Evaluation of biogas improvement in secondary reactor of agricultural anaerobic digestion plant by mechanical and physical-chemical processes

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EVALUATION OF BIOGAS IMPROVEMENT IN SECONDARY REACTOR OF AGRICULTURAL ANAEROBIC DIGESTION PLANT BY MECHANICAL AND PHYSICAL-CHEMICAL PROCESSES

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INTRODUCTION

European survey (Foged, 2011) revealed that anaerobic digestion (AD) is the most commonly used option for livestock manure processing, in a favourable context with incentives for the production of electricity from AD plants. Most of the existing AD plants treating livestock effluents are composed by two or more reactors in series with long hydraulic retention times (HRT) (Weiland 2010). Although with the presence of more reactors, most biogas is produced in the first digester and the final effluent has residual methane yield not negligible (Ruile et al. 2015). Improving the second reactor performance can improve the total biogas production, deplete higher amount of solids and reduce the GHG emission in the storage tanks.
The biodegradability of the livestock effluents is limited by slow hydrolysis rate because of their molecular structure which is poorly accessible to microorganisms and their enzymes (Montgomery and Bochmann, 2014). Several studies show that hydrolysis rate depends on both the size and the surface of the particles (Veeken and Hamelers, 1999). Mechanical pretreatments, such as grinding, decrease the size of the particles and consequently increase the total accessible specific surface area of the substrate (Dumas et al., 2015). In order to enhance biodegradability, grinding process can be used alone or even combined with other chemical and physical treatments.
In this study, the effect of pretreatments on digestate biodegradability was evaluated with particular attention paid on grinding pretreatment. The combinations of mechanical/thermal and mechanical/chemical pretreatment were also studied.

MATERIALS AND METHODS

Two samples of digestate from first stage of AD were collected in two different periods (Table 1) from a mesophilic full-scale plant with two digesters in series. The plant treats a mixture of manure, green waste and other agricultural residues in variable proportion along the year.

Table 1. Characteristics of digestate used as substrate in this study (TS: total solids, VS: volatile solids, pH, total alkalinity, sCOD: soluble Chemical Oxygen Demand, tCOD: total Chemical Oxygen Demand, NH_4^+: Ammonium)

	TS (g/kg)	VS (g/kg)	pH	Total alkalinity (g $CaCO_3$/l)	sCOD (gO_2/l)	tCOD (gO_2/l)	NH_4^+ (gN/l)
Digestate 1	95.9	65.5	8.5	16.0	9.3	113.0	1.1
Digestate 2	71.9	48.8	8.0	12.9	10.5	85.7	nd

The digestates were grinded with a cutting device (Brandt BLE615EG) at maximal rate for different treatment periods. The period of 10 minutes was chosen for the AD tests as the best compromise between solubilization rate and temperature increase (see results and discussion).

Four mesophilic anaerobic digesters (6 l of working volume) were run in parallel for 90 days. Two reactors filled with raw and grinded digestates respectively were operated in batch mode without using any inoculum, in order to understand the effect of grinding on potential biogas production and on biomass activity. Biogas production and composition were monitored and the final digestates were characterized (TS, VS, COD, nitrogen, granulometric distribution). The other two reactors were filled with anaerobic granule seed from UASB reactor and operated in semi-continuous mode by feeding with raw and grinded digestates respectively. Hydraulic retention time of 30 days was applied to simulate the condition in the secondary digester of the full-scale plant. Semi-continuous trials allowed the evaluation of the long-term impact of pretreatment on an unadapted active biomass. Stability parameters and digestate characteristics (TS, VS, sCOD, NH_4^+ and total nitrogen) were weekly determined while biogas production was monitored online. Grinding process alone was compared with i) ultrasound pretreatment, ii) combination of grinding with chemical treatments (NaOH, HCl and H_2O_2) and iii) combination of grinding with thermal processes. COD solubilization and particle size were determined for each treatment. Methane yields were determined by BMP (Biochemical Methane Potential) tests at 37°C.

RESULTS AND DISCUSSION

Optimization of grinding treatment

Increase of grinding period (up to 105 min) improves the COD solubilization (up to a threefold increase of sCOD). However, long treatment also causes heating of digestate (temperature higher than 50°C), that combines the thermal solubilization to the grinding one. Moreover, high temperature associated with long mechanical process, can also lead to losses of organic material (Carlsson et al., 2012).

Measure of insoluble lignin, cellulose and hemicellulose confirmed the partial solubilization of these compounds after 10 minutes of mechanical treatment. Considering the sCOD concentration and the final temperature around 40°C, the treatment period of 10 minutes was considered in the AD trials.

Comparison of batch mode reactors

Batch tests showed that pretreatment caused an initial inhibition of degradation highlighted by 10 days of lag-phase. However, the maximum biogas production rate and the potential biogas production (estimated by modified Gompertz model) are higher than with raw digestate. Maximum biogas production rate ranged from 0.88 to 1.20 l/d. The biogas production slightly increased from 0.084 to 0.093 $l/gVS_{initial}$ respectively with raw and grinded digestates.

Semi-continuous processes

Semi-continuous reactors had comparable stability parameters while the biogas production increased on the basis of initial digestate characteristics. The preliminary results showed that grinding effect on the process performances was associated with the feeding mixture of the main reactor and consequently with initial digestate characteristics (i.e. sCOD/tCOD ratio). The effect of grinding was better for well-stabilized digestate with low residual biogas potential (+58% of biogas production) compared to non-stabilized digestate (only +10% biogas production).

Other pretreatments

BMP tests of digestate after combined pre-treatment gave encouraging results. In particular, thermal pre-treatment of grinded digestate (165°C, 15 atm) increased the hydrolysis rate and improved the biogas production (+95%) in the first 20 days.

CONCLUSIONS

Grinding pretreatment of the first stage anaerobic digestion effluent reduces insoluble lignin concentration and consequently improves the solubility and bioavailability of organic matter. An initial inhibition of the anaerobic microorganisms activity was observed after grinding. However, the biodegradability increased after a longer period. Semi-continuous trials showed that biogas yields depended from initial digestate characteristics: biogas yields of well-stabilized digestate increased significantly after grinding. The effect of pretreatment could improve if the mechanical process is combined with chemical or thermal process.

REFERENCES

Carlsson, M., Lagerkvist, A., Morgan-Sagastume, F. (2012) The effects of substrate pretreatment on anaerobic digestion systems: a review. Waste Management. 32: 1634–50.

Dumas, C., Silva Ghizzi Damasceno, G., Abdellatif, B., Carrère, H., Steyer, J.-P., Rouau, X. (2015) Effects of grinding processes on anaerobic digestion of wheat straw. Industrial Crops and Products 74: 450–456.

Foged, H.L., 2011. Inventory of Manure Processing.

Montgomery, L., Bochmann, G. (2014) Pretreatment of feedstock for enhanced biogas production. IEA Bioenergy 24.

Ruile, S., Schmitz, S., Mönch-Tegeder, M., Oechsner, H. (2015) Degradation efficiency of agricultural biogas plants--a full-scale study. Bioresource Technology 178: 341–9.

Veeken, A., Hamelers, B. (1999) Effect of temperature on hydrolysis rates of selected biowaste components. Bioresource Technology 69: 249–254.

Weiland, P., 2010. Biogas production: Current state and perspectives. Applied Microbiology and Biotechnology 85: 849–860.