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Accelerating natural cycles with anaerobic digestion

How can pretreatments overcome the limitations of the main solid feedstock anaerobic digestion?

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Abstract: Pretreatment technologies for improving the anaerobic digestion of solid wastes have been intensively investigated during the last decade. Manure, sludge and the organic fraction of municipal solid wastes (OFMSW) are among the most studied anaerobic digestion solid feedstock. Indeed, there has been an exponential increase in the number of publications including the pretreatment of solid feedstock like sludge, manure and OFMSW, but also lignocellulosic biomass and algae. Clearly the most appropriate pretreatment depends on the properties of each feedstock. In the case of sludge, pretreatments are intended to release intracellular compounds, being biological, thermal and mechanical technologies already applied at full-scale. Lignocellulosic biomass requires delignification and cellulose solubilisation, achieved through biological, chemical and /or mechanical methods. Manure pretreatments are generally biological (i.e. composting) or mechanical. As far as animal by-products are concerned, thermal pretreatments are compulsory to ensure sanitation, but mechanical ones are also applied.

Keywords: Anaerobic digestion, Pretreatment technologies, Solid feedstock

Session: *Pretreatment technologies (physicochemical/biological)*

Introduction

The bottleneck of solid feedstock anaerobic digestion is the hydrolysis, which in practise hinders the anaerobic digestion rate and extent. For this reason, several pretreatment techniques have been investigated during the last years, and some of them are already applied at full-scale plants.

A bibliometric study shows that manure and sludge, along with the organic fraction of municipal solid waste and food waste (OFMSW) are the most addressed feedstock in papers dealing with the anaerobic digestion of solid waste, with over 3,500 references each (Figure 1A). If we look at the amount of papers including a feedstock pretreatment, they represent some 20% in the case of manure, animal by-products (ABP) and the OFMSW, whereas this proportion increases to 30% for algae, 34% for sludge and even 80% for lignocellulosic biomass. This percentage is certainly correlated to the recalcitrance of the feedstock. Figure 1B shows the publication dynamic of papers dealing with the pretreatment of each kind of feedstock prior to their anaerobic digestion. Sludge is by far the most studied substrate, with more than 20 papers per year since 2006. Lignocellulosic biomass, the OFMSW and manure display the same pattern, with more than 20 papers per year since 2010; and algae since 2013. All of them show an exponential increase in the number of publications. Conversely, animal by-products or fatty waste have been addressed in relatively few papers, and do not show any relevant increase.

The objective of this presentation is to provide a comprehensive overview on the limitations of the main anaerobic digestion solid feedstock and the application of pretreatments to overcome these limitations.

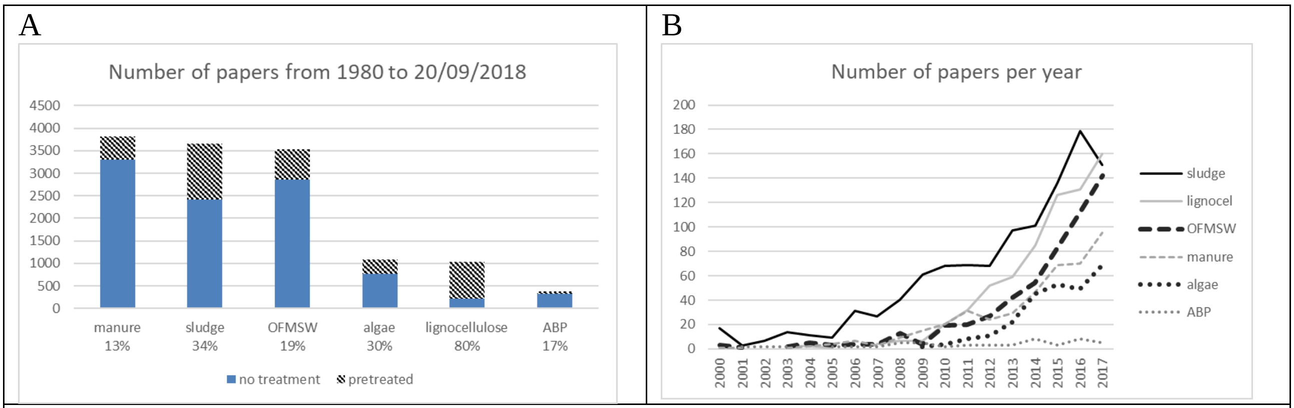

Figure 1. Bibliometric study from Web of Science.
A. Number of papers and percentage of papers with pretreatment.
Total (no treatment + pretreated): « anaerobic digestion or biogas » and « feedstock » as topic.
Pretreated: « anaerobic digestion or biogas »and « pretreatment » and « feedstock » as topic.
B. Number of papers /year with « anaerobic digestion or biogas » and pretreatment » and « feedstock » as topic
Feedstock : « manure », « sludge », OFMSW : « OFMSW or municipal_solid_waste or food_waste », « *alga* », « lignocell* », ABP : « animal byproducts or fatty waste or slaughterhouse »

Limitations of the main solid feedstock anaerobic digestion

Sludge and microalgae

The main limitation for the anaerobic digestion of sewage sludge, in particular waste activated sludge, is the low accessibility of biodegradable compounds, like exopolymeric substances ensuring the floc cohesion and, above all, intracellular compounds. It is also the case for microalgae, with however some differences in the composition of cellular membranes and taking into account that most microalgae have cell wall. The pretreatment goal is thus the solubilisation of intracellular materials (Zeng et al. 2017).

Lignocellulosic biomass and manure

In lignocellulosic biomass, biodegradable material consists in soluble compounds (proteins, sugars) and cellulose and hemicellulose polymers. However, polysaccharide polymers (in particular cellulose) are hardly accessible to enzymes because they are embedded within the lignocellulosic matric, lignin being the main barrier. According to their biodegradability, polysacharides can be classified as follow: hemicellulose ≥ amorphous cellulose >> crystalline cellulose. The pretreatment primary objectives are the breakage of bounds between polysaccharides and lignin, degradation and solubilisation of lignin, and increase of accessible surface area; while secondary objectives are the reduction of cellulose crystallinity and degree of polymerisation. Manure is often associated to lignocellulosic biomass as it contains straw or even plant residues digested by animals, a difference being its content in nitrogen.

Fatty waste and animal by-products

The main drawbacks of fatty waste include the insolubility in water, which hinders the contact between microorganisms and substrate; and the inhibiting properties of long chain fatty acids. Thus, pretreatments aim at solubilising fatty acids. In addition to fats, animal by-products are also rich in proteins, which after degradation may lead to ammonia inhibition. Besides, animal by-products sanitation is compulsory.

Food and organic fraction of municipal solid waste

The OFMSW is generally composed of food waste and green waste (i.e. lignocellulosic biomass). However, food waste is so biodegradable that it may undergo fermentation during the storage or transportation, eventually causing acidification problems during anaerobic digestion, especially in batch and solid state processes. Another issue is the preservation of carbon and methane potential (Parthiba Karthikeyan et al., 2018). Pretreatments should aim at i) preserving the methane potential, ii) avoiding acidification problems, and iii) increasing the availably of hardly accessible material.

Overview of the main pretreatments

Features of the main pretreatments are summarised in Table 1. Biological pretreatments may involve enzymes, anaerobic or aerobic processes. Whereas ensiling is widely used to store energy crops, some aerobic treatments are capable of degrading lignin but at the expenses of carbon loss as CO_2 (Bremond et al., 2018). Thermal pretreatments gather low temperature (50-70°C for few hours-days, which imply biological mechanisms) and high temperature (150-170°C) or steam explosion. They are quite efficient for sludge and microalgae solubilisation. Thermoacid pretreatments are efficient in polysaccharide solubilisation, whereas alkali and thermoalkali ones lead to protein solubilisation, lipid saponification and lignin degradation. Some mechanical techniques such as grinding, maceration, extrusion aim at reducing the particle size and are generally used to manage the feedstock and digester feeding. Other mechanical pretreatments such as sonication, high pressure, electroporation or lysing centrifuge are applied at full-scale anaerobic digestion of sludge.

Table 1. Features of main pretreatments applied in the anaerobic digestion (AD) of solid wastes.

Pretreatment	Results	Advantages	Drawbacks	TRL
Enzymatic	Decrease of viscosity Low impact on biogas	Can be added in digester	Cost Enzyme/substrate specificity	Full-scale (lignocellulose and sludge) Lab-scale, promising (fatty waste)
Composting (aerobic)	Temperature increase Can decrease acidification risks in food waste AD Increase in waste biodegradability	Low energy demand	Carbon loss	Full-scale (manure dry AD) Pilot scale (OFMSW)
Fungi (aerobic)	Increase of lignocellulosic biomass biodegradability, making feedstock with high lignin content suitable for AD	Low energy demand	Carbon loss Long duration	Lab-scale, promising (high lignin content biomass)
Ensiling (anaerobic)	Storage method for energy crops No/low impact on biogas	Low energy demand		Full-scale (energy crops)
Thermal at low temperature (50-70°C) (anaerobic)	High increase of biogas production (sludge and microalgae)	Sanitation Low energy demand	Long duration	Full-scale (compulsory for animal by products)
Hydrothermal at high temperature (130-170°C) and steam explosion	High increase of biogas production (sludge and microalgae)	Sanitation Short duration	High energy demand High CAPEX Dewatered biomass Risk of recalcitrant compounds formation	Full-scale (sludge, OFMSW,animal by products)

Thermo-chemical	High increase of biogas production : saponification (fatty waste) and alkaline pretreatment (lignocellulosic biomass)	Lower energy demand than thermal pretreatments	Cost Chemical contamination Risk of inhibitors formation	Lab-scale promising for animal by-product Full-scale for other applications of lignocellulose (2G bioethanol)
Chemical	High increase of biogas production with alkaline pretreatment (lignocellulosic biomass)	Lower energy demand Easy scale-up	Cost Chemical contamination Risk of inhibitors formation	Lab-scale, promising (lignocellulosic biomass)
Grinding, maceration pulping	Size reduction No/low increase in biogas production	Ease feedstock management No risk of recalcitrant compounds formation	High electricity demand	Full-scale (lignocellulosic biomass, animal by-products, manure)
Extrusion	Size reduction Low increase in biogas production	Ease feedstock management No risk of recalcitrant compounds formation Can be combined with chemicals	Electricity demand	Full-scale (lignocellulosic biomass, manure) Pilot-scale (OFMSW, sludge)
High pressure	Low increase in biogas production (sludge)			Full-scale (sludge)
Ultrasound	High increase of biogas production (sludge) Low increase of biogas production (microalgae)	No risk of recalcitrant compounds formation	High electricity demand	Full-scale (sludge)
Electroporation/ pulsed power	High increase of biogas production (sludge)		Electricity demand	Full-scale (sludge)
Lysing centrifuge	Low increase of biogas production (sludge)	Low cost (adaptation from classical centrifuge)		Full-scale (sludge)
Microwave	High increase of biogas production (sludge and microalgae) Low increase of biogas production (lignocellulosic biomass)		High electricity demand Scalability	Lab-scale

Conclusion

The most appropriate pretreatment depends on the properties of each feedstock. Several pretreatment technologies are currently applied at full-scale, mainly for sewage sludge, but also for lignocellulosic biomass, manure, the OFMSW and animal by-products. These include biological (enzymatic, aerobic and anaerobic), thermal (low and high temperature) and mechanical (grinding, maceration pulping, extrusion, high pressure, sonication, etc.) methods.

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