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Facile fabrication of superhydrophobic sand: Potential advantages for practical application in oil–water separation

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ABSTRACT

Development of cost-effective and handy functional materials that can separate oil from water readily by a convenient method is highly desirable and still challenge. Herein, sand-based superhydrophobic surfaces were easily achieved by coating sand particles with silane, and the whole fabrication process was time-saving and facile to carry out. The superhydrophobic surfaces can be applied as an oil sorbent scaffold to absorb oil from water selectively because of their water-repelling and oil-attracting properties. In addition, the time required for oil–water separation was shortened significantly by combining the separation process with a vacuum system. Importantly, the superhydrophobic surfaces can maintain their high selectivity and separation efficiency even after several cycles of oil–water separation, thus providing great potential and advantage for practical application in oil–water separation.

1. Introduction

With increasing occurrence of industrial oily wastewater and oil spill accidents [1–4], developing novel materials that can effectively separate oils from industrial wastewaters, polluted oceanic waters, and oil-spill mixtures is highly desired. Current methods to address this challenge mainly include collection of oil from water surface, mixing of oil with water using dispersing agents to facilitate natural degradation, and in situ burning of oil spills [5]. The collection of oil is often preferred because it allows proper disposal of oil. To enhance recovery of the oil, researchers have mostly commonly developed oil–water separation materials through conferring opposite wetting behavior to water and oil on material substrates [6]; and approaches adopted to realize this goal include mold pressing [7,8], phase separation [9], dip coating [10-13], chemical vapor deposition [14], wet-chemical method [15] and others [16–26]. However, some of the materials usually required complicated and expensive fabrication procedures, while others displayed limited reusability. These limitations severely hindered their use in practical applications. Generally, an ideal oil–water separation material should have the properties such as facile fabrication process, low cost, high selectivity, excellent recyclability, environmentally benign, and so on. Moreover, speed and efficiency for oil–water separation are also key factors for practical applications and should be considered into fabrication of the materials.

Sand, one of the raw materials in nature, offers benefits of rich source, low cost, and nontoxicity to environment, and thus is a good candidate to construct oil–water separation materials. In this study, we developed a facile approach to fabricate a sand-based superhydrophobic surface applied for oil–water separation by coating sand particle surfaces with silane. Our strategy to design the superhydrophobic surface with performance of oil–water separation is shown in Fig. 1. The whole procedure was conducted under a mild environment, and no intricate instruments and expensive chemicals were needed. It is noteworthy that nonfluorinated dispersion for the formation of functional sand was used during the procedure, which has low environmental impact and shows definitely environmentally benign. Water droplets could roll off the obtained surface easily, while organic liquids such as hexadecane wet it completely. The application of the functional sands was demonstrated by separating oils from water surface efficiently. In addition, the speed for oil–water separation can be improved significantly, when applied in conjunction with a vacuum system. Moreover, the applied scale for oil–water separation can be controlled easily via adjustable usage amount of the functional sands. In general, micro/nanostructures of many superhydrophobic surfaces are easily destroyed under atrocious weather or other conditions, therefore leading to permanent destruction of the surface superhydrophobicity. However, unlike the conventional materials, the surface wettability of our functional sands was retained after molding sand into any shape due to random accumulation of

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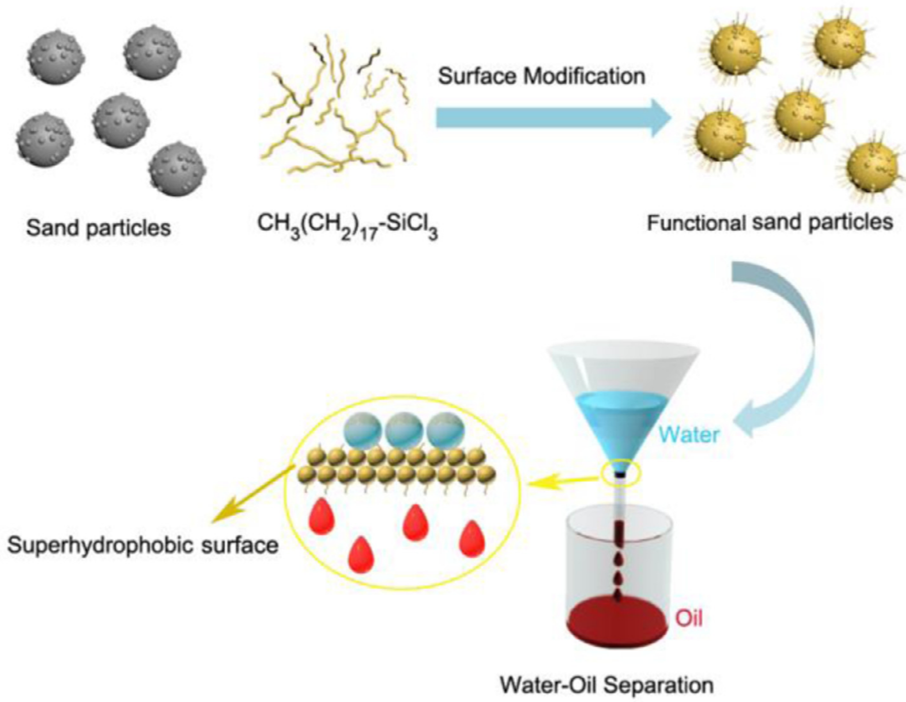

Fig. 1. Schematic illustration of fabrication process and oil–water separation of the superhydrophobic sand.

the sand particles. More importantly, no complicated apparatus or expensive materials are required, which can significantly decrease material and operating cost of the oil–water separation. Therefore, we hope this study could contribute to the development of advanced oil–water separation materials for practical applications.

2. Experimental

2.1. Materials

Octadecyltrichlorosilane was provided by Shanghai Boer Chemical Reagent Co., Ltd., China. Hexadecane and chloroform were provided by Tianjin Kermel Chemical Reagent Co., Ltd., China. Commercially available sand (diameter: 100–500 μm) was purchased from a local store and was cleaned with ethanol and deionized water sequentially in an ultrasonic cleaner before use. The other chemicals are of analytical grade and used as received.

2.2. Surface functionalization of sand particles

10 g sand was ultrasonically dispersed in 200 ml toluene, and 10 ml of octadecyltrichlorosilane was added dropwise under stirring at ambient temperature. The reaction mixture was stirred at ambient temperature for 2 h. Finally, the resultant suspension was centrifuged and placed to dry in an oven for 30 min at 80 °C to obtain the functional sand particles (hydrophobic).

2.3. oil–water separation test

For oil–water separation, a filter module composed of the functional sand and cotton is fixed into a cone-shaped funnel; and a mixture of distilled water (dyed with methylene blue) and chloroform (colored with oil red O) was poured into the filter module, and spontaneously separated. In addition, in order to shorten the time requiring for oil–water separation, the filter flask is connected with vacuum pump (SHZ-D (III), China) by rubber pipe.

2.4. Characterization

Contact angle (CA) and sliding angle (SA) measurements were performed using a KRÜSS DSA 100 (KRÜSS Company, Ltd., Germany) apparatus at ambient temperature. The volume of water and oil droplet in each measurement was 5 μL. Scanning electron microscopy measurements were carried out using a JSM-6701F field-emission scanning electron microscopy (FESEM, JEOL, Japan). Fourier transform infrared (FTIR) spectra were collected on a Bruker IFS66 V/S spectrometer. Thermal measurement was carried out using a thermogravimetric analysis instrument (TGA, PerkinElmer PE7) under air atmosphere at a rate of 10 °C/min. The optical images were captured by a digital camera (Canon).

3. Results and discussion

Fig. 2 shows surface morphology of the sands before and after coating with silane. Sand particles collision with each other under vigorous stirring leading to the average diameter of modified sands became smaller compared with original sand (Fig 2A and B). EDS spectra (Fig. 2C and D) were employed to investigate the composition difference of the sand before and after functionalization. Compared with the pristine sand, the content of carbon in EDS spectra of the functional sand increases greatly, indicating that the silane was successfully coated on surfaces of the sand particles.

FTIR analysis shows that two absorption peaks positioned at 2922 cm^{-1} and 2850 cm^{-1} appeared which was corresponding to stretching vibration of $-CH_3$ group (see Fig. 3A). This result indicates that alkyl group has been successfully attached on the sand surface. Moreover, we also investigated the content of silane modified on the surface. TGA analysis indicates that the content of it on the sand surface is about 3.84 wt%, as shown in Fig. 3B. The coated silane significantly lowers the surface energy of the sand surface. This low surface energy, combined with the rough surface texture, led to the silane coated surface exhibit superhydrophobic property. For further understanding of thermal stability of the superhydrophobic surface, related measurements were investigated (Fig. S1), and results showed that