Analysis of Oil-Mineral Aggregate Formation in Turbulent Conditions

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ABSTRACT

During an oil spill, the dispersed oil droplets undergo aggregation with the marine sediments to form oil-mineral-aggregates (OMAs). In coastal regions, the nature of OMAs depend on the turbulent kinetic energy of the sea state. In this work, we examine the formation of OMA by two clay sediments, bentonite and kaolinite at different energy states of fluid. The sediment to oil ratio is kept constant in all experiments and the energy states of low, medium and high are investigated using a magnetic stirrer. It was seen that there is maximum oil removal efficiency for low energy state.

KEY WORDS: oil spill; oil mineral aggregates; oil droplets; oil aggregation; natural remediation; oil removal; oil pollution

INTRODUCTION

Oil spills are environmental disasters causing huge threat to the marine and coastal ecosystem. The spilled oil undergoes multiple weathering and transport processes such as evaporation, dissolution, emulsification, spreading, advection, turbulent diffusion, sedimentation, entrainment, photo-oxidation, biodegradation, etc. (Spaulding 2017). In the coastal regions, the weathered spill containing heavier fractions of the crude can get deposited on the sea floor forming tar residues such as tar balls, tar mats, etc. (Warnock et al. 2015). The benthic regions get contaminated with these sediment-oil agglomerates and may get washed off the shoreline (Grant et al. 1996; Gustitus and Clement 2017). This was seen evidently in multiple oil spill incidents such as the 1989 Exxon Valdez oil spill, the 2010 Deepwater Horizon blowout, the 2020 MV Wakashio oil spill and the 2017 Enmore oil spill. A precursor of these agglomerates are oil-mineral particles (OMAs). The formation of OMA is attributed to the presence of oil droplets and fine suspended sediments in the water column (Muschenheim and Lee 2002). When a portion of the spill gets dispersed in the water column due to wave action and turbulence of fluid, oil droplets are formed (Cui et al. 2020; Delvigne and Sweeney 1988). Additionally, one of the response measures for non-recoverable oil spills is the use of dispersants that disperse the oil into droplets (Rahsepar et al. 2016). This is done in order to enhance the bio-availability of the oil droplets to the indigenous hydrocarbon degrading bacteria. The droplets that retain in the seawater can induce toxicity or bioaccumulation to the marine organisms if ingested. These oil droplets are of sizes around 1 μm to 30 μm and are thus capable of interacting with the fine suspended sediments and biological matter in the water column. In coastal regions, where the suspended sediments concentrations and wave action are comparatively higher than offshore regions, oil droplets are readily formed and aggregate with the fine sediments to form oil mineral aggregates (OMAs) (Stoffyn-Egli and Lee 2002; Zhong et al. 2022). Typical sizes of OMAs range from 10 μm to 500 μm (Zhao et al. 2016). Due to OMA formation, there is an increase in the effective density of clay-oil agglomerate that cause sinking of the OMAs, allowing oil to reach the sea bed. The settled OMAs can be dredged and removed, preventing further contamination of the coasts. This process acts as a natural remediation strategy. However, the role of turbulent shear due to wave action on the OMA formation and oil removal efficiency needs to be investigated. Unlike the offshore regions, where the turbulent shear of seawater contributes predominantly towards coagulation of marine particles (Burd 2013), in coastal regions, the turbulent shear of the fluid can cause both coagulation and breaking of aggregates until an equilibrium is achieved. Therefore, in this paper, we investigate the effects of turbulence of fluid on OMA size distribution and its oil removal efficiency for two types of clay minerals at different mixing speeds.

MATERIALS AND METHODS

The OMAs were formed using light crude oil and two types of clay: bentonite and kaolinite. The concentration of crude oil was taken as 250 mg/L and the concentration of clay was 500 mg/L, giving a sediment to oil ratio of 2. This concentration of clay was chosen as it is typical for a coastal suspended sediment concentration and oil concentration is taken to match typical entrained oil concentrations during an oil spill (Wade et al. 2017). This concentration was fixed for all experimental set. All experiments were carried out in a magnetic stirrer to impart mixing due to turbulence. This instrument provides a free vortex flow with the fluid subjected to centrifugal forces away from the source of spin. This allows the particle present in the control volume to experience collision due to forces that push them apart. Thereby, the effect of turbulent shear similar