Bioresource Technology 200 (2016) 722–730

Contents lists available at ScienceDirect

Bioresource Technology

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

# A new activated primary tank developed for recovering carbon source and its application

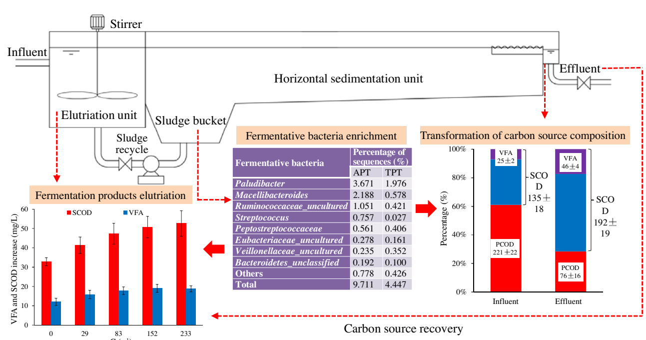
Pengkang Jin [a,*], Xianbao Wang [a], Qionghua Zhang [a], Xiaochang Wang [a], Huu Hao Ngo [b], Lei Yang [c]

[a] School of Environmental and Municipal Engineering, Xi'an University of Architecture and Technology, Xi'an 710055, China
[b] Centre for Technology in Water and Wastewater, School of Civil and Environmental Engineering, University of Technology Sydney, Sydney, NSW 2007, Australia
[c] Department of Chemistry-Ångström Laboratory, Uppsala University, Uppsala 75120, Sweden

## HIGHLIGHTS

- A new activated primary tank (APT) was developed to recover carbon source from sludge.
- APT was beneficial for the breeding of fermentative bacteria and maximised VFAs yield.
- Mechanical elutriation significantly promoted the release of fermentation products.
- APT was applied in a sewage treatment plant and recovered carbon source successfully.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 23 August 2015
Received in revised form 29 October 2015
Accepted 30 October 2015
Available online 4 November 2015

*Keywords:*
Activated primary tank
Primary sludge
Carbon source recovery
Sludge elutriation
Microbial community

## ABSTRACT

A novel activated primary tank process (APT) was developed for recovering carbon source by fermentation and elutriation of primary sludge. The effects of solids retention time (SRT), elutriation intensity (G) and return sludge ratio (RSR) on this recovery were evaluated in a pilot scale reactor. Results indicated that SRT significantly influenced carbon source recovery, and mechanical elutriation could promote soluble COD (SCOD) and VFA yields. The optimal conditions of APT were SRT = 5 d, $G = 152\ s^{-1}$ and RSR = 10%, SCOD and VFA production were 57.0 mg/L and 21.7 mg/L. Particulate organic matter in sludge was converted into SCOD and VFAs as fermentative bacteria were significantly enriched in APT. Moreover, the APT process was applied in a wastewater treatment plant to solve the problem of insufficient carbon source. The outcomes demonstrated that influent SCOD of biological tank increased by 31.1%, which improved the efficiency of removing nitrogen and phosphorus.



## 1. Introduction

The activated sludge biological treatment process has been extensively used in urban wastewater treatment plants (WWTP). In this process, both biological denitrification and phosphorus removal depend on the available biodegradable carbon. For the wastewater treatment plants with sufficient carbon source, the removal of nutrients is strongly affected by the operating conditions of biological system, especially the recycling ratios from aerobic tank to anoxic tank. However, for the wastewater treatment plants with low carbon source, by optimising the recycling ratios, it was difficult to solve the problem of insufficient carbon source, and removal of nitrogen and phosphorus was not ideal. The content of carbon source directly influences the efficiency of denitrification and phosphorus removal, especially in wastewater

* Corresponding author. Tel./fax: +86 2982205652.
*E-mail address:* pkjin@hotmail.com (P. Jin).

http://dx.doi.org/10.1016/j.biortech.2015.10.097
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treatment plants with low C/N and C/P ratios (Li et al., 2008; Wang et al., 2010). As the standards for the effluent quality of wastewater treatment plants become more stringent, the insufficient carbon source has become the dominant factor limiting the efficiency of biological denitrification and phosphorus removal in wastewater treatment plants. Thus, the problem of carbon source shortages needs to be solved urgently.

Adding an external carbon source such as acetate, glucose, methanol and ethanol increases the operational costs in wastewater treatment plants (Gao et al., 2011). Therefore, employing an internal carbon source produced by hydrolysis and acidification of primary and secondary sludge, in recent years has been recognised as the main method for solving the problem of insufficient carbon source (Peng et al., 2012; Zhang et al., 2013). Large amount of VFAs can be produced from the hydrolysis and fermentation of sludge, which not only offers carbon source for biological systems but also significantly improves the efficiency of nitrogen and phosphorus removal (Liu et al., 2012a). To improve the efficiency of sludge hydrolysis and fermentation, the effects on sludge fermentation were studied, such as solids retention time (SRT) (Yuan et al., 2009), temperature (Luo et al., 2014) and pH (Wu et al., 2009; Feng et al., 2009). Meanwhile the sludge fermentation conditions were optimised. However, in practice, the application of the method can hardly be accomplished in certain wastewater treatment plants due to limitation of site area. Although it is allowed to have larger site area in some wastewater treatment plants, the cost of setting up and operating fermenters is high. Furthermore, it is not flexible for the fermenters to accommodate the modifications of the flows, retention times (Munch and Koch, 1999). The previous studies have shown that 40% to 60% of the carbon source in the influent consists of particulate organic matter in urban wastewater treatment plants in China (Wang et al., 2007). A large amount of particulate carbon source is lost with suspended solid removal by sedimentation in traditional primary settling tanks, which further exacerbates the shortage of carbon source for biological nitrogen and phosphorus removal. However, withdrawal of the primary sedimentation tank will significantly increase the loading of the biological system and hinder the operation. Therefore, the activated primary tank process is developed comprising: (1) allowing settled raw sludge solids to accumulate in the bottom of the primary settler tanks; (2) partially recycling this sludge to elutriate the fermentation products out of the sludge (Chanona et al., 2006; Bouzas et al., 2007; Ahn and Speece, 2006).

A good sludge fermentation outcome was recorded in the activated primary tank, but the release of fermentation products out of the sludge was incomplete. Some fermentation products were adsorbed by the primary sludge, this portion of the carbon source is difficult to elutriate (Peng et al., 2012), which hinders the release and recovery of carbon sources. In this study, a novel activated primary tank process equipped with a mechanical elutriation function is developed. The mechanical elutriation unit is installed in front of the traditional primary sedimentation tank to elutriate the return sludge and convert fermentation products into water. The aim of the analysis was to suggest a new activated primary tank so that carbon source recovery from primary sludge could be improved. The modification proposed of the primary tank for recovering carbon source could be needed for plants designed for biological nutrients removal (like AAO) probably not for conventional activated sludge plants designed only for carbon removal and nitrification. The new activated primary tank process was operated at the front of the biological treatment system, and it will not interfere with the operation of biological treatment system (especially the recycling ratios). Under the biological system optimal operation conditions, the APT could recover the carbon source from primary sludge and increase the SCOD concentration of sewage. The APT can solve the problem of insufficient carbon source in the wastewater treatment plants, and enhanced the nitrogen and phosphorus removal of biological system. The optimal operating conditions of the system were established, and an examination of the microbial community in the system was conducted by high-throughput pyrosequencing. Additionally, the activated primary tank was utilised in a wastewater treatment plant to verify the technology's feasibility and good outcomes. This study proposed a novel activated primary tank process to do two things: firstly, realise carbon source recovery; and secondly, solve the problem of insufficient carbon source in wastewater treatment plants.

## 2. Methods

### *2.1. Activated primary tank pilot scale reactor and its application*

The pilot scale experimental device is shown in Fig. 1a. A mechanical elutriation unit was installed in front of a traditional horizontal-flow primary sedimentation tank. A stirrer with adjustable stirring intensity was installed in the elutriation unit. A perforated wall separated the sludge elutriation unit and the sedimentation area to prevent interference from the flow fields of the two units. The volume of the sludge bucket in the primary sedimentation tank and the solid retention time were extended to improve the effects of the sludge hydrolysis and fermentation. A return sludge system was positioned between the sludge bucket and the mechanical elutriation unit so that primary sludge from the sludge bucket could be returned to the mechanical elutriation unit. The mechanical stirring device adequately mixed the sludge with the influent, whereby the fermentation products were elutriated into the influent. The treatment capacity of the activated primary tank was 0.5 $m^3$/h, the hydraulic retention time (HRT) of the elutriation unit and sedimentation zone was 0.4 h and 1.5 h, respectively.

The activated primary tank process was applied in Xi'an No. 4 Wastewater Treatment Plant (WWTP); the traditional primary sedimentation tank was transformed into an activated primary tank (Fig. 1b). Section 2.4 describes the wastewater treatment plant.

### *2.2. Operating conditions of the pilot scale reactor*

The APT was installed at Xi'an No. 4 wastewater treatment plant. The influent of the reactor is the grit chamber effluent of this plant. The solids retention time (SRT) of the primary sludge was controlled at 1, 3, 5 and 7 d according to the sludge height in the sludge bucket. The stirring blades' rotation speeds in the mechanical elutriation unit varied at 0, 20, 40, 60 and 80 rpm, with the corresponding stirring velocity gradients (G) being 0, 29, 83, 152, and 233 $s^{-1}$, respectively. The return sludge ratios (the ratio of return sludge flow to influent flow) were 0%, 5%, 10% and 15%, respectively. The reactor was the traditional primary settling tank when the return sludge ratio (RSR) was 0%. Water quality analysis was conducted for 21 days under each operational condition.

### *2.3. The batch experiments*

To analyse the effect of velocity gradient on sludge sizes, the batch fermentation experiments were conducted in two identical reactors with working volume of 2 L. The primary sludge was taken from the primary sedimentation tank of the Xi'an No. 4 Wastewater Treatment Plant. The two reactors were stirred with velocity gradient of 31 $s^{-1}$ and 160 $s^{-1}$, respectively. The changes of sludge size during the process of sludge fermentation with different velocity gradient were analysed.

The trial experiments were conducted to analyze the function of mechanical elutriation in promoting SCOD release from sludge.