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Review

Insight into chemical phosphate recovery from municipal wastewater

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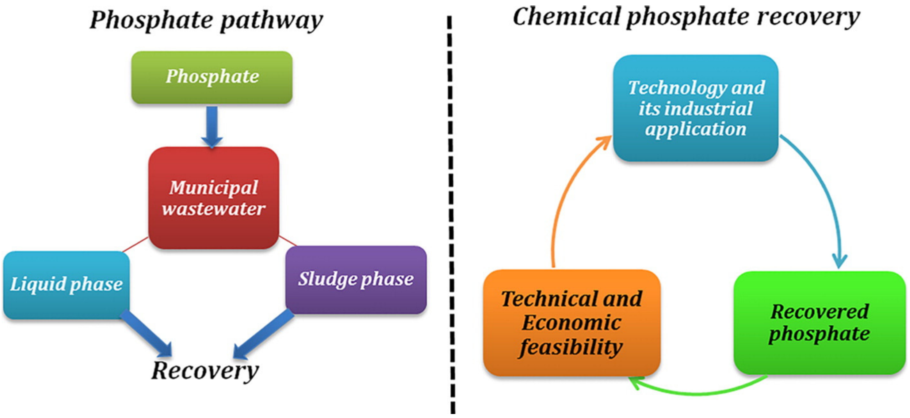
HIGHLIGHTS

- Chemical phosphate recovery from sewage in liquid and sludge phases was reviewed.
- Chemical process can stably achieve high efficiency of phosphate recovery.
- Recovering phosphate from the liquid phase is simpler and more economical.

GRAPHICAL ABSTRACT



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ABSTRACT

Phosphate plays an irreplaceable role in the production of fertilizers. However, its finite availability may not be enough to satisfy increasing demands for the fertilizer production worldwide. In this scenario, phosphate recovery can effectively alleviate this problem. Municipal wastewater has received high priority to recover phosphate because its quantity is considerable. Therefore, phosphate recovery from municipal wastewater can bring many benefits such as relieving the burden of increasing production of fertilizers and reduction in occurrence of eutrophication caused by the excessive concentration of phosphate in the released effluent. The chemical processes are the most widely applied in phosphate recovery in municipal wastewater treatment because they are highly stable and efficient, and simple to operate. This paper compares chemical technologies for phosphate recovery from municipal wastewater. As phosphate in the influent is transferred to the liquid and sludge phases, a technical overview of chemical phosphate recovery in both phases is presented with reference to mechanism, efficiency and the main governing parameters. Moreover, an analysis on their applications at plant-scale is also presented. The properties of recovered phosphate and its impact on crops and plants are also assessed with a discussion on the economic feasibility of the technologies.

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1. Introduction

Phosphorus as a nutrient is essential to biological growth (Jalali and Jalali, 2016; Selbig, 2016; Thitanuwat et al., 2016). However, a high level of phosphate in the aquatic environment can lead to excessive proliferation of blue-green algae, for which dissolved oxygen will be largely consumed and fish and other aquatic life will die. This phenomenon is called eutrophication and it can endanger human life (Lu et al., 2016; Stapanian et al., 2016; Zoboli et al., 2016). To reduce the level of eutrophication, the maximum allowable concentration of P in effluent should decrease from 1 to 2 to 0.1 mg·P/L in municipal wastewater treatment, according to the Water Framework Directive in Europe (Shepherd et al., 2016) while the P concentration is required to be <0.025 mg·P/L in most aquatic environments. The latter measurement is based on Australian and New Zealand water quality guidelines (Anzecc, 2000). Since the world's population is increasing, more production of food and fertilizers is needed (van der Salm et al., 2016; Wu et al., 2016). However, the natural supplies of phosphate rock are non-renewable and it is predicted that deposits will be exhausted in 30–300 years (Mew, 2016; Reijnders, 2014); no material can substitute for the role of P in the production of fertilizers (TU DARMSTADT, 2007; Matsubae et al., 2016).

Normally, the objective of wastewater treatment is to remove phosphate rather than recover. However, researchers has increasingly recognized the importance of phosphate recovery from wastewater (Ahmed et al., 2015; Kumar and Pal, 2015; Nieminen, 2010) as wastewater provides rich sources for phosphate recovery (TNN, 2011). Recovering phosphate from wastewater can eliminate eutrophication to some extent and produce fertilizers as a supplementary source. Furthermore, the problem of global warming can also be alleviated through phosphate recovery (Bradford-Hartke et al., 2015). Some wastewater resources such as livestock wastes and manure have high concentrations of phosphate (Nancharaiah et al., 2016; Tao et al., 2016) while the amounts of such resources are limited. In comparison to them, municipal wastewater has the greatest potential for phosphate recovery (Mehta et al., 2015) because it has high quantities despite containing small concentrations of phosphate (Zhou et al., 2016). Specifically, it was reported that municipal wastewater flows contain rich phosphorus with about 60,000–70,000 t P/a in Germany (Adam, 2011). Hence, municipal wastewater is prioritized to recover phosphate.

In conventional municipal wastewater treatment, Tarayre et al. (2016) reported that approximately 90% of incoming P-load is concentrated in the sewage sludge. In this scenario, 11% of total P-load is incorporated into the sewage sludge through primary settlement while another 28% is incorporated into biomass and removed with the discharge of surplus sludge (Cornel and Schaum, 2009). Thus, the remaining 50% of incoming P load can be removed through other processes (e.g. adsorption and chemical precipitation). Consequently, phosphate in municipal wastewater treatment can be divided into liquid and sludge phases, and both of them can potentially recover phosphate (Nguyen et al., 2016).

Four potential aspects of traditional sewage treatment can be utilized for phosphate recovery (Cornel and Schaum, 2009). As shown in Fig. 1, the liquid phase for phosphate recovery is sludge liquor (A) while the dewatered sewage sludge (1) and ash (2) are considered to constitute the sludge phase for the phosphate recovery (Bourioug et al., 2015; Egle et al., 2016; Li et al., 2016b). In addition, the sludge liquor is returned to the influent in the municipal wastewater treatment so as the P recovery from the sludge liquor can decrease the load of P by up to 20% (Evans, 2007). Through the incineration of sewage sludge (SS), sewage sludge ash (SSA) is achieved with the simultaneous removal of organic matter. In this process, although mercury is removed in its gaseous form because of its low boiling point, most of the heavy metals are enriched in SSA (Lederer and Rechberger, 2010). SS and SSA previously have been applied to agriculture as a fertilizer due to their high amounts of phosphate (Gong et al., 2015; Sartorius et al., 2011; Zhang et al., 2002). However, their application has been forbidden in some European countries such as Switzerland due to the fact they consist of pathogens, toxic matter and heavy metals (Schoumans et al., 2015). Compared to SS, SSA exhibits better plant availability of phosphate as a raw material for the production of fertilizers as no organic matter is retained in it. It is worth mentioning that the incineration process can only be utilized for SS which contains over 25% of dry solids and conducted in a fluidised sand bed reactor. The reactor is exposed to 800–900 °C with enough oxygen (Zhang et al., 2013) and this temperature range can make P thermally stable and non-volatile. Following the incineration, all the water in SS can be vaporized with the simultaneous removal of organic matter including organic pollutants in their gaseous form such as CO_2 and NO_x, resulting in the phosphate enrichment in SSA. However, the loss of carbon and nitrogen may also reduce the potential value of SSA while being applied as a supplementary source for fertilizer production.

The chemical phosphate recovery from municipal wastewater has been used widely because of its high stability and efficiency (Verstraete et al., 2009). The current state of the main chemical phosphate recovery techniques in municipal wastewater treatment are summarized in Table 1.