Development of Regenerable Adsorbents for the Removal of Emerging Contaminants from Water
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Abstract
There are many reports indicating the presence of various emerging contaminants (ECs) in treated wastewater and other water sources. The detection of such contaminants in environment and the ability of these contaminants to pose potential threats to environment at very low concentrations have led to a need for more efficient treatment technologies. Through this research, successful attempts have been made for the synthesis of regenerable adsorbents based on β-cyclodextrin (BCD), a glucose-based molecule that has high affinity for adsorption of organic contaminants. In this research, hybrid adsorbents were synthesized by coating BCD onto silica and then were tested for the removal of selected ECs. 17β-estradiol (E2), perfluorooctanoic acid (PFOA) and bisphenol-A (BPA) were selected as model contaminants to represent ECs.

Results and Discussions
Screening of adsorbents
14 different adsorbents prepared by following three different approaches were tested for the removal of ECs. 17β estradiol, PFOA and BPA were used as model contaminants to represent ECs. The results are summarized in Table 1. The best adsorbent was selected based on its performance in removing the selected ECs in MQ water. The method was further optimized by synthesizing four different ECs, with BCD loading of 0.15, 0.23, 0.5, and 0.76 g/l. It was observed that BCD loading of 0.23 was optimum in removing the target ECs and was used for further experiments.

To analyze the experimental data, two commonly used isotherm models, the Langmuir (Eq 1) and Freundlich (Eq 2) equations were used which can be expressed as

$$ q = \frac{q_m \times C}{1 + k \times C} \quad \text{(1)} $$

$$ q = q_0 \times C^{1/n} \quad \text{(2)} $$

Where, $q_m$ is the equilibrium sorption amount, $C$ is the equilibrium concentration, $q_0$ is the maximum sorption capacity, $b$ is sorption equilibrium constant, $K$ is a constant representing the sorption capacity and $n$ represents the sorption intensity.

Comparison with F400: Removal of ECs
The adsorption capacity of BCD/Silica adsorbent was compared with that of commercially available commonly used activated carbon F400 in MQ water for the removal of the model contaminants. The data obtained from isotherm experiments were used to determine the adsorption capacity of each adsorbent for a given contaminant at an equilibrium concentration of 2 µg/L. The results showed higher adsorption capacity of BCD/Silica adsorbent for E2 and PFOA than F400.

Experimental Approach
Synthesis of adsorbents: Various adsorbents were synthesized by coating BCD onto silica by using three different methods. The first method was based on use of two different crosslinking agents epichlorohydrin (EPI) and hexamethylene disocyanate (HMDI). The second method was based on use of two different copolymers glycidyltrimethoxysilane (GPTMS) and aminopropyl triethoxysilane (APTES). In third method, both crosslinking agents as well as copolymers were used for coating processes.

Batch adsorption: Experiments were carried out in series using 500 mL amber bottles, containing 400 mL working solution of ECs (in MQ water). The adsorbent was added into these bottles and shaken at 140 rpm on a shaker at room temperature till the equilibrium was ascertained. The amount of ECs adsorbed on the adsorbents was calculated from the differences between the concentrations of the contaminants before and after the treatment.

Figure 1. Removal of ECs with the best adsorbent

Figure 2. Removal of PFCs in multicomponent systems

Figure 3. Schematic representation of inclusion-complex formation between 17β-estradiol (guest) and BCD (host) molecules

Figure 4. Regeneration study with methanol

Figure 5. Regeneration study with Ozone

The mechanism of removal of ECs by BCD may be explained in a two-step process. First, the hydrophobic nature of the contaminants provide necessary conditions to enter into the cavity of BCD and then the stability of this complex formation is governed by the formation of inter-molecular hydrogen bonding (Fig 3).

Regeneration experiments
In order to regenerate the adsorbent, two approaches were used. First of all, methanol was used to desorb the adsorbed contaminants in order to regenerate the adsorbent. The adsorbent showed good regeneration potential with methanol for the desorption of mixture of estrogens and PFOA (Figure 4). Another approach was used where the used adsorbent was exposed to ozone in order to destroy the adsorbed contaminants. The results showed successful regeneration of the adsorbent by destroying the contaminant (trapped in the cavity of BCD) with ozone over seven successive cycles without significant loss in its adsorption capacity (Figure 5).

Conclusions
- High-efficiency, Regenearable adsorbent was synthesized and represented.
- The developed adsorbent was effective in removing estrogens, PFCs and BPA from water.
- The adsorbent could be regenerated with ozone for seven successive cycles without significant loss in its adsorption capacity.
- Possible to have a water filter to remove ECs (the filter could be regenerated and reused).

References

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