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Water treatment sludge for phosphate removal from the effluent of UASB reactor treating municipal wastewater

*Abhilash T. Nair**, *M. Mansoor Ahammed*

Civil Engineering Department, S.V. National Institute of Technology, Surat 395 007, India

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ABSTRACT

Aluminium-based water treatment sludge was used as a coagulant for removing/recovering phosphate from the effluent of upflow anaerobic sludge blanket (UASB) reactor treating municipal wastewater. The effect of three variables, namely sludge dose, initial pH and fresh coagulant (poly-aluminium chloride, PACl) dose was studied using response surface methodology. About 87% phosphate removal could be obtained at the optimum conditions of sludge dose 13.8 g/L, initial pH 6, and fresh PACl dose 5.8 mg Al/L. In order to achieve a similar phosphate removal, a dose in the range of 30–40 mg Al/L of fresh PACl was required. The results suggest that water treatment sludge can be reused as a coagulant for post-treatment of UASB reactor effluent treating municipal wastewater and can be considered as a promising alternative for removing phosphate which can substantially reduce the consumption of fresh PACl. The sludge generated during this process could potentially be used in land application which results in recycling of phosphate.

1. Introduction

Large quantities of drinking-water treatment sludge (WTS) are produced in most water treatment plants processing surface water. In developing countries, WTS is usually disposed of into receiving streams or sanitary sewers while in developed countries it is finally disposed of into landfill after treatments such as sludge lagooning, mechanical dewatering and thickening (Babatunde and Zhao, 2007; Makris and O'Connor, 2007). However, recent studies have showed that disposal of WTS in the water bodies can induce toxic effect to aquatic life (Muisa et al., 2011). With the raising environmental concerns, it is likely that there will be more stringent regulations on their disposal in most of the countries. Increasing environmental restraints along with increasing disposal cost associated with WTS have necessitated research on WTS reuse in beneficial ways (Ippolito et al., 2011).

The upflow anaerobic sludge blanket (UASB) reactors have emerged as one of the most commonly used methods for the treatment of municipal wastewater especially in tropical countries. Low capital investment, less land and energy requirements, less sludge generation, low maintenance cost and the potential to generate biogas have popularised the UASB process in tropical countries (Chernicharo, 2006; Khan et al., 2011). However, post-treatment of UASB reactor effluent is necessary to meet the discharge standards especially in terms of pathogens and nutrients (Chernicharo, 2006; Khan et al., 2011). Little phosphorus removal is achieved in UASB reactors as organic phosphorus is hydrolysed to phosphates which in turn are released in the effluent (Khan et al., 2011). Phosphorus discharge causes eutrophication in surface water bodies (Wang and Pei, 2013). Therefore, post-treatment of UASB reactor effluents to remove phosphorus is necessary to comply with environmental regulations.

* *Corresponding author*. Tel.: +91 9574280439.
E-mail addresses: nairabhilast@gmail.com (A.T. Nair), mansoorahammed@gmail.com (M.M. Ahammed).
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Table 1 – Different post-treatment techniques for recovering phosphorus from UASB reactor effluent.

Post-treatment method	Phosphorus removal (%)	References
Polishing ponds	28	von Sperling and Mascarenhas (2005)
Dissolved air floatation (DAF) with $FeCl_3$ and anionic polymers as coagulant	86	Reali et al. (2001)
Sequential batch reactors (SBR)	65–90	Callado and Foresti (2001), Moawad et al. (2009)
Constructed wetlands	90	de Sousa et al. (2001)
Duckweed pond system	88.5	Mohapatra et al. (2012)

Different post-treatment options studied/employed for phosphorus removal from UASB reactor effluent are presented in Table 1. Most of the processes gave high phosphorus removal but are not sustainable due to high energy cost involved, complicated process and high sludge volume generated. It is, therefore, desirable to develop cost-effective processes for phosphorus removal from UASB effluents. In fact, presence of phosphates in UASB reactor effluent gives the opportunity to develop processes to recover it.

Phosphate adsorption onto WTS has recently been studied. High affinity of amorphous Al and Fe present in WTS for phosphorus along with large surface area of WTS makes WTS a potential adsorbent for phosphorus (Oliver et al., 2011; Wang and Pei, 2013; Yang et al., 2006). WTS has been used as adsorbent for phosphorus removal from sewage (Babatunde et al., 2008), agricultural wastewater (Zhao et al., 2009), storm water runoff (O'Neill and Davis, 2012), aquaculture processing water (Mortula and Gagnon, 2007) and supernatant of the sludge thickening process and anaerobically digested sludge (Yang et al., 2009). No studies have been reported in the literature on the use of water treatment sludge as a coagulant for phosphate removal from the effluent of UASB reactor treating municipal wastewater.

Traditional optimisation methods vary only one factor at a time which makes them time and resource consuming. Also, true optimum conditions are not obtained due to the inability to consider the interactions among the factors (Myers et al., 2009; Nair et al., 2014). In response surface methodology (RSM), several variables are tested simultaneously at different level combinations with minimum experimentation which helps the researchers to incorporate the interaction effects amongst the factors along with the individual effects of the factors and help to reach the true optimum conditions (Myers et al., 2009).

In the present study the potential of polyaluminium chloride (PACl)-based water treatment sludge as a low-cost coagulant was investigated as a sustainable approach to remove phosphorus from the effluent of UASB reactor treating municipal wastewater. Wet sludge as obtained from water treatment plant was used in this study. RSM was used to optimise the process parameters that included sludge dose, initial wastewater pH and fresh PACl dose.

2. Materials and methods

2.1. Materials

Aluminium-based WTS was obtained from the clariflocculator of the Katargam Water Treatment Plant (WTP) at Surat, India. Al-based WTS was produced in WTP upon addition of polyaluminium chloride (PACl) as a coagulant to treat raw water from Tapi River. The UASB reactor effluent was collected from the municipal wastewater treatment plant located at Bamroli, Surat, India. Both the sludge samples and UASB reactor effluent, collected in 20 L plastic containers, were immediately transported to the Environmental Engineering Laboratory of S.V. National Institute of Technology, Surat, India. Characterisation of samples was carried out in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA/AWWA/WEF, 1998). The characteristics of WTS used in this study are presented in Table 2.

Table 2 – Physico-chemical characteristics of water treatment sludge.

Parameter	Value
pH	6.3
Solid content (%)	5.2
VSS/SS	0.20
Al (mg/g dry sludge)	104.37
Fe (mg/g dry sludge)	37.14
Ca (mg/g dry sludge)	17.11
Mg (mg/g dry sludge)	8.42
Si (mg/g dry sludge)	4.34

2.2. Experimental design and evaluation

Design of experiments (DoE) is a structured and systematic method of experimentation applied to establish the interactions between factors affecting the response and to derive an optimum condition (Myers et al., 2009). Box–Behnken design (BBD), a standard design of DoE, with response surface methodology was used to estimate main effects, interaction effects and quadratic effects of three independent variables viz. WTS dose, initial wastewater pH and fresh PACl dose on phosphate removal. Table 3 shows the independent variables along with their coded and actual values. Experimental range for WTS dose and PACl dose were selected based on the results from the preliminary experimentation reported in (Nair and Ahammed, 2015). A pH range of 6–9 was used in the study in order to reduce chemical consumption during coagulation and subsequent neutralisation before disposal of treated effluent. Further, high acidic or alkaline pH causes resolubility of metals from WTS (Ishikawa et al., 2007). The experimental design matrix for BBD is presented in Table 4. The experimental

Table 3 – Experimental range and levels of the independent variables.

Variables	Factors	Coded factor levels		
		−1	0	+1
WTS dose (g/L)	x_1	5	10	15
pH	x_2	6	7.5	9
Fresh PACl dose (mg Al/L)	x_3	0	7.5	15