



Development of surface modified PU foam with improved oil absorption and reusability via an environmentally friendly and rapid pathway

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ABSTRACT

Although the commercial polyurethane (PU) foams are hydrophobic in nature, they generally show low degree of reusability for oil and organic solvent absorption. In this work, we proposed a solvent-free and rapid surface functionalization approach based on chemical vapor deposition (CVD) process to improve the surface characteristics of PU foam, increasing not only its reusability but also its absorption capacity. Among the monomers used to functionalize the surface of foam, our results showed that only hexamethyldisiloxane (HMDSO) and 2,2,3,4,4,4-hexafluorobutyl acrylate (HFBA) were promising to increase the absorption performance of the control PU foam, owing to the enhanced foam's surface hydrophobicity (with contact angle increased from $\sim 106^\circ$ to $120\text{--}135^\circ$) without altering the foam's porosity. These promising features are attributed to the formation of ultrathin highly hydrophobic yet uniform layer on the foam surface. Further investigation indicated that the modified foams outperformed the control foam for the multicycle cyclohexane and crude oil absorption (up to 10 cycles) by showing significantly higher absorption capacity. The reusability of the modified foams could be further improved when ethanol was employed to rinse the saturated foam after each absorption cycle. Such solvent rinsing help in maintaining the foam absorption capacity. In conclusion, the proposed greener surface modification method clearly demonstrated its effectiveness in functionalizing the PU foam, leading to higher absorption capacity against cyclohexane and crude oil as well as higher degree of reusability.

1. Introduction

Following the increase in global population, the consumption and production of petroleum products and its subsequent environmental impacts also mount accordingly. Despite substantial advancement in technological and regulatory prevention measures, the threat of major oil spills persists. Marine oil spills and illegal organic solvents/oil products discharge are especially harmful to the ecosystem and human health due to the large array of oils released ranging from heavy and persistent fuels to light, volatile and toxic fuels that may have high bioaccumulation ability [1–3]. Given this, cost-efficient and reliable oil spill removal approaches are important to address the problems.

At present, the commonly used oil removal methods are chemical coagulation, electrocoagulation, physical removal (e.g., coalescence and filtration), biological degradation and absorption [4]. In this regard, absorption is perhaps the most advantageous technology in large-scale oil spill cleanups due to its high efficiency (high processing speed and

capacity at low cost) and better oil recoverability [5]. Among the absorptive materials (also known as absorbents or sorbents) available (e.g., activated carbon, bentonite and cotton fibers), 3D polyurethane (PU) foam is generally considered one of the best materials as it could provide abundant oil storage spaces to maximize oil adsorption capacity owing to its high surface area and porosity [6].

Although PU foam in general, is a good sorbent, its characteristic that could absorb both oil and water molecules due to its ether-ester, carbamate and amide groups tend to compromise its oil absorption efficiency [7]. Hence, considerable research on oil-water separation using surface-modified PU foams have been done to improve its hydrophobicity as well as reusability [8]. These surface modification techniques are normally based on either layer-by-layer (LbL) assembly [9], dip coating [10,11], co-polymerization [12] or solvothermal [13]. However, it must be noted that most of the techniques are associated with shortcomings including time-consuming, complex procedures, usage of expensive and hazardous reagents, etc. All these adversely affect the

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practicability of mass production of the foams. For example, Anju et al. [10] synthesized magnetically-actuated PU foams by immersing it in a coating solution containing expensive nanomaterials (i.e., graphene oxide) for 24 h. In separate work, Liu et al. [14] and Mo et al. [15] respectively employed hazardous coupling agents, i.e., tetraethyl orthosilicate (TEOS) and 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide (EDC) during foam surface modification.

Hence, besides having high oil absorption efficiency and reusability, there are growing requirements for new generation absorbents, namely simple and scalable fabrication, environmentally friendly manufacturing, low cost and other specific features such as magnetism [16]. From this perspective, surface modification via chemical vapor deposition (CVD) method fulfills the criteria above as it is low cost, rapid, solvent-free and easily scalable. Previous studies reported that the highly controllable and uniform properties of polymeric films could be established via plasma-enhanced CVD (PECVD) [17] and initiated CVD (iCVD) [18,19]. Compared to other CVD processes such as photo-assisted CVD, atomic layer deposition, and chemical beam epitaxy, PECVD and iCVD are the most advanced form of the processes.

It becomes apparent that polymeric coatings from PECVD typically have a more branched structure with a greater degree of cross-linking when compared to iCVD, although excessive ion bombardment could damage the desired chemical structures of the deposited coating [20]. It should be noted that a comparison between these two CVD processes have been previously made where a single substrate was modified using either PECVD or iCVD and tested for the same application [21,22]. Keeping these in mind, this study aims to investigate the absorption capacity and reusability of CVD-functionalized PU foams in oil and organic solvents. Three hydrophobic monomers were used in this work for the surface modification of the PU foams. They were hexamethyldisiloxane (HMDSO), perfluorodecyl acrylate (PFDA) and 2,2,3,4,4,4-hexafluorobutyl acrylate (HFBA). Depending on the monomer chosen, either PECVD or iCVD process was employed during PU foam modification. All the CVD-functionalized foams were characterized using a series of instruments including Fourier transform infrared (FTIR) spectroscope, X-ray photoelectron spectroscope (XPS), contact angle (CA) goniometer and field emission scanning electron microscope (FESEM). At last, the absorption capacity and reusability (up to 10 cycles) of the functionalized foams were investigated to provide an insight on the improved performance of CVD-functionalized foams in comparison to the control foam.

2. Experimental

2.1. Materials

Commercial PU foam with a density of 13 kg/m³ supplied by Preeco Engineering Sdn. Bhd., Malaysia was used in this study. Three different monomers, i.e., HMDSO (≥98%), HFBA (95%) and PFDA (97%) obtained from Sigma Aldrich, USA were utilized for PU foam surface modification. Di-tert butyl peroxide (TBPO, 98%) supplied by Sigma Aldrich, USA was used as initiator during iCVD process. Organic solvents that were tested in this study were crude oil obtained from Terengganu Crude Oil Terminal, Malaysia (Location: RE110), lubricating oil (Castrol GTX 10W-30 Modern Engine oil), cyclohexane (≥99%, Fisher Scientific, USA) and gasoline (RON95, Shell, Malaysia). For the foam reusability test, ethanol (≥95%, Sigma Aldrich, USA) was used to rinse the foams after each cycle of absorption. All chemicals/materials were used as received without any further modification or purification.

2.2. Surface functionalization of PU foam

Two CVD functionalization approaches (PECVD and iCVD) were employed to modify the PU foam surface as detailed in our previous work [22]. The optimized deposition time for all monomers in PECVD and iCVD processes was at 5 min. Detailed setup of the PECVD [23] and

iCVD [24] system can be found elsewhere. Fig. 1 shows the chemical structure of the monomers used in this study.

In brief, PECVD functionalization was initiated by placing the PU foam samples (Dimension: 1.5 cm × 1.5 cm × 1.5 cm) in a rotating Pyrex glass chamber followed by vacuum purging to remove impurities from the chamber. Then, HMDSO was fed into the reactor at room temperature and subsequently plasmarized in the chamber, forming a polymerized HMDSO film on the PU foam. The optimized deposition conditions were fixed at 75 mtorr reactor pressure, 70 W plasma power and 1 sccm monomer flowrate. The functionalized foam sample was then denoted as PU/PHMDSO.

For iCVD modification, the PU foam samples were placed in a stainless-steel reactor attached to a heat exchanger, followed by similar vacuum purging. The initiator (TBPO) along with HFBA or PFDA monomer were then fed into the reactor. The activation energy to initiate polymerization in iCVD was supplied by a heated tungsten filament in the reactor. The monomer jar temperature, manifold pipeline temperature, chamber pressure, filament temperature, monomer flowrate and initiator flowrate were respectively optimized at 30 °C, 40 °C, 1100 mtorr, 200 °C, 2 sccm and 2 sccm for HFBA functionalization and 55 °C, 70 °C, 150 mtorr, 280 °C, 0.5 sccm and 0.8 sccm for PFDA functionalization. After functionalization, the samples were designated as PU/PHFBA_i or PU/PPFDA_i, based on the type of monomers used.

2.3. Characterization

A Fourier transform infrared (FTIR) spectroscope (Perkin Elmer Frontier, USA) was used to analyze the PU foam surface chemistry under attenuated total reflectance (ATR) mode. The presence of specific functional groups on the foam surface was identified by collecting the FTIR spectrum from 650 to 4000 cm⁻¹. The elemental composition of the PU foam samples was determined using X-ray photoelectron spectroscope (XPS, Kratos Axis Ultra DLD, UK) with Al K_α (1486 eV) radiation. The elements scanned and their respective binding energies are carbon (C, 285 eV), nitrogen (N, 399 eV), oxygen (O, 532 eV) and fluorine (F, 689 eV). A contact angle goniometer (DataPhysics OCA 15Pro, Germany) was used to investigate the wettability of PU foams via the sessile drop method, with RO water as the probe liquid. The droplet volume during contact angle measurement was fixed at 2 μL. Ten measurements were taken and its average was recorded. The hydrophobicity of PU and PU/PHMDSO samples were compared by observing the absorption rate of a crude oil droplet on the foam surface for up to 35 s. Structural morphology of the foam samples were observed using field emission scanning electron microscope (FESEM, Hitachi SU8000, Japan). Prior to scanning, platinum was sputter-coated onto the sample surface to ensure that the samples are electrically conductive.

2.4. Absorption capacity test

The absorption capacity test was conducted using a weighing method based on the Standard Test Method for Sorbent Performance of Adsorbents (ASTM F726–99). Prior to analysis, the dry weight of clean PU foam sample (Dimension: 1.5 cm × 1.5 cm × 1.5 cm) was recorded, followed by immersion in a glass beaker containing 100 mL of tested solvent (either reverse osmosis (RO) water, lubricating oil, crude oil, cyclohexane or gasoline) for 5 min. Thereafter, the saturated foam was removed from the tested solvent and kept in the air for 5 s to drain off the loosely-adhered solvent. The final saturated weight was then measured using a high precision digital balance (readability: 0.0001 g). The absorption capacity of PU foams was calculated using the following formula:

$$\text{Absorption capacity (g/g)} = \frac{W_t - W_0}{W_0} \quad (1)$$

where W_0 and W_t are the initial dry weight and final saturated weight of

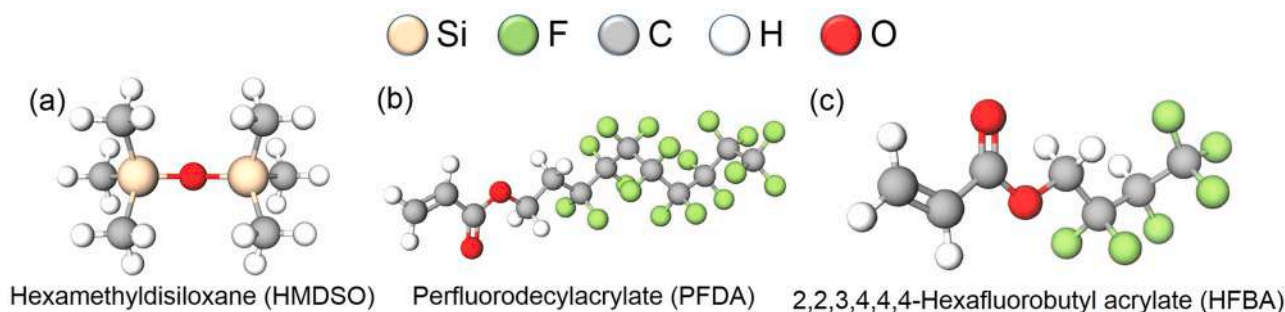


Fig. 1. Organic structure of (a) HMDSO ($\text{O}[\text{Si}(\text{CH}_3)_3]_2$; MW: 162.4 g/mol), (b) PFDA ($\text{H}_2\text{C}=\text{CHCO}_2\text{CH}_2\text{CH}_2(\text{CF}_2)_7\text{CF}_3$; MW: 518.2 g/mol) and (c) HFBA ($\text{H}_2\text{C}=\text{CHCO}_2\text{CH}_2\text{CF}_2\text{CH}(\text{F})\text{CF}_3$; MW: 236.1 g/mol).

the PU foam sample, respectively.

The absorption kinetics of PU foam samples in viscous lubricating oil solvent were investigated using a similar weighing method, except that the absorption capacity was measured every 1 min for a total duration of 10 min.

2.5. Reusability test

The reusability of PU foam was further investigated by subjecting it to selected solvents' absorption for up to 10 cycles. The absorption capacity of PU foam after each absorption cycle was measured using a similar approach described in Section 2.4, except the same foam was sandwiched in tissue and mechanically pressed to remove excess solvent after each cycle. To investigate the effect of ethanol rinsing on PU foam reusability, another test was further conducted using only crude oil as the tested solvent. Instead of mechanical pressing, the saturated PU foams were rinsed using ethanol to remove the excess oil after each cycle. In the ethanol rinsing step, the saturated PU foam was directly placed in a covered glass beaker containing 100-mL ethanol and shaken at 200 rpm for 45 min. Then, the rinsed PU foam was removed from the beaker and dried in a 60 °C oven for 15 min before it was reused in the next cycle. For both reusability tests, the oils or organic solvent absorption capacities measured were then normalized to their initial values to determine their performance change after each cycle.

3. Results and discussion

3.1 Characterization of control and modified PU Foams

Fig. 2(a) presents the ATR-FTIR spectra of control and modified PU foams at two different wavenumber ranges. The surface chemistry for the unmodified PU foam can be verified at several peaks, i.e., 3282 cm^{-1} , 2850–3000 cm^{-1} , 1710 cm^{-1} , 1640 cm^{-1} , 1505 cm^{-1} and 1087 cm^{-1} [22,25]. These peaks are respectively attributed to the N-H stretching, $-\text{CH}_2$ stretching, C=O stretching of ester, C=O stretching of urea, N-H deformation and C-O stretching. For the modified foams, the presence of two peculiar peaks at 1015 cm^{-1} (Si-O-Si stretching vibration) and 841 cm^{-1} (Si-C rocking vibration) [26] in the PU/PHMDSO and the new peak detected at 1146 cm^{-1} ($\text{CF}_2\text{-CF}_3$ end group) [27] in the PU/PPFDA_i clearly indicate that the surface of PU foam has been successfully functionalized. However, no distinct difference is found for the PU/PHFBA_i by comparing it with the typical PU owing to its extremely low concentration [22]. Because of this, XPS analysis was further conducted to examine the changes on the PU/PHFBA_i and the results are presented in Fig. 2(b). Since PU foam ($\text{C}_{17}\text{H}_{16}\text{N}_2\text{O}_4$) does not contain F element in its structure, the detection of fluorine (F) in the PU/PHFBA_i confirms the existence of HFBA on the PU foam. The important functional groups that contribute to the FTIR peaks and XPS spectrum are presented in Fig. 1.

The water contact angle of control and modified PU foams was also

measured to investigate the effects of surface modifications on the hydrophobicity of PU foams and the results are shown in Fig. 2(c). The water contact angle which is greater than 100° implies that the control PU foam is naturally hydrophobic. Our results show that the hydrophobicity of PU foam could be further elevated by depositing a thin layer of highly hydrophobic materials on its surface. The water contact angle increases in the order of control PU (106.18°) < PU/PHFBA_i (120.69°) < PU/PHMDSO (134.89°) < PU/PPFDA_i (136.43°). The increased contact angle of modified PU foams after the deposition of hydrophobic polymers is attributed to the reduced surface energy of PU foams [28,29]. The relatively higher water contact angle of PU/PPFDA_i, when compared to PU/PHFBA_i, is due to its longer fluorinated side groups [30].

Fig. 2(d) shows the photographs of a crude oil droplet on the surface of PU and PU/PHMDSO which is captured at increasing time interval. As can be seen, the oil droplet is instantaneously absorbed into the PU/PHMDSO within 5 s, whereas the droplet remains on the control PU for up to 15 s before being absorbed into the foam. In addition, the oil droplet on PU/PHMDSO spreads out faster compared to the oil droplet on the control PU and this is attributed to the additional hydrophobic functional groups that aid in spreading the oil droplet towards its structure. The improved surface hydrophobicity of modified foam is strongly supported by its greater water contact angle in comparison to the control foam (Fig. 2(c)).

Fig. 3 shows the FESEM images of PU foam surfaces modified with different polymers. As can be seen, there is no notable change in the porous structure of the PU foam before (see Fig. 3(a)) and after surface modification (see Fig. 3(b)–(d)). This suggests that the coating layer deposited via CVD approach is extremely thin and conformal [29,31]. On the foam surface, it is found that the surface of PU foams becomes smoother upon surface modification. Depending on the material deposited, the pattern of the foam surface is varied. The PU/PPFDA_i is found to exhibit the roughest surface followed by the PU/PHFBA_i and PU/PHMDSO foam.

3.2 Absorption capacity of control and modified PU foams

The absorption capacity of control and modified PU foams for water, oils (i.e., lubricating oil, crude oil and gasoline) and organic solvent (i.e., cyclohexane) is demonstrated in Fig. 4. Compared to the modified PU foams, the control PU foam exhibits a relatively higher absorption capacity for water. This indicates that control PU foam has a higher affinity for water and is naturally less effective for selective removal of oils from water.

The hydrophobic surface modifications of PU foams via CVD method (except for PU/PPFDA_i) are found to improve their absorption capacity for oils and organic solvent. The improved surface hydrophobicity of foam as evidenced in this work is in good agreement with other studies that also demonstrated the superhydrophobic properties of PHMDSO [32] and PHFBA [33] film coated on a substrate via CVD method. Our

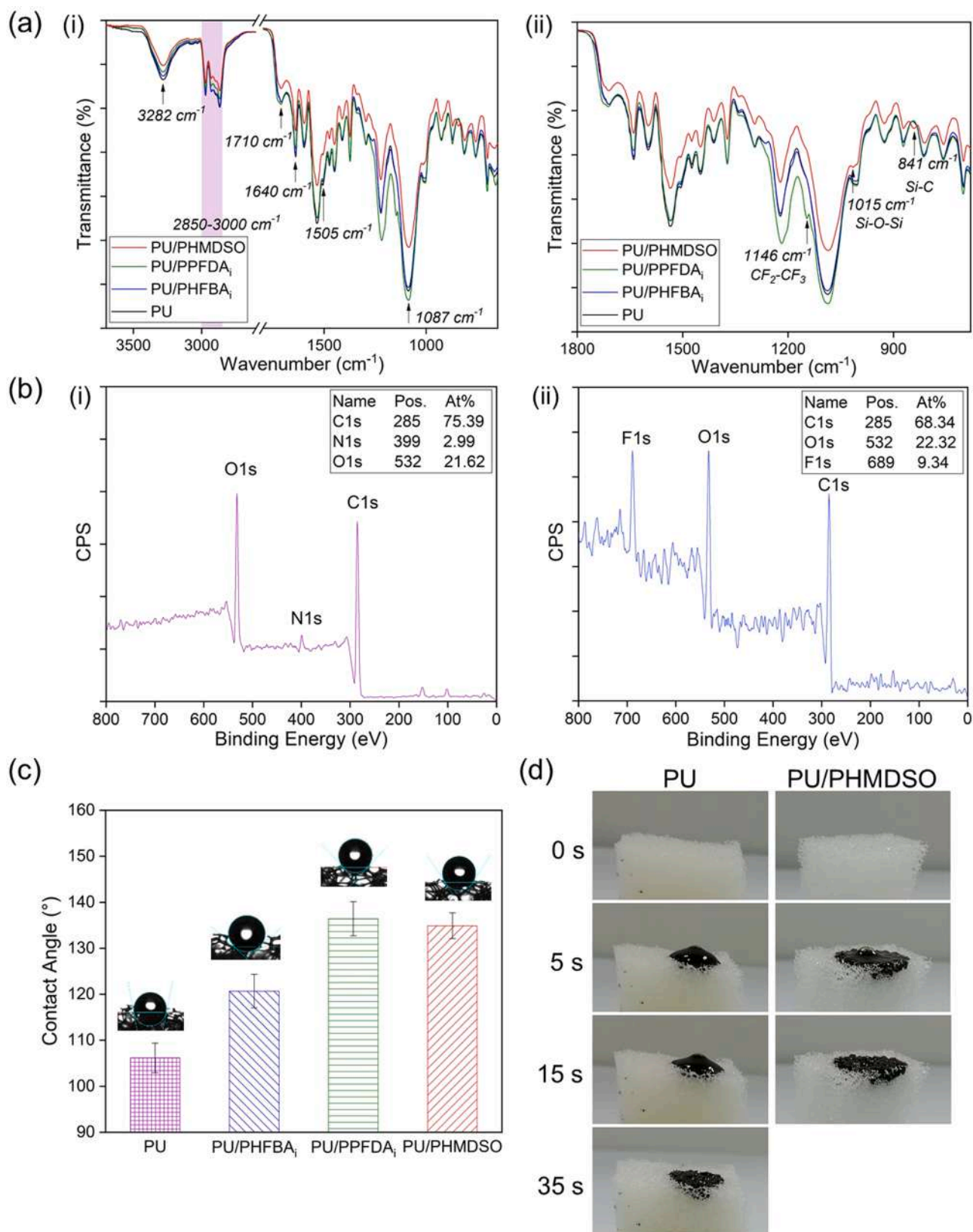


Fig. 2. (a) ATR-FTIR spectra of the control and modified PU foams at different wavenumber range, (i) 3700–650 cm⁻¹ (full range) and (ii) 1800–680 cm⁻¹ (narrow range), (b) XPS spectra of (i) PU and (ii) PU/PHFBA₁, (c) Water contact angle of control and modified PU foams (Inset: photograph of a water droplet on sample surface) and (d) photographs of crude oil droplet (~0.1 mL) on the surface of PU and PU/PHMDSO at increasing absorption time.

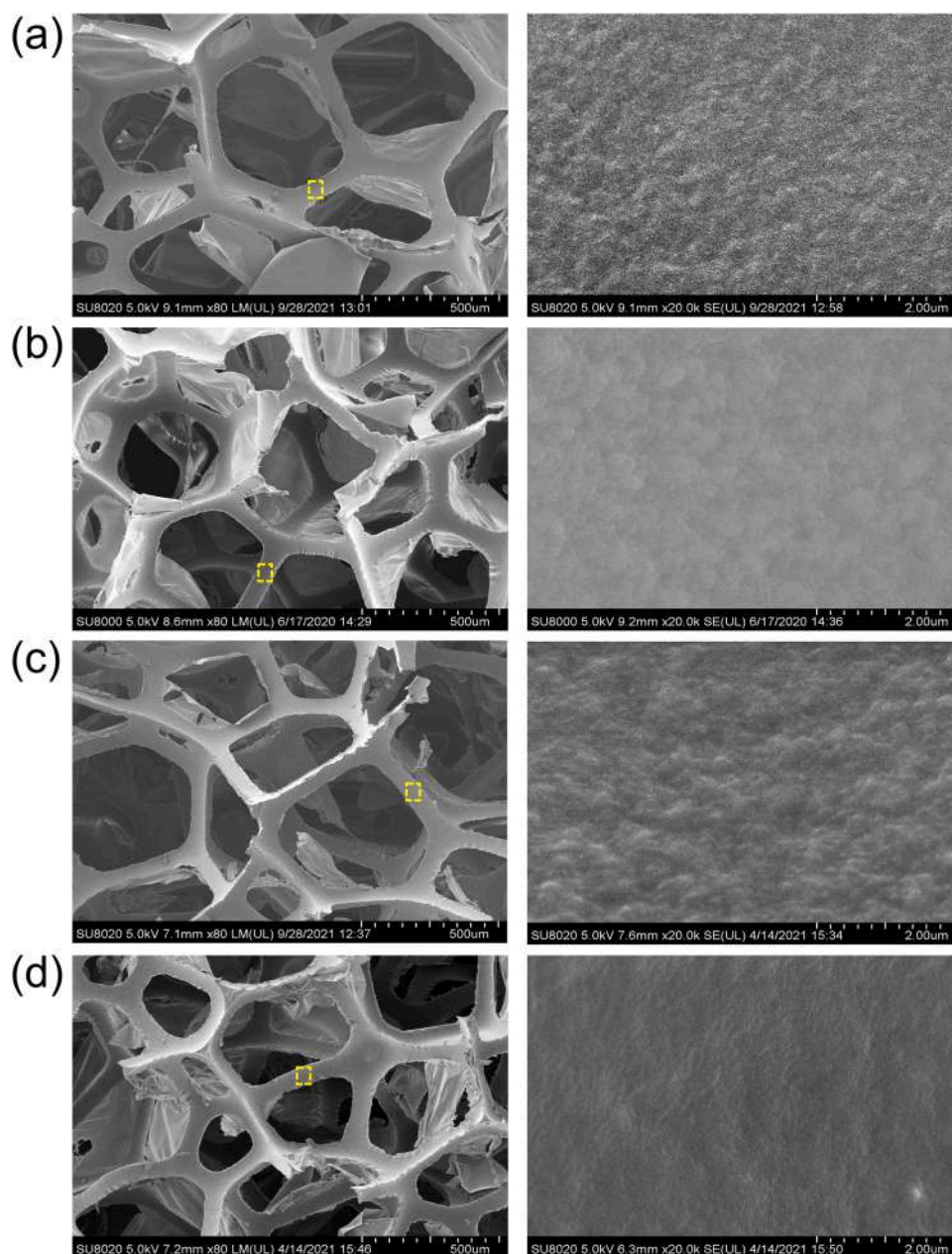


Fig. 3. FESEM images of foam viewed at lower (Scale bar: 500 μm , Left) and higher magnification (Scale bar: 2 μm , Right), (a) control PU, (b) PU/PHFBA_i, (c) PU/PPFDA_i and (d) PU/PHMDSO. Note: The yellow empty box was the area of the foam that was further viewed at higher magnification.

results also show that these modified PU foams exhibit lowered water affinity. Such observation is caused by the reduced surface energy of PU foam upon hydrophobic modifications, leading to an increase in hydrophobic solvent adsorption [34]. Although PPFDA coating is similarly hydrophobic, the lower absorption capacity of PU/PPFDA_i for almost all types of oils/organic solvent is possibly due to its lower porosity. It was revealed in our previous study that surface modification could slightly reduce the porosity of foam and affect its absorption capacity [22]. Foam with lower porosity provides a smaller pore volume for oils/organic solvent storage, leading to a lower absorption capacity. As evidenced, our previous study showed that the PU/PPFDA_i foam exhibited a porosity of 0.91 while the PU, PU/PHFBA_i and PU/PHMDSO recorded a value of 0.95, 0.95 and 0.93, respectively [22].

The change in absorption capacity of oils/organic solvents is also affected by the density and viscosity of oils/organic solvent [35,36]. The properties of oils/organic solvent tested are summarized in Table 1. In general, the absorption capacity for oils/organic solvent decreases in the

order of cyclohexane > gasoline > crude oil > lubricating oil. The less viscous oils/organic solvents (e.g., cyclohexane, gasoline and crude oil) can diffuse faster into the foam when compared to the more viscous oil (e.g., lubricating oil) [37], resulting in their relatively higher absorption capacity. Although the high viscosity of lubricating oil makes it difficult to diffuse into the foam, its absorption capacity is still considerably high, possibly due to its high density. Oil with high density can increase the weight of foam following the absorption process when it adheres to the surface of the foam.

Gasoline, with the lowest viscosity among oils/organic solvent tested, results in its easy diffusion through foams. This allowed the foam to show a relatively high absorption capacity even without surface modification. However, the deposition of hydrophobic polymers via CVD method tends to reduce not only the foam porosity but also its space available for storing solvent. As a result, all modified PU foams exhibit a slightly lower absorption capacity for gasoline.

Further analysis (absorption kinetic) indicates that the diffusion

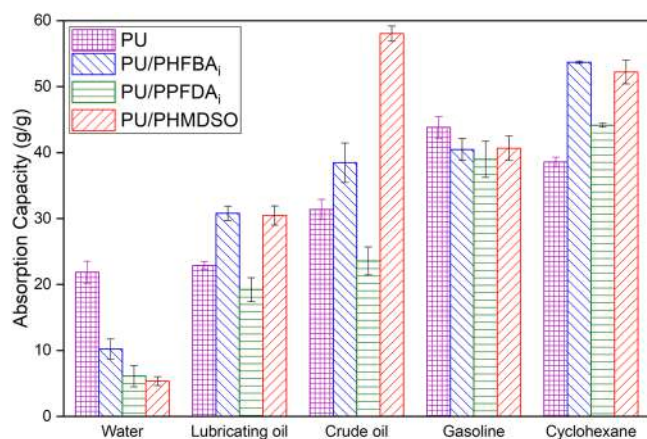


Fig. 4. Absorption capacities of control PU and modified PU foams against water, oils (lubricating oil, crude oil and gasoline) and organic solvents (cyclohexane).

Table 1

Properties of oil and organic solvents.

| Sample | Viscosity (mPas) | Density (kg/m ³) |
|-----------------|------------------|------------------------------|
| Crude oil | 3.581 | 808.65 |
| Lubricating oil | 68 | < 1000 |
| Gasoline | 0.5–0.75 | 725–780 |
| Cyclohexane | 0.894 | 773.9 |

Note: Data for lubricating oil and gasoline (RON 95) are obtained from their corresponding chemical's safety data sheets while data for crude oil and cyclohexane are obtained from [38] and [39], respectively.

velocity of viscous lubricating oil into the PU/PHMDSO foam is the highest compared to other modified foams, signifying its superior solvent absorption potential (Fig. 5). Although the initial diffusion velocity of PU/PHFBA₁ foam is lower than the PU/PHMDSO foam (most likely due its lower hydrophobicity as seen in Fig. 2(c)), both foams exhibit similar absorption capacity after 6 min and achieve similar saturation status at the end of experiment, supporting the results shown in Fig. 4. The PU/PPFDA₁ foam meanwhile exhibits the lowest absorption velocity and the results are consistent with the absorption trend shown in Fig. 4.

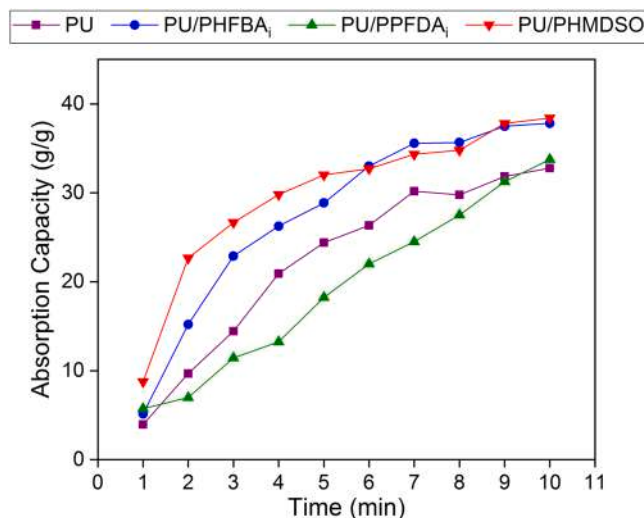


Fig. 5. Absorption kinetics of modified and unmodified PU foams using viscous lubricating oil as solvent.

3.3 Reusability test

The reusability of selected PU foams is first evaluated by repeatedly immersing the foam in oils or organic solvent for adsorption to take place and manually pressing the foam to drain off the adsorbed materials before the next adsorption process. The normalized absorption capacity of control PU and modified PU foams for lubricating oil, cyclohexane and crude oil during 10 continuous cycles is presented in Fig. 6. Since mechanical removal does not completely remove adsorbed oils or organic solvent from the foam sample, a significant drop in absorption capacity is typically observed after the 1st cycle regardless of oils/organic solvent or foam tested.

All foams are found to exhibit higher absorption reusability for both cyclohexane and crude oil owing to their relatively lower viscosity when compared to lubricating oil. As the absorption performances of modified foams for cyclohexane and crude oil are consistently higher compared to the control foam throughout the 10 testing cycles, we can confidently say that the PHFBA and PHMDSO coatings are well-retained on the PU foam even after repeated application of mechanical force. Compared to the PU foam, the modified PU/PHFBA₁ and PU/PHMDSO foams show higher absorption capacity for multicycles for both cyclohexane and crude oil due to its improved surface chemistry (i.e., hydrophobicity) as discussed previously. On the other hand, the slightly higher or similar absorption reusability of PU/PHFBA₁ and PU/PHMDSO foams for lubricating oil when compared to the control PU may be attributed to the high viscosity of the tested oil. As mentioned previously, solvent viscosity has a large impact on the foam absorption capacity. Therefore, the highly viscous lubricating oil (the highest viscosity among the solvents tested) is very likely to create a thicker oil layer on the foam surface, making it unable to absorb oil effectively after the 1st cycle.

Generally, the amount of oils or organic solvent left attached on the surface or within the foam after each cycle greatly impacts the foam reusability as its absorption capacity will inadvertently be lowered in the following cycle. Therefore, compared to the mechanical removal (i.e., pressing), chemical treatment using ethanol is significantly effective in removing the amount of adsorbed oils or organic solvent from the saturated foam (Fig. 7a). Fig. 7(b) shows the effect of ethanol rinsing on the reusability of selected PU foams tested using crude oil. Notably, both PU/PHFBA₁ and PU/PHMDSO foams exhibit minimal drop from their initial absorption capacity due to the effective ethanol cleaning that could greatly remove most of the adsorbed oil. The control PU foam shows an almost linear drop in absorption capacity after the 4th cycle, most likely due to the swelling of PU foam caused by ethanol. In comparison, the presence of hydrophobic functional groups on the modified foams is able to overcome the swelling impact, ensuring a high absorption capacity throughout the testing cycles.

4. Conclusion

In this study, we demonstrated a solvent-free and rapid surface functionalization approach to improve the surface chemistry of PU foam for the effective removal of oils and organic solvents via absorption. Such an approach based on the chemical vapor deposition (CVD) process only required 5 min to achieve desired properties and the modified foam could be directly used for adsorption without needing to go through any post-treatment. We have functionalized the surface of PU foam with three different monomers, namely HMDSO, HFBA and PFDA and our results showed that only foams modified with HMDSO and HFBA (i.e., PU/PHMDSO and PU/PHFBA₁) exhibited higher absorption capacity against the test oils/solvents, i.e., lubricating oil, crude oil and cyclohexane compared to the control foam. The improved absorption capacity of modified foams could be mainly attributed to the increase in the foam's hydrophobicity (from water contact angle of control foam of ~106° to 120–135°) without compromising its porosity. Findings from the reusability tests (up to 10 cycles) further confirmed the practical use of PU/PHMDSO and PU/PHFBA₁ for cyclohexane and crude oil. Our

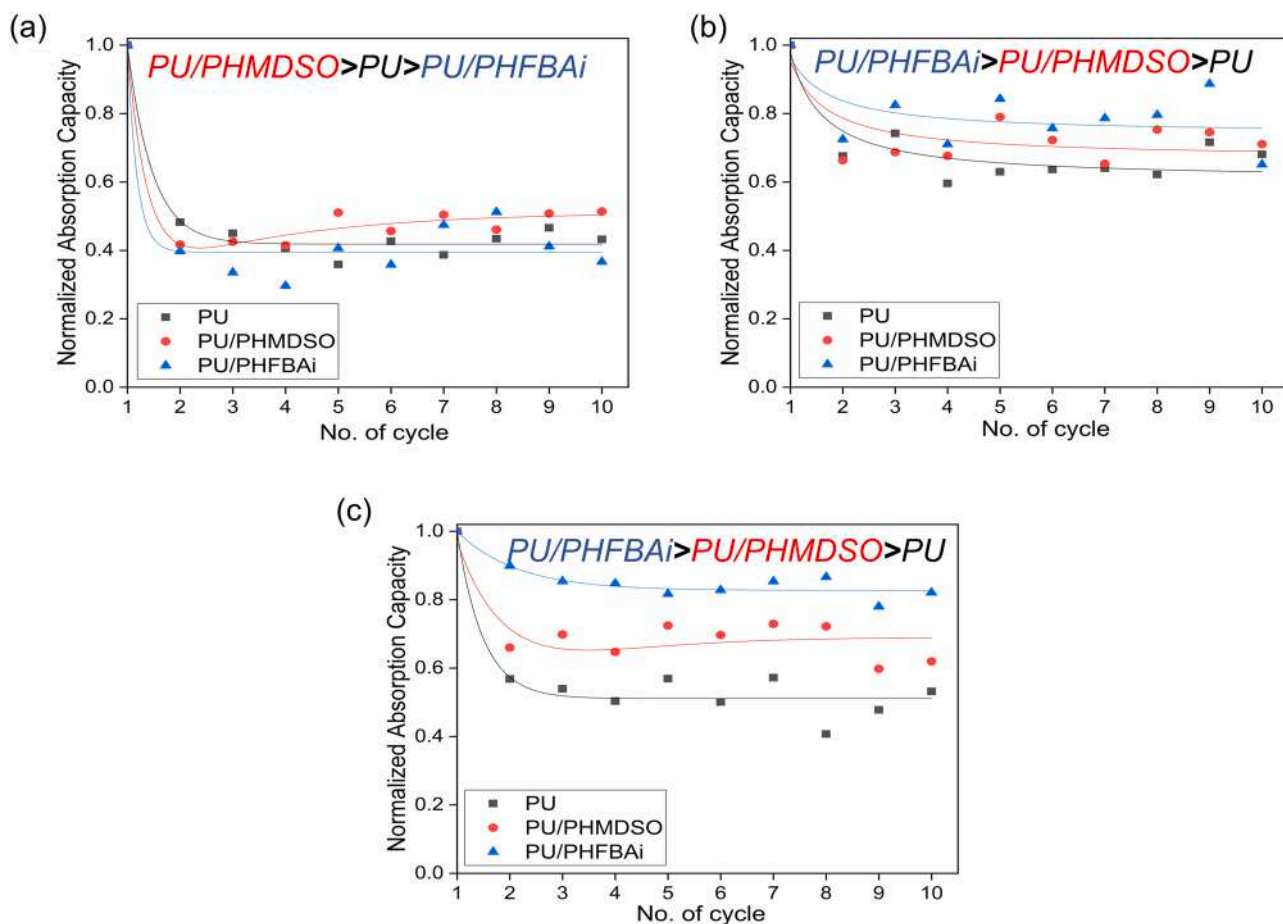


Fig. 6. Reusability of control PU, PU/PHFBA_i and PU/PHMDSO against (a) lubricating oil, (b) cyclohexane and (c) crude oil for up to 10 cycles. The foam is pressed multiple times to remove the absorbed oil before each cycle.

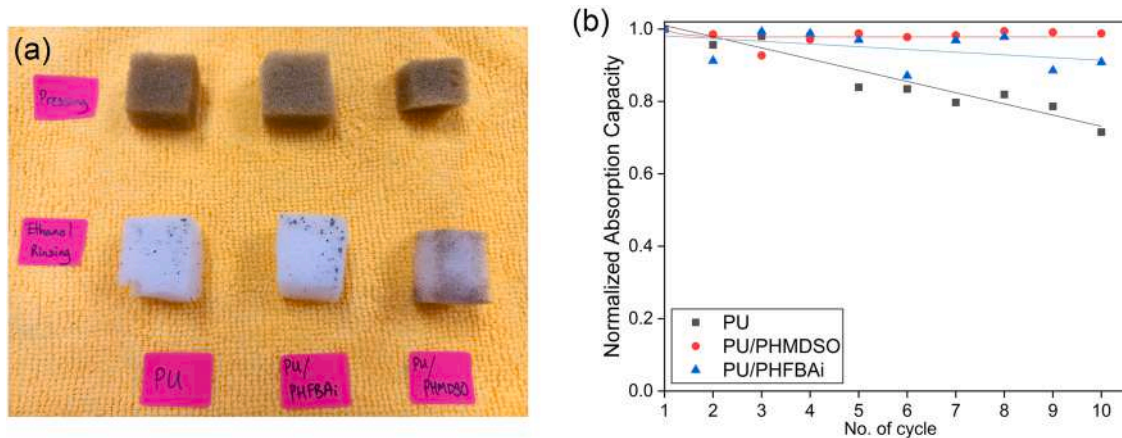


Fig. 7. (a) Photograph of PU foams after solvent (crude oil) removal via pressing or ethanol rinsing method for 1st cycle of reusability test and (b) reusability of control PU, PU/PHFBA_i and PU/PHMDSO against crude oil for up to 10 cycles. The foam is rinsed with ethanol to remove the absorbed crude oil before the next cycle is initiated.

results showed that when ethanol was used to rinse the saturated foam (after each testing cycle), both PU/PHMDSO and PU/PHFBA_i exhibited minimal drop from their initial absorption capacity. The control PU foam meanwhile suffered from an almost linear drop in absorption capacity after the 4th cycle. In conclusion, the proposed method to functionalize the PU foam could produce a much better result for oils and organic solvents removal. Most importantly, the proposed method is environmentally friendly (solvent-free) and is capable of achieving the

desired functionality in a very short duration (5 min).

CRediT authorship contribution statement

Mei Qun Seah: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Zhi Chien Ng:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Woei Jye**

Lau: Funding acquisition, Supervision, Validation, Writing – review & editing. **Gursoy Mehmet Gürsoy:** Methodology. **Mustafa Karaman:** Methodology. **Tuck-Whye Wong:** Project administration, Writing – review & editing. **Ahmad Fauzi Ismail:** Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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