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Valuation of OSA process and folic acid addition as excess sludge minimization alternatives applied in the activated sludge process

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ABSTRACT

The aim of this study was to investigate the ability of the oxic-settling-anaerobic (OSA)-process and the folic acid addition applied in the activated sludge process to reduce the excess sludge production. The study was monitored during two distinct periods: activated sludge system with OSA-process, and activated sludge system with folic acid addition. The observed sludge yields (Y_{obs}) were 0.30 and 0.08 kgTSS kg^{-1} chemical oxygen demand (COD), control phase and OSA-process (period 1); 0.33 and 0.18 kgTSS kg^{-1} COD, control phase and folic acid addition (period 2). The Y_{obs} decreased by 73 and 45% in phases with the OSA-process and folic acid addition, respectively, compared with the control phases. The sludge minimization alternatives result in a decrease in excess sludge production, without negatively affecting the performance of the effluent treatment.

Key words | folic acid addition, oxic-settling-anaerobic process, sludge minimization

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INTRODUCTION

Activated sludge is an efficient process widely used for biological wastewater treatment. However, the large amount of excess sludge generated in wastewater treatment plants (WWTPs) is one of the most critical challenges in the field of sewage treatment. Operating costs associated with the more stringent effluent regulations may contribute to make the current conventional alternatives for sludge treatment and disposal limited or unviable in the near future (Liu & Tay 2001). An ideal approach to solve the waste sludge problem would be the reduction of excess sludge production within the WWTP. Various side-stream technologies involving different mechanisms have been proposed for the reduction of excess sludge production, based on mechanical, physical-chemical or biological processes. The treatment should be cost effective and not affect the effluent quality and the settling properties (Foladori *et al.* 2010).

The side-stream anaerobic reactor system modifies the conventional activated sludge system by inserting an anaerobic tank in the recycling line of the sludge obtaining an oxic-settling-anaerobic (OSA) process. The main hypotheses to explain the mechanisms of sludge reduction in the OSA process are uncoupling metabolism (Troiani *et al.* 2011), cell lysis-cryptic growth (Wei *et al.* 2003) or sludge decay (An & Chen 2008). The sludge reduction mechanisms are obtained by submitting the biomass to alternate cycles of anaerobic and aerobic conditions. The process has been confirmed to reduce sludge production at laboratory and pilot scales, with sludge reduction from 20 to 60% (Foladori *et al.* 2010). The sludge reduction performance is affected by variations in feed, type of wastewater, redox potential (ORP), sludge age or interchange rate (Saby *et al.* 2003).

The addition of folic acid (B-vitamin) as a nutrient source to improve the biological activity and sludge flocculation has been shown to be an effective alternative to reduce the production of excess sludge (Akerboom *et al.* 1994). Folic acid addition on WWTPs serves the particular function of regulating 1-carbon metabolism; a fast metabolic activity in the activated sludge process decreases the daily growth of sludge. Initial operational testing with this product in Germany has supported the possibility of a reduction of excess sludge to the order of 30–60 (Strunkheide 2004). Operational data evaluated in more than 60 municipal and industrial WWTPs in North and South America have confirmed that the addition of folic acid reduced the production of excess sludge by approximately 50% (Senörer & Barlas 2004).

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Many of the previous studies on OSA processes have used soluble synthetic wastewater or a combination of synthetic and real wastewater (Foladori *et al.* 2010; Chon *et al.* 2011; Semblante *et al.* 2014), which enables easier control of the typical operation parameters and simplifies the data acquisition of sludge generation. Coma *et al.* (2015) and Foladori *et al.* (2015) are the only studies treating real wastewater, although demonstrating lower sludge reduction (up to 20%). The former study applied the OSA process in a distinct configuration (UCT-configuration), and the latter operated at a full-scale plant with long hydraulic retention time of the sludge in the anaerobic tank (approximately 7–8 days). Thus, no previous research has been reported in the literature about an OSA process applied to a modified activated sludge system operating short sludge retention time in the anaerobic tank, and using real wastewater, which have a considerable role in sludge generation and in sludge reduction efficiency due to the presence of inert organics and non-volatile suspended solids.

In previous studies on folic acid addition, the solid retention time (SRT) was not always controlled; it increased as a result of the reduction in the wastage sludge flow. The SRT is a key operational parameter for net sludge production in activated sludge systems (Sperandio *et al.* 2013). It is thus not possible to clearly identify if the reduced Y_{obs} observed in folic acid addition systems results from the increased SRT or from the specific daily folic acid dosage in the systems. Therefore, this paper focuses on the use of folic acid for the sludge minimization proposal maintaining the overall SRT of the modified activated sludge system.

In this context, the aim of this study was to investigate the ability of the OSA-process and folic acid addition to minimize the excess sludge production in a pilot-scale WWTP. The purpose was to investigate the reduction of sludge production and the wastewater treatment performance in the system using different configurations; such as conventional activated sludge and modified activated sludge based on OSA-process and folic acid addition.

MATERIAL AND METHODS

Configurations of the pilot system and operational conditions

A schematic of the pilot-scale system used in this study is shown in Figure 1. The system consists of an aerobic tank (AT) of 2,000 L, a settling tank (ST) of 250 L, and a minimization tank (MT) of 1,000 L. The system was fed with domestic sewage taken from the municipal sewage collecting

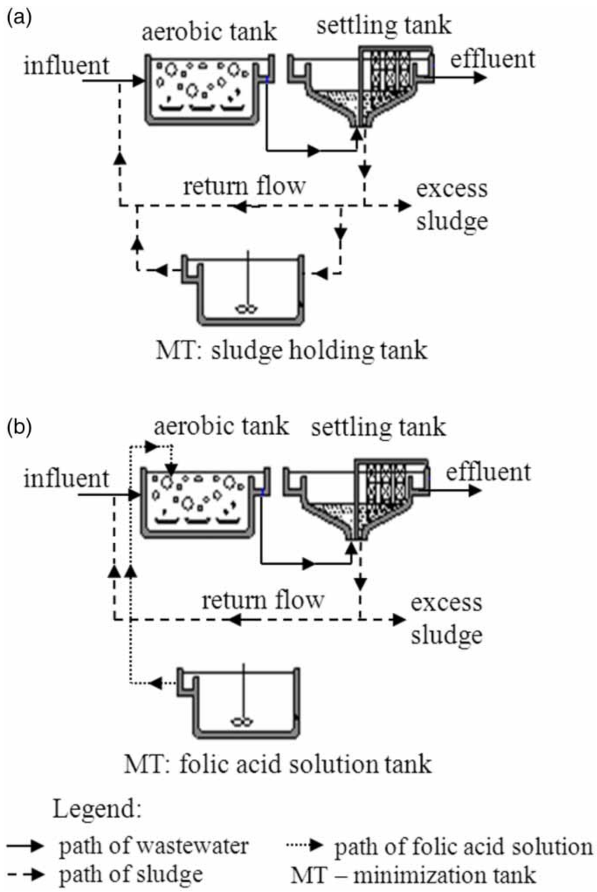

Figure 1 | Schematic diagram of the pilot-scale system: (a) period 1: OSA-process and (b) period 2: folic acid addition.

system (Florianópolis, Brazil, 27°35′49″S/48°32′56″W) by a submerged pump. The average influent data for the system were characterized: chemical oxygen demand (COD) 421–455 mg L^{-1}; ammonium-nitrogen 50.4–59.5 mg L^{-1}; total phosphorus (TP) 6–7 mg L^{-1}; and total suspended solids (TSS) 150–228 mg L^{-1}.

Mixing and air supply in the aerobic tank was provided by an air compressor from the bottom of the tank through air diffusers. The air flow rate was maintained at a sufficient level to achieve a dissolved oxygen level above 3 mg L^{-1}. The pH was maintained at 6.4–7.4 in the aerobic tank. The system was operated at a continuous flow rate of 3 m^3 d^{-1}. Sludge wasting was performed once a week to maintain the desired SRT of 20 days.

A microbial seed, which was obtained from Insular WWTP (Florianópolis-Brazil), was inoculated into the aerobic tank and characterized: TSS 4.5–5.0 mg L^{-1} and sludge volume index (SVI) 210–260 mL g^{-1}. After 45 days (period 1) and 50 days (period 2) of sludge cultivation, the sludge in the system was acclimatized. Sludge minimization alternatives were applied during the stable operational period of the system.

The pilot plant was operated in different configurations during two distinct periods.

- Period 1: activated sludge system with OSA process (96 d), in this period the minimization tank worked as a sludge holding tank, providing an anaerobic sludge zone in the sludge return line.
- Period 2: activated sludge system with folic acid (FA) addition (122 d), in this period the minimization tank worked as a folic acid reservoir from which the folic acid solution was pumped into the aerobic tank.

For both periods the initial control phase, with the pilot system working as a conventional activated sludge, was maintained.

The characteristics of the system operation varied with respect to sludge minimization alternatives.

- OSA process: The hydraulic retention time of the OSA process was established over 24 hours and 50% of the total return flow of the activated sludge was recirculated every day between the aeration basin and the anaerobic treatment.
- Folic acid addition: A peristaltic pump was used to apply the reagent folic acid directly and continuously in the aerobic tank at dosages of 0.2 mg L^{-1}.

Analytical methods

The system was monitored twice a week. The samples were analyzed to determine the pH, temperature, dissolved oxygen, total COD, ammonium nitrogen (NH_4^+–N), and TSS. The dissolved oxygen concentration, pH, and temperature were measured online with a multiparameter sonde (YSI6600). All of the analyses were conducted according to *Standard Methods* (APHA, 2005).

Optical microscopy (OlympusBX-40) observations were performed to verify the possibility of biomass changes within the aerobic tank due to the operation of the sludge minimization alternatives.

Calculation of the observed sludge yield (Y_{obs})

The observed sludge yield (Y_{obs}) was determined using a regression method applied to the masses of TSS produced and organic matter removed (Chon *et al.* 2011).

The mass of TSS produced ($\Delta TSS_{produced}$) was calculated as follows:

$$\Delta TSS_{produced} = \Delta X_{AS} \cdot V_{AS} + ((Q_W \cdot X_W + Q_{ef} \cdot X_{ef}) \cdot \Delta t)$$

where ΔX_{AS}, X_W and X_{ef} are the variations of solids in the activated sludge tank, in the wastage sludge, and in the effluent, respectively (kgTSS). V_{AS} is the aerobic tank volume (m^3), Q_{in} is the influent flow (L d^{-1}), and equal to Q_{ef}, and Q_W is the wastage sludge flow (L d^{-1}). Δt is the elapsed time in days between each sampling.

The mass of COD removed ($\Delta COD_{removed}$) was calculated as follows:

$$\Delta COD_{removed} = (Q_{in} \cdot (COD_{in} - COD_{ef})) \cdot \Delta t$$

where Q_{in} is the influent flow (L d^{-1}), and equal to Q_{ef}. COD_{in} and COD_{ef} correspond to the COD concentration (mg L^{-1}) in the influent and effluent wastewater, respectively. Δt is the elapsed time in days between each sampling.

The mean value of Y_{obs} was calculated as the slope of the linear regression curve obtained from the data for the cumulative TSS produced versus the cumulative COD removed:

$$Y_{obs} = \frac{TSS_{produced}}{COD_{removed}}$$

RESULTS AND DISCUSSION

Influence of the sludge minimization alternatives to effluent quality

Figure 2 shows the COD removal rates in the entire experimental period. The mean COD removal efficiencies in the control phases were 84% (period 1) and 89% (period 2). In the OSA-process with sludge retained for 24 hours in the sludge holding tank, the efficiency was 86% (period 1), and during the folic acid addition the efficiency was 90%

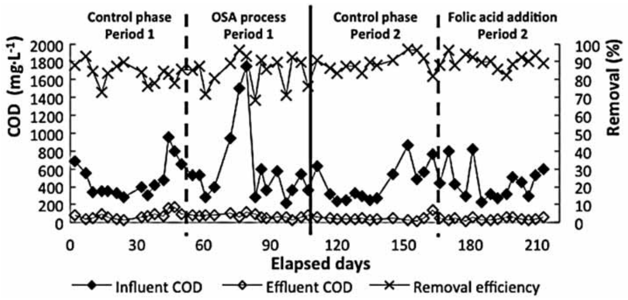

Figure 2 | Variations of COD concentrations and removal efficiencies in the control phases and in the sludge minimization alternatives: period 1: OSA-process and period 2: folic acid addition.

(period 2). It was realized that the substrate removal efficiencies in the OSA-process and in the folic acid addition were not affected significantly by the insertion of the sludge minimization alternatives. The substrate removal capacity slightly increased during the application of the sludge minimization alternatives.

The results demonstrated in these experiments were consistent with those reported by Saby *et al.* (2003), who showed that the OSA-process is able to improve COD removal efficiency due to the increased rate of substrate uptake imposed by stress conditions (low availability of substrate and high concentration of biomass). In their study, a sludge retention time of 10.6 h in the anoxic holding tank was employed. Likewise, Velho *et al.* (2014), monitoring a full-scale OSA-process, demonstrated that the average COD removal efficiencies remained over 95%. The authors verified that, despite the considerable generation of soluble biodegradable organic matter in the anaerobic treatment (soluble COD of 226–255 mg L^{-1} even in the anaerobically treated sludge), no interference on COD removal efficiencies was observed.

Figure 3 demonstrates that the effluent NH_4^+–N concentrations and removal efficiencies during period 1 were not affected by insertion of the sludge holding tank, the removal efficiencies were maintained in the same range, the efficiencies were 77 and 73%, during the control phase and OSA-process, respectively. The results were consistent with those presented by Velho *et al.* (2014), who demonstrated that the nitrification process was complete during the full-scale OSA-process operation, producing average effluent NH_4^+–N concentrations lower than 2.1 mg L^{-1}, resulting in removal efficiencies of 98%. According to Ye *et al.* (2008), the nitrogen-ammonium removal efficiency is kept in the same range as conventional activated sludge, due to the oxic-anaerobic recycling of sludge in the OSA-process, resulting in a nitrification–denitrification effect.

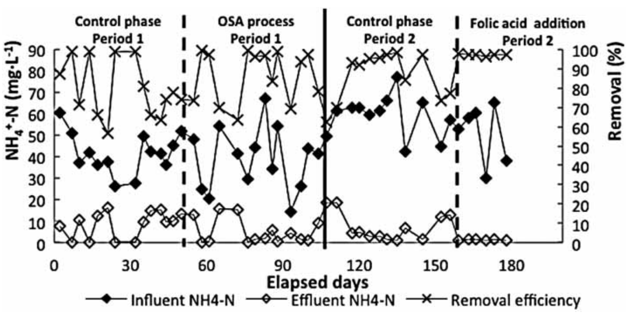

Figure 3 | Variations of NH_4^+–N concentrations and removal efficiencies in the control phases and in the sludge minimization alternatives: period 1: OSA-process and period 2: folic acid addition.

During period 2, an increase in NH_4^+–N removal efficiency with folic acid addition (97%) was observed compared to the control phase (89%), resulting in effluent concentrations lower than 2 mg L^{-1}. Folic acid addition accelerates metabolism activity, which could result in greater substrate and nutrient consumption, thus providing additional efficiency compared to conventional activated sludge. Nevertheless, several studies investigating folic acid addition described no significant interference in the substrate and nutrients removal efficiencies (Akerboom *et al.* 1994; Senörer & Barlas 2004).

Influence of the sludge minimization alternatives to sludge production and characteristics

Figure 4 shows the observed sludge yield (Y_{obs}) obtained during the entire experiment. During period 1, in the control phase, the observed sludge production rate was 0.30 kgTSS kg^{-1} COD, while in the OSA-process, which retained sludge for 24 h in the holding tank, the rate dropped to 0.08 kgTSS kg^{-1} COD. In period 2, the control phase showed an observed sludge yield of 0.33 kgTSS kg^{-1} COD, while in the folic acid addition the Y_{obs} was 0.18 kgTSS kg^{-1} COD. The OSA-process had the highest observed sludge yield, showing 73% of reduction in Y_{obs} compared with the control phase of period 1. The Y_{obs} of the folic acid addition also showed great reduction, with 45% less yield than the control phase of period 2. Comparing the excess sludge production in the sludge minimization phases with control phases, it could be assumed that the processes can reduce excess sludge effectively, presenting good stability of the process operation.

The hydraulic retention time of the sludge in the anaerobic treatment in this study was longer than those reported by Ye *et al.* (2008), who showed that the OSA process can reduce excess sludge by 14–33% when sludge is retained in the anaerobic tank for 5.5–11.5 hours. Similarly, Saby

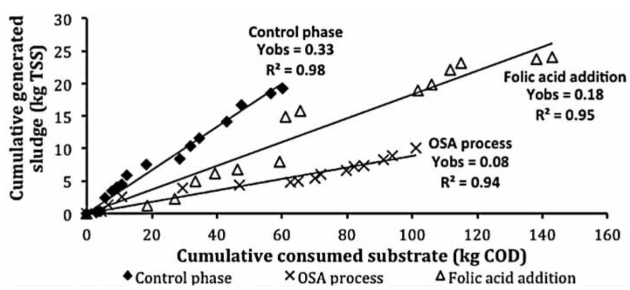

Figure 4 | The observed sludge yield in the control phases and the sludge minimization alternatives (OSA-process and folic acid addition).

et al. (2003) obtained 23–58% and Coma *et al.* (2015) observed 18% sludge reduction efficiency with 10.4 and 24 hours of sludge retention time, respectively.

The TSS concentrations in the aerobic reactor decreased from 2.1 to 1.9 kg m^{-3} after the insertion of the sludge minimization alternatives and remained stable for the subsequent entire phase. SVI data presented stable and effective sludge settling with average SVI values of 96–118 mL g^{-1}TSS. However, SVI values trend to decrease gradually during the sludge minimization phases. These results were consistent with previous observations which have shown that OSA-process does not affect sludge settleability (Saby *et al.* 2003; An & Chen 2008), or the process could even improve the sludge settleability due to the better flocculation promoted by the alternation of aerobic and anaerobic conditions (Ye *et al.* 2008).

The sludge reduction results obtained with folic acid addition in this study were consistent with those reported in the literature, which range from 30 to 60% (Senörer & Barlas 2004; Strunkheide 2004). Furthermore, previous studies demonstrated the improvement of sludge settleability after folic acid addition in an active sludge system, reporting SVI data reductions by 75 and 63% with average values of 250 and 147 mL g^{-1}, respectively (Dubé *et al.* 2002; Strunkheide 2004).

Microscopic examination showed qualitative similarities, microbes agglomerated in dense flocs and predominantly cocci and short bacilli. Samples of the mixed liquor presented both fixed and free swimming ciliated protozoa, such as *Paramecium, Litonotus, Aspidisca*, *Arcella* and *Vorticella*. Representatives of metazoan such as *Rotifera* and *Nematoda* were also verified. According to Zhou *et al.* (2008), these organisms are very important for the system because they feed mainly on bacteria. Consequently, they maintain the bacterial densities and rejuvenate the population via predation. They also contribute to improving the effluent quality by functioning as effective flocculation agents. The composition of the sludge in the system was not markedly different. Overall, the sludge minimization alternatives did not promote great differences in the biomass characteristics; the system maintained good sludge settleability and a stable efficiency.

ECONOMIC AND ENVIRONMENTAL BENEFITS OF SLUDGE REDUCTION ALTERNATIVES

A simulation of the economical assessment of Insular WWTP (design treatment capacity of 226,000 PE on COD basis, from where microbial seed was obtained) was realised if OSA-process or folic acid addition had been held. The sludge management cost was calculated as 35.5 UD m^{-3} sludge in terms of dewatering energy, reagents and disposal, taking into account the real annual costs of the plant for sludge management. As the quantity of sludge would be reduced when applying the OSA-process and folic acid addition, the cost of sludge management would present a considerable annual reduction of 73% with OSA-process. Although folic acid addition promotes 45% of sludge reduction, the sludge management cost would be decreased by 35%, this configuration adds operational costs (pumping energy and folic acid dosage) that should be taken into account.

The environmental gain can be achieved by reducing the final volume of waste sludge being treated and disposed of. Therefore, negative impacts associated with the ultimate disposal of the sludge in landfills, such as exceeding the landfill capacity and the secondary pollution produced, can be avoided or diminished.

The consistent results obtained under such configurations maintained or even improved the treatment efficiencies and sludge settleability, presenting low-cost, good stability of operation and easy implementation in the current facility of WWTP, which proved the viability of the process for further scale-up.

CONCLUSIONS

All the removal efficiencies during the OSA-process and folic acid addition are consistent with the previous control phase, or even better. The performance of the pilot treatment plant was not affected in a negative way by the application of sludge minimization alternatives.

OSA-process presented the highest observed sludge yield, showing 73% of reduction in Y_{obs}. The folic acid addition also showed great reduction with 45% less yield. It could be assumed that the processes can reduce excess sludge effectively, presenting good stability with no worsening of sludge settleability and effluent quality.

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REFERENCES

Akerboom, R. K., Lutz, P. & Berger, H. F. 1994 Folic acid reduces the use of secondary treatment additives in treating wastewater from paper recycling. In: *International Environmental Conference*, Portland, Oregon.

American Public Health Association (APHA) 2005 *Standard Methods for the Examination of Water and Wastewater*, 21st edn. APHA, AWWA (American Water Works Association), and WEF (Water Environment Federation), Washington, DC.

An, K. & Chen, G. 2008 Chemical oxygen demand and the mechanism of excess sludge reduction in an oxic-settling-anaerobic activated sludge process. *Journal of Environmental Engineering* **134** (6), 469–477.

Chon, D., Rome, M., Kim, Y. M., Park, K. Y. & Park, C. 2011 Investigation of the sludge reduction mechanism in the anaerobic side-stream reactor process using several control biological wastewater treatment processes. *Water Research* **45**, 6021–6029.

Coma, M., Rovira, S., Canals, J. & Colprim, J. 2015 Integrated side-stream reactor for biological nutrient removal and minimization of sludge production. *Water Science and Technology* **71** (7), 1056–1064.

Dubé, E., Gagnon, D., Lavallée, H. C. & Robert, S. 2002 Applications of folic acid in secondary wastewater treatment. In: *International Environmental Conference and Exhibit*, Montreal, Canada.

Foladori, P., Andreottola, G. & Ziglio, G. 2010 *Sludge Reduction Technologies in Wastewater Treatment Plants*. IWA Publishing, London.

Foladori, P., Velho, V. F., Costa, R. H. R., Bruni, L., Quaranta, A. & Andreottola, G. 2015 Concerning the role of cell lysis-cryptic growth in anaerobic side-stream reactors: the single-cell analysis of viable, dead and lysed bacteria. *Water Research* **74**, 132–142.

Liu, Y. & Tay, J. H. 2001 Strategy for minimization of excess sludge production from the activated sludge process. *Water Research* **19**, 97–107.

Saby, S., Djafer, M. & Chen, G. H. 2003 Effect of low ORP in anoxic sludge zone on excess sludge production in oxic-settling-anoxic activated sludge process. *Water Research* **37** (1), 11–20.

Semblante, G. U., Hai, F. I., Ngo, H. H., Guo, W., You, S.-J., Price, W. E. & Nghiem, L. D. 2014 Sludge cycling between aerobic, anoxic and anaerobic regimes to reduce sludge production during wastewater treatment: performance, mechanisms, and implications. *Bioresource Technology* **155**, 395–409.

Senörer, E. & Barlas, H. 2004 Effects of folic acid on the efficiency of biological wastewater treatment. *Fresenius Environmental Bulletin* **13** (10), 1036–1039.

Sperandio, M., Labelle, M. A., Ramdani, A., Gadbois, A., Paul, E., Comeau, Y. & Dold, P. L. 2013 Modelling the degradation of endogenous residue and ‘unbiodegradable’ influent organic suspended solids to predict sludge production. *Water Science and Technology* **67** (4), 789–796.

Strunkheide, J. 2004 Stabilized folic acid vitamin for the reduction of excess sludge in sewage treatment plants: experimental reports, masters and doctoral dissertations and publications on the use of DOSFOLAT® from 1986 to 2004. Available from: www.dosfolat.de.

Troiani, C., Eusebi, A. L. & Battistoni, P. 2011 Excess sludge reduction by biological way: from experimental experience to a real full scale application. *Bioresource Technology* **102**, 10352–10358.

Velho, V. F., Costa, R. H. R., Nardelli, P. & Foladori, P. 2014 Influence of sludge retention time in an anaerobic side-stream reactor to reduce excess sludge production in a full-scale plant. In: *IWA World Water Congress & Exhibition*, Lisbon, Portugal.

Wei, Y. S., Van Houten, R. T., Borgerm, A. R., Eikelboom, D. H. & Fan, Y. B. 2003 Minimization of excess sludge production for biological wastewater treatment. *Water Research* **37** (18), 4453–4467.

Ye, F., Zhu, R. & Li, Y. 2008 Effect of sludge retention time in sludge holding tank on excess sludge production in the oxic-settling-anoxic (OSA) activated sludge process. *Journal of Chemical Technology and Biotechnology* **83** (1), 109–114.

Zhou, K., Xu, M., Liu, B. & Cao, H. 2008 Characteristics of microfauna and their relationships with the performance of an activated sludge plant in China. *Journal of Environmental Sciences* **20**, 482–486.

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