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Short communication

Viscous effects on the interaction of granular particles with floating oils in water

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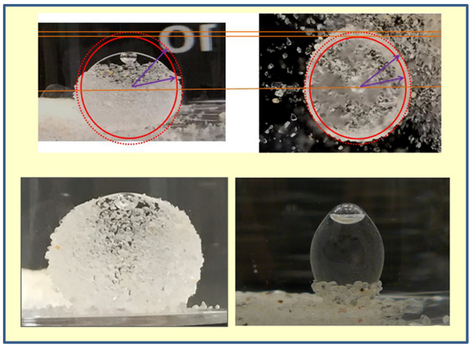
HIGHLIGHTS

- Light hydrophobic liquids (LHLs) can be submerged in water by granular particles.
- Interaction of silicone oils with different viscosities was tested with sand particles.
- Silicone oils submerged by forming granular encapsulated oil sacks in water.
- Encapsulation coverage was highly dependent on the granular particle size.
- Size of the submerged oil sacks increased with increasing oil viscosity.

GRAPHICAL ABSTRACT



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ABSTRACT

Light hydrophobic liquids (LHLs) can be submerged in water with granular particles by forming particle encapsulated liquid sacks. Formation and submergence of granular encapsulated LHL sacks can be an effective method for capturing and controlling the fate of floating oils. However, formation characteristics of the LHL sacks and effect of LHL viscosity on their behavior are not well understood. In this study, we examined the encapsulation characteristics of LHL sacks depending on liquid viscosity. Silicone oils with viscosities ranging from 10 cSt to 1000 cSt were used as the LHLs. Sand with two different particle sizes (40–100 mesh and 20–30 mesh) were used as the granular particles. The submerged LHL sacks were stable and remained separate from each other without collapsing or aggregating over time. They could be moved in water by sliding while keeping their encapsulation.

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1. Introduction

In recent years, particle stabilized interfaces have received attention for development of structured materials and novel applications (Binks and Murakami, 2006; Bormashenko et al., 2012; McHale and Newton, 2015). The particle stabilized liquid interfaces have been used in droplet form (e.g., ink jet printing), as well as encapsulation of different types of liquids with nanoparticles. Applications in spray form using atomization or jetting techniques by dispersion of liquid phase into small droplets (ranging from submicron to several hundred microns in diameter) are of interest in industrial applications such as agriculture, printing, painting, liquid fuel injection, where spreading of liquid in air (e.g., fertilizer application) or fine coating of liquid on a solid surface (e.g., ink jet

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Table 1
Properties of the silicone oils used (at 25 °C).

Kinematic viscosity[a] (cSt)	Specific gravity[a] (g/cm^3)	Surface tension[b] (mN/m)	Interfacial tension with water[c] (mN/m)
10	0.930	20.1	45.8
50	0.959	20.7	46.6
100	0.965	20.9	46.2
1000	0.970	21.2	46.0

[a] Source: http://www.powerchemical.net/library/Silicone_Oil.pdf.
[b] Source: Sigma Aldrich http://www.sigmaaldrich.com/materials-science/material-science-products.html?TablePage=20204397.
[c] Source: G.A. Padron Aldana (Padron, 2004) http://drum.lib.umd.edu/bitstream/handle/1903/2160/umi-umd-2140.pdf;jsessionid=08DC914F51D799E2BC5E92774A022D7F?sequence=1.

printing on paper) is required. Applications with much larger drops (or liquid sacks) of hydrophobic liquids ranging from several millimeters to a few centimeters in water are of interest for potential applications for capturing and controlling the fate of oils after release to the marine environment or industrial applications (Abkarian et al., 2013; Boglaienko and Tansel, 2015; Boglaienko et al., 2016).

The liquid globules which can transport a small amount of liquid on a hydrophobic solid surface have recently been called liquid marbles due to their quasi spherical shapes, soft solid characteristics, and reduced adhesion to the solid surface (Aussillous and Quere, 2006; Bergeron, 2003; Bormashenko et al., 2010; Tavacoli et al., 2012; Fernandes et al., 2014). The same underlying interfacial energy principles at the micro scale also allow larger particles (i.e., granular) to encapsulate floating oils into stable globules to form granular

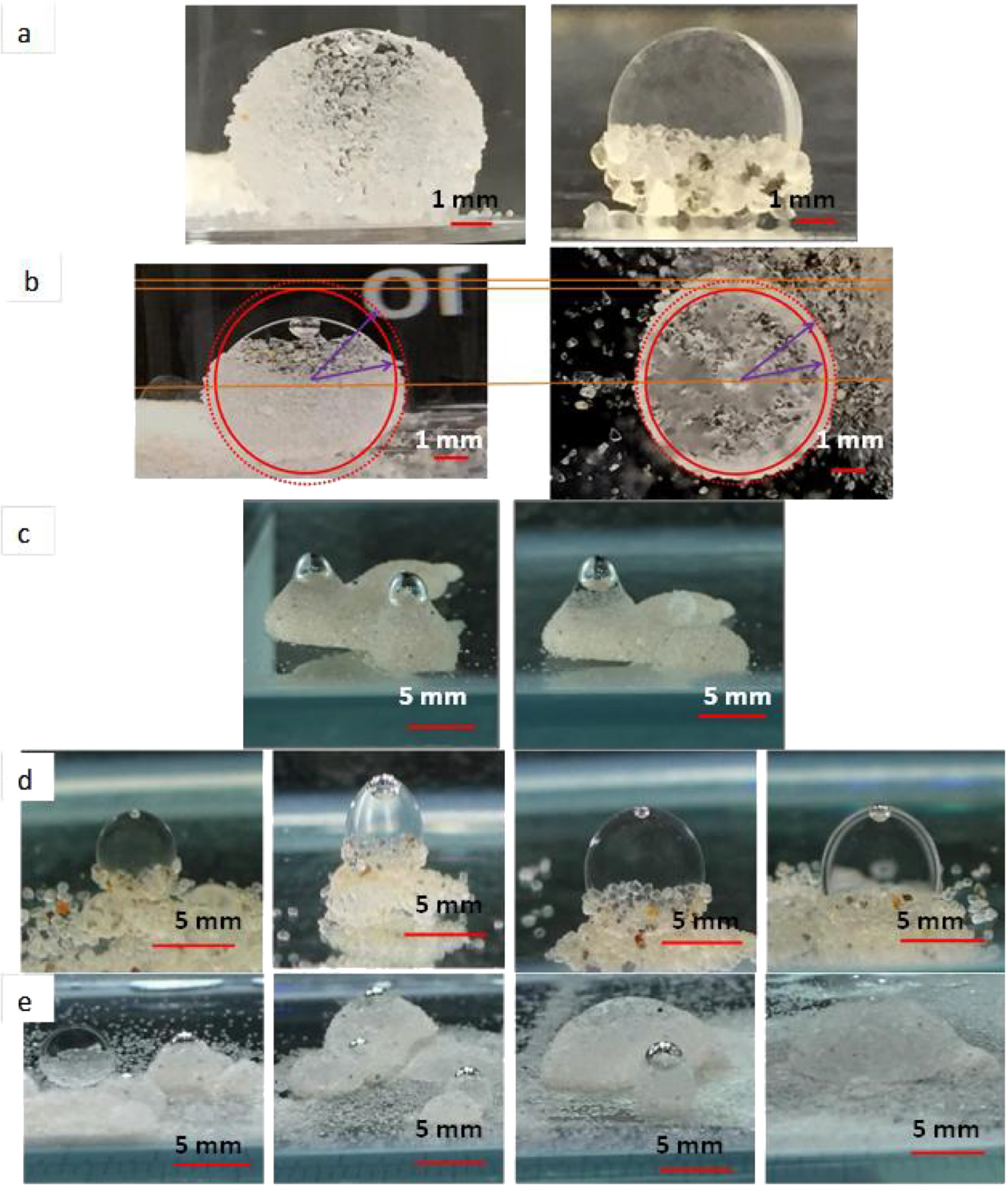

Fig. 1. Granular particle encapsulated oil sacks in aqueous medium after submergence. a. Surface coverage with small and large sand particles (sand: grain size 0.15–0.42 mm (left), 0.60–0.85 mm (right)); silicone oil viscosity: 1000 cSt (left), 10 cSt (right). b. Sand encapsulated silicone oil in water (sand: grain size 0.15–0.42 mm, silicone oil viscosity: 100 cSt). The red circles delineate the sand layer outside the oil sack. c. Oil sack elongation due to air bubble formation; shape of encapsulated sack before (left) and after (right) the air bubble is released (sand: grain size 0.15–0.42 mm, silicone oil viscosity 50 cSt). d. Comparison of oil sacks formed with silicone oils with different viscosities (with sand particles 0.60–0.85 mm) left to right: 10, 50, 100, 1000 cSt; 50 cSt: sack elongation due to larger air bubble. e. Comparison of oil sacks formed with silicone oils with different viscosities (with sand particles 0.15–0.42 mm) left to right: 10, 50, 100, 1000 cSt. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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