

2014

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(11), 2014 [5757-5762]

The effect of Ca^{2+} , Al^{3+} and Fe^{3+} on phosphate sorption on sediment

Wenwei Wu^{1,2}, Di Wu², Fengle Yang², Kunzhi Li^{1*}¹Faculty of Environmental Science & Engineering, Kunming University of Science & Technology, Kunming 650500, (CHINA)²Yunnan Institute of Environmental Science, Kunming 650500, (CHINA)

E-mail : kevenwd@yahoo.com.cn

ABSTRACT

Metal ions have very important influence on the sorption behavior of phosphate on sediments. In this research, the overlying water and sediment from Dianchi Lake were took as the sorbate and sorbent, respectively, to investigate the effect of Ca^{2+} , Al^{3+} and Fe^{3+} on phosphate sorption on sediment. As the results showed, all these three metal ions can improve the sorption of phosphate, which in overlying water, on sediment. By contrast, the abilities of three metal ions to improve phosphate sorption on sediment were followed the order: $\text{Ca}^{2+} < \text{Al}^{3+} < \text{Fe}^{3+}$. This indicated that Fe^{3+} is of great effect for reducing the concentration of phosphate in overlying water.

KEYWORDS

Metal ion; Phosphate; Sediment and sorption.



INTRODUCTION

Phosphorus is one of the limiting factors of eutrophication, can be divided into endogenous and exogenous phosphorus. For lake in which the exogenous phosphorus is well-controlled, the endogenous phosphorus is an important cause of eutrophication^[1]. Sediment, is an important part of water environment, is considered as "sink" and "source" of phosphorus that can directly influence the eutrophication in a certain degree. Therefore, the sorption and desorption behaviors on sediment are important processes of migration, transformation and bioavailability of phosphorus^[2,3].

Phosphate is an important form of phosphorus. It was reported that the sorption-desorption behavior of phosphate on sediment was not only related with physicochemical properties of sediments, water natural conditions (pH, temperature) and hydraulic conditions^[4-6], but also with the metal ions which in overlying water^[7,8]. These metal ions can reduce the concentration of phosphate by forming precipitate with soluble phosphate^[9]. Therefore, studying the influence of metal ions on phosphate sorption is of great significance for predicting and controlling the eutrophication.

This research studied the influence of Ca^{2+} , Al^{3+} and Fe^{3+} on phosphate sorption on sediment in a simulated overlying water-sediment system of Dianchi Lake.

MATERIALS AND METHODS

Collection and pretreatment of samples

The overlying water and sediment used in this research were collected in Dianchi Lake far from industrial district. This area was located in Kunming, Yunnan province, China, with geographical coordinates of N 24°57'43.9", E 102°38'47.6" and altitude of 1891 m. The collected sediment samples were freeze-dried, ground, and sieved through a 2-mm sieve. Plant residues were picked out manually. The properties of these overlying water and sediment samples were list in TABLE 1.

TABLE 1 : Properties of overlying water and sediment

| pH | Overlying water | | | Sediment | |
|------|-------------------------|--------------------------|-----------------------|--------------------------|--------------------------------------|
| | Totle phosphorus (mg/L) | Soluble phosphate (mg/L) | Organic matter (g/kg) | Totle phosphorus (mg/kg) | Interstitial water phosphorus (mg/L) |
| 7.35 | 0.78 | 0.46 | 17.96 | 522.81 | 0.23 |

Instrument and reagent

The major experimental instruments include 725-ultraviolet spectrophotometer, ZD-8-oven controlled crystal oscillator, and pH electrode. K_2HPO_4 (GR) was used as the standard sample to measure the concentration of phosphate. All the sources of Ca^{2+} , Al^{3+} and Fe^{3+} were their chloride (AR). The overlying water was used as background liquid.

Research methods

In research the influence of Ca^{2+} on phosphate sorption on sediment, the sediment dry samples (2000 mg) were put in acid washed conical flask, then were mixed with Ca^{2+} (200 mL), which concentration was 0, 125, 250, 375 or 500 mg/L, respectively. After the conical flasks were capped, all of them were kept in dark and were shaken in an air-bath shaker at 25 °C for 24 h. After the equilibration, all of the conical flasks were centrifuged at 1000 r/min for 10 min and the supernatants were filtered by 0.45 μm filter membrane. The filtrates were collected to measure the concentration of phosphate by ultraviolet spectrophotometer (Mo-Sb Anti-spectrophotometer).

Research methods the influence of Al^{3+} and Fe^{3+} on phosphate sorption on sediment were the same as below, except the concentration of Al^{3+} was 0, 25, 50, 75 or 100 mg/L, respectively, and the concentration of Fe^{3+} was 0, 25, 50, 75 or 100 mg/L, respectively.

Data processing

The increased solid phase concentrations, ΔS_e (mg/kg), were calculated based on mass balance: $\Delta S_e = (C_e' - C_e) \cdot (V/W)$, where C_e' and C_e (mg/L) are equilibrium aqueous phase concentrations of control (without metal ions) and experimental group (with metal ions), respectively. V/W (L/kg) is the aqueous:solid ratio. Besides, C_0 (mg/L) is initially added concentrations of metal ions.

RESULTS AND DISCUSSION

Influence of Ca^{2+} on phosphate sorption

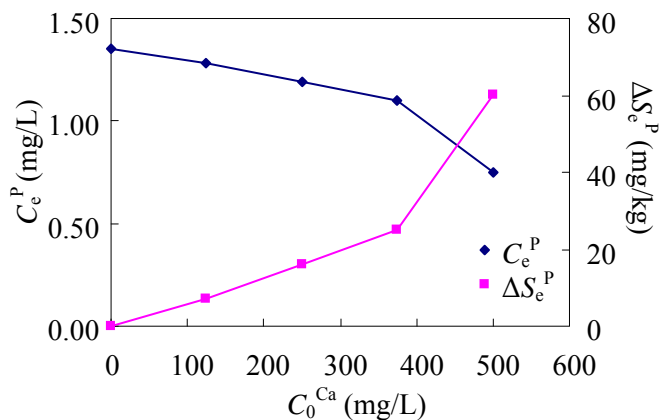


Figure 1 : Influence of Ca^{2+} on phosphate sorption on sediment

The concentration of phosphate in overlying water was 0.46 mg/L (TABLE 1). After mixed with sediment, equilibrium aqueous phase concentrations of phosphate rose to 1.35 mg/L (Figure 1). This was possible because the release of phosphate in equilibrium process. Ca^{2+} could promote phosphate sorption on sediment and reduce phosphate concentration in overlying water. In addition, with the increase of Ca^{2+} , the apparent sorption of phosphate on sediment was promoted as well. The influence of Ca^{2+} on phosphate sorption on sediment was attributed to three possible mechanisms: 1) Ca^{2+} precipitated phosphate^[10]; 2) phosphate was adsorbed by precipitate which generated by Ca^{2+} and B anion^[11]; 3) after Ca^{2+} has been adsorbed by sediment, phosphate combined with adsorbed Ca^{2+} by cation bridging^[12]. All these three cases could lead to the decreased phosphate concentration in overlying water and increased phosphate sorption on sediment.

Influence of Al^{3+} on phosphate sorption

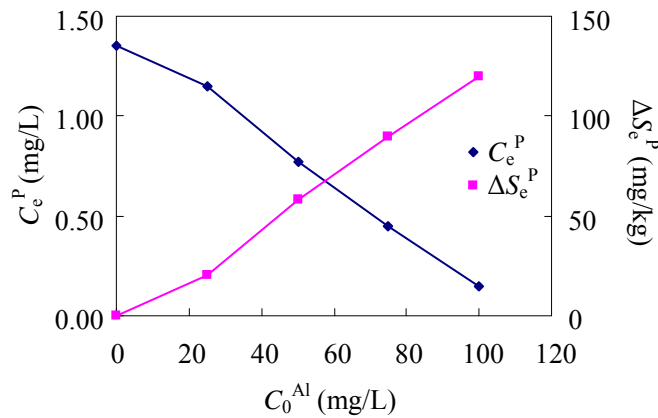


Figure 2 : Influence of Al^{3+} on phosphate sorption on sediment

Al^{3+} could also promote phosphate sorption on sediment and reduce phosphate concentration in overlying water. In addition, with the increase of Al^{3+} , the apparent sorption of phosphate on sediment was promoted as well (Figure 2). The above three possible mechanisms could account for the influence of Al^{3+} on phosphate sorption on sediment. Moreover, Al^{3+} could also stabilize internal phosphate, which included phosphate in interstitial water and adsorbed phosphate, in sediment in the form of aluminium phosphate. This promoted the sorption of phosphate on sediment^[13,14].

TABLE 2 : Solubility product constant and single-point sorption C_e^{P} and S_e^{P} of $\text{Ca}_3(\text{PO}_4)_2$, AlPO_4 and FePO_4 , respectively

| Phosphate | K_{sp} | C_e^{P} (mg/L) at C_0 =(mg/L) | | | S_e^{P} (mg/kg) at C_0 =(mg/L) | | |
|------------------|-----------------------|--|------|-------|---|-------|-------|
| | | 12.5 | 50.0 | 100.0 | 12.5 | 50.0 | 100.0 |
| Ca^{2+} | 1.0×10^{-25} | 1.36 | 1.38 | 1.41 | 0.7 | 2.8 | 5.6 |
| Al^{3+} | 5.8×10^{-19} | 1.2 | 0.8 | 0.2 | 15.0 | 60.0 | 120.0 |
| Fe^{3+} | 1.3×10^{-22} | 0.8 | 1.2 | 1.3 | 55.0 | 115.0 | 133.0 |

Comparing with the single-point sorption C_e^{P} and S_e^{P} (TABLE 2), it pointed out that Al^{3+} could promote more phosphate sorption on sediment than Ca^{2+} . This might be attributed to phosphate solubility product constant of different metal ions^[15]. The solubility product constant of AlPO_4 is greater than that of $\text{Ca}_3(\text{PO}_4)_2$. It illustrated that AlPO_4 is easier to precipitate than $\text{Ca}_3(\text{PO}_4)_2$. Therefore, Al^{3+} promoted more phosphate sorption on sediment than Ca^{2+} .

Influence of Fe^{3+} on phosphate sorption

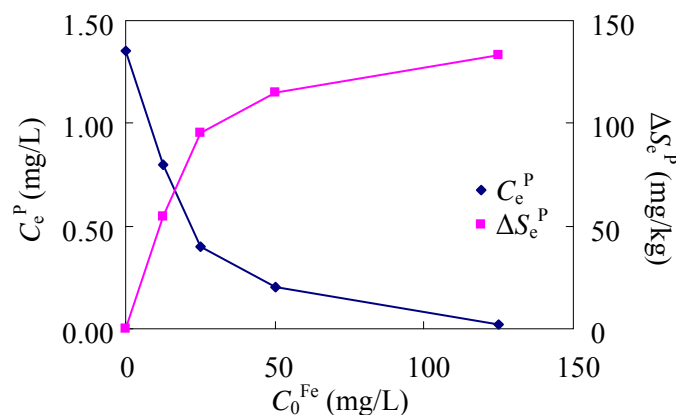


Figure 3 : Influence of Fe^{3+} on phosphate sorption on sediment

Fe^{3+} could also promote phosphate sorption on sediment and reduce phosphate concentration in overlying water. In addition, with the increase of Fe^{3+} , the apparent sorption of phosphate on sediment was promoted as well (Figure 3). Fe^{3+} could precipitate phosphate. Besides, all above four possible mechanisms could account for the influence of Fe^{3+} on phosphate sorption on sediment.

Comparing with Ca^{2+} and Al^{3+} , Fe^{3+} promoted the most phosphate sorption on sediment (TABLE 2). Although the solubility product constant of FePO_4 is greater than that of $\text{Ca}_3(\text{PO}_4)_2$, it is less than that of AlPO_4 . Therefore, the ability for forming precipitate may not be the main reason that Fe^{3+} promoted the most phosphate sorption on sediment. Fe^{3+} has great flocculation effect. Because the overlying water is slightly alkaline ($\text{pH}=7.35$), Fe^{3+} is easy to form $[\text{Fe}(\text{OH})_3]_x$ colloid. $[\text{Fe}(\text{OH})_3]_x$ colloid is positively charged, can adsorb negatively charged phosphate (including PO_4^{3-} , HPO_4^{2-} , or H_2PO_4^-). Moreover, $[\text{Fe}(\text{OH})_3]_x$ colloid can form a oxide film on sediment surface, then generate FeOOH-PO_4 complex with phosphate^[16]. These made Fe^{3+} promote more phosphate sorption on sediment.

CONCLUSION

The research result showed that Ca^{2+} , Al^{3+} and Fe^{3+} could promote phosphate sorption on sediment. In contrast, the promoted abilities of these three metal ions followed the order: $\text{Ca}^{2+} < \text{Al}^{3+} < \text{Fe}^{3+}$. The solubility product constant of $\text{Ca}_3(\text{PO}_4)_2$ is the smallest of these three phosphate. This was the possible reason for the weakest ability of Ca^{2+} to promote phosphate sorption. Fe^{3+} is easy to form $[\text{Fe}(\text{OH})_3]_x$ colloid, which can form a oxide film on sediment surface, then generate FeOOH-PO_4 complex with phosphate was the possible reason for the strongest ability of Fe^{3+} to promote phosphate sorption. This illustrated that in order to reduce phosphate concentration in overlying water of Dianchi Lake, Fe^{3+} could be best choice of these three metal ions. Besides, using chemical reagent method to reduce the phosphate concentration, the safe concentration of chemical reagent should be considered for preventing secondary pollution caused by the metal ions.

ACKNOWLEDGEMENTS

This research is funded by The demonstration of key technology and engineering to repair the river inflowing into lake of China (2012ZX07102-002).

REFERENCES

- [1] A.Kaiserli et al.; Phosphorus fractionation in lake sediments—Lakes Volvi and Koronia, N.Greece, *Chemosphere*, **46**, 1147-1155 (2002).
- [2] H.Pant, K.Reddy; Phosphorus sorption characteristics of estuarine sediments under different redox conditions, *Journal of Environmental Quality*, **30**, 1474-1480 (2001).
- [3] S.Kuo, E.Lotse; Kinetics of phosphate adsorption and desorption by lake sediments, *Soil Science Society of America Journal*, **38**, 50-54 (1974).
- [4] B.Singh, J.Jones; Phosphorus sorption isotherm for evaluating phosphorus requirements of lettuce at five temperature regimes, *Plant and Soil*, **46**, 31-44 (1977).
- [5] N.E.Detenbeck, P.L.Brezonik; Phosphorus sorption by sediments from a soft-water seepage lake. 2. Effects of pH and sediment composition, *Environmental science & technology*, **25**, 403-409 (1991).
- [6] B.Bar-Yosef et al.; Phosphorus adsorption by kaolinite and montmorillonite: I. Effect of time, ionic strength, and pH, *Soil Science Society of America Journal*, **52**, 1580-1585 (1988).
- [7] G.A.Barry et al.; Estimating sludge application rates to land based on heavy metal and phosphorus sorption characteristics of soil, *Water Research*, **29**, 2031-2034 (1995).
- [8] J.H.Bhadha et al.; Seasonal delivery of organic matter and metals to farm canals: effect on sediment phosphorus storage capacity, *Journal of Soils and Sediments*, 1-13 (2014).

- [9] G.Morse et al.; Review: phosphorus removal and recovery technologies, *Science of The Total Environment*, **212**, 69-81 (1998).
- [10] M.Jordan et al.; Transfecting mammalian cells: optimization of critical parameters affecting calcium-phosphate precipitate formation, *Nucleic acids research*, **24**, 596-601 (1996).
- [11] U.Berg et al.; Sediment capping in eutrophic lakes—efficiency of undisturbed calcite barriers to immobilize phosphorus, *Applied Geochemistry*, **19**, 1759-1771 (2004).
- [12] R.Parfitt; The availability of P from phosphate-goethite bridging complexes. Desorption and uptake by ryegrass, *Plant and Soil*, **53**, 55-65 (1979).
- [13] L.Lijklema; Interaction of orthophosphate with iron (III) and aluminum hydroxides, *Environmental science & technology*, **14**, 537-541 (1980).
- [14] J.Kopáček et al.; Aluminum control of phosphorus sorption by lake sediments, *Environmental science & technology*, **39**, 8784-8789 (2005).
- [15] J.Freeman, D.Rowell; The adsorption and precipitation of phosphate onto calcite, *Journal of Soil Science*, **32**, 75-84 (1981).
- [16] E.Roden, J.Edmonds; Phosphate mobilization in iron-rich anaerobic sediments: microbial Fe (III) oxide reduction versus iron-sulfide formation, *Archiv Für Hydrobiologie*, **139**, 347-378 (1997).