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Enhancing phosphorus recovery by a new internal recycle seeding MAP reactor

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Abstract

Phosphorus is a depleting resource that needs recovery from wastewater streams. The magnesium ammonium phosphate (MAP) crystallization process could simultaneously recover ammonium nitrogen and phosphorus at equal molar basis to yield slow-release MAP fertilizer. However, the present MAP processes are not efficient in recovering phosphorus at low P concentrations. This work presented and tested the performance of a newly proposed MAP reactor, the internal recycle seeding reactor (IRSR) that comprised of a reaction zone and a settling zone connecting with an internal recirculation loop. Owing to the enhanced secondary nucleation rates of MAP crystals in reaction zone under controlled circumstance, the proposed IRSR recovered 78% of phosphorus from wastewater at a low level of 21.7 mg-P L^{-1}. The optimal operation parameters for the IRSR were investigated with synthetic wastewater and determined as that the Mg/PO_4^{3-}-P molar ratio was 1.3–1.5:1, THRT was up to or longer than 1.14 h, the seed concentration of reaction zone was 0.40–1.0 g L^{-1}. Further needs for the proposed IRSR strategies were also discussed.

Keywords: MAP; Internal recycle seeding reactor; Phosphorus recovery; Seed

1. Introduction

Phosphorus is a depleting resource (Steen, 1998). In addition, as a result of its consumption, it returns the environment as the waste or through wastewater, which has potential to cause eutrophication or blue green algal blooms of receiving waters. Thus, it is obligatory and necessary to remove and recover phosphorus from waste or wastewater in order to contribute toward sustainable development, alleviate the environmental pressure and meet the increasingly strict regulations for phosphorus discharge. Recovery and removal of phosphorus from wastewater streams can be achieved via various processes, such as metal precipitation, constructed wetland systems, biological nutrient removal (BNR) processes, enhanced biological phosphorus removal (EBPR) processes, MAP (magnesium ammonium phosphate) crystallization process, and others (de-Bashan and Bashan, 2004). Among these processes, the magnesium ammonium phosphate (MAP, mineralogically as struvite) crystallization has been regarded as a promising method, because it can simultaneously recover ammonium nitrogen and phosphorus at equal molar basis to yield slow-release MAP fertilizer (Li and Zhao, 2003).

Process parameters and mechanisms of MAP crystallization were conducted and summarized (Battistoni et al., 2002; Doyle and Parsons, 2002; Jaffer et al., 2002). Studies had been performed to realize effects of numerous process

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parameters on MAP performance, including pH (Ohlinger et al., 1998; Mijangos et al., 2004), reactant origins (Chimenos et al., 2003; Yang and Sun, 2004), molar ratios of Mg/N/P (Altinbas et al., 2002), temperature (Mijangos et al., 2004), the presence of foreign ions (Le Corre et al., 2005; Kabdaşli et al., 2006), and mixing energy (Ohlinger et al., 1999). MAP crystallization is applied to treat phosphorus or ammonium nitrogen laden wastewaters (Battistoni et al., 2002; Li and Zhao, 2002, 2003; Lee et al., 2003; Kim et al., 2004; Quintana et al., 2004; Tunay et al., 2004; Wu and Bishop, 2004) and separated human urine (Ban and Dave, 2004). Three types of batch reactors were adopted with sufficient phosphorus recovery: mechanically stirring reactor (MSR) (Stratful et al., 2004; Yoshino et al., 2003), air agitated fluidized bed reactor (AAFBR) (Jaffer et al., 2002; Le Corre et al., 2007a), and water agitated fluidized bed reactor (WAFBR) (Battistoni et al., 2000, 2001; Adnan et al., 2003). The configuration and operation of MSR is simple, but consumes considerable amount of mixing energy (Wu and Bishop, 2004). Struvite crystals can grow rapidly in the AAFBR and WAFBR, however, the corresponding energy demand is also high (Battistoni et al., 2005). Additionally, large MAP crystals thus formed are not only poorly fluidized in the reactors, but also reduce MAP recovery owing to low surface area (Shimamura et al., 2001). Suzuki et al. (2007) and Le Corre et al. (2007b) recently inserted stainless steel meshes in the upper section of AAFBR to reduce energy demand and to minimize fines remaining in solution, thereby enhancing phosphorus recovery. Shimamura et al. (2003) devised a two-tank reactor to keep MAP crystal size constant in the reaction tank and phosphorus recovery efficiency stable.

Difficulties were noted to operate these MAP reactors. Suzuki et al. (2007) and Le Corre et al. (2007b) demonstrated the quantity of struvite crystal needed in the reaction zone was hard to control. Suzuki et al. (2007) noted shortcut flow between reaction zone and precipitation zone in the reactor reduced recovery efficiency. Moreover, reactor proposed by Le Corre et al. (2007b) and Shimamura et al. (2003) required external recirculation loops to fluidize and recycle seed crystals, respectively. To overcome the mentioned difficulties, in this study, a new MAP reactor, namely, the internal recycle seeding reactor (IRSR), was proposed and its effect and operation performance in phosphorus recovery from wastewater were tested and determined, in order to provide a potential and practical reactor used in the future for phosphorus recovery from wastewater. Burns et al. (2003) and Adnan et al. (2004) claimed that crystal seeding strategy insignificantly affected the MAP reactor performance, but Wu and Bishop (2004), Lee et al. (2005) and Wang et al. (2006) reported seeding could enhance the MAP reaction rate, increased crystal size and improved crystal settleability. Thus, the other objective of this work is to investigate into whether crystal seeding affects the performance of the proposed IRSR.

2. Methods

2.1. Reactor design and preliminary test

The IRSR consisted of two concentric columns (Fig. 1), with an internal column of 0.35 L effective volume for reaction, and an external column of 2.5 L effective volume for crystal sedimentation. Seed were lifted continuously by air to reaction zone to contact with wastewater for forming new MAP crystals. Then the agglomerates were settled in the external settling zone. The crystal concentration, including primary and new MAP crystals in the reaction zone, could be controlled by adjusting the circulation flow rate and the quantity of crystals at the bottom, respectively or both. The circulation flow rate of air lift pipe depended on the flow rate of main air pipe, while the crystal quantity in crystal zone was kept by discharge amounts of crystal. Three sub air pipes fixed on the inner wall of the internal column in proportional spacing provided blending power to avoid potential shortcut.

All chemicals were in analytical reagent grade and were used without further purification. The synthetic wastewater was made by mixing tap water, NH_4Cl, and $Na_2HPO_4 \cdot 12H_2O$ salts, whose pH was adjusted to 9.2–9.7 using NaOH. The synthetic wastewater was settled for 8–10 h before use to minimize the effects of Ca^{2+}, Mg^{2+} and Fe^{3+} originated potentially from tap water by spontaneous precipitation at base condition. The magnesium solution was prepared using $MgCl \cdot 6H_2$ salt due to its superiority in MAP crystallization (Le and Li, 2006). Both magnesium solution and synthetic wastewater were injected by peristaltic pump (YZ1515w, Baoding Longer

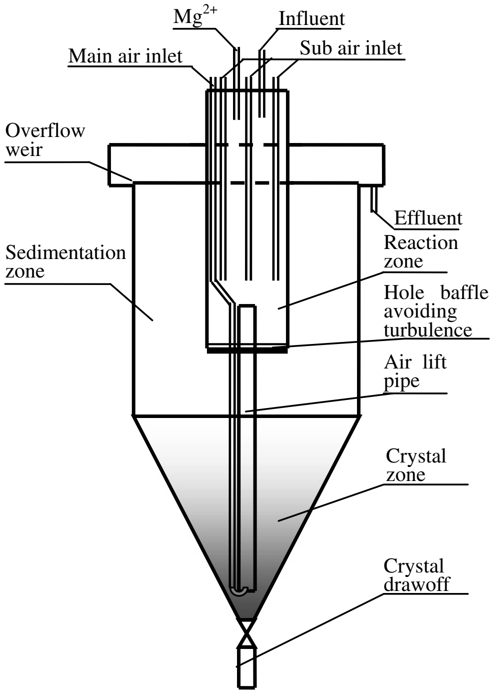

Fig. 1. Configuration of IRSR.