Science of the Total Environment 556 (2016) 146–153

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Gravity induced densification of floating crude oil by granular materials: Effect of particle size and surface morphology

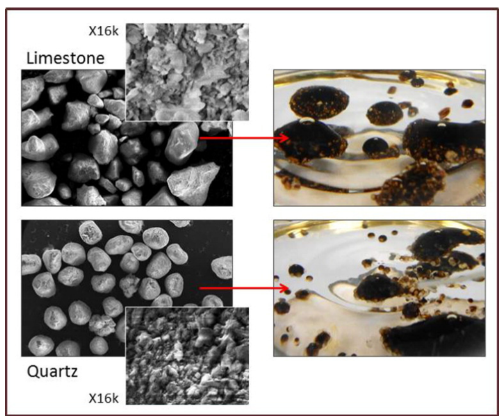
Daria Boglaienko *, Berrin Tansel [1]

Florida International University, Civil and Environmental Engineering Department, Miami, FL, USA

HIGHLIGHTS

- Granular materials were evaluated for capturing and submerging floating crude oil.
- Densification occurred by entrapment of particles within the oil phase.
- High surface porosity resulted in higher capture efficiencies.
- Surface pore size did not have a significant effect on capturing floating oil.
- There is optimum particle size range (passing 10 mesh) for effective aggregation.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 November 2015
Received in revised form 29 January 2016
Accepted 30 January 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Oil spills
Crude oil
Granular materials
Floating oil
Aggregation
Microscopy

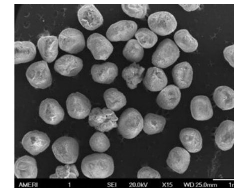
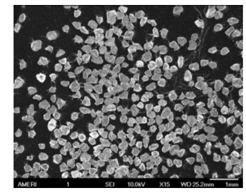
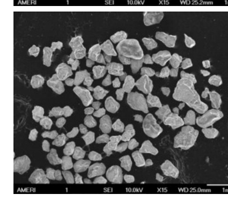
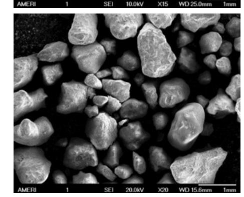
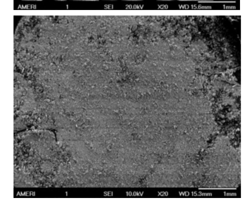
ABSTRACT

Densification and sedimentation of floating crude oil to the bottom of water column reduces the radius of a spill and its mobility, preventing direct contamination of beaches, coastal flora and fauna. Performances of different natural granular materials were evaluated for capturing efficiency of floating fresh South Louisiana crude oil. The granular materials studied were quartz sand with medium (20–30 mesh) and fine (40–100 mesh) particle size, limestone with coarse (4–10 mesh) and medium (16–40 mesh) particle size, beach sand (20–80 mesh), and clay (kaolin with ferric oxide; passing 200 mesh). Beach sand (mixture of quartz and limestone 20–80 mesh) and limestone (16–40 mesh) demonstrated better performance for capture, densification and submergence of the crude oil among the materials evaluated. The behavior of granular particles with the hydrophobic phase can be classified as (1) immersion entrapment inside the hydrophobic phase (slurry), and (2) partial encapsulation of the hydrophobic phase by a single layer of particles (raft). With crude oil, the particles were primarily entrapped within the hydrophobic phase. Study of the effect of particle size and morphology (i.e., porosity) of the granular materials on capture performance showed that average surface pore size did not have a significant effect on aggregation with oil, however, higher capture efficiency was observed with materials of higher surface porosity (beach sand and limestone). The experiments revealed that there is a critical particle size range (passing 10 mesh) which resulted in more effective aggregation of the granular materials with crude oil.

* Corresponding author at: Florida International University, Civil and Environmental Engineering Department, 10555 W. Flagler Street, EC 3781, Miami, FL 33174, USA.
E-mail addresses: dbogl003@fiu.edu (D. Boglaienko), tanselb@fiu.edu (B. Tansel).
[1] B. Tansel, Florida International University, Civil and Environmental Engineering Department, Miami, Florida 33174, USA (10555 W. Flagler Street, EC 3676).

http://dx.doi.org/10.1016/j.scitotenv.2016.01.214
0048-9697/

Table 1
Granular materials: particle size and bulk density; composition by Energy Dispersive Spectroscopy (EDS) and images by Scanning Electron Microscopy (SEM): ×15 for medium quartz sand, fine quartz sand, and beach sand; ×20 for limestone and clay.

Material	Mesh size/opening, mm	Bulk density, g/cm^3	Composition, weight %	Image[a]
Medium quartz sand	20–30/0.85–0.60	1.68	Si: 54.12 O: 45.88	
Fine quartz sand	40–100/ 0.42–0.15	1.56	O: 51.98 Si: 48.02	
Beach sand	20–80/0.85–0.18	1.47	O: 52.83 Si: 33.46 Ca: 13.72	
Limestone	16–40/1.18–0.42	1.38	O: 53.10 Ca: 26.15 Si: 19.18 Al: 1.56	
Clay	<200/<0.07	0.78	O: 48.50 Si: 28.40 Al: 14.53 Fe: 8.57	

[a] Scale bar: 1 mm.

1. Introduction

The World oil production has increased from 8.5 million tons in 1985–11.7 million tons in 2000 in parallel with the number of offshore platforms also increased from a few thousand in 1985 to about 8300 in 2000 (Kvenvolden and Cooper, 2003; Input of Oil to the Sea, 2003). The amount of oil entering marine waters globally is estimated at 1.3 million tons per year with 0.6 million tons from natural seeps, 0.150 due to spills during transportation, and 0.450 million tons from spills during consumption of petroleum (Input of Oil to the Sea, 2003). Oil spills at sea have significant impacts in both open seas and near shore environments due to spreading behavior of the floating oil (Tansel, 2014). The effects of a petroleum release depend on the rate of release, characteristics of the petroleum, and the local physical and biological character of the exposed ecosystems (Input of Oil to the Sea, 2003). Fresh spills of crude or petroleum based oils at sea move with currents and mixing due to wind and sea conditions, quickly enlarging the impact radius. Spills near coastal areas effect the ecosystems that are nesting grounds of both land and sea organisms as well as economically important marine resources (e.g., fish, shrimp beds, beaches) (Tansel et al., 2013, 2014). For large oil spills at sea, the most commonly used response method is the dispersant application by spraying. However, dispersants, as primary response method for oil spills, have limitations for use near coastal areas and can be applied in areas farther than 5.6 km (or 3 nautical miles) from shore and in waters deeper than 30 ft (or 10 m) (Anon, 2005, 2015).

Transport of oil to sediments is considered as important natural removal mechanism (Payne et al.; Bandara et al., 2011; Gong et al., 2014) and is called 'surf washing' (Lee, 2002; Owens and Lee, 2003; Sterling et al., 2004). In coastal areas, crude oil has a tendency to form clay-oil flocs that add to shoreline cleansing (Bragg and Owens, 1995). It was proposed to accelerate clay-oil flocculation process via spreading the mineral fines (clays) on the shoreline (Bragg and Yang, 1996). Overall, it was summarized that between 20 and 30% of the total amount spilled can be naturally submerged and transported to the sea bed as clay-oil flocs (Muschenheim and Lee, 2002); the other scenario simulations go up to 65% of removed oil in the aggregated form with sediments (Bandara et al., 2011).

Our previous studies showed that capture (and densification) and aggregation efficiency of fresh South Louisiana crude oil with granular materials can be as much as 80% when dry granular materials (i.e., limestone or quartz sand) are applied directly on the floating oil slick (Boglaienko and Tansel, 2015; Boglaienko et al., 2016). When granular particles are applied to the floating oil layer, they contact with the oil phase first, hence, become hydrophobic before reaching the water phase. This is a significantly different process from the above mentioned studies, and allows achieving much higher efficiency for aggregation and capture of floating oil. The granular particle induced submergence of floating oil, referred as raft formation (as a special case)