Challenges in biological treatment plants: the approach of zero sludge waste

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Abstract

The current trend in operation of biological Wastewater Treatment Plants (WWTPs) is the minimization of sludge wastage due to its labor and cost intensive management process. Minimization of sludge can be achieved by increasing the solids retention time (SRT) in a WWTP, up to an almost complete retention of solids. This operational modification can induce problems that compromise effluent quality, such as: (a) excessive accumulation of sludge, (b) Dissolved Oxygen availability, (c) changes of C:N:P nutrient ratio, (d) changes of microbiological and morphological characteristics of biomass and (e) insufficient treatment. By imposing specific WWTP design and operational conditions, the SRT related problems can be resolved. The current study presents results based on monitoring five full scale industrial and municipal WWTPs, operating towards “complete solids retention”. The results showed that under high SRT and after the modification in the design and operation of a WWTP, successful microbial manipulation can be achieved. This leads to (i) excess sludge minimization, up to 95%, (ii) good sludge settling characteristics, with SVI < 120 ml/g, (iii) sufficient wastewater treatment, with removal efficiencies, up to 99%, 98% and 99% for COD, TN and TP respectively.

Keywords: biological treatment, sludge minimization, complete solids retention

1. Introduction

The quantity of excess sludge in conventional activated sludge (CAS) processes is significantly high. The worldwide average of waste sludge production per population equivalent, per year is approximately 20 kg to 40 kg (Xie et al., 2016). Worth mentioning that treatment and disposal of excess sludge accounts for up to 60% of the total operational costs of a wastewater treatment plant (Sperling and Andreoli, 2007). Due to the large quantities of excess sludge produced in CAS processes and due to the associated problems (environmental threats, health issues etc.), the major problem of excess sludge management and disposal has emerged. Therefore, European Union aims to reduce landfill sludge disposal by 20% and 50% by the year 2010 and 2050 respectively, compared to the amount of sludge waste disposed in the year 2000 (Lundin et al., 2004).

In recent years, many techniques have been applied to reduce biomass production during wastewater treatment, on the basis of total mass balance of the inputs and outputs, such as biological, high temperature oxidation and mechanical treatments, ozonation, or using chemical compounds (Foladori et al., 2010). An innovative approach towards waste sludge minimization is well described by the complete solids retention activated sludge (CRAS) process. CRAS process is based on the following operating parameters: a) the longer possible solids retention time (SRT) up to complete retention; b) the maintenance of highly aerobic conditions in the aerobic bioreactors; c) the successful microbial manipulation; d) the efficient solids/liquid separation (Samiotis et al., 2018). By this approach, efficient wastewater treatment, minimization of sludge accumulation in the WWTP and significant reduction of excess sludge is achieved, with relatively low specific energy consumption (Trikoilidou et al., 2016).

This study evaluates the effect of applying CRAS process in the production of excess sludge and the energy consumption of an AS WWTP, by comparing specific operational parameters of five AS WWTPs that apply CRAS process to a different extend.

2. Materials and Methods

The first two of the five studied WWTPs, named WWTP-1 and WWTP-2, are designed for treating slaughterhouse’s wastewater; the third, named WWTP-3, for treating snack industry’s wastewater; the fourth, named WWTP-4, for treating fruit processing industry’s wastewater; the fifth, named WWTP-5, for treating municipal wastewater. All five WWTPs have microbial selectors, which can prevent filamentous bacteria growth (Henze et al., 2008). Influent and effluent characteristics, operational parameters, energy consumption and excess sludge production were recorded for each of the five WWTPs. WWTP-1, WWTP-2 and WWTP-3 design and operation is based on CRAS process. WWTP-4 was a conventional aerobic activated sludge system that was modified, both in design and operation, in order to achieve as high SRT as possible, while WWTP-5 was designed and operated as a conventional municipal wastewater treatment plant with relatively high SRT. The increase of SRT in each of the studied WWTP was limited by its design and the installed electromechanical equipment.

3. Results and Discussion

Influent composition, flowrates and operational conditions are significantly different between the five studied WWTPs. Relevant data are presented in Table 1 and Table 2. WWTP-1, WWTP-2 and WWTP-3, which were designed and operated based on CRAS process, presented the lowest biomass yields (Y_{obs} = 0,015 - 0,033 kgSS/kgCOD) and therefore up to 95% less waste sludge that other activated sludge processes (Table 2). After the modifications for adapting CRAS process on WWTP-4 (additional sedimentation tanks, recirculation pumps, air diffusers and blowers), the observed biomass yield was decreased over 70% compared to previous years of operation, as well as compared to other activated sludge processes (Samiotis et al., 2018). WWTP-5 that was modified only in its operating conditions (SRT, RAS and DO) presented the highest Y_{obs} of the five studied WWTPs. Nevertheless, the observed yield of WWTP-5 corresponds to the lowest observed yields of other AS processes (WEF, 1998), as presented in Table 2.

Table 2 shows that the specific energy consumption of the five WWTPs (expressed in relation to their influent organic compounds removal, i.e. kWh/kgCODremoved), compared with the results obtained from other studies (ENERWATER, 2015), correspond to the lowest values of the most common biological wastewater treatment technologies. COD, nitrogen and phosphorous removal was over 97%, 90% and 87% and up to 99%, 98% and 99% respectively in all five WWTPs. Due to the high MLVSS concentrations, phosphorus was removed in high efficiencies despite the absence of anaerobic biological treatment stage (except WWTP-5 that has an anaerobic treatment stage).

Table 1. Operational characteristics of the five studied WWTPs.

Operational characteristics	**WWTP-1**	**WWTP-2**	**WWTP-3**	**WWTP-4**	**WWTP-5**
Average HRT (days)	7,14	3,13	3,73	1,47	0,98
Average DO in aeration (mg/L)	4,6	5,1	4,9	2,4	4,2
Average SVI (ml/g)	64	93	59	87	71
Average Wastewater COD:N:P ratio	150:18,2:1,4	150:9,8:0,9	150:3,1:0,6	150:0,33:0,2	150:5,2:1,3

Table 2. Typical operational parameters and energy consumption in common activated sludge processes (WEF, 1998; ENERWATER, 2015) **-** Corresponding experimental values of the five WWTPs studied.

Parameter	**Activated sludge process**		**Studied WWTPs**				
	Conventional	**Extended aeration**	**WWTP-1**	**WWTP-2**	**WWTP-3**	**WWTP-4**	**WWTP-5**
F/M ratio (kgBOD/KgVSS_d)	0,2-0,4	0,05-0,15	0,06	0,05	0,09	0,28	0,21
SRT (days)	3-15	20-30	359	334	348	169	30
BOD removal (%)	45-90	75-90	98,9	99,2	98,5	98,6	99,2
MLSS (g/L)	1,5-3,0	4,0-7,0	14,3	16,9	16,2	7,9	9,1
Air supply rate (m^3/kgBOD)	45-90	90-125	40,5	35,3	30,2	31,5	60,1
Sludge growth yield - Y_{obs} (kgSS/kgCOD)	0,4-0,7	0,2-0,3	0,028	0,032	0,022	0,014	0,146
Specific energy consumption ($kWh/kgCOD_{removed}$)	0,19-3,15 (median 0,60)	0,28-6,57 (median 1,40)	0,73	0,62	0,33	0,47	0,57

4. Conclusions

The challenges of efficient biological wastewater treatment with minimized excess sludge production, relatively low energy consumption can be adressed, up to a significant degree, by adapting CRAS process. The keys for applying CRAS process and avoiding sludge related problems are (a) the implementation of a preliminary biological treatment stage, (b) the increase of SRT up to complete solids retention, (c) the increase of DO concentration in aeration tanks and (d) the efficient solids/liquid separation.

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