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Expanded graphene oxide-supported molecularly imprinted polymer nanoparticles based on polystyrene for dibenzothiophene removal

Mohammad Saleh Vosoughi, Mahshid Fallah-Darrehchi and Payam Zahedi

Department of Polymer, School of Chemical Engineering, College of Engineering, University of Tehran, Tehran, Iran

ABSTRACT
This work aimed at synthesizing molecularly imprinted polymer (MIP)-based nanoadsorbent consisting of styrene as functional monomer, expanded graphene oxide (EGO) functionalized with (3-mercaptopropyl) trimethoxysilane (MPS) as support, and dibenzothiophene (DBT) as template. The main goal was to enhance the efficiency of the sample for DBT removal from hexane, and petroleum media. For this purpose, FTIR results at the characteristic peak of 1100 cm\textsuperscript{−1}, and SEM images showed that a complete functionalization of EGO platelets using MPS, and an appropriate changing graphene oxide (GO) to EGO, respectively. The synthesis of styrene-based MIP nanoparticles onto the surface of EGO/MPS was carried out by adjusting the template: monomer molar ratio of 1:4 in which the highest imprinting factor (IF) with a value of 1.81, and the average nanoparticles diameter of 540 nm were attained. Moreover, FTIR outcomes exhibited that EGO/MPS support could remain even after washing of the template from the polymerized nanoparticles to form MIPs. Finally, by evaluating the equilibrium adsorption of DBT using the EGO/MPS-supported MIPs based on polystyrene from hexane (\(\sim 150\) mg/g of the nanoadsorbent), and petroleum (\(\sim 34\)% after six cycles), it was found that the sample had high potential to adsorb DBT as the main contaminant in the refinery industry.

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Dibenzothiophene; molecular imprinting; styrene; graphene oxide; adsorption

CONTACT
Payam Zahedi  phdzahedi@ut.ac.ir
Department of Polymer, School of Chemical Engineering, College of Engineering, University of Tehran, P. O. Box: 11155-4563, Tehran, Iran

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1. Introduction

In recent decades, the elimination of aromatic sulfur-based compositions from fossil fuels provides a pathway of research works to examine different methods for adsorption of these substances as the main reason for the reduction of the fuels efficiency. Some desulfurization techniques such as hydro-desulfurization, adsorptive, extractive, and oxidative desulfurization have been abundantly used so far [1–6]. One of the most problematic substances which requires deep desulfurization approach is dibenzothiophene (DBT) in the subset of thiophenes. Sulfur-based substances are susceptible to turn into sulfur oxides during the burning process of fuels, thereby causing severe air pollution, acidic rain, and catalytic converter for the toxic materials [7,8]. Amid the desulfurization methods, adsorption is a suitable solution for removing the aromatic sulfur-based pollutants from the fuels [9,10]. In this line, designating an adsorbent is an indispensable key point to achieve a high removal percentage of thiophenes. In order to attain a practical separation approach, various inorganic and organic adsorbents such as zeolite [11–13], silica [14,15], carbon nanomaterials [16–18], and recently molecularly imprinted polymers (MIPs) are potentially used as effective adsorbents for DBT removal [9,17,19,20].

Carbon-based materials especially those modified by physical and chemical treatments have attracted a great deal of attention up to present. Earlier, Haji and Erkey [21] compared the carbon aerogels with naphthalene for DBT removal from contaminated diesel fuel. The obtained results showed that however, naphthalene has a similar structure to DBT, carbon aerogel with larger pore size could represent better performance. In the following, Yu and coworkers [22] focused on the capability extent of activated carbon for adsorption of sulfur containing polyaromatics from fuel oils. Their study confirmed that the activated
carbon treated with 65 wt. % of nitric acid (HNO₃) due to inserting the oxygen containing functional groups could efficiently separate thiophenes such as benzothiophene (BT), and DBT. In addition, scientists tried to remoldify the activated carbon by using different active metal oxides [23]. For example, Saleh et al. [24] worked on the activated carbon treated with manganese oxide to optimize the performance of the sample for desulfurization process. Their findings exhibited that the removal efficacy of polyaromatics could be improved conspicuously by means of metal treatment.

Among the carbon-based adsorbents, graphite derivatives such as graphene, and graphene oxide (GO) have been taken to consideration for the separation of sulfur containing aromatics due to their lattice-like structure which is similar to BT, and DBT configurations as well as their modifyable surface [25–27]. To assess the performance of graphene as an adsorbent, Wang et al. [28] studied four types of carbons including the activated carbon, Maxsorb (a super activated carbon), mesoporous templated carbon, and graphene. By immersing them into the fuel-like liquid, graphene exhibited the highest capacity for the thiophenes removal. Also, the combination of metal oxides with graphene has been performed in order to reach more effectiveness owing to their catalysis role through the adsorption procedure. In general, oxidized graphene which contains a number of active functional groups onto the surface of graphene layers can be utilized either lonely as an adsorbent or as a support for the new class of materials namely MIPs to enhance their performance in the field [9,19,29–33]. In a recent work, Jin et al. [34] investigated the selectivity and sensitivity of gastrodin based on nickel foam modified with reduced GO/silver nanoparticles complex-encapsulated MIPs. They showed that the synthesized MIP nanoparticles sample had an excellent capability of gastrodin detection, and recovery in human serum samples.

Nanoparticles produced by means of molecular imprinting technique (MIT) are potentially used for toxic materials separation owing to their active recognition sites based on memory effect on the shape in accordance with template molecules [17,19,35]. Li and coworkers [36] investigated the molecular imprinted particles for the recognition, and separation of DBT, thereby recognizing, and adsorbing this substance efficiently. Moreover, to increase the extent of adsorption, some research works demonstrated that supporting the MIPs by the use of porous carbon nanomaterials owing to their high active surface area was able to improve their efficacy. Amid the various derivatives of carbon, GO is one of the most operative materials which can remarkably increase the extent of DBT removal [35,37,38]. Duan et al. [9] synthesized poly (methacrylic acid)-based MIPs in which functionalized GO was used to obtain more appropriate performance. The adsorption results showed that the prepared MIP/GO displayed a significant adsorption capacity. By following up the literature, a case study on styrene as a new monomer for MIP synthesis with expanded GO (EGO) support for DBT removal has not been reported.

This work aimed at evaluating the performance of DBT template-based MIP nanoparticles consisting of polystyrene supported by EGO for DBT removal. For this purpose, EGO samples were prepared at two different temperatures to employ them as a support for MIP nanoparticles and Fourier transform infrared (FTIR) spectroscopy, scanning electron microscopy (SEM), and the adsorption experiments were carried out. Also, the performance of the samples was evaluated in the real environment based on petroleum. The obtained results were reported and discussed concisely.
2. Results and discussion

2.1. Specific surface area measurements of GO and EGO by means of BET method

Obviously, the parameter of specific surface area has an indispensable role on the adsorption of the template. In accordance with the above mentioned concept, this value for GO, and EGO was measured by using an inert gas (nitrogen) which passes through a thin layer of those samples. As can be seen from Table 1, the specific surface areas of GO, and EGO at two temperatures of 500°C, and 900°C were 3.21 m²/g, and 154.63 m²/g, as well as 202.47 m²/g, respectively. By comparing these reported values, it could be concluded that the thermal treatment extremely enhanced the specific surface area of EGO at 500°C approximately 50 fold compared to GO sample. On the other hand, this value was increased in EGO sample at 900°C with the amount of 1.3 fold with respect to the sample expanded at 500°C. Consequently, the higher temperature led to increase the specific surface area of EGO, thereby enhancing the DBT removal from the solution.

2.2. Determination of the optimum molar ratio of monomer (styrene): template (DBT)

To optimize the molar ratio of the monomer to template, five different MIP samples without EGO/MPS including MIP₂, MIP₄, MIP₆, MIP₈, and MIP₁₀ and also those samples in the presence of EGO/MPS were synthesized. As mentioned earlier, IF is the main parameter for investigating the sample’s efficiency to adsorb DBT from the hexane medium. Accordingly, the high IF value leads to the high performance of the synthesized MIPs for the adsorption of the template from the solution. Moreover, by incorporating the EGO/MPS as the support for MIP samples, it could be predicted the adsorption enhancement. Table 2 shows the IF values for the different samples in which the samples coded by MIP₄ for both synthesis systems have the best performance to adsorb DBT from hexane solution with IF values of 1.42, and 1.81 for the samples in the absence and presence of EGO/MPS, respectively. Therefore, the EGO-supported MIP₄ nanoparticles based on polystyrene was selected as the optimum sample for further evaluation.

### Table 1. The BET values of GO, and EGO at two different temperatures for 30 s.

<table>
<thead>
<tr>
<th>Sample</th>
<th>GO</th>
<th>EGO at 500°C</th>
<th>EGO at 900°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific surface area (m²/g)</td>
<td>3.21</td>
<td>154.63</td>
<td>202.47</td>
</tr>
</tbody>
</table>

### Table 2. The synthesized MIPs in the presence and absence of EGO support with different molar ratios of styrene: DBT and their IF values.

<table>
<thead>
<tr>
<th>Sample</th>
<th>IF</th>
<th>Sample</th>
<th>IF</th>
<th>Styrene: DBT (molar ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIP₂</td>
<td>1.25</td>
<td>EGO/MPS-based MIP₂</td>
<td>1.37</td>
<td>1:2</td>
</tr>
<tr>
<td>MIP₄</td>
<td>1.42</td>
<td>EGO/MPS-based MIP₄</td>
<td>1.81</td>
<td>1:4</td>
</tr>
<tr>
<td>MIP₆</td>
<td>1.36</td>
<td>EGO/MPS-based MIP₆</td>
<td>1.69</td>
<td>1:6</td>
</tr>
<tr>
<td>MIP₈</td>
<td>1.29</td>
<td>EGO/MPS-based MIP₈</td>
<td>1.59</td>
<td>1:8</td>
</tr>
<tr>
<td>MIP₁₀</td>
<td>1.22</td>
<td>EGO/MPS-based MIP₁₀</td>
<td>1.34</td>
<td>1:10</td>
</tr>
</tbody>
</table>
Figure 1. (a) FTIR spectra of GO, EGO, and EGO/MPS samples, and (b) FTIR spectra of DBT, EGO/MPS-supported MIP, and EGO-supported MIP nanoparticles samples.

2.3. Recognition of active sites of EGO, EGO/MPS, and EGO/MPS-supported MIP nanoparticles

FTIR spectroscopy is a qualitative and appropriate method to recognize and compare the newly formed and available active sites on the samples surfaces. Hereby, MPS which contained free vinyl functional groups, could react with EGO layers and increase their capability for adsorption by creating active sites for the polymerization. Figure 1(a) shows the FTIR spectra of GO, EGO, and EGO/MPS samples. As can be seen, all three samples have the characteristic peaks at 3420 cm$^{-1}$ corresponding to hydroxyl groups ($-\text{OH}$), 2860 cm$^{-1}$ assigning to alkyl groups (C–H), 1720 cm$^{-1}$ attributing to carboxyl groups.
Figure 2. SEM micrograph images of (a) GO, (b) EGO at 500°C, and (c) EGO at 900°C (the scale bar is 1 micron).

(C = O), and 1500–1650 cm\(^{-1}\) related to carbon double bonds (C = C). These relatively unchanged peaks confirmed that thermal expansion of GO did not affect the chemical structure. By adding MPS to EGO, a characteristic peak at 1100 cm\(^{-1}\) was appeared which obviously referred to silica groups (Si–O). It is noteworthy to mention that some bonds were susceptible to decompose during the thermal expansion process of GO, however, this procedure increased the free space between its layers simultaneously. Figure 1(b) indicates the characteristic peaks of the three samples such as DBT template-based EGO-supported MIPs, DBT template-based EGO/MPS-supported MIPs, and DBT template alone. The appearance of peak at 1510 cm\(^{-1}\) referred to the carbon double bonds for MIP nanoparticles containing EGO, and EGO/MPS which confirmed the presence of EGO linkages even after the washing process. Likewise, the peak located at 1100 cm\(^{-1}\) (Si-O bonds) in the spectrum of EGO/MPS-supported MIP sample showed that MPS was successfully functionalized onto the surface of EGO after the template removal.

2.4. Morphology studies

2.4.1. Investigation of GO and EGO morphologies

Figure 2(a–c) illustrates the SEM micrograph images of GO (Figure 2(a)), EGO at 500°C (Figure 2(b)), and EGO at 900°C (Figure 2(c)). By observing them, it could be concluded that the thermal expansion process caused to separate the graphene layers. Figure 2(a) indicates that without the thermal treatment, the layers were not susceptible to separate and stuck together. Contrary, by applying the thermal process, it seemed that the EGO layers found a larger free space with more increase in their volume compared to GO plates (Figure 2(b)). On the other hand, by growing the temperature from 500°C to 900°C (Figure 2(c)), the distance between the layers of EGO could be increased which led to an increase in MPS deposition followed by enhancing a number of styrene monomer, thereby providing more active sites on the MIP surface for the highest efficiency to adsorb DBT. The increase of EGO layers at higher temperature was confirmed by BET analysis (Table 1).

2.4.2. The morphology investigation of EGO/MPS-supported MIP, and NIP nanoparticles

Figure 3(a–d) depicts the SEM micrograph images alongside the diameters distribution curves of EGO/MPS-supported MIP, and NIP nanoparticles. As is shown, (Figure 3(a,b)), and (Figure 3(c,d)) were related to the MIP, and NIP samples, respectively. Accordingly, the
MIP-based sample has a uniform and spherical shape for the nanoparticles which proved that they were a suitable candidate for the adsorption. The MIP sample has larger average diameter (around 570 nm) than NIP ones (around 314 nm) due to the presence of active sites in its cavities. As mentioned earlier, the IF of EGO/MPS-supported MIP₄ sample has the highest value among the synthesized samples which could be emphasized that this sample has the most numbers of the active sites. Moreover, the morphology of NIP₄ sample (right-hand side) has an irregular shape and the nanoparticles tended to be agglomerated, thereby showing less DBT loading than MIPs.

### 2.5. DBT removal studies using the different samples

Besides the physicochemical characteristics of the synthesized EGO/MPS-supported MIP nanoparticles, four types of samples including GO, EGO, EGO/MPS-supported MIPs, and EGO/MPS-supported NIPs were investigated and compared to adsorb DBT in two different media such as hexane and petroleum. Figure 4 indicates the adsorption trends of each sample for 60 min. Predictably, GO platelets had the minimum amount of adsorption due to the small free space between the layers, and also the absence of enough available functional groups for DBT adsorption (∼75 mg/g of total dissolved DBT in hexane). On the other hand, the EGO sample showed better adsorption than GO with the amount of approximately 100 mg/g. As is shown in Figure 6, after exposing GO platelets (section A)
to 900°C for expansion, they were converted to EGO (section B) followed by inserting in MPS solution. In the presence of MPS, the –OH functional groups onto the surface of EGO first were broken which in turn Si–O functional groups were created (section C) [9]. Then EGO/MPS was used as the support for the DBT template-based MIPs synthesis by using the radical polymerization of styrene monomer. After removing the template, a series of active cavities similar to the structure of DBT was formed for the adsorption process. However, in the case of EGO/MPS-supported MIP nanoparticles, an appropriate result was obtained in which the maximum DBT adsorption was observed with the value of approximately 150 mg/g, and this value was higher than that of EGO/MPS-supported NIPs. The reason was referred to the presence of active sites corresponding to the functional groups onto the surface of DBT.

For further evaluation, the results of the equilibrium adsorption of DBT reported in the literature and their comparison with the obtained value in this work are represented in Table 3. In this line, the DBT adsorption of the samples such as MAA-based MIPs on the surface of porous magnetic carbon nanospheres [39], and the double-template MIPs on the surface of magnetic mesoporous silica [40] as well as the other works was lower than that value reported for EGO/MPS-supported MIPs based on styrene monomer. In exception, the sample based on GO/MAA-based MIPs reported by Duan et al. [9] had better performance than the synthesized sample in this work due to the type of monomer.

For further investigation, this test was carried out in the petroleum medium which was not a pure environment like hexane. As a real medium, the results of DBT adsorption by using EGO/MPS-supported MIP based on polystyrene were evaluated three times during 5 h for the capability of the sample in view of recyclability. Figure 5 demonstrates the amounts of DBT removal through six cycles in the petroleum environment. As is evident, in the first cycle which the sample was fresh, the DBT adsorption was approximately 54%. In the second, third, and fourth cycles, the same values were obtained at about 50%. In the
Table 3. A comparison between the MIPs samples for equilibrium adsorption of DBT in the literature.

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>Equilibrium adsorption (mg/g)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>GO/MAA-based MIPs</td>
<td>181.9</td>
<td>[9]</td>
</tr>
<tr>
<td>MAA-based MIPs/porous magnetic carbon nanospheres</td>
<td>32</td>
<td>[39]</td>
</tr>
<tr>
<td>Hollow surface MAA-based MIPs/porous magnetic carbon microspheres</td>
<td>62.06</td>
<td>[20]</td>
</tr>
<tr>
<td>Double-template MIPs/magnetic mesoporous silica</td>
<td>104.2</td>
<td>[40]</td>
</tr>
<tr>
<td>MAA-based MIPs/magnetic multi-walled carbon nanotubes</td>
<td>47.8</td>
<td>[38]</td>
</tr>
<tr>
<td>EGO/MPS-supported MIPs based on styrene monomer</td>
<td>150</td>
<td>Current work</td>
</tr>
</tbody>
</table>

Figure 5. The recyclability of EGO/MPS-supported MIP nanoparticles for DBT removal in petroleum after 5 h.

following, a significant reduction occurred for adsorption of DBT for the sample in fifth and sixth cycles with an amount of 34%. The reason for this trend was related to the active sites occupation within the MIP cavities. However, the sample had good DBT adsorption in petroleum environment even after six cycles of adsorption/desorption processes.

3. Conclusion

The MIP samples containing styrene as functional monomer, EGO/MPS as the effective support, and BDT as template were successfully synthesized as a nanoadsorbent for DBT removal. Based on IF values, the best template to monomer molar ratio was selected with the amount of 1–4 which the candidate sample was denoted by MIP₄. Subsequently, to enhance the performance of GO, the thermal expansion process at a temperature of 900°C was selected based on BET, and SEM results to convert it to EGO. For more efficiency of EGO, it was functionalized with MPS, namely EGO/MPS which the accuracy of the process was proved by FTIR spectroscopy. In the following step, the DBT template-based MIP nanoparticles were synthesized using precipitation polymerization in the exposure of EGO/MPS support. Finally, the measurements of DBT adsorption from hexane, and
petroleum media were carried out and the results showed that this sample was a promising candidate to remove the aromatic sulfur-based contaminant with high efficacy. It is worth noting that the authors of this work believe that this research field should be extended with the rationale of the following items: using a wide range of functional monomers, investigating another carbon allotropes such as Fullerene, and studying the different adsorption isotherm models.

4. Experimental

4.1. Materials

Styrene (functional monomer, synthetic grade with purity > 98%), ethylene glycol dimethylacrylate (EGDMA, crosslinking agent), azobisisobutironitri le (AIBN, thermal initiator, a white powder with 98% purity), and dibenzothiophene (DBT, C_{12}H_{8}S, colorless and solid) were purchased from Merck Co., Germany. (3-mercaptopropyl) trimethoxysilane (MPS, purity of 95%, liquid) was provided from Sigma-Aldrich Co., The Netherlands. Graphene oxide (GO) with the nanoplatelets thickness of 3.4–7 nm was supplied from US Research Nanomaterials Inc., United States. All the other chemicals were analytical reagent grades and used without further purification.

4.2. Preparation of EGO

To prepare the EGO layers, 500 mg of GO was placed in a high-temperature furnace equipped with nitrogen purge. Then, EGO samples were formed at two different temperatures (500°C, and 900°C) during 100 s. The most important reason for this procedure was to create smaller particles with larger spacing between the EGO nanoplatelet compared to origin GO, thereby increasing its overall efficiency for DBT adsorption.

4.3. Synthesis of silane-functionalized EGO

To synthesis of silane-functionalized EGO, MPS as a polymerizable silane-based coupling agent was utilized. In the procedure, 1 mL of MPS, and 0.1 g of EGO were added to the mixture of acetonitrile: distilled water (1:2), and sonicated for 14 min. Thereafter, the mixture was stirred gently at a temperature of 70°C for 4 h. For separating the functionalized EGO, the mixture was centrifuged at 4000 rpm for 3 min. Subsequently, the functionalized EGO was precipitated, and washed by using methanol three times, and dried in an oven at 40°C to evaporate residual moisture.

4.4. Synthesis of EGO/MPS-supported MIP nanoparticles

The first step through the MIP synthesis is the formation of a complex between template and functional monomer. Five different molar ratios of template to monomer [DBT: styrene (mmol)] were selected as follows: 1:2 (MIP₂), 1:4 (MIP₄), 1:6 (MIP₆), 1:8 (MIP₈), and 1:10 (MIP₁₀). In this line, the amounts of the other components were kept constant including EGO/MPS ratio of 0.1 g/mL, and EGDMA of 16 mmol. The predetermined amounts of DBT were added to 25 mL of acetonitrile in separate within glass bottles, and sonicated in order to reach well-dispersed solutions containing the template, and porogenic
solvent in an ice-water bath. After 6–8 h, predetermined amounts of EGDMA, AIBN, and MPS-functionalized EGO were added to the mixture. For initializing the polymerization process, first the atmosphere of polymerization medium was replaced with nitrogen gas completely for all bottles. Then they were inserted in an oil bath at the temperature of 65°C for 48 h. The precipitation polymerization of styrene monomer was completed, and the final solutions were centrifuged at the speed of 8000 rpm for 10 min. The deposited polymers were dried in a vacuum chamber at the temperature of 30°C overnight.

Finally, the synthesized samples were washed by using methanol: acetic acid (9:1) mixture within a Soxhlet apparatus for 2 days to remove the template completely. It is worth noting that besides the MIP samples, the non-imprinted polymers (NIPs) samples were also synthesized based on the mentioned procedure for the MIPs preparation in the absence of DBT as template.

The adsorption capacity (Q) of the different synthesized MIPs was measured based on the Equation (1) as follows:

\[ Q = \frac{C_0 - C_e}{m \times V} \]

where ‘\( C_0 \)’ (mg L\(^{-1}\)) is the initial concentration, and ‘\( C_e \)’ is the equilibrium concentration of DBT in the supernatant. Also, ‘\( V \)’ (mL) is the volume of adsorption medium and ‘\( m \)’ (mg) refers to the mass of nanoparticles. Moreover, the imprinting factor (IF) which indicates the performance of the MIP samples is defined by using Equation (2):

\[ IF = \frac{Q_{MIP}}{Q_{NIP}} \]

The overall schematic of the process related to the EGO/MPS-supported MIP nanoparticles based on polystyrene containing DBT template is represented in Figure 6.

### 4.5. Characterization

For qualitative investigation of the formed bonds between different components through reaction medium, a Fourier transform infrared spectroscopy (FTIR, model Spectrum Two, PerkinElmer Inc., United States) was utilized at room temperature with wavenumbers in the range of 400–4000 cm\(^{-1}\) using a KBr tablet at a resolution of 4 cm\(^{-1}\). On the other hand, the morphology observations of the MIP and NIP samples, and GO as well as EGO were carried out by using a scanning electron microscopy (SEM, model CamScan MV2300, Oxford, England) at 5000 X and 30,000 X magnifications.

To study the binding capacity of EGO/MPS-supported MIP nanoparticles in the exposure of DBT in hexane medium, an ultraviolet-visible spectrophotometry (UV-vis, model UNICO 2800, United States) was utilized in order to measure the amount of remained DBT in the supernatant which has not been adsorbed using the sample. By considering the Equation (3), it can be calculated the extent of the adsorbed DBT according to Beer–Lambert law at maximum adsorption wavelength of 290 nm.

\[ A = \varepsilon \times c \times l = 290 \times c, \]

where ‘\( \varepsilon \)’ is the extinction coefficient of DBT solution, ‘\( c \)’ is the concentration of DBT in hexane, and ‘\( l \)’ is the distance which the light travels through the sample.
Moreover, the amount of DBT adsorption in petroleum as a real environment has been carried out. In advance, a specific concentration of DBT in petroleum (20 ppm) was prepared. Then, 30 mg of EGO/MPS-based MIP nanoparticles were added to the prepared solution (50 mL). To measure the DBT adsorbed using the sample, the mixture was stirred at 25°C for 5 h, and subsequently, the supernatant was read by means of UV-vis spectrophotometry. Furthermore, to evaluate the recyclability of the sample, they were centrifuged, washed using methanol/acetic acid mixture within a Soxhlet apparatus for 48 h. After the sample was dried in an oven at 50°C it was employed for the DBT adsorption again with the same condition above mentioned. This trend was done for 6 cycles.

Finally, Brunauer–Emmett–Teller (BET, model Belsorp-mini II, Japan) was investigated to obtain the specific surface area of GO, and EGO followed by comparing their capacity for the adsorption, and the effect of thermal expansion processes.

Figure 6. The overall schematic of sample preparation: (A) GO structure, (B) EGO structure, (C) functionalizing EGO with MPS (EGO/MPS), (D) synthesis of polystyrene-based nanoparticles on EGO/MPS as support, and (E) the formation of MIP samples after removing the template (EGO/MPS-supported MIP nanoparticles).
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ORCID

Payam Zahedi http://orcid.org/0000-0001-6636-4534

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