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Study of the oil interaction towards oil spill recovery skimmer material: Effect of the oil weathering and emulsification properties

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ABSTRACT

The primary aim of this research was to identify the physicochemical properties of the oil and water-in-oil (W/O) emulsions used during a NOFO Oil-on-Water field trials that reduced the performance of the skimmers recovery efficacy during the trials. Extensive studies were performed at SINTEF laboratories with the residues of oil topped (i.e. evaporative loss of crude oil components by distillation process at large scale) for the field trial and compared it with different residues of oil topped by bench scale laboratory procedures. In order to obtain a sufficient stable W/O emulsion for the field trial, bunker fuel oil (IFO380) and various concentrations of an emulsifier (Paramul®) were also added to the residues of oil topped on large scale and investigated through interfacial tension, contact angle, droplet adhesion and "dip and withdraw" tests. The investigations revealed that the addition of an emulsifier lowered the interfacial tension of oil residues, which consequently reduced the adherence properties of the oil and emulsions to the surface of the skimmer material. Too high concentration of an emulsifier (> 0,5%) also had a negative effect on the stability of W/O emulsion.

1. Introduction

The goal of any response strategy during oil spill accidents is to select the effective and efficient countermeasures that minimize the overall impact of the oil spill on the environment. Net Environmental Benefit Analysis (NEBA) that was renamed as Spill Impact Mitigation Assessment (SIMA) is a structured approach that formalizes the evaluation and comparison of the expected response effectiveness versus the potential environmental impacts of the oil spill, as well as impacts from response options (IPIECA-IOGP-API, 2017; Taylor and Cramer, 2017, Taylor et al., 2018; Camus and Smit, 2018). The output from the NEBA/SIMA process is the selection of response technique(s) that promote the most rapid recovery and restoration of the affected area, and consequently limit the overall impacts of a potential spill on the environment (IPIECA-IOGP-API, 2017). Mechanical recovery techniques (boom and skimmers) along with oil spill dispersants and in-situ burning are the main strategies that need to be assessed through a NEBA/SIMA process. Previous operational experiences for assessing the effectiveness of the use of multiple response techniques deployed during different oil spill situations (e.g. type of oil, release and environmental conditions) is an important part of such NEBA/SIMA process (IPIECA-IOGP-API, 2017).

The efficacy and window of opportunity of mechanical oil spill cleanup operations in the marine environment will vary depending on many parameters such as: the selection of skimming principle, environmental conditions, response time, platforms, the boom confinement capacity, oil thickness in the boom, type and weathering degree of the oil. The effectiveness for use of different skimmers, related to the changes in oil properties is highly dependent on the interfacial tension between oil and water, oil stickiness/adhesiveness, rate of evaporation, photo-oxidation, W/O emulsification, water content and stability of emulsion, the subsequent increase in the viscosity, and their effect on the various skimming principles (Ornitz and Champ, 2002; Fingas, 2011). Depending on the physical mechanisms employed, skimmers can be categorized into the five main types: sorbent surface, weir, suction, elevating, and submersion. Comparatively, the skimmers using an oleophilic sorbent surface in the form of discs, drums, belts, brushes, or ropes are most suitable for rougher water that is characteristics of the open sea and coastlines (Fingas, 2011).

Sorbent (oleophilic) skimmers are one of the most common types of mechanical recovery techniques. Recovery is based on the adhesion of the oil to a rotating oleophilic skimmer surface. The rotating surface lifts the oil out of the water to an oil removal device (e.g. scraper, roller, etc.) (Fingas, 2011; Keller et al., 2007; Broje and Keller, 2006). The adhesion surface is the most critical element of the skimmer since it will have large influence on the effectiveness of the oil recovery. The

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materials used to manufacture the surface of adhesion skimmers are normally steel, aluminium and plastics. In general, material selection has not been based on the surface adhesive properties, but rather on historical practice, price and availability. Limited efforts are attempted to systematically study the surface properties of the skimmer materials and utilize this knowledge for improving the oil spill recovery processes (Broje and Keller, 2005; Jokuty et al., 1996; Keller et al., 2007; Liukkonen et al., 1995; Sassi et al., 2017).

It is important to understand the oil chemistry as well as the physical processes associated with oil adhesion to the recovery surface. The adhesion between spilled oil and the recovery surface depends on the oil composition and its properties at the time of recovery; these characteristics change over time as the oils and emulsions weathered at sea. It was confirmed that certain oil properties, especially its viscosity, significantly influence on the oil adhesion to skimmer surface and recovery efficiency (Sassi et al., 2017; Broje and Keller, 2007a; Daling et al., 2003; Moldestad et al., 2006).

Over the past decades, intensive research on wettability and adhesion processes between solids and liquids has been conducted in the fields of petroleum reservoirs (Buckley, 1997; Buckley et al., 1998; Drummond and Israelachvili, 2002; Jarrahian et al., 2012; Kathel and Mohanty, 2013) and polymer sciences (Jamadagni et al., 2009; Kobayashi et al., 2012; Mittal, 2009). Although polymeric materials have been tested for their affinity to various chemicals, their affinity to weathered oil and W/O emulsions has barely been studied. Jokuty et al. (1996, 1995) and Liukkonen et al. (1995) employed “dip-and-withdraw” technique to determine the adhesion between oil and test materials. Adhesion was determined as the weight of oil remaining after withdrawal, per unit area of a test surface.

Contact angles of liquids on solid surfaces are widely used to predict wetting and adhesion properties of materials (Zhang et al., 2016; Dunderdale et al., 2015; Mittal, 2009). The research conducted at the University of California, Santa Barbara, showed that modern Dynamic Contact Angle Analyzer can be used for selection of materials that can be most efficiently employed during the oil spill cleanup operations (Broje and Keller, 2007b, 2005). The study found that the contact angle formed between oil and test surface can be used to characterize the affinity of material to oil. It was recommended that to find the relationship between the oil properties and recovery materials, contact angle measurements can be performed along with “dip and withdraw” tests (Broje and Keller, 2007b).

According to Norwegian regulations, the capabilities and functionalities of oil spill counter measuring methods should be documented through realistic field test conditions. Since 1978, Norwegian Clean Seas Association for Operating Companies (NOFO) has performed full scale, Oil-on-Water field trials, almost on a yearly basis. In 2013, NOFO performed field trials in the North Sea where one of the main objectives was to verify newly developed oil spill response equipment under realistic conditions and documented its recovery capacity. For representing a crude oil weathered at sea for minimum 0.5–2 days under the breaking wave conditions with a viscosity of 2500–3000 cP, the W/O emulsion was prepared from the crude oil topped to 190 °C+ residue (i.e. evaporative loss of light hydrocarbon components of crude oil by distillation process below 190 °C) at large scale vacuum distillation facility. To increase the viscosity and stability of the W/O emulsion, NOFO decided to add (spiked) 5 wt% of bunker fuel oil (IFO380) and 0.37 wt% of the commercially available emulsifier (Paramul®) to the crude oil residue before preparing the W/O emulsion where 65 wt% of seawater was mixed into the oil residues using centrifugal pumps. During the field trials, it was found that the skimmer was not adequately effective and the W/O emulsion was not properly trapped and recovered by the discs of the skimmer (NOFO, 2013).

After the field trials, SINTEF was contacted by the NOFO for testing the effectiveness and physicochemical properties of W/O emulsion that was used during the full-scale field trials. At SINTEF, there has been continuous R&D activities on oil spill weathering and behavior of oils and W/O emulsions at sea since the Ekofisk Bravo accident in the North Sea, Norway, in 1977 (Daling et al., 1990, 2003, 2014, Daling and Strøm, 1999). The purpose within this study was to identify the properties of the tested oil and W/O emulsion used during the 2013 field trial and to determine if the results could clarify the reduced performance of the skimmers. Systematic laboratory studies with the residues of the oil topped at large scale (for the field trial) were performed and compared with different residues of the oil topped on smaller scale at the SINTEF laboratory. To mimic the oil residue used for preparing the W/O emulsion during the NOFO field trials, the residue from the large-scale topping of the oil (for the field trial) was tested with addition of bunker fuel oil (IFO380) and various concentrations of the emulsifier Paramul®. A disc from the skimmer (High Density Polyethylene, HDPE) used during the field trial was cut into different sizes and tested to study the adhesion properties of different oil residues and their emulsions.

2. Experimental

2.1. Evaporation of crude oil

For preparing the different oil residues, crude oil was evaporated (topped) by following two different approaches and scales.

2.1.1. Evaporation of crude oil at small laboratory scale

Crude oil was evaporated at small scale in the SINTEF laboratory by following a procedure described by Stiver and Mackay (1984). Evaporation of the lighter compounds from the fresh crude oil was carried out in a simple one-step distillation to vapour temperatures of 190 °C+ and 225 °C+, which resulted in remaining topped residues with an evaporation loss (depending on environmental conditions) corresponding to approximately 1–3 h to < 1 day of oil weathering on the sea surface, respectively. These residues are referred to as Oseberg oil small scale weathering (OB-SSW) 190 °C+ and OB-SSW 225 °C+ throughout the paper. It is important to mention that the described method have been accepted at several oil spills research laboratories to generate artificial residues that simulate evaporative loss of spilled oils at sea (Daling et al., 2014).

2.1.2. Evaporation of crude oil at large scale

For preparation of the artificial weathered oil used in the NOFO field trials 2013, crude oil was evaporated on large scale by the vacuum distillation facilities at Indus AS, Arnatveit, Norway. This was done by vacuum distillation in a closed system, and the oil was evaporated equivalent to 190 °C+ steam temperature. The 190 °C+ weathered residue of crude oil that was evaporated based on the vacuum distillation large scale method, is referred as OB-LSW 190 °C+ in this paper. This was the same topped oil residue which was provided to NOFO for preparing the W/O emulsion used during the Oil-on-Water field trials in 2013.

2.2. Addition of bunker fuel oil and emulsifier

For obtaining a stable W/O emulsion to be used during the field trial in 2013, NOFO had added (spiked) 5 wt% bunker fuel oil (IFO380) and the emulsifier Paramul® to the weathered crude oil residue (OB-LSW 190 °C) received from the large-scale facilities at Indus AS. To study the potential effect of this addition, in the SINTEF laboratory different samples of the OB-LSW 190 °C+ residue was prepared with successive addition of IFO380 and the emulsifier Paramul®.

A sample of the large scale 190 °C+ weathered residue of crude oil (LSW-190 °C+) that was received by SINTEF for testing, added with 5 wt% IFO380. This spiked oil sample was further mixed with 0.37 wt% and 0.75 wt% of an emulsifier Paramul®. The addition was done by heating the topped oil sample and IFO380, and afterwards mixed the oils in specified proportion. After mixing, the blended oil was further