

Fabricating Self-assembled Porous Silica for Microplastic Adsorption in Electrolyzed Drinking Water

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Abstract

Microplastic contamination (1-5000 μm) in drinking water has been reported worldwide. The ingestion of microplastic-contaminated water poses potential health risks due to the accumulation of microplastics in human blood, placenta, and breast milk. This study aims to design and develop a porous silica-based filter (pore size 50-100 μm) with the capacity to adsorb microplastics from drinking water. The preparation of the modified porous silica material involved two stages: (1) synthesis of porous silica (SiO_2) templates using CaCl_2 , and (2) surface modification of silica with 3-aminopropyltriethoxysilane (APTES). The porous structure emerged through chemobrionic self-assembly followed by acid leaching, which produced tubular pores at the micron scale for polyethylene microplastic particle capture. Presence of silica pores, morphologies, and amine functional groups are identified through FTIR and SEM-EDX analysis. The adsorption tests assessed the removal of polyethylene microplastics from electrolyzed drinking water through Nile Red-assisted flow cytometry to measure the extent of microplastic removal and evidence of microplastic removal is observed during 24-hour contact test. Surface analysis following adsorption showed carbon-rich agglomerates which confirmed that polyethylene particles formed bonds with the silica network. Overall, APTES-modified porous silica shows potential as an amine-functional adsorbent to remove microplastics from drinking water treatmentsystems.

Keywords: *adsorption; drinking water; electrolysis; microplastics; porous silica.*

Introduction

Microplastics, defined as particles ranging from 1 μm to 5000 μm in size (Frias & Nash, 2019), are considered emerging contaminants. These particles have been found to pollute aquatic environments (Haribowo et al., 2023; Pariatamby et al., 2020; Ta et al., 2020), including the organisms within them (Asadi et al., 2022; Senathirajah et al., 2023), as well as drinking water (Chowdhury et al., 2023; Koelmans et al., 2019; Y. Li et al., 2020; Novotna et al., 2019), all of which are consumed by humans. Groundwater, tap water, bottled water, and refillable packaged water have all been documented to contain microplastic contamination (Mintenig et al., 2019; Oßmann, 2021; Schymanski et al., 2018). Among various drinking water sources, the highest concentrations of microplastics have been found in bottled water (Singh & Bhagwat, 2022). Since drinking water is a basic daily necessity, the presence of microplastics in water consumed by humans poses a potential food safety risk.

Drinking water treatment may contribute to microplastic (MP) pollution as conventional treatment technologies struggle to remove these particles due to their physicochemical properties (Cherian et al., 2023). Membrane filtration, as synthetic organic membranes, is widely applied as the final barrier to contaminants. However, stresses from mechanical abrasion, chemical cleaning, and age-degradation may result in the release of microplastics (MPs) and nanoplastics (NPs) from such membranes, raising additional health concerns. Additionally, the hydrophobic nature of MPs and NPs enables them to adsorb halogenated by-products, thereby exposing water distribution to secondary contamination (Ding et al., 2021). To counteract such challenges, several alternative membrane materials have been researched. Ceramic and silica-based adsorbents are considered promising options, with silica in particular offering versatility and demonstrated applicability across multiple fields (Steven et al., 2022; Susmanto et al., 2020). However, their wider applications are hindered by costly, environmentally unsuitable synthesis routes, low recyclability, and

diminished performance through pore blockage, as smaller pore diameters restrict adsorption capacity (Omorie & Helmreich, 2024).

Chemobronic self-assembly has emerged as a potential strategy to overcome these challenges. This process enables the formation of complex nano to macroscale structures from organic and inorganic precursors, including tubular structures with diameters of approximately 50-100 μm -sufficient for the adsorption of MPs with sizes below 50 μm (Hughes et al., 2021; Reigl et al., 2025). Silica self-assembly can also be achieved through reactions between sodium sulfate (Na_2SiO_3) and calcium chloride (CaCl_2), providing a practical route to functional silica adsorbent materials (Rieder et al., 2022; Thouvenel-Romans et al., 2004). Moreover, post-synthesis treatment offers a strategy to modify silica hydrophobicity and surface characteristics, thus enabling the design of adsorbents with defined functional properties (Wahyuningsih et al., 2021).

Previous studies on MPs removal have mostly focused on carbon-based adsorbents. These materials typically display microporous and heterogeneous structures, which may limit control over pore structure and surface uniformity (Khamkeaw et al., 2020). In contrast, silica-based adsorbents synthesized via self-assembly offer better control over pore size and distribution (Mohammed et al., 2021). Additionally, the adsorption behavior of MPs on these functionalized silica materials remains insufficiently understood. Contrary to dissolved and colloidal pollutants, MPs are considered particulates (Tsochatzis et al., 2024). Therefore, their adsorption behavior is more likely influenced by contact time and the physical interactions occurring between the MPs particles and the adsorbent surface.

This study aims to investigate the adsorption performance of functionalized self-assembled porous silica toward polyethylene (PE) MPs under controlled experimental conditions. The removal efficiency was quantified using flow cytometry based on Nile Red staining, with its structural as well as chemical changes were examined. The novelty of this work lies in its evaluation of contact time-dependent adsorption supported by multiple characterization techniques, providing clearer insight into how the structural properties of functionalized self-assembled porous silica influence microplastic adsorption.

Materials and Methods

Synthesis of Modified Porous Silica Materials

Porous Silica Synthesis

The silica precursor, sodium silicate (Na_2SiO_3) from Sigma-Aldrich®, was dissolved in distilled water at a ratio of 1 g : 4 mL at 80 °C, and then stirred with a magnetic stirrer at 85 rpm until completely dissolved and cooled to room temperature. Calcium chloride (CaCl_2) from Sigma-Aldrich® was then ground and sieved to a particle size of 105-250 μm , and added as a templating agent at a ratio of 1:100 (gr/ml). The mixture was aged for 1 hour, resulting in the formation of CaSiO_3 tubes that served as temporary templates. The mixture was then treated with 1 M HCl (Merck®) until the pH reached 7, resulting in the formation of a silica gel, which was subsequently aged for 24 hours (Behede et al., 2022; Setyawan et al., 2021; Zhu et al., 2006). The silica gel was dried at 55 °C for 72 hours (3 days) to remove residual water, then ground, and sieved through a 105-250 μm mesh to obtain uniformly sized silica particles. A total of 1 g of silica was reacted with 20 mL of 5 M HCl at 80 °C for 2 hours to remove CaSiO_3 and generate microscopic pores. The mixture was then filtered and washed with distilled water to remove residual CaSiO_3 from the template, resulting in porous silica with pore sizes up to 50 μm , which were observed using an optical microscope. The overall procedure for the preparation of porous silica is illustrated in Figure 1.

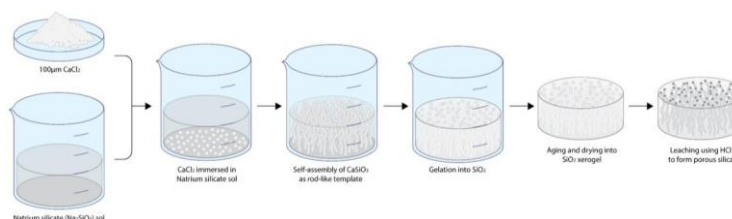


Figure 1 Porous silica synthesis from Na_2SiO_3 precursor through the self-assembly method.

Porous Silica Surface Modification

The synthesized porous silica was surface-modified using a 10% (v/v) solution of APTES (3-aminopropyltriethoxysilane, Sigma-Aldrich®). The procedure was carried out by immersing the silica in the APTES solution at a mass-to-volume ratio of 1:40 (w/v), followed by stirring at 150 rpm at room temperature for 8 hours to allow the surface modification reaction to occur (Mahtabani et al., 2020; Silviana et al., 2022). This process aimed to produce positively charged silica surfaces through the formation of bonds between silanol groups (-SiOH) on the silica and amine groups from APTES. After modification, the mixture was aged at room temperature for 24 hours to ensure complete reaction. The silica was then purified by washing with distilled water and dried at 40 °C under atmospheric pressure to obtain activated silica, where the surface modification was confirmed by analyzing functional group changes using FTIR and measuring the pore size using a microscope.

Application of Modified Porous Silica MP Adsorbents

The microplastic (MP) used in this study was reference PE material obtained from Sigma Aldrich with a particle size of approximately 40-48 µm. Alkaline electrolyzed water (AEW) was prepared through electrolysis using drinking water as its feed. The process was carried out for 9-12 hours at 12 V/50 Hz and 400 W, yielding about 900-1000 mL of AEW with a basic pH (7.5-8.5), containing OH⁻ ions according to the electrolysis reaction.



The reference PE-MP was then dispersed in AEW, forming a 10 ppm MP-AEW solution, followed by the addition of 2.0 g of modified porous silica into 250 mL of the MP-AEW solution. The mixture was shaken briefly for 5 minutes and left for 6 different contact times (10, 25, 40 minutes and 1, 2, 24 hours). All samples were analyzed in triplicate. Blank analyses were conducted to correct the results of MPs analysis on the samples. The total MPs in the samples before and after adsorption were calculated to determine the optimal adsorbed MPs in each contact time. The adsorption performance of polyethylene MPs by the modified silica was evaluated by detecting MPs using flow cytometry and examining morphological changes before and after application using SEM-EDX, as well as functional group changes analyzed by micro-FTIR (IR Tracer100 & AIM 9000, Shimadzu).

Analysis by Flow Cytometer

Analysis was performed using flow cytometry, a simple and robust method based on the fluorescent staining of Nile Red (NR). The surface of PE plastics was bound by NR and detected in the form of particles/µL. The NR staining protocol followed that used DMSO 15% as the NR staining solution for flow cytometry analysis (J. Li et al., 2023). In order to stain, 100 µL of samples were added to NR stock solution (1.5 µL, 1 mg/mL) and vortexed to mix the samples. Unstained electrolyzed water and adsorbent were analyzed as negative control. All samples were detected under flow cytometer (Guava easyCyte, Luminex) using a blue laser (488 nm excitation). The number of adsorbed PE on modified silica was calculated by subtracting the number of microplastics before and after the adsorption process.

Results

Characterization of Porous Silica Material

The pore size distribution of 100 silica particles obtained from washing NaSiO₃ with 5 M HCl is shown in Figure 2. It shows that most particles have pore sizes between 60-100 µm, with a median value (50th percentile) of 80.89 µm. The distribution is slightly skewed to the right: the number of particles is high at intermediate sizes (around 60-80 µm) and then decreases gradually at larger pore sizes.

However, there is still a fraction of particles with large pores (micro-silica) in the range of ≥120 to ±180 µm, although the number is relatively small compared to the intermediate size group. This indicates that the silica material washed with NaSiO₃ with 5 M HCl already contains some large-pore particles, but the proportion can still be increased if the intended application requires a predominance of large-pore micro-silica.

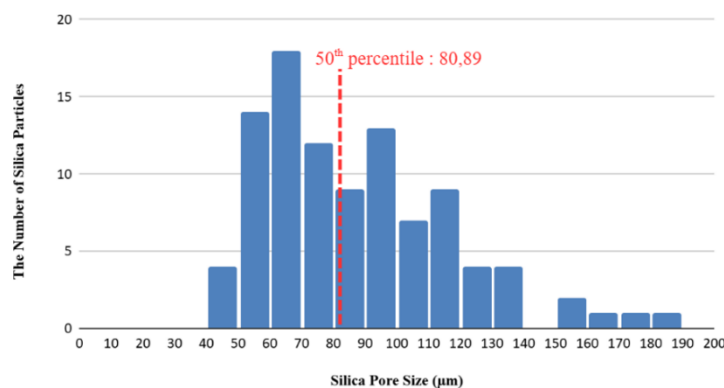


Figure 2 Pore size distribution of silica material after washing with 5M HCl.

Functional Group

To identify the surface functional group of adsorbents, FTIR spectra were recorded. Figure 3 interprets the functional group of porous silica material before and after surface modification using APTES. Both adsorbent and modified adsorbent have three main characteristics of silica stretching vibration as main functional group at 1400 cm^{-1} and 700 cm^{-1} which correspond to the vibrations of Si-O groups in the siloxane group (Si-O-Si) (Susmanto et al., 2020). Peak at 1600 and 3400 cm^{-1} indicates the formation of Si-OH after porous silica synthesis. The peak at 1631 cm^{-1} shifted to the 1643 cm^{-1} after modification indicated that -OH groups have been used to bind APTES. The broader peak in the range of $3500 - 3200\text{ cm}^{-1}$ has formed due to the overlapping peak between -OH and -NH stretching vibration. The amine group, which is considered as the active site, appears in the peak at 3221 cm^{-1} after modification treatment. This functional group plays an important role in the MPs adsorption in electrolyzed drinking water. Peak in wave numbers 1458 cm^{-1} showed amine firmly bound to the silica (Rahman et al., 2022). The peak at 3400 cm^{-1} from adsorbent is broader than silica reference material due to the formation of -OH from porous silica material and the ability of silica to adsorb water. Porous silica material has 700 of its similarity score with silica reference material and indicates that the synthesis of porous silica material did not change its main silica structure.

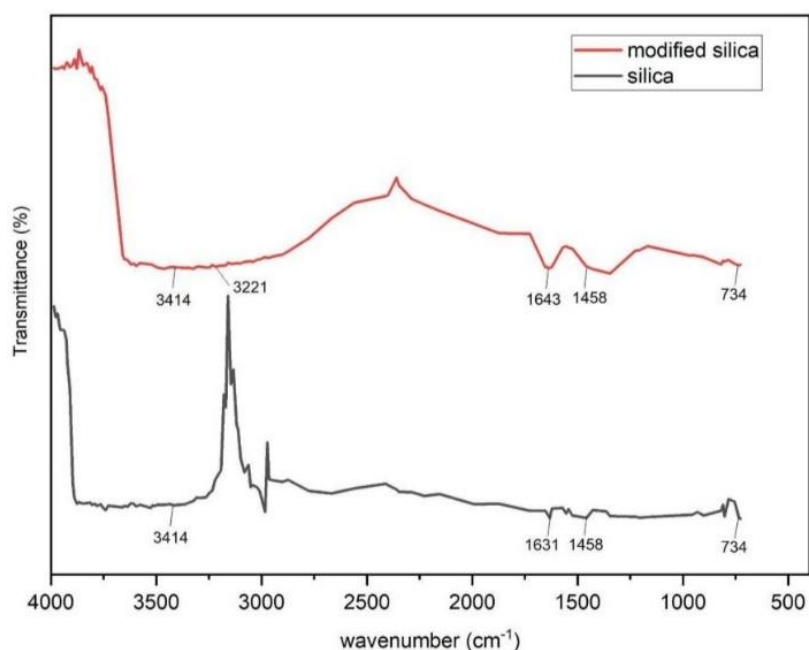


Figure 3 FTIR spectra of silica and modified silica.

Morphology and Element Composition

The porous silica material was characterized using Scanning Electron Microscope-Energy Dispersive X-ray (SEM-EDX) (Figure 4) to see the microstructural of material formed and the composition of atoms contained in its material. SEM figures support the microscope data of pore size variation. Silica material shows the irregular morphology with the pore size in the range of 40-micron (porous) and less than 5-micron (sub-porous) in the magnification of 500x and

10,000x. EDX results revealed the presence of Nitrogen (N) atoms after modification (Figure 5). This supports data for the potential of modified porous material to adsorb negatively charged microplastic from electrolyzed water.

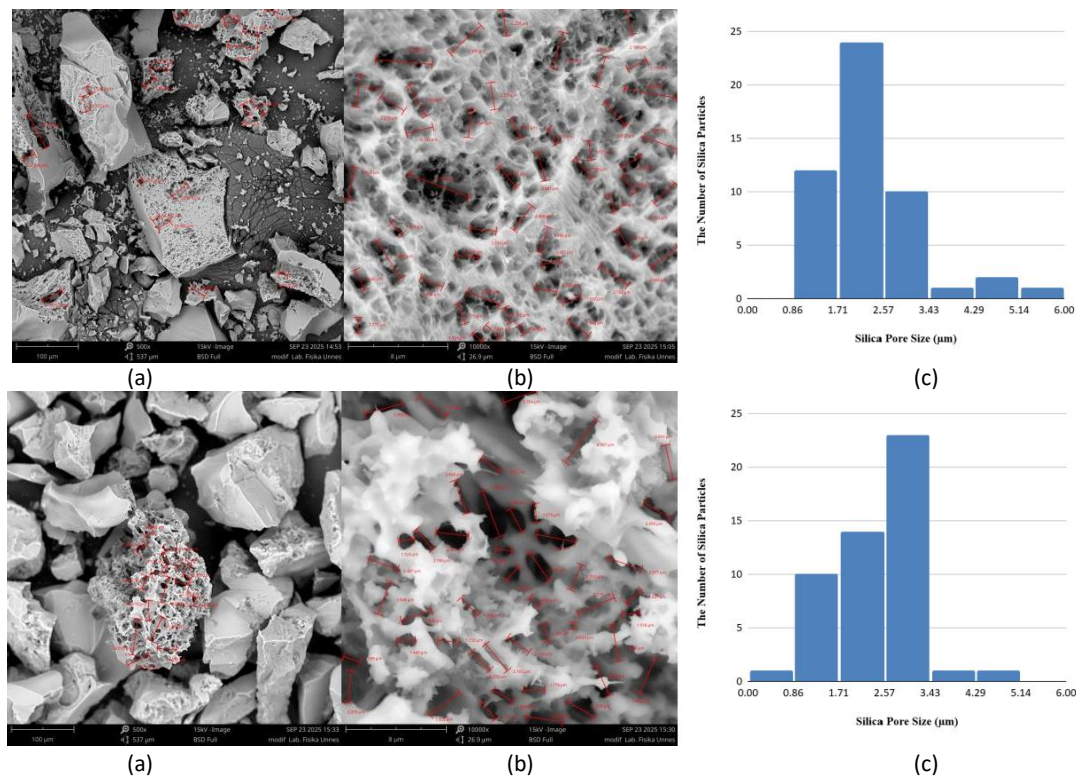


Figure 4 Porous silica material (a) 500x magnification, (b) 10,000x magnification, (c) pore.

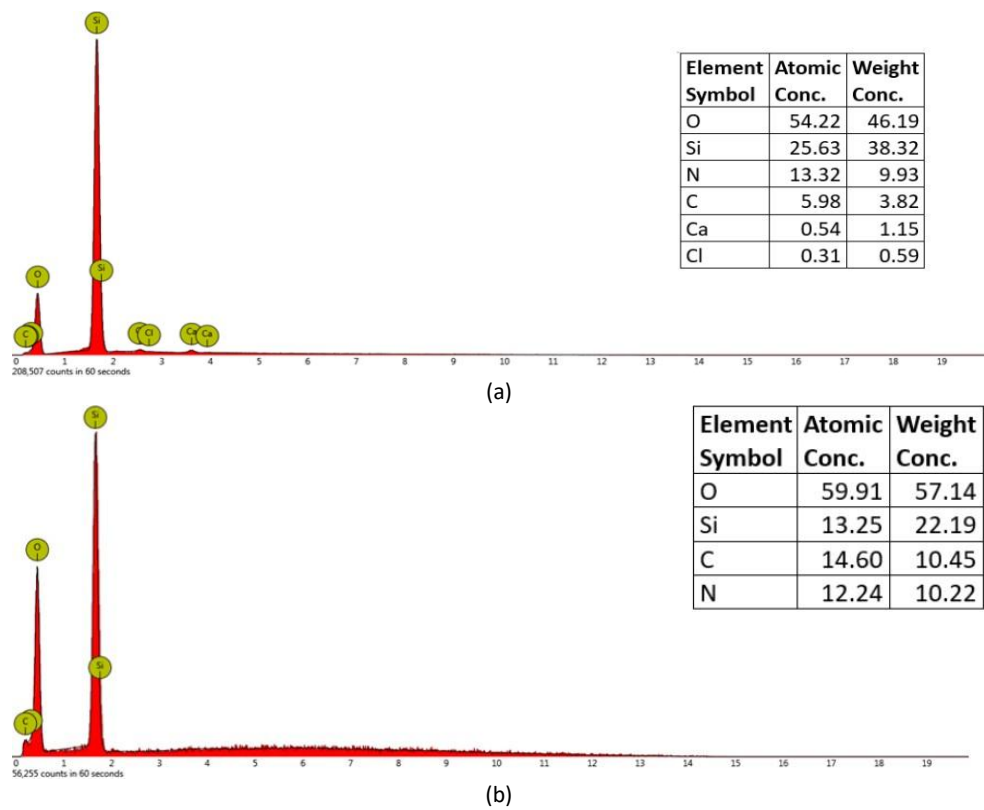


Figure 5 EDX porous silica material (a) modified porous silica material (b).

Adsorption Studies

Flow Cytometry Analysis

The potential of modified silica as PE MPs adsorption in electrolyzed water was proved by flow cytometry method. The absorption process was carried out with three different contact times between adsorbent and water (10, 25, 40 minutes and 1, 2, 24 hours) to know the optimal contact time for the adsorption process. Furthermore, mixing has been used to help physical and chemical interaction between active sites on the surface adsorbent with PE. Stirring was applied five minutes for each sample prior to the varying adsorption time. The volume of the sample analyzed by flow cytometer was measured to estimate the number of microplastic particles per μL . The sample volume for flow cytometry analysis was 500 μL . The particle concentration before and after adsorption can be shown in Table 1. Microplastic particles in field samples were counted based upon their signal in terms of side light scatter (SSC) for complexity in a group and fluorescence in a band of PE (green laser) and PerCP (red laser) as shown in Figure 6.

Table 1 Concentration of MPs in electrolyzed water

Contact time	Total MPs in electrolyzed water (particles/500 μL)		Concentration of MP particles adsorbed in electrolyzed water	
	Before adsorption	After adsorption	particle/500 μL	particles/L
10 (min)	17.17 ± 3.54	17.17 ± 3.54	0 ± 0	0 ± 0
25 (min)	17.17 ± 3.54	17.17 ± 3.54	0 ± 0	0 ± 0
40 (min)	17.17 ± 3.54	17.17 ± 3.54	0 ± 0	0 ± 0
1 (h)	17.17 ± 3.54	16.67 ± 2.83	0.50 ± 0.70	$997 \pm 1,409$
2 (h)	17.17 ± 3.54	14.50 ± 0.23	2.67 ± 3.77	$5,330 \pm 7,537$
24 (h)	17.17 ± 3.54	0 ± 0	17.17 ± 3.54	$34,333 \pm 7,071$

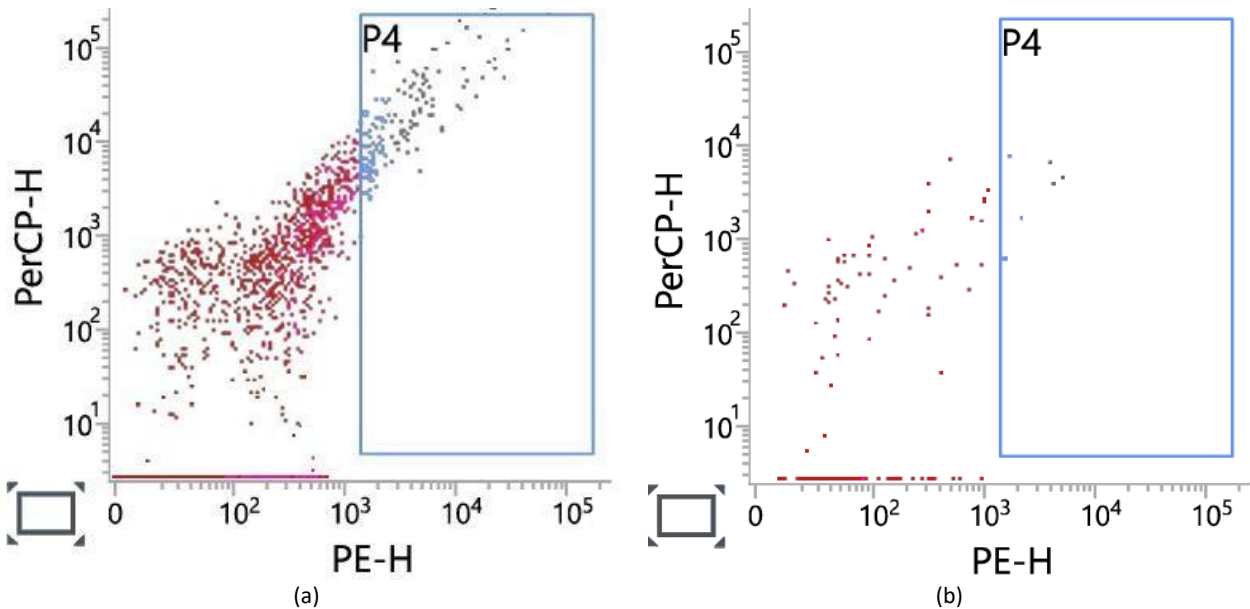


Figure 6 Flow cytometry analysis of NR stained field samples. (a) Scattergram of electrolyzed water control and (b) scattergram of sample in 1h contact time. Each dot is the signal response from a particle in the sample. The x-axis is PE and the y-axis is PerCP. The blue gate represents particles considered to be microplastics.

Adsorbent Characterization

FTIR characterization of modified silica as adsorbent before and after adsorption was shown in Figure 7. The -OH functional group from silica is at wave number of 3414 cm^{-1} and it does not change before and after adsorption application (Caroles et al., 2024). Adsorption of PE on modified silica adsorbent resulted in disappearance of the adsorption band at 1458 cm^{-1} characteristic to amine groups vibration. This change may indicate possible interaction

between amine groups and PE. A similar finding has been reported and shows that the disappearance of specific bands is associated with the adsorption process (Moritz & Łaniecki, 2012). Whereas, wave numbers at 1328 cm^{-1} and 1199 cm^{-1} appeared after adsorption which corresponds to the CH_3 symmetric deformation and wagging deformation of PE, respectively (Gulmine et al., 2002). The APTES site at 1643 cm^{-1} after modification has shifted to the 1645 cm^{-1} after adsorption indicated that PE has interacted with this site.

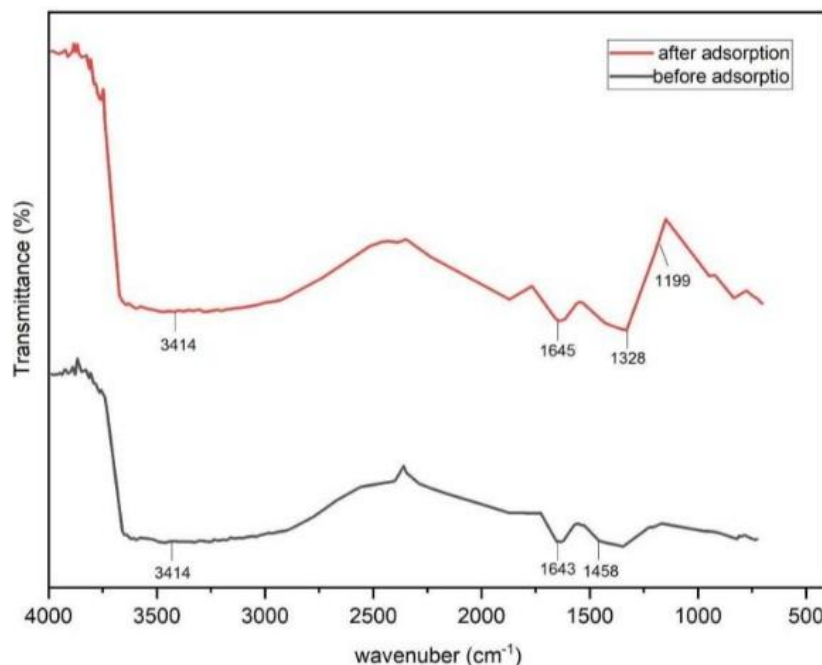


Figure 7 FTIR spectra of modified silica before and after adsorption.

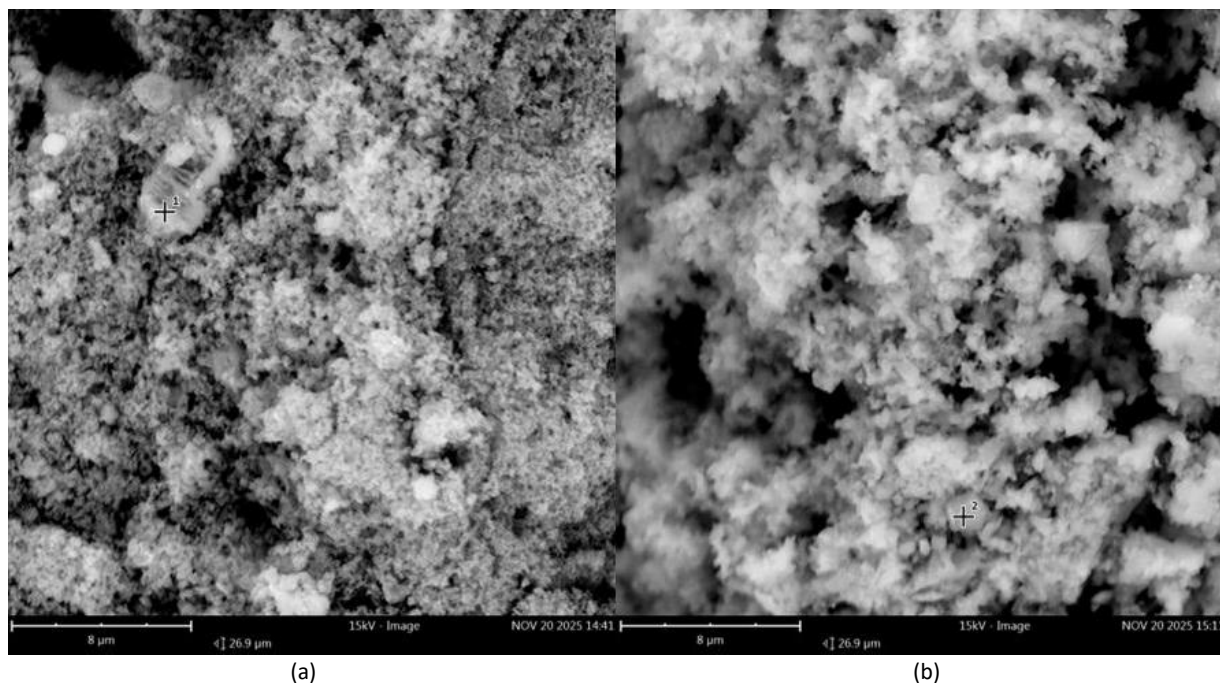


Figure 8 EDX result of modified porous silica material: (a) before and (b) after MPs adsorption.

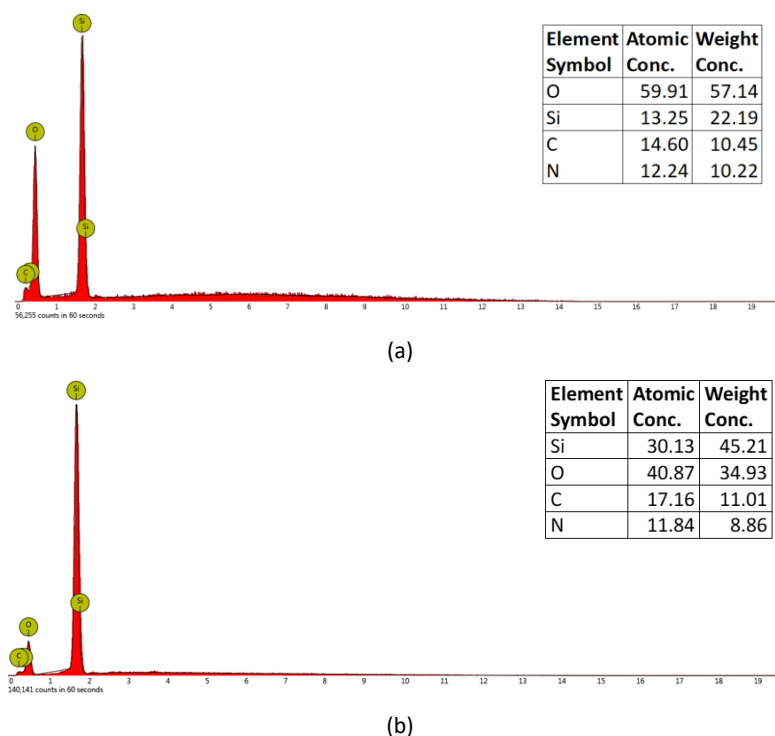


Figure 9 FTIR Morphology of modified porous silica material before adsorption (a) and after microplastic adsorption (b).

From Figure 8(a), SEM-EDX analysis shows small particles that distribute evenly throughout a matrix surface. This surface morphology shows minimal particle contact between particles and a small amount of particle cluster formation. However, a distinct phenomenon is observed in the SEM-EDX image shown in Figure 8(b), with different surface characteristics observed because it contains bigger particles and surface area expansions. Meanwhile, DX spectrum shows a significant rise in carbon (C) signal, which increases from 10.45 %w to 11.01 %w, after the porous silica went through microplastics adsorption as shown in Figure 9. The surface carbon content directly relates to larger particle formation because these areas appear together in the sample.

Discussion

Fabrication of Modified-silica Porous Adsorbent

Porous Silica Material Synthesis

The silica precursor, sodium silicate (Na_2SiO_3), was dissolved in distilled water at a ratio of 1 g : 4 mL at a temperature of 80 °C. Water acts as a solvent medium that facilitates the breakdown of the solid silicate structure into active aqueous species, where the presence of hydroxyl ions is essential for the dissolution of the solid silicate (Luukkonen et al., 2020). In an alkaline aqueous environment, hydroxyl groups attack and break the solid silica network into dissolved silica species (Alam et al., 2019). This process is an endothermic reaction that requires the absorption of heat energy (Luukkonen et al., 2020) therefore, a temperature of 40 °C is used so that the solid can dissolve completely (Rasuli et al., 248 2022).

Calcium chloride (CaCl_2) was added as a templating agent. Its high hygroscopicity allows it to interact strongly with water molecules, where Ca^{2+} ions can associate with silanol groups (Si-OH) in the forming silica network. Its high solubility also enables this compound to function as a sacrificial template to form temporary spatial domains that will later be removed through washing (Zhu et al., 2006). After aging for 1 hour, the solution was acidified with 1 M HCl until pH 7. The addition of HCl neutralizes the sodium silicate, allowing the gelation process and formation of a solid silica network to occur (Setyawan et al., 2021).

The silica gel was then dried, ground, and sieved to obtain particles sized 105-250 μm . Particles within this micron range have been shown to possess excellent specific surface area and pore volume (Zhi et al., 2018), which greatly contribute to the high adsorption capacity for pollutant molecules (Ulfa et al., 2022). Maintaining a lower limit of 50 microns is also crucial to prevent pore plugging. The silica was then reacted with 5 M HCl solution at 80 °C for 2 hours. This acid treatment

is recommended to dissolve impurity compounds such as calcium oxide (Chindaprasirt & Rattanasak, 2020), allowing calcium to be released from the silica matrix, thereby increasing purity and opening the pores (Dhaneswara et al., 2020). A duration of 2 hours at high temperature provides optimal conditions for dissolving metallic elements without damaging the main material (Chindaprasirt & Rattanasak, 2020).

Surface Modification of Porous Silica

The silica material was modified using a 10% (v/v) APTES solution to introduce amine groups onto the particle surface. These amine groups can be protonated to -NH_3^+ in aqueous media, resulting in a positively charged silica surface (Mahtabani et al., 2020). The aging process at room temperature for 24 hours, based on Mahtabani et al. (2020), allows greater opportunity for hydrolysis and condensation reactions to occur completely, thereby increasing the number of APTES molecules bound to the surface.

After rinsing with distilled water, the silica was dried at 40 °C. A low drying temperature was used because the grafted organic groups are highly sensitive to heat and may begin to decompose at temperatures above 140 °C (Tumurbaatar et al., 2022). Additionally, high temperatures after washing can trigger excessive condensation and cross-linking between APTES molecules (Mahtabani et al., 2021), as well as cause shrinkage of the silica network and dehydroxylation, which leads to the formation of a denser matrix with reduced surface area (Grozdanova et al., 2025). Therefore, mild drying is strongly recommended to prevent shrinkage of the silica pores (Grozdanova et al., 2025).

Application of Modified Porous Silica Adsorbent

The adsorption process was carried out using Activated Electrolyzed Water (AEW) under alkaline conditions. Water produced on the cathode side has a basic pH and a high concentration of hydroxide ions. This alkaline environment was selected so that the adsorption process could generate strong interactions between the positively charged silica surface and the target microplastics in water, which tend to carry negative charges (Shih et al., 2022).

The surface of porous silica contains numerous silanol groups after its initial synthesis process. The surface modification with APTES enables different attachment methods between silica and organosilane molecules because of the available hydroxyl sites. The modification process produces surface arrangements based on the extent of APTES condensation and attachment to the silica surface as shown in Figure 10.

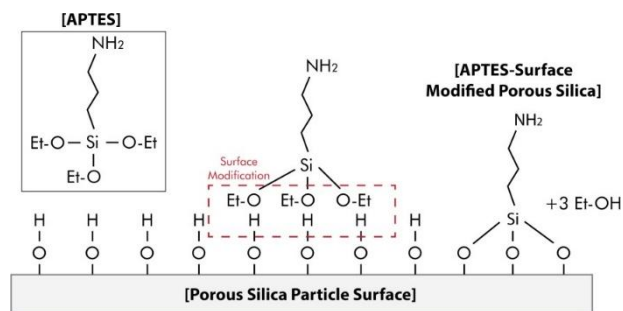


Figure 10 Bonding configurations of APTES on the porous silica surfaces.

The surface modification process results in various bonding patterns because APTES molecules either undergo partial hydrolysis or form monodentate bonds or they completely condense into bidentate or tridentate attachments and occasionally develop surface oligomers as explained in previous studies (Acres et al., 2012; Sypabekova et al., 2022). Although this study does not show the exact surface arrangement, still, aminopropyl group attachments can be proven through FTIR spectral analysis. As shown in Figure 3, FTIR spectral changes show that organosilane species have bonded with silanol groups because new functional bands appear for N-H, C-H, and Si-O-Si bands which show different characteristics than unmodified silica. The observed spectral changes demonstrate successful surface modification and prove that APTES has been successfully attached to porous silica. The adsorption occurred in the specific pH condition (pH = 7.8) controlled by a water electrolysis machine. Solution pH is one of the factors that significantly influences the adsorption of adsorbates onto adsorbents (Omorigie & Helmreich, 2024). In the basic solution, PE as a targeted polymer tends to be negatively charged due to the presence of OH^- , while the adsorbent surface has a positively-charged surface (NH_3^+). Modified silica with APTES has successfully shifted the isoelectric point to 9.2 which means that under that pH, the adsorbent surface is positively charged due to protonation (Liu et al., 2024). The electrostatic repulsion occurred between the functional group of adsorbents and adsorbates because of the different ion charges between them (Omorigie & Helmreich, 2024). A study from Omorigie and Helmreich (2025) observed that Polystyrene

(PS) MPs became positive charge in acidic conditions and slightly negative when pH was increased. The adsorption varies depending on pH values. The electrostatic interaction occurred between PS MPs with functional groups on the adsorbent surface. Electrostatic repulsion will influence the number of adsorbed MPs (Omorie & Helmreich, 2024). Additionally, physical entrapment may contribute to the removal of PE due to the dominant size range of silica material being the same and larger than PE size range. This is also supported by the presence of PE MPs on the adsorbent surface of SEM analysis (Figure 9). The shifting of wave number around 1600 cm^{-1} in FTIR spectra indicates the usage of these APTES sites to interact with PE.

Application and Optimization of Microplastics Adsorption

The APTES surface-modified porous silica material underwent microplastics adsorption process by subjecting the porous silica to electrolyzed drinking water added with polyethylene reference materials. Followed by washing and drying procedures, this porous silica is then used for surface imaging and chemical element detection to study the complete structural and elemental changes of the samples. The SEM imaging technique allowed the study of particle arrangement and pore structure changes and also agglomeration behavior of the samples. The EDX analysis of the samples revealed elemental composition, in which the presence of carbon could indicate PE material accumulation on the silica surface as shown in Figures 4 and 5.

From Figure 4, two results show different morphological patterns because particles expanded and merged during processing which created a dense particle cluster from their original scattered state. Concurrently, as shown in Figure 5, the increasing carbon content in the material indicates that a carbon-rich substance has become more visible at the surface which is likely polyethylene or another hydrocarbon-based polymer. The combination of rising carbon content and particle cluster formation enables the identification of new agglomerates as PE-rich material phases.

Similar studies also found that agglomerated structures through high-resolution microscopy were formed after adsorption (Ahmad Aftab et al., 2023; Ansari et al., 2025; Sen et al., 2024). Similar findings also show that EDX carbon readings increase when polyethylene exists in materials' structures and SEM confirms these findings through morphological evidence (Furfaro et al., 2022; Nakatani et al., 2023). The SEM-EDX results from this research study shows that modified porous silica may adsorb PE microplastics from electrolyzed drinking water while forming larger agglomerate particles throughout the processes.

The optimal adsorption process has been measured by varying contact time between adsorbents and adsorbates in the same condition. This study revealed that the MP-PE adsorption process with SILEC adsorbent follows the previous study (Omorie & Helmreich, 2024) through multiple modifications. The process involved adding 1 gram of SILEC to 250 mL MP-PE solution at room temperature, for various contact time periods. Magnetic stirrer is used to enhance the number of microplastic particle interactions with adsorbent material during the entire contact period. The stirring process lasted five minutes before the mixture underwent different settling periods which lasted from 10 minutes to 24 hours. The adsorbent separation took place through filtration after the contact period reached its completion. The calculated capacity of modified porous silica material to adsorb PE MPs was approximately 17,166 particles/g or $5.35 \times 10^{-3}\text{ mg/g}$. It was observed that the adsorption capacity of PE by modified porous silica material increased from 10 minutes to 24 h of contact time. Additionally, after 24 h, all particles have been adsorbed and corresponded to the 100% removal efficiency. This result has relatively lower adsorption capacity than modified silica with zeolite composite which showed 2.41 mg/g of Polystyrene (PS) adsorption capacity in drinking water after 180 minutes (Omorie & Helmreich, 2024). However, our findings demonstrated a higher removal efficiency, equivalent to the adsorption of polyethylene terephthalate (PET) and polyvinyl chloride (PVC) in drinking water when using granular activated carbon (GAC), ion exchange (IX), and microfiltration (MF) as a Point of Use device (Cherian et al., 2023). This supports the potential application of modified porous silica as drinking water treatment adsorbent. The flow cytometer measured MP-PE concentrations at two different points during the adsorption experiment.

The modified silica material showed its ability to extract PE microplastics from electrolyzed water through flow cytometry analysis. The adsorption experiment used six different contact times between the adsorbent and water to find the best time for adsorption which included 10, 25, 40 minutes and 1, 3 and 24 hours. The mixing process allowed active sites on the adsorbent surface to form physical and chemical bonds with PE. The stirring process lasted five minutes for all samples before starting the adsorption treatment with different contact times.

Conclusion

Modified porous silica material demonstrates potential in reducing PE MPs from electrolyzed drinking water. The adsorption performance of porous silica is enhanced after the fabrication of tubular pore formation and amine functionalization and finds that 34,333 microplastic particles/L can be adsorbed within 24 hours. The adsorption process was confirmed through structural and chemical tests which showed that the material developed pores and surface modifications and microplastic binding occurred through nitrogen and carbon-based chemical changes. The removal efficiency reaches 100% with adsorption capacity of 5.35×10^{-3} mg/g. However, reproducibility of material needs to be evaluated for practical applicability. Further studies incorporating adsorption kinetics and isotherm modeling are necessary to provide a more comprehensive understanding of the adsorption mechanism. Further studies incorporating the effects of temperature, adsorption kinetics, adsorption capacity variations, isotherm modeling, and combinations of different polymers are necessary to provide a more comprehensive understanding of the adsorption mechanism. In addition, adsorbent surface characterization could be conducted to further explain the interaction between the adsorbent and adsorbate.

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Compliance with ethics guidelines

The authors declare they have no conflict of interest or financial conflicts to disclose.

This article contains no studies with human or animal subjects performed by the authors.

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