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Thermal pre-treatment of aerobic granular sludge: Impact on anaerobic biodegradability

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ABSTRACT

The aerobic granular systems are a good alternative to the conventional activated sludge (AS) ones to reduce the production of sludge generated in wastewater treatment plants (WWTP). Although the quantity of produced sludge is low its post-treatment is still necessary. In the present work the application of the anaerobic digestion combined with a thermal pre-treatment was studied to treat two different aerobic granular biomasses: one from a reactor fed with pig manure (G1) and another from a reactor fed with a synthetic medium to simulate an urban wastewater (G2). The results obtained with the untreated aerobic granular biomasses showed that their anaerobic biodegradability (BD) (33% for G1 and 49% for G2) was similar to that obtained for an activated sludge (30–50%) and demonstrate the feasibility of their anaerobic digestion. The thermal pre-treatment before the anaerobic digestion was proposed as a good option to enhance the BD when this was initially low (33% G1) with an enhancement between 20% at 60 °C and 88% at 170 °C with respect to the untreated sludge. However when the initial BD was higher (49% G2) the thermal pre-treatment produced a slight improvement in the methane production (14% and 18%) and at high temperatures (190 and 210 °C) which did not justify the application of such a treatment.

1. Introduction

The sewage sludge production has increased in the European Union (EU) from 5.5 million tons of dry matter in 1992 to 10.1 million tons in 2008, and it is estimated that it will reach 13.0 million tons in 2020 (http, 2011). According to the European Commission (EC) this increase is mainly due to the implementation of the Directive 91/271/EEC for Urban Waste Water Treatment (CEC, 1991) as well as the rise up in the number of households connected to sewers and in the level of treatment. The disposal of this excess sludge represents up to 50% of the total operational costs of a waste water treatment plant (WWTP) (Appels et al., 2008). The quantity of this waste which is spread on land for agricultural use is near 40% of the total produced amount in the EU and it is regulated by the Directive 86/278/EEC (CEC, 1986). In this context the sewage sludge

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production represents an important environmental and economic point to be considered in the design of the WWTPs and new technologies have to be developed in order to, firstly, reduce its production in the process of origin and, also, to improve its subsequent treatment.

The reduction of the sludge production in the origin is an interesting alternative. In this sense, the application of the aerobic granular technology in the WWTPs instead of the conventional activated sludge process could decrease the amount of sludge generated during the secondary treatment (Campos et al., 2009). This technology, where the biomass is forced to grow in compact aggregates in sequencing batch reactors (SBRs), presents various advantages in comparison with the conventional activated sludge process: better settling properties and biomass retention, possibility to carry out simultaneous biological removal processes, capacity to treat higher loads, less surface requirements for its implantation and less sludge production. Liu et al. (2005) estimated the theoretical growth yield of aerobic granules as 0.2 g VSS/g $COD_{removed}$, which is in accordance with the results obtained by Mosquera-Corral et al. (2005) operating an aerobic granular reactor fed with a synthetic medium containing acetate. This value involves a reduction of sludge production around 30% with respect to the conventional activated sludge characterized by a sludge growth yield of around 0.3 g VSS/g $COD_{removed}$ (Heijnen and van Dijken, 1992).

However the development of the aerobic granular biomass is still recent and the research has mainly been focused on the establishment of the different optimum parameters for the reactor operation and formation of aerobic aggregates and nowadays on the scale up from laboratory to pilot reactors and to full scale plants. Up to now, no study has been focused on the treatment of this type of sludge before its disposal. Although granular sludge is expected to have anaerobic degradation potential similar to the activated sludge due to their similar origin, specific studies are necessary to prove it.

The type of treatment applied to the sludge depends on its composition and its final application but normally the first step consists of a thickening to remove the major quantity of water from the solids and reduce its volume. In this sense the dewatering cost of the aerobic granular sludge could be lower than that of activated sludge due to its higher hydrophobicity (Wang et al., 2005) and better settling properties (Beun et al., 2000).

After thickening, the biological digestion (anaerobic digestion, aerobic digestion and composting) is commonly used to transform the amount of highly degradable organic matter into a stable residue and to reduce the number of disease-causing micro-organisms present in the solids before their disposal, for example as fertilizer in agriculture. Among the biological sludge treatments the anaerobic digestion is the most suitable option due to the fact that it allows the stabilization of the sludge and also the production of energy as biogas. From previous research works it has been observed that the anaerobic biodegradability of the sewage sludge ranges from 30 to 50% depending on the type of degraded sludge and its initial organic composition (Mottet et al., 2010). To improve this conversion yield many studies have been performed applying different kinds of pre-treatment (thermal, mechanical and chemical) before the sludge anaerobic digestion (Appels et al., 2008; Carrère et al., 2010). The main objective of these pre-treatments is to improve the solids hydrolysis rate since it is the limiting step in the anaerobic digestion and also allow reducing the final amount of sludge to be disposed.

Carrère et al. (2010) compared different pre-treatment methods used to favor the biodegradability of the sludge. Although extracting a simplified conclusion is difficult, these authors observed that the low energy consuming methods, such as sonication and mechanical pre-treatment, increase the hydrolysis rate but with a limited improvement on VS reduction, while the high impact methods, such as thermal hydrolysis and oxidation, have a significant improvement on both aspects, but with higher operational costs.

Although the thermal pre-treatment presents high energy consumption, the main part of this energy to heat can be recovered from the biogas produced in the anaerobic process. The literature shows that the thermal treatment can be applied in different ranges of temperature and with different times of treatment. Zheng et al. (1998) used a rapid thermal conditioning (30 s) at high temperature (220 °C) and obtained a VS reduction of 55% and a total increase in gas production of 80%, while Gavala et al. (2003) applied the pre-treatment of sludge at 70 °C during 7 days to obtain an increase of 26% in the methane production. Furthermore to know the impact that each pre-treatment has, on each sludge biodegradability, an anaerobic test under batch or continuous conditions is normally performed, which implies long operational periods (between 20 and 30 days for batch tests). In this context Mottet et al. (2010) proposed an estimating model to predict the anaerobic biodegradability of waste activated sludge based on the link between the initial composition of the sludge and its biochemical methane potential (BMP). These authors used the partial least square (PLS) regression technique to obtain a model where both macroscopic (soluble organic carbon and COD/TOC ratio) and biochemical (carbohydrates, proteins and lipids concentrations) parameters were used to predict the anaerobic biodegradability of waste activated sludge.

The aim of this study was to test the effect of the thermal pre-treatment on the macroscopic and biochemical characteristics of the aerobic granular sludge and also to determine the anaerobic biodegradability enhancement when this pre-treatment is applied. The obtained results were also used to validate the model proposed by Mottet et al. (2010) to estimate the anaerobic biodegradability of the aerobic granular biomass.

2. Material and methods

2.1. *Aerobic granular sludge samples*

The aerobic granular sludge samples were taken from two sequencing batch reactors (SBRs) at pilot scale (useful volume of 100 L each). The first tested sludge (G1) was collected from a reactor located at Santiago de Compostela (Spain) fed with the liquid fraction of pig slurry. In this reactor the removal of organic matter and nitrogen occurred in a SBR operated in cycles of 3 h distributed according to the following periods: 3 min of feeding, 171 min of aeration, 4 min of settling and