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Interaction of tetrabromobisphenol A (TBBPA) with microplastics-sediment (MPs-S) complexes: A comparison between binary and simple systems☆

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ABSTRACT

The presence of microplastics (MPs) and the associated organic pollutants in the aquatic environment has attracted growing concern in recent years. MPs could compete with chemicals for adsorption sites on the surface of sediment, affecting the sorption processes of pollutants on sediment. However, few studies focused on the binary system of microplastics-sediment (MPs-S), which appear much common in aquatic environment. Herein, we investigated the interactions between a continuously used flame retardant tetrabromobisphenol A (TBBPA) and four MPs-S complexes (PVC–S, PE-S, PP-S and PS-S). The equilibrium adsorption capacities were 17.1, 15.6, 15.4, and 14.0 mg/kg for PVC-S, PS-S, PE-S, and PP-S, respectively. Kinetics suggest that adsorption behavior of TBBPA was fitted by pseudo-second-order model. Co-adsorption of TBBPA in binary systems were much lower than the sum of each simple system, which may be due to the mutually occupied adsorption sites. Higher ionic strength and lower dissolved organic matter strengthened the sorption of TBBPA onto MPs-S complexes. The enhanced sorption capacities for TBBPA were observed with elevated proportion and small particle size of MPs in the MPs-S complexes. This study contributes to the knowledge on the impact of MPs in partitioning of organic pollutants in-between solid and aqueous phases in the aquatic environment.

1. Introduction

Occurrence of microplastics (MPs) in the aquatic environment has garnered increasing attention as it has become a global concern (Wang et al., 2018; Klingelhöfer et al., 2020; Arienzo et al., 2021). Due to the large specific surface area and strong surface hydrophobicity, many MPs can easily adsorb contaminants such as heavy metals and organic chemicals from water (Tang et al., 2021; Xiang et al., 2022; Menéndez-Pedriza and Jaumot, 2020), serving as potential vectors and sinks for these pollutants. Nevertheless, it is currently questioned whether MPs as sinks and vectors for pollutants are of such significant. (Tang et al., 2021; Arienzo et al., 2021; Wang et al., 2018). MPs are sometimes considered to be secondary vectors of affiliated chemicals, especially with respect to the more presence of other organic matters such as dissolved organic matters (DOM) from sediment, in the real field scenarios of aquatic environment (Xiang et al., 2022; Arienzo et al., 2021). To examine the contribution of MPs to the accumulation of pollutants, the interaction including sorption kinetics, isotherms and influence factors between MPs and certain chemicals have been previously investigated (Tang et al., 2021; Xu et al., 2018; Li et al., 2021). However, the studies were generally performed in simple system consisting of MPs and water environment, and few of these studies focused on more complex systems, e.g., binary system of MPs-sediment (MPs-S), which appear much common in real aquatic environment. Sediment (or DOM from sediment) could compete with other chemicals for adsorption sites on the surface of MPs, affecting the sorption processes of pollutants on MPs and certainly the distribution of these chemicals in different phases (Menéndez-Pedriza and Jaumot, 2020), whereas knowledge on this effect, as well as corresponding interaction between the pollutants and the composite system, is still scarce.

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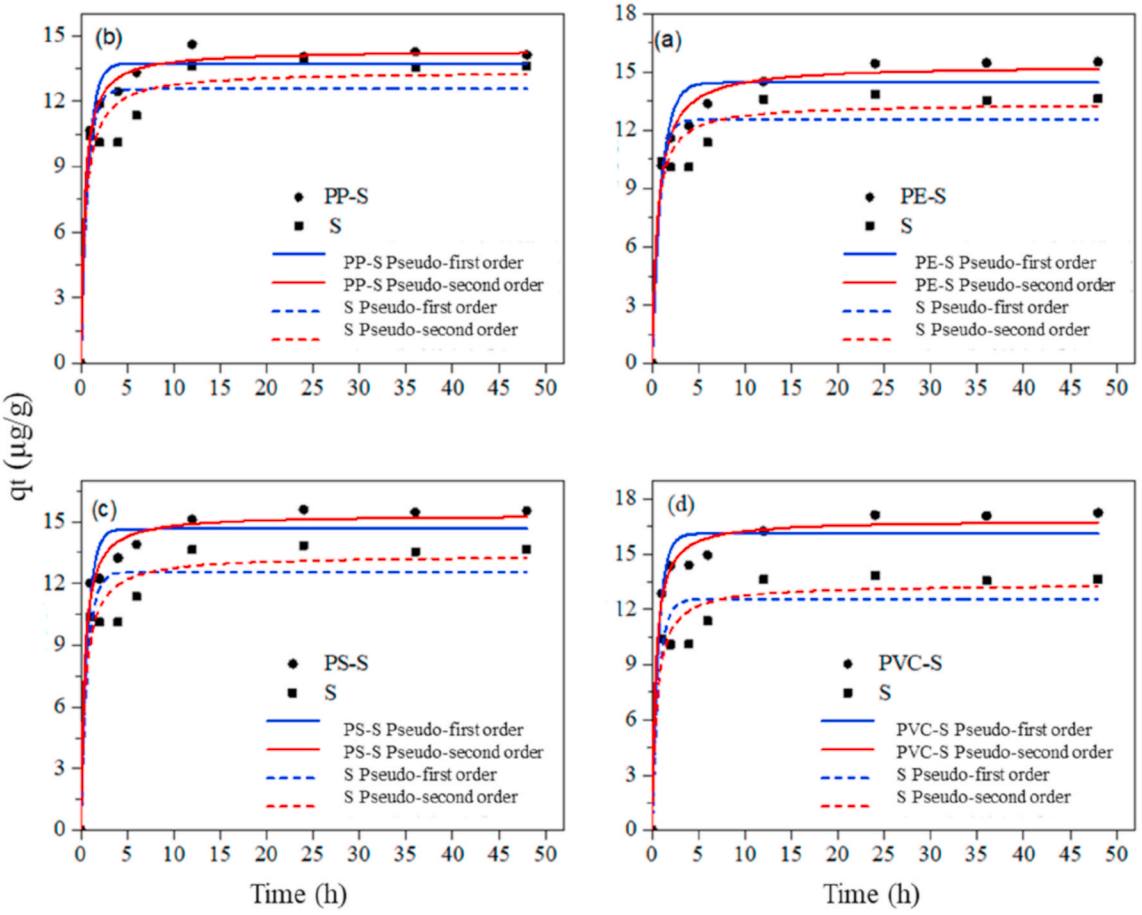

Fig. 1. Sorption kinetics of TBBPA on sediment and MPs-sediment complexes.

MPs are prone to sedimentation (Su et al., 2020), resulting in increasing numbers of MPs accumulation in sediment. Currently, MPs occur ubiquitous in sediment of rivers, lakes, reservoirs, estuaries, seas and deep-seas at global scale (Gray et al., 2018; Barrett et al., 2020; Yang et al., 2020; Zhang et al., 2020; Uddin et al., 2021). In summary, the numbers of MPs in sediment generally ranged from tens to thousands per kilogram; the particle sizes were mostly less than 1 mm; the most common polymer types were polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC). In addition to MPs, sediment are also sinks of organic contaminants, such as organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and Tetrabromobisphenol A (TBBPA) (Meng et al., 2017; Feng et al., 2012). Compared to simple MPs in water, the intervention of sediment for MPs-S systems could affect the sorption of these pollutants by MPs. Although studies on the MPs-S composite systems are limited, DOM has been found to promoted the adsorption of Cu on MPs of PS (Qiao et al., 2019), while decrease the adsorption of antibiotics by MPs of PE (Wu et al., 2016). Our previous investigation also revealed that humic acid (HA), a common type of natural organic matter, exhibited negative effect on TBBPA sorption by MPs (Li et al., 2021). These findings imply different sorption and partitioning processes of pollutants onto MPs-S binary system compared to that of simple system.

TBBPA is one of the most used brominated flame retardants (BFRs), accounting for 60% of the total BFRs market (Liu et al., 2016a, b; Yu et al., 2019). Because of its bulk production and application, TBBPA is frequently detected in aquatic environment, especially in sediment (Liu et al., 2016a, b; Yang et al., 2012). Owing to its high octanol/water partition coefficient (log K_{OW}) (Wu et al., 2021), TBBPA is more readily distributed in sediment than water. However, few study has focused on the partitioning of TBBPA in-between sediment and aqueous phases in presence of MPs. Our previous study has investigated the interaction between TBBPA and four types of MPs commonly used, revealing the sorption capacities of 102, 78.9, 58.6, and 49.4 mg/kg for PVC, PS, PP, and PE respectively (Li et al., 2021). To promote understanding on the adsorption and partitioning of TBBPA in binary (water-MPs-sediment) system, this study aims to (1) investigate the adsorption mechanisms of TBBPA onto the MPs-S complexes, with MPs types including PP, PE, PS, and PVC; (2) assess the partitioning of TBBPA between solid (MPs and sediment) and aqueous phases. This study may increase our understanding on environmental behavior of TBBPA in water environment, which is important in ecotoxicological assessment for aquatic organisms.

2. Materials and methods

2.1. Materials and chemicals

Sediment used in this study were collected from Xinfengjiang reservoir (114°23′51.71″ E, 23°45′08.27″ N), Guangdong province, China. Four types of MPs (PS, PP, PE, and PVC) were acquired from Aladdin (SH, CN). TBBPA standard (>99% pure) was purchased from Signa-Aldrich (St. Louis, MO, USA). HA (>90% pure) and $CaCl_2$ (>96% pure) were supplied by J&K Scientific Ltd. (BJ, CN). HPLC grade of methanol was purchased from Apel Scientific (SH, CN). Ultrapure water was obtained from a Milli-Q system (Millipore, Milford, MA, USA).

The physicochemical properties (Table S1 and S2) and characterization of the sediment and MPs are shown in Supporting Information (SI).

2.2. Batch sorption and factors influencing sorption

2.2.1. Adsorption kinetic and adsorption isotherm experiments

For the sorption kinetics experiments, approximately 100 mg of sediment and MPs-S complexes (1:4, w/w) samples were added into 50-ml amber flasks, respectively, followed by the background solution containing 0.01% (w/v) NaN_3 and 0.01M $CaCl_2$ to maintain the ionic strength of the suspension and to inhibit microbial degradation. Afterwards, the stock solution of TBBPA prepared in methanol was added into the flask, and the stock solution was set below 0.1% (v/v) to minimize cosolvent effects. The pH of the solution was kept 7.0 ± 0.2 by HCl and NaOH during the experiments. The mixture solutions were agitated in a thermostat shaker at 150 rpm at room temperature (25 °C) to reach apparent sorption equilibrium. The initial concentration of TBBPA was set at 100 μg/L. Samples were then withdrawn at 0 h, 1 h, 2 h, 4 h, 6 h, 12 h, 24 h, 36 h, and 48 h according to previous study (Li et al., 2021), and filtered through 0.22 μm PTFE membranes prior to instrumental analysis.

Additional batch experiments were conducted to study the sorption isotherm with 100 mg of MPs-S complexes (1:4, w/w) samples. The initial concentrations of TBBPA were set from 5 to 100 μg/L, and the incubation time was set for 48h on account of the kinetic results. Samples were collected at the end of the incubation in triplicate and filtered before instrumental analysis.

2.2.2. Factors influencing sorption

Effects of ionic strength and dissolved organic matter (DOM) on the sorption of TBBPA were assessed using $CaCl_2$ and humic acid (HA), respectively. Details of the factors influencing sorption were provided in SI. QA/QC were conducted with spiked TBBPA without MPs-S to evaluate procedure loss during incubation, and MPs-S spiked control group without TBBPA to detect the possible release of TBBPA from the MPs-S which proved to be undetectable. All batch sorption and factors influencing sorption were run in duplicate.

2.3. Instrumental analysis

TBBPA concentrations were analyzed using a liquid chromatograph coupled to a tandem mass spectrometer (AB Sciex API 4000$^+$). The target chemicals were determined on a Poroshell 120 EC-C18 column (3.0 × 50 mm, 2.7 μm; Agilent, CA, USA) maintained at 40 °C. Methanol and deionized water (9:1, v/v) were used as mobile phase, and the flow rate was kept at 200 μL/min. Details of instrumental analysis were provided in previous study (Yu et al., 2020).

2.4. Model simulation

The nonlinear models of pseudo-first-order (Eq. S1), pseudo-second-order (Eq. S2), and intra-particle diffusion model (Eq. S3) were adopted to fit sorption kinetics. The sorption isotherms were fitted with Linear model (Eq. S4), Freundlich model (Eq. S5), Langmuir model (Eq. S6), Temkin model (Eq. S7), and Dubinine-Radushkevich model (Eq. S8). The solid-water distribution coefficients (K_d) were calculated by Eq. (1):

$$K_d = \frac{C_S}{C_w} \quad (1)$$

where C_s is the concentration in solid phase (including sediment, MPs, and MPs-S complexes); C_w is the TBBPA concentration in aqueous phase.

3. Results and discussion

3.1. Adsorption kinetics and isotherms

The adsorption kinetics of TBBPA onto four types of MPs-S complexes are illustrated in Fig. 1. For each type of complexes, a high adsorption rate was observed at the initial time (0–4h), subsequently gradual decreased as the adsorption capacity tended to saturate within 4–12 h, and finally the adsorption equilibrium arrived at about 24h. The equilibrium adsorption capacities of TBBPA were 17.1 mg kg^{-1} for PVC-S, 15.6 mg kg^{-1} for PS-S, 15.4 mg kg^{-1} for PE-S, and 14.0 mg kg^{-1} for PP-S, with corresponding TBBPA adsorption proportion of 86.2%, 79.1%, 77.6%, and 70.6%, respectively. The parameters of two kinetic model revealed that the pseudo-second-order model (R^2 = 0.94–0.99) fitted better than the first-order model (R^2 = 0.88–0.97) (Table 1), inferring that the pseudo-second-order model might be more available to the adsorption of TBBPA. This finding implied that TBBPA could be adsorbed to different binding sites in the MPs-S complexes (Li et al., 2021). Moreover, besides the sorption onto surface sites, intraparticle diffusion and mass transfer were also involved in the TBBPA adsorption process in the MPs-S binary systems (Annadurai et al., 2008).

Table 1
Sorption kinetic parameters of TBBPA onto sediment and MPs-sediment complexes.

Materials	Qe.exp	pseudo-first-order			pseudo-second-order		
	(mg/kg)	K_1	Qe	R^2	K_2	Qe	R^2
S	13.9	1.38	12.6	0.879	0.156	13.4	0.938
PE-S	15.4	0.989	14.5	0.941	0.104	15.4	0.986
PP-S	14.0	1.32	13.7	0.972	0.182	14.3	0.993
PS-S	15.6	1.43	14.7	0.952	0.173	15.3	0.985
PVC-S	17.1	1.46	16.1	0.959	0.162	16.8	0.986

Interactions between TBBPA and MPs-S complexes based on the Linear, Freundlich, Langmuir, Temkin, and Dubinine-Radushkevich models were shown in Fig. 2. The calculated parameters of isotherm models by nonlinear fitting were summarized in Table 2, which showed that the linear Dubinine-Radushkevich model was available to the four MP-S complexes (R^2 = 0.84–0.99). The Dubinin–Radushkevich model can estimate the theoretical isotherm saturation capacity (Qs) and free energy (E) of sorption (Wang et al., 2018; Xu et al., 2019). Qs indicated that the adsorption affinity of sorbate for adsorbent and those for PS-S, PE-S, PVC-S, and PP-S were 296, 194, 128, and 51.3 mg/kg, respectively. The E values for PE-S, PP-S, PS-S, and PVC-S were 9.58, 10.2, 12.4, and 14.5 kJ/mol, respectively, which were lower than 40 kJ/mol. In this case, physical sorption was the predominant sorption mode of TBBPA onto MPs-S complexes, and it was a spontaneous endothermic sorption process (Horsfall, 2005; Xu et al., 2019).

To further discuss the potential mechanisms, the Temkin model was chosen to evaluate the adsorption potentials of interactions between adsorbent and sorbate. According to the R^2 values shown in Table 2, the Temkin model was more appropriate for PE-S and PS-S among the four MPs-S complexes. The A_t values suggested that PS-S presented higher sorption potential than that of PE-S. The B_t values for PE-S and PS-S were 0.736 and 0.898 kJ/mol, respectively. Previous studies (Horsfall, 2005; Xu et al., 2019) have found that the range of bonding energy for ion-exchange mechanism is 8–16 kJ/mol. Thus, the low value in the present study indicated that interactions between TBBPA and PE-S/PS-S did not involve an ion-exchange mechanism. Similar phenomena were also observed for the sorption of polybrominated diphenyl ethers by MPs (Xu et al., 2019). Furthermore, the regression coefficients for the Linear, Freundlich, and Langmuir models were high for PE-S, indicating that hydrophobic interaction, multilayer adsorption, and electrostatic force probably participated in this sorption engineering simultaneously.

3.2. Comparison between binary and simple systems

Relatively higher equilibrium adsorption capacities of TBBPA were found in MPs-S complexes than that of sediment (Table 1), indicating that the presence of MPs in sediment could enhance the adsorption capacity for TBBPA (Alimi et al., 2018). Meanwhile, significant co-adsorption effects were also observed in binary systems. According to

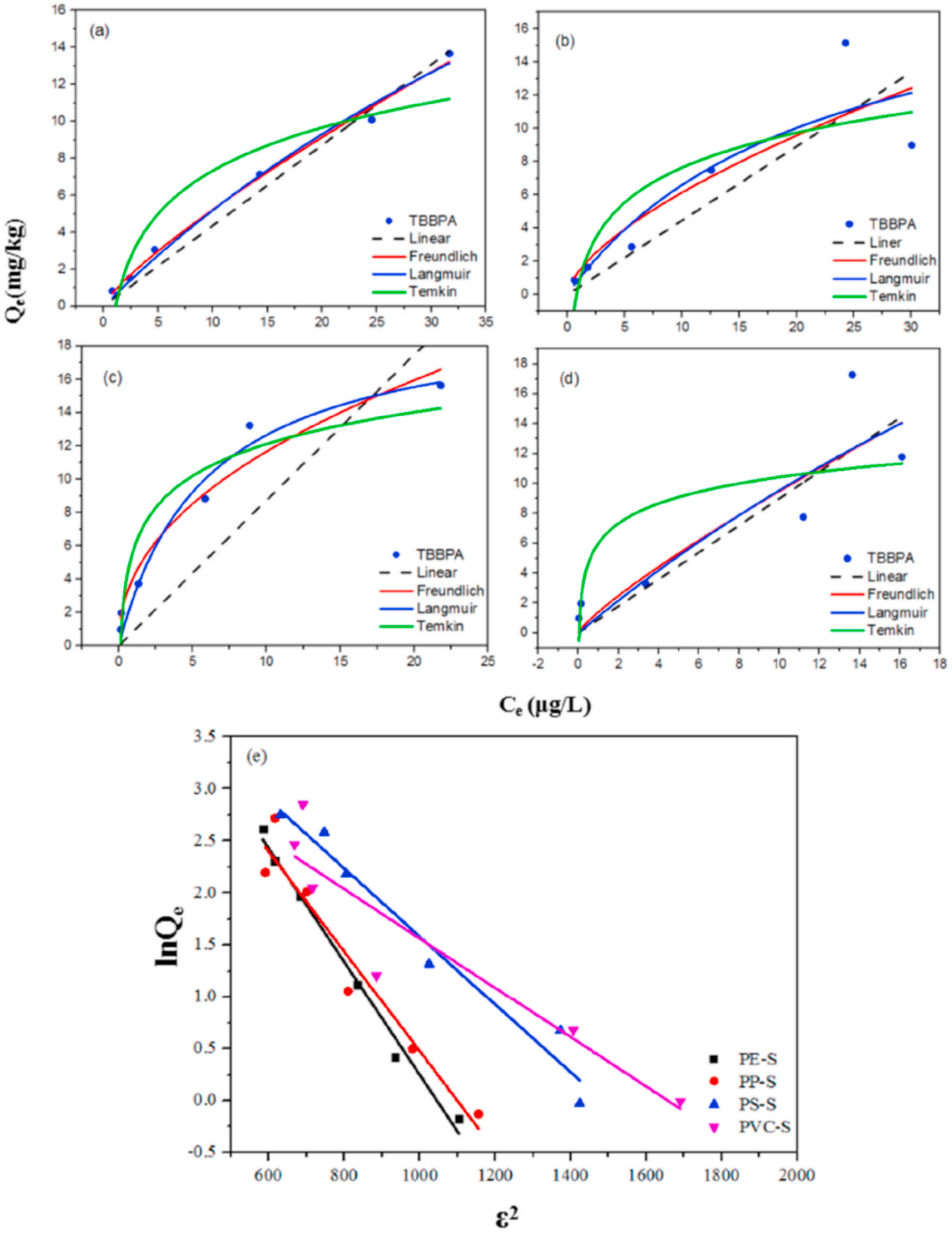

Fig. 2. Adsorption isotherms of TBBPA onto MPs-S complexes. (a) PE-S, (b) PP-S, (c) PS-S, (d) PVC-S for the Linear, Freundlich, Langmuir, and Temkin models, respectively. (e) PE-S, PP-S, PS-S, and PVC-S for the Dubinine-Radushkevich model.

the adsorption amount of TBBPA onto MPs (simple system) in our previous study (Li et al., 2021), the theoretical adsorption amount of TBBPA onto PVC-S, PS-S, PP-S, and PE-S complexes were estimated to be 3.15, 2.69, 2.28, and 2.10 μg (the sum of MPs and sediment adsorption amount separately), whereas the factual adsorption amounts in the present study were only 1.71, 1.56, 1.40, and 1.54 μg, respectively. The lower adsorption capacity for TBBPA in the binary systems than theoretical value could be attributed to the mutual adsorption of sediment and MPs, which occupy each other's adsorption sites. This hypothesis is further supported by the fact that organic pollutants accumulation by MPs and sediment both followed pseudo-second-order kinetic model (Wang and Wang, 2018), indicating similar adsorption mechanism.

3.3. *The effect of ionic strength*

The effect of Ca^{2+} on the adsorption of TBBPA are shown in Fig. 3a. Ca^{2+} exhibits similar effects on adsorption of TBBPA onto the four MPs-S composite systems, leading to an increase in equilibrium adsorption

Table 2
Sorption isotherm parameters of TBBPA onto MPs-S complexes.

Isotherm models	Complexes	Parameters			
Linear		K_d	R^2		
	PE-S	0.436	0.980		
	PP-S	0.440	0.713		
	PS-S	0.874	0.649		
	PVC-S	0.90	0.793		
Freundlich		K_f	n	R^2	
	PE-S	0.815	0.807	0.993	
	PP-S	1.40	0.641	0.728	
	PS-S	4.12	0.452	0.952	
	PVC-S	1.40	0.830	0.747	
Langmuir		Q_m	b	R^2	
	PE-S	45.0	0.0130	0.988	
	PP-S	20.9	0.0460	0.758	
	PS-S	20.1	0.0169	0.967	
	PVC-S	62.4	0.0181	0.746	
Temkin		A_t (L/μg)	B_t	R^2	
	PE-S	1.30	0.736	0.881	
	PP-S	1.51	0.817	0.729	
	PS-S	18.3	0.898	0.910	
	PVC-S	112876	1.29	0.633	
Dubinine-Radushkevich		K_{ad} (mol^2/kJ^2)	Q_s (mg/kg)	E (kJ/mol)	R^2
	PE-S	0.00545	296	9.58	0.987
	PP-S	0.00479	194	10.2	0.924
	PS-S	0.00327	128	12.4	0.957
	PVC-S	0.00238	51.3	14.5	0.843

with increasing ionic concentrations. With the ionic concentrations being increased from 0 to 0.1 mol/L (equivalent to the corresponding salinity of 0–11.1%), the sorption of TBBPA onto PE-S, PP-S, PS-S, and PVC-S complexes increased by 40.5%, 30.1%, 23.6%, and 14.2%, respectively. As the salinity of brackish waters were in the range of 0.5–30%, the adsorption capacity of TBBPA onto MPs-S complexes could be enhanced in brackish waters, e.g., marine waters, estuaries, and inland salt lakes.

It is reported that the sorption of organic pollutants on MPs increased with increasing ion concentrations (Liu et al., 2019; Zhang et al., 2010), which is similar with the present study. Salting-out effect and the charge on the adsorbent surface are possible explanations for the observed results (Liu et al., 2019; Wu et al., 2019). On the one hand, the salting-out effect reduces the solubility of TBBPA in solution (Liu et al., 2019), which enhances its surface affinity with the adsorbent. On the other hand, due to the electrostatic force, the adsorption sites are preferentially occupied by a large number of higher concentrations of Ca^{2+}, and the large accumulated Ca^{2+} compresses the adsorbent bilayer, weakening the electrostatic interaction between the adsorbent surface and TBBPA, resulting in difficult access of TBBPA (Wu et al., 2019). As Ca^{2+} increases to a certain degree, the ions around the MPs and sediment tend to saturate, leading to a less effective adsorption, and thus slowing down the adsorption rate.

3.4. The effect of dissolved organic matter

The effect of HA on the sorption of TBBPA are shown in Fig. 3b. The

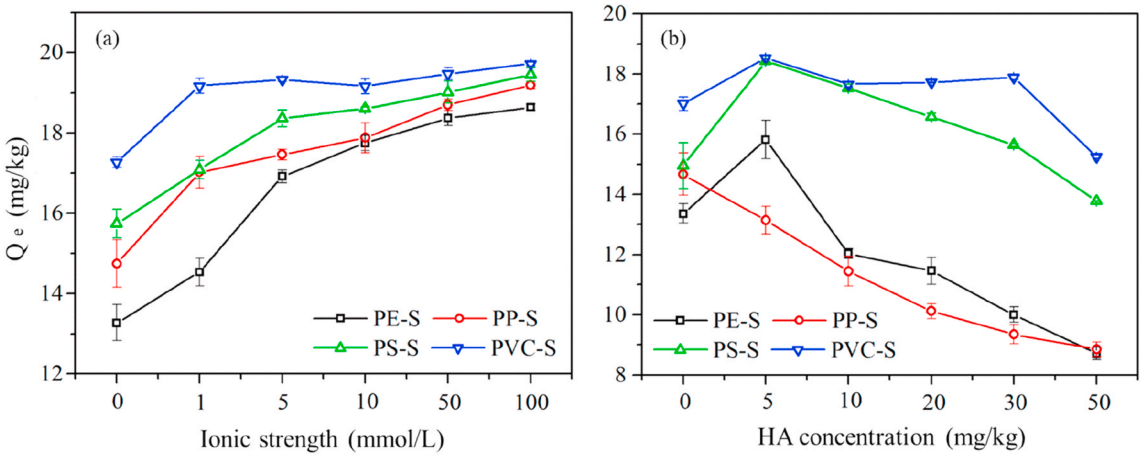

Fig. 3. Effects of ionic strength (a) and HA concentration (b) on MPs-S complexes sorption of TBBPA.

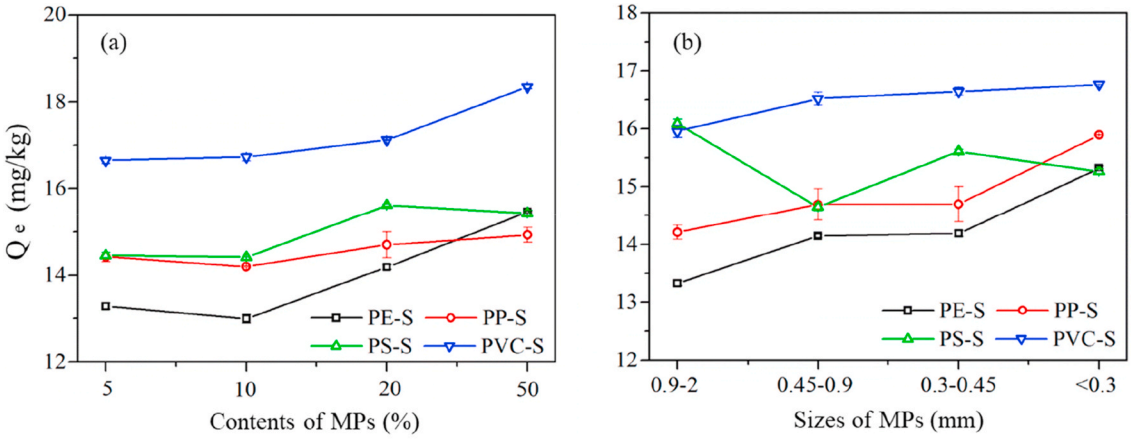

Fig. 4. Effects of MP contents (a) and particle sizes (b) on MPs-S complexes sorption of TBBPA.

Table 3
K_d of TBBPA on MPs-S complexes with different contents of MPs.

MP-Sed (%)	PE-S			PP-S			PS-S			PVC-S		
	Ap [a]	MPs	Sed [b]	Ap	MPs	Sed	Ap	MPs	Sed	Ap	MPs	Sed
5–95	1	0.56	1.37	1	0.95	1.53	1	0.87	1.67	1	1.32	3.48
10–90	1	0.61	1.18	1	0.88	1.58	1	0.96	1.61	1	1.41	3.47
20–80	1	0.73	1.66	1	0.82	2.29	1	0.81	2.71	1	1.49	4.48
50–50	1	1.15	2.23	1	0.95	2.19	1	1.17	2.10	1	2.82	7.82

[a] Aqueous phase.
[b] Sediment.

Table 4
K_d of TBBPA on MPs-S complexes with different sizes of MPs.

Particle sizes (mm)	PE-S			PP-S			PS-S			PVC-S		
	Ap [a]	MPs	Sed [b]	Ap	MPs	Sed	Ap	MPs	Sed	Ap	MPs	Sed
2	1	0.44	1.53	1	0.57	1.78	1	0.62	3.36	1	0.89	2.88
0.9	1	0.63	1.81	1	0.62	1.89	1	0.68	1.99	1	1.25	3.25
0.45	1	0.73	1.66	1	0.82	2.29	1	0.81	2.71	1	1.32	3.48
0.2	1	1.04	2.18	1	0.88	3.00	1	0.70	2.46	1	1.33	3.85

[a] Aqueous phase.
[b] Sediment.

elevated concentration of HA inhibited the sorption of TBBPA onto the four MPs-S complexes. With the increase of HA concentration from 0 to 50 mg/kg, the sorption decrement of TBBPA on four MPs-S complexes are as follow: PP-S (39.6%) > PE-S (34.8%) > PVC-S (10.4%) > PS-S (7.9%). A previous study found that the combination of BPA and DOM improve the solubility of BPA in water, which is consistent with our present study (Sun et al., 2021). As a natural organic matter, the negative charge contained in HA could offer new sorption sites for sorbates in aqueous medium, causing the competitive adsorption interactions in-between TBBPA, HA, and MPs-S. Further, with larger molecular, HA could preferentially enter the pores of adsorbent or cover on the surface of the adsorbents preventing the entry of TBBPA in sorption sites. It is possibly that molecular sieving and pore blockage may primarily dominate in the process, as different types of MPs may interact with different functional groups of HA. PP-S and PE-S are more readily affected by the presence of HA than that of PVC-S and PS-S, which may be attributed to the polar functional groups. The polarities of PVC and PS are higher than those of PE and PP, because of the substitution of one C–H by C–Cl and C-π for each unit (Chen et al., 2019).

3.5. Partitioning of TBBPA in-between solid (MPs and sediment) and aqueous phases

To further understand sorption of TBBPA onto MPs-S complexes, the solid-water distribution coefficients (K_d) were calculated by Eq. 7. All four MPs-S complexes exhibited higher sorption capacities (Table S3) than that on sediment, and PVC-S was the highest. TBBPA are more readily absorbed to MPs than sediment, with the sorption capacities of MPs ranged from 1.19 to 1.75 folds higher than that on sediment. Meanwhile, the K_d of sediment is 2.26 while the K_d of PVC-S, PS-S, PP-S, and PE-S were 4.48, 2.71, 2.29, and 1.66, respectively (Table S4). Except for PE-S, the presence of MPs increased the partition of TBBPA in solid phase, which also enhanced the sorption capacities of the MPs-S complexes.

Furthermore, the effects of content and size of MPs on the sorption of TBBPA were investigated. Elevated MP proportions in the MPs-S complexes increased the sorption capacities for TBBPA (Fig. 4a). With the contents of MPs increased from 5% to 50%, the growing rates of the sorption capacities were 16%, 10%, 7%, and 4% for PE-S, PVC-S, PS-S, and PP-S, respectively, and PVC-S showed the highest sorption capacity among four MPs-S complexes. The K_d values (Table 3) indicated that with the increasing ratio of MPs in the MPs-S complexes, both MPs and sediment showed higher adsorption efficiencies (Figure S1). The higher proportions of MPs may increase the total specific surface areas and pore structures of the MPs-S complexes, which consequently enhanced the adsorption efficiencies (Guo et al., 2018; Liu et al., 2018). Meanwhile, the saturated adsorption sites of sediment were released with the declined amount of sediment, leading to the enhancement in adsorption affinity for TBBPA. Similar tendency was observed with the decreased particle sizes of the MPs (Fig. 4b, Figure S2). The reduction of particle size promoted the partitioning of TBBPA onto both MPs and sediment (Table 4). Smaller particle size means larger specific surface area, which could provide more adsorption sites for TBBPA. Moreover, it is reported that organic matters from the ambient background of the sediment may sorb to MPs until equilibrium is reached (Kleinteich et al., 2018), thereby providing more adsorption sites for TBBPA onto sediment.

4. Conclusions

Interactions between a continuously used flame retardant TBBPA and four commonly applied MPs in sediment complexes were investigated in this study. Surface sorption, intraparticle diffusion, and mass transfer might be involved in the sorption process of TBBPA onto MPs-S complexes, which could be strengthened by higher ionic strength and lower dissolved organic matter. Co-adsorption effects significantly limited the combined adsorption capacities of the binary systems, though the enhanced sorption capacities for TBBPA were observed with elevated proportion and small particle size of MPs in the MPs-S complexes. These findings indicate that the presence of MPs in sediment may largely influence the partitioning of TBBPA in-between solid and aqueous phases, which is important in assessing ecotoxicity of organic pollutants in aquatic environment.

Author statement

Zongrui Li: Writing – original draft preparation, Conceptualization, Data curation, Investigation. Shengsheng Li: Data curation, Writing – original draft preparation. Liangzhong Li: Data curation, Formal analysis, Conceptualization. Lin Tao: Writing - Reviewing and Editing, Investigation. Xiaohui Zhu: Methodology, Investigation. Ruixue Ma: Conceptualization, Investigation. Yanhong Zhang: Writing - Reviewing and Editing. Yunjiang Yu: Conceptualization, Methodology, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2022.118991.

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