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Characterization and phosphorus removal of poly-silicic-ferric coagulant

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Abstract

An inorganic polymer, poly-silicic-ferric (PSF) coagulant was prepared by co-polymerization, and the hydrolysis products distribution of PSF was calculated from the pH changes during the hydrolysis process of PSF. The characterization of PSF and total phosphorus (TP) removal by PSF were studied in comparison with that of polyferric aluminum (PFA). The results revealed that PSF has more than 30% TP removal than PFA. The optimal metal/phosphorus molar ratio of TP removal by PSF is from 0.6 to 1.2 for the synthetic water and from 1 to 2 for the sewage water, respectively. PSF has higher TP removal at both neutral and higher pH sides from 7 to 12 for the synthetic water and from 7 to 13 for the sewage water, in comparison with PFA which has much higher pH side from 11 to 12 for the synthetic water and from 11 to 13 for the sewage water, respectively. PSF mainly removes TP by complexation or adsorption, in which $FePO_4$ precipitation contributes a little.

Keywords: Si; Fe; Phosphorus; Coagulant; Characterization; Mechanism

1. Introduction

Phosphate presented in wastewaters is a growth-nutrient for microorganism in water bodies. As a result of increased phosphorus concentration, an excessive growth of photosynthetic aquatic micro- and macroorganisms occurs and ultimately becomes one of the main causes of eutrophication [1, 2] (extraordinary growth of algae as a result of excess nutrients in water bodies) of rivers, lakes, and seas worldwide [3, 4]. Consequently, disposal of wastewaters produces a constant threat to dwindling fresh water on a global scale [5].

Before discharging wastewater into water bodies, removing phosphate is usually obligatory, even though in many cases it is not performed, which leads to major contamination on

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a worldwide level. Phosphate removal from wastewater has received considerable attention since the late 1960s [6, 7]. The wastewater treatment industry presently uses several methods to remove phosphorus [8, 9].

The aim of removing phosphorus is to convert the phosphorus ions in wastewater into a solid fraction [10]. This fraction can be an insoluble salt precipitate, a microbial mass in an activated sludge, or a plant biomass in constructed wetlands [11]. Phosphorus removal techniques fall into three major categories: (1) physical, (2) chemical, and (3) biological methods. Physical method has proved to be expensive [12]. Though biological method has been studied widely [13–16], phosphorus removal by biological removal techniques performed by microorganisms has a relatively low efficiency [8, 17]. Thus engineers developed the enhanced biological phosphorus removal (EBPR) approach which is an enhanced biological treatment [18–20]. EBPR is a major avenue for contemporary and future development of phosphorus removal with microorganisms, which perhaps will become as important as metal precipitation method that is widely employed at present. Today, the main commercial processes for removing phosphorus from wastewater effluents are chemical precipitation with iron, alum, or calcium [21–25]. Among them, calcium–phosphorus precipitation is common, mainly because of low cost and ease of handling, but solution pH value is a key factor influencing the precipitation process [26, 27]. Aluminum hydroxide, $Al(OH)_3$, is a strong adsorption agent for orthophosphate and condensed phosphate [11], but sludge produced from aluminum cannot be reused as a raw material for the fertilizer industry due to its possible cumulative toxicity [28, 29]. Iron-based compounds can effectively serve as coagulants for phosphorus removal [30, 31], in addition, iron was nontoxic to human or other oganisms [12], so it is important for iron-based coagulant to remove phosphorus [31].

In conjunction with normal chemical precipitants, polyelectrolyte additives for phosphorus removal are usually used as they improve floc aggregation [32]. Based on this aim, we produce poly-silicic-ferric (PSF) coagulant by combining iron positively charged and polysilicic (PS) acid negatively charged, and discuss the efficiency and the mechanism of removing phosphorus by characterization, hydrolysis experiments, and jar tests.

2. Experimental study

Polyferric aluminum (PFA, $w(Al_2O_3) = 6.76\%$, $w(Fe) = 0.6\%$) was provided by water treatment plant from Hunan province in China. Double-deionized water was used to make all solutions.

In the following work, the concentration unit of working solution of coagulants was $g.l^{-1}$, as Fe in PSF and Al in PFA.

2.1. Preparation of poly-silicic-ferric (PSF) coagulant

2.1.1. Preparation of polysilicic (PS) acid solution

Water glass (modulus = 3.1–3.4, $\rho = 1.36$ $kg.dm^{-3}$, $w(SiO_2) = 26\%$, industrial grade) was diluted to a concentration of 7.5% ($w(SiO_2)$) with double-deionized water. The 98 ml diluted water glass was added slowly into H_2SO_4 solution (20%, 8 ml, analytical grade) under magnetic stirring at 20 °C to obtain a PS solution, which was then aged for 2 h. The final pH of PS was 3.2.

2.1.2. Preparation of poly-silicic-ferric (PSF) coagulant

First, 35.21 g $FeSO_47H_2O$ (analytical grade) was dissolved in H_2SO_4 solution (60%, 42 ml, analytical grade) to obtain a $FeSO_4$ solution. The second step is to mix $FeSO_4$ solution and the PS solution under 40–60 °C stirring, and then immediately add 1.5 g $NaClO_3$ (analytical grade) and stir for 30 min, which is followed