Enhancing biogas production from recalcitrant lignocellulosic residue - DTU Orbit

(28/09/2019)

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Lignocellulosic substrates are abundant in agricultural areas around the world and lately, are utilized for biogas production in full-scale anaerobic digesters. However, the anaerobic digestion (AD) of these substrates is associated with specific difficulties due to their recalcitrant nature which protects them from enzymatic attack. Hence, the main purpose of this work was to define diverse ways to improve the performance of AD systems using these unconventional biomasses. Thus, mechanical and thermal alkaline pretreatments, microaeration and bioaugmentation with hydrolytic microbes were examined. The studied substrates were fresh and ensiled meadow grass, regularly cultivated ensiled grass, digested manure fibers and wheat straw. AD of lignocellulosic substrates is time demanding and an extended incubation period is often needed. Initially, diverse analytical methods were used (i.e. electrical conductivity, soluble chemical oxygen demand and enzymatic hydrolysis) as a rapid way to predict the methane production. However, the precision of methane yield prediction was not high (R2 < 0.68) and thus, the biochemical methane potential (BMP) test is concluded to be the most precise method to estimate the biomethanation process. Various mechanical pretreatments were examined on ensiled meadow grass biodegradability by applying shearing forces. Preliminary results showed that the methane production of ensiled meadow grass can be efficiently increased up to 25% compared to untreated samples. Hence, the most efficient method was further applied on the same substrate, focusing on different age of vegetation under mono- and co-digestion with livestock manures (i.e. poultry, mink and cattle manure). The differences on biomass’ chemical composition were also determined in order to demonstrate the effect of vegetation stage. Clear alterations were revealed due to late harvest time and specifically, the lignin content was markedly augmented (~30% of dry matter) with advancing age, implying the need of pretreatment. Mechanically pretreated biomass of increased maturity was co-digested with diverse livestock manures in order to define the optimum silage/manure ratio in the feedstock. Results showed that the ideal lignocellulose/manure contribution differs among the examined substrates and that the chemical characteristics of the feedstock mixture significantly influenced the biomethanation process. The application of shearing forces was also examined on the hardly degradable fraction of digested manure fibers. However, limited efficacy was observed on biomethanation and the remaining volatile solids (VS) were not highly utilized. Conversely, the well-studied thermal alkaline pretreatments using sodium hydroxide as a catalyst promoted the yield from approximately 42 mLCH4/gVS to 170 mLCH4/gVS. Furthermore, the positive results were validated in the co-digestion of biofibers with cattle manure under continuous mode operation. Mechanical and thermal alkaline pretreatment (6% NaOH at 55 °C for 24 h) had an effect of 7% and 26% respectively, without provoking process inhibition. Focusing on full-scale practices, the application of simple and efficient treatment methods is generally suggested. Accordingly, the reduction of supply chain steps prior to AD could eventually improve the energy budget and subsequently, process profitability. Hence, the integration of mechanical pretreatment at harvesting step was examined as a solution to scale-up the used mechanical method in real-life applications. On this topic, an innovative Disc-mower (named as Excoriator) was studied in order to simultaneously harvest and pretreat fresh meadow grass through the application of shearing forces. Kinetic studies showed that the lag phase was decreased, the methane production rate was increased and finally, the methane yield was significantly enhanced by up to 27% under optimal conditions. Further investigations on full-scale experiments mowing regularly cultivated grass confirmed the positive effect due to the selection of the most appropriate harvester. The modern harvester poses the ability improve the energy balance and subsequently, the sustainability of lignocellulose-based AD. The co-digestion of pig manure and lignocellulosic silage was assessed in continuous stirred tank reactors (CSTR). Addition of mechanically pretreated silage in the feedstock positively affected the methane yield (+16%) and in parallel, reduced the risk of ammonia inhibition compared to mono-digestion of pig manure. Furthermore, metagenomic analysis was performed to determine differences among the microbial communities in CSTRs operating under mono- and co-digestion. Species similar to Clostridium thermocellum, with increased cellulolytic activity, were detected to be adherent to the solid fraction of digested feedstock and concluded to be key cultures due to their cellulosic solubilization. Moreover, the results showed that the increased methane production rate is due to the effect of oxygen load (O2), pulse repeatability and treatment period on the AD of wheat straw. The results obtained from this study demonstrated a 7.2% increase in methane yield after a 3 days microaeration period, using 5 mL O2/gVS served by once. In addition, an optimisation study was conducted and the analysis indicated that the methane yield could have been increased by 9%, if 7.3 mL O2/gVS were injected. It was indicated that microaeration can be an alternative solution for augmented biomass solubilization without causing inhibition to the mandatory anaerobic methanogenic community. Based on the initial microbial analysis, the bioaugmentation with the typically abundant in AD systems C. thermocellum was examined in biogas reactors fed with wheat straw. Bioaugmentation with the hydrolytic strain had immediately a remarkable result on methane production. Nevertheless, the long term monitoring showed that routine bioaugmentation is needed to retain a positive effect of approximately 7%. Moreover, it was indicated that the bioaugmentation with C. thermocellum can be periodically applied in biogas reactors in order to extract the residual methane from the amassing materials and avoid potential accumulation. Additionally, the facultative anaerobic Melioribacter roseus was inoculated in a replicate CSTR following different bioaugmentation strategies, either strictly anaerobic or micro-aerobic conditions. Nevertheless, the novel strain did not enhance the biomethanation process and the metagenomic analysis revealed that the inoculated strain did not adapt in the biogas reactor. The results obtained confirm that lignocellulose-based AD can lead to high biogas yield. At lab-scale experiments, the bioenergy production can be further improved using micro-aeration, bioaugmentation with C. thermocellum, thermal-alkaline or mechanical pretreatments. Further insights into AD microbiome can improve and optimize the used processes. Among the examined pretreatments, only mechanical methods were evaluated in full-scale operation due to their easiness in application. On this topic, modern harvesting technology simulating the process applied in lab-scale could generate similar enhancement under full-scale trials. Machineries orientated to pretreat biomass using simplified techniques can positively affect the industrial applications.