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# Enhancement of methane production in mesophilic anaerobic digestion of secondary sewage sludge by advanced thermal hydrolysis pretreatment

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ARTICLE INFO

*Article history:*
Received 16 August 2014
Received in revised form
10 November 2014
Accepted 16 December 2014
Available online 24 December 2014

*Keywords:*
Secondary sewage sludge
Thermal hydrolysis
Advanced thermal hydrolysis
Mesophilic anaerobic digestion
Biochemical methane potential tests
Methane production

ABSTRACT

Studies on the development and evolution of anaerobic digestion (AD) pretreatments are nowadays becoming widespread, due to the outstanding benefits that these processes could entail in the management of sewage sludge. Production of sewage sludge in wastewater treatment plants (WWTPs) is becoming an extremely important environmental issue. The work presented in this paper is a continuation of our previous studies with the aim of understanding and developing the advanced thermal hydrolysis (ATH) process. ATH is a novel AD pretreatment based on a thermal hydrolysis (TH) process plus hydrogen peroxide ($H_2O_2$) addition that takes advantage of a peroxidation/direct steam injection synergistic effect. The main goal of the present research was to compare the performance of TH and ATH, conducted at a wide range of operating conditions, as pretreatments of mesophilic AD with an emphasis on methane production enhancement as a key parameter and its connection with the sludge solubilization. Results showed that both TH and ATH patently improved methane production in subsequent mesophilic BMP (biochemical methane potential) tests in comparison with BMP control tests (raw secondary sewage sludge). Besides other interesting results and discussions, a promising result was obtained since ATH, operated at temperature (115 °C), pretreatment time (5 min) and pressure (1 bar) considerably below those typically used in TH (170 °C, 30 min, 8 bar), managed to enhance the methane production in subsequent mesophilic BMP tests [biodegradability factor ($f_B$) = *cumulative* $CH_4$ *production/cumulative* $CH_4$ *production (Control)* = 1.51 ± 0.01] to quite similar levels than conventional TH pretreatment [$f_B$ = 1.52 ± 0.03].



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http://dx.doi.org/10.1016/j.watres.2014.12.027
0043-1354/

## 1. Introduction

The increasing amount of sludge that is produced in wastewater treatment plants (WWTPs) encourages researchers and engineers to pay more attention to particular aspects of its management, especially to recycling and waste-to-energy issues.

According with the literature in the field of the anaerobic digestion (AD) of sewage sludge, two major concerns are the improvement of the organic dry solids degradation efficiency and the methane production in the mesophilic AD process (Weiland, 2010; Appels et al., 2011a; Mudhoo, 2012; Schievano et al., 2012; Wang et al., 2013; Ruiz-Hernando et al., 2014).

Although nowadays AD is considered an economic and environmentally friendly technology and a major and essential part of a modern WWTP, AD presents certain limitations regarding high retention times, restricted methanogenic production and low overall organic dry solids degradation efficiency (30–50% in mesophilic AD) (Strong et al., 2011). Many authors in the literature agree that these mainly are inherent consequences of the low performance of the microorganisms involved in the hydrolysis stage of solids such as flocs, microflocs, aggregates of extracellular polymeric substances (EPS), recalcitrant compounds of proteins and lipids, as well as components of hard cell walls (cellulose, hemicellulose and lignin) (Carballa et al., 2011). However, other works in the literature stated that for certain experimental conditions soluble organics [soluble chemical oxygen demand (SCOD), soluble carbohydrates and soluble proteins] do not influence the biochemical methane potential (BMP) (Appels et al., 2011b). It was also stated that the slow increase in methanogens is the kinetic bottleneck for methane production due to, for instance, possible inhibitory effects by certain compounds and/or the lack of required compounds (Strong et al., 2011). This latter statement was already mentioned as hypothesis in our previous work (Abelleira et al., 2012a).

The conventional mesophilic AD presents a low yield [<40% sludge reduction and biogas production (mostly $CH_4$ and $CO_2$)] (Pérez-Elvira et al., 2011). It is extensively known that biogas presents high potential as an energy source (1 $m^3$ $CH_4$ = 10 kWh) (Kepp et al., 2000). Hence, many efforts are being employed in order to develop technologies for enhancing the biogas production, quality and energy use. In fact, a very common proposal in order to improve the methane production is the implementation of pretreatment processes prior to AD. An enormous quantity of works dealing with the study, design and development of alternative AD pretreatments can be found in the literature (Appels et al., 2008; Wilson and Novak, 2009; Hii et al., 2013; Ruiz-Hernando et al., 2014).

On the one hand, among AD pretreatments, thermal hydrolysis (TH) (with heating by injection of live steam from a boiler) has a high level of acceptance in the scientific and industrial fields, with an increasing number of full scale units in WWTPs all over the world (Morgan-Sagastume et al., 2011). A general consensus does exist on the optimum TH operating conditions at industrial scale, which are 170 °C, 30 min and 8 bar (equilibrium pressure corresponding to saturated steam inside the reactor) (Fdz-Polanco et al., 2008). Quite remarkable results on the AD methane production enhancement thanks to TH (170 °C, 30 min, 8 bar) can be consulted in the literature. Working with mixed sludge, Kepp et al. (2000) estimated that the net electricity production from the combination TH + AD would be over 20% higher than with conventional AD. Pérez-Elvira et al. (2010a) reported 40% higher yield of biogas from the system TH + AD than from the conventional AD, experimenting with mixed sludge. Donoso-Bravo et al. (2011) reported around 55% higher yield of biogas from the system TH + AD than from the conventional AD, testing with waste activated sludge. Results from Wang and Wang (2005) are also consistent with those ones. Its advocates state that another advantage of the combination TH + AD is that the energy input needed for the hydrolysis process is thermal energy that can be satisfied from the excess energy production of the process itself, resulting in an energetically self-sufficient process (Pérez-Elvira et al., 2012).

On the other hand, thermochemical pretreatments of the AD have been widely studied and proposed as alternatives to the TH process (Appels et al., 2008). Examples of them are alkaline thermal hydrolysis (Neyens et al., 2003a; Vlyssides and Karlis, 2004; Liu et al., 2008; Carrère et al., 2010; Zhang et al., 2010), acid thermal hydrolysis (Neyens et al., 2003b; Liu et al., 2008, 2009), or, to a lesser extent, wet oxidation (Khalil et al., 2005; Takashima and Tanaka, 2008; Strong et al., 2011; Appels et al., 2012). In this field of study, recent investigations concerning the combination of hydrogen peroxide ($H_2O_2$) or ozone ($O_3$) addition and thermal treatment (without steam injection) can also be found in the literature (Genç et al., 2002; Valo et al., 2004; Cacho-Rivero and Suidan, 2006; Takashima and Tanaka, 2008). In comparison with TH, despite recording some interesting results the thermochemical pretreatments do not show an overall satisfactory efficiency in terms of the $CH_4$ production enhancement in subsequent AD, as can be checked in the literature. In this sense it is also a reality that, as it was verified by the authors, there are few works that deal with the comparison between TH and thermochemical pretreatments of sewage sludge. Moreover, none of them include experimentation with heating by injection of live steam from a boiler, neither an exhaustive comparative study of several operating conditions (Kim et al., 2003; Valo et al., 2004; Takashima and Tanaka, 2008; Strong et al., 2011).

Additionally, in our previous works another thermochemical alternative to the TH process was reported and studied (Abelleira et al., 2012a,b). This novel process, called Advanced Thermal Hydrolysis (ATH), exploits the synergistic effect of peroxidation plus direct steam injections, without using catalysts, and is intended to operate under conditions that are less severe than those in other thermal or thermochemical pretreatments. In those works, the ATH process was demonstrated to have a high efficiency yielding quite good results. ATH produced a high enhancement on the solubilization of secondary sewage sludge, at temperatures ($T$ = 115 °C) and reaction times ($t$ < 30 min) less severe than those commonly applied in the TH process (170 °C, 30 min) (Abelleira et al., 2012a,b).

The aim of this research was to compare the performance of TH and ATH as pretreatments of mesophilic AD, with an emphasis on the methane production enhancement as a key