Journal of Environmental Management 177 (2016) 223–230

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Anaerobic side-stream reactor for excess sludge reduction: 5-year management of a full-scale plant

V.F. Velho [a], P. Foladori [b, *], G. Andreottola [b], R.H.R. Costa [a]

[a] Department of Sanitary and Environmental Engineering, UFSC/CTC/ENS, Campus Universitário, Trindade, Florianópolis, SC 88.040-900, Brazil
[b] Department of Civil, Environmental and Mechanical Engineering, University of Trento, Via Mesiano, 77, 38123, Trento, Italy

ARTICLE INFO

Article history:
Received 25 November 2015
Received in revised form
5 April 2016
Accepted 8 April 2016
Available online 20 April 2016

Keywords:
Wastewater treatment
Activated sludge
Excess sludge production
Sludge reduction
Oxic-settling-anaerobic process
Anaerobic side-stream reactor

ABSTRACT

The long-term performances of a full-scale anaerobic side-stream reactor (ASSR) aimed at sludge reduction have been monitored for the first time, in comparison with a conventional activated sludge process (CAS). The plant was integrated with an ASSR treatment of 2293–3293 m^3. Operational parameters in the ASSR were: ORP -250 mV, interchange ratio of 7–10%, hydraulic retention time of 7 d. No worsening of effluent quality was observed in the ASSR configuration and removal efficiency of COD and NH_4 was above 95%. A slight increase in the Sludge Volume Index did not cause worsening in effluent solids concentration. The observed sludge yield (Y_{obs}) passed from 0.44 kgTSS/kgCOD in the CAS to 0.35 in the ASSR configuration. The reduction of Y_{obs} by 20% is lower than expected from the literature where sythetic wastewater is used, indicating that sludge reduction efficiency is largely affected by inert mass fed with influent real wastewater. An increase by 45% of the ASSR volume did not promote a further reduction of Y_{obs}, because sludge reduction is affected not solely by endogenous decay but also by other factors such as interchange ratio and aerobiosis/anaerobiosis alternation.

1. Introduction

The large amount of excess sludge generated in wastewater treatment plants (WWTP) is one of the most critical issues in sewage treatment. Management and disposal of excess sludge takes up 20–60% of the total operational costs in a WWTP (Liu and Tay, 2001). Various approaches are being proposed to reduce the production of excess sludge directly in biological reactors during wastewater treatment in WWTPs (Andreottola and Foladori, 2007; Foladori et al., 2010a, 2010b). In view of full-scale applications, sludge reduction technologies must be cost effective, with simple design and management, and without negative impacts on effluent quality and activated sludge settleability.

The Anaerobic Side-Stream Reactor (ASSR) has been proposed for efficiently reducing excess sludge production. The activated sludge configuration includes an anaerobic sludge tank in the sludge return line, obtaining a configuration similar to the Oxic-Settling-Anaerobic process (OSA) proposed by Chudoba et al. (1992a). The sludge hydrolysed in the anaerobic tank is returned to activated sludge reactors to complete its oxidation. The OSA process and ASSR differ in the percentage of the return sludge treated in the anaerobic holding tank. In the OSA process, all the return sludge is recirculated to the anaerobic tank, while in the ASSR only a portion of the return flow (around 10%) is treated daily in the anaerobic tank, while the most part returns to the activated sludge stages without treatment (Kim et al., 2012). The OSA-like process permits to reduce excess sludge production by 20–60% compared to conventional activated sludge (*inter alia* Saby et al., 2003; Novak et al., 2007; Foladori et al., 2010a). The wide variation in sludge reduction is attributed to variations in feed, type of wastewater, operational conditions, sludge retention time or interchange rate.

Up to now studies regarding OSA-like processes only used mostly soluble synthetic wastewater as a feed substrate and were applied at lab- or pilot-scale (*inter alia* Chon et al., 2011a; Chon et al. 2011b; Kim et al., 2012; Khanthongthip et al., 2015; Rodriguez-Perez and Fermoso, 2016). Soluble synthetic wastewater facilitates plant operations, but differs from real wastewater due to the absence of inert organics and non-volatile solids, which have a considerable role in sludge generation at full-scale. To our knowledge, the work of Coma et al. (2013), who implemented an ASSR with a long sludge age, is the only study treating real raw wastewater, but the study was carried out at pilot-scale. When

* Corresponding author.
E-mail address: paola.foladori@unitn.it (P. Foladori).

http://dx.doi.org/10.1016/j.jenvman.2016.04.020
0301-4797/

transferring results from pilot-to full-scale, some operational problems not addressed before, could originate. Guo et al. (2013) underlined that the experience in the OSA process at full-scale is insufficient due to some obstacles that block its practical application.

The first full-scale ASSR in Europe was put into operation in 2008 in the Levico WWTP (Italy), treating a population equivalent of 48,000. The plant is based on an activated sludge scheme for organic matter and nitrogen removal according to the European discharge limits in sensitive areas (Directive 91/271/EC). The ASSR was built according to the commercial process Cannibal®, which includes some physico-mechanical devices (screening, hydrocyclones) to separate inert solids. The ASSR was in continuous operation for more than 5 years (from 2008 to 2013), undergoing one modification (volume increase) to enhance sludge reduction.

This paper presents the performances in the Levico WWTP before and after the implementation of the ASSR, for an overall period of 9 years. As far as we know, no previous research has been reported about an OSA-like process or an ASSR applied to full-scale WWTPs and monitored for long periods. This lack of information in real plants has motivated this paper which focuses on effluent quality, sludge settleability and excess sludge reduction after the implementation of the ASSR system at full-scale. New insights have been gained from the full-scale experience, regarding the role of the type of wastewater, the sludge retention time and the interchange rate. These may contribute to a better understanding of the ASSRs systems when applied in the treatment of real wastewater at full-scale.

2. Materials and methods

2.1. Full scale WWTP and implementation of ASSR

The Levico WWTP is composed of pre-treatments (screening, degritting), biological pre-denitrification (1 reactor, 1000 m^3), oxidation/nitrification basins (3 reactors, total volume of 6000 m^3) and final settlers (Fig. 1). The configuration was modified in 2008 to include an anaerobic side-stream reactor (here called $ASSR_1$, volume of 2293 m^3) configured as a Cannibal® process: the reactor was placed in the return activated sludge (RAS) circuit, between the settlers and the pre-denitrification tank. The RAS circuit was divided into two lines (Fig. 1):

1) a fraction of RAS (330 m^3/d), depending on the interchange rate, was pumped into the Cannibal® process; this fraction passed through a screening and hydrocyclones for coarse particles and grit removal and then through the ASSR before being returned to the activated sludge stages;
2) the remaining RAS was recirculated directly into the activated sludge stages without treatment.

A second anaerobic side-stream reactor ($ASSR_2$, volume of 1000 m^3) was added in 2009 to treat an additional fraction of RAS of 150 m^3/d. The simultaneous presence of two anaerobic holding tanks originated the configuration called $ASSR_{1,2}$ (total anaerobic volume of 3293 m^3).

2.2. Four monitoring phases

Four configurations were monitored in the WWTP for an overall period of 9 years (2005–2014), as follows:

- CAS_1 phase: the conventional activated sludge stage was monitored from 2005 to 2008 (duration of 36 months) before the ASSR installation; this period was used as a control;
- AS + $ASSR_1$ phase: the activated sludge system was modified to include one ASSR tank (2008–2009; 16 months);
- AS + $ASSR_{1,2}$ phase: the activated sludge system was modified to include two ASSR tanks (2009–2013; 47 months);
- CAS_2 phase: conventional activated sludge stage was restored during a period of maintenance (from 2013; 7 months); this period was used as a further control.

2.3. Operational conditions

Operational parameters in the AS + ASSR configurations are summarised in Table 1.

The interchange rate is calculated as the percent of sludge mass interchanged between the activated sludge stages and the anaerobic reactor on daily basis. An amount of 7.6% of the activated sludge mass was recirculated daily in the $ASSR_1$ and 10.6% in the $ASSR_{1,2}$. This interchange rate is lower than that usually applied in the OSA processes (where 100% of RAS is recirculated) but in agreement with other ASSR systems which used interchange rates of 10% (Chon et al., 2011b; Kim et al., 2012).

Due to the lower recirculated flow into the ASSR compared to the OSA process, the hydraulic retention time (HRT) in the anaerobic holding tank is usually longer in the ASSR system than in the OSA process. In our plant, average HRT in the anaerobic holding tanks was 6.7–6.9 d, in agreement with HRT of 10 d reported by Kim et al. (2012).

The TSS concentration inside the ASSR tanks was 9.3 and 10.1 kgTSS/m^3 in the phases AS + $ASSR_1$ and AS + $ASSR_{1,2}$ respectively. These values are almost double the TSS concentration measured by Coma et al. (2013) in a similar ASSR system and by Chon et al. (2011b). The high TSS concentrations maintained in our ASSR is due to the high concentration of solids in the RAS and may be the reason for the scarce sedimentation and separation between sludge and supernatant in the anaerobic holding tank.

The applied sludge loading rate (ASLR) in the ASSR tanks indicates the quantity of sludge treated in the anaerobic holding tank per unit of volume and was calculated according to Coma et al. (2013), taking into account the flow rate and the VSS concentration entering the ASSR divided by the ASSR volume. ASLR of 1.5–1.6 kgVSS m^{-3} d^{-1} was calculated in our system, lower than the range 3.3–17.8 kgVSS m^{-3} d^{-1} reported by Coma et al. (2013).

The relatively long HRT in the ASSR resulted in stable and low ORP which was always below −250 mV; small variations up to −150 mV were observed during 30-min feeding applied once a day and during a 1-h aeration applied twice a week to control odour emissions. ORP of −250 mV was confirmed by An and Chen (2008) as being effective in sludge reduction in OSA-like processes. Values of pH in the ASSR were 6–6.5.

Intermittent mixing was provided in the ASSRs to ensure homogenous conditions in the sludge.

The hydrocyclones, based on centrifugal forces, were included for separating heavy organic material, grit and dense inorganic particles from RAS. During operation the mass separated was negligible (less than 70 kg of dry solids per day), maybe because the influent wastewater was already treated in a degritting unit. Thus the use of hydrocyclones was stopped.

2.4. Analytical methods

Biochemical Oxygen Demand at 5 days (BOD_5), Chemical Oxygen Demand (COD), total nitrogen (TN), nitrogen ions (NH_4–N, NO_3–N), total phosphorus (TP) and Total Suspended Solids (TSS) were analysed in the influent and effluent wastewater according to Standard Methods (APHA, 2005).