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Pretreatment methods to enhance anaerobic digestion of organic solid waste

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HIGHLIGHTS

- Pretreating organic solid wastes leads to an enhanced anaerobic digestion process.
- Pretreatments may also reduce the cost for post treatment of digestates.
- Efficiency of pretreatment methods depends on the substrates' characteristics.
- Only few pretreatment methods are successfully applied at full-scale to date.

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ABSTRACT

This paper reviews pretreatment techniques to enhance the anaerobic digestion of organic solid waste, including mechanical, thermal, chemical and biological methods. The effects of various pretreatment methods are discussed independently and in combination. Pretreatment methods are compared in terms of their efficiency, energy balance, environmental sustainability as well as capital, operational and maintenance costs. Based on the comparison, thermal pretreatment at low (<110 °C) temperatures and two-stage anaerobic digestion methods result in a more cost-effective process performance as compared to other pretreatment methods.

Contents

Abbreviations: AD, anaerobic digestion; COD, chemical oxygen demand; CSTR, continuously stirred reactor; FW, food waste; HHW, household waste; HMF, hydroxymethylfurfural; HPH, high pressure homogenizer; HRT, hydraulic retention time; MSW, municipal solid waste; OFMSW, organic fraction of municipal solid waste; OLR, organic loading rate; OM, operational and maintenance; OSW, organic solid waste; PEF, pulsed electric field; SRT, solid retention time; SS, sewage sludge; THP, thermal hydrolysis process; TPAD, temperature phased anaerobic digestion; WWTP, wastewater treatment plant; TS, total solid; UASB, upflow anaerobic sludge blanket; VS, volatile solid; VFA, volatile fatty acid; WAS, waste activated sludge.

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1. Introduction

Anaerobic digestion (AD) is one of the oldest and well-studied technologies for stabilizing organic wastes [1]. Among the treatment technologies available for treating organic solid wastes (OSW), AD is very suitable because of its limited environmental impacts [2–5] and high potential for energy recovery [2,3,6]. Such positive aspects coupled with the recent concerns on rapid population growth, increasing energy demand, and global warming have promoted further research on the AD process development and improvement in order to enhance biogas production, achieve faster degradation rates and reduce the amount of final residue to be disposed [3,4,7].

AD is a biological process that converts complex substrates into biogas and digestate by microbial action in the absence of oxygen through four main steps, namely hydrolysis, acidogenesis, acetogenesis and methanogenesis. Most researchers report that the rate-limiting step for complex organic substrates is the hydrolysis step [8–26], due to the formation of toxic by-products (complex heterocyclic compounds) or non desirable volatile fatty acids (VFA) formed during the hydrolysis step [27,28]; whereas methanogenesis is the rate-limiting step for easily biodegradable substrates [24,27,29,30]. Extensive research has been conducted on pretreatment methods to accelerate the hydrolysis step [31,32] and to obtain suitable by-products from this step [28], as well as to improve the quality of useful components like nitrogen and phosphorus to be recycled [33].

According to European Union Regulation EC1772/2002, substrates such as municipal solid waste (MSW), food waste (FW), and slaughterhouse wastes need to be pasteurized or sterilized before and/or after AD. Taking this regulation into account, pretreatment methods could be applied, thus obtaining a higher energy recovery and eliminating the extra cost for pasteurization and/or sterilization [34,35]. Pretreatment methods could nevertheless be unsustainable in terms of environmental footprints, even if they enhance the AD process performance [36]. The effects of various pretreatment methods are highly different depending on the characteristics of the substrates and the pretreatment type. Hence, it is difficult to compare and systematically assess the applicability and sustainability of such methods at a full scale.

In the recent past a number of reviews have been published with a common aim to assess the pretreatment effects. Table 1 shows that most of the research on pretreatment methods has been conducted on wastewater treatment plant (WWTP) sludge and/or lignocellulosic substrates; whereas there is a limited number of reviews on the recently growing interest of pretreatment methods to enhance AD of OSW, specifically the organic fraction of municipal solid waste (OFMSW). Therefore, this paper aims to review the most recently studied pretreatment methods including mechanical, thermal, chemical and biological methods to enhance AD of OSW, with an emphasis on OFMSW. The pretreatment methods will be compared in terms of efficiency, energy balance, cost and process sustainability.

2. Mechanical pretreatment

2.1. Process description and mode of action

Mechanical pretreatment disintegrates and/or grinds solid particles of the substrates, thus releasing cell compounds and increasing the specific surface area. An increased surface area provides better contact between substrate and anaerobic bacteria, thus enhancing the AD process [3,24,25]. Esposito et al. suggested that a larger particle radius results in lower chemical oxygen demand (COD) degradation and a lower methane production rate [37]. Likewise, Kim et al. showed that particle size is inversely proportional to the maximum substrate utilization rate of the anaerobic microbes [38]. Therefore, mechanical pretreatments such as sonication, lysis-centrifuge, liquid shear, collision, high-pressure homogenizer, maceration, and liquefaction are conducted in order to reduce the substrate particle size.

In addition to size reduction, some methods result in other effects depending on the pretreatment. Hartmann et al. reported that the effect of maceration is more due to shearing than cutting of the fibers [39]. Sonication pretreatment generated by a vibrating probe mechanically disrupts the cell structure and floc matrix [40]. The main effect of ultrasonic pretreatment is particle size reduction at low frequency (20–40 kHz) sound waves [41]. High-frequency sound waves also cause the formation of radicals such as OH^*, HO_2^*, H^*, which results in oxidation of solid substances [42].