Application of Porous Polydimethylsiloxane (PDMS) in oil absorption

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Abstract. Porous polydimethylsiloxane (PDMS) displays both hydrophobic and oleophilic behaviour which makes it a suitable material to absorb oil in an aqueous stream. Furthermore, its elastomeric nature means that porous PDMS can be a reusable sorbent for oil. For such application, porous PDMS has to (i) absorb oil from aqueous stream quickly and (ii) discharge oil rapidly when compressed. In this study, porous polydimethylsiloxane (PDMS) has been fabricated using sugar templating method. The ability of porous PDMS to absorb olive, sunflower and vegetable oils with and without vibration was investigated. Small amplitude vibration was found to accelerate the oil uptake process and accelerates the absorption of olive and vegetable oil by 2.5 and 3 times, respectively. Compressive stress-strain curves over compression rates between 2 and 100 mm per min are similar and indicate mechanical property of porous PDMS does not vary significantly and can be rapidly compressed.

1. Introduction
Unwanted oil release is a serious environmental and health issue and may result in damages to property, poisoning and death of animals. To mitigate the effects of oil pollution, a wide range of material solutions have been developed that disperse, absorb, solidify (coagulates) and contain organic sources. Absorbent materials are particularly attractive as they promises complete removal of oil pollutants and are may be reusable [1]. Porous materials with unique wettability to water and oil, e.g., porous fibrous mats, superhydrophobic textiles and superhydrophilic / superoleophobic hygro-responsive membranes have recently attracted significant attention for oil/water separation [2]. The collection of oil using materials with both hydrophobic and oleophilic properties is often preferred because it allows for the proper disposal of oil and does not cause secondary pollution [3]. The first example of oil water separation was been reported by Jiang et al. using a mesh coated with hydrophobic and oleophilic materials [4].

Polydimethylsiloxane (PDMS) is an elastomer with desirable properties including clarity, durability, chemically inertness, non-toxicity and non-flammability. It is widely used for biological and medical applications such as in prosthesis, biomedical devices and implants as it is a biocompatible material. Furthermore, PDMS has a low glass transition temperature, low surface tension, no surface viscosity, low boiling point and high compressibility [5]. Unlike bulk polymers, its compressibility is more than 80% without side-wall buckling [6]. The PDMS sponge can completely recover its original shape even after 50 cycles of 90% strain and the elongation at breaking the sponge is as high as 97%. [2].

In this study, porous PDMS was investigated as a medium for oil absorption. Porous PDMS was
fabricated using the sugar templating method. It was found that low amplitude vibration increases its oil absorption performance. Its mechanical properties of under compression at various strain rates was investigated. Polydimethylsiloxane has been proven to be safe and present no risk to human and environment.

2. Experimental studies

Chemicals used in this study were purchased from suppliers and used in the as-received condition. Polydimethylsiloxane (PDMS) used in this study was commercial grade Sylgard 184 silicone elastomer (Dow Corning) purchased from a commercial supplier. The elastomer kit consists of a resin and cross-linking agent and used as per manufacturer’s instruction. White sugar ‘cubes’ to be used as templates and three types of oil (olive, sunflower and vegetable) were all purchased from a local supermarket.

![Figure 1. (a) Schematic process flow to fabricate porous PDMS. (b) Oil absorption test showing five porous PDMS ‘cuboids’ in an 2 % (by volume) oil and water suspension.](image)

2.1. Fabrication of porous PDMS

Porous PDMS were manufactured using the templating method with sugar ‘cubes’ used as templates. Figure 1(a) is a schematic of the process flow. Polydimethylsiloxane resin and crosslinking agent were mixed in the ratio 1 part cross link agent to 10 parts resin as per manufacturer’s recommendations. Mixing was done gently to prevent bubbles from forming. The mixture was then poured onto sugar ‘cubes’ which are then stored under vacuum at room temperature overnight. The PDMS-infiltrated sugar ‘cubes’ were then placed in boiling water for 15 to 20 mins to dissolve away sugar. After the sugar has been completely removed, porous PDMS foams were dried thoroughly.

2.2. Characterization of structural, mechanical and oil absorption properties

Microstructure of porous PDMS fabricated was investigated using optical microscopy (Nikon). Micrographs obtained were analysed using an open source image analysis software (ImageJ). Average diameter was computed from at least twenty pores observed on the surface of porous PDMS.

Mechanical property of porous PDMS at different strain rates was compared using compression tests using an Instron test machine with a load of cell of 5 kN. Tests were done at constant compression rates by means of Bluehill software. All tests were carried out at room temperature and ambient humidity.

Oil absorption ability was investigated by soaking porous PDMS in a suspension of 2 % oil in water as shown in figure 1(b). Mixtures of oil and water were mixed thoroughly before porous PDMS samples were added. During an oil absorption test five porous PDMS samples were placed in a beaker and the time taken for the PDMS cubes to absorb oil completely was recorded. The average of three closest time durations were computed. Two types of oil absorption experiments were carried out; with and without mechanical agitation. Agitation was induced using a proprietary equipment that applied low amplitude
vibration on the base of the beakers.

3. Results and discussion
A typical porous PDMS sample formed is shown in figure 2. Typical porous PDMS formed are cuboids of dimensions 18.5 x 18.5 and 10.5 mm, figure 2(a). Porous PDMS has an open cellular structure and the pores were observed to be cuboids; of similar shape to particles in the sugar ‘cube’ templates. Each pore connects to adjacent ones to form an interconnected network resulting in the open cell network. Thickness of cell walls range in size between about 25 to 750 μm. Diameter of pores in foams range between about 50 to 500 μm, figure 2(b).

Figure 2. (a) Fabricated porous PDMS cuboid. (b) Optical micrograph showing hexahedral pores which are replicated from particles in the sugar cube. (c) Representative stress-strain curves at 2 and 100 mm/min. (d) Time for complete absorption is reduced significantly with vibration.

Figure 2(c) shows representative stress-strain curves of porous PDMS when compressed at 2 and 100 mm/min. These curves are typical of PDMS during compression with two distinct regions; a gradual linear elastic region followed by another in which stress increases rapidly in a non-linear manner with strain [7]. There is no significant difference between compression curves at various compression rates used in this study although porous PDMS were observed soften at higher compression rates. This observation suggests that the energy cost of compressing oil-laden porous PDMS to discharge the absorbed oil will be lower when compression is carried out at higher compression rates.

During initial stages of compression, ligaments in porous PDMS deforms which leads to pore collapse. Ligament deformation does not require large force which explains the gradual increase in stress over this region. As compressive strain increases, ligament deformation and pore collapse continues until most, if not all, pores in the porous PDMS collapsed. This process occurs between a strain of about 50 - 60 %. As strain increase further, densification of porous PDMS occurred which involved compression of the ’densified’ porous PDMS. At this stage, a small increase in strain results in a large increase in stress which explains the rapid increase in stress shown in figure 2(c).

Results of oil absorption tests are shown in figure 2(d). In general, porous PDMS absorbed between 44 % to 96 % by mass of oil relative to its mass. The speed at which oil is absorbed depended on whether
vibration was used. When vibration was not used, porous PDMS was able to completely absorb olive, sunflower and vegetable oil after 260, 310 and 370 s respectively. When vibration was applied during the oil absorption tests, the corresponding time durations were 105, 110 and 120 s respectively. Hence, vibration shortens duration needed to completely absorb olive, sunflower and vegetable oils by 2.5, 2.9 and 3.1 times, respectively. PDMS is a hydrophobic and oleophilic material. During absorption, PDMS has to uptake oil from the aqueous suspension. Uptake involves mass transfer through flow and diffusion processes. It is postulated that vibration accelerates such mass transfer processes by supplying energy to overcome hindrances during these processes.

4. Conclusion
In conclusion, porous polydimethylsiloxane (PDMS) was fabricated using sugar templating method. The uptake of olive, sunflower and vegetable oils by porous PDMS ‘cuboids’ with and without vibration was investigated. Applying small amplitude vibration significantly shortens the time duration needed for oil uptake. Time needed to absorb olive, sunflower and vegetable oils was shortened by 2.5, 2.9 and 3.1 times, respectively. Compressive stress-strain curves over compression rates between 2 and 100 mm per min are similar and indicate mechanical property of porous PDMS does not vary significantly and can be rapidly compressed.

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