Heliyon 10 (2024) e31574

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Oil-recovery performance of a superhydrophobic sponge-covered disc skimmer

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A R T I C L E I N F O

Keywords:
Superhydrophobic
Sponge
Diesel oil
Disc skimmer
Recovery rate

A B S T R A C T

Frequent oil spill accidents caused by transportation, storage and usage may lead to severe damage on aquatic and ecological environments. Effective methods for rapid oil recovery are urgently in demand. Polyvinyl chloride, hydrophobic nano-SiO_2, expanded graphite were separately applied to polyurethane and melamine sponge to fabricate superhydrophobic sponge material. The selected superhydrophobic sponge was introduced to establish sponge - covered disc skimmer. Oil recovery tests of the device were conducted to determine the optimum parameters. The examined operating conditions encompassed sponge thickness, immersion depth, rotational speed, oil slick thickness, operation time. The results showed that the melamine sponge modified by both polyvinyl chloride and hydrophobic nano-SiO_2 exhibits super-hydrophobicity with a water contact angle of 150.3°. The absorption capacity for diesel oil can reach 53.89 g/g. The absorption capacity can still achieve 90 % of its initial capacity even after 500 extrusion-absorption separation tests. The results indicate the superiority of the superhydrophobic sponge covered surface in oil recovery over the standard steel surface regardless of the operating conditions. The recovery rate of the device can still achieve 96.4 % of its initial capacity with 95 % efficiency even after 85 h operation. The results suggest the superhydrophobic sponge - covered disc skimmer may have great application perspectives in oil spill recovery.

1. Introduction

With the rapid development of energy-chemical industry, there is an increasing demand for oil and its derivatives. In the processes of production, storage and transportation, oil spill accidents have gradually become a major problem threatening aquatic ecosystem and environment faced by the world [1–3]. The crude oil spill accident at 2010 in the Gulf of Mexico set a remarkable example for oil leak accidents. 4.9 million barrels of crude oil was released, resulting in extensive damage to marine habitats and human health [4]. A recent example is the oil leak accident caused by tanker collision in the Huanghai Sea at 2022. An estimated 20,000 tons of oils was released into the ocean, which caused severe damage to marine organisms, costal zones and fishing industry. Global oil spill was estimated at 164,000 tons per year [5]. The selection of response technique along with the speed of response are considered as the most important factors on reducing the risk and minimizing the overall impact on the environment [6–8].

Oils generally have low density and will spread over the water surface. To prevent this spread of oil, mechanical skimmers are

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https://doi.org/10.1016/j.heliyon.2024.e31574
Received 6 April 2024; Received in revised form 14 May 2024; Accepted 19 May 2024
Available online 20 May 2024
2405-8440/

employed [9]. Mechanical skimmer represents one of the most common recovery techniques, which exert no negative effects [10,11]. Several skimmers have been developed to clean up oil spillage, including i) disc skimmer, ii) drum skimmer, iii) rope skimmer, iv) brush skimmer, v) belt skimmer. Recovery is based on the adhesion of oil to a rotating skimmer surface, the oil attached to the surface be lifted out of the water, then be scraped from the surface and transported to the recovery tank. The oil recovery efficiency was highly influenced by the adhesion between the oil sticked and the skimmer surface [12,13]. The main limitations of mechanical skimmers are represented by the low oil recovery rate and poor stability over time. Several researches were performed on the properties of the skimmer to improve oil recovery efficiency. Broje and Keller [14] studied the interfacial processes between skimmer surfaces and oils. The results reported that oleophilic elastomers such as Hypalon and Neoprene have better potential for oil spill recovery due to high oil-retaining capacity, indicating the surface material may have great influence on oil recovery efficiency. According to Khalil [15], with the application of the nano - ceramics coating, the recovery rate of drum skimmer was highly improved. Moreover, the relationship between the geometry of the skimmer surface and recovery efficiency was investigated [16], the results indicated that the recovered oil of grooved drum was much higher than the smooth drum. The configuration of oil skimmer can be made to improve recovery rate. Recently, An et al. [17] manufactured a novel skimmer combining cyclone separation and free surface vortex. The oil recovery process can be speed up with higher split ratio.

Various studies were carried out on superhydrophobic adsorbents or absorbents for high selective sorption capacity with a thin oil layer [18,19]. Several three-dimensional absorbents have been developed for oil spill removal, including i) silicone gel, ii) polyurethane sponge, iii) melamine sponge, iv) carbon aerogel. Hayase et al. [20] fabricated a superamphiphobic marshmallow-like macroporous silicone monolith with high flexibility and size controllability, which may be used like a sponge for quick removal of oils from water/oil mixture. Shi et al. [21] synthesized a superhydrophobic polyurethane sponge using activated carbon-TiO_2-PDMS coating by simple soaking method, which presented high absorption capacities (up to 100−158 g/g) for diverse oils. The main drawback of these superhydrophobic absorbents is that the recovery process is non-continuous. Saturated absorbents need to be collected and desorbed manually, which is labor- and time-consuming and inefficient. According to Wang et al. [22], a circulating oil/water separation system was built with an external self-priming pump introduced, based on self-developed carbonaceous aerogel. The floating diesel oil can be separated and collected continuously. Hu et al. [23] fabricated superhydrophobic melamine sponge with coatings of PDA, PDMS and Fe_3O_4, which showed high absorption capacity (52.39–91.52 g/g) for various kinds of organic solvents. The continuous oil removal can be achieved with gravity filtration and peristaltic pump assisted.

None of the previous studies considered the combination of disc skimmers with absorbents. In this work, polyurethane sponge and melamine sponge were applied as matrix. Polyvinyl chloride, hydrophobic nano-SiO_2 and expanded graphite were used as modifiers separately to fabricate superhydrophobic sponge with high recyclability. The effect of covering disc skimmer surface by self-developed superhydrophobic sponge on oil recovery performance was examined. The main operating parameters such as sponge thickness, immersion depth, rotational speed, oil slick thickness, and operation time were considered.

2. Experimental

2.1. Materials

Melamine sponge (MS-I, 0.009 g/cm^3, porosity 85.2 %), nano sponge (MS-II, 0.013 g/cm^3, porosity 97.5 %), high-density sponge (MS-III, 0.018 g/cm^3, porosity 98 %), sofa sponge (PU–I, 0.056 g/cm^3, porosity 82.1 %), polyurethane sponge (PU-II, 0.024 g/cm^3, porosity 90.8 %), expanded graphite (120 m^2/g, 364 mL/g), poly-vinyl chloride (PVC, K-value 59-55), hydrophobic nano-SiO_2 (SiO_2, Hydrophobic-115), 3-Aminopropyltriethoxy silane coupling agent (KH550). MS-I, MS-II, MS-III and PU-I was purchased from Guangzhou Jiuwang Sponge Factory. PU-II and expanded graphite was obtained from Tianjin University. Diesel oil was purchased from Sinopec Gas Station. Ethanol, tetrahydrofuran, methanol, ethyl acetate, nitric acid, sulfuric acid, and sudan III were all analytically pure and obtained from Sinopharm Chemical Reagent Co., Ltd.

2.2. Fabrication of modified sponges

Pieces of sponge samples cut to a size of 2 cm × 2 cm × 2 cm were ultrasonically cleaned for 30 min, then dried in an oven for 24 h. 0.1 g SiO_2 was uniformly dispersed in 20 mL ethyl acetate via ultrasonic (modifier I). KH550 (0.1 wt%) dispersed in ethyl acetate was then added into the modifier I solvent to prepare modifier II. 0.1 g expanded graphite was added in the mixture of concentrated sulfuric

Table 1
Fabrication methods of modified sponges.

Sample	Matrix	Modifier	Agent
1#MS-I	MS-I	modifier I	SiO_2
2#MS-I	MS-I	modifier II	SiO_2, KH550
3#MS-I	MS-I	modifier III	expanded graphite
4#MS-I	MS-I	modifier IV	SiO_2, PVC
4#MS-II	MS-II	modifier IV	SiO_2, PVC
4#MS-III	MS-III	modifier IV	SiO_2, PVC
4#PU-I	PU-I	modifier IV	SiO_2, PVC
4#PU-II	PU-II	modifier IV	SiO_2, PVC

acid and nitric acid (V/V = 7/3) for 24 h. The acidized expanded graphite was then added into the ethyl acetate solvent of KH550 (0.25 mg/mL) to acquire modifier III. 0.1 g PVC was dissolved in 10 mL tetrahydrofuran by ultrasonic dispersion at room temperature. Then 0.2 g hydrophobic SiO_2 nanoparticles uniformly dispersed in KH550 was added in the mixture. The mixture solution was then magnetically stirred for at least 2 h to obtain modifier IV.

The dried MS-I cubes were then respectively impregnated with aqueous modifier solutions (modifier I, modifier II, modifier III, modifier IV) for 12h. After drying at 60 °C for 6h, $1^{\#}$MS-I, $2^{\#}$MS-I, $3^{\#}$MS-I and $4^{\#}$MS-I were obtained.

The dried MS-II, MS-III, PU-I, PU-II cubes were respectively impregnated with modifier IV for 12h. After drying at 60 °C for 6h, $4^{\#}$MS-II, $4^{\#}$MS-III, $4^{\#}$PU-I, $4^{\#}$PU-II were obtained (see Table 1).

$4^{\#}$MS-II implemented comprised a sponge layer for covering disc skimmer surface to fabricate superhydrophobic sponge-covered disc skimmer.

2.3. Characterization

The water contact angle (WCA) was measured with a water droplet of 5 μL using a contact angle meter (OCA20, DataPhysics, Stuttgart, Germany) at room temperature. The microstructure of the sponge samples was analyzed by a field emission scanning electron microscopy (SEM, S-4800, Hitachi, Japan).

2.4. Oil absorption capacity measurement

The diesel oil absorption capacity of the modified sponge samples was tested as follows: the samples ($4^{\#}$MS-II, $4^{\#}$MS-III, $4^{\#}$PU-I, $4^{\#}$PU-II) were immersed in diesel oil until saturation absorption. The samples were removed and held for 30 s before being weight. After being squeezed completely, the weights of the sponge samples were measured again. The absorption capacity (Q) was calculated by Equation (1):

$$Q = \frac{M_2 - M_1}{M_1}$$

where M_1 (g) is the original mass of the sponge sample, M_2 (g) is the final weight of the sponge sample until saturation absorption.

The recyclability of the modified sponge samples was evaluated through the following method: a piece of sponge sample was immersed in diesel oil until saturation absorption. Afterwards, the saturated sponge was removed and held for 30 s before being weight. Then the saturated sponge was squeezed completely to remove the absorbed oil. The above process was repeated for 500 times.

The absorption rate of the modified sponge sample was tested as follows: 2 ml diesel oil dyed by Sudan III was dropped on the water surface. The modified sponge sample was placed on the water surface to absorb the dyed oil. The absorption time was recorded.

2.5. Experimental apparatus

Fig. 1 shows the disc skimmer test apparatus. The test apparatus was composed of steel frame, variable speed motor, oil recovery tank, rotating disc and squeeze unit. Two surface materials, plain steel and modified sponge-covered steel (see Fig. 2) were employed in the experiments. The floating oil was absorbed selectively by modified sponge covered disc, then be extruded via a squeeze unit to remove and collect the absorbed oil. The collected oil and water levels were measured by measuring cylinders. The effects of the operating variables on the recovery performance were tested. The oil recovery rates were examined at room temperature

2.6. Oil recovery performance test

According to the ASTM standard [24], the diesel oil absorption performance of the disc skimmer test apparatus was tested as follows: four surface materials were employed in the experiments, namely plain steel, 5 mm $4^{\#}$MS-II -covered steel, 15 mm $4^{\#}$MS–II–covered steel, 25 mm $4^{\#}$MS–II–covered steel. The thickness of diesel oil was approximately 75 mm, the floating oil was then collected by the disc skimmer test apparatus until the thickness approaches 50 mm in about 30 s. The immersion depth of the disc was

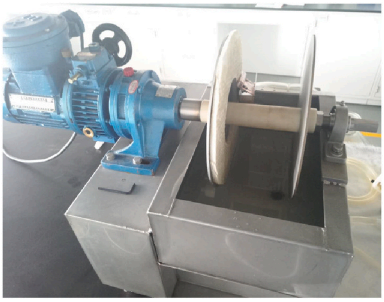

Fig. 1. The disc skimmer test apparatus.

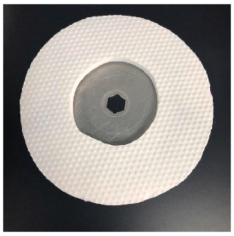

Fig. 2. The modified sponge-covered steel.

set at R (disk radius), 1/2R, 1/4R. The rotational speed can be changed from 5 r/min up to 58 r/min. The oil slick thickness was 0.1 mm、1 mm、5 mm、10 mm、20 mm、50 mm and 75 mm. All tests were conducted three times. In addition, the disc skimmer was operated continuously for 85 h at a rotating speed of 25 r/min when the oil film thickness was 50 mm.

The recovery rate follows the equation below:

$$NRR = \frac{V_0}{t} \times 100\%$$

The recovery efficiency can be calculated as follows:

$$RE = \frac{V_0}{V} \times 100\%$$

where, V_0 (mL) is the volume of the diesel oil recovered, V (mL) is the volume of the total liquid collected, and t (s) is the elapsed time.

3. Results and discussion

3.1. Materials characterization

To confirm the hydrophobicity of the sponges modified by various methods, the results were analyzed by the contact angle method. As can be seen from the upper part of Fig. 3, the water droplets deposited on the surfaces and not absorbed by modified MS-I samples, which indicates hydrophobic properties. However, superhydrophobic surface was obtained on none of them. Fig. 3d) shows $4^{\#}$MS-I with a WCA of 139.6°, while $3^{\#}$MS-I was only 129.2° (Fig. 3c). This may because the molecules of the modifier cannot diffuse sufficiently into the internal network of MS-I with poor porosity. The above results suggest that modifier IV is the best candidate for superhydrophobic sponge preparation. Fig. 3 f) displays that $4^{\#}$MS-III shows superhydrophilicity with a WCA of 150.3°. A water droplet can stand steadily on the surface of $4^{\#}$MS-III and attain spherical shapes [25]. From Fig. 3 e), the water droplet exhibits low adhesion and can be easily rolled off from the surface of $4^{\#}$MS-II, which shows super-hydrophobicity. The results imply that melamine sponge with low density and high porosity is more suitable to fabricate superhydrophobic sponge by modifier IV. This may due to the fact that melamine sponge with high porosity and permeability is more easily to be impregnated and coated by modifier solution molecules [26]. Herein, PVC can be attached to both the pores and surfaces of the sponge more easily, providing more binding sites for hydrophobic SiO_2 nanoparticles and thereby constructing a denser water-repellent coating.

The XPS analysis was applied to analyze chemical composition of $4^{\#}$MS-II. Fig. 4 shows that the elements such as C, O, Si and Cl are found in the XPS spectrum. The peak located at 100 eV can be attributed to the Si 2p of SiO_2, which is consistent with the binding

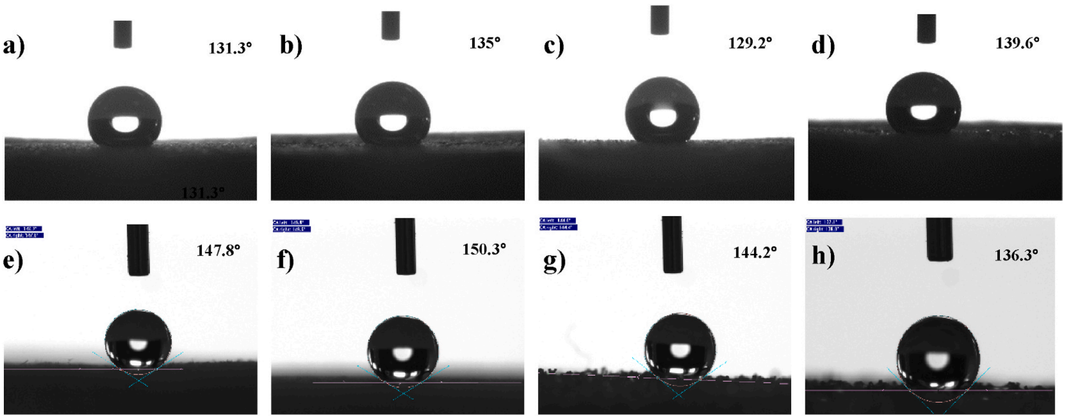

Fig. 3. The WCAs of modified sponge samples a) $1^{\#}$MS-I, b) $2^{\#}$MS-I, c) $3^{\#}$MS-I, d) $4^{\#}$MS-I, e) $4^{\#}$MS-II, f) $4^{\#}$ MS-III, g) $4^{\#}$ PU-I, h) $4^{\#}$PU- II.

energy value for Si in SiO_2. The binding energy of 200 eV can be attributed to the Cl 2p1, which is in agreement with those observed in PVC. The XPS result indicates that PVC and SiO_2 coexist on the surface of 4$^{\#}$MS-II, contributing to the super-hydrophobicity of 4$^{\#}$MS-II and 4$^{\#}$MS-III. Thus, 4$^{\#}$MS-II and 4$^{\#}$MS-III with super-hydrophobicity may be selected as candidates for covering disc skimmer surface.

Maximum absorption capacity and recyclability are critical factors for evaluating the performance of absorption materials under practical application [27]. Fig. 5a) displays the maximum absorption capacity of 4$^{\#}$MS-II, 4$^{\#}$MS-III, 4$^{\#}$PU-I, 4$^{\#}$PU-II is 53.89 g/g, 50.71 g/g, 28.7 g/g and 14.04 g/g, respectively. It can be seen that the absorption capacity of 4$^{\#}$MS-II is much higher than that of 4$^{\#}$PU-II, which is due to the larger storage volume with the same bulk. Fig. 5b) depicts the absorption capacity of 4$^{\#}$MS-II and 4$^{\#}$MS-III for diesel oil over 500 cycles. It can be seen that diesel oil absorption capacity of 4$^{\#}$MS-II maintained at 90 % of its maximum absorption capacity over 500 cycles, demonstrating good recyclability. Based on the excellent absorption capacity and recyclability, 4$^{\#}$MS-II can be selected as a candidate for covering disc skimmer surface.

Fig. 6 shows the SEM images of MS-II and 4$^{\#}$MS-II. As shown in Fig. 6a), b), 4$^{\#}$MS-II maintained its original structure. Fig. 6a) reveals a perfectly smooth surface of MS-II, while Fig. 6b) shows that the skeleton surface of 4$^{\#}$MS-II was rougher with many peaks and troughs, attributing to the successful fabrication of hydrophobic SiO_2 coating, which is beneficial to the formation of super-hydrophobic surface. This is consistent with the result in Fig. 3e), the water contact angle of 4$^{\#}$MS-II increased sharply from 0 to 147.8°.

To evaluate the feasibility of 4$^{\#}$MS-II applied in actual oil spill recovery, a rapid oil/water separation experiment was conducted, the results are shown in Fig. 7. Fig. 7 a) shows an oil/water interface was formed with 5 mL diesel oil (dyed by Sudan III) floating on the surface of 10 ml water. As can be seen from Fig. 7 b)-c), diesel oil was completely absorbed by 4$^{\#}$MS-II within 10s without any external force. 4$^{\#}$MS-II was placed on the water surface for another 10 s before taken out. As shown in Fig. 7 d), the water still retained transparent and clean. The results proved rapid and successful separation of oil and water by 4$^{\#}$MS-II.

3.2. Effect of surface material

4$^{\#}$MS-II was introduced to establish sponge - covered disc skimmer. Fig. 8 demonstrates a comparison between the diesel oil recovery rates for steel surfaces loaded with 0 mm, 5 mm, 15 mm, 25 mm 4$^{\#}$MS-II. The results suggest the advantage of 4$^{\#}$MS-II over steel surface. The 25 mm 4$^{\#}$MS-II increased the recovery rate up to 470 % compared to the original steel surface at 50 mm oil film. As shown in Fig. 8, when the diesel oil film thickness is deeper than 20 mm, the descending order of recovery rate is as follows: 25 mm > 15 mm > 5 mm > 0 mm. This may due to the porous structure of 4$^{\#}$MS-II which increases the effective surface area and storage space. When the oil film thickness is lower than 10 mm, it can be observed the order of recovery rate is as follows: 15 mm > 0 mm > 25 mm. It can be ascribed to the truth that the effective surface area between 25 mm 4$^{\#}$MS-II and oil decreases when the oil film thickness become thinner. The results indicate the advantage of 15 mm 4$^{\#}$MS-II, which is expected to be applied on the original disc skimmer.

3.3. Effect of immersion depth

Fig. 9 compares the effect of immersion depth on the recovery rate. The bar graphs indicate that the 15 mm 4$^{\#}$MS-II increased the recovery rate up to 316 % compared to the original steel surface at 1/2R. Fig. 9 shows that the rate of oil recovery increases with the increase of immersion depth. This may because as the immersion depth decreases, the oil layer spends less time covering the disc, which allows less detention time between the oil layer and the 4$^{\#}$MS-II sponge layer, resulting in lower recovery rate of oil. The results suggest that as the immersion depth increases, more oil can be absorbed by the 4$^{\#}$MS-II sponge layer. However, considering the buoyancy force and the extrusion desorption of the sponge - covered disc skimmer in actual working conditions, 1/2R is set as the immersion depth.

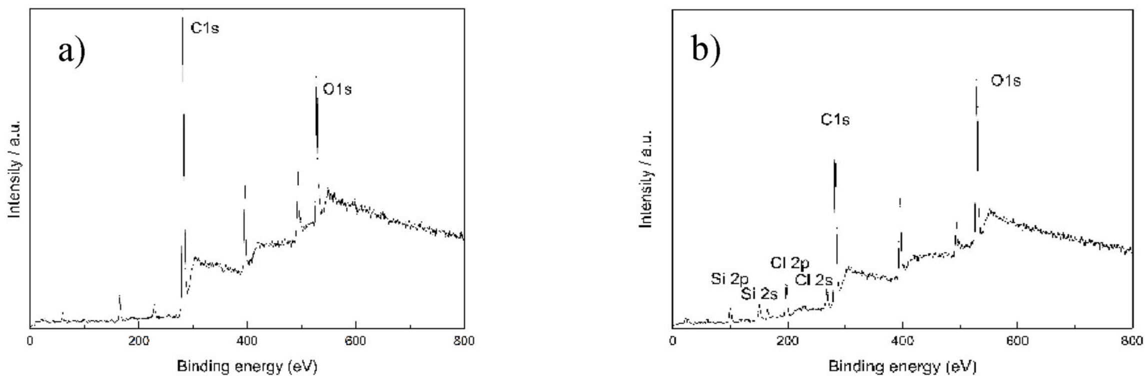

Fig. 4. The XPS survey spectra of a) MS-II, b) 4$^{\#}$ MS-II.

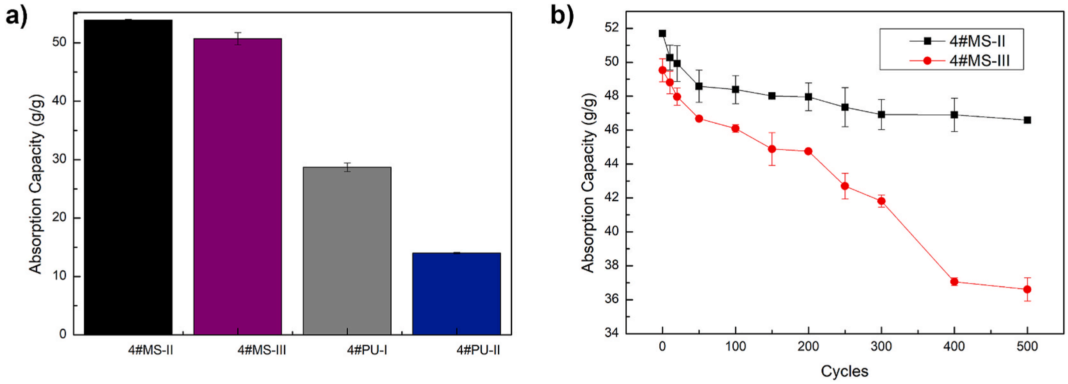

Fig. 5. Absorption performance of modified sponge samples a) Absorption capacity for diesel oil, b) Relationship between absorption capacity and the number of used cycles.

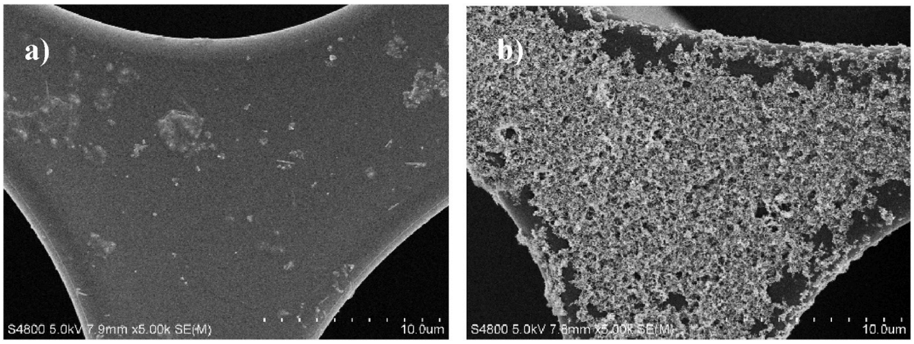

Fig. 6. SEM images of sponge samples a) MS-II, b) $4^{\#}$MS-II.

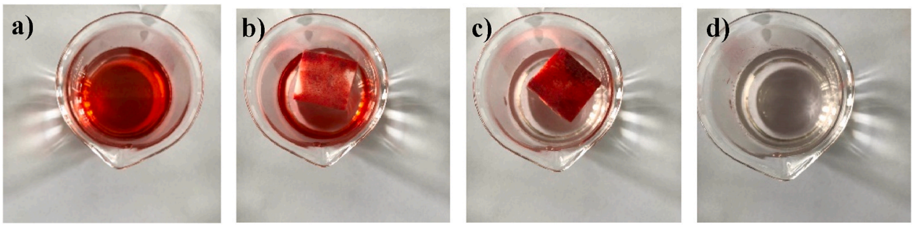

Fig. 7. Rapid absorption process of diesel oil by $4^{\#}$MS-II.

3.4. *Effect of rotational speed*

Fig. 10 illustrates the effect of rotational speed on the recovery rate. The result shows that the increase in rotational speed caused the oil recovery rate to increase with either surface. 15 mm $4^{\#}$MS-II exhibits great advantage at different rotational speed over steel surface and MS-II. This superiority is due to the super-hydrophobicity and porous structure of $4^{\#}$MS-II which full of capillary tube channels and allows oils to be spontaneously and selectively inhaled by capillary force [28]. 22.7 times higher of the recovery rate was achieved when increasing the rotational speed from 14 to 50 rpm in case of the 15 mm $4^{\#}$MS-II. This mainly because with the increase of rotational speed, the centrifugal force was enhanced [29], which accelerated the expansion process of the oil layer on the $4^{\#}$MS-II sponge layer, resulting in higher recovery rate.

3.5. *Effect of oil film thickness*

Fig. 11 shows the effect of oil film thickness on the recovery rate. The result demonstrates that the increase in oil film thickness caused the oil recovery rate to increase with either surface. In case of 15 mm $4^{\#}$ MS-II, 5.9 times higher of the recovery rate was obtained when increasing the oil film thickness from 5 to 50 mm. This is because the thicker oil film allowed longer detention time between the oil layer and the $4^{\#}$MS-II sponge layer, which benefited the oil absorption process, resulting in deeper oil penetration

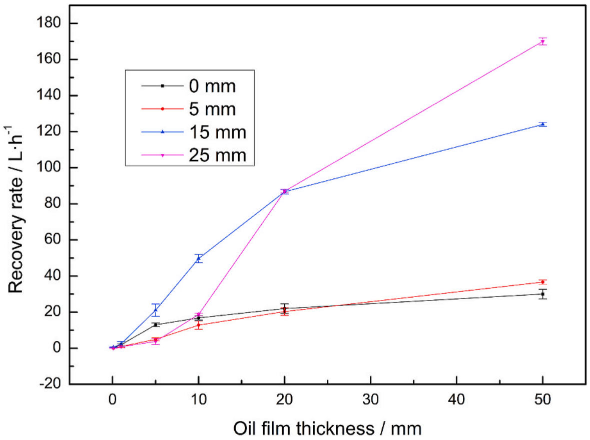

Fig. 8. Effect of surface material and film thickness on the recovery rate.

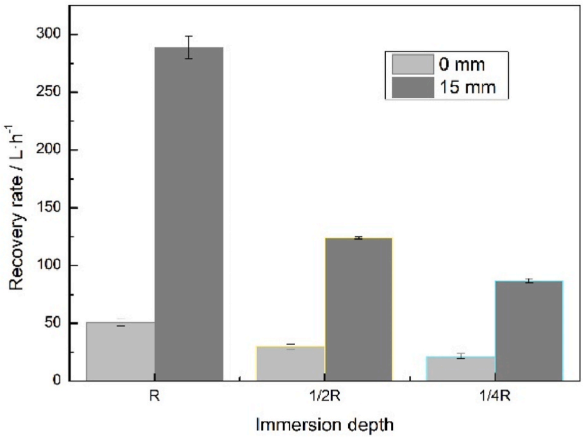

Fig. 9. Effect of immersion depth on the recovery rate.

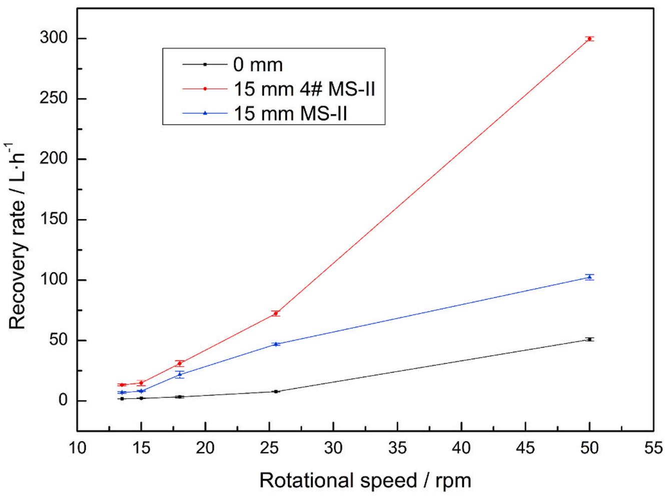

Fig. 10. Effect of rotational speed on the recovery rate.

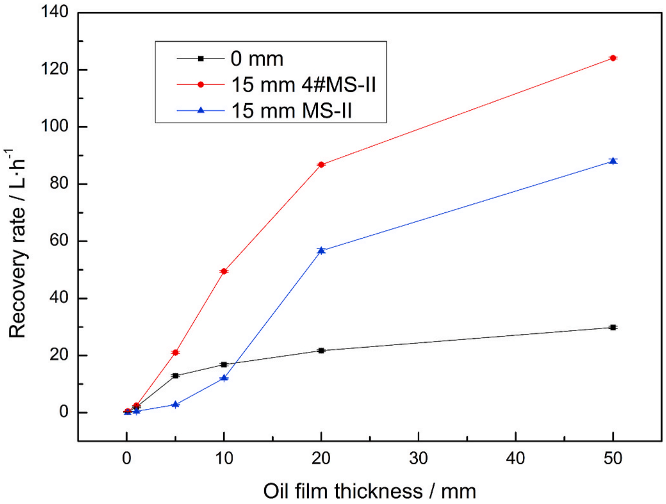

Fig. 11. Effect of oil film thickness on the recovery rate.

through the pores of $4^{\#}$MS-II. At 50 mm, the oil recovery rate of 15 mm $4^{\#}$MS-II (124.1 L/h) was significantly higher than that of 15 mm MS-II (88 L/h) and the steel surface (29.8 L/h). Also, the recovery efficiency of 15 mm $4^{\#}$MS-II reached 98.7 %, which was higher than that of steel surface (93.6 %) and 15 mm MS-II (51.2 %). 15 mm $4^{\#}$MS-II shows great advantage even at thin oil film. This may due to the fact that the detention time between the steel disc and the oil layer was not enough, for the oil layer tended to move downward under gravity in case of steel surface. Diesel oil can be absorbed spontaneously and rapidly by $4^{\#}$MS-II under capillary force, which overcomes the gravity, resulting in better recovery performance.

3.6. *Effect of operation time*

To investigate the operation stability of sponge - covered disc skimmer, long - run experiment was conducted with seawater from Jiaozhou Bay. Fig. 12 displays the effect of time on the recovery rate. The figure indicated that the increase in time caused the oil recovery rate to decrease with either surface. For 15 mm $4^{\#}$MS-II, a decrease of only 1.5 % in the recovery rate was achieved from 1 to 85 h. At 85 h, the oil recovery rate of 15 mm $4^{\#}$MS-II (124.1 L/h) was still higher than that of steel disc (88 L/h), with 95 % recovery efficiency, which can be attributed to the super-hydrophobicity, high elasticity and great recyclability of $4^{\#}$MS-II [30].

4. Conclusion

In this study, different modifiers were separately applied on polyurethane and melamine sponge to fabricate superhydrophobic sponge material. The effect of superhydrophobic sponge material on the disc skimmer performance was investigated. The main conclusions were drawn as follows:

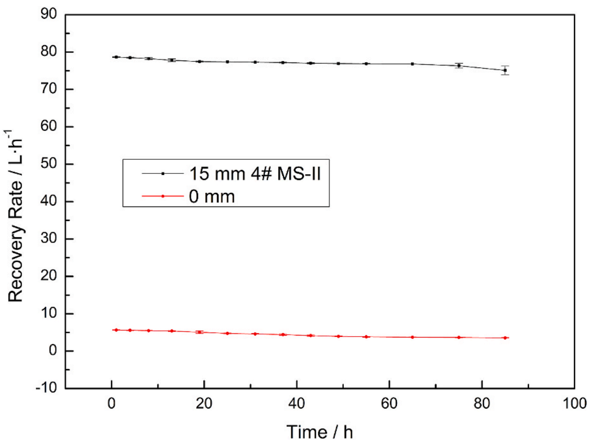

Fig. 12. Effect of time on the recovery rate.

- The melamine sponge, nano sponge, high-density sponge, sofa sponge, and polyurethane sponge were modified by nano-SiO_2, expanded graphite, and polyvinyl chloride with nano-SiO_2 separately. It was found that melamine sponge with high porosity and permeability is more easily to be impregnated and coated by modifier solution molecules. The melamine sponge modified by both polyvinyl chloride and nano-SiO_2 exhibits super-hydrophobicity with the water contact angle of 150.3°.
- $4^{\#}$MS-II, the melamine sponge modified by both polyvinyl chloride and hydrophobic nano-SiO_2, exhibits super-hydrophobicity. The absorption capacity of $4^{\#}$MS-II for diesel oil can reach 53.89 g/g. The absorption capacity can still achieve 90 % of its initial capacity even after 500 extrusion-absorption separation tests. Based on the excellent absorption capacity and recyclability, $4^{\#}$MS-II can be selected as a candidate for covering disc skimmer surface.
- To optimize the implementation mode of the $4^{\#}$MS-II sponge layer, effect of contact surface area, detention time, and absorption time between the oil layer and the $4^{\#}$MS-II sponge layer on the recovery rate was investigated. The loading thickness 15 mm, the immersion depth 1/2 R, and the rotational speed 50 rpm were selected as the operating parameters.
- 15 mm $4^{\#}$MS-II sponge layer covered proved a positive effect on the oil recovery performance of the disc skimmer with the plain steel surface. The diesel oil recovery rate (299.7L/h) of 15 mm $4^{\#}$MS-II was 5.7 times that of the plain steel surface material (50.68L/h) under ASTM standard test conditions. And after 85 h continuous operation, the recovery rate still reached 96.4 % of its initial performance, the recovery efficiency was stable at more than 95 %.

This research attempts to apply self-developed absorbents to the mechanical disc skimmer, encouraging superhydrophobic absorbents at theoretical laboratory stage to enter into an engineering application phase, which benefits mutual development of function materials and oil-recovery device. The superhydrophobic sponge significantly improves the oil recovery performance of the original mechanical disc skimmer, indicating the superhydrophobic sponge – covered disc skimmer provides better alternatives for oil spill recovery.

CRediT authorship contribution statement

Xi Yan: Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **Yan Xie:** Validation, Resources, Methodology, Formal analysis. **Shucai Zhang:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Xuejia Sheng:** Visualization, Data curation. **Jiancheng Sun:** Validation, Resources. **Wei Wang:** Investigation, Data curation. **Jingru Liu:** Validation, Resources. **Xiaohan Dou:** Investigation.

Declaration of competing interest

The authors declare that we have no conflicts of interest in this work.We declare that we have no financial or personal relationship with other people or organizations that can inappropriately influence our work. There is no commercial or associative interest that represents a conflict of interest in connection with the work submitted.

Acknowledgement

This research was supported by the National Key Project of "Science and Technology Boosting Economy 2020".

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e31574.

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