully terminated with a close match between the "target droplet size" and the measured droplet size at a stable dispersant dosage, see example in Figure 3.

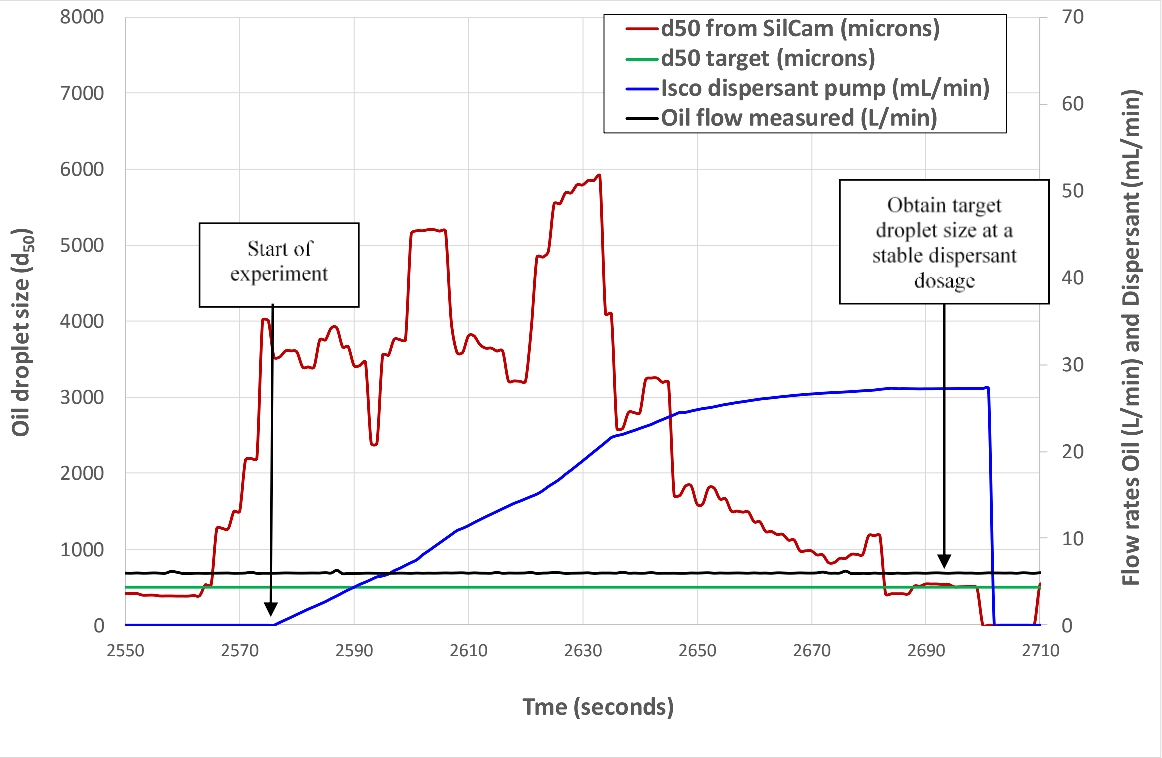

Figure 3: Monitored and set values for the down-scaled concept testing. The "target droplet size" was set to 500 microns and dispersant dosage (insertion tool) was automatically regulated (increased) by the Controller until a stable droplet size was measured.

After the dispersant injection was initiated the measured droplet sizes will vary due to variation in the rising velocity of the different droplet sizes. After dispersant injection, it took at least 30 seconds before a homogenous plume was established, at the SilCam position (4.5 meters above nozzle). When the SilCam measured a reduction in the d_{50}, the controller reduces the slope of the dispersant injection and it leveled out as the droplet size approaches the target size. The constants used in the regulation algorithm in the Controller (the Labview code) were based on previous experience from the Tower basin. The largest challenge was the time lag between the increase in dispersant injection and the measured response by the SilCam (approximate 30 seconds).

5 Full-scale testing

After down-scaled concept testing in the SINTEF Tower basin, full-scale verification with the actual regulator and a full-size offshore ROV was performed in Oceaneering`s ROV test pool in Stavanger (1 200 m^3), see Figure 5.

It was not desirable to use oil in the ROV test pool due to the high cleaning costs, so the full-size verification was done with a release of water and air bubbles. Water & air was released through a pipe and the gas bubble distribution was monitored by the SilCam. Instead of dispersants, water was injected into the release pipe and the increased turbulence (exit velocity) from the injected water, influenced (reduced) the air bubble size.

During the verification testing, the water injected into the release pipe (simulating dispersant) had a small, proportional and detectable effect on the air bubble sizes formed in the release pipe. This information (d_{50}) was used to simulate reduction in oil droplet size sent to the Control unit. When the oil droplet setpoint was lower than actual droplet (or bubble) size, the dispersant flow regulator valve (see Figure 1) increased the flow so that more water was injected into the simulated blowout, this resulting in smaller droplet (or bubble) sizes. When the SilCam setpoint was higher than actual bubble size, the dispersant flow regulator valve decreased the water flow so that less water was injected into the simulated blowout. This resulted in increased bubble size.

Even though dispersant was not used, the results from this test showed that the SilCam and the SSDI Regulation Kit communicated according to plan and can be used to establish a regulation loop optimizing the dispersant injection into a blow-out.

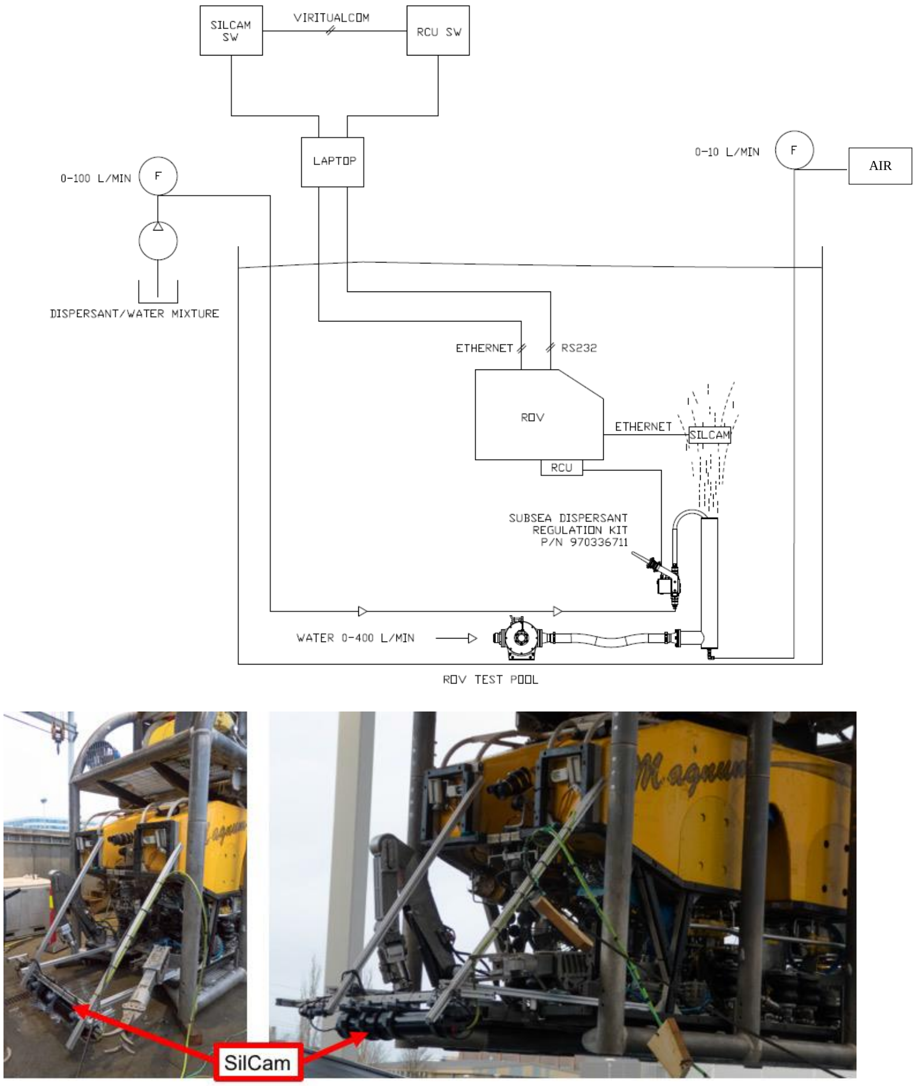

Figure 4: Upper: Schematics of the full-scale verification. Lower: SilCam installed on ROV.

6 Conclusions

This study tested wands for subsea dispersant injection, a sensor to quantify SSDI effectiveness (oil droplet sizes) and a regulator system for controlling dispersant dosage. The complete system can be used to automatically adjust dispersant dosage (0.5 – 2%) to obtain a pre-set droplet size (d_{50}). The system also provides documentation on, oil and gas particle sizes, dispersant usage and treatment effectiveness. See principle drawing of system in Figure 5. The performance was successfully verified by laboratory testing of a down-scaled system and a full-scale version in an ROV pool.

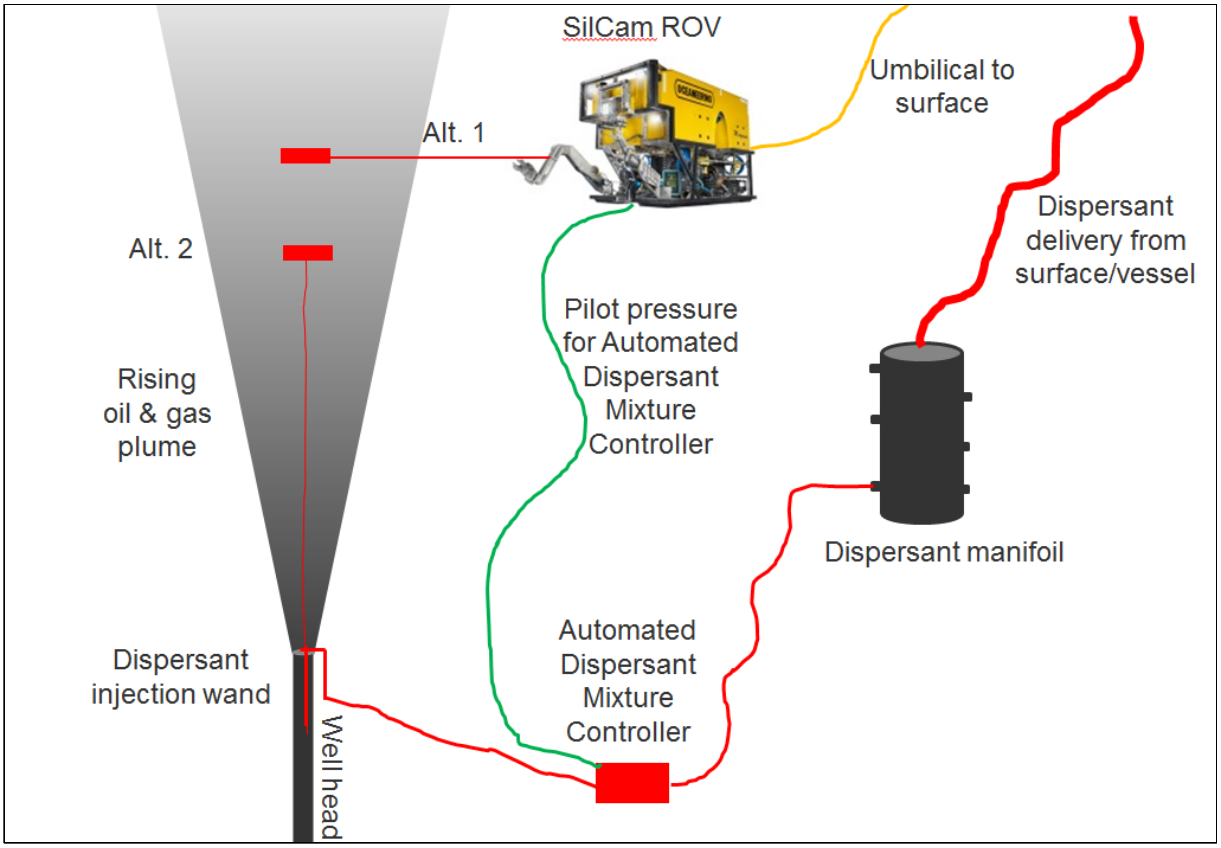

Figure 5: Principles for automated dosage control and monitoring of effectiveness. Dispersant is injected into the well, SilCam is used to monitor oil droplet sizes and regulate dispersant dosage. The SilCam can either by positioned in the oil & gas plume by an ROV (alternative 1) or more permanently positioned in the plume (alternative 2).

In the final full-scale verification, a complete prototype of the SSDI Regulation Kit was tested together with a standard Magnum ROV system. The test showed that the system is able to continuously regulate the dispersant flow injected into a blowout. The test also confirmed that the SSDI system could be operated through/by a standard ROV system, using the ROV as a communication link between the subsea components (RCU/Regulation Kit) and the top side components (SilCam/SSDI software).

7 Recommendations

- Performing a field full-scale verification test with an experimental oil & gas release.
- Updating existing Dispersant Tool Kits (response packages) with this new dispersant monitoring and regulation kit.

8 Acknowledgement

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