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Effect of organic matter on phosphorus recovery from sewage sludge subjected to microwave hybrid pretreatment

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A B S T R A C T

Microwave (MW) hybrid processes are able to disrupt the flocculent structure of complex waste activated sludge, and help promote the recovery of phosphorus as struvite. In this study, to optimize struvite yield, (1) the characteristics of matter released in MW-hybrid treatments were compared, including MW, MW-acid, MW-alkali, MW-H_2O_2, and MW-H_2O_2-alkali. The results showed that selective release of carbon, nitrogen, phosphorus, Ca^{2+}, and Mg^{2+} achieved by sludge pretreatment using MW-hybrid processes. MW-H_2O_2 is the recommended sludge pretreatment process for phosphorus recovery in the form of struvite. The ratio of Mg^{2+}:NH_4^+-N:PO_4^{3-}-P was 1.2:2.9:1 in the supernatant. (2) To clarify the effects of organic matter on struvite recovery, the composition and molecular weight distribution of organic matters were analyzed. Low molecular weight COD was found to facilitate the removal rate of NH_4^+-N and PO_4^{3}-P *via* crystallization, and the amorphous struvite crystals (<1 kDa) from the filtered solutions had high purity. Therefore, the present study reveals the necessity of taking into consideration the interference effect of high molecular weight organic matters during struvite crystallization from sewage sludge.

Introduction

The amount of sludge produced by biological sewage treatment plants around the world has been constantly increasing. Thus, the treatment and disposal of excess sewage sludge are becoming a challenge for wastewater treatment plants (WWTPs). The challenges have been amplified by current legal constraints, land shortages, rising costs, and public sensitivity. For the purpose of preventing eutrophication, biological nutrient removal (BNR) technologies are used worldwide, wherein phosphorus is locked into the structure and polymers of the sewage sludge.

Phosphate-based fertilizers have helped spur agricultural gains over the past century. However, global phosphorus resources have been rapidly depleted (Gilbert, 2009), and prices continue to soar as this commodity shortage worsens. The phosphorus content of sludge, due to the application of BNR processes, ranges between 4% and 9% (Barlindhaug and Odegaard, 1996). Sewage and sludge are the main channels for phosphorus loss to the environment. Therefore, phosphate recovery from sewage sludge could provide a key solution to the phosphate shortage.

One of the main obstacles for sludge reduction and resource recovery is that the complex organic materials that

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make up cell walls and membranes protect intracellular materials from biodegradation. In recent studies, sludge pretreatment processes have been of great interest for the release of organic matter, nitrogen, and phosphorus, in order to enhance the anaerobic digestibility of waste activated sludge (WAS) for biogas production. These pretreatment methods also aid the recovery of phosphorus in appropriate forms from WAS (Wong et al., 2006b).

As a promising sludge pretreatment technology, microwave (MW) hybrid pre-treatment is able to disrupt the flocculent structure of complex waste activated sludge (Xiao et al., 2012), which is a key issue for most sludge 3R (reduce, reuse, and recycle) technologies.

MW and hybrid sludge pretreatment techniques (*e.g.*, MW with pressure) have gained popularity due to the ease of their control and high efficiency. Methods such as MW-acid and MW-alkali (Cheng et al., 2009), MW-H_2O_2 (Wong et al., 2006a), and MW coupled with an advanced oxidation process (AOP) have been used to improve sludge dissolution and disinfection. Current studies on sludge pretreatment for sludge reduction have mainly addressed the issues of particle size distribution and the release efficiencies of carbon, nitrogen, and phosphorus (Wang et al., 2015).

Struvite precipitation is an ideal phosphorus recovery technique for sludge because struvite (magnesium ammonium phosphate) is an excellent slow-release fertilizer (Ye et al., 2014). Phosphorus recovery in the form of struvite has earned recognition owing to its technical feasibility and economic viability (Guadie et al., 2014). Sludge pretreatment is designed to maximize the release of organic release simultaneous with NH_4^+-N, PO_4^{3-}-P, and Mg^{2+}, which could reduce the chemical costs of struvite recovery.

The main factors governing struvite crystallization are the initial reaction parameters (*e.g.*, pH, ionic strength, ionic ratio) (Doyle and Parsons, 2002), and the operating parameters (*e.g.*, initial temperature, reaction time, stirring intensity) (Stratful et al., 2001). Although many methods (*e.g.*, mechanical, heat, chemical, and hybrid technologies) have been applied to rupture sludge particles and recover phosphorus (Bi et al., 2014), few studies have considered the effect of organic matter on this process. In a previous study, it was found that organic matters with molecular weight (MWt) < 8 kDa acted as a trigger for recover struvite in cat urine (Matsumoto and Funaba, 2008). These authors proposed that a substance of the proper MWt could enhance struvite recovery after sludge pretreatment. However, for pretreated sludge, there are few studies focused on the effects of organic matter on struvite crystallization during phosphorus recovery. Knowledge about the molecular weight distribution (MWtD) of treated sludge is required for its further utilization, but this has not received particular attention. Additionally, the effect of the organic-particle size distribution on the recovery of phosphorus as struvite after WAS pretreatment is still unknown. Furthermore, to date, there has been no research focused on the effect of MW-hybrid sludge treatments on the evaluation of organic matter release characteristics, such as their influence on the MWtD of the organics, or subsequent effects on struvite recovery from sludge.

This study had two goals: The first goal was to investigate the characteristics of sludge disintegration that resulted from MW-hybrid treatments (*i.e.*, MW, MW-acid, MW-alkali, MW-H_2O_2, and MW-H_2O_2-alkali). These characteristics would first be evaluated in terms of the release of carbon, nitrogen, phosphorus, calcium, and magnesium. They would also be evaluated in terms of the MWtD of the proteins, sugars, and other organics released. The second goal was to investigate the effects of the MWtD of the organic matter in the pretreated sludge on struvite crystallization, to optimize struvite yield and purity.

1. Materials and methods

1.1. Sludge pretreatment by MW-hybrid processes

Sludge was collected at a wastewater treatment station in Beijing, passed through a 60-mesh screen, then adjusted to a concentration of about 20 g/L of mixed liquor suspended solids (MLSS) for batch tests. The WAS characteristics were as follows: MLSS was 18.96 ± 0.17 g/L, mixed liquor volatile suspended solids (MLVSS) 11.43 ± 0.11 g/L, total chemical oxygen demand (TCOD) 19.21 ± 0.12 g/L, total phosphorus (TP) 0.58 ± 0.05 g/L, total nitrogen (TN) 0.80 ± 0.02 g/L, and pH was 7.29 ± 0.03.

The operational parameters used for sludge pretreatment with the MW-hybrid processes are listed in Table 1 (Wang et al., 2015). One-liter concentrated sludge samples (20 g/L) were treated using MW irradiation. Details of the microwave oven (2450 GHz, 1000 W; Julong, China) were described previously (Wang et al., 2009).

1.2. Molecular weight distribution of organic matter in the supernatant

The organic matter in the sludge supernatant mainly consisted of proteins, sugars, and organic acids after microwave pretreatment (Mehdizadeh et al., 2013). The MWtD of the organic matter is influenced by the types of pretreatment and by the operation parameters. The filtration method successfully separated the organic matter for examination of

Table 1 – Operational parameters of sludge pretreatment by microwave hybrid processes.

Processes	Methods of sludge pretreatment
MW	Sludge was heated directly to 100°C with microwave (MW) irradiation.
MW-acid	The sludge pH was adjusted to 2.5 using a 5.0 mol/L HCl solution, and then treated with MW.
MW-alkali	The sludge pH was adjusted to 10.0 using a 5.0 mol/L NaOH solution, and then treated with MW.
MW-H_2O_2	The sludge was heated to 80°C with MW irradiation, then H_2O_2 was added at a ratio of H_2O_2:MLSS [a] = 0.2, with continued heating to 100°C by MW irradiation.
MW-alkali-H_2O_2	The sludge pH was adjusted to 10.0 using a 5.0 N NaOH solution, and then treated as with the MW-H_2O_2 treatment.

[a] Mixed liquor suspended solids; Source: Wang et al., 2015.