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Evaluation of natural organic matter release from alum sludge reuse in wastewater treatment and its role in P adsorption

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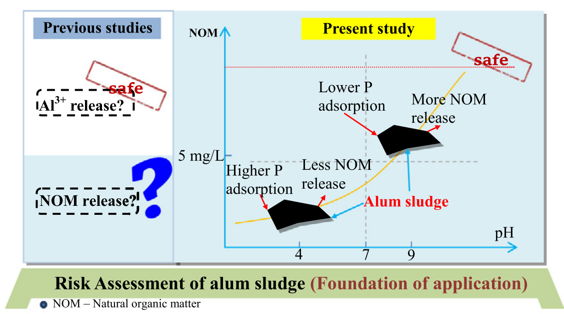
HIGHLIGHTS

- Alkaline condition, fine size of alum sludge and P adsorption could induce more NOM leakage.
- NOM has particularly strong positive relation with P adsorbed.
- NOM was believed to be an important replacement for P adsorption in ligand exchange process.
- Alum sludge has a function of pH neutralization.
- Overall, NOM release was not a big concern.

GRAPHICAL ABSTRACT



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ABSTRACT

Risks evaluation of alum sludge reuse is the first step to promote its popularization in wastewater treatment engineering, such as alum sludge-based constructed wetland. The present study, for the first time, is focusing on evaluating the concern of natural organic matter (NOM) leakage from the alum sludge. A series of lab-scale trials including static tests, column tests and sequencing batch reactor (SBR) trials were designed and conducted to assess the potential NOM release from the alum sludge and its behavior on the effect of phosphorus adsorption. The results have demonstrated that alkaline condition, fine particle size of alum sludge and P adsorption could induce more NOM leakage where the quantity of leakage has particularly strong positive relation with P adsorbed. NOM was believed to be an important replacement for P adsorption in ligand exchange process. Moreover, alum sludge has the function of pH neutralization via ligand exchange between OH^- and NOM, which could benefit to wastewater treatment, such as nitrification. Overall, the NOM release was not a big concern.

1. Introduction

Water treatment residuals (WTRs), in terms of alum sludge and/or ferric sludge, are inevitable by-product in water treatment processes. Due to their increased production caused by the escalating population and thereby the increasing demand to drinking water, their disposal becomes a concern and more economically sustainable and environment-friendly management is desirable in the future. Indeed, WTRs have been on trial for reuse and identified as the valuable resource [1,2] for versatile application. Several trials have recently been conducted to focus on the use of WTRs to immobilize phosphorus (P) in co-conditioning and dewatering with sewage sludge [3,4] and in constructed wetland as main substrate for enhanced P removal [5,6]. These valuable trials have enlightened novel pathways to turn the WTRs from a “waste” to useful material for wastewater treatment and have attracted much attention on further study of wide range reuse as WTRs are characterized as a reliable adsorbent to P and other pollutants [7,8].

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Noteworthy, the reuse of WTRs is currently with the assumption that WTRs are non-hazardous under current legislation [9]. However their future status will depend on future legislative reviews and possible emerging pollutants inside the WTRs. Even though the WTRs are considered safe in most conditions, some concerns also appeared, such as the possible disintegration of polymers [10], release of Al^{3+} [2], leakage of heavy metals etc. (Fig. 1). Actually, studies have been conducted to investigate the problem of Al^{3+} leakage from alum sludge as the increase of Al^{3+} content in water bodies could influence the lives or even humans' health. As demonstrated by the studies [11,12], Al^{3+} release would not likely create any toxic problem with the soil pH above 5 in land and agricultural applications. However, there is still a lack of systematic analysis and study about the potential toxicity of WTRs in their reuse due to variance in different conditions and influencing factors. For instance, the Al^{3+} release related to alum sludge utilization in land and wastewater could be different as alum sludge exposing to atmosphere will crystalize more easily than submerged in water as crystallization is a factor influencing the Al^{3+} soluble degree [13].

A group in University College Dublin, Ireland, firstly proposed the idea to reuse alum sludge as matrix in constructed wetland to treat piggery wastewater [5] and thoroughly evaluated the risk of Al^{3+} release from the alum sludge reuse. The Al^{3+} release was carefully monitored in both lab- and pilot-scale reactors for a long-term [14]. Both the results showed that the soluble Al^{3+} in the effluent ranged from 0.03 to 0.11 mg/L in lab-scale reactor and 0.02–0.06 mg/L in field-scale reactor. The Al^{3+} leakage along the whole running period was always below regulatory drinking water limitation. Moreover, the P adsorption by alum sludge did not increase the release of Al^{3+} but mitigated its leakage. Therefore, Al^{3+} leakage should not be a big concern in the reuse of alum sludge.

However, there is still a concern on the probable leakage of natural organic matter (NOM) from alum sludge reuse. As analyzed in the previous work, alum-sludge in Ireland is mainly composed of aluminum (30–40% in mass) and natural organic matter (NOM, 10–20% in mass). The average amount of NOM in alum-sludge is 100–200 mg-C/g DAS (dry alum sludge) [8]. As illustrated in the literature [15], organics contained in alum sludge is usually humic substance which is entrapped into sludge by coagulation process induced by aluminum salts [15]. Compared with concern of Al^{3+} leakage, NOM would be more apt to release as NOM carries same negative charge with other competitive ions in wastewater. Moreover, humic substance is hardly biodegradable organics in wastewater treatment series and they will enter the surface water directly once released. Although the direct toxicity of NOM is not significant, the probable by-product could be more hazardous. Disinfection by-products (DPBs) which could present health risk to humans are mainly derived from NOMs [16–18]. With the context of increasing NOM problem [19], the organic from wastewater treatment should be carefully reduced and monitored.

Nevertheless, few studies have been conducted to systematically assess the risk of alum sludge utilization in wastewater treatment. This may be one of the reasons impeding the popularity of alum sludge utilization due to lack of risk information thereby lack of regulation or guidelines. The current study was designed to evaluate the degree and influencing factors of NOM release from alum sludge when it was utilized to enhance P removal in wastewater treatment processes. A series of batch tests and column tests were conducted to explore the NOM release from alum sludge qualitatively and quantitatively. In addition, a sequencing batch reactor (SBR) embedded with an alum sludge column was also examined for the possible NOM release. It is believed that the present study will undoubtedly bridge the gap between alum sludge utilization and the concern in lack of risk assessment and accordingly the proper regulation and guidelines for alum sludge reuse.

2. Experimental setup

2.1. Dynamic column test for TOC leakage

Laboratory scale systems were assembled with four identical polyethylene columns (height-30 cm; diameter-7.5 cm) as presented in Fig. 2a. The columns were filled with dewatered alum sludge in different particle size as noted in Table 1. The alum sludge was collected from an industrial filter press of the sludge dewatering unit of a Water Treatment Works in Southwest Dublin, Ireland, where aluminum sulfate is used as coagulant. The average mass percentages of aluminum and NOM in dried alum sludge sample are 29.7 ± 13.3% and 10.5 ± 3.4%, respectively. Synthetic influent with different initial pH (simulating the pH range of most wastewaters, such as landfill leachate with pH range 4.9–9.5) and P concentrations was prepared as described in Table 2 and was introduced into the columns from their bottom by peristaltic pumps while effluent overflowed from the top.

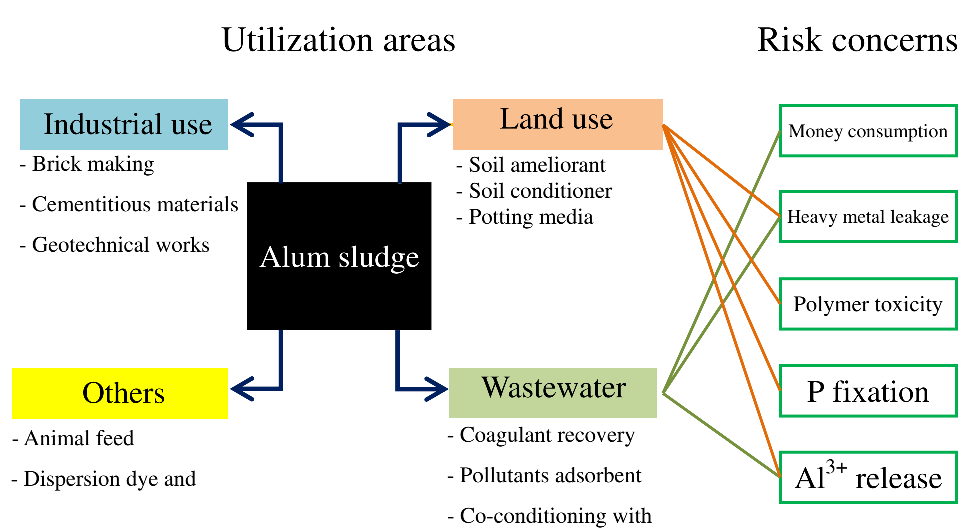

Fig. 1. Reuse and utilization of alum sludge with corresponding concerns.