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Improving Biogas Production of Sugarcane Bagasse by Hydrothermal Pretreatment

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Abstract: Sugarcane bagasse is a biological waste which is widely generated from sugar mill industries. Its use in these factories is a potential way of environmental pollution and that's why it needs to be valorized like by-products in biorefineries sectors, especially for biogas production. Sugarcane bagasse has been characterized and pretreated by hydrothermolysis in a reactor for enabling the inoculums activity. The anaerobic digestion has been experimented in batch process and biogas volume has been followed during 23 days of production time. The aim of this work is to investigate the effect of hydrothermolysis on the chemical composition, the potential and the kinetics of biogas production from sugarcane bagasse. The hydrothermal treatment produces 42.86% of hydrolysis yield, by increasing the amount of lignin from 22% to 47% of dry matter, without degradation of cellulose. Hydrothermolysis increased biogas yield (to approximately 15%) from 85.63 Nl/gVS and 100.57 Nl/gVS and accelerates biogas production kinetics without pH changes.

Keywords: Sugarcane Bagasse, Hydrothermolysis, Anaerobic Digestion, Biogas

1. Introduction

Sugarcane bagasse is a fibrous residue produced by extraction of juice and is classified like a waste which is widely throwing out to sugar-refineries about 234 millions of tons per year in world [1]. In Cameroon, this by-product represents a great renewable substrate with potential estimated to 227.112 tons per year [2]. Sugarcane bagasse is used as fodder, input in paper mill and cement works. In sugar refineries, 60% of that is used for cogeneration but this process raises gas emissions and conflagrations in cause of his flammable nature. In spite of these ways of valorization of this by-product, it stays an important useless and noisy stock in excess, 41.165 tons per year, which can be potentially used in biorefineries sector [2]. Many biological treatments (bioethanol production, composting…) have been applied for a renewable management of this waste but biogas technology proves to be one of the most efficient process either in factories (energy) or in agriculture (fertilizers) [3]. Sugarcane bagasse is classified among recalcitrant substrates to biodegradation in cause of his high content of fibers (lignin, hemicelluloses) despite his biogas potential which is 45.074.880 normolitres per ton of dry matter [3]. Therefore, pretreatment remains necessary to enable the accessibility of organic matte rand accelerate the anaerobic digestion process [3]. Various techniques have been tried, including mechanical treatments [4], thermochemical treatments [5], biological treatments [6] and thermal treatments [5]. Hydrothermolysis constitutes one of the most efficient physicochemical treatments because it has a great advantage to realize a selective hydrolysis of hemicellulosic fraction by using a cheap reagent and provides biofuels production [1]. The aim of this work is to determine the influence of optimal conditions of hydrothermolysis on the yield and kinetics of biogas production of sugarcane bagasse.

2. Experimental

2.1. Substrate

Sugarcane bagasse procured from a sugar mill at Nkoteng, Cameroon (SOSUCAM) was used as a source of lignocellulosic biomass. The substrate was washed and dried to remove the unwanted particles and then sieved into powder form (1mm).

2.2. Inoculum

The sewage sludge used as the inoculums was collected from a domestic anaerobic digester in Bini-Dang, Ngaoundere III^e, Cameroon and stored at 4°C until further chemical analysis.

2.3. Pretreatment

Hydrothermolysis was performed in a 150 ml stainless steel batch reactor constructed at mechanical Laboratory (ENSAI). Hydrothermal treatment was applied at 170°C during 2h using a liquid/solid ratio of 4:1 (w/w). After the samples were filtered and solid residues were dried until constant weight.

2.4. Analytical Methods

The raw and the pretreated bagasse samples were analyzed and dry matter (DM), volatile solids (VS), Total Nitrogen (TN) and organic carbon (OC) were determined according to standard methods [7]. The pH value was measured by pH meter (Consort C863, multi parameter analyzer, Belgium). The content of lignin (LIG), cellulose (CELL), hemicelluloses (HEM) were determined according to the method proposed by Van Soest et al. (1991). Total sugars (TS) were determined according to the procedures proposed by Dubois et al. (1956). Weight loss (WL) was determined by directly weighing substrates before and after treatments, after drying in an oven at 105°C to a constant weight.

2.5. Biomethane Potential Tests

Methane production was assessed by batch biochemical potential (BMP) test in mesophilic conditions. The anaerobic digestion system was designed to quantify the biogas and its quality was demonstrated using a laboratory Bunsen burner by the flammability test.

2.5.1. Experimental Design

Each sample was wet before mixing in a 1000 ml polytetrafluoroethane (PTFE) bottle with the degassed inoculum according to the method proposed by Angelidaki et al. (2009) [8].

To conduct the experiments, the ratio Inoculum/Substrate (I/S) was fixed to 20/80 for raw and pretreated substrate. In addition, 10 g/l of sodium bicarbonate was also introduced in each reactor to buffer against pH changes during the anaerobic digestion. The digesters were closed air tight with rubber caps and were incubated in water baths at 37°C (figure 1). The inputs were periodically stirred by shaking individual reactor and the digestion time for all treatments was 23 days. Biogas volume produced was monitored by replacement method. The replacement method used for quantifying the produced biogas was applied by measuring the liquid displacement in the inverted cylinder and 2% sodium hydroxide solution was used for the dissolution of carbon dioxide (CO_2) from the biogas. The measured volumes were corrected for pressure and temperature differences and all volumes were expressed as normalized volumes. The pH of each digester was periodically measured for acidity control and the daily measured volumes were compared with the blank tests, where the biogas is produced only by the inoculum. The flammability was then tested by lighting the burner after switching on the gas valve.

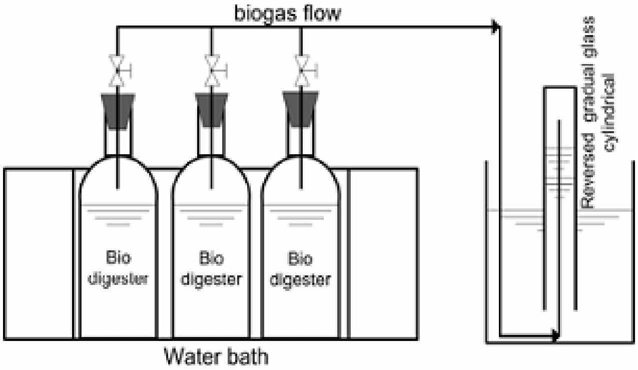

Fig. 1. *Experimental set up of anaerobic digestion process.*

2.5.2. Biodegradation Kinetics Modeling

Daily cumulative biogas yield was modeled using a modified form of Gompertz growth model. This model assumes that daily cumulative biogas production V (ml/gVS) is a function of digestion time *t* (day) described by the following equation (1):

$$V(t) = V_{max}.\exp\left[-\exp\left(\left(\frac{R_{max}.e}{V_{max}}\right).(\lambda - t) + 1\right)\right] \quad (1)$$

Where V_{max} is biogas yield potential (ml/gVS), R_{max} is the maximum biogas production rate (ml/gVS.d) and λ is the yield lag time in day. The three parameters of the model (V_{max}, R_{max} and λ) for biogas yields potentials in each treatment were estimated by the Levenberg-Marquadt algorithm in SCILAB curve fitting software (SCILAB®Version5.4.1).

3. Results and Discussion

3.1. Sugarcane Bagasse Composition

The chemical composition (lignin, cellulose, hemicelluloses) of the raw sugarcane bagasse sample used in the present study is shown in the table 1. The results of total solids, volatile solids, ash content, organic carbon and total nitrogen are also shown in this table.

Table 1. *Chemical composition of raw sugarcane bagasse.*

Item	Raw sugarcane bagasse
Total solids (%RM)	90.5±0.4
Ash content (%DM)	2.4±0.1
Volatile solids (%DM)	97.7±0.1
Organic carbon (%DM)	56.68±0.05
Total nitrogen (%DM)	0.4±0.2
C/N ratio	131.81
Lignin (%DM)	22±1
Cellulose (%DM)	43.6±0.1
Hemicelluloses (%DM)	17.2

DM: dry matter; RM: raw material

As shown in table 1, the results of total solids, volatile solids and organic carbon showed great methane potential due to the most important biodegradable fraction which exists in sugarcane bagasse [9]. The total nitrogen content of these samples was very low and was reflected in their C/N ratio, which was beyond the optimum range of C/N ratio for biogas production, which is 20–30 [3]. The compositions of the main components (cellulose, hemicelluloses and lignin) are in agreement with the previously reported values, whose percentages ranged from 40-48% for cellulose, 16-30% for hemicelluloses and 17-21% for lignin [10]. These values indicated that most of the cellulose of sugarcane bagasse was not available for bacterial degradation due to the fact that digestibility of a substrate is a function of its lignin content.

3.2. Pretreatment

The hydrothermal treatment was aimed to fractionate bagasse into a solid fraction containing as much cellulose as possible. Total solids, ash content, weight loss, lignin and cellulose were observed after pretreatment and shown in table 2.

Table 2. *Chemical composition of pretreated sugarcane bagasse.*

Item	Pretreated sugarcane bagasse
Total solids (%RM)	94.66±0.04
Ash content (%DM)	7.33±0.02
Organic carbon (%DM)	53.81±0.01
Weight loss (%)	45
Lignin (%DM)	47±1
Cellulose (%DM)	43±3

During hydrothermolysis, the composition of sugarcane bagasse has been changed overtime. As shown in table 2, the bagasse solubilization was observed with 45% of weight loss. This indicates that a great amount of matter have been excluded by vaporization of water (steam) and represents the degradation of lignocellulosic biomass [11].

Cellulose on the other hand, was less solubilized and degraded from 43.6% to 43%. This is due to the fact that cellulose is known to be much more recalcitrant towards hydrolysis and, because of the surface-governed reaction mechanism, is expected to be substantially less hydrolyzed than hemicelluloses [12]. When sugarcane bagasse was treated at 170°C during 2 h, the amount of lignin increased from 22% to 47% for all assays. This indicates that hydrothermolysis is not a delignification process because it was observed simultaneously a reduction of hemicelluloses without significant degradation of cellulose. These results are similar to those obtained by Vasconceloos et al. (2012) and Silva et al. (2010) who respectively used a pretreatment with 0.20% phosphoric acid at 180°C, 8 min and an hydrothermal treatment at 185°C, 10min. Otherwise, these results are not in agreement with the findings by Candido et al. (2012) who observed a low removal of lignin after 40 min by pretreatment of sugarcane bagasse with 10% sulfuric acid at 100°C.

3.3. Biogas Production

3.3.1. Effect of the Hydrothermal Treatment

The raw and pretreated sugarcane bagasses were anaerobically digested to investigate the effect of hydrothermal treatment on biogas production. These substrates were kept in batch mode reactor for 23 days in thermostatic system at 37°C. The figure 2 shows the cumulative biogas production of blank test (Vc ino), raw (Vc) and pretreated bagasse (Vc HT).

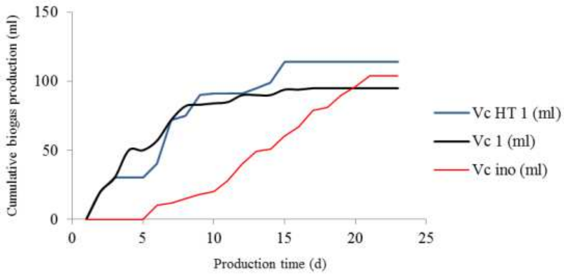

Fig. 2. *Cumulative biogas production of raw and pretreated sugarcane bagasse.*

The results in figure 2 show that sugarcane bagasse pretreated by hydrothermolysis obtained highest biogas production of 114 ml, which was 16.67% higher than the raw one. These findings could be possibly explained by the great availability of biodegradable organic matter, especially cellulose (total sugars) face to enzymes of the inoculum. In spite of fluctuations during 15 days, the stationary phase appeared the same time for the raw and the pretreated bagasse.

3.3.2. Effect on Biogas Production Rate

The biogas production rate was evaluated for studying the effect of hydrothermal treatment on the sugarcane bagasse anaerobic degradation. The figure 3 shows the biogas specific production rate during 23 days. The results show a high rate of biogas production during the first ten days of the experiments for the raw and the pretreated bagasse. This high rate was due to maximal hydrolytic activity of the ferment which caused a rapid generation of CO_2. Therefore, the normal biogas production started from the fifth day of the process with a gradual increase up about 9–11 days. Then, the daily production gradually decreased. The maximal biogas specific daily rates of raw and pretreated sugarcane bagasse were respectively 20 ml/d and 32 ml/d. The trends of biogas production of bagasse were very similar except for the blank test which presented along lag time (5 days).

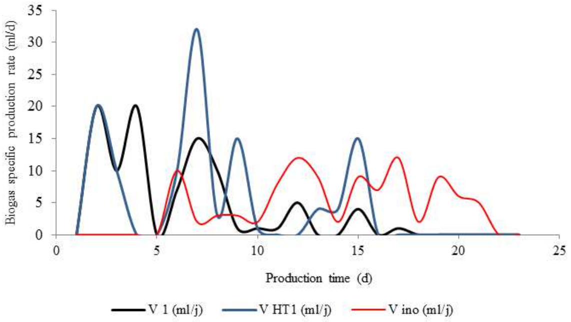

Fig. 3. *Biogas specific production rate of raw and pretreated sugarcane bagasse.*

3.3.3. Evolution of pH

pH is an important parameter to control during anaerobic fermentation. After feeding the digesters at an optimal loading rate (ratio inoculum/substrate to 20/80) [13], the pH in each reactor was kept within the desired range of the optimal growth of neutrophils microbes (5.5-8.5). Figure 4 presents the variation of pH during the anaerobic process. All of the curves had in general, similar behavior until the twentieth day. We observe a reduction of pH during 12 days for the inoculum, raw and pretreated sugarcane bagasse. This indicates a high generation of acid compounds in the biodigester due to the maximal production of volatile fatty acids (VFA). These results are similar to those obtained by Kalloum et al. (2007) [14]. After the first twelve days, the pH of the substrates increased until pH 8. For instance, a stabilization of the pH of inoculum was observed around the same value. This is due to the reaction of the sodium bicarbonate.

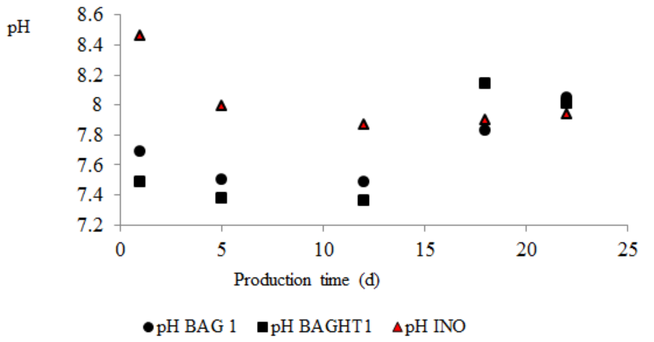

Fig. 4. *Variations of pH during the biogas production.*

On the other hand, despite the slight gap between the pH of different reactors, pretreated bagasse by hydrothermolysis presented the highest biogas yield of 100,57 normolitres per gram of volatile solids (Nl/gVS) while 85,63 normolitres per gram of volatile solids (Nl/gVS) were recorded for raw sugarcane bagasse.

4. Conclusion

Sugarcane bagasse is considered as one of the most abundant waste generated from food industries. It constitutes a renewable resource with a great potential of biofuels production, especially biogas. The results in this study showed that hydrothermal pretreatment applied to optimal conditions of temperature and time may promote biogas production. Based on the results, it can be seen that hydrothermal treatment significantly degrades hemicelluloses without modification of cellulose, which results in a high biogas production. The biochemical methane potential (BMP) test results found could be due to the choice of inoculum and the loading rate of these organics. It should be noted that it is necessary to study the efficiency of hydrothermal treatment (reactor performance, pressure regulation…) and the activity of potential inhibitors during the biogas production.

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Biography

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Fotso Simo William Salomon is a PhD student in the Department of Process Engineering of the National School of Agro-Industrial Sciences (ENSAI) in the University of Ngaoundere (Cameroon). He works in biorefinery sector, especially on anaerobic digestion processes of sugarcane residues (reactor design, pretreatment, monitoring-on-line, conversion, biogas purification, and optimization).