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TÍTULO DO TRABALHO:

Tools and Instruments for Oil Droplet Subsea Mechanical Dispersion Evaluation: An Overview

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TOOLS AND INSTRUMENTS FOR OIL DROPLET SUBSEA MECHANICAL DISPERSION EVALUTION: AN OVERVIEW

Resumo

Este artigo apresenta sistematicamente as principais ferramentas técnicas utilizadas para avaliar experimentalmente a redução do tamanho das gotículas de óleo, com o objetivo de mitigar o dano ambiental causado por derramamentos ou liberações de óleo. O principal objetivo de reduzir o tamanho das gotículas de óleo em uma liberação submarina é minimizar o impacto do óleo liberado no ambiente marinho. A principal contribuição deste artigo é oferecer uma visão geral abrangente de várias ferramentas, fornecendo um recurso consolidado para o planejamento de novos experimentos para medir a redução das gotículas de óleo e a densidade da pluma. São discutidas as vantagens e desvantagens de diferentes abordagens para medições do tamanho das gotículas de óleo e sua aplicabilidade a diversas situações. Geralmente, essas informações técnicas estão dispersas em artigos individuais para experimentos específicos, e, até onde os autores sabem, não existe uma revisão sistemática sobre este tópico. Inicialmente, a pesquisa é conduzida utilizando palavras-chave específicas em principais bancos de dados bibliográficos. Além disso, são consultados relatórios técnicos particulares, informações de fornecedores e folhas de dados. Observa-se que alguns instrumentos usados para medir a velocidade em diferentes aplicações, como sedimentos, bolhas de gás e gotículas de óleo e água, também podem medir o tamanho das gotículas ou bolhas. A característica chave desses instrumentos é a gama de tamanhos que medem. Nota-se que o mesmo instrumento pode frequentemente ser usado tanto para dispersão mecânica quanto por injeção. Esta pesquisa possibilita a seleção de ferramentas adequadas para experimentos específicos com base em fatores como custo, tamanho e velocidade. Este artigo fornece diretrizes para o desenvolvimento de experimentos de derramamento de óleo para aprimorar a medição do tamanho das gotículas de óleo em testes experimentais.

Palavras-chave: Subsea Mechanical Dispersion (SSMD), Dynamic Light Scattering (DLS), Acoustic Doppler Velocimetry (ADV), Conductivity Measurements, Laser Diffraction, Optical Microscopy, Acoustic Resonance Spectroscopy (ARS)

Abstract

This paper systematically presents the main technical tools used to experimentally evaluate the reduction of oil droplet sizes, with the aim of mitigating environmental harm caused by oil spills or releases. The primary objective of reducing oil droplet sizes from a subsea oil release is to lessen the impact of the released oil on the marine environment. The main contribution of this paper is to offer a comprehensive overview of various tools, providing a consolidated resource for designing new experiments to measure the reduction of oil droplets and plume density. It is discussed the advantages and disadvantages of different approaches to oil droplet size measurements and their applicability to various situations. Generally, this technical information is scattered across individual papers for specific experiments, and to the best of the authors' knowledge, no systematic review on this topic exists. Initially, research is conducted using specific keywords in major bibliographic databases. Additionally, particular technical reports, vendor information, and data sheets are consulted. It is observed that some instruments used for measuring velocity in different applications, such as sediments, gas bubbles, and oil and water droplets, could also measure droplet or bubble size. The key characteristic of these instruments is the range of sizes they measure. It is noted that the same instrument can often be used for both mechanical and injection dispersion. This research enables the selection of suitable tools for particular experiments based on factors such as cost, size, and velocity. This paper provides guidelines for developing oil spill experiments to enhance oil droplet size measurement in experimental tests.

Keywords: Subsea Mechanical Dispersion (SSMD), Dynamic Light Scattering (DLS), Acoustic Doppler Velocimetry (ADV), Conductivity Measurements, Laser Diffraction, Optical Microscopy, Acoustic Resonance Spectroscopy (ARS.

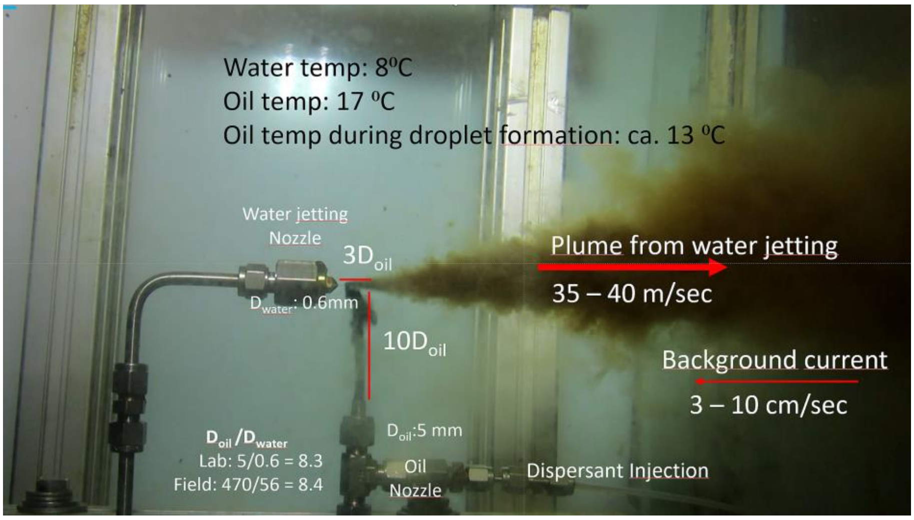

Figure 1: MBasic setup for testing in SINTEF Wave basin showing the oil release nozzle, the water jetting nozzle and the dispersant injection tube.[BLHM23]

Introduction

This research explores various experimental the techniques to measuere oil droplet sizes from subsea oil releases, aiming to mitigate environmental impacts. Some previous studies include a comprehensive review of measurement tools and their application in different scenarios, such as subsea mechanical dispersion, spray cooling for heat dissipation, and particle-laden jets relevant to disease transmission. It highlights the effectiveness of methods like water jets in reducing droplet sizes as shown in figure 1 , with potential for full-scale field testing, and compares traditional and advanced analytical techniques for droplet size measurement, emphasizing the need for precise, noninvasive methods. In this section, some cases are mentioned in order to highlight the subject importance. The experimental study on the release of diesel oil from a vertical pipe in a crossflow utilized advanced tools like Acoustic Doppler Velocimetry (ADV) and shadowgraph cameras to measure oil droplet sizes and displacement. The plume shape was photographed, and oil droplets were measured at two vertical locations on the plume's center axis. ADV data, captured at different positions, provided three-dimensional velocity measurements, which were compared to numerical predictions using large eddy simulation (LES) and a mixture multiphase model. The shadowgraph cameras revealed the droplet size distribution near the plume's upper and lower boundaries. This combined use of ADV and shadowgraph cameras enabled accurate characterization of the plume dynamics and droplet dynamics and droplet behavior as in figure 2, enhancing the understanding of the interaction between the jet and crossflow, and the formation of flow structures and vortices within the plume. Some experimental results showed diesel oil released from a vertical pipe in a crossflow [DCB+20]. Plume shape was photographed and oil droplets measured at two vertical locations, with Acoustic Doppler Velocimetry data compared to numerical predictions. Large eddy simulation and the mixture multiphase model captured oil buoyancy impacts, though the LES couldn't resolve small droplets, affecting the accuracy of plume boundary estimates and interaction dynamics. This study compared the effectiveness of subsea mechanical dispersion and subsea dispersant injection using five different oil types, measuring droplet size reduction with a Silhouette camera [BLHM23]. Results showed that both technologies had comparable effectiveness across all tested oils, with effectiveness varying based on oil properties. An in situ particle imaging system measures high concentrations of suspended particles ranging from µm to several mm in diameter [DBLN17]. It provides quasi-silhouettes and shows good agreement with spherical standards and the LISST-100. The system classifies particle types based on transmittance, applied to mixtures of oil droplets, gas bubbles, and oil-coated gas bubbles, and is used for in situ measurements in a Norwegian Fjord. Small droplets are used in thermal management systems that aims to maintaining optimal temperatures in various applications, including buildings, electronic devices, the automobile industry, and solar PV systems. Spray cooling has emerged as a promising technique for heat dissipation, offering rapid transfer rates and low energy requirements. Some researchers discusses key factors such as surface-to-nozzle distance and nozzle design [GSV+24]. The study on subsea mechanical dispersion (SSMD) demonstrates that using water jets effectively reduces oil droplet sizes from subsea releases, with effectiveness increasing from small-scale to large scale experiments [BDK+23]. Results show a reduction of droplet sizes by five-fold in small-scale tests and over ten-fold in large-scale tests. The technology is now ready for full-scale prototyping and field testing, with large-scale experiments suggesting SSMD could be as effective as subsea dispersant injection (SSDI). The experiments measured flow rate and initial droplet size across the full relevant range of superheats. The size distribution of oil droplets from subsea blowouts affects their environmental impact, with smaller droplets having slower rise rates and greater potential for biodegradation [BKL+21]. Subsea Mechanical Dispersion (SSMD) is a promising method for reducing droplet sizes without chemicals, enhancing oil spill response capabilities. A feasibility study, initiated by BP and continued by a consortium including Equinor and Total Norge, demonstrated SSMD's potential through various techniques, with recent large-scale testing focusing on subsea water jetting. Accurate modeling of subsea oil distribution from deep-sea blowouts requires reliable initial droplet size data, which is often limited to small-scale experiments. Some studies compares lab-scale and pilot-plant-scale two-phase oil-in-water jet experiments to refine droplet size predictions [PKR+20]. Findings indicate that scaling up from lab to field conditions can lead to significant deviations, but incorporating an upper limit for droplet stability into model correlations improves predictions across scales.

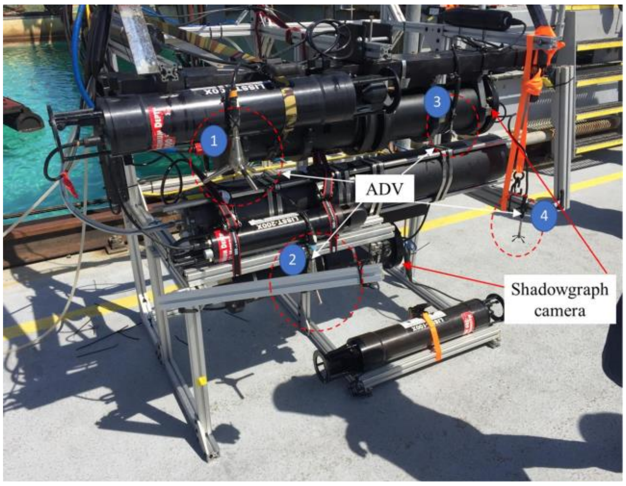

Figure 2: Metallic frame used to hold all instruments including two ADVs Vectrino Probe, Nortek Inc. and two Vectrino Vector, Nortek Inc and two shadowgraph cameras.[DCB+20]

Methodology

To systematically evaluate the reduction of oil droplet sizes and develop a comprehensive understanding of various measurement techniques, a structured research methodology was employed. The primary focus was on collecting and analyzing data from major bibliographic databases, including Google Academic (GA), ScienceDirect (SD), IEEE Xplore (IX), and PubMed (PM). Specific keywords such as ”oil droplet size reduction,” ”subsea oil spill,” ”mechanical dispersion,” ”biphasic oil droplet,” and ”Subsea Mechanical Dispersion (SSMD)” were used to identify relevant studies and technical reports. The search results yielded significant datasets: GA (1,650,000) and SD (127,803) for ”Oil Droplet Size,” GA (8,950) and SD (726) for ”SSMD,” and a combined total from various other related terms over the past 10 years.

A thorough literature review was conducted, initially gathering research articles, technical reports, and vendor information. This review included both theoretical and experimental studies to understand the state-of-the-art methods in oil droplet size measurement and the effectiveness of subsea mechanical dispersion (SSMD). Data sheets from manufacturers were also analyzed to compare the performance and specifications of different instruments used for droplet size measurement. The review highlighted the versatility of some instruments in measuring both droplet size and velocity in various applications, including sediments, gas bubbles, and oil-water droplets.

The gathered data was systematically categorized based on factors such as the range of sizes measured, the applicability of the instruments to different environmental conditions, and their cost-effectiveness. This categorization facilitated the selection of suitable tools for specific experimental setups. Furthermore, the research included experimental studies on SSMD and its comparison to other methods like subsea dispersant injection (SSDI). The performance of various spray nozzles, their spray patterns, and their impact on droplet size reduction were also investigated. This comprehensive approach enabled the development of guidelines for designing new experiments to measure oil droplet reduction and plume density effectively. The findings from these studies were used to enhance the understanding and modeling of oil droplet distribution from subsea blowouts, with implications for improving oil spill response strategies.

Results and Discussions

The research identified and analyzed various tools for measuring oil droplet sizes from subsea oil releases, highlighting the advantages and limitations of each. Tools like Acoustic Doppler Velocimetry (ADV) and Silhouette cameras demonstrated effectiveness in measuring droplet sizes and velocities. The table illustrates a comparative analysis of these tools, including their main functions, range, speed, cost, robustness, and depth capabilities. For instance, the ADV 100Hz Probe offers high temporal resolution for measuring water velocity profiles, while the SILCAM provides detailed particle size distribution using holographic imaging technology.

The study underscores the importance of selecting appropriate measurement tools based on specific experimental needs. Instruments like the LISST-200X and LISST-100X are robust and capable of operating at significant depths, making them suitable for harsh underwater environments. However, their cost and specific range capabilities vary. The research found that combining tools, such as using ADV with shadowgraph cameras, enhances the accuracy of measuring droplet sizes and understanding plume dynamics. The results indicate that both subsea mechanical dispersion and subsea dispersant injection are effective in reducing oil droplet sizes, with their effectiveness influenced by oil properties and experimental conditions.

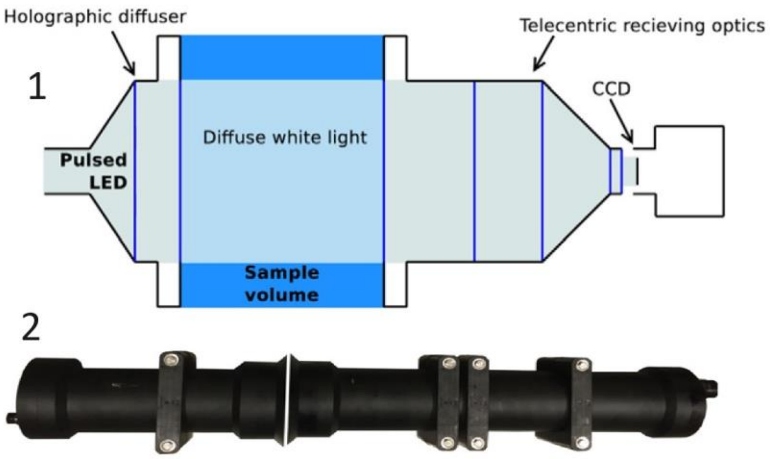

Figure 3: 1- Schematic illustration of the optical configuration of the silhouette system.2- Photograph of the system within a high-pressure housing.[DBLN17]

	ADV 100Hz PROBE	ADV200Hz PROBE	ADV 100Hz VECTOR	SILCAM LISST-DEEP	SILCAM LISST HOLO2	SILCAM LISST-100X	SILCAM LISST-200X
Main Function;	Measures three-dimensional water velocity profiles.	Measures three-dimensional water velocity with high accuracy.	Measures three-dimensional water velocity profiles and turbulence in aquatic environments.	Measures particle size distribution and concentration in water.	Measures the size and concentration of particles in water using holographic imaging technology.	Measures particle size distribution and concentration in aquatic environments	Measures particle size distribution and concentration in water;
Range;	Velocity range: ±0.01 to ±7 m/s; profiling range: 3 cm to 7 cm.	Measurement volume: 14.9 cm^3, Velocity range: ±0.01 to ±7.0 m/s	Measurement range typically up to 1 meter (**).	1.25 to 250 microns for particle size measurement.	10 - 5000 microns for particle size.	2.5 to 500 micrometers	0.5 to 500 micrometers;
Frames;	High sampling frequency up to 100 Hz (100 samples per second).	High sampling rate with 200 Hz frequency	Continuous data collection; specific frame rate depends on deployment configuration.	Continuous data collection (specific frame rate not typically specified).	Captures images in 3D holograms for detailed particle analysis.	Not applicable (provides continuous data rather than frames)	Not applicable;
Speed;	Capable of measuring rapid changes in water velocity with high temporal resolution.	Capable of measuring velocities up to 200 samples per second	Data sampling rate of up to 100 Hz.	Data sampling rate up to several Hz (varies with configuration).	Can process particle sizes and concentrations in real-time with high efficiency.	Real-time data acquisition (typically records at 1 Hz)	Sample rate: 1 Hz;
Cost;	Approximately $10,000 - $20,000 (*)	Approximately $20,000 - $30,000 (*)	Approximately $20,000 - $30,000 (*)	Approximately $100,000 - $150,000 (*)	Approximately $70,000 - $100,000 USD (*)	Approximately $60,000 - $100,000 (*)	Approximately $50,000 to $60,000 USD (*)
Robustness;	Designed for field and laboratory use; robust and durable for various aquatic environments.	Designed for both laboratory and field use; robust and durable	Designed for various aquatic environments; high durability and reliability.	Designed for harsh underwater environments; high durability and reliability.	Designed for harsh marine environments, with durable and corrosion-resistant materials.	Highly robust and designed for harsh underwater environments	Designed for harsh environments, highly durable, submersible up to 600 meters;
Depth;	Can be deployed up to 100 meters depth (***).	Capable of operating at depths up to 100 meters (328 feet)	Capable of operating at depths up to 300 meters (984 feet).	Capable of operating at depths up to 3,000 meters (9,843 feet).	Rated for submersion up to 600 meters.	Rated for use at depths up to 300 meters	Rated for depths up to 600 meters;

* (depending varies with options and accessories). **(dependent on water conditions and configuration). ***(depending on the specific model and configuration).

Table 1: 1- Schematic illustration of the optical configuration of the silhouette system.2- Photograph of the system within a high-pressure hou able 1

Conclusion

In conclusion, this study emphasizes the importance of selecting and developing appropriate equipment to simulate a jet for cutting small bubbles using subsea mechanical dispersion (SSMD). The goal of SSMD is to reduce the size of oil droplets from subsea releases, significantly influencing the fate and behavior of the oil in the marine environment. Various measurement tools, including optical microscopy, high-speed imaging, conductivity measurements, acoustic methods, ultrasonic sensors, laser diffraction, dynamic light scattering, and SILCAM, were evaluated for their effectiveness in analyzing droplet size, distribution, and dynamics. The findings suggest that a diverse range of measurement equipment is essential for accurate mathematical modeling, enabling better predictions of droplet behavior under varying conditions. However, it is necessary to limit the research scope based on available resources and expected outcomes, as different tools offer unique advantages and limitations. The study concludes that by considering factors such as pressure, oil flow rate, and temperature, a more comprehensive understanding of SSMD processes can be achieved, ultimately leading to more effective strategies for managing subsea oil releases. n conclusion, this study emphasizes the importance of selecting and developing appropriate equipment to simulate[DCB+20] a jet for cutting small bubbles using subsea mechanical dispersion (SSMD). The goal of SSMD is to reduce the size of oil droplets from subsea releases, significantly influencing the fate and behavior of the oil in the marine environment. Various measurement tools, including optical microscopy, high-speed imaging, conductivity measurements, acoustic methods, ultrasonic sensors, laser diffraction, dynamic light scattering, and SILCAM, were evaluated for their effectiveness in analyzing droplet size, distribution, and dynamics. The findings suggest that a diverse range of measurement equipment is essential for accurate mathematical modeling[BSDL19], enabling better predictions of droplet behavior under varying conditions. However, it is necessary to limit the research scope based on available resources and expected outcomes, as different tools offer unique advantages and limitations. The study concludes that by considering factors such as pressure, oil flow rate, and temperature, a more comprehensive understanding of SSMD processes can be achieved, ultimately leading to more effective strategies for managing subsea oil releases.

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