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Alkyl polyglucose enhancing propionic acid enriched short-chain fatty acids production during anaerobic treatment of waste activated sludge and mechanisms

Jingyang Luo [a], Leiyu Feng [a,b,*], Yinguang Chen [a,*], Han Sun [a], Qiuting Shen [a], Xiang Li [c], Hong Chen [c]

[a] State Key Laboratory of Pollution Control and Resources Reuse, School of Environmental Science and Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, China

[b] Research & Service Center for Environmental Industry, Yancheng 224051, Jiangsu Province, China

[c] School of Environmental Science and Engineering, Donghua University, 2999 North Renmin Road, Shanghai, 201620, China

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ABSTRACT

Adding alkyl polyglucose (APG) into an anaerobic treatment system of waste activated sludge (WAS) was reported to remarkably improve the production of short-chain fatty acids (SCFAs), especially propionic acid *via* simultaneously accelerating solubilization and hydrolysis, enhancing acidification, inhibiting methanogenesis and balancing carbon to nitrogen (C/N) ratio of substrate. Not only the production of SCFAs, especially propionic acid, was significantly improved by APG, but also the feasible operation time was shortened. The SCFAs yield at 0.3 g APG per gram of total suspended solids (TSS) within 4 d was 2988 ± 60 mg chemical oxygen demand (COD) per liter, much higher than that those from sole WAS or sole WAS plus sole APG. The corresponding yield of propionic acid was 1312 ± 25 mg COD/L, 7.9-fold of sole WAS. Mechanism investigation showed that during anaerobic treatment of WAS in the presence of APG both the solubilization and hydrolysis were accelerated and the acidification was enhanced, while the methanogenesis was inhibited. Moreover, the activities of key enzymes involved in WAS hydrolysis and acidification were improved through the adjustment of C/N ratio of substrates with APG. The abundance of microorganisms responsible for organic compounds hydrolysis and SCFAs production was also observed to be greatly enhanced with APG *via* 454 high-throughput pyrosequencing analysis.

* *Corresponding authors*. State Key Laboratory of Pollution Control and Resources Reuse, School of Environmental Science and Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, China. Tel.: +86 21 65981263; fax: +86 21 65986313.

E-mail addresses: leiyufeng_tj@yahoo.com (L. Feng), yinguangchen@yahoo.com (Y. Chen).

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1. Introduction

Huge amounts of waste activated sludge (WAS) were generated every year in wastewater treatment plants (WWTPs), which must be effectively disposed to avoid its secondary pollution to the environment. Anaerobic treatment is a proven efficient method to stabilize WAS and simultaneously recover renewable resources, such as SCFAs and methane (Chen et al., 2007; Zhang et al., 2010). Normally, the complicated and strict operating conditions were required for methane production, resulting in the high cost when the long fermentation time and the complexities of purifying and collecting methane were considered. However, the production of SCFAs from WAS by anaerobic treatment was relatively simple with lower expenses, and the products can be supplied into WWTPs directly for a higher performance of biological nutrient removal (BNR) (Chen et al., 2004). Commonly, the removal of 1 mg N and 1 mg P requires 1.07–1.82 and 1.87–3.00 mg SCFAs, respectively (Daigger and Bowen, 1994; Elefsiniotis and Li, 2006). Nevertheless, the content of biodegradable substrates, especially SCFAs, in the influent of WWTPs is always insufficient (Tong and Chen, 2009; Yuan et al., 2006). Thus, the supplement of SCFAs to WWTPs is highly required to drive biological nitrogen and phosphorus removal.

Among those SCFAs, propionic acid has been demonstrated to the most preferred carbon source for BNR (Chen et al., 2013a; Oehmen et al., 2005). However, the efficient production of SCFAs, especially propionic acid, from WAS are hampered by a fatal drawback of sludge, *e.g*: low carbon to nitrogen mass ratio (C/N), which is closely related with the metabolism activities of propionic acid-forming microorganisms (Feng et al., 2009). The balance of C/N ratio should be adjusted to achieve higher performance of propionic acid accumulation during WAS anaerobic treatment. Moreover, WAS is a complex mixture of particulate organic and inorganic matters and various microorganisms (Ormeci and Vesilind, 2000), and hydrolysis along with solubilization, acidification and methanogenesis are the main steps involved in its anaerobic treatment (Fig. 1). The initial solubilization and hydrolysis of particulate macromolecular organics to soluble micromolecular ones are considered as the rate-limiting steps of WAS treatment (Chen et al., 2007). Mechanical, thermal and alkaline pretreatments were once proposed as effective methods to accelerate the solubilization and hydrolysis of sludge (Wilson and Novak, 2009; Yan et al., 2010; Yuan et al., 2006). However, high energy consumption has limited their applications in large scale (Jang et al., 2014). Acidification is an acid-forming process of anaerobic treatment, during which SCFAs are generated. However, most of the produced SCFAs would be consumed and converted into methane in the following step of methanogenesis. Thus, in order to achieve high performance of SCFAs accumulation from WAS, the steps of solubilization, hydrolysis and acidification were expected to be accelerated or enhanced, meanwhile the methanogenesis must be inhibited. Nevertheless, by far little information is available on the adjustment of C/N ratio of WAS for more production of SCFAs, especially propionic acid (Feng et al., 2009; Zhou et al., 2013), especially under the conditions that the solubilization, hydrolysis and acidification of organic matters were simultaneously enhanced and meanwhile the methanogenesis of SCFAs was inhibited.

This study, therefore, explored an efficient strategy by applying alkyl polyglucose (APG), which is an emerging nonionic biosurfactant with properties of fast biodegradability and good ecological compatibility, into WAS treatment systems to improve the solubilization, hydrolysis and acidification of particulate organic compounds, inhibit the methanogenesis, and synchronously increase the C/N ratio of substrates, for remarkably enhancing the accumulation of SCFAs, especially propionic acid. The effects of APG dosage on SCFAs production and the content of propionic acid were investigated. More importantly, the mechanisms for the accumulation of SCFAs, especially propionic acid significantly enhanced by APG were discussed in details. Also, the microorganisms responsible for improved SCFAs production in WAS treatment systems fed with APG were studied by 454 high-throughput pyrosequencing technique.

2. Materials and methods

2.1. WAS and APG

WAS was withdrawn from the secondary sedimentation tank of a municipal WWTP in Shanghai, China. The collected WAS was concentrated by settling at 4 °C for 24 h, and was filtrated from stainless steel mesh (2.0 mm). The main characteristics of WAS (average data plus standard deviation of three measurements) are as follows: total suspended solids (TSS) 14,270 ± 275 mg/L, volatile suspended solids (VSS) 10,050 ± 180 mg/L, total chemical oxygen demand (TCOD) 14,090 ± 230 mg/L, soluble chemical oxygen demand (SCOD)

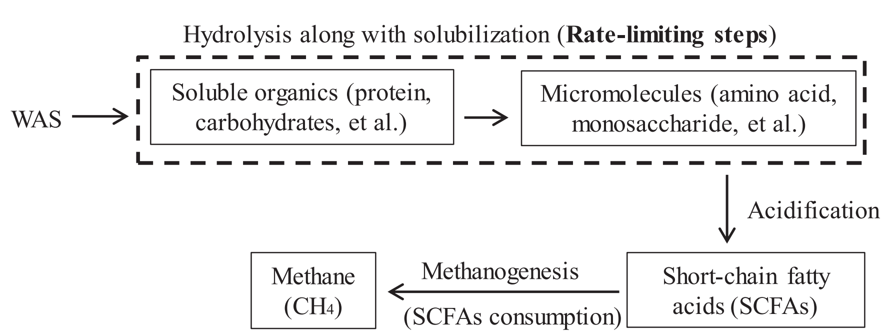

Fig. 1 – Steps involved in anaerobic treatment of waste activated sludge.