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Adsorption characteristics of used brick for phosphorus removal from phosphate solution

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ABSTRACT

Phosphorus is one of the main causes for eutrophication in waterbodies. The techniques for phosphorus removal from wastewater and waterbodies have become a hot topic in the world. In this study, used brick was chosen as an experimental adsorbent for removing phosphorus from phosphate solution, and the effects of brick dosage, pH, temperature and vibration time on phosphorus adsorption characteristics were evaluated. Results showed that phosphorus could be effectively removed using brick powders, and the optimum brick dosages were 4, 9 and 35 g/L in the presence of 5, 10 and 50 mg/L of phosphorus concentrations, respectively. A significant linear correlation ($R^2 = 0.9904$) between phosphorus concentration and optimum brick dosage was observed. The optimum condition was determined to be: brick dosage 20 g/L, phosphorus concentration 25 mg/L, pH 5, temperature 25° C and vibration time 2 h.

Keywords: Used brick; Phosphorus; Adsorption; Influencing factors

1. Introduction

Eutrophication has become a global common problem for many freshwater bodies in the world. One of the main causes for eutrophication was excessive phosphorus in the water and sediment [1,2]. In recent years, in order to control or alleviate eutrophication, phosphorus in the wastewater must be treated and reduced to a low level prior to discharging into waterbodies. Many treatment methods for phosphorus removal, including chemical, biological and adsorption, have been developed [3–5]. Among them, chemical method is reliable and easily operated, but high cost and secondary pollution caused by the generation of large quantities chemical sludge are its main shortcomings [6]. In contrast, biological treatment is low-cost and less secondary pollution, but its removal efficiency is highly inconsistent due to environmental factors such as temperature, pH, and so on [7,8].

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Adsorption method, which combines the advantages of the two above-mentioned methods, is probably a better choice for phosphorus removal.

The key factor for adsorption method is the selection of suitable adsorbents. Various materials, including natural material (such as zeolite, bentonite, laterite and kaoline), industrial wastes (such as fly ash, blast furnace slag, and slag), activated aluminum oxide, porosint, synthetic material, etc., have been used [9–13]. Meanwhile, some other wastes, such as eggshell [14], giant reed [15], skin split [16], coir pith [5], sugarcane bagasse fibers [17], and pine sawdust [18–20], have been modified to adsorb phosphorus. In addition, some new approaches, such as lithium intercalated gibbsite [21], magnetic ion-exchange resin [22], chitosan hydrogel beads after the removal of copper (Ⅱ) [23], activated carbon loaded with Fe(III) oxide [24], zirconium(IV)-loaded fibrous [25], have also been developed to remove phosphorus.

As a result of the rapid development of economy in China, huge building wastes are being generated. The disposal of such building wastes has become a challenging problem. Since building materials, including cement and brick, are rich in calcium, aluminum and iron, they could bind with phosphorus in water. Thus, if building wastes could be used as an adsorbent, a double win of phosphorus removal and waste recycling could be achieved.

The purposes of this study were to determine the following: (1) the feasibility of used brick to absorb phosphorus from phosphate solution; and (2) the optimal conditions of used brick for phosphorus removal.

2. Materials and methods

2.1. Experimental materials

The used bricks used in the experiment were obtained from a housing project in Wuhan, China. The bricks were crushed into coarse grain and ground into fine powder, followed by sieving through 100 mesh prior to air dry. The quantities of Fe_2O_3, Al_2O_3, CaO, MgO and SO_3 were determined by titrimetry with EDTA. SiO_2 and the loss on ignition was determined using potassium fluosilicate volumetric and incandesce method, respectively. The composition of the material is shown in Table 1.

2.2. Phosphate solutions

Phosphate solutions with different concentrations (0, 5, 10, 25, 50 mg P/L) were prepared by dissolving potassium dihydrogen orthophosphate (KH_2PO_4) in deionized water.

2.3. Experimental methods

Different dosages of brick powder were placed in 250-mL Erlenmeyer flasks, followed by addition of different concentrations of 100 mL phosphate solution. The pH value of the solution was manually adjusted with diluted HCl or NaOH solutions using a pH meter (METTLER TOLEDO DELTA 300). The flasks were then capped and shaken on a thermostatic oscillator (TONE GXZ) at the desired temperature and constant rate of 150 rpm. The suspension was poured into 50-mL centrifugal tubes and centrifuged at 4,000 rpm for 5 min using an EBA 21 centrifuge. Phosphorus concentration in the clear solution was determined using the ascorbic acid method at 700 nm with a SHIMADZU UV1800 spectrophotometer [26].

2.4. Statistical analysis

The experiments were conducted in triplicate, and data were reported as mean values ±standard deviation. Statistical analyses were performed using Origin Pro 8.0 Statistical Software.

3. Results

3.1. Optimum brick dosages under different phosphorus concentrations

The optimum brick dosages for phosphate solution containing four phosphorus concentrations (5, 10, 25 and 50 mg/L) were evaluated at pH 5, temperature 25℃ and vibration time 2 h (Fig. 1).

As seen from Fig. 1, in the presence of 5 mg/L of phosphorus, the phosphorus removal efficiency increased significantly from 19.52 to 71.67% with the increase of brick dosages from 1 to 4 g/L. However, since the removal efficiency did not improve much (only by 5.82%) as dosages increased from 4 to 6 g/L, 4 g/L was selected as the optimum brick dosage. Likewise, similar trends for the removal efficiencies

Table 1
Composition of the brick (%)

Components	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	SiO_2	Loss on ignition
Content (%)	7.07	16.50	1.28	1.60	0.11	69.71	1.64

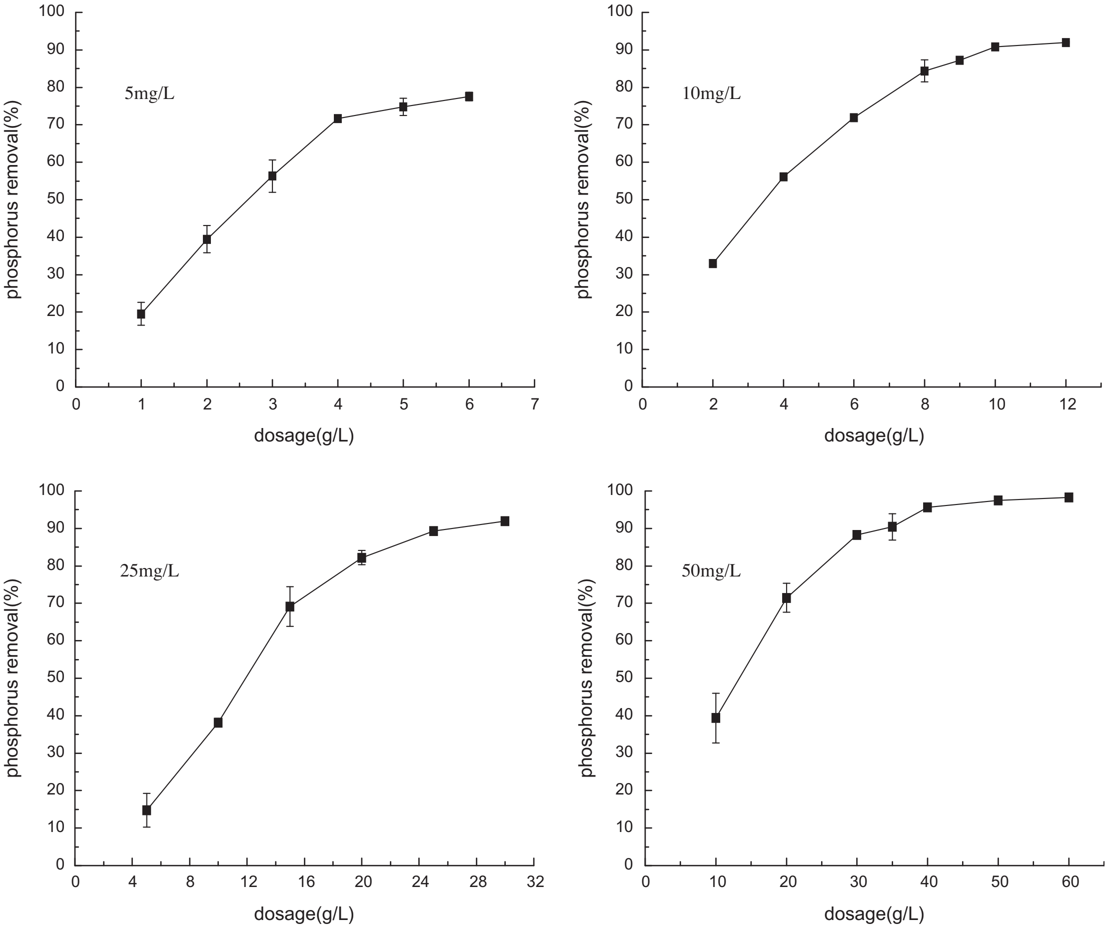

Fig. 1. Removal efficiencies under different phosphorus concentrations.

were observed for other phosphorus concentrations. The optimum dosages for phosphorus concentrations of 10, 25, and 50 mg/L were 9, 20, and 35 g/L, respectively.

Fig. 2 shows a significant correlation between phosphorus concentrations and optimum brick dosages, with an equation of $y = 0.6776x + 1.7551$ ($R^2 = 0.9904$), where x is the phosphorus concentration and y the optimum brick dosage.

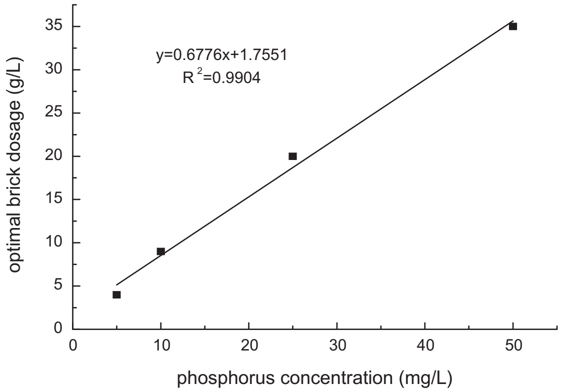

Fig. 2. Correlations between phosphorus concentrations and optimum brick dosages.

3.2. Effect of brick dosage on phosphorus adsorption

According to the typical phosphorus concentrations in the phosphate solution, 25 mg/L was chosen to study the effect of brick dosage, pH, temperature and vibration time on phosphorus adsorption characteristics.

The effect of brick dosages (0, 5, 10, 15, 20, 25, and 30 g/L) on phosphorus adsorption at phosphorus concentration 25 mg/L, pH 7, temperature 25℃, and vibration time 24 h was studied, and the results are shown in Fig. 3.

As shown in Fig. 3, the removal efficiency for phosphorus increased significantly from 14.70 to 87.29% as brick dosages increased from 5 to 20 g/L. However, only a small increase (9.76%) was achieved when dosages increased from 20 to 30 g/L. After thorough evaluation of removal efficiencies and treatment

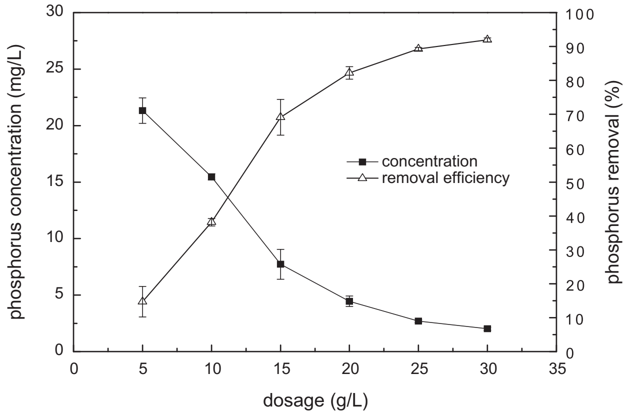

Fig. 3. Effects of brick dosages on phosphorus adsorption.

costs, 20 g/L was selected as the optimum dosage for brick powder.

3.3. Effect of pH value on phosphorus adsorption

The effect of pH (2, 5, 7, 9, and 12) on phosphorus adsorption at phosphorus concentration 25 mg/L, brick dosage 20 g/L, temperature 25℃, and vibration–time 24 h was plotted in Fig. 4.

As seen from Fig. 4, pH had a great influence on the phosphorus adsorption. The phosphorus removal efficiencies increased from 8.05 to 96.65% as pH increased from 2 to 5 and then decreased sharply with increasing pH. Therefore, for optimum performance the pH of phosphate solution should be maintained between 5 and 7.

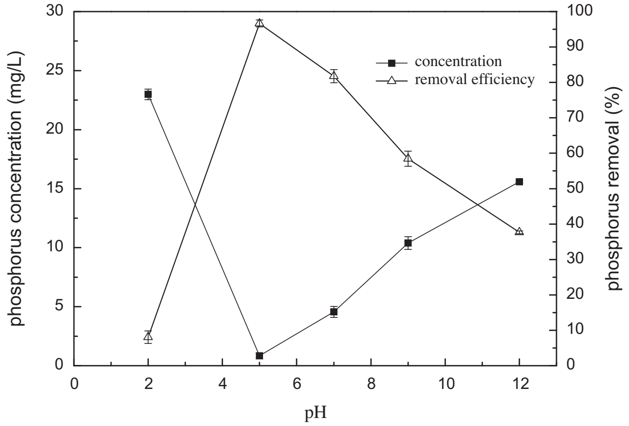

Fig. 4. Effect of pH on phosphorus adsorption.

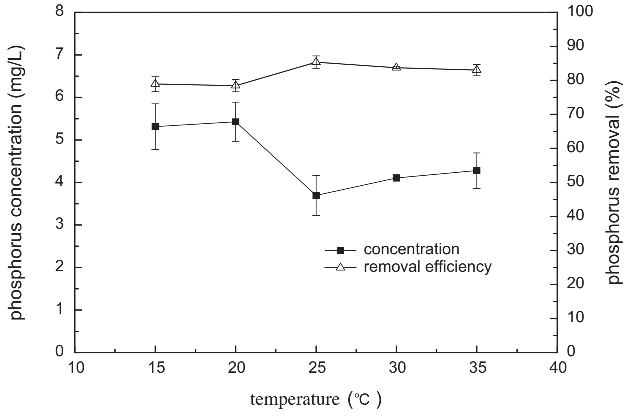

Fig. 5. Effect of temperatures on phosphorus adsorption.

3.4. Effect of temperature on phosphorus adsorption

The effect of temperatures (15, 20, 25, 30, and 35° C) on phosphorus adsorption at phosphorus concentration 25 mg/L, brick dosage 20 g/L, pH 7 and vibration time 24 h is shown in Fig. 5.

As shown in Fig. 5, the effect of temperatures on the phosphorus removal by brick was not significant. The removal efficiencies increased from 78.92 to 85.33% as temperatures increased from 15 to 25℃, and then leveled off at higher temperatures. The optimum temperature was determined to be 25℃.

3.5. Effect of vibration time on phosphorus adsorption

The effect of vibration times (2, 4, 8, 12, 18, 24, 36 and 48 h) on phosphorus adsorption at phosphorus concentration 25 mg/L, brick dosage 20 g/L, pH 7 and temperature 25℃ is shown in Fig. 6.

As seen from Fig. 6, the influence of vibration time on phosphorus adsorption was apparent. The phosphorus removal efficiencies were 87.82% (2 h), 80.61% (8 h), and 90.98% (18 h). The optimum vibration time of 2 h was selected.

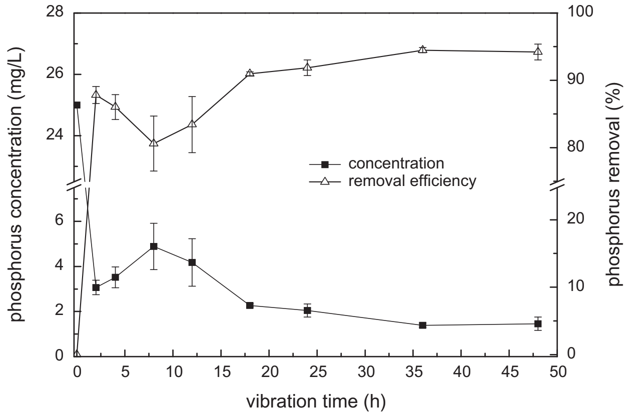

Fig. 6. Effect of vibration time on phosphorus adsorption.

4. Discussion

In selecting an appropriate adsorbent, it is necessary to evaluate the characteristics of adsorbing material. Wang et al. [27] reported that the simulated adsorption capacity of red clay varied in the range of 0.52–0.86 and 0.52–1.18 mg P/g at solution concentrations of 35 and 50 mg/L, respectively, and phosphate removal was attributed to Al_2O_3 and Fe_2O_3 in the clay. A novel cellulose-based adsorbent, [Fe(III)–AM-PGMACell], was used to remove phosphate from waterbodies and wastewater, and a maximum removal efficiency of 99.1% was observed for phosphorus concentration of 25 mg/L at pH 6 with an adsorbent dosage of 2.0 g/L [28]. Kuzawa et al. [29] reported a maximum adsorption of 47.3 mg P/g for a synthetic hydrotalcite. Li et al. [30] found that the raw red mud (RW) could remove 99% of phosphate from solution containing 155 mg/L phosphate at optimum pH 7 and 25℃.

In this experiment, the adsorption capacities of used brick under phosphorus concentrations of 5, 10, 25 and 50 mg/L were 0.90, 0.97, 1.09 and 1.29 mg P/g, respectively. The result is similar to natural zeolite, which has similar components with brick and the capacities were 0.05, 0.10, 0.08 and 0.50 mg P/g with the same phosphorus concentrations, respectively [31]. The high phosphorus removal efficiency could be attributed to the high concentrations of Al^{3+}, Fe^{3+} and Ca^{2+} in the used brick, and their hydroxide or oxide groups could precipitate and ion exchange with phosphorus ions [32–35]. In addition, brick powders had large surface areas, which was beneficial to enhance phosphorus adsorption capacity [35].

It was generally regarded that pH value was one of the main influencing factors for phosphorus adsorption. The variability of phosphorus adsorption with pH values could be attributed to the impact of H^+ or OH^-. In strong acid solution, the protonation effect on the surface of Al^{3+} ions and Fe^{3+} ions could be increased due to the presence of abundant H^+ ions, thus reduce their bonding abilities to phosphate [36]. As for the strong alkali solutions, the large amount of OH^- ions could compete with phosphate ions for the adsorption sites, and the competition would result in the reduction of phosphorus adsorption capacity [37]. Zeng et al. [38] reported that the removal capacity of iron oxide tailings reduced as pH increased. Onyango et al. [39] also found that the phosphate removal efficiencies increased with increasing adsorbent dosages, but a decrease for phosphate removal efficiencies was achieved as pH decreased.

In our experiment, it was found that the phosphorus removal efficiency of brick powder reached the maximum at pH 5 and decreased slightly when pH was 7. In addition to remove phosphorus from phosphate solution, brick powder could also be used effectively to remove phosphorus from waterbodies with neutral pH.

5. Conclusions

Used brick powder has the potential to remove phosphorus effectively from phosphate solutions. The main factors such as dosage, pH, temperature and vibration time could affect phosphorus adsorption. The optimum brick dosages were 4, 9 and 35 g/L in the presence of 5, 10 and 50 mg/L of phosphorus concentrations, respectively. A significant linear correlation ($R^2 = 0.9904$) between phosphorus concentration and optimum brick dosage was observed. The optimum condition was determined to be: brick dosage 20 g/L, pH 5, temperature 25℃ and vibration time 2 h at phosphorus concentration of 25 mg/L. Its application is a double-win for both phosphorus removal and reuse of building wastes.

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