

# Chapter 10

## Effects of Oil Properties and Slick Thickness on Dispersant Field Effectiveness and Oil Fate



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**Abstract** One of the available oil spill response options is to enhance the natural dispersion process by the addition of dispersants known as chemical dispersion. An informed decision for such response requires insight about the added effects of treatment with dispersants on the oil slick fate. To provide such insight, a mathematical model for oil slick elongation as a result of dispersion was developed including the effects of oil viscosity, dispersed oil droplet sizes, and oil layer thickness. This chapter briefly revisits this oil slick elongation model to explain the consequences of different key parameters on dispersion, vertical droplet size distribution, formation of a comet-like tail and oil slick (dis)appearance, as well as the implications of the results for future decision-making. The model outcomes indicate that wind speed is a very dominant factor in dispersion and subsequent slick behavior. More surprising, the influence of oil type on the elongation process is only limited. The increased density of the high-viscosity oil types allows larger droplets to be stably suspended. High-viscosity oil, however, was found to benefit less from a decrease in interfacial tension than a low-viscosity oil. Weighing estimated risks for adverse effects in the water column with a reduced surface oil presence allows for future dispersant decisions based on a thorough Spill Impact Mitigation Analysis (SIMA).

**Keywords** Dispersion · Dispersant · Spill modelling · Wind speed · Oil type

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## 10.1 Introduction

The decision to apply chemical dispersants on surface oil is a trade-off between surface effects (impact of floating and stranded oil) and subsurface effects (direct impact of suspended oil and potential for sedimentation and sinking). Making an informed decision regarding such response requires insight into the induced changes in fate and adverse effects of the oil.

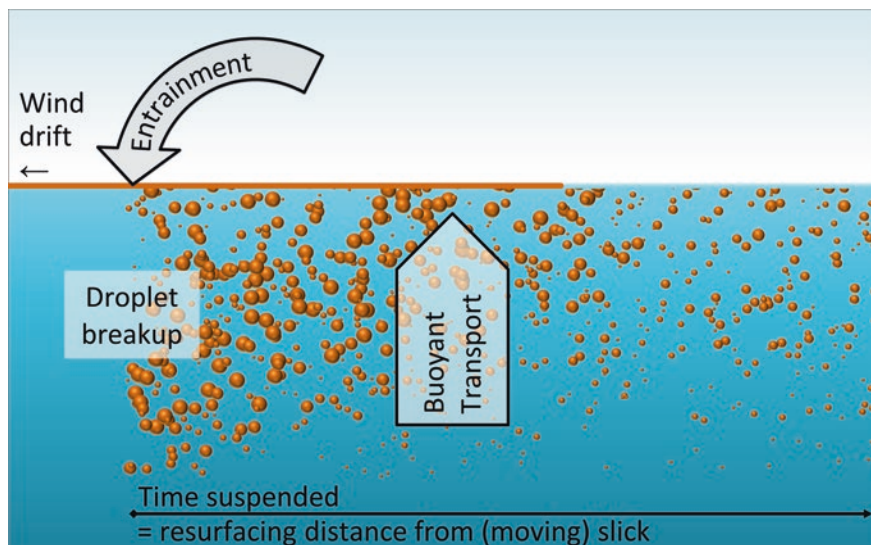
Natural dispersion calculations in the currently available oil fate and transport models are based on the empirical results of Delvigne and Sweeney, although it is generally agreed these can be improved (Delvigne and Sweeney 1988; Reed et al. 1999; National Research Council of the National Academies 2005). Furthermore, these calculations do not permit prediction of chemical dispersion. The calculation of chemical dispersion in the current oil fate and transport models requires knowledge of the estimated effectiveness of dispersant application rather than providing output thereof (National Research Council of the National Academies 2005). Estimating dispersant effectiveness in advance of commencing such oil spill response relies heavily on expert judgment.

A small group of researchers under the C-IMAGE project (as part of the Gulf of Mexico Research Initiative) set out to create insight into the processes governing natural and chemical dispersion of spilled surface oil and to provide a strategy to assess and predict the added value of chemical dispersion for specific spill conditions and oil qualities. The tiered experimental design allowed for structured analysis of available laboratory results and the identification of unknown parameters (Zeinstra-Helfrich et al. 2015b). Additionally, the process of entrainment, or initial submergence of the oil, can be examined more thoroughly in a laboratory environment to quantitatively capture the influence of layer thickness and oil properties on vertical oil droplet size distribution (Zeinstra-Helfrich et al. 2015a, 2016). Ultimately, a model was proposed that calculates the evolution of the surface oil slick as a result of the dispersion process (Zeinstra-Helfrich et al. 2017).

This chapter examines the oil slick elongation model (Sect. 10.2) in order to explain the influence of different key parameters on dispersion and oil slick (dis)appearance (Sect. 10.3) and the implications of the results for future decision-making (Sect. 10.4).

## 10.2 How Natural or Chemical Dispersion Affects Oil Slick Fate

Dispersion is not a singular event but rather a combination of several processes (Fig. 10.1). Breaking waves temporarily submerge oil through entrainment. The entrained oil is broken up into droplets, and their size distribution in the water column is dependent on mixing energy, oil properties, and slick thickness. As most oil is still lighter than water, the droplets rise back to the surface at a rate dependent on



**Fig. 10.1** Visualization of the mixing processes. Under a breaking wave, oil is entrained, broken into droplets of various sizes, and distributed over a certain depth. While the oil droplets are suspended, the slick is pushed along by the wind. Droplets resurface upwind from their original location in the moving slick, of which the distance depends on the time in suspension. As a droplet's rise velocity is determined by its diameter, the residence time in the water column is determined by its mixing depth and droplet diameter. (Reprinted from Zeinstra-Helfrich et al. (2015b), Copyright (2015), with permission from Elsevier)

their size and the oil's density. Some of these droplets reach the water surface relatively quickly, while others are remixed by subsequent breaking wave events. As the floating oil moves downwind at a faster rate than the suspended droplets, some of the oil resurfaces upwind of the slick, elongating and diluting the slick.

The oil dispersion model (Zeinstra-Helfrich et al. 2017) uses a number of relatively simple input parameters (wind speed, oil viscosity, oil density, oil-water interfacial tension, and initial slick thickness and length) to calculate the entrainment and subsequent resurfacing of oil over a predefined period of time, yielding the slick length, displacement, and mass distribution between slick and water column and across the slick length.

The modelling outcomes reveal that the mechanism by which the oil slick disappears from the water surface ultimately determines the nature of the oil slick over time. In ideal dispersion conditions, identified by very high wind speed paired with low-viscosity oil and dispersants, the disappearing of the oil slick is a vertical process. The abundance of breaking waves provides ample "entrainment events," where a substantial amount of oil is temporarily transferred to the water column. High mixing energy combined with oil properties that enable easy breakup results in a large portion of the entrained oil, now in small droplets, to remain suspended in the water column for a long period of time before resurfacing. As a result, a substantial fraction of the oil is quickly moved to the water column. The resulting thin-

ner slick will disperse more efficiently, and the mass balance increasingly shifts to the water column. Visible on the water surface is an oil slick that contains only a fraction of the oil, with the thickest part being central in the slick. This slick movement relative to the wind is less than expected, as most of the mass is underwater and not affected by wind.

In less than ideal dispersion conditions, characterized by low wind speed and high oil viscosity, the initial slick remains largely intact with a long comet-like tail forming upwind. The tail continues to increase in length, while the thickness of the downwind “main” slick gradually decreases. While thickness decreases, dispersion efficiency slowly increases as relatively more small droplets are formed, and the mass balance shifts slowly toward the water column. If the thickness decreases sufficiently, the oil slick behavior begins to transition toward that described above with most of the oil mass in the water column and not affected by the wind.

These findings are consistent with in situ observations, where long slicks with a thick portion downwind are found in conditions with low wind speeds and/or viscous oils and more favorable conditions create smaller slicks with the thickest portion in the center (Reed et al. 1994).

### 10.3 Influence of Individual Key Parameters on Dispersion and Oil Slick Elongation

With model application, we can investigate the theoretical influence of different parameters on the dispersion process and the development of the oil slick over time with its eventual disappearance from the water surface.

The volume fraction of oil that is broken up into droplets that are sufficiently small to be stably suspended can be calculated from oil properties, wind speed, and initial oil layer thickness (Zeinstra-Helfrich et al. 2017). This variable, named dispersibility factor, represents the combined result of the different dispersion processes and provides a good indicator of dispersion success. In this chapter, the term dispersibility refers to the favorability of conditions for creating small stable droplets without considering oil slick behavior over time.

When discussing oil slick behavior, the most relevant aspects are thickness profile, slick length, and the lifetime of the oil slick. This surface expression of a spill can be summarized with the “time-integrated length of oil slick exceeding the effects threshold of 25  $\mu\text{m}$ ” (Zeinstra-Helfrich et al. 2017). With equal oil slick dimensions, this parameter correlates well with dispersibility factor: A highly dispersible slick will disappear quickly and have a low surface expression value. In case of low dispersibility, a slick is present on the surface for a long period of time and increases in size before disappearing, resulting in a high value for surface expression.

In the following paragraphs, the influence of the different key parameters on the oil dispersibility as well as oil slick behavior is discussed in more detail.

### 10.3.1 Main Oil Properties

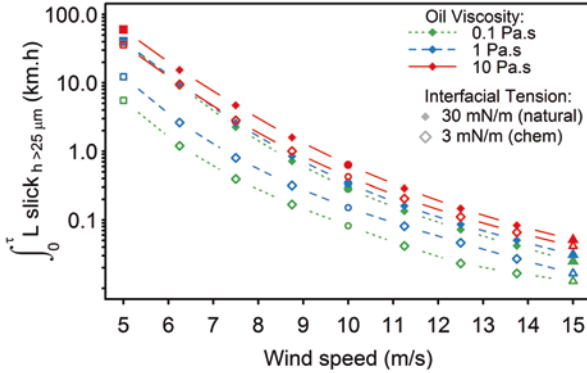
The viscosity of the oil is considered one of the most important parameters in the dispersion process. As viscosity is a counteracting force to droplet breakup (Walstra 2005), high-viscosity oil results in larger oil droplets. The influence of viscosity as a factor in oil droplet breakup is commonly reported in small- and large-scale dispersion tests (Zeinstra-Helfrich et al. 2015b) as oil droplet sizes increase with oil viscosity.

Following Stokes' law, the oil density is known to increase oil droplet rise speed (Robbins et al. 1995) and bias dispersibility tests that incorporate a settling step as a consequence (SL Ross Environmental Research LTD and MAR Incorporated 2011). However, in current oil spill modelling, often a fixed droplet size is assumed and considered to be stably suspended, regardless of environmental conditions or oil density (Reed et al. 1999).

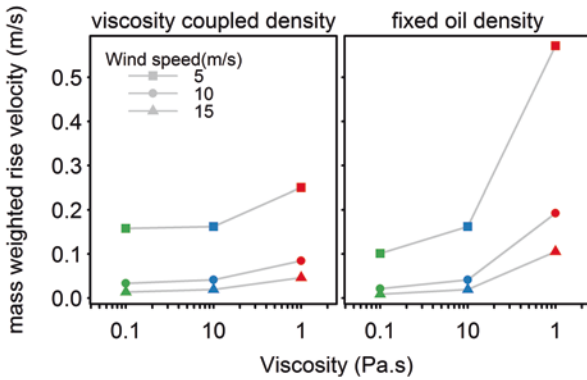
In laboratory experiments, oil type did not significantly influence the volume of oil entrained, with the exception of high-viscosity oil (above 5 Pa.s), of which 60–80% less was entrained than expected based on oil layer thickness (Zeinstra-Helfrich et al. 2016). Images of the entrainment process during plunge impact provided evidence demonstrating that the high-viscosity oil layer may prevent droplets from being sheared off.

A similar entrainment limitation in a plunging jet test was observed by other researchers (Reed et al. 2009). Reed et al. (2009) reported a twice as high maximum viscosity but also used a two times greater plunge height. An increasing maximum viscosity with plunge/wave height is logical as the impact from larger wave heights is expected to be more successful in separating oil from the floating layer. More elaborate experiments could provide experimental data to further calculate the entrainment thresholds for larger wave heights.

Although oil properties clearly influence the process of droplet breakup and thus droplet size, dispersion model calculations reveal that oil type hardly affects the overall dispersibility and the oil slick behavior outputs of the model (Fig. 10.2), partly because weather conditions are a more dominant factor in the model outcome and partly because of the correlation between oil viscosity and density resulting in opposite effects. Although high-viscosity oil results in a larger mean droplet size, these high-density droplets rise slower to the water surface than equally sized low-viscosity (and low-density) oil droplets. The mean droplet rise velocity of the full droplet size distribution for different oil types therefore only shows little variation (Fig. 10.3, left panel). In the unrealistic scenario with equal densities for the chosen three oil types (Fig. 10.3, right panel), mean rise velocity would be much more affected by oil type. Evidently, the density-viscosity correlation strongly reduces the influence of viscosity on the mean droplet rise velocity. This means that, when modelling dispersion, both viscosity and density should be separate inputs, as a disproportion between these qualities can seriously affect the dispersibility.



**Fig. 10.2** “Time-integrated length (km.h) of the slick part with a thickness  $>25 \mu\text{m}$ ”, as a function of oil viscosity, interfacial tension, and wind speed (Note the logarithmic Y axis.). Model calculations using method and inputs as described in Zeinstra-Helfrich et al. (2017) for a larger number of wind speed settings. Initial oil slick length was 250 m and thickness 1 mm



**Fig. 10.3** Calculated mean droplet rise velocity for droplet size distributions formed from of different oil types (colors) and under different wind speeds (symbols). In the model inputs, the oil density either matched viscosity (left) or was kept equal for the three oil types (right). Droplet size distributions are calculated using a Weber and Reynolds relation (Zeinstra-Helfrich et al. 2017), assuming an oil layer thickness of 0.5 mm and no dispersant

Summarizing, viscosity above a wave height-dependent threshold impedes oil entrainment and will limit the dispersion and elongation of the slick. Below this viscosity threshold, oil droplet size is positively related with viscosity, yet the resulting effect on droplet suspension time is limited due to the compensating influence of higher density on droplet rising velocity.

### 10.3.2 Oil Layer Thickness

In operational guidelines for chemical dispersion of oil, oil layer thickness is not considered very relevant for oil fate modelling. It mainly is seen as a parameter relevant for dispersant dosages: spraying dispersants on a slick that's too thin would cause the dispersant to fall through and be lost to the water column (Tamis et al. 2012). Spraying the thicker areas of the slick is advised; however, for too high thicknesses, multiple spray passes are advised to reach the effective dosage (EMSA 2009).

Using a plunging jet setup (Zeinstra-Helfrich et al. 2015a, 2016), the importance of the oil layer thickness in both entrainment and droplet breakup was revealed: The volume of oil entrained increases proportionally with layer thickness. The availability of oil per unit surface area (oil layer thickness) clearly determines the volume entrained per "mixing event." With increasing oil layer thickness, the mean oil droplet size increases, but due to the enhanced entrainment volume, the absolute amount of oil in small droplets also increases. Still, thin layers have a higher dispersibility than thick layers due to the larger *relative* portion of small droplets produced by an impact. This influence of layer thickness on dispersibility also is crucial for the modelled behavior of the slick over time. With the same oil mass, a longer, thin slick is dispersed faster than a short thicker slick (Zeinstra-Helfrich et al. 2017). Such rapid removal of the thin slick areas, while thicker parts remain, has also been observed in situ (Lewis et al. 1998).

These observations confirm that aiming any response at the thick slick portions (National Research Council of the National Academies 2005) is most effective as the thin slick part will naturally disperse more easily. Additionally, for mechanical recovery, removal rates are higher in thick oil.

Based on these outcomes, one can hypothesize that mechanical dispersion on thicker portions of the slick to enhance spreading could be effective as the resulting thinner slick will subsequently disperse more easily.

### 10.3.3 Initial Slick Size

The model study (Zeinstra-Helfrich et al. 2017) only briefly examined the influence of initial slick length on the dispersion process. It is, however, possible to make some prognoses based on the different elongation mechanisms.

For favorable conditions (dispersibility factor  $>0.4$ ), the initial slick length will not have a large influence on the dispersion process: In these situations, the oil mass will be rapidly entrained into the water phase. For a larger slick oil will simply move to the water phase over the larger area.

For less favorable conditions, initial slick length is expected to influence the outcome. The absolute elongation is minimally affected by initial slick length: A

longer initial slick means that resurfacing oil from the downwind edge “feeds” the main slick instead of the tail. The oil resurfacing back into the main slick slows down the decrease in thickness that is necessary to transition into the more efficient vertical dispersion regime. In this case, dispersant application could assist by enhancing dispersibility and transitioning into the vertical regime more quickly.

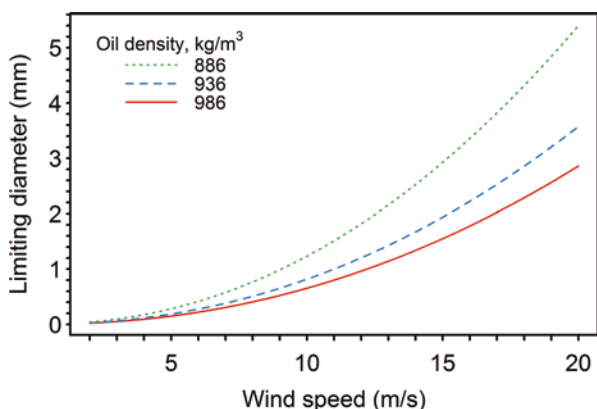
### 10.3.4 Wind Speed

Wind speed is considered an important variable in the dispersion process, as it indirectly provides the energy for the dispersion to occur.

In the dispersion model studies (Zeinstra-Helfrich et al. 2017), indeed, wind speed is a very dominant factor in the outcome. This input parameter plays a role in several process parameters. Firstly, the amount of entrainment and energy levels indeed depend on wind speed:

- The area fraction agitated increases  $A_{\text{mix}} \sim U_{\text{wind}}^{2.26}$ , resulting in a proportional increase of volume of oil entrained.
- The plunge height increases  $H_{\text{plunge}} \sim U_{\text{wind}}^2$ , causing smaller oil droplets to be formed.

As the mixing depth increases,  $z_1 \sim U_{\text{wind}}^2$ , and the time between breaking waves decreases,  $T_{\text{bw}} \sim U_{\text{wind}}^{-2.26}$ , as a consequence, much larger droplets can remain suspended until the next breaking wave hits (Fig. 10.4). Thus, in contrast to commonly assumed in current models (Reed et al. 1999), the droplet size that is stably suspended is wind speed dependent: in more energetic conditions, larger droplets can successfully remain suspended.



**Fig. 10.4** Limiting diameter, largest droplet diameter that can remain suspended until the next breaking wave hits, as a function of wind speed. Calculated based on the equations given in Zeinstra-Helfrich et al. (2017)



In addition, at a higher wind speed, the slick moves faster causing more of the suspended droplets to resurface in the tail instead of in the main slick area, thus increasing the relatively thin slick area with more effective natural dispersion.

### 10.3.5 Dispersants

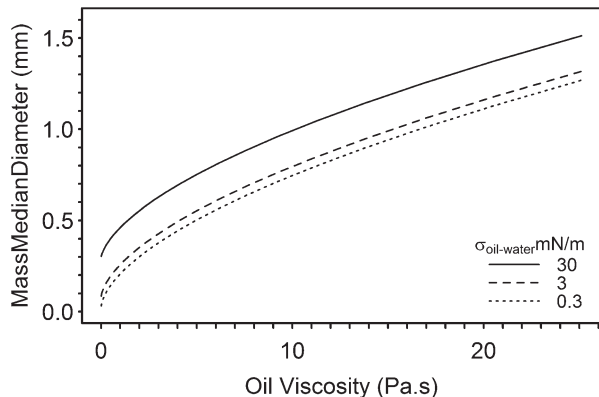
It is self-evident that addition of dispersants enhances the dispersion process. The main mode of dispersant action is to reduce the oil-water interfacial tension, thereby allowing smaller droplets to be formed.

In the slick elongation model, dispersant application is simulated by a decrease of the input value for oil-water interfacial tension. This parameter affects the droplet breakup process by decreasing the resulting droplet sizes but has no impact on the other steps in the dispersion and elongation process.

The droplet sizes of the entrained oil are calculated with a Weber and Reynolds number relation fitted to the experimental results (Zeinstra-Helfrich et al. 2017). Using this calculation, the absolute decrease of mass median droplet size with decreasing interfacial tension hardly depends on oil viscosity (Fig. 10.5). As the relative dispersant-induced decrease in droplet size is much smaller for high-viscosity oils, the increase of dispersibility is lower for these oil types.

Apart from affecting droplet size, dispersants can influence entrainment in specific situations: In the absence of breaking waves, oil with dispersant dosages of 1:20 or more was entrained with unintentional and less energetic vertical input (SL Ross Environmental Research LTD et al. 2006). This is because such dispersant dosages can cause the oil-water interfacial tension to drop down to values close to  $10^{-6}$  N/m (Khelifa and So 2009), at which minimal energy is needed to commence droplet formation (Walstra 1993). This potential extra entrainment is currently not accounted for in the oil slick elongation model, as it is unlikely that it will significantly influence oil slick behavior in at-sea conditions. For such highly dispersible oil, even at 5 m/s winds, the weak and infrequent breaking wave impact already

**Fig. 10.5** Mass median oil droplet diameter as a function of oil viscosity, calculated using the Weber and Reynolds number relation (Zeinstra-Helfrich et al. 2017). Input data used: wind speed of 10 m/s and oil layer thickness of 0.4 mm



causes such a stable dispersion (when  $\mu_{oil} = 0.1 \text{ Pas}$  and  $\sigma_{oil} = 10^{-6} \text{ N/m}$ , dispersibility factor: 0.63) that additional entrainment only minimally impacts mass balance. Although breaking waves decline even further at lower wind speeds, so does the presence of other sea surface features that could cause additional entrainment, for instance, Langmuir circulation (Moum and Smyth 1994).

The oil slick elongation model requires input of the oil-water interfacial tension with or without dispersant application. The oil-water interfacial tension after dispersant application depends on success of dispersant application (logistics, targeting, incorporation into the slick, dispersant effect on oil properties). Currently no exact data on the effective dispersant dosage in the field and resulting oil-water interfacial tension are readily available, partly as it depends on so many factors (falling of the dispersant droplet, oil slick skin formation and the composition of the oil and the dispersant) and partly as interfacial tension measurements in the lab are highly influenced by the test settings and are not in agreement with each other. Therefore, expert judgment is still required to parametrize this effect.

More information on the chemical effectiveness of dispersants could be obtained via small-scale laboratory tests such as the baffled flask dispersibility test. These easy and repeatable tests provide a measure of the susceptibility to breakup of the dispersant-oil combination; therefore the test results provide an indication of the change in dispersibility after addition of dispersants. The effect of dispersants can be determined from the change in results between treated and untreated oil.

## 10.4 Decision-Making About Application of Chemical Dispersion

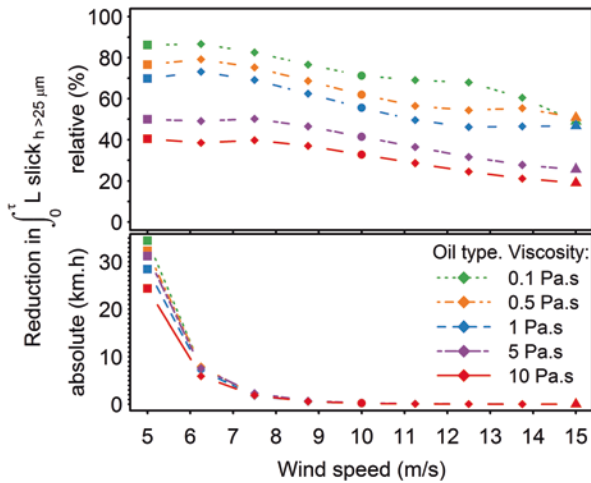
For selecting an oil spill response strategy, either in preparation or in active spill situation, the implications of available response options are considered. An explicit and structured approach to analyzing the trade-offs between strategies was formerly referred to as NEBA (net environmental benefit analysis) and recently renamed SIMA (spill impact mitigation assessment) (IPIECA 2017). Because the implications of dispersant application span multiple environmental compartments, SIMA can be a particularly useful tool for this response technique.

Assessment of the extent to which application of dispersants aids mitigation of the impacts considers three factors: (1) the logistical feasibility, (2) the effectiveness, and (3) the effects or environmental benefit. The logistical feasibility of chemical dispersion is a practical consideration based on dispersant and equipment stocks and the travel time to reach the slick location and will not be discussed in this chapter. The following paragraphs summarize how to assess the effectiveness of chemical dispersion as well as the potential environmental benefit.

### 10.4.1 Effectiveness

When applying dispersants on a surface oil slick with the goal of mitigating the effects of the floating oil, the term “effectiveness” should express that aspect. Assuming a minimal oil layer thickness above which impacts occur (in this case 25 μm), potential for oil slick impact can be inferred from the size of the oil slick above this threshold and its lifetime. The parameter “time-integrated length of slick exceeding the effects threshold of 25 μm” was devised for this purpose. This parameter allows for comparison of potential impact in different conditions, as well as for direct calculation of dispersant success (Fig. 10.6). For wind speeds exceeding 10 m/s, the slick area with a thickness of 25 μm or more is very small and will disappear very quickly (Fig. 10.2;  $L_{\text{slick}_{h > 25 \mu\text{m}}} < 1 \text{ km.h}$ ). These conditions create a small symmetrical surface slick, while most mass is in the water column. Dispersants will speed up the displacement of oil to the water column, yet the absolute effect is only slight as the surface area of such slicks is already relatively small.

At lower wind speeds, both the absolute and relative impacts of dispersant application are much larger (Fig. 10.6). Although the theoretical dispersant effectiveness seems highest for the lowest wind speed shown here (5 m/s), one should be aware of the possibly limited improvement of the situation. In the worst-case scenario (heavy oil, 5 m/s wind), our simulated dispersant addition to the natural dispersion drops the “time-integrated slick length with  $H_{\text{oil}} > 25\mu\text{m}$ ” from 60.2 to 35.9 km.h,



**Fig. 10.6** Modelled decrease in “time-integrated slick length with  $H_{\text{oil}} > 25 \mu\text{m}$ ” as a result of a factor 10 reduction in oil-water interfacial tension, simulating dispersant addition. Shown as a percentage of the untreated slick (top) or as absolute decrease (in km.h) (bottom). Model calculations as described in Zeinstra-Helfrich et al. (2017) for a larger number of wind speed and oil-type settings. Initial oil slick length was 250 m and thickness 1 mm

meaning that the treated oil slick will still have substantial size and lifetime. The response decision should include whether the result is worth the effort and costs for the specific situation.

As expected, a certain reduction in interfacial tension is most effective on low-viscosity oil, as the relative change in droplet size is higher (Sect. 10.3.5). Together with the observation that high viscosity hinders dispersant incorporation into the oil slick (Canevari 1984), this means that chemical dispersion is relatively and absolutely less effective on higher-viscosity than on low-viscosity oils.

Sub-optimal natural dispersion causes the oil slick to elongate substantially in the wind direction, where the thick slick portion is followed by a long tail in the upwind direction. Dispersants can be beneficial in these situations, accelerating the spreading of the thick slick part and the subsequent transition into the phase where size is slowly reduced as more mass is moved to the water column. The chemical as well as operational effectiveness of dispersants does decrease with increasing viscosity.

The added benefit of dispersants is limited in conditions that are optimal for natural dispersion, resulting in only slight slick elongation and with a slick thickness that is symmetrical in the wind direction.

## 10.4.2 Effects

As explained, the environmental benefit of dispersant application lies mainly in removing oil from the water surface: Depending on the effectiveness, dispersants can have a positive influence on mitigation of surface effects. However, the enhanced volumes of suspended/dissolved oil can enhance adverse effects in other compartments of the environment (O'Sullivan and Jacques 2001).

### 10.4.2.1 Water Column

Although the dispersants themselves are designed to be low in toxicity, the resulting enhanced exposure to hydrocarbons can potentially cause toxic effects to water column biota. Where physical surface oil impacts are mass independent for thicknesses above the effects threshold (Jongbloed et al. 2002), potential water column effects are more transient and are determined by exposure time and maximum concentration (Lee et al. 2015).

The increased exposure to hydrocarbons by enhanced dispersion is only brief, as concentrations are expected to diminish quickly due to dilution (Lee et al. 2015). This dilution is less evident in case of continuous dispersion of large or prolonged spills such as the *Deepwater Horizon* incident or in shallow or enclosed waters (BfR Wissenschaft 2016). Assessment of potential toxic effects encompasses uncertainties such as species-dependent sensitivity. Moreover, the precise exposure of the organisms over time depends on the specific spill conditions, oil qualities, as

well as the behavior of the organisms (Tamis et al. 2012). Different laboratory tests are available simulating various exposure regimes (Redman and Parkerton 2015), yet these may not necessarily match exposure regimes at sea.

In addition to chemical dispersion aiming to “dilute” the pollutant quicker, it is also considered to enhance biodegradation of the suspended oil. The role of biodegradation in natural and chemically dispersed oil is unclear. Theoretically dispersed oil is more bioavailable, but bacteria may also experience more acute toxic effects (Rahsepar et al. 2016). Conditions are heterogenic in space and time and difficult to replicate in a laboratory. As a result, conflicting information is available indicating either biodegradation is enhanced, decreased, or indifferent of chemical dispersion (Lee et al. 2013; Kleindienst et al. 2016; Rahsepar et al. 2016).

#### 10.4.2.2 Benthic

Dispersed oil can also reconcentrate on the seafloor, either as a result of suspended sediments adhering to oil droplets and sinking (Khelifa et al. 2008) or via the observed so-called MOSSFA mechanism (Marine Oil Snow Sedimentation and Flocculent Accumulation). This effect is enhanced in situations with phytoplankton blooms combined with particulate matter in the water column (Vonk et al. 2015; Daly et al. 2016; van Eenennaam et al. 2016). This MOSSFA could cause long-lasting effects as the oil will be concentrated on/in the sediment followed by reduced biodegradation under oxygen-limited conditions (Langenhoff et al. 2020) and may cause prolonged local exposure to hydrocarbons (Lee et al. 2015). This applies even more so for “marine oil snow,” which was found to cause more adverse effects in benthic invertebrates than oil-sediment aggregates (van Eenennaam et al. 2018; Schwing et al. 2020).

### 10.5 Concluding Remarks

The notion that dispersants should not be applied if their effectiveness is unsure stands to reason. Apart from the limited cost-effectiveness in such a case, the resulting change in oil properties can hamper effectiveness of mechanical removal methods (ITOPF 2012).

However, for a given spill situation, if we can prove that addition of dispersants can successfully mitigate potential for effects on the water surface and coastlines, as well as demonstrate that risks for adverse effects in other compartments are acceptable, dispersants provide a useful response strategy that can work in conditions where other methods are unsuccessful.

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