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Biological hydrolysis and acidification of sludge under anaerobic conditions: The effect of sludge type and origin on the production and composition of volatile fatty acids☆

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ABSTRACT

New wastewater treatment processes resulting in considerably reduced sludge production and more effective treatment are needed. This is due to the more stringent legislations controlling discharges of wastewater treatment plants (WWTPs) and existing problems such as high sludge production. In this study, the feasibility of implementing biological hydrolysis and acidification process on different types of municipal sludge was investigated by batch and semi-continuous experiments. The municipal sludge originated from six major treatment plants located in Denmark were used. The results showed that fermentation of primary sludge produced the highest amount of volatile fatty acids (VFAs) and generated significantly higher COD- and VFA-yields compared to the other sludge types regardless of which WWTP the sludge originated from. Fermentation of activated and primary sludge resulted in 1.9–5.6% and 8.1–12.6% COD-yields, soluble COD (SCOD)/total COD (TCOD), in batch experiments, respectively. The COD-yields for primary, activated and mixed sludge were 19.1%, 6.5% and 21.37%, respectively, in semi-continuous experiments operated at solids retention time (SRT) of 5 d and temperature of 37 °C. The benefit of fermentation for full-scale application was roughly estimated based on the experiments performed in semi-continuous reactors. The results revealed that even though the VFA production of primary sludge was higher compared to activated sludge, substantial amounts of VFA could be produced by fermentation of activated sludge due to the substantially higher production of activated sludge in WWTPs.

1. Introduction

Treatment of wastewater has many challenges. An important option today is to use as few resources as possible for the treatment process, both with respect to energy and materials. The biological nutrient removal (BNR) processes have been extensively studied and full-scale applications are present worldwide. The magnitude of the nutrient removal with biological processes is closely linked to the presence of easily biodegradable carbon source, which is often the limiting

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factor in the process (Moser-Engeler et al., 1998; Ucisik and Henze, 2004; Tsuneda et al., 2005). Thus, it is necessary to add an external easily biodegradable carbon source to the treatment process to fulfill effluent demands for removal of nutrients with biological processes. However, the addition of the soluble organic compounds increases both the operational cost and sludge production at the wastewater treatment plants (WWTPs).

The excess sludge production is also considered as an inevitable drawback inherent to the activated sludge processes. The sludge produced within these processes must be disposed and this accounts up to 60% of the total operating costs for WWTPs (Horan, 1990). Thus, many efforts have been devoted on the sludge treatment after withdrawal of excess biomass from the activated sludge process, such as sludge digestion, dewatering, and incineration (Rulkens, 2008). The use of sewage sludge for agricultural purposes is considered as the most environmental friendly solution. At present, the application of sludge on farmland is with 60% the most important sludge outlet in Denmark, while 15% of the sewage sludge is incinerated. However, it is not without problems. There are several constrains on sludge use due to heavy metals, pathogens and what has been recently recognized as a major problem, the content of xenobiotic compounds. Although several initiatives have been taken to find new ways to dispose or treat the large amounts of sludge produced, very little has been done in the direction of updating the existing treatment processes, which could result in minimizing the amounts of sludge produced. Therefore, wastewater treatment processes resulting in considerably reduced sludge production would be of great value for society.

To comply with more stringent legislations controlling discharges of WWTPs and existing problems such as high sludge production, it is possible to apply biological hydrolysis and acidification of sludge. The use of produced internal carbon source instead of commercial organic materials would decrease the sludge production in the treatment plant. The hydrolysis of particulate organic matter to soluble substrates, however, was identified as the rate-limiting step during the acidogenesis phase of anaerobic digestion (Eastman and Ferguson, 1981). Parkin and Owen (1986) indicated that only 30–50% of total COD (TCOD) or volatile solids (VS) in waste activated sludge, the maximum degradable fraction without chemical change, were biodegraded in 30 days unless the organic particulate organic matters contain in the sludge were properly solubilized. To increase the rate of hydrolysis and maximize the production of VFAs, operational parameters such as solids retention time (SRT), pH, temperature and sludge thickness were investigated. Elefsiniotis and Oldham (1991) studied the effect of SRT, pH and hydraulic retention time (HRT) on the fermentation of primary sludge at ambient temperature in both completely mixed and upflow anaerobic sludge blanket (UASB) reactors. Highest VFA production rates occurred at SRT between 15 and 20 days and at an HRT of 12 h. The effect of pH was found negligible within the range of 4.3 and 7.0. Ahn and Speece (2006) studied the effect of pH at thermophilic conditions in the reactors fed by primary sludge in the range of 7–11. They concluded that under alkaline conditions, the VFA production and solubilization of organic matter was high and thus, fermentation of primary sludge under alkaline conditions was beneficial. Bouzas et al. (2002) obtained maximum soluble COD and VFA production at the highest solids concentration at almost the same solids concentration range, 0.64–2.73 %. VFA production from primary sludge was optimized by adjusting SRT to 6 days at 20 °C (Bouzas et al., 2002; Bouzas et al., 2007). All these studies solely focused on the fermentation of the primary sludge to generate volatile fatty acids that leads full-scale implementation including both in-line and side-stream fermentation configurations (Münch and Koch, 1999; Bouzas et al., 2007).

Primary sludge fermentation reduces sludge volume and minimizes the operational cost of supplementary carbon dosing. However, VFA production from primary sludge fermentation is not enough to ensure efficient nutrient removal in all WWTPs such as Noosa BNR plant (Thomas et al., 2003). Addition of VFAs from activated sludge would be beneficial when the VFAs from the influent wastewater or fermented primary solids are insufficient. The hydrolysate from activated sludge fermentation can be used without any separation from the sludge which means that all the produced easily biodegradable organics can be utilized after the process unlike in primary sludge fermentation. A substantial part of the hydrolysate remains in the sludge phase after separation during fermentation of primary sludge. However, activated sludge showed low tendency to biodegradation and VFA-yields. In full-scale experiments, Andreasen et al. (1997) observed a yield of 9–16% in terms of soluble COD (SCOD) to TCOD ratio during primary sludge fermentation at 20 °C. The corresponding value found for activated sludge fermentation was 2.5% at ambient temperature, 8–17 °C. Production of VFAs from activated sludge, however, can be significantly enhanced under alkaline conditions (Yuan et al., 2006; Chen et al., 2007) and by addition of surfactant (Jiang et al., 2007a,b).

The activated sludge, generated in a substantial quantity in WWTPs is often used for methane production in digesters. However, an alternative usage of activated sludge as internal carbon source for existing biological processes in treatment plants would be of great value. The objectives of this study were thus to examine the efficiency of acid fermentation with relatively short SRT on various sludge types, especially on activated sludge, to investigate the influence of sludge origin on the acid fermentation with respect to the VFA production and composition, and to test the feasibility of implementing fermentation on different sludge types rather than the primary sludge as an internal carbon source production method for BNR processes.

2. Materials and methods

2.1. Feed sources and bench-scale experiments

Activated sludge used in this study was obtained from the aeration tank of different municipal WWTPs located in Denmark: Dragør, Avedøre, Lundtofte, and Måløv. Primary sludge was taken from Lundtofte, Lynetten, Avedøre and Helsingør WWTPs, while mixed sludge was originated from Lundtofte WWTP. The activated sludge used in semi-continuous experiments was obtained from the return-sludge stream between