Research Article

QiaoLing Xu*, Li Wang, Minxia Tan, Xiaolei Wang, Jiajie Li, and Hejun Geng

Phosphorus removal from aqueous solution by adsorption using wetland-based biochar: Batch experiment

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Abstract: This article experiments wetland-based biochar as an effective adsorbent for phosphorus removal. In this experiment, four common wetland plants, canna (C), umbrella palm (U), bamboo reed (B), and Thalia dealbata (T), were used as the main raw materials. Twelve kinds of biochar (C300, C500, C700, U300, U500, U700, B300, B500, B700, T300, T500, and T700) were obtained at three pyrolysis temperatures (300°C, 500°C, and 700°C). The results show that canna (C) and umbrella palm (U) are more suitable as raw materials for phosphorus removal using biochar. If bamboo reed (B) and Thalia dealbata (T) are used as raw materials for phosphorus removal using biochar, there is a greater risk of phosphorus release. With the increase of pyrolysis temperature (700°C > 500°C > 300°C), there is an increasing trend of phosphorus adsorption effect. The theoretical maximum adsorption capacity of C700, U700, and C500 was 39.24, 7.08, and 7.26 mg P·g⁻¹ at an initial concentration of 50 mg L⁻¹ phosphorus, respectively. The theoretical adsorption capacity of C700 (Qmax = 39.24 mg P·g⁻¹) was much higher than that of the general modified adsorption materials. It also has a larger tolerance range to pH (3–11). The results of kinetic model fitting showed that the adsorption mechanism of C700, U700, and C500 on phosphorus can be better simulated by intra-particle diffusion and Elovich model, and the adsorption mechanism includes surface adsorption and intra-particle diffusion. The fitting of isothermal adsorption model showed that Langmuir–Freundlich equation is more suitable for the description of adsorption characteristics of C700, U700, and C500, and the fitting coefficient R² is 0.9928, 0.9949, and 0.9897, respectively. It indicates that the adsorption of phosphorus on C700, U700, and C500 has a balance of uniform and nonuniform surface, and monolayer and multilayer adsorption could occur. The results from this work demonstrated that the biochar obtained from canna at 700°C has good adsorption and phosphorus removal potential without modification, and it can be used as the preferred biochar for phosphorus removal of high concentration with large pH changes. In the final validation experiment, the phosphorus removal rate of C700 was up to 77.4% on the treatment of actual phosphorus containing wastewater.

Keywords: wetland-based, biochar, adsorption of phosphorus removal, kinetic model, Langmuir–Freundlich equation

1 Introduction

Eutrophication has become one of the most serious water environment problems in the world. According to Liebig’s least factor law, phosphorus is often considered as one of the main inducing factors of eutrophication in water bodies. It is generally considered internationally that the concentration of phosphorus exceeds 0.02 mg·L⁻¹; that is, it meets the standard of eutrophication in water [1]. Therefore, phosphorus removal from water environment is an important concern. At present, some methods, such as constructed wetland, crystallization, adsorption, and other methods, are used to treat phosphorus wastewater [2]. In the adsorption method, the selection and preparation of adsorbent is the key adsorption technology for its successful application. At present, biomass adsorbent or its derivatives have attracted much attention due to their rich sources, with simple preparation and good adsorption effect [3]. The most common adsorbent is activated carbon, but the high cost limits its widespread use. Therefore, alternative sorbents are urgently needed. In recent years, biochar has attracted extensive attention due to its large specific surface area, multiphase
pore structure, abundant surface functional groups, and abundant inherent minerals, which indicate that biochar can be used as an excellent adsorbent. Biochar is a carbon-rich product derived from the pyrolysis of waste biomass under anaerobic conditions [4,5]. As a multifunctional environment friendly material, it also has good adsorption characteristics and can effectively remove pollutants in wastewater [6]. At present, the raw materials for biochar preparation mainly focus on agricultural straw, wood chips, fruit shells, sludge, and livestock and poultry feces, but systematic studies on wetland plants are rare. In 2021, China took constructed wetlands as an important measure to improve the ecological environment of rivers and lakes [7]. With the increase of wetland scale, the yield of wetland plants also increases, and it will cause secondary pollution if not harvested in time. In today’s situation of increasingly prominent resources and energy problems, the utilization of wetland plant resources can not only avoid the secondary pollution caused by incineration and landfill, but also alleviate the situation of resource shortage. Study has shown that biochar was a kind of adsorbent with negative charge on the surface and has weak adsorption capacity for inorganic phosphate and other anions in water [8]. Besides, biochar itself contains phosphorus, which may have a tendency to release phosphorus in the process of use [9]. Previous studies have shown that adding unmodified biochar to wetland substrates can improve the removal efficiency of nitrogen and phosphorus. Studies have found that biochar generated from different plant bases at the same pyrolysis temperature contains different functional groups [10], which may result in different adsorption effects of different plant-based biochar on various target pollutants. Therefore, in this study, four common wetland plants in Southwest China were used as raw materials for biochar, and 12 kinds of biochar were obtained at three different pyrolysis temperatures, and to study the phosphorus removal ability of these biochars, providing another feasible way for eutrophication water purification and reuse of wetland plant resources.

## 2 Materials and methods

### 2.1 Raw material preparation

Macrophytes (canna, umbrella palm, bamboo reed, and *Thalia dealbata*) were collected from a wetland park in Guiyang, Guizhou Province, China. Impurities on macrophyte were washed off with distilled water, and the macrophyte was dried in an oven at 80°C. Later, the dried macrophyte was crushed and passed through a 100-mesh sieve.

### 2.2 Preparation of wetland plant-based biochar

The dried macrophyte powder was then placed in a quartz crucible, and then the crucible was put in a muffle furnace. The pyrolysis temperature was increased to target temperature (300°C, 500°C, and 700°C) at a heating rate of 5°C-min⁻¹ and held for 2 h. After cooling to room temperature, the biochar was removed and was washed with distilled water until the elute was nearly neutral. Canna (C), umbrella palm (U), bamboo reed (B), and *Thalia dealbata* (T) were pyrolyzed at three temperatures (300°C, 500°C, and 700°C). A total of 12 kinds of biochar can be obtained: C300, C500, C700; U300, U500, U700; B300, B500, B700; T300, T500, and T700.

### 2.3 Adsorption experiments

#### 2.3.1 Dynamic adsorption experiment

About 0.200 g of the biochar was accurately weighed and placed in the sample bottle. About 30 mL of KH₂PO₄ (potassium dihydrogen phosphate) solution (pH = 7) with an initial concentration of 50 mg·L⁻¹ was added. Set a series of time points (5, 10, 15, 30, 60, 90, 120, 180, 240, 480, 780, 1,440, and 2,160 min) and repeat three times for each point. The sample bottles were placed in a thermostatic oscillator and oscillated at a speed of 160 rpm·min⁻¹ at 28°C. After balancing, the liquid was filtered and the concentration of phosphorus was determined by molybdenum antimony anti-spectrophotometry. The adsorption capacity $Q_t$ (mg·g⁻¹) of biochar at different times can be calculated by the following formula:

$$Q_t = (C_0 - C_f) \times \frac{V}{m}$$

where $Q_t$ is the capacity for biochar adsorption on biochar at time $t$ (mg·g⁻¹); $C_0$ is the initial concentration of P, mg·L⁻¹; $C_f$ is filtrate phosphorus concentration after adsorption, mg·L⁻¹; $V$ is the volume of solution, L; $m$ is the mass of carbon, g. Pseudo-first-order, pseudo-second-order, intraparticle diffusion, and Elovich dynamic model equations were used for simulation.
Pseudo-first-order:

$$q_t = q_e (1 - e^{-kt})$$ \hspace{1cm} (2)

Pseudo-second-order:

$$q_t = \frac{q_e^2 k_t t}{1 + q_e k_t t}$$ \hspace{1cm} (3)

Intra-particle diffusion:

$$q_t = k_3 \sqrt{t} + a_1$$ \hspace{1cm} (4)

Elovich dynamic model equations:

$$q_t = a_2 + k_4 \ln t$$ \hspace{1cm} (5)

where \( q_e \) is the adsorption capacity of adsorbent at \( t \) (mg·g\(^{-1}\)); \( q_e \) is the adsorption capacity of adsorbent at equilibrium time (mg·g\(^{-1}\)); \( k_i \) is adsorption rate constant of pseudo-first-order, mg·L\(^{-1}\)·min\(^{-1}\); \( k_2 \) is adsorption rate constant of pseudo-second-order, mg·g\(^{-1}\)·min\(^{-1}\); \( a_1 \) is the kinetic constant, mg·L\(^{-1}\); \( k_3 \) is the diffusion rate constant, mg·g\(^{-1}\)·min\(^{-1}\); \( a_2 \) is the kinetic constant, mg·L\(^{-1}\); \( k_4 \) is the rate constant of Elovich model, mg·g\(^{-1}\)·min\(^{-1}\).

2.3.2 Isothermal adsorption experiment

About 0.200 g of the sample was accurately weighed and placed in the sample bottle, and 30 mL of potassium dihydrogen phosphate solution with the initial concentration of 0, 1, 2, 5, 8, 10, 30, 50, 100, and 200 mg·L\(^{-1}\) was added, respectively, and repeated three times for each concentration. The sample bottle was placed in a thermostatic oscillator at a speed of 160 rpm·min\(^{-1}\) and oscillated at 28°C for 24 h. After balancing, the filtrate was filtered and the concentration of phosphorus was determined by molybdenum antimony anti-spectrophotometry:

$$Q_e = (C_0 - C_t) V / m$$ \hspace{1cm} (6)

where \( Q_e \) is the adsorption capacity of biochar to be measured at equilibrium, mg·g\(^{-1}\); \( C_0 \) is the initial concentration of phosphorus, mg·L\(^{-1}\); \( C_t \) is the concentration of filtrate phosphorus at adsorption equilibrium, mg·L\(^{-1}\); \( V \) is the volume of solution, L; \( m \) is the mass of carbon, g. Langmuir, Freundlich, and Langmuir–Freundlich isothermal adsorption equations were used to fit the experimental data, respectively.

Langmuir model (Eq. 7):

$$q_e = \frac{K_L q_m C_e}{1 + K_L C_e}$$ \hspace{1cm} (7)

Freundlich model (Eq. 8):

$$q_e = K_F C_e^n$$ \hspace{1cm} (8)

2.3.3 Influence of pH value

In the experiment, 0.5 mol·L\(^{-1}\) H\(_2\)SO\(_4\) and NaOH solution were used to modulate the initial pH value of 50 mg·L\(^{-1}\) potassium dihydrogen phosphate solution, and the initial pH was set to 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, and 11.0. About 0.200 g biochar was accurately weighed into the sample bottle, and 30 mL of solutions with different initial pH values were added, and each pH point was repeated three times. The sample bottle was placed in a thermostatic oscillator at a speed of 160 rpm·min\(^{-1}\) and oscillated at 28°C for 24 h. After balancing, the filtrate was filtered and the phosphorus concentration was determined by molybdenum antimony anti-spectrophotometry. The adsorption capacity of biochar at equilibrium, \( Q \) (mg·g\(^{-1}\)), can be calculated from the following equation:

$$Q_t = (C_0 - C_t) \times V / m$$ \hspace{1cm} (10)

2.4 Data analysis

Excel 2007 was used for data analysis and data processing. Origin 9.0 was used for graph drawing and model fitting.

3 Results and discussion

3.1 Adsorption kinetics

Phosphorus adsorption kinetics of 12 wetland plant-based biochars are shown in Figure 1. The phosphorus adsorption
capacity of the 12 biochars is significantly different. The adsorption capacity of phosphorus for C700 and U700 reached equilibrium basically at 750 min. When the adsorption time is 1,440 min, the phosphorus removal of C700, U700, and C500 biochars is the highest, reaching 98.6%, 20.5%, and 11.3%, respectively. It indicates that the different wetland plants as biochar raw materials using phosphorus adsorption are significantly different. Different pyrolysis temperatures also have great influence on the phosphorus adsorption capacity of biochar derived from the same wetland plant. When the adsorption time is 2,160 min, the adsorption capacity of C700 and U700 is positive, while for the other ten kinds of biochar it is negative, indicating that canna and umbrella palm of the four wetland plants are more suitable as biochar raw materials for phosphorus adsorption. In this experiment, canna showed a greater potential for phosphorus adsorption. The actual adsorption capacity is as high as 7.62 mg·g⁻¹, which is significantly higher than the cotton stalk biochar loaded with iron oxide (0.963 mg P·g⁻¹) [11] and ginkgo shell Fe/C composite (1.62 mg·g⁻¹) [12]. Although the adsorption capacity of C700 on phosphorus is lower than that of nano-silver studied by Tuyen [13], Table 1 comprehensively shows that the adsorption capacity of C700 on phosphorus is greater than that of adsorbents prepared by many other materials.

In this experiment, pseudo-first-order, pseudo-second-order, intra-particle diffusion, and Elovich kinetic model are used to fit the experimental data, and the influence mechanism of 12 kinds of biochar on phosphorus adsorption is analyzed from the perspective of kinetics. The error between fitting results and experimental values is

| Adsorbents                        | T (°C) | pH  | Adsorbent added (g·L⁻¹) | q_m (mg·g⁻¹) |
|-----------------------------------|--------|-----|-------------------------|--------------|
| Magnetic nanoparticles            | 25     | 3   | 1                       | 9.72 [15]    |
| Canna biochar                     | 28     | 3–11| 6                       | 7.62 (this study) |
| H₂SO₄-modified activated carbon   | 35     | 3–10| 4                       | 7.26 [16]    |
| ZnCl₂-modified activated carbon   | 35     | 6–10| 6                       | 5.1 [17]     |
| Iron-supported water hyacinth biochar | 25     | 3–9 | 5                       | 5.07 [18]    |
| Modified attapulgite clay         | 25     | 4–6 | 1                       | 4 [19]       |
| Alum sludge                       | 20     | 4–5 | 5–6                     | 3.20 [20]    |
| Orange peel magnetic biochar      | 25     | —   | 6.25                    | 0.22–1.2 [21] |
expressed by correlation coefficient $R^2$, and the larger $R^2$ value is, the closer the description of the adsorption process by the model. As shown in Table 2, it is found that the adsorption of phosphorus by C700, C300, and B300 accords with the characteristics of pseudo-first-order, with $R^2$ values of 0.889, 0.925, and 0.911, respectively, and the adsorption of phosphorus by 12 carbons did not accord with the pseudo-second-order kinetics simulation. The C700 and U700 biochars with the best adsorption effect were more consistent with the intra-particle diffusion and Elovich model, and their fitting correlation coefficients are 0.874, 0.861 and 0.947, 0.939, respectively. The Elovich fitting effect is the best, with $R^2 > 0.9$. This indicates that the adsorption process of phosphorus on C700 and U700 mainly includes surface adsorption, internal particle diffusion, and external liquid film diffusion [14]. In the Elovich equation, $K_a$ is an indicator of how fast the adsorption rate changes over time, and the larger its value is, the faster the adsorption rate decreases. As shown in Table 3, the adsorption rate of U700 ($K_a = 0.406$) decreases over time than that of biochar C700 ($K_a = 0.804$) slowly; that is, although the phosphorus adsorption capacity of U700 was lower than that of C700, however, U700 has better continuous phosphorus removal effect.

### 3.2 Isothermal adsorption

The isothermal adsorption of phosphorus by 12 wetland plant-based biochars is shown in Figure 2. There is significant difference among these 12 biochars in adsorption capacity of phosphorus. C700, U700, and C500 have an adsorption effect on phosphorus, while the other nine kinds of biochar were negative on phosphorus removal. With the increase of phosphorus concentration, the adsorption capacity of C700, U700, and C500 increases gradually, indicating that this unmodified carbon was more suitable for high-concentration phosphorus removal. In addition, the adsorption capacity of C700 on phosphorus is significantly better than that of U700 and C500. Langmuir, Freundlich, and Langmuir–Freundlich equations are used to simulate the isothermal adsorption of phosphorus on 12 biochars.

The best fitting process is determined by comparing $R^2$. The results showed (Table 4) that the adsorption of phosphorus by C700, U700, and C500 biochars is the combination of Langmuir and Freundlich models; that is, the Langmuir–Freundlich equation had the highest fitting degree for C700, U700, and C500 biochars, and $R^2$ is 0.9928, 0.9949, and 0.9897, which is described as

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**Table 2: Pseudo first-order and pseudo second-order kinetic fitting parameters**

| Biochar | $k_1$ (min$^{-1}$) | $q_e$ (mg·g$^{-1}$) | $R^2$ |
|---------|----------------|------------------|-------|
| U300    | 0.127          | -3.00            | 0.793 |
| U500    | 0.057          | -1.47            | 0.676 |
| U700    | 0.002          | 1.71             | 0.889 |
| C300    | 0.269          | -8.75            | 0.925 |
| C500    | -1.119         | 1.41             | -2.342 |
| C700    | 0.06           | 5.98             | 0.383 |
| B300    | 0.092          | -2.36            | 0.911 |
| B500    | 0.002          | -0.93            | 0.756 |
| B700    | 3.053          | -0.73            | -5.773 |
| T300    | 0.465          | -3.59            | 0.063 |
| T500    | 0.289          | -1.79            | 0.445 |
| T700    | 0.372          | -2.69            | 0.252 |

| Biochar | $k_2$ (min$^{-1}$) | $q_e$ (mg·g$^{-1}$) | $R^2$ |
|---------|----------------|------------------|-------|
| U300    | -1.049         | -2.78            | -1.43 × 10$^6$ |
| U500    | 3.49 × 10$^4$  | -1.26            | -6.656 |
| U700    | -2.546         | 0.5              | -5.979 |
| C300    | -2.925         | -8.52            | -1.001 |
| C500    | 9.35 × 10$^4$  | -1.35            | -4.381 |
| C700    | 2.05 × 10$^4$  | 5.23             | -1.913 |
| B300    | -2.429         | -2.12            | -1.609 |
| B500    | 2.78 × 10$^4$  | -0.41            | -2.02 × 10$^4$ |
| B700    | 3.39 × 10$^4$  | -0.73            | -8.418 |
| T300    | -7.749         | -3.56            | -6.292 |
| T500    | 6.73 × 10$^4$  | -1.75            | -1.91 × 10$^6$ |
| T700    | 1.34 × 10$^4$  | -2.46            | -4.6 |

**Table 3: Intra-particle diffusion and Elovich kinetic fitting parameters**

| Biochar | $a_1$ | $k_2$ (min$^{-1}$) | $R^2$ | $a_2$ | $k_3$ (min$^{-1}$) | $R^2$ |
|---------|------|----------------|-------|------|----------------|-------|
| U300    | -2.394 | -0.024          | 0.437 | -1.678 | -0.232          | 0.727 |
| U500    | -0.904 | -0.022          | 0.686 | -0.353 | -0.191          | 0.909 |
| U700    | -0.312 | 0.051           | 0.874 | -1.290 | 0.406           | 0.947 |
| C300    | -1.468 | -0.022          | 0.253 | -7.388 | -0.238          | 0.534 |
| C500    | -1.931 | 0.049           | 0.781 | -2.767 | 0.339           | 0.694 |
| C700    | 3.534  | 0.106           | 0.861 | 1.610  | 0.804           | 0.939 |
| U300    | -1.808 | -0.019          | 0.290 | -1.133 | -0.207          | 0.595 |
| U500    | -0.06  | -0.021          | 0.835 | 0.336  | -0.156          | 0.791 |
| U700    | -0.936 | 0.012           | 0.500 | -1.174 | 0.092           | 0.490 |
| C300    | -3.284 | -0.017          | 0.511 | -2.969 | -0.124          | 0.479 |
| C500    | -5.003 | 0.000           | 0.124 | -1.609 | -0.062          | 0.565 |
| C700    | -1.632 | -0.007          | 0.469 | -1.46  | -0.062          | 0.565 |
| T300    | -2.448 | -0.264          | 0.003 | -2.297 | -0.034          | 0.101 |
equilibrium on uniform and nonuniform surfaces, applied to low and high adsorbent concentrations.

The theoretical maximum adsorption capacity of C700, U700, and C500 is 39.24, 7.08, and 7.26 mg P g⁻¹, respectively. These theoretical adsorption amounts are close to the real adsorption amounts (Figure 2), which also indicates that the Langmuir–Freundlich equation is suitable for simulating the phosphorus adsorption process of these three carbons. The theoretical adsorption capacity of C700 on phosphorus (Q_{max} = 39.24 mg P g⁻¹) is much higher than that of previous studies. For example, sesame stalk biochar was modified with ZnCl₂ and MgO (8.67–9.68 mg P g⁻¹) [22], Orange peel biochar was modified with Fe₂O₃ (0.22–1.24 mg P g⁻¹) [23], and cotton straw biochar was modified with Fe₂O₃ (0.96 mg P g⁻¹) [11]. Therefore, canna, a kind of wetland plant, is an excellent biochar adsorbent raw material for phosphorous removal.

### 3.3 pH effect

As can be seen from Figure 3, C700, U700, C500, and U500 have adsorption effect on phosphorus when pH is in the range of 3–11, while the removal rates of the other eight kinds of biochar are all negative, showing no effect on phosphorus removal. pH has different effects on phosphorus adsorption by different biochars. U500 showed a rising trend with the increase of pH, indicating that

|     | Q₃₃₃ | Q₅₀₀ | Q₇₀₀ |
|-----|------|------|------|
| U300 | 7.433 | −4.08 | 1.917 |
| U500 | 0.0194 | 1.159 | 0.6023 |
| U700 | 0.0159 | 8.074 | 0.9917 |
| C300 | −16.776 | −8.522 | −63.69 |
| C500 | 0.0199 | 8.354 | 0.9865 |
| C700 | −5.511 | 10.10 | 0.0590 |
| B300 | 0.0015 | −3.179 | −2.7808 |
| B500 | −4.675 | −1.581 | −2.902 |
| B700 | 0.0000 | −0.947 | −0.273 |
| T300 | −6.248 | −2.772 | −8.786 |
| T500 | 1.87 × 10⁻⁴ | −1.044 | −0.359 |
| T700 | −49.812 | −2.612 | −1.905 |

*Table 4: Isothermal adsorption fitting parameters*
alkaline environment can promote absorption of phosphorus of U500. U700 decreased with the increase of pH, indicating that U700 is favorable for phosphorus adsorption in acidic environment. The influence of pH on C700 is small. When pH = 7, the adsorption capacity of the biochar to phosphorus is slightly lower; however, the adsorption capacity of C700 is up to 7.0 mg·g⁻¹. It showed that C700 can be used to treat high-concentration phosphorus of industrial wastewater with a wide range of pH tolerance.

3.4 Effect of biochar on removal of actual phosphorus containing wastewater

In order to verify the performance of the biochar (C700) with the best phosphorus removal effect screened in the batch experiment in practical application, we used C700 as the adsorbent to remove phosphorus in the actual wastewater. After 24 h of oscillation, the total phosphorus reduction amount in the wastewater reached 126.3 mg·L⁻¹, with an average removal rate of 77.4% (Table 5).

### Table 5: Effect of biochar (C700) on the treatment of real wastewater containing phosphorus

|                         | C700  |
|-------------------------|-------|
| Initial phosphorus concentration (mg·L⁻¹) | 163.2 |
| Post-treatment phosphorus concentration (mg·L⁻¹) | 36.9 ± 3.3 |
| Removal rate of phosphorus (%)              | 77.4 ± 2.0 |

4 Conclusion

1. The adsorption kinetics model fitting results showed that the adsorption mechanism of C700 and U700 on phosphorus can be better simulated by intra-particle diffusion and Elovich model. The adsorption mechanism includes surface adsorption and intra-particle diffusion. The Langmuir–Freundlich equation is more suitable to describe the adsorption characteristics of C700 and U700, which indicated that the adsorption of C700 and U700 has a balance of uniform and nonuniform surface, and both single and multilayer adsorption can occur.

2. In the range of pH 3–11, C700, U700, C500, and U500 have adsorption effect on phosphorus, and pH has different effects on them. Therefore, in the practical application of biochar, more attention should be paid to the pH of the target wastewater, and biochar with a wide range of pH tolerance should be selected. The C700 in this experiment has a wide range of pH adaptation, which can be used as the preferred biochar for the treatment of high-concentration phosphorous wastewater with a wide range of pH variation.

3. It is found that the adsorption and desorption capacity of the biochar produced by different wetland plant-based biochar and produced by the same plants at different pyrolysis temperatures are significantly different. From the perspective of plant species, the adsorption and desorption capacities of the four wetland plant-based biochar, canna (C), umbrella palm (U), bamboo reed (B), and Thalia dealbata (T) show significant differences. Bamboo reed and Thalia dealbata did not have the ability to adsorb phosphorus, indicating that if unmodified biochar of B and T were directly used for phosphorus removal, there would be a greater risk of exceeding the standard of phosphorus due to phosphorus desorption. C and U are more suitable as the raw material for biochar using phosphorus adsorption. In terms of pyrolysis temperature, taking C, U as an example, it shows that with the increase of pyrolysis temperature (700°C > 500°C > 300°C), the increasing trend of phosphorus adsorption effect. The results showed that the biochar obtained under 700°C condition is more conducive to phosphorus adsorption. When the pyrolysis temperature of canna is 700°C, the biochar C700 has the best phosphorus removal capacity, and the maximum theoretical adsorption capacity is up to 39.24 mg·P·g⁻¹, which is higher than the maximum theoretical adsorption capacity of many modified biochar. In addition, the phosphorus removal rate of C700 was up to 77.4% through a validation experiment on the treatment of actual phosphorus containing wastewater.
wastewater. Therefore, it can be used as an alternative adsorbent with greater adsorption potential.

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