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Stainless steel mesh coated with silica for oil–water separation

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A B S T R A C T

Stainless steel mesh with its high compressive strength, anti-chemical erosion and not readily stained with water properties has been used in the application of oil–water separation. This study describes a facile method for fabricating both highly hydrophobic and superoleophilic meshes by coating silica particles. After the modification of silica particles, the stainless steel mesh became more hydrophobic and oleophilic. The water contact angle on the modified mesh was up to 135.3°, while the oil droplets could penetrate the mesh rapidly. The modified meshes could separate oil from water effectively without depending on any extra power or chemical agent. It could be a good potential candidate in the employment of oil–water separation.

1. Introduction

As is well known, a large amount of oily waste-water is being produced everyday due to the industrial processing as well as domestic water, such as metal finishing, chemical fuel and restaurant leftovers [1–3]. Apparently, the bad influence of this kind of waste-water for people and environment is long term and lethal [4,5], which can be evidenced by the consequences of the oil spill accidents that occurred in recent years. Needless to say, the oily waste-water must be appropriately handled owing to environmental and health requirements.

Till now, kinds of technologies, such as gravity separation [6], coagulation [7], air flotation [8] and oil absorbents [9,10] have been applied to separate oil–water mixtures. Among them, some of the materials have been developed for oil–water separation. For example, due to the flexibility, large surface area and pore volume, as well as commercial availability, porous materials such as sponges [11,12], graphene foam [13], cotton fabrics [14] and copper meshes [15–19] have been investigated to separate oily water. However, these materials have their limitations in recyclability, firmness and large scale production, which have reduced their practical applications in oil–water separation.

In this work reported herein, we chose stainless steel mesh as the substrate which is anti-chemical erosion [20,21], anti-hot aging, firm and easy to obtain. In general, superhydrophobic surface can be achieved by combining proper surface roughness with hydrophobic materials. Therefore, stainless steel mesh with proper pore size was modified by silica particles using dip-coating method. The water contact angle about this modified mesh (size of 50 μm) was up to 135.3°, and the hydrophobicity of modified mesh increased a lot. The oil droplets could penetrate the mesh immediately. What's more, the mesh is cheap, facile and fast to process, which can be employed effectively for the separation of oil and water.

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2. Experimental

2.1. Materials

Stainless steel meshes (180, 150, 75 and 50 μm) were obtained from Shanghai Hongxiang Metal Mesh Co., Ltd. Ethanol (95%), ammonia (28%), acetone, tetraethoxysilane (TEOS, 98%), tetrahydrofuran (THF) and polystyrene (PS) were all pure analytically and purchased from Sinopharm Chemical Reagent Company, Ltd. (Shanghai, China). Methyltrichlorosilane (MTS) used for surface hydrophobic modification was purchased from Aladdin Industrial Co., Ltd. (Shanghai, China). All of the chemicals were used as received without further purification. Diesel (density at 20 °C = 0.8170 g/cm^3, viscosity = 6.51 mm^2/s) was obtained from Minghe petrol station of Sinopec in Baoshan district (Shanghai, China). Pumping oil (density at 20 °C = 0.7881 g/cm^3, viscosity = 47–57 mm^2/s) was obtained from Shanghai Hasitai lubricating oil Company, Ltd. (Shanghai, China). Soybean oil (density at 20 °C = 0.9275 g/cm^3, viscosity = 8.5 mm^2/s) was purchased from Wal-Mart supermarket (Shanghai, China).

2.2. Fabrication of silica particles

With the condition of magnetic stirring, TEOS (5 ml) as well as NH_4OH (5 ml, as the catalyst) was added into the absolute ethanol (50 ml) at ambient temperature [22]. Keep the stirring for one hour. Later, the mixture solution was stalled and aged at room temperature for 12 h. Then MTS reagent (0.3 ml) was mixed into this solution via 12 h of magnetic stirring. Finally, the modified silica particles were collected and purified by repeated centrifugation for three times in absolute ethanol, and then dried in a vacuum oven at 60 °C for 12 h.

2.3. Preparation of highly hydrophobic stainless steel

First of all, different sizes of stainless steel meshes were cut into square shape (~5 cm both in width and in length). Then they were cleaned with acetone and distilled water for 30 min successively by using an ultrasonic cleaner. After that, they were dried in an oven at 60 °C for several minutes to remove the moisture completely. In the typical process, PS (0.1 g) was completely dissolved in THF (5 ml), and soon afterwards, the as-prepared modified silica particles (0.1 g) were ultrasonically dispersed in THF solution at ambient temperature. Followed the stainless steel meshes were dip-coated by the mixture for several minutes, and then dried at 75 °C for about 2 h. Finally, the highly hydrophobic stainless steel meshes were obtained by this one-step dip-coating procedure.

2.4. Oil–water separation experiment

The prepared stainless steel meshes were fixed between two glass tubes. The oil–water mixture (about 100 ml of diesel oil and 100 ml of water were mixed through a shake process) was poured into the upper glass tube. The photos were recorded on a camera (Nikon, D7100).

2.5. Instrumentation and characterization

Water contact angles (WCAs) were measured with 8 μL droplets of deionized water using a JC 2000D5 (provided by Shanghai Zhongchen Digital Technology Apparatus Company, Ltd.) apparatus at ambient temperature. The final contact angle values were attained by averaging at least three results at different positions on the same surface. The surface morphology of different meshes of stainless steel before and after modification was observed with the use of scanning electron microscopy (SEM, HITACHI SU-1500, HITACHI Company, Ltd., Japan). Energy dispersive X-ray spectrometer (EDS) analysis was also carried out on the same machine to determine the chemical composition of the modified stainless steel meshes. X-ray photoelectron spectroscopy (XPS) data was obtained by using an electron spectrometer from Thermofisher Scientific Company, Ltd., China.

3. Results and discussion

3.1. Fabrication process of silica particles

According to the well-known Stober method [23,24], the silica particles were prepared by a typical sol–gel process, which included the hydrolysis of TEOS and the condensation of hydrolyzed silica particles [22]. What's more, the reaction time and the concentration of NH_4OH were all strictly controlled based on the Stober method. The fabrication process of silica particles is shown in Fig. 1. When the silica particles were synthesized, they were modified by the MTS. The modified silica particles were then ultrasonic dispersed into the PS and THF solutions. Afterwards, cleaned stainless steel meshes with different sizes were dip-coated with the above mixed solution for several minutes. The highly hydrophobic and superoleophilic oil–water separation membranes were obtained.