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Research article

Carbonaized carbon aerogels derived from pomelo peels for sorption of some organic solvents

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Abstract

Importance of the work: Agricultural waste materials can be used to fabricate carbon aerogels that can absorb contaminated organic solvents.
Objectives: To investigate the potential of pomelo peel carbon aerogel (PCA) as a potential sorbent for organic solvents from the surface of water.
Materials & Methods: The peel was removed from pomelo fruits and cut into small pieces, before placing in a freezer at -20°C for 24 hr, followed by freeze-drying at -80 °C for 48 hr and then carbonizing in a muffle furnace at 300°C for 3 hr. Afterward, the carbonized product was characterized for morphology and tested for sorption capacity and reusability.
Results: The average density and porosity of the PCA were 0.0777 g/cm^3 and 96.12%, respectively. PCA had an interconnected, porous morphology and contained hydrophobic functional groups. The PCA sorption capacities for *n*-hexane, benzene and toluene floating on the surface of water for 10 s, 20 s and 30 s were in the ranges 5.20–5.96 g/g, 5.34–6.06 g/g and 6.66–7.66 g/g, respectively. The maximum PCA sorption capacities for *n*-hexane and benzene were at 20 s, while for toluene the maximum sorption capacity was at 10 s. At 20 s, the PCA absorbed more toluene (7.48 ± 0.26 g/g; mean ± SD) than benzene (6.06 ± 0.24 g/g) and *n*-hexane (5.96 ± 0.16 g/g), respectively. After five cycles of reuse, the PCA sorption capacities for *n*-hexane, benzene and toluene remained similar to the high values of the initial uptake.
Main finding: The PCA, as characterized by water contact angle, the Brunauer-Emmett-Teller specific surface area, field-emission scanning electron microscopy and Fourier transform infrared spectroscopy, had an interconnected, porous morphology and hydrophobic functional groups. PCA expressed good sorption capacity for *n*-hexane, benzene and toluene floating on surface water and had sustained reusability for five cycles.

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Introduction

Chemical organic solvents are widely used in industry and their leakage or disposal results in regular environmental contamination, causing serious pollution to local water resources and ecological systems (Zhu et al., 2017). Organic solvents, especially, *n*-hexane, benzene and toluene, can leak into surface water and soil. *n*-Hexane is a major constituent of gasoline oil and rubber cement and also is used in laboratories; it is toxic to the nervous system, as characterized by weakness initially in the legs and arms, followed by headaches, dizziness difficulty in breathing and possibly paralysis (Hughes, 1996). In industry, benzene is used as a solvent and as a chemical intermediate in the synthesis of numerous chemicals such as in making plastics, resins, dyes and pesticides. Benzene is found in gasoline (New Jersey Department of Health, 2024a). Benzene is absorbed through the skin or via the respiratory system and is very toxic to organisms, likely as a result of its metabolites rather than directly from benzene (Hughes, 1996). Toluene is used as a solvent, in aviation gasoline, and in making chemicals, perfumes, medicines, dyes, explosives and detergents; however, it can cause severe neurological hazard (New Jersey Department of Health, 2024b). Inhalation is the primary route of entrance for both benzene and toluene, with toxicity predominately involving central nervous system depression (Hughes, 1996).

The treatment of organic and oil pollutants from water has attracted considerable academic and commercial interest. Several methods have been developed to treat oily wastewater and water contaminated with organic solvents, such as, *in situ* combustion, chemical treatment, biodegradation, flotation, gravity separation and physical sorption (Gupta et al., 2017; Shi et al., 2019). Among these methods, physical sorption has been reportedly effective in the removal of oil and organic pollutants (Gupta et al., 2017). Many inorganic sorbents have reported disadvantages, such as their low organic solvent sorption capacities and high densities (Li et al., 2014). In addition, many natural organic sorbents have low hydrophobicity, resulting in high levels of water uptake (Zhu et al., 2017). Therefore, new sorbents are needed with high sorption capacity for oil and organic solvents, with additional requirements of being highly hydrophobic, low in density, reusable, have a low cost and be environmentally friendly (Maleki, 2016).

Aerogels are lightweight, porous materials with a low density and have been introduced into oil/water separation systems (Jiang and Hsieh, 2014). Carbon aerogels are a class of important aerogels that are spongy, three-dimensional, structured materials with millions of small, open pores filled with air (Wan et al., 2016). As carbon aerogels have multifunctional properties, such as a high surface area, an abundant porous structure and a low mass density, they are considered as ideal sorbents for oil-spill remediation treatments (Feng et al., 2015). Aerogels or sponges have been fabricated as light-density, three-dimensional, carbon-based, porous sorbents. Carbon materials from agricultural waste have been investigated for the separation of oil and organic pollutants because these carbon materials are abundant and have medium or high efficiency and a low price (Tai et al., 2015). Furthermore, nanosheet-like sorghum biomass has been prepared (Kim et al., 2023), where N and S are co-doped with hard carbon (NSSC) using direct carbonization of the nanosheet-like sorghum biomass mixed with thiourea. NSSC-600 has a high K-ion storage performance as an anode material. Kim et al. (2022) also synthesized microporous carbon, hollow microporous carbon and hierarchically porous carbon to investigate strategic nanoarchitecture designs for an advanced catalyst (or electrode) material, especially in the context of an oxygen reduction reaction.

Pomelo (*Citrus maxima* (Burm.)) Merr is a type of Southeast Asia fruit, with its peel (PP) making up about 40% of the total weight of the fruit (Shi et al., 2019). PP is inedible to humans and is mostly discarded in landfills, where it releases toxic gases that cause environmental problems (Zhu et al., 2017). PP is a composite of two layers: the flavedo (rich in essential oils) and the albedo (rich in carbohydrate fibers, such as cellulose, pectin and hemicellulose). In addition, PP is composed of many plant fibers with many functional groups, such as hydroxyl, carbonyl, carboxyl, and aromatic groups; therefore, PP should be a promising absorbent material (Chai et al., 2015; Zhu et al., 2017). PP has been used to fabricate activated carbons (Zheng et al., 2020), carbon aerogel (Zhu et al., 2017) and sponge aerogel (Shi et al., 2019, Pung et al., 2022). As the surface of PP is porous with many macropores (2–20 µm), it can provide sufficient space to absorb oil and organic pollutants. A new family of carbon aerogels using waste PP was fabricated through a hydrothermal, freeze-drying and pyrolysis process in a tubular furnace under a nitrogen flow and heated up to 600°C, 700°C and 800°C, respectively, for 1 hr. These carbon aerogels had excellent sorption ability for variety of oils and organic pollutants, with the sorption ability decreasing slightly as the calcination temperature increased (Zhu et al., 2017).

Carbon aerogels are lightweight materials with a highly porous structure, and they are typically prepared through a series of steps that involve the pyrolysis of a precursor material, often at high temperatures. However, due to cost limitations many laboratories cannot afford a tubular furnace operating under a nitrogen flow, while some commercial production of carbon aerogels cannot afford to include the pyrolysis process. Therefore, the pyrolysis process was modified to carbonization in a muffle furnace at lower temperature, with achieving full carbonization at a lower temperature potentially being challenging. Therefore, the current aimed to fabricate carbon aerogels from PP based on a simple process involving a hydrothermal treatment, freeze-drying and carbonization in a muffle furnace at 300°C. The characteristics of the PP carbon aerogel (PCA) were investigated using a contact angle system, scanning electron microscopy and Fourier transform infrared spectroscopy. Finally, the sorption capacity of the PCA for *n*-hexane, benzene and toluene was evaluated, with its reusability assessed based on 5 cycles of use. The developed PCA could be a potential sorbent for organic solvents, such as *n*-hexane, benzene and toluene on the surface of water.

Materials and Methods

Materials

Pomelo (*Citrus maxima* (Burm.)) Merr peels were obtained from a local market in Nakhon Pathom province, Thailand. Chemical reagents (*n*-hexane, benzene, toluene, ethyl acetate and Sudan red III) were purchased from Sigma Aldrich Co. Ltd. All analytical grade chemicals were used as received without any further purification.

Preparation of carbon aerogels

Pomelo peels (PPs) were peeled off the exocuticle and cut into small pieces with dimensions of approximately 3 cm × 3 cm × 1 cm and washed with deionized water several times to remove any dirt particles. Then, they were placed into a hot-air oven at 100°C for 24 hr, followed by washing with hot water (70°C) several times. The rinsed hydrogels were placed in a freezer at -20°C for 24 hr, followed by freeze-drying at -80°C for 48 hr to produce aerogels. Then, these aerogels were loaded into a muffle furnace for the carbonization process. The furnace was heated to 300°C at 5°C/min and held at this temperature for 3 hr to achieve the carbonization. Then the carbonized carbon aerogels were cooled to room temperature to produce black, lightweight PP carbon aerogels (PCAs). The PCAs were placed in a desiccator at room temperature until used.

Characterization

The mass of aerogel was determined using a Mettler-Toledo instrument (ML204). The width, length and height of the aerogels were measured using a set of Vernier calipers. A static optical contact angle meter (SL 150E; Kino) was used to measure the water contact angle (WCA) and the WCA of each sample was determined based on the average at 10 different positions on the material. A water droplet (0.4 μL) was deposited on the sample surface via the syringe system of the tester at 25°C. The nitrogen adsorption-desorption experiment was performed using a surface area analyzer at 77 K (Micromeritics; 3Flex 3500 series with Smart VacPrep) and the sample was de-gassed at 100°C for 12 hr.

The percentage porosity of the PCA was calculated using Equation 1:

$$P = (1 - \rho / \rho_c) \times 100 \qquad (1)$$

where P and ρ are the porosity and density of the PP and PCA, respectively, and ρ_c is the density of amorphous carbon that can be defined as the typical value for carbon black or activated carbon, namely 2 g/cm^3 (Li et al., 2014; Ya et al., 2017).

The morphologies of the PP and PCA were observed using a field-emission scanning electron microscope (JEOL Ltd.; JSM-7600F). The functional groups of the PP and PCA surfaces were investigated using Fourier transform infrared (FTIR) spectroscopy (Perkin Elmer; Spectrum II) in the range 400–4000 cm^{-1}.

Sorption experiments

Sorption test of organic solvents

At room temperature (28–29°C), a piece of PCA was weighed and immersed in 20 mL of organic solvents using a pair of scientific-grade forceps. The organic solvents used were *n*-hexane, benzene and toluene. The static sorption process was maintained for 30 s and 300 s. Then, the saturated PCA was separated from the liquid and immediately weighed. Each experiment was repeated 10 times. The sorption capacity (Q_e) of PCA was calculated using Equation 2 (Shi et al., 2019) and the percentage removal was determined using Equation 3:

$$Q_e = (m_2 - m_1) / m_1 \quad (2)$$

$$\% \text{ Removal of solvent} = (m_2 – m_1 / w) \times 100 \quad (3)$$

where m_1 and m_2 are the weight of the PCA samples before and after sorption, respectively, and w is the weight of solvent before sorption, with all measurements in grams.

Sorption test of organic solvents floating on water surface

The organic solvents were colored with Sudan red III (an organic dye that dissolves only in organic solvent), according to Ya et al. (2017) and Zhu et al. (2017). Sudan red III (1%) in *n*-hexane was prepared. Five drops of the 1% Sudan red III were added into 100 mL of each organic solvent and mixed until homogeneous. Then, 45 mL of deionized water was poured into a beaker and 5 mL of the colored organic solvent was weighed and added into the deionized water. The mixture separated into two phases, with the colored organic solvents floating on the water surface. A piece of weighed PCA was immersed in the organic solvent phase. Then, the PCA was removed from the solvent and immediately weighed. The experiment was performed for 10 s, 20 s and 30 s, separately and each was repeated seven times. The sorption capacity of the PCA was evaluated using Equations 2 and 3.

Reusability

After static sorption for 20 s, the PCA was washed in ethyl acetate (Zhu et al., 2017) several times and dried at 120°C for 20 min to obtain the regenerated carbon aerogel. Then, the regenerated PCA was tested for its sorption capacity of the organic solvents floating on the surface of the water. The experiment was repeated five times and the sorption capacity of the sample after each cycle was calculated using Equation 2.

Results and Discussion

Characterization

The raw PP was white, odorless, fibrous and lumpy (Fig. 1A). The average dimensions of the PP were 2.53 cm × 2.73 cm × 1.25 cm, with a low average density of 0.2315 g/cm^3 and porosity of 88.43% (Table 1). The PP floated on water. The appearance of PCA was black, odorless, lumpy and it was very light (Fig. 1B). The PCA surface was rough and brittle. The average dimensions of the PCA were 2.44 cm × 2.46 cm ×.96 cm, with a very low average density of 0.0777 g/cm^3. The porosity of the PCA was 96.12% and it floated on water (Table 1).

Water droplets deposited on the PP and PCA surfaces had spherical shapes. The average contact angles (θ) of the PP and PCA were 108.65° and 105.58°, respectively (Figs. 2A and 2B). Both these water contact angle (WCA) values were higher than 90°, confirming their hydrophobicity (Law, 2014). Therefore, the PCA was hydrophobic. The WCA of the PCA in the current research was lower than the WCA values of some biomass-derived carbon aerogels, such as durian shell carbon aerogel (112.26°; Ya et al., 2017), cellulose aerogels (134–138°; Jin et al., 2015) and pomelo peel carbon aerogel (132.4°; Zhu et al., 2017). The WCA of the current PCA was lower reported by Zhu et al. (2017) for their pomelo peel carbon aerogel due to the lower temperature of the carbonization process in the muffle furnace than from pyrolysis by tubular furnace 600–800°C, resulting in a lower hydrophobicity.

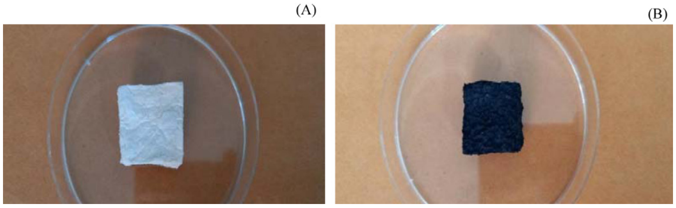

Fig. 1 (A) Raw pomelo peel; (B) carbon aerogel from pomelo peel

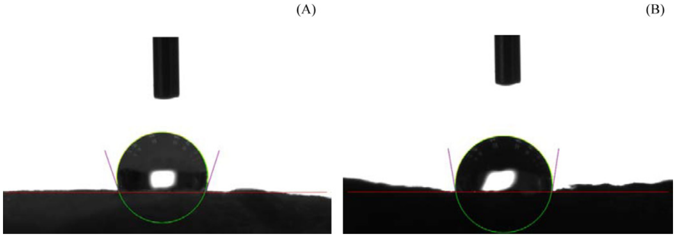

Fig. 2 Water contact angles: (A) pomelo peel; (B) pomelo peel carbon aerogel

Table 1 Density, porosity and hydrophobicity of pomelo peel (PP) and pomelo peel carbon aerogel (PCA)

Aerogel	Average weight (g)	Average volume (cm^3)	Apparent density (g/cm^3)	Porosity (%)	Hydrophobic property
PP	1.9975	8.63	0.2315	88.43	Floats on water
PCA	0.4473	5.76	0.0777	96.12	Floats on water

The morphology and sorption ability of PCA were analyzed. The nitrogen gas adsorption-desorption experiments were carried out to determine the textural porosity of the PCA. Fig. 3A shows the nitrogen adsorption-desorption isotherm. A small hysteresis loop at a relative pressure at 0.6–0.7 and 0.85–0.95 indicated that microporosity and mesoporosity may have coexisted in the PCA sample. The desorption plot went below the adsorption plot at a low relative pressure because at a low relative pressure in the adsorption phase, nitrogen gas flowed to macropores and mesopores; these pores probably condensed to smaller pores holding some nitrogen gas and therefore, the desorption phase would be lower. However, at high relative pressure, the desorption plot went lower because there were some mesopores and micropores in which the nitrogen gas was held; consequently, the desorption plot was less. Fig. 3B shows the pore size distribution curve, which confirmed that mesoporosity (pore diameter 2–6 nm) was dominant and microporosity (pore diameter less than 2 nm) was also distributed in the pore structure in PCA. The Brunauer-Emmett-Teller specific surface area, average pore size and total pore volume of PCA were 1.0348 m^2/g, 5.0824 nm and 0.001315 cm^3/g, respectively. The PCA specific surface area and total pore volume were lower than reported by Zhu et al. (2017). Carbonization in the muffle furnace at 300°C probably generated more incomplete meso- and micro-pores than the pyrolysis in the tubular furnace. However, these results indicated that the surfaces of the PCA were both mesoporous and microporous.

The surface morphologies of the PP and PCA were observed based on scanning electron microscopy (SEM) images (Fig. 4). In the SEM images of the raw PP (Figs. 4A and 4B), there were nest-like structure composed of irregular, flaky tissues of plants and some micropores and mesopores. The PCA had an interconnected, three-dimensional, porous microstructure and greater numbers of micropores and mesopores (Figs. 4C and 4D) than the raw PP. Therefore, many tunnel structures were distributed in the PCA, which made it easy for organic pollutants to enter the internal spaces within the PCA.

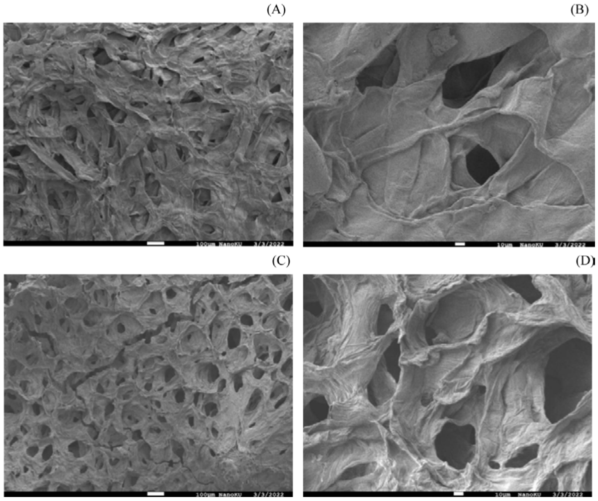

Fig. 4 Scanning electron micrographs of raw pomelo peel: (A) at ×70 magnification and scale bar = 100 µm; (B) at ×400 magnification and scale bar = 10 µm Scanning electron micrographs of carbon aerogel from pomelo peel; (C) at ×70 magnification and scale bar = 100 µm; (D) at ×400 magnification and scale bar = 10 µm

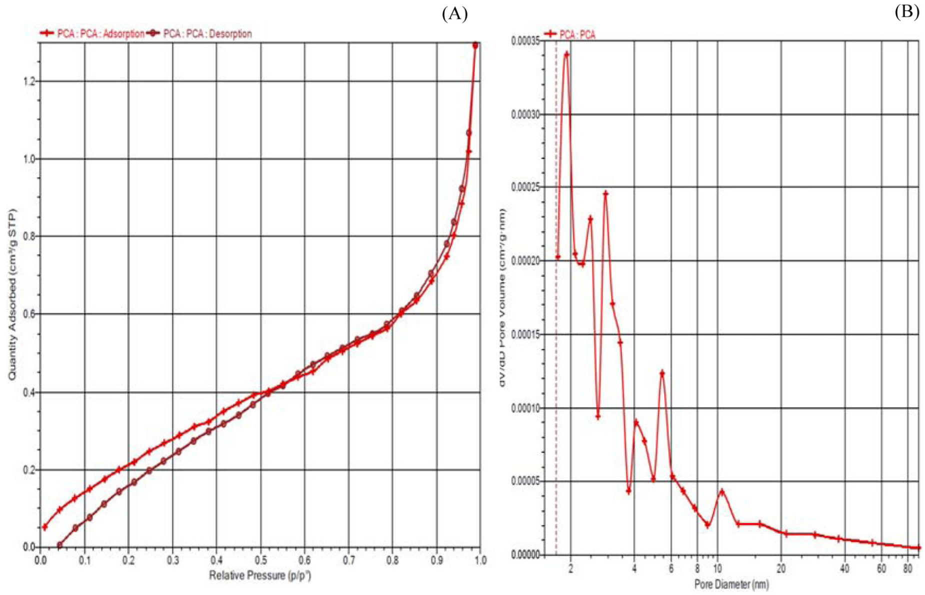

Fig. 3 Pomelo peel carbon aerogel: (A) nitrogen adsorption-desorption isotherm; X-axis is Absolute pressure (mmHg), Y-axis is Quantity adsorbed (cm^3/g STP (standard temperature and pressure)), (B) pore size distribution curve; X-axis is Pore diameter (nm), Y-axis is Pore volume ($cm^3/g.nm$)

The FTIR spectra of the PP and PCA had similar patterns (Fig. 5). The broad peaks at 3230–3460 cm^{-1} were attributed to the stretching vibration of -OH group, which might be attributed to the physically adsorbed water molecules. The small peak at 2926–2932 cm^{-1} was attributed to the C-H stretching vibrations from cellulose (Fan et al., 2012). The peaks at 1738–1742 and 1602–1609 cm^{-1} were attributed to the stretching vibrations of C=O and -OH, respectively, indicating that the existence of the carbonyl and -OH bending (absorbed water). The peak at 1046–1055 cm^{-1} could be attributed to the C-O-C stretching vibration or C-C framework vibration. The signal at 1009–1015 cm^{-1} was attributed to C-O vibration from cellulose (Fan et al., 2012).

The IR spectral results suggested that the surfaces of the raw PP were rich in hydroxyl, carbonyl and carboxyl groups. After the hydrothermal and carbonization treatments, the peaks in the PCA spectrum at 3230–3460 cm^{-1} and 1046–1055 cm^{-1} became weaker, indicating that these groups had decreased in number, resulting in the PCA surface being less hydrophilic or more hydrophobic than the PP.

Sorption of organic solvents

PCA had abundant microporous and mesoporous structures and its surface was hydrophobic. Therefore, PCA could be a promising sorbent to remove organic solvents. Next, the PCA was tested for its sorption activity for *n*-hexane, benzene and toluene. A piece of PCA was immersed into the organic solvents for 30 s and 300 s. The results showed that for 30 s, PCA absorbed toluene 9.20±0.52 g/g the most, followed by benzene (8.78±0.65 g/g) and *n*-hexane (4.87±0.19 g/g), respectively (Fig. 6A). However, the sorption capacities for benzene and toluene at 300 s dropped. However, the percentage removal of these solvents within 30 s was not significantly different from at 300 s (Fig. 6B), indicating that a sorption time of 30 s was sufficient.

Sorption capacity of organic solvents floating on water surface

The sorption behavior of *n*-hexane floating on the water surface with PCA is shown in Fig. 7. When a piece of PCA came into contact with *n*-hexane (stained with Sudan red III) floating on the water surface, the PCA effectively absorbed the *n*-hexane and it appeared to absorb only *n*-hexane and water. Therefore, the PCA sorption capacity for the tested organic solvents (*n*-hexane, benzene and toluene) floating on the water surface was confirmed.

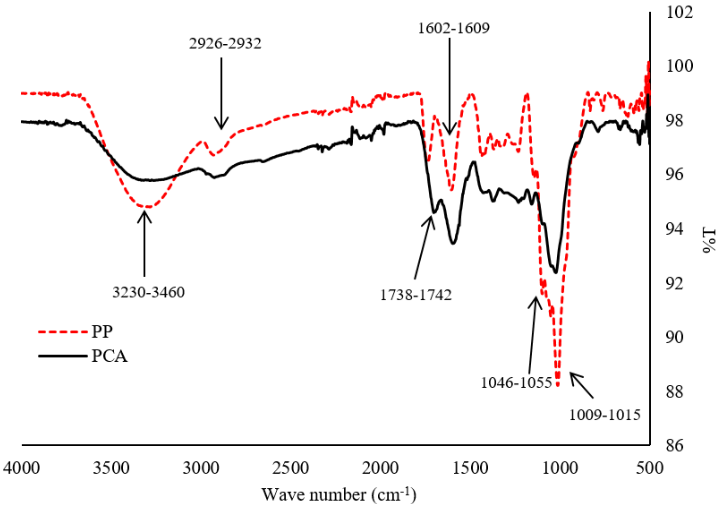

Fig. 5 FTIR spectra of raw pomelo peel (PP) and carbon aerogel from pomelo peel (PCA); %T = % Transmittance

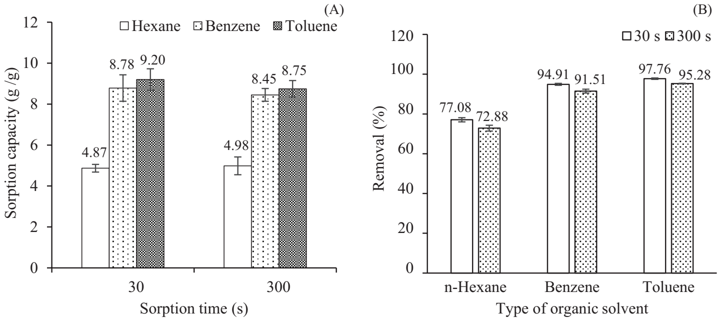

Fig. 6 Pomelo peel carbon aerogel testing with *n*-hexane, benzene, and toluene at 30 s and 300 s: (A) sorption capacity; (B) percentage removal; error bars indicate ± SD

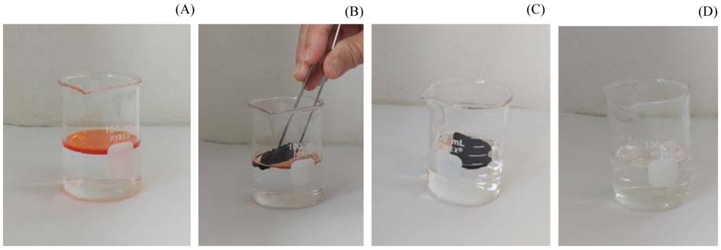

Fig. 7 Absorption behavior of *n*-hexane floating on water surface using pomelo peel carbon aerogel: (A) *n*-hexane floating on water surface; (B) carbon aerogel contacting and absorbing *n*-hexane; (C) carbon aerogel floating on *n*-hexane; (D) residual *n*-hexane floating on water surface after absorption

The PCA sorption capacities for *n*-hexane, benzene and toluene floating on the water surface for 10 s, 20 s and 30 s are shown in Fig. 8A, with values for *n*-hexane, benzene and toluene of 5.20–5.96 g/g, 5.34–6.06 g/g and 6.66–7.66 g/g, respectively. The maximum sorption capacities for *n*-hexane and benzene were at 20 s, whereas for toluene it was at 10 s. At 20 s, the PCA absorbed more toluene (7.48±0.26 g/g) than benzene (6.06±0.24 g/g) and *n*-hexane (5.96±0.16 g/g), respectively. The percentage removal of the solvents by the PCA is provided in Fig. 8B. The percent of removal was for toluene (81.55–90.19 %), following by *n*-hexane (69.55–77.36%) and benzene (55.54–76.36 %), respectively. When a piece of PCA was immersed into *n*-hexane, benzene or toluene for only a few seconds, the solvent around the PCA was absorbed immediately, becoming completely soaked up at 20–30 s. The results were consistent with those for carbon aerogels derived from waste pomelo peels reported by Zhu et al. (2017), where their carbon aerogels had excellent sorption ability for a variety of organic solvents. Their carbon aerogels from pomelo peels that had been subjected to pyrolysis at 600–800°C removed more toluene (22–27 g/g) than the PCA in the current study (6.66–7.66 g/g), perhaps because the laboratory setup used in the current study did not have a tubular nitrogen flow furnace, using instead carbonization in a muffle furnace at the lower temperature of 300°C for 3 hr. A muffle furnace is commonly used in a scientific laboratory. Another reason for using the muffle furnace was to avoid producing excessive ash and to reduce the energy required for carbonization. The sorption process of the aerogel was based on its macro- and micro-porous structures and the inter- and intra-fiber interactions of the aerogel (Jiang and Hsieh, 2014). The oil sorption capability of cellulose-based aerogel has been attributed to their low density, high porosity and three-dimensional network structure. For example, Pung et al. (2022) used pomelo peel sponge aerogels modified with hexadecyltrimethoxysilane (HPSA-1) for the removal of oils and some organic solvents (toluene). They found that HPSA-1 absorbed a minimal amount of toluene (1.77–2.24 g/g), with a percentage removal of 26.41–31.26%. The current study was much more successful, with the PCA absorbing more toluene than HPSA-1.

Reusability of pomelo peel carbon aerogel

The reusability of sorbents is another important property. Many procedures have been used to recycle sorbents, such as washing, vacuum filtration, mechanical squeezing and heating. Washing with ethyl acetate and heating were selected in the current study to regenerate the PCA. The sorption and regeneration processes were performed and repeated for five cycles. The infrared spectrum of the regenerated PCA was similar to the original PCA spectrum. The regenerated PCA was studied after it had repeatedly been used to absorb *n*-hexane, benzene and toluene, as shown in Fig. 9. After five absorption and regenerating recycles, the PCA sorption capacities for *n*-hexane, benzene and toluene remained high at 101.6%, 100.3% and 100.5% of the initial uptake, respectively. Zhu et al. (2017) reported that their carbon aerogels also maintained high values of 98% and 92% of the initial uptake of ethanol and acetone, respectively, after five adsorption-regeneration cycles. During the reusability experiment, some aerogel sheets that were brittle could have broken off the surface, resulting in a decrease in the PCA weight in the experiment. Therefore, the calculated Q_e would be higher. When compared with the initial Q_e value, the value was slightly higher than 100. The current study attempted to carbonize the aerogel in the muffle furnace at 500°C but the aerogel burnt and produced only a white ash. Thus, 300°C was chosen to facilitate a comparison with pyrolysis aerogels at 300°C, since that was the most suitable temperature for the current experiment, with the furnace time increased to 3 hr to achieve carbonization.

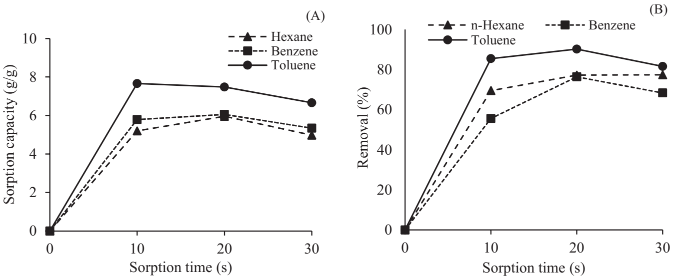

Fig. 8 Sorption capacity of organic solvents floating on water surface: (A) sorption capacity; (B) percentage removal of organic solvent

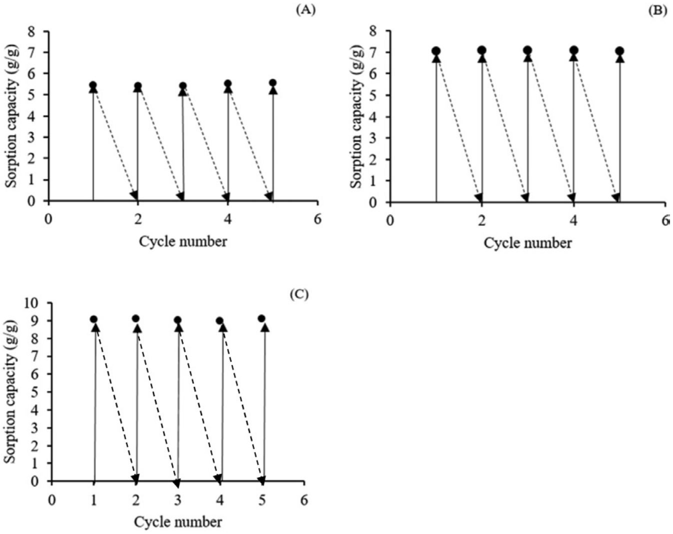

Fig. 9 Reusability of pomelo peel carbon aerogel for sorption of: (A) *n*-hexane; (B) benzene; (C) toluene

Conclusions

The PCA derived from waste pomelo peels was fabricated using freeze-drying, followed by carbonization in a muffle furnace at 300°C for 3 hr. It was characterized based on the water contact angle, the Brunauer-Emmett-Teller specific surface area, field-emission scanning electron microscopy and Fourier transform infrared spectroscopy, which indicated that PCA had an interconnected porous morphology and more hydrophobic functional groups. The static sorption tests showed that the PCA had good sorption capacities for *n*-hexane, benzene and toluene floating on the water surface. At 20 s, the PCA absorbed more toluene (7.48±0.26 g/g) floating on the water surface than benzene (6.06±0.24 g/g) and *n*-hexane (5.96±0.16 g/g), respectively. Furthermore, the reusability of the sorbent was confirmed by absorption-regeneration tests for five cycles with toluene, benzene and *n*-hexane, as their sorption capacities maintained high values. Therefore, the PCA might be another sorbent option for the removal of organic solvents from the surface of water because the PCA had good sorption capacity and reusability.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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