Improving microalgae anaerobic digestion in algal-based wastewater treatment systems: co-digestion and pretreatment strategies

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IMPROVING MICROALGAE ANAEROBIC DIGESTION IN ALGAL-BASED WASTEWATER TREATMENT SYSTEMS: CO-DIGESTION AND PRETREATMENT STRATEGIES

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INTRODUCTION

Microalgae-based wastewater treatment systems rely on the symbiosis between microalgae and heterotrophic bacteria, which degrade organic matter consuming oxygen provided by microalgae photosynthesis. At the same time, microalgae enable nutrient removal from wastewater by assimilation. Moreover, microalgae can be harvested and reused to produce bioenergy. Anaerobic digestion is a well-known technology implemented in many wastewater treatment plants (WWTP) to convert biodegradable organic matter into biogas. Several studies have demonstrated the feasibility to produce biogas from microalgae grown in WWTP (Ward et *al*., 2014). However, several limitations have been pointed out: a) microalgae have a resistant cell wall which limits its bioconversion; b) their production shows a seasonal pattern; c) they are substrates with high nitrogen content (e.g. they may lead to unbalanced C/N and risk of ammonia toxicity). To overcome these drawbacks, the bioconversion process can be improved by applying pretreatments prior to anaerobic digestion. Also, microalgae can be co-digested with other carbon-rich substrates to achieve high organic loading rates (OLR) over the year and a balanced C/N ratio.

In this work different strategies to enhance microalgae anaerobic digestion have been evaluated. To this end, co-digestion with different substrates was analyzed applying different pretreatments depending on the properties of the co-substrates. Wastes produced in WWTP (i.e. primary sludge and trap grease) were tested as co-substrates. In addition, co-digestion with storable agricultural by-products (i.e. wheat straw) was also evaluated. Pretreatments with minimal energy input and environmental impact were preferred.

MATERIAL AND METHODS

Microalgal biomass (A) was grown in a pilot high-rate algal pond treating real wastewater from a municipal sewer in Barcelona. The algal pond received the primary effluent of a settling tank and was used as secondary treatment unit. Primary sludge (PS) and trap grease (TG) were collected from a municipal WWTP near Barcelona. Wheat straw (WS), grown in France, was milled and sieved before use (400 µm -1 mm).

Firstly, investigation was focused on co-digestion of microalgae with waste from WWTP. Co-digestion of microalgal biomass with PS was initially investigated by means of Biochemical Methane Potential (BMP) tests (glass bottles of 160 ml) and the best conditions were validated in continuous-flow reactors (2 L), operated under mesophilic conditions and at 20-days of Hydraulic Retention Time (HRT). Microalgae were tested with and without thermal pretreatment whereas no pretreatments were applied to PS since it is a more readily degradable substrate. Thermal pretreatment of microalgae was conducted in glass bottles of 250 ml under continuous stirring at 75ºC during 10 h, since previous research reported promising results under similar conditions (Passos & Ferrer, 2014). Then, the addition of TG during anaerobic co-digestion performance was evaluated in BMPs.

Finally, co-digestion of microalgae with agricultural by-products was also tested. To this end, anaerobic co-digestion of microalgae and wheat straw was performed in BMP for substrates with and without pretreatment. In this case, lime pretreatment at mild temperatures (thermo-alkaline) was applied (10% of CaO w/w at 72ºC for 24h). Co-digestion of microalgae and wheat straw in continuous-flow reactors is currently being investigated.

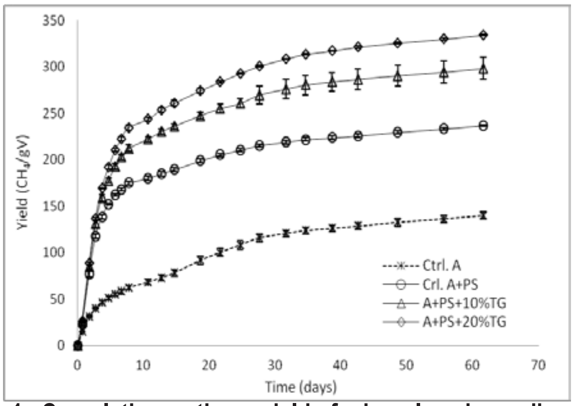
RESULTS AND DISCUSSION

Regarding microalgae and PS co-digestion, results showed that PS enhanced the anaerobic digestion of microalgal biomass in both cases. Compared to control (without PS), methane yields were increased by 65% for non-pretreated and by 155% for pretreated microalgal biomass, respectively (Table 1). With the results obtained, an energy assessment was showed to determine the viability of the pretreatment and co-digestion. The study concluded that while the energy balance of pretreated microalgal biomass as a sole substrate was neutral, co-digestion with primary sludge led to 300% energy surplus. This energy gain points out the feasibility of anaerobic co-digestion of microalgal biomass with PS in full-scale WWTPs. To close the material cycle, digestate was characterised and proved to be suitable for agricultural reuse as organic fertilizer. In addition, some properties of the digestate, such as the dewaterability, were significantly improved after co-digestion. Further BMP tests showed that significant methane yield increase (25-40%) could be achieved if microalgae and PS were co-digested with trap grease bringing 10-20% of volatile solids added (Figure 1).

Regarding anaerobic co-digestion of microalgae and wheat straw, the best performance was observed with pretreated samples that showed an increase of 23% in methane yield compared to untreated microalgae. The first-order degradation rate constant was also increased from 0.09 d^{-1} up to 0.16 d^{-1}.

Table 1. Anaerobic co-digestion performance of microalgal biomass with PS and controls for microalgae anaerobic digestion as sole substrate. First period without without pretreatment and second period with thermally pre-treated microalgae. Mean Values (Standard Deviation) of 10 measurements.

	Without pretreatment		With pretreatment	
	Microalgae	Co-digestion	Microalgae	Co-digestion
OLR (g VS/L·d)	1.92 (0.28)	1.87 (0.20)	1.20 (0.07)	1.21 (0.04)
Methane production rate (L CH_4/L·d)	0.38 (0.10)	0.63 (0.13)	0.20 (0.05)	0.53 (0.29)
Methane yield (L CH_4/g VS_{added})	0.20 (0.04)	0.33 (0.07)	0.18 (0.02)	0.46 (0.24)
VS removal (%)	23.1 (5.3)	43.9 (1.9)	27.2 (2.2)	32.2 (3.7)



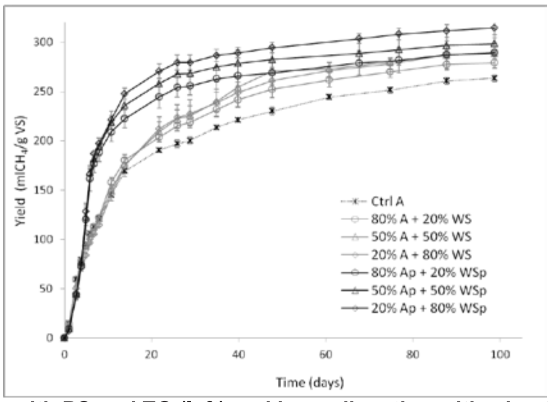


Fig. 1. Cumulative methane yield of microalgae in co-digestion with PS and TG (left) and in co-digestion with wheat straw (right). A: microalgal biomass, Ap: pretreated-A; WS: wheat straw; WSp: pretreated-WS.

CONCLUSIONS

Co-digestion of thermally-pretreated microalgae and PS appears to be the most suitable alternative to improve microalgae digestion as PS is a readily available and degradable substrate produced in the same WWTP. Additionally, co-digestion with trap grease from WWTP is a potential strategy to further increase methane production. Also, the use of wheat straw as a storable co-substrate can provide carbon and increase the OLR during seasons with low microalgae production. In this case, thermo-alkaline pretreatment is recommended.

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