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Review

Technologies for reducing sludge production in wastewater treatment plants: State of the art

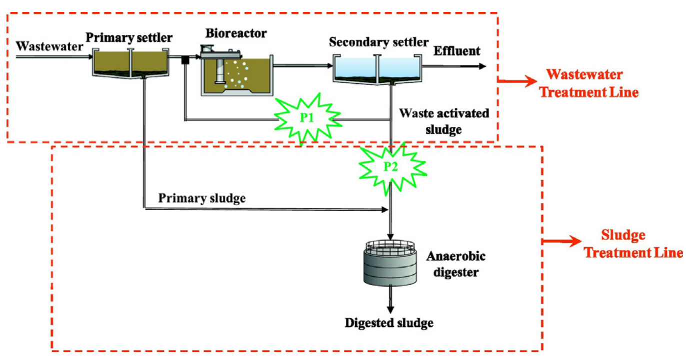
Qilin Wang [a,b,*], Wei Wei [a], Yanyan Gong [c], Qiming Yu [b], Qin Li [b,d], Jing Sun [a], Zhiguo Yuan [a]

[a] Advanced Water Management Centre (AWMC), The University of Queensland, QLD 4072, Australia
[b] Griffith School of Engineering, Griffith University, Nathan Campus, QLD 4111, Australia
[c] School of Environment, Guangzhou Key Laboratory of Environmental Exposure and Health, Guangdong Key Laboratory of Environmental Pollution and Health, Jinan University, Guangzhou 510632, China
[d] Queensland Miro- and Nanotechnology Centre, Griffith University, Nathan Campus, QLD 4111, Australia

HIGHLIGHTS

- State-of-the-art sludge reduction technologies were reviewed.
- Advantages and disadvantages of sludge reduction technologies were discussed.
- Free nitrous acid technology seems good in wastewater treatment line.
- Thermal pretreatment and TPAD are superior in sludge treatment line.
- Future perspectives of sludge reduction technologies were elucidated.

GRAPHICAL ABSTRACT



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ABSTRACT

This review presents the state-of-the-art sludge reduction technologies applied in both wastewater and sludge treatment lines. They include chemical, mechanical, thermal, electrical treatment, addition of chemical uncoupler, and predation of protozoa/metazoa in wastewater treatment line, and physical, chemical and biological pretreatment in sludge treatment line. Emphasis was put on their effect on sludge reduction performance, with 10% sludge reduction to zero sludge production in wastewater treatment line and enhanced TS (total solids) or volatile solids removal of 5–40% in sludge treatment line. Free nitrous acid (FNA) technology seems good in wastewater treatment line but it is only under the lab-scale trial. In sludge treatment line, thermal, ultrasonic (<4400 kJ/kg TS), FNA pretreatment and temperature-phased anaerobic digestion (TPAD) are promising if pathogen inactivation is not a concern. However, thermal pretreatment and TPAD are superior to other pretreatment technologies when pathogen inactivation is required. The new wastewater treatment processes including SANI®, high-rate activated sludge coupled autotrophic nitrogen removal and anaerobic membrane bioreactor coupled autotrophic nitrogen removal also have a great potential to reduce sludge production. In the future, an effort should be put on the effect of sludge reduction technologies on the removal of organic micropollutants and heavy metals.

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* Corresponding author.
E-mail addresses: qilin.wang@griffith.edu.au, q.wang@awmc.uq.edu.au (Q. Wang).

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1. Introduction

Biological wastewater treatment plants (WWTPs) have been employed throughout the world to treat municipal wastewater. Despite the fact that it is efficient in removing organics, large amounts of excess sludge are generated. For example, the average annual production of excess sludge is 3 million wet tons in Australia, and 240 million wet tons in Europe, USA and China combined (Pritchard et al., 2010). The main methods for sludge disposal have been and still are landfill, agricultural use and incineration, all incurring very large costs (e.g. $30–70 per wet ton in Australia and €30–100 per wet ton in Europe) (Batstone et al., 2011). Therefore, reducing sludge production in WWTPs has become a hot topic for both practitioners and researchers.

The excess sludge can be classified into primary sludge and secondary sludge (or waste activated sludge, i.e. WAS) (Metcalf and Eddy, 2003). Primary sludge is the sludge composed of settleable solids removed from raw wastewater in primary settler. WAS is the sludge produced by biological process such as activated sludge process. WAS mainly consists of bacteria growing on organic and inorganic substances, extracellular polymeric substances (EPS) excreted by bacteria, recalcitrant organics originating from wastewater or formed during bacterial decay, and inorganics from wastewater. In general, the biodegradability of primary sludge is high and thus it would be quite difficult to further enhance its degradation through pretreatment technologies (Carrere et al., 2010). In contrast, WAS has low biodegradability (Carrere et al., 2010). Therefore, lots of technologies have been developed to reduce WAS production.

For the time being, technologies for achieving sludge reduction can be divided into two types, (a) reducing sludge production in wastewater treatment line, and (b) achieving sludge reduction in sludge treatment line (see Fig. 1). In general, they are not implemented simultaneously in the same WWTP. For instance, reducing sludge production in wastewater treatment line is applied in the small WWTPs where anaerobic digesters do not exist, whereas achieving sludge reduction in sludge treatment line is implemented in the large WWTPs with anaerobic digesters (Perez-Elvira et al., 2009; US EPA, 2011).

The commonly used approach for reducing sludge production in wastewater treatment line is to implement technologies to treat return activated sludge, which is then recirculated to the main-stream bioreactor for further biodegradation (see P1 in Fig. 1). These treatment technologies include chemical treatment, mechanical treatment, thermal treatment and electrical treatment (Camacho et al., 2005; Heinz, 2007; Mohammadi et al., 2011; Wang et al., 2013a; Semblante et al., 2014; Romero et al., 2015). They cause cell lysis with subsequent release of intracellular and extracellular substances, which become substrate available for biodegradation (van Loosdrecht and Henze, 1999; Hao et al., 2010), whereby sludge reduction is achieved. In addition to the treatment technologies, the other technologies for reducing sludge production in wastewater treatment line include addition of chemical uncoupler, and predation of protozoa and metazoa (Feng et al., 2014; Basim et al., 2016; Xiao et al., 2016; Zhu et al., 2016).

In the sludge treatment line, sludge is subject to thickening, stabilization, dewatering and final disposal. Anaerobic digestion is the most commonly used sludge stabilization method, which is used to reduce the mass of sludge (Appels et al., 2008). However, anaerobic digestion is generally limited by the poor biodegradability of WAS (Appels et al., 2008; Wang et al., 2013b). Therefore, analogous to the technologies applied in wastewater treatment line, a number of pre-treatment technologies have been integrated into the sludge treatment line before anaerobic digestions to achieve sludge reduction (P2 in Fig. 1). They include physical pre-treatment, chemical pre-treatment and biological pretreatment (Ge et al., 2011; Bolzonella et al., 2012; Abelleira-Peraira et al.,

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