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Enhancement of Biogas Production from Laying Hen Manure via Sonolysis as Pretreatment

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Abstract

Aim of this study is to investigate the effect of sonication as a pretreatment on the efficiency of anaerobic digestion of Laying Hen Manure (LHM) under mesophilic conditions. In this study,the pretreatment studies were carried out using two different sonotrode (BS2d22 and BS2d40) and two different types of booster (B2-1,4 and B2-1,8) at four different amplitudes (9, 31, 40, 81 µm) at two time settings (5 and 15 min duration). Biochemical Methane production Potential (BMP) test protocol was also employed in order to evaluate the effect of sonication under varying amplitudes on the biogas production for 50 days. The BMP results obtained in this work suggested that sonication significantly enhanced the biogas productivity of chicken manure which was much lower if it was digested alone. Between 12-70% increase in methane production depending on the sonolysis matrix used was obtained in comparison to control group which had no sonication as pretreatment. The best result was obtained at an amplitude of 81 µm and 5 min sonication duration which is a combination of BS2d22/B2-1,4. The results of experiment demonstrated that use of this pretreatment technology could significantly enhance the biogas production from chicken manure.

Keywords: Anaerobic digestion; Biogas; Chicken manure; Methane; Pretreatment; Ultrasound

Introduction

Ultrasonication (US) has been considered as an environmentally and economically sound pretreatment strategy [1]. Several studies found in the literature have shown that sonication is an effective pretreatment for the enhancement of anaerobic biodegradation of organic wastes [1-3]. Sonication is the application of ultrasound waves to a confined liquid resulting in violent collapse and turbulence which then drives thermal destruction and forming of radicals [4]. Sonication is reported to result in increased solubilisation and reduction of particle size allowing for greater biodegradability [5]. Anaerobic Digestion (AD) processes are frequently preferred for biomethane production from organic wastes, especially animal manure. However, efficiency of anaerobic conversion for biogas production have always been questioned because of the fact that some potential wastes for bioconversion are relatively problematic including chicken manure [1,2]. The prime drawbacks of the conventional AD technology is the need for extremely long hydraulic retention times and large bioreactor volumes due to the lower microbial conversion rates. The non-availability of the readily biodegradable soluble and organic matters and lower digestion rate constant necessitates the pretreatment of biomass to be digested [6]. Some pretreatment strategies are capable of separating the lignin from the readably degradable cellulose fibers, allowing for greater AD efficiency. Therefore, applying a pre-treatment process are preferred in order to improve the rate limiting step of the AD process as a result of the existence of the lignocellulose and hemicellulose and to shorten the required reaction time for biomethane production [6-11]. The efficiency of disintegration depends on the sonication parameters and also on biomass characteristics, therefore the evaluation of the optimum parameters varies with the type of sonicator and biomass to be treated. With this inspiration from literature, it was decided to test the hypothesis that whether or not the sonication would enhance the anaerobic conversion of laying hen manure to biomethane and up to what extent.

Materials and Methods

The laying hen manure used in this study was kindly obtained from a local farm located in Izmir, Turkey.All the Chicken Manure (CM) was stored in a refrigerator at +4°C until used. Some characteristic parameters of stock CM were 85% DM (organic dry matter) and 30% DM (dry matter), this stock manure was then diluted down to 5% DM before sonication experiments.

The anaerobic consortium was obtained from the anaerobic sludge digester of a local yeast factory and was used as inoculum in BMP (Biochemical Methane Production Potential) assay.

Pretreatment process

All sonication experiments were carried out in 1000 ml glass container at room temperature. The ultrasonic processor used in this study was a Hielsher UIP 1000HD which has a maximum operating power of 1000 W, operational frequency of 20 kHz ± 1 kHz and maximum amplitude value up to 150 µm depending on sonotrode and booster (Figure 1).

The ultrasonic pretreatment studies were carried out using two different sonotrode (BS2d22 and BS2d40)and booster (B2-1,4 and B2-1,8) at three different amplitudes (9, 31, 81 µm) and at two time settings (5 and 15 min) as shown in Table 1. 800 ml of manure mixture having 5% DM content in 1000 ml glass container was sonicated according to

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Figure 1: Experimental apparatus used during the sonication tests.

UIP1000hd	Frontal area [cm²]	Max. Amplitude* at 100% [µm]				
		Booster as Reducer			Booster as Booster	
Sonotrode		B2-1,8	B2-1,4	No Booster	B2-1,4	B2-1,8
BS2d22 (F)	3,8	26	**40**	57	**81**	106*
BS2d40 (F)	12,5	**9**	14	17	26	**31**

*With amplitudes >100 µm, the lifetime of sonotrodes will be reduced drastically

Table 1: Experimental conditions during sonication.

the experimental conditions given in table 1 (bold figures) for 5 and 15 min of reaction times.

Biochemical Methane Potential (BMP) Assay

Biochemical Methane Potential assay (BMP) was used to monitor the anaerobic biodegradability of chicken manure [12]. The BMP assay was performed in serum bottles (working volume is 100 ml) and these test was applied to both raw and pre-treated samples for comparison purpose in parallel. Each BMP bottle was seeded with anaerobic stock culture (40 ml), basal medium (15 ml) and chicken manure (20 ml; 5% DM). The control serum bottles that contained only anaerobic stock culture and basal medium but no organic wastes were also run in all experiments to determine the background gas production.After seeding the BMP test bottles, they were purged with N_2 gas for 2-3 min to maintain anaerobic conditions and then sealed with natural rubber stoppers and plastic screw-caps. The serum bottles were then incubated at 36 ± 1°C and were shaken at 150 rpm throughout the study. Total gas production recorded daily for at least 50 days by a glass syringe and the methane content of biogas in the headspace was determined by Gas Chromatography (GC). All experiments were run as triplicate and the mean values of net biogas production were reported in this study.

Analytical methods

The pH measurements were taken with a pH meter (WTW pH meter). Dry matter and Suspended Solids (SS) values were measured by following the standard methods. The methane and carbon dioxide content of the biogas was measured on an Agilent gas chromatograph equipped with a flame ionization detector and a DB-FFAP 30 m × 0.32 mm × 0.25 mm capillary column (J&W Scientific, USA).

Results and Discussions

Figure 2 shows the results of batch anaerobic digestion tests applied to both raw and pretreated chicken manure under various sonication conditions having amplitude values of 9, 31,40 and 81 µm (peak-to-peak measurement, producer information) as given in Table 1. The aim of these tests was to comparatively evaluate the effect of various combinations of sonotrode and booster couples on the enhancement of anaerobic conversion of chicken manure tested. Figure 2 also displays the volumetric daily methane production over time for all pretreatments and a control set that had no pretreatment at all.All BMP tests were carried out for at least 50 days. Each test group was tested against the control group which had no US pretreatment. As shown in Figure 2, in most instances the methane content could be increased by acoustic cavitation in comparison to the untreated sample. Best results could be reached on the one hand with high amplitudes and low reaction time and on the other hand with low amplitudes and long reaction time. The cumulative biomethane measurements for all tests (except for one condition) showed that sonication resulted in a higher biomethane conversion (obvious indication of better biodegradability) with respect to quantity of biomethane produced in comparison to control group (untreated raw sample). If the final biomethane gas production values at day 50 are carefully evaluated, the sonication pretreatment resulted in varying amount of percentage increase biomethane production varying between 0% and 74%. Lower left corner in Figure 2 shows the results of sonication experiments with amplitude of 9 µm and varying reaction time between 5 to 15 min. When the amplitude was increased to 31 µm as seen in the upper left corner of Figure 2, both reaction time resulted in almost equal increase in biomethane production which is better than the control one. It is quite obvious from the lower right corner of the Figure 2 that 40 µm amplitude was the best one in terms of biomethane production but needing longer reaction time. On the other hand, the use of amplitude of 81 µm required only 5 min reaction time to achieve the same high biomethane production. It is seen from the Figure 2 that even though sonication pretreatment resulted in higher biogas production than the control one and an increase in ultrasound amplitude had a positive effect on the biomethane yield in general, furthermore the effect of reaction time is also significant. It is known that increasing reaction time and amplitude leads to a higher number of cavitation bubbles and therefore to increased cavitational effects. Perez-Elvira (2009) studied the effect of ultrasound pretreatment for anaerobic digestion improvement in both batch experiments and continuously fed plot bioreactor [13]. The authors reported up to 42% increase in biogas production with batch tests. Their data from continuously operating digester with a volume of 100 L also indicated that pretreatment of sludge resulted in higher volatile solids removal and increased biogas production varying between 25-37%. These results were achieved at HRT value of 15 d which could actually be obtained in a bioreactor fed with non-pretreated at HRT=20 d. This result indicated that pretreatment also allowed use of higher organic loading rates resulting shorter HRT values

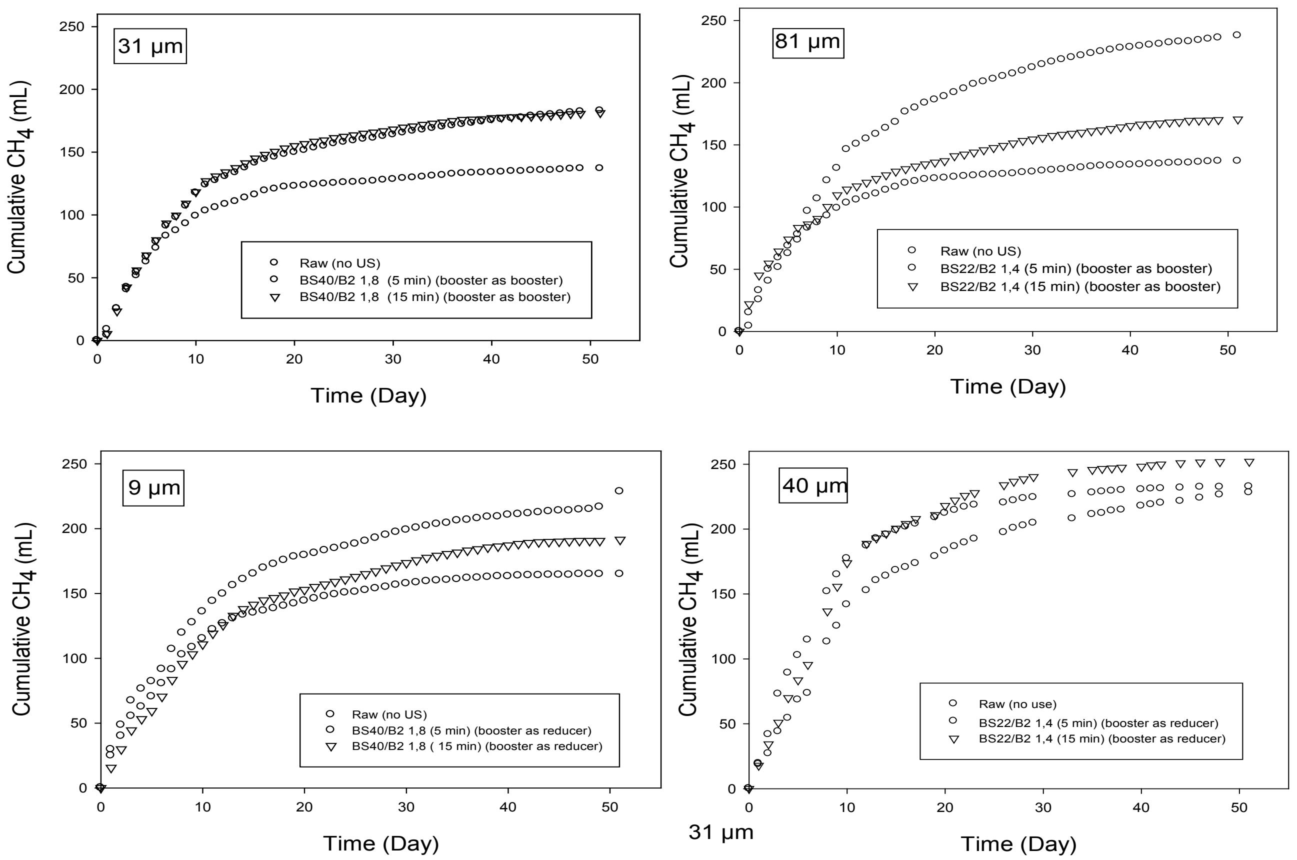

Figure 1: The results of batch anaerobic digestion tests.

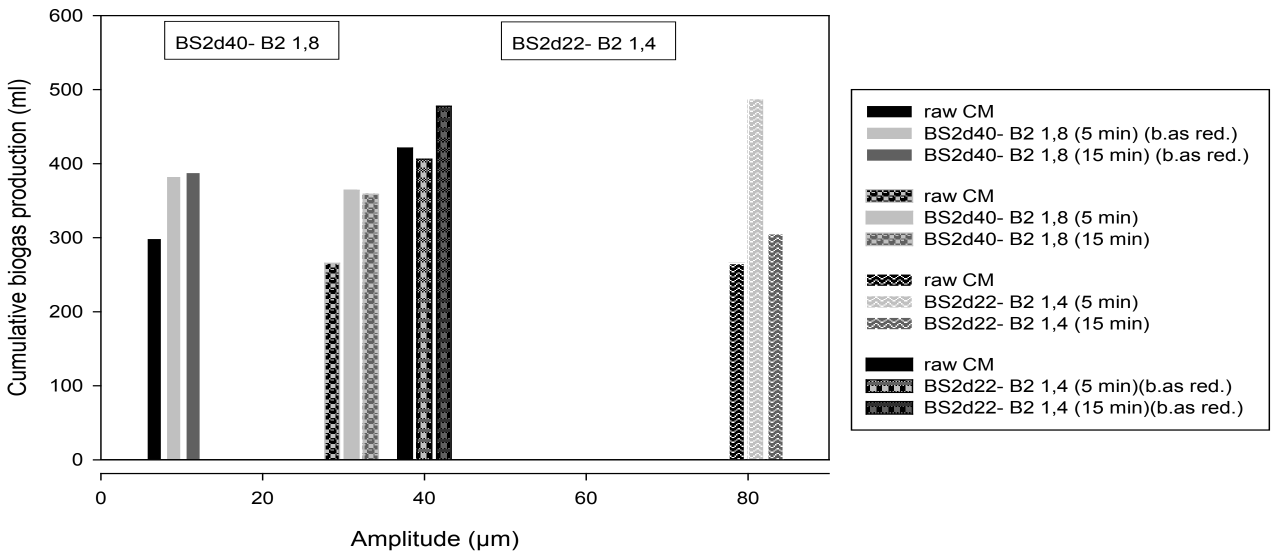

Figure 3: The effect of amplitude values on BMP test for each operational condition.

Figure 3 shows the effect of amplitude values on BMP test for each operational condition. It is obvious from Figure 3 that both amplitude and reaction time are significant factors. Up to the amplitude of 40 µm in general (except for 31 µm), increasing biogas volume was observed in comparison to control group that had no pretreatment. While the best result in terms of highest biogas production was obtained at an amplitude of 81 µm (BS2d22/B2-1, 4 as booster), longer reaction time (>5 min) has detrimental effect resulting in reducing biogas production.

It is important to note that the experiment using the amplitude of 40 μm (BS2d22/B2-1, 4 as reducer) showed high biogas production but needed 3 times longer reaction time (15 min).

Sonication has been increasingly used for enhancing the digestion of wastewater treatment plant sludge, animal manures in both Europe and USA. According to Hogan et al. sonication provides improved solids destruction, substantially increased biogas production, enhanced dewatering, decreased sludge production, reduced operating costs, and a reasonable payback period [14]. Muller et al. also reported that various disintegration pretreatment methods such as maceration, sonication and ozonation at full scale significantly increased improvement of biogas production due to increased solubilisation of degradable material [15]. Cesaro et al. reported 24% higher biogas production than untreated one when sonication was applied to solid waste samples. Cesaro et al. explained the mechanism that sonolysis significantly improved the solubilisation of organic waste [16]. Personal communication of the authors with large scale user of sonolysis technology as a pre-treatment in biogas production indicated higher biogas production up to 20% in comparison to those which had no similar pre-treatment.

Conclusions

Various pre-treatment strategies for AD including sonication were tested before which was quite less for laying hen manure. Disintegration via ultrasonication improves biomass digestibility by disrupting biosolids and bacterial cells, releasing intracellular components due to the solubilisation of the particulate matter, decreasing Solid Retention Time (SRT) and improving the overall performance of anaerobic digestion. Laboratory test resulted in promising results for the applications of full-scale systems indicating that pre-treatment is capable of increasing the efficiency, productivity and applicability of AD systems. The full-scale installations of ultrasonication also provided promising results which would be as high as 50% increase in the biogas generation.

Even though, each pretreatment would increase the capital cost of AD plant, obvious benefits such as increase in biomethane volume per unit mass of manure would make sonication more affordable and preferable. Literature reports indicate that the average ratio of the net energy gain to electric consumed by the ultrasound device is 2.5. In addition, strict environmental regulations and legislations have great impact on agricultural operations forcing farmers to rethink environmentally sound and economically tolerable novel solutions for the safe disposal of animal manure. In this manner, animal farms, especially chicken farms, have been experiencing significantly increasing waste management stress that needs the incorporation of the technologies that will comply with strict regulations while being capable of marinating profitability. Last but not least, profitability will drive the agricultural sector implement these technologies and exploit the benefits.

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