Journal of Cleaner Production xxx (2013) 1–10

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

The reuse of water treatment sludge as a coagulant for post-treatment of UASB reactor treating urban wastewater

Abhilash T. Nair, M. Mansoor Ahammed*

Civil Engineering Department, S V National Institute of Technology, Surat 395007, India

ARTICLE INFO

Article history:
Received 28 September 2013
Received in revised form
21 November 2013
Accepted 13 December 2013
Available online xxx

Keywords:
Water treatment sludge
Sludge reuse
Coagulation
UASB reactor
Urban wastewater treatment
Response surface methodology

ABSTRACT

The feasibility of reusing polyaluminium chloride-based water treatment sludge as a coagulant for the post-treatment of upflow anaerobic sludge blanket (UASB) reactor treating urban wastewater was assessed. Response surface methodology with Box-Behnken design was employed to optimise three variables affecting coagulation/flocculation process namely sludge dose, initial pH and fresh coagulant dose. Results of the modelling study gave the following optimum conditions: sludge dose 15 g/L, initial pH 9 and fresh coagulant dose 4.2 mg Al/L; and predicted 72% COD removal and 88% turbidity removal. Confirmative experiments at the optimum conditions gave COD and turbidity removals of 74% and 89%, respectively, which were in close agreement with the predicted values. Further, at optimum conditions high removals of phosphate (79%), suspended solids (84%), BOD (78%) and total coliforms (99.7%) were obtained. The experiments also showed that a combination of water treatment sludge with fresh coagulant would give a substantially higher contaminant removal compared to the removals obtained by fresh coagulant alone. The study presents a novel reuse alternative for water treatment sludge and the results suggest that reuse of water treatment sludge as a coagulant for the post-treatment of UASB reactor effluent would be an attractive option.

1. Introduction

The upflow anaerobic sludge blanket (UASB) process has been recognised as one of the environmentally friendly methods for treatment of urban wastewater in tropical countries due to its low initial capital investment, less land and energy requirements, less sludge generation, low maintenance cost and its potential to generate biogas (Schink, 2002; Chernicharo, 2006). Effluent from the UASB reactor, however, does not meet disposal standards/guidelines specifically in relation to organic content, suspended solids, nutrients and pathogen content. (Chernicharo, 2006; Khan et al., 2011; Sato et al., 2006; Tawfik et al., 2010). This makes the post-treatment of UASB reactor effluent necessary before its discharge into water bodies or for its reuse in irrigation.

Different post-treatment methods that have been used/tested for UASB reactor effluent include anaerobic or aerobic biological processes like rotating biological contactors, activated sludge, downflow hanging sponge, physicochemical processes such as flotation, aeration and coagulation, and natural treatment systems such as constructed wetlands and stabilisation ponds (Chernicharo, 2006; Khan et al., 2011; Tawfik et al., 2010). While some of these methods are energy intensive, some others like polishing ponds/stabilisation ponds require large area, and thus the choice of a proper reliable and efficient post-treatment method is a great challenge. Jayaprakash et al. (2007) reported the use of coagulation–flocculation as a post-treatment method for UASB reactor effluent. Performance of four coagulants, ferric chloride, ferric sulphate, alum and polyaluminium chloride (PACl) were assessed as a post-treatment option for UASB reactor effluent in terms of BOD, suspended solids, nutrients and coliform removals. The method was effective in producing effluent that met the discharge standards except in the case of coliforms. Similar study was carried out by Diamadopoulos et al. (2007) using alum, aluminium chloride, polyaluminium chloride, ferric chloride and polyferrric chloride. However, coagulation process may not be a sustainable option for post-treatment of UASB reactor effluent due to high cost of coagulants. Thus there is a need to find a low-cost coagulant for treatment of UASB reactor effluent.

Large quantities of water treatment sludge/residuals (WTS) are produced globally as by-product of coagulation–flocculation process while removing colloidal impurities from the raw water. Generally aluminium and iron salts are used as coagulants. The aluminium salts hydrolyse to form precipitates of aluminium

* Corresponding author. Tel.: + 91 98258 75162.
E-mail addresses: mansoorahammed@gmail.com, mma@ced.svnit.ac.in (M. M. Ahammed).

0959-6526/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jclepro.2013.12.037

hydroxides when added to water. The impurities in water are removed by charge neutralisation, sweep floc mechanism and adsorption on the hydroxide precipitates (Trinh and Kang, 2011). Aluminium hydroxide ($Al(OH)_3$) flocs constitute the major portion of the Al-WTS along with silt, clay, sand and humic particles removed from the raw water and other chemicals used during the water purification process (Babatunde and Zhao, 2007). At present these WTRs are disposed (a) to sanitary sewers, (b) into a receiving stream; (c) by land application, and (d) to a landfill, assuming that these residuals do not possess any toxic characteristics (Babatunde and Zhao, 2007; Makris and O'Connor, 2007). However, with the realisation of adverse impacts of Al-WTRs on the environment, it is likely that stringent regulations would be implemented soon. This has initiated greater interest in the reuse of these residuals. Recently great efforts have been made to reuse WTS in different ways which include its use in water and wastewater treatment and for soil improvement. Wet/dry sludge has been used as a coagulant/adsorbent to remove different contaminants like phosphate (Gibbons et al., 2009; Mortula and Gagnon, 2007), arsenic (Makris et al., 2006; Nagar et al., 2010), lead (Chu, 1999; Putra and Tanaka, 2011; Zhou and Haynes, 2011), boron (Irawan et al., 2011), selenium (Ippolito et al., 2009), fluoride (Sujana et al., 1998; Vinitnantharat et al., 2010), mercury (Hovsepyan and Bonzongo, 2009) and chromium (Zhou and Haynes, 2011). WTS has be proven to be a cost-effective material for treating wastewater with high phosphorus content (Babatunde et al., 2011), to reduce nutrients in surface runoff from agricultural land (Gallimore et al., 1999) and to immobilise phosphorus from lake sediments and help in lake restoration (Wang et al., 2012, 2013).

Reuse of WTS as a coagulant has been reported by many researchers. Chu (2001) assessed the feasibility of reusing WTR to treat textile wastewater. Guan et al. (2005) studied the reuse WTS for treating sewage. Jangkorn et al. (2011) investigated the reuse of alum sludge as a coagulant to treat industrial wastewater containing mixed anionic surfactants. However, the use of WTS for the post-treatment of UASB reactor effluent has not yet been reported.

Coagulation–flocculation is a widely employed process for wastewater treatment, and different factors that affect the process include type and dosage of coagulant and coagulation pH (Wang et al., 2007; Trinh and Kang, 2011). Optimizing these factors is desirable to reduce coagulant consumption and treatment cost. In the present study the response surface methodology (RSM) is used to obtain optimum conditions as it can predict the interaction effects between different variables along with the effect of individual variables (Montgomery, 2010). Several researchers have used RSM to optimise the coagulation–flocculation process in water and wastewater treatment (Wang et al., 2007; Ghafari et al., 2009; Trinh and Kang, 2011; Zainal-Abideen et al., 2012). In the present study, effect of WTS dose, initial pH and fresh PACl dose on COD and turbidity removals were studied using RSM to determine the optimum operating conditions.

Thus the objective of the present study was to investigate the feasibility of reusing aluminium-WTS as a coagulant for post-treatment of UASB reactor effluent treating urban wastewater. RSM was used to optimise the coagulation process with WTS dose, initial pH and PACl dose as the variables and COD removal and turbidity removal as the responses. At the optimum conditions removal of coliforms and nutrients were also evaluated.

2. Conceptual framework for water treatment sludge reuse

Striving towards a more sustainable and cleaner production technique is important both from a competitive as well as in an environmental perspective (Lundkvist et al., 2013). Introduction of sustainability concepts in water and wastewater treatment processes poses a great challenge to environmental engineers. The population explosion and economic development have put great pressure on water management. Use of alternative water source such as roof-harvested rainwater, recycled wastewater and desalinated water have been proposed for sustainable water management, which reduces the depletion of natural water bodies and waste generation (Nápoles-Rivera et al., 2013). However, traditional sources of water such as surface water still constitute the main source of water supply in most urban centres of the world. In water treatment facilities which use surface water, coagulation is a common process and aluminium-based coagulants are most commonly used as the coagulant. This generates large quantity of aluminium-based water treatment sludge (WTS). In developing countries, the residuals are generally disposed in landfills, while in most developing countries, WTS is generally disposed into downstream river (Babatunde and Zhao, 2007; Makris and O'Connor, 2007). The residuals discharged into water bodies affect water quality and prove toxic to aquatic life (Muisa et al., 2011). Life cycle assessment of water treatment plants carried out by Igos et al. (in press) showed heavy metal toxicity from WTS ranging from 0.10 to 0.55 millipoints/kg sludge. Adoption of cost-effective and environmentally friendly disposal options for WTS has become inevitable due to stringent environmental regulations and increasing public awareness.

On the other hand, UASB reactors have emerged as one of the most commonly used processes for treatment of urban wastewater especially in tropical countries. However, post-treatment of UASB reactor effluent is required to meet the discharge standards. Most of the currently used post-treatment methods are not cost effective or require large land area (Khan et al., 2011; Sato et al., 2006; Walia et al., 2011). Recent studies have shown the effectiveness of WTS in treating sewage and industrial wastewater (Guan et al., 2005; Jangkorn et al., 2011). The presence of highly reactive $Al(OH)_3$ species with their large surface area makes Al-WTS a potential adsorbent for nutrients (Gibbons et al., 2009; Makris et al., 2005; Mortula and Gagnon, 2007; Zhao et al., 2009, 2011).

In the present study the potential of WTS as a coagulant for post-treatment of UASB reactor treating urban wastewater is investigated. The conceptual framework for this scheme is presented in Fig. 1. Easy availability of WTS in large quantity at a low cost in urban areas would make this concept sustainable.

3. Materials and methods

3.1. Sample collection and characterisation

Aluminium sludge was collected from the clariflocculator of the Katargam Water Treatment Plant at Surat, India, which treats water from Tapi River. The plant uses polyaluminium chloride (PACl) as the coagulant. The same batch of sludge was used in all the tests. The UASB reactor effluent was collected from the municipal wastewater treatment plant located at Bamroli, Surat, India. Several samples were collected during the study period. Both the UASB reactor effluent and the sludge samples were collected in 20 L plastic containers, transported immediately to the Environmental Engineering Laboratory of S V National Institute of Technology, Surat, India and preserved at 4 °C. Characterisation was carried out immediately as the samples arrived in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA, 1998). The characteristics of WTS and UASB reactor effluent are presented in Tables 1and 2, respectively. Fresh PACl was obtained from the water treatment plant and had an aluminium content of 60.6%.

Please cite this article in press as: Nair, A.T., Ahammed, M.M., The reuse of water treatment sludge as a coagulant for post-treatment of UASB reactor treating urban wastewater, Journal of Cleaner Production (2013), http://dx.doi.org/10.1016/j.jclepro.2013.12.037