Adsorption Characteristics of Polyethylene Microplastics on Polyoxyethylene Lauryl Ether

Qi ZHANG, Shasha LIU*

School of Environmental and Chemical Engineering, Zhaoqing University, Zhaoqing 526061, China

Abstract [**Objectives**] This study was conducted to assess the combined pollution risk of surfactants and microplastics coexisting in aquatic environments over the long term. [**Methods**] Polyethylene and polyoxyethylene lauryl ether (Brij30) were selected as representatives of microplastics and surfactants, respectively. The adsorption kinetics, isothermal adsorption characteristics, and the effects of environmental factors including temperature, salinity, and pH on the adsorption process were systematically investigated. [**Results**] The results showed that the adsorption of Brij30 onto polyethylene reached equilibrium within 72 h, and the adsorption kinetics exhibited a twostage pattern of rapid adsorption followed by slow equilibration. Increasing temperature inhibited the adsorption process. As salinity increased, the adsorption capacity first slightly increased and then decreased continuously. Changes in pH had a relatively minor overall effect on the adsorption capacity. [**Conclusions**] This study can provide a reference for understanding the environmental behavior and risk assessment of microplastics and surfactants in aquatic environments.

Key words Polyethylene; Brij30; Adsorption

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The extensive use of plastics and their products has led to their continuous entry into the environment. Over time, they undergo gradual fragmentation and decomposition through physical abrasion, solar radiation, high temperature, oxidation, and biodegradation, forming microplastics with particle sizes smaller than 5 mm. The resulting microplastic pollution has become a research hotspot in environmental and ecological sciences[1-4]. However, most plastic waste is not effectively recycled, but enters the environment through landfilling, incineration, or indiscriminate disposal instead, leading to the continuous accumulation of plastics in the environment and posing a serious threat to ecosystems[5]. It is estimated that by 2050, a cumulative total of approximately 12 billion metric tons of plastics will be discarded into the environment[6]. Surfactants are widely used in daily chemical products such as detergents and emulsifiers, leading to a continuous increase in the discharge of surfactant-containing wastewater[7], which not only pollutes water bodies, but also poses potential risks to human health[8-9].

Microplastics have stable properties, and can persist in aquatic environments for long periods[10]. They can adsorb other pollutants in water, forming combined pollution[11] and altering their transport processes and toxic effects[12]. Surfactants contain hydrophobic and hydrophilic groups, and their hydrophobic end tends to bind to microplastics, exposing the hydrophilic end to the outside and reducing the hydrophobicity of the microplastic surface, making it more prone to transport with water flow[13-14]. Consequently, they increase the environmental hazards of microplastics. However, research on the adsorption-desorption behavior of surfactants on microplastic surfaces remains insufficient. In this study, with polyethylene as a representative microplastic and nonionic surfactant Brij30 as the target adsorbate, the adsorption characteristics of Brij30 onto polyethylene were investigated in the context of various environmental factors.

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Qi ZHANG (2024-), female, P. R. China, Environmental Engineering major, devoted to research about remediation of microplastics pollution.

* Corresponding author. Shasha LIU, associate professor, devoted to research about ecological effects and remediation of microplastic pollution.

Materials and Methods

Experimental materials

The reagents used included hydrochloric acid, sodium hydroxide, Brij30, polyethylene, I_2, and KI. The experimental instruments comprised volumetric flasks, pipettes, conical flasks, test tubes, disposable sterile syringes, and syringe filters.

Reagent preparation

KI-I_2 chromogenic reagent: First, 1.000 g of I2 and 2.000 g of KI were dissolved in ultrapure water, and diluted to a constant volume of 100 ml. Then, the reagent was stored in a sealed container protected from light.

HCl solution: HCl solution was prepared by mixing concentrated hydrochloric acid with ultrapure water at a volume ratio of 1∶5.

Experimental design

Adsorption kinetics experiment The addition concentration of polyethylene was set at 100 mg/L. The initial concentrations of Brij30 were set at 5, 15, 20, 50, 100, 200, and 300 mg/L. The temperature was maintained at 25 ℃. Samples were taken at 0.5, 1, 2, 4, 8, 12, 24, 48, and 72 h to determine the adsorption equilibrium time.

Adsorption isotherm experiment The temperatures were set at 25, 30, and 35 ℃. The addition amount of polyethylene and Brij30 concentration gradients were consistent with those in the kinetics experiment to investigate the effect of temperature on adsorption equilibrium.

Experiment of environmental factors on adsorption

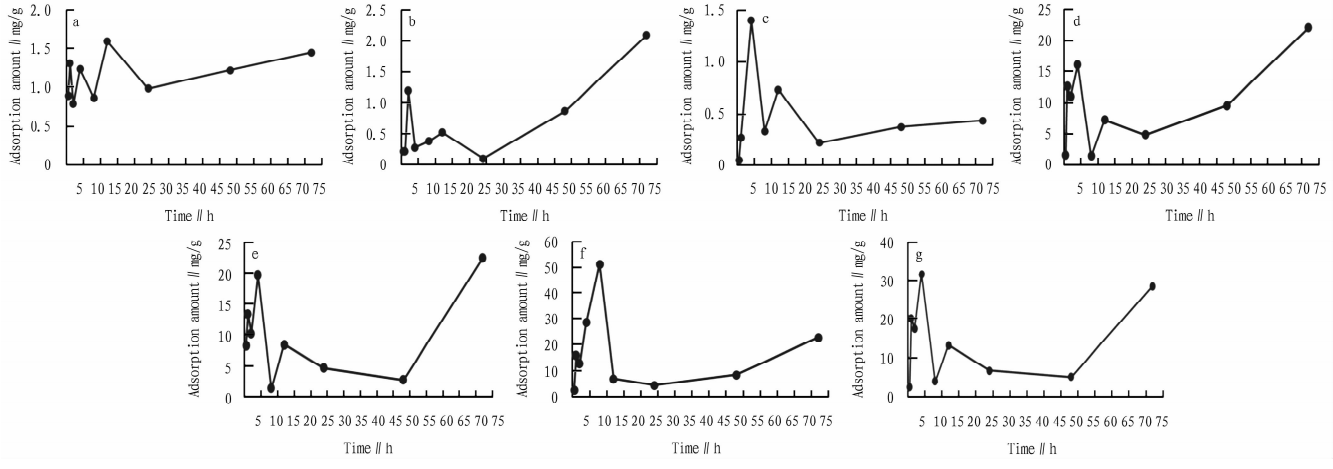
(1) pH: The pH of the system was adjusted to 5, 6, 7, 8, and 9 using HCl and NaOH. The temperature was kept at 25 ℃, and the adsorption equilibrium time was 72 h.

(2) Salinity: Brij30 stock solutions were prepared using aqueous solutions with NaCl concentrations of 0, 8, 16, 24, and 32‰. The temperature was kept at 25 ℃, and the adsorption equilibrium time was 72 h.

Results and Analysis

Adsorption kinetics experiment

The adsorption kinetics of Brij30 onto polyethylene at different concentrations are shown in Fig. 1. With the adsorption time increasing, the adsorption amount of Brij30 onto polyethylene exhibited a typical three-stage pattern: rapid increase, slow growth, and eventual stabilization, and the adsorption equilibrium was reached at 72 h. In the initial stage (0 – 4 h), the adsorption amount increased sharply, mainly due to the abundance of unoccupied adsorption sites on the polyethylene surface, and the rapid diffusion of Brij30 molecules toward the microplastic surface and the adsorption under the mass transfer of concentration gradient. After 4 h, as the adsorption sites on the microplastic surface gradually became occupied and approached saturation, the number of available binding sites decreased substantially, and the diffusion resistance between molecules gradually increased. Consequently, the adsorption rate dropped markedly, and the growth of adsorption capacity slows down. When the adsorption time reached 72 h, the adsorption of Brij30 molecules from the solution and the desorption of already adsorbed molecules reached a dynamic equilibrium, and the adsorption amount no longer showed significant changes with the further increase in time.



a: 5 mg/L; b: 15 mg/L; c: 20 mg/L; d: 50 mg/L; e: 100 mg/L; f: 200 mg/L; g: 300 mg/L.

Fig. 1 Adsorption of different concentrations of Brij30 onto polyethylene

Adsorption isotherm experiment

With the temperature increasing, the adsorption capacity of polyethylene for Brij30 at different concentrations gradually decreased. Rainer *et al.* [15] suggested that the effect of temperature on the adsorption of organic pollutants onto microplastics is mainly related to the partition coefficient of the organic pollutants. The partition coefficient of some organic pollutants in solution increases with the temperature increasing, and the adsorption capacity of microplastics also increases with the temperature increasing. Therefore, it can be inferred that the partition coefficient of Brij30 decreases with increasing temperature.

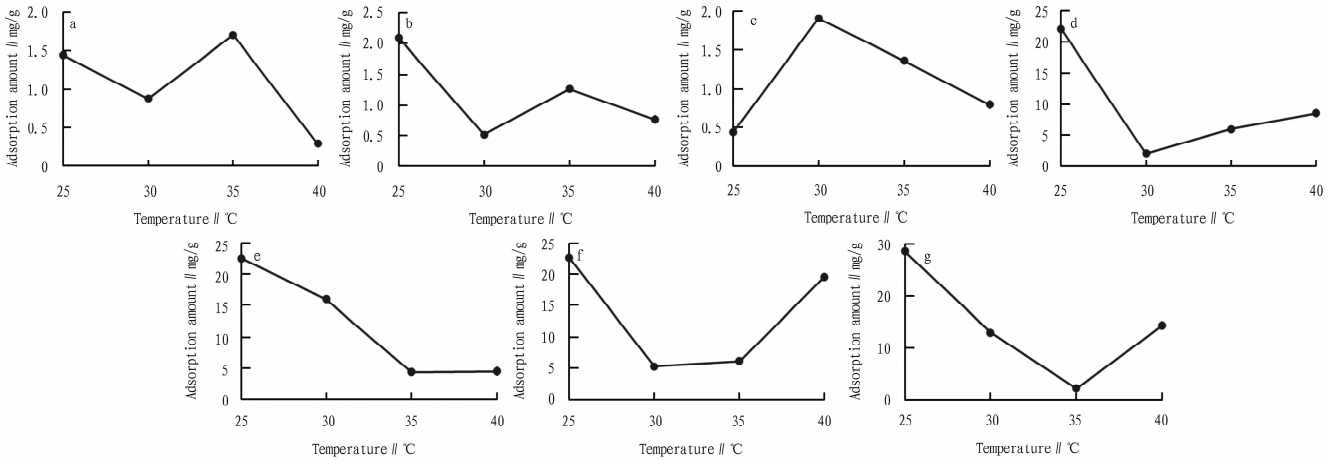
Environmental factor experiment

Effect of salinity on the adsorption of Brij30 onto polyethylene As shown in Fig. 3, with the salinity increasing, the adsorption capacity of polyethylene for Brij30 showed a trend of first a slight increase and then a continuous decrease. In the low salinity range (0‰ – 8‰), the increase in salinity had a certain promoting effect on the adsorption process. When the salinity exceeded 8‰, the adsorption capacity of polyethylene for Brij30 began to decrease, and the higher the salinity, the more significant the reduction in adsorption capacity. This may be attributed to the effect of salinity on the aggregation behavior of microplastics[12]. Wu *et al.* [16] reported that as NaCl concentration increased, the hydrodynamic size of microplastics also increased, enhancing their aggregation. Gigault *et al.* [17] found that with the concentration of NaCl increasing, microplastics tended to aggregate, and the reduction in adsorption sites hindered the adsorption process. Therefore, the adsorption capacity of polyethylene for Brij30 decreased as the salinity increased.

Effect of pH on the adsorption of Brij30 onto polyethylene

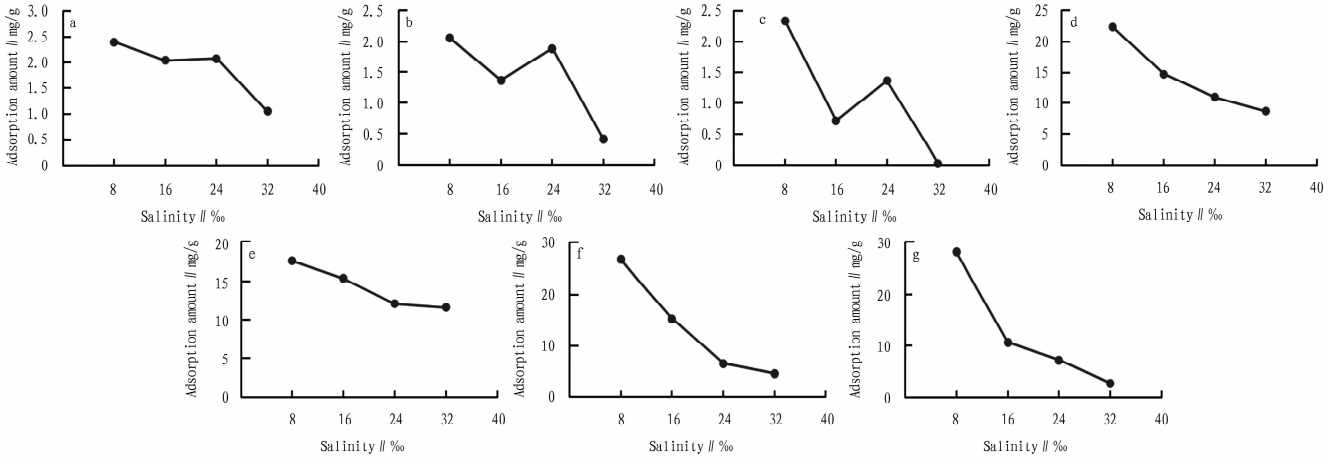
As shown in Fig. 4, the change of pH had a relatively minor effect on the adsorption of Brij30 onto polyethylene, and the adsorption capacity remained relatively stable as a whole. with the adsorption capacity remaining generally stable across the tested pH range. At neutral pH (pH = 7), the adsorption capacity of polyethylene for Brij30 at all concentrations was the highest among the pH gradients tested. Under weakly acidic (pH 5, 6) and weakly alkaline (pH 8, 9) conditions, the adsorption capacity decreased slightly,

but the reductions were small and not statistically significant. Changes in pH can affect the surface charge of microplastics. When the pH is below the isoelectric point, microplastics are positively charged. When the pH is above the isoelectric point, they carry a negative charge, because at higher pH value, the proton concentration decreases and is replaced by negatively charged anions[18].



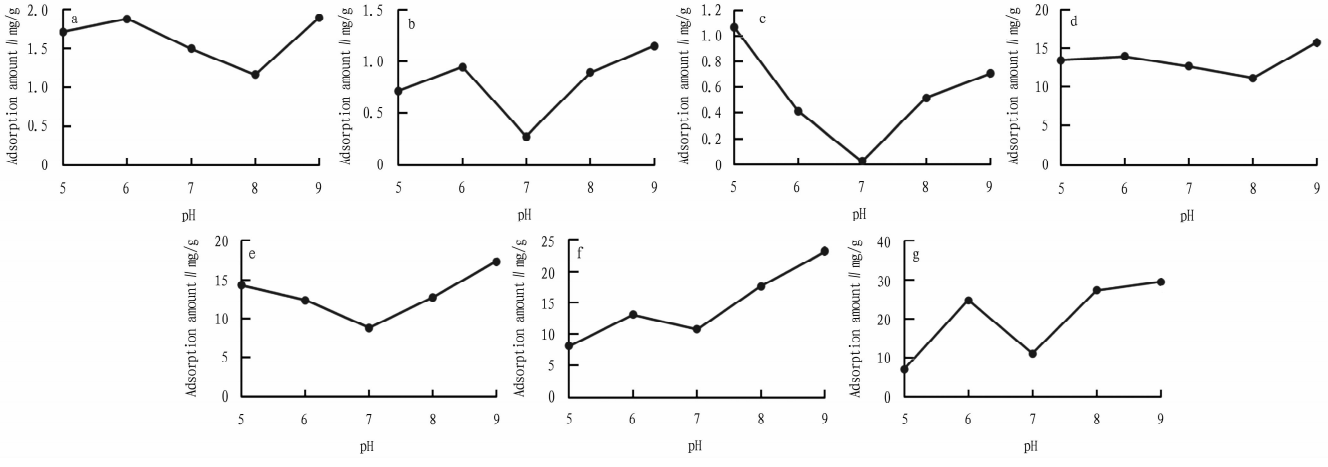
a: 5 mg/L; b: 15 mg/L; c: 20 mg/L; d: 50 mg/L; e: 100 mg/L; f: 200 mg/L; g: 300 mg/L.

Fig. 2 Effect of temperature on the adsorption of different concentrations of Brij30 onto polyethylene



a: 5 mg/L; b: 15 mg/L; c: 20 mg/L; d: 50 mg/L; e: 100 mg/L; f: 200 mg/L; g: 300 mg/L.

Fig. 3 Effect of salinity on the adsorption of different concentrations of Brij30 onto polyethylene



a: 5 mg/L; b: 15 mg/L; c: 20 mg/L; d: 50 mg/L; e: 100 mg/L; f: 200 mg/L; g: 300 mg/L.

Fig. 4 Effect of pH on the adsorption of different concentrations of Brij30 onto polyethylene

Conclusions and Discussion

In this study, the adsorption characteristics of Brij30 onto polyethylene and the effects of environmental factors were investigated. The adsorption process of Brij30 onto polyethylene microplastics exhibited distinct stage characteristics. The adsorption started with a rapid initial adsorption stage followed by a gradual increase, and essentially reached equilibrium after 72 h. Increasing temperature (25 – 35℃) significantly inhibited the adsorption of Brij30 onto polyethylene microplastics, and the equilibrium adsorption capacity continuously decreased with the temperature increasing, indicating that lower temperatures were more favorable for the adsorption process. Salinity exhibited a threshold effect, with low concentrations promoting adsorption and high concentrations inhibiting it (at 8‰). Within the pH range of 5 – 9, the adsorption capacity of polyethylene for Brij30 remained relatively stable, with only a slight peak observed at pH 7, suggesting that pH had a negligible effect on the adsorption system.

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