Adsorption and Desorption Characteristics of Phosphorus on Sediments in Panzhihua Section of Jinsha River, China

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Abstract. To characterize P adsorption-desorption in the riverbed sediments, we studied sediment physicochemical parameters affecting P dynamics, adsorption-desorption parameters such as P desorption maximum, equilibrium P concentration and P desorption capacity of bed sediments by a batch experiment. The results showed that the adsorption-desorption rate of phosphorus on sediment obviously increased, then slightly decreased, and finally reached equilibrium at 90 min of reaction. The desorption concentration of phosphorus on the surface of sediment was 0.45 mg/L when the rotational speed was 250 r/min. The increase of sediment concentration facilitated the transformation of phosphorus from dissolved state to adsorbed state. When the sediment particle size was less than 0.074 mm, the equilibrium adsorption and desorption capacity of phosphorus were 0.47 mg/g and 0.43 mg/L, respectively. In addition, high temperature was beneficial to the adsorption of phosphorus, but rarely affect the desorption of phosphorus in the sediment. The pH value of solution has little impact on the adsorption and desorption of phosphorus.

1. Introduction
Phosphorus (P) is an important nutrient element in water, and has been recognized as the primary cause of freshwater eutrophication and main factor to the growth of algae in surface water [1, 2, 3, 4, 5]. There are many factors affecting P’s adsorption and release, including sediment properties, P occurrence forms, and environmental conditions such as temperature, pH, disturbance intensity [6]. At present, it is generally believed that P, with no significant air flux, mainly exists in the form of dissolved and granular in the water environment, and has a strong affinity with sediment [7]. Generally, P undergoes a dynamic exchange balance between sediment and overlying water. When the conditions change, P can be released through a complex process and become the internal cause of eutrophication [8, 9]. Therefore, the degree of eutrophication of the water body can be controlled by adjusting the P content.

Riverbed sediments play an important buffer role in the adsorption or desorption of P in river ecosystems [10, 11, 12]. Sediment is the interface layer connecting the overlying water body and the aerated zone in the river ecosystem, and it is the main channel for P to enter the groundwater [13]. Sediments adsorption process will reduce the concentration of P in the overlying water, play a “sink
item" role to the dissolved P in the water body, and in the desorption process, the sediments also act as a "source item" role [14, 15, 16]. The process of P adsorption and desorption on sediments directly affects the P exchange capacity at the sediment-water interface. Sediment will adsorb P in the water to re-establish an equilibrium environment when the concentration of phosphate in the water exceeds the equilibrium concentration. However, the phosphate adsorbed by the sediment will be released into the water again when the concentration of phosphate in the water is low [17]. For example, evidence has indicated that the gradually decrease of P concentration from upstream to downstream in the three Gorges reservoir area is due to the adsorption of sediment in this region from 2008 to 2013 [18].

Jinsha River traverses the Panzhihua city from west to east and turns to flow from north to south below the junction of Yalong River. According to the water quality monitoring data of seven monitoring sections in Panzhihua section of Jinsha River by the research group in March 2018, the release of total P from sediments of some sections was closed to the limits of class III water of national water quality standard. Moreover, the hydropower station in Panzhihua section of Jinsha River has an impact on the hydrological situation and water quality of the river section while exerting its power generation and flood control benefits, such as the slowdown of the flow rate, the reduction of pollutant migration and diffusion capacity, and the reduction of the water environmental capacity in the water function area of the river section. This indicates that phosphorus was an important factor leading to eutrophication in Panzhihua section of Jinsha River. Little research has been done to study the role of environmental factors between adsorption and desorption in the bed sediments of river system, quantifying the transport behavior of P in riverbed sediments is beneficial to evaluate their potential contributions to the overlying water [19,20]. Therefore, the purpose of this study was to comparatively analyze the adsorption/desorption characters of P on sediments by investigated disturbance intensity, temperature, and pH value of solution, etc. The results are expected to offer insights into theoretical and technical basis for the later evaluation of water level uplift in Panzhihua section of Jinsha River.

2. Materials and Methods

2.1. Sample collection of sediments

The Panzhihua section of the Jinsha River starts from the dam site of Guanyinyan Hydropower Station and goes down to the end Wudong Hydropower Station reservoir (near Sanduizi Hydrological Station at the lower reaches of the Yalong River). The river is about 57 km long with a drop of about 38 m and a confluence area of 132,100 km².

The sediment samples of the Lazha section of Panzhihua section of the Jinsha River (26°22'24" N; 101°55'41" E) were collected and identified as a P source system (Fig.1). Sediment samples collected were naturally air-dried in a cool, dry and pollution-free ventilated place. After picking out sundries such as plant remains, stones and shells, samples were ground to 200 mesh. All samples were kept in a brown bottle and placed in a cool dark place.

The pH value of sediment was determined by the glass electrode and the particle size composition of sediment was measured by the sieving analysis. The contents of carbon, hydrogen, nitrogen and sulfur in samples with different particle sizes were detected by Elementary Vario MACRO Cube. The physical and chemical properties of the sediment were shown in Table 1.
2.2. The experimental method

2.2.1. P adsorption experiment on sediments. The effects of sediment particle size (< 0.074 mm, 0.074~0.15 mm, 0.15~0.20 mm and 0.20 mm~0.45 mm), concentration (0.4 g/L~6.4 g/L, 5 groups), reaction time (0~120 min, 6 groups), temperature (15 ℃~35 ℃, 5 groups) and solution pH (6.0~9.0, 4 groups) on the adsorption capacity of sediments were studied. The specific surface area of sediment samples used in the experiment was 2.3 m²/g.

The specific operation steps are as follows: 100 mL triangle flasks were added with different concentrations of sediment and 20 mL P solution with initial concentration of 2.0 mg/L. The mixture was placed in the constant temperature oscillator and set the corresponding conditions such as rotational speed, reaction temperature, and reaction time. The oscillated sample was placed in a centrifuge to separate the sediment from the solution, and the concentration of P in the supernatant was determined.

2.2.2. Desorption experiment of P on the surface of sediment. Additionally, the effects of various factors on the desorption of P on the surface of sediments were studied. The specific operation steps were as follows: 100 mL triangle flasks were added with different concentrations of sediment and initial concentration 2.0 mg/L of P solution 20 mL. After adsorption equilibrium, the sediment was centrifuged and deionized water was used as overlying water for desorption experiment. Put it in the constant temperature oscillator and set the corresponding conditions such as oscillation speed, reaction temperature, and reaction time. The oscillated sample was placed in a centrifuge to separate the sediment from the solution, and the concentration of P in the supernatant was determined.

2.3. Data processes

The P adsorption quantity at adsorption equilibrium and total adsorption quantity were calculated with Eqs. (1) and (2)
\[ Q_e = \frac{C_0 - C_{eq}}{V} \cdot m \]

(1)

\[ Q_{total} = Q_e \cdot m \]

(2)

Where \( Q_e \) and \( Q_{total} \) are the P adsorption at equilibrium (mg/g) and total adsorption (mg), respectively; \( C_0 \) is the P initial concentration (mg/L); \( C_{eq} \) is the P concentration at adsorption equilibrium (mg/L); \( V \) is the solution volume (mL); \( m \) is the weight of riverbed sediments (g).

The P desorption quantity at desorption equilibrium and total desorption quantity were calculated with Eqs. (3) and (4)

\[ Q_{de} = \frac{C_{d0} - C_{de}}{V} \cdot m \]

(3)

\[ Q_{de-total} = Q_{de} \cdot m \]

(4)

Where \( Q_{de} \) and \( Q_{de-total} \) are the P desorption at equilibrium (mg/g) and total adsorption (mg), respectively; \( C_{d0} \) is the P concentration on sediments (mg/L) and \( C_{d0} = C_0 - C_{eq} \); \( C_{de} \) is the P concentration at desorption equilibrium (mg/L).

3. Results and Discussion

3.1. The influence of different factors on adsorption

Influence of reaction time on the P adsorption capacity of the sediment was carried out in the range of 0 min to 120 min was shown in Fig. 2(A). The P adsorption capacity of the sediment were increased rapidly during the reaction time of 0~40 min, which could be due to the availability of abundant adsorption sites on the adsorbent surface. After 90 min of reaction, adsorption of P reached equilibrium, and the equilibrium adsorption capacity was 0.42 mg/g.

The effect of rotate speed the P adsorption capacity of the sediment was shown in Fig. 2(B). When the rotate speed was weak (100 r/min), the adsorption capacity of P was 0.07 mg/g, which was slightly higher than that without disturbance (0.03 mg/g), this was mainly due to the large particle size of the sediment. In the case of low disturbance intensity, the sediment was mostly concentrated at the bottom of the solution and has less contact with phosphate. When the disturbance intensity increased to 180 r/min and 250 r/min, the P adsorption capacity of sediments were 0.27 mg/g and 0.42 mg/g, respectively, which was 9 times and 12 times of the static adsorption capacity. This could be ascribed to that contact probability between dissolved P and sediments in the solution increased under strong disturbance.

![Figure 2](image-url)

**Figure 2.** (A) The influence of reaction time on P adsorption by sediment (Particle size: <0.074 mm; dosage of Sediment: 1.0 g/L; r (rotate speed):250 r/min; pH: 8; T: 25°C); (B) The influence of disturbance intensity on the adsorption of P by sediments (Particle size: <0.074mm; Dosage of Sediment: 1.0 g/L; pH: 8; t: 90min; T: 25°C)
Effect of sediment concentration on the adsorption of P was shown in Fig. 3(A). The adsorption capacities of P per unit sediment were gradually decreased with the increase of sediment concentration, which could be due to the uneven adsorption sites of P on the sediment surface, that is, P was first adsorbed at the high active sites, and then adsorbed at the low active sites. Therefore, the amount of P adsorption per unit mass of sediment decreases with the increase of sediment concentration. P adsorption capacity were decreased from 0.45 mg/g to 0.26 mg/g when the sediments concentration was increased from 0.40 g/L to 3.20 g/L. However, the total amounts of P adsorption were significantly increased from 0.005 mg/g to 0.021 mg/g as the sediment concentration increased from 0.40 g/L to 3.20 g/L. The reason could be that the availability of abundant adsorption sites.

The effect of sediment particle size on P adsorption was shown in Fig. 3(B). The adsorption kinetics of P on sediments with different particle sizes were basically the same. the adsorption amount of P by the sediment increased rapidly in the first 30 min of the adsorption time, After the increase of adsorption capacity decreased. It can also be seen that the particle size of the sediment has a great influence on the adsorption of P by the sediment. The smaller the particles were, the greater the adsorption capacity of P was. The equilibrium adsorption capacities of P on sediments with particle size less than 0.074 mm and 0.20–0.45 mm were 0.47 mg/g and 0.25 mg/g, respectively. Therefore, we could not only consider the sediment concentration in water, but also pay more attention to the particle size distribution of sediment when studying the adsorption and desorption of P by sediment concentration.

The effect of temperature on P adsorption by sediments was shown in Fig. 4(A). After the reaction reached equilibrium, the adsorption capacities of P were increased from 0.19 mg/g to 0.38 mg/g when temperatures were increased from 15 °C to 35 °C. These results indicated that elevation of temperature has boosted the affinity of P adsorption on the surface of the sediment.

The experiments about effect of solution initial pH value on P adsorption was conducted in the range of 6.0–9.0. As shown in Fig. 4(B), when initial pH values were 6 and 8, P adsorption capacities were no change dramatically (< 8%). With the further increase of solution pH values, the adsorption capacities of P on the sediment surface were slightly increased. The reason could be that the charge and polymerization form of sediment surface change with the increase of solution pH values, and the interaction of electrostatic force has an effect on the adsorption of P.
3.2. The influence of different factors on desorption

Influence of reaction time on the P desorption of the sediment was carried out in the range of 0 min to 120 min was shown in Fig. 5(A). After adsorption the sediments were placed in deionized water, the concentration of P desorbed from the sediments were increased rapidly during 0~40 min of the reaction time. For example, the concentration of P in the solution reached 0.13 mg/L after 10 min of reaction, which was 50 % of maximum desorption capacity. When reaction time was extended from 40 min to 90 min, the concentration of P released from the solution was 0.24 mg/L.

Intensity of disturbance was an important factor for P desorption and the experiments about effect of rotate speed on the P desorption of the sediment were carried out in the range of 0 r/min to 120 r/min. As shown in Fig. 5(B), when the rotate speed was less than 100 r/min, the desorption concentration of P was maintained at 0.25 mg/L after 90 min of desorption reaction. The equilibrium release concentration of P was rapidly increased when rotate speed were more than 100 r/min. For example, the equilibrium release concentration of P was 0.45 mg/L when the rotate speed was 250 r/min, which concentration of P release was more than the class V standard of surface water environmental quality.

Figure 4. (A) The influence of temperature on the adsorption of P in sediments (Particle size: <0.074 mm; r: 250 r/min; Dosage of Sediment: 1.0 g/L; pH: 8; t: 90 min); (B) The influence of solution on P adsorption by sediment (Particle size: <0.074 mm; r: 250 r/min; Dosage of Sediment: 1.0 g/L; T: 25 ℃; t: 90 min)

Figure 5. (A) The influence of reaction time on P desorption concentration (Particle size: <0.074 mm; Dosage of Sediment: 1.0 g/L; r: 250 r/min; pH: 8; T: 25 ℃); (B) The influence of rotate speed on P desorption concentration (Particle size: <0.074 mm; Dosage of Sediment: 1.0 g/L; pH: 8; t: 90 min; T: 25 ℃)
Effect of sediment concentration on the desorption of P was shown in Fig. 6(A). The desorption capacities of P per unit sediment were gradually increased with the increase of sediment concentration, which was different from adsorption, and the desorption concentration of P increases multiple. There was an approximate linear relationship between the total amount of P desorption and the sediment concentration, when the sediment concentration was increased from 1.60 g/L to 6.4 g/L.

The effect of sediment size on P desorption was shown in Fig. 6(B). The desorption amount of P on the sediment was the maximum when the particle size of the sediment was less than 0.074 mm. After 90 min of desorption time, the desorption amount of P in the solution was reached 0.43 mg/L. The desorption amount was only 35% of the desorption concentration of sediment with particle size less than 0.074 mm when the sediment particle size was 0.20–0.45 mm. The results show that the sediment particle size has a significant effect on the adsorption and desorption of P on the sediment.

Figure 6. (A) The influence of sediment concentration on P desorption (Particle size: <0.074 mm; r: 250 r/min; pH: 8; t: 90 min; T: 25 ℃); (B) The influence of particle size on P desorption (r: 250 r/min; Dosage of Sediment: 1.0 g/L; pH: 8; t: 90 min; T: 25 ℃)

The effect of temperature on P desorption on sediment was shown in Fig. 7(A). After the reaction reached equilibrium, the desorption concentration of P in the solution was increased rapidly from 0.30 mg/L to 0.45 mg/L when the solution temperature increases from 15 °C to 25 °C. However, the desorption concentration of P does not obviously change when the temperatures were increased from 25 °C to 35 °C. Compared with the effect of temperature on P adsorption, the increase of temperature was favourable for adsorption, but has little effect on desorption.

The effect of pH value on the desorption concentration of P in the solution was shown in Fig. 7(B). The pH value of the solution has little effect on P desorption, which was consistent with adsorption. The desorption concentration of P was slightly increased from 0.49 mg/L to 0.61 mg/L when the pH value of the solution was increased from 6.0 to 9.0.

Figure 7. (A) The influence of Temperature on P desorption (Particle size: <0.074 mm; r: 250 r/min; Dosage of Sediment: 1.0 g/L; pH: 8; t: 90 min); (B) The influence of solution pH on P desorption concentration (Particle size: <0.074 mm; r: 250 r/min; Dosage of Sediment: 1.0 g/L; T: 25 ℃; t: 90 min)
4. Conclusion
This study investigated the adsorption-desorption characteristics of P on the sediment from Panzhihua section of Jinsha River. The main conclusion is that the release concentration of P was higher than the class V standard of surface water environmental quality under the condition of high intensity disturbance. Therefore, the situation of sediment as "source" should be fully considered when establishing an experimental platform suitable for the transport and transformation of P on the surface of sediments in Panzhihua section of Jinsha River.

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