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A critical review on anaerobic co-digestion achievements between 2010 and 2013

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ABSTRACT

Anaerobic digestion is a commercial reality for several kinds of waste. Nonetheless, anaerobic digestion of single substrates presents some drawbacks linked to substrate characteristics. Anaerobic co-digestion, the simultaneous digestion of two or more substrates, is a feasible option to overcome the drawbacks of mono-digestion and to improve plant's economic feasibility. At present, since 50% of the publication has been published in the last two years, anaerobic co-digestion can be considered the most relevant topic within anaerobic digestion research. The aim of this paper is to present a review of the achievements and perspectives of anaerobic co-digestion within the period 2010–2013, which represents a continuation of the previous review made by the authors [3]. In the present review, the publications have been classified as for the main substrate, i.e., animal manures, sewage sludge and biowaste. Animal manures stand as the most reported substrate, agro-industrial waste and the organic fraction of the municipal solid waste being the most reported co-substrate. Special emphasis has been made to the effect of the co-digestion over digestate quality, since land application seems to be the best option for digestate recycling. Traditionally, anaerobic co-digestion between sewage sludge and the organic fraction of the municipal solid waste has been the most reported co-digestion mixture. However, between 2010 and 2013 the publications dealing with fats, oils and greases and algae as sludge co-substrate have increased. This is because both co-substrates can be obtained at the same wastewater treatment plant. In contrast, biowaste as a main substrate has not been as studied as manures or sewage sludge. Finally, three interdisciplinary sections have been written for addressing novelty aspects in anaerobic co-digestion, i.e., pre-treatments, microbial dynamics and modeling. However, much effort needs to be done in these later aspects to better understand and predict anaerobic co-digestion.

Contents

1. Introduction . . . 413
2. Animal manures as a main substrate . . . 413
   2.1. Traditional and new co-substrates for animal manure co-digestion . . . 414
   2.2. Digestate quality for agricultural use . . . 416
3. Sewage sludge as a main substrate . . . 417
   3.1. Sewage sludge co-digestion with biowaste . . . 417
   3.2. Sewage sludge co-digestion with fats, oils and greases . . . 417
   3.3. Sewage sludge co-digestion with other organic wastes . . . 419

Abbreviations: AcoD, anaerobic co-digestion; AD, anaerobic digestion; BMP, biomethane potential test; CM, cow manure; CSTR, continuous stirred tank reactor; C/N, carbon-to-nitrogen ratio; DGGE, denaturing gradient gel electrophoresis; EU, European Union; FISH, fluorescence in situ hybridization; FOG, fat, oil and grease; FVW, fruit and vegetable waste; FW, food waste; GLY, glycerol; HRT, hydraulic retention time; IBR, induced bed reactor; LCFA, long chain fatty acids; MSW, municipal solid waste; OLR, organic loading rate; OLR_{FOG}, FOG organic loading rate; OFMSW, organic fraction of municipal solid waste; OMW, olive mill waste; PCR, polymerase chain reaction; PS, primary sludge; PM, pig manure; SHW, slaughterhouse wastes; SMP, specific methane production; SS, sewage sludge; TOC, total organic carbon; TS, total solids; TSS, total suspended solids; T-RFLP, terminal restriction fragment length polymorphism; WAS, waste activated sludge; US, ultrasound pre-treatment; VFA, volatile fatty acid; VS, volatile solids; VSS, volatile suspended solids; WW, wastewater; WWTP, wastewater treatment plant

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3.4. Sewage sludge co-digestion in full-scale plants . . . 420
4. Biowaste as a main substrate . . . 420
5. Pre-treatments as option to improve AcoD performance . . . 421
6. Microbial dynamics . . . 422
6.1. Biomass dynamics in full-scale plants . . . 423
7. Anaerobic co-digestion modeling . . . 423
8. Conclusions . . . 423
References . . . 424

1. Introduction

Anaerobic digestion (AD) is a biological treatment performed in the absence of oxygen to stabilize organic matter while producing biogas, a mixture formed mainly of methane and carbon dioxide. The oldest and more widespread application of AD is the treatment of sewage sludge (SS). AD experienced an important growth after the first energy crisis in the 1970s, especially with the appearance of immobilized biomass systems to treat soluble effluents, and now it can be considered a mature technology [1,2]. Nonetheless, AD of single substrates (mono-digestion) presents some drawbacks linked to substrate properties. For instance, (i) SS is characterized by low organic loads, (ii) animal manures have low organic loads and high N concentrations, that may inhibit methanogens, (iii) the organic fraction of municipal solid waste (OFMSW) has improper materials as well as a relatively high concentration of heavy metals, (iv) crops and agro-industrial wastes are seasonal substrates, which might lack N, and (v) slaughterhouse wastes (SHW) include risks associated with the high concentration of N and/or long chain fatty acids (LCFA), both potential inhibitors of the methanogenic activity. Most of these problems can be solved by the addition of a co-substrate in what has been recently called anaerobic co-digestion (AcoD).

AcoD, the simultaneous AD of two or more substrates, is a feasible option to overcome the drawbacks of mono-digestion and to improve the economic viability of AD plants due to higher methane production [1]. Initially, because of the research perspective, AcoD focused on mixing substrates which favor positive interactions, i.e. macro- and micronutrient equilibrium, moisture balance and/or dilute inhibitory or toxic compounds [3]. Under these circumstances, $1+1>2$ may be achieved, that means, co-digestion is producing more methane than the addition of the methane produced in both single digestions. However, nowadays, because of the industrial outlook and since the improvement of methane production is mainly a consequence of the increase in the organic loading rate (OLR) rather than synergisms, all kinds of mixtures are considered and used. Actually, the transport cost of the co-substrate from the generation point to the AD plant is the first selection criteria. Despite this fact, it is still important to choose the best co-substrate and blend ratio with the aim of favoring synergisms, dilute harmful compounds, optimize methane production and not disrupt digestate quality.

As illustrated in Fig. 1, AcoD publications have experienced a dramatic increase in the last years. In fact, at the present time, AcoD can be considered the most relevant topic within anaerobic digestion research. As can be seen, 50% of the overall papers have been published between 2012 and 2013, whereas 75% of them have been published in the period 2009–2013.

Examining the papers published between 2010 and 2013, it appears that the most frequent main substrates are animal manures (54%), SS (22%) and the OFMSW (11%). At the same time, the most used co-substrates are industrial waste (41%), agricultural waste (23%) and municipal waste (20%) (Fig. 2).

The aim of this paper is to present a review of the achievements and perspectives of anaerobic co-digestion within the period 2010–2013 (up to the 13th World Congress on Anaerobic Digestion), which represents a continuation of the previous review made by the authors [3]. The use of manures, sewage sludge, and organic fraction of municipal solid waste as main substrates, either full-scale or research experiences, is discussed throughout the paper. Furthermore, the review also pays attention to other aspects like pretreatments, digestate quality, microbial community dynamics, and modeling.

2. Animal manures as a main substrate

In the rural sector, AD has been established as an important economical alternative, specifically as a renewable energy source; hence animal manures have become an important raw material [3]. Nonetheless, manures are often associated with poor methane yields. AcoD of manures with other substrates has been applied as a cost-effective alternative to improve process efficiency and consequently make plants economically feasible [4–6]. Two main models can be chosen for the implementation of agriculture-based

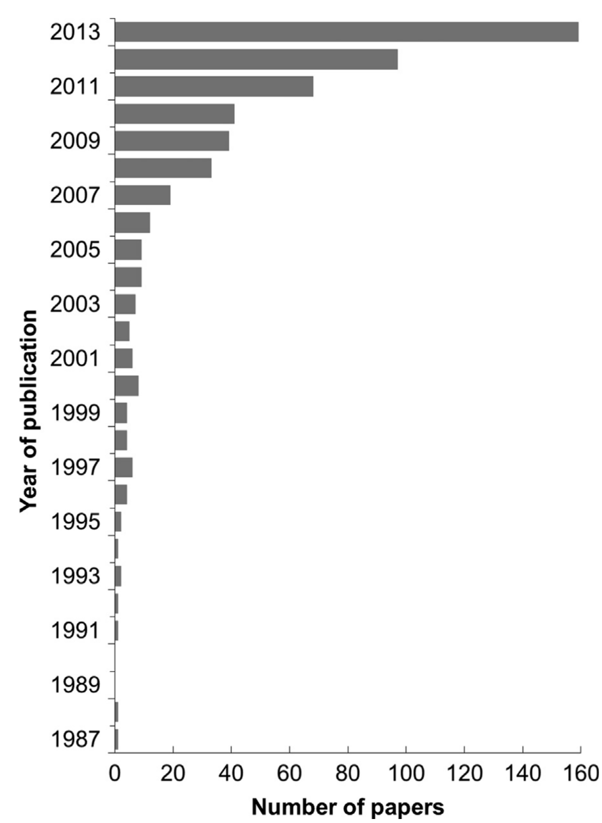

Fig. 1. Evolution of number of papers published with the words co-digestion or co-digestion in its title.