Enhanced anaerobic co-digestion of rice straw by alkaline thermal pre-treatment

Saidkhilli Hamasa and Dhanya M.S.*
Department of Environmental Science and Technology, Central University of Punjab, Bathinda, Punjab, INDIA
*ms.dhanya@cup.edu.in

Abstract

The carbon content in the rice straw is a good feedstock for biogas production by anaerobic digestion. The study evaluated the impact of sodium hydroxide (5% w/v) pre-treatment of rice straw at 121°C for 15 minutes on biogas production from anaerobic co-digestion with cattle dung in 2:1 ratio. The anaerobic co-digestion was performed at a loading rate of 15% (w/v) and a temperature of 33±2°C for hydraulic retention time of 50 days. The alkaline thermal pre-treatment of rice straw prior to co-digestion had improved biogas production by 3.34 folds than the cattle dung.

The Scanning electron microscopic images confirmed the degradation of cellulosic fibres in the structural composition of rice straw. The alkaline thermal pretreatment improved delignification of rice straw and resulted in higher biogas production for energy from lignocellulosic waste to achieve United Nations Sustainable Development Goals.

Keywords: Rice straw, Alkaline thermal treatment, Anaerobic Co-digestion, Biogas.

Introduction

The rice is the staple food for majority of Asian population with around 90 percent of production from Asia[19,22]. The rice grain production had also produced nearly 800 million dry tons of rice straw as by-product[5]. The management of rice straw is the need of the hour from the environmental and health concerns of open burning and dumping[3,15]. The rice straw burning is one of the major sources of air pollution and green-house gas emissions. The anaerobic digestion for biogas generation is a viable option for energy and manure recovery[10,25]. But one of the challenges in biogas production from rice straw is the pre-treatment requirement from structural composition with lignin[1,21,26]. The various pre-treatments like physical, thermal, chemical and biological alter the morphology and hydrolysis process[20]. The hemicellulose and cellulose get solubilised by chemical pre-treatments and help to increase the digestibility.

The alkali pre-treatment using sodium hydroxide for biogas production from lignocellulosic wastes was studied by Zhu et al[27], Mancini et al[13] and Novakovic et al[18]. The pre-treatments were generally conducted at mesophilic temperature for the biogas production[4,16]. The thermal treatments were found beneficial for increased biogas production as reported by a few researchers[6,11]. The focus of the study was to examine the influence of sodium hydroxide under thermal pre-treatment of rice straw for a short period time on the anaerobic co-digestion with cattle dung.

Material and Methods

Substrates used for anaerobic digestion: The rice straw was collected from farmer's field at Ghudda village of Bathinda district of Punjab, India. The straw harvested by mechanical harvester and the straw size was measured by sieve method. The fresh cattle dung was also collected from the local household in the village Ghudda, Bathinda. The moisture analysis of rice straw and cattle dung was carried out by gravimetric method after oven drying at 105°C for 8h.

Thermal and alkaline thermal pre-treatment of rice straw: The thermal treatment of rice straw was carried out in distilled water at a temperature of 121°C for 15 minutes. The alkali used for the study was sodium hydroxide at a concentration of 5% (w/v). The alkaline thermal treatment of rice straw was studied with sodium hydroxide treatment of rice straw at a temperature of 121°C for 15 minutes. The morphological change in the structure of rice straw after alkaline thermal pretreatment was analysed by Field Emission Scanning Electron Microscopy (Carl Zeiss Merlin Compact, Germany). Fourier Transform Infrared spectroscopy (Bruker, Germany) analysis was also carried out at a scanning range of 4000–500 cm^{-1} to study the changes in structural composition of pre-treated rice straw.

Experimental lay out for anaerobic co-digestion of rice straw and cattle dung: Three treatments namely, T1: cattle dung as a control (CD), T2: thermally treated rice straw co-digested with cattle dung (Thermally treated RS+CD) and T3: thermally and NaOH treated rice straw co-digested with cattle dung (Thermally treated NaOH- RS+CD), were used for anaerobic digestion. The pre-treated rice straw was subjected to anaerobic co-digestion by mixing with cattle dung at a total solid loading of 15% (dw/v). The set up for anaerobic digestion had conical flask as a digester connected by silicon rubber tube to the measuring cylinder with graduation for estimation of biogas using water displacement method. The experiment was conducted at a temperature (33 ± 2°C) for a hydraulic retention time of 50 days.

The experiment with all the treatments was performed in triplicate. The results are expressed as mean with standard deviation. The statistical significance in biogas production from alkaline thermal pre-treated rice straw with cattle dung was studied with Student's t-test.

Results and Discussion

Characterization of substrates: The pH and electrical conductivity of rice straw are 6.3 and 0.761 mS/cm respectively. The pH of cattle dung was 8.02 ± 0.04 and had an electrical conductivity of 1.58 mS/cm. The rice straw used for the study was chopped to an average size of 10 mm. The results of sieve analysis of rice straw showed 57 percent of size >2.36 mm, 17 percent of 1.18- 2.36 mm and 26 percent <1.18 mm. The pH of the rice straw after sodium hydroxide and thermal pretreatment was 13 ± 0.28. The moisture content in rice straw was 11 percent. The total solid content in cattle dung was 18 percent.

Biogas production from anaerobic co-digestion of alkaline thermal pre-treated rice straw with cattle dung: Due to the hydrolysis and acidogenesis stages of anaerobic digestion, the initial biogas production was delayed by three days and thereafter started biogas generation. The biogas production was higher for cattle dung the first week and attained maximum within 14 days. The anaerobic co-digestion of thermally pre-treated rice straw with cattle dung generated 95 percent of biogas equal to cattle dung in the first week which shows the contribution of one-third rice straw in the co-digestion. The biogas production from thermally pre-treated rice straw during second and third week was only 61.5 percent and maximum biogas production had reached at fourth week which was 93 percent of cattle dung.

There was no significant difference in biogas production from mono-digestion of cattle dung and co-digestion of cattle dung and thermally treated rice straw in 2:1 ratio. The improved biogas production was observed for the anaerobic co-digestion of NaOH pre-treated rice straw with cattle dung (Fig. 1). The biogas generated from co-digestion of NaOH and thermally pre-treated rice straw was more than cattle dung from second week by 46 percent and increased to maximum of 3.34 folds in the sixth week. The alkaline thermal pre-treatment had attained 2.7 times more biogas production in fourth week in comparison to thermal treatment and 3.6 times more in the sixth week.

The substantial increase in biogas production from NaOH thermal pre-treated rice straw by anaerobic co-digestion with cattle dung was 2.34 and 2.59 times than cattle dung and thermally treated rice straw respectively (Fig. 2). This improvement in biogas production was the result of alkaline pre-treatment at a higher temperature. The biogas production from rice straw by alkaline thermal pre-treatment was found statistically significant by t- test and p-value was less than 1% level.

The thermal pre-treatment helped the breakdown of hydrogen bonds and alkaline pre-treatment reduced the crystallinity of cellulose in rice straw. The increase in biogas yield by NaOH pre-treatment was also reported by He et al[8], Chandra et al[2] and Mancini et al[13]. Nong et al[17] also reported the increased rate of biodegradation by sodium hydroxide pre-treatment. The alkali pretreatment helped in delignification of rice straw which further enhanced accessibility to micro-organisms for anaerobic co-digestion. The lignin content reduced from depolymerisation and partial degradation[14]. The synergistic effect on biogas production by thermal and chemical pre-treatment of lignocellulosic materials was also reported by Sambusiti et al[23].

The SEM images confirmed the reduction in cellulose crystallinity, increase in amorphous nature and removal of lignin (Fig. 3). The rigidity of the rice straw structure was removed after the loosening of cell wall layers. This was also reported by Kaur and Phutela[9]. The change in the structural composition occurred due to break down of linkages between lignin, cellulose and hemicellulose by alkali pre-treatment[8]. The modifications in structural composition and functional groups were also confirmed by Fourier Transform Infrared spectroscopy.

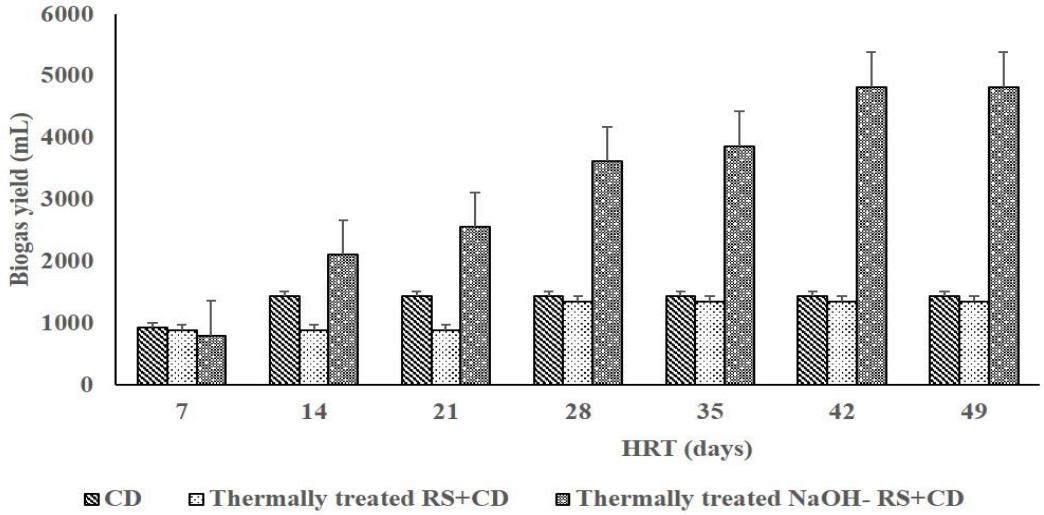

Figure 1: Effect of thermal NaOH pretreatment on weekly biogas production from rice straw by anaerobic co-digestion with cattle dung

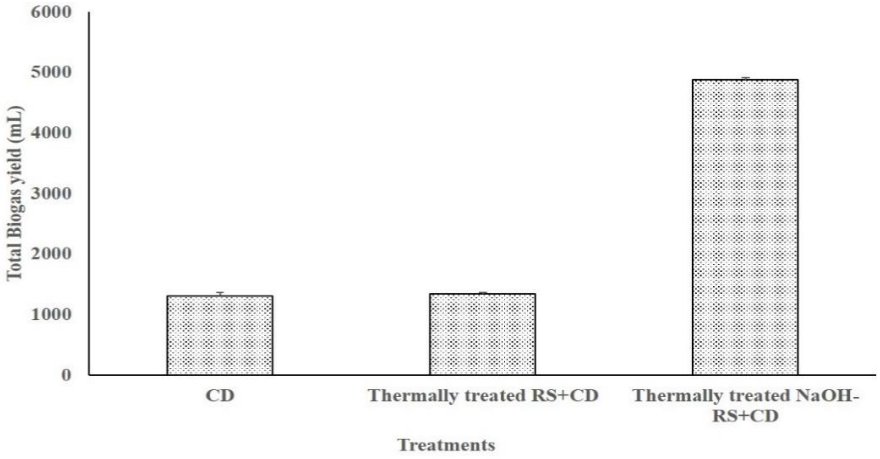

Figure 2: Total biogas production from alkaline thermal NaOH pre-treated rice straw by anaerobic co-digestion with cattle dung

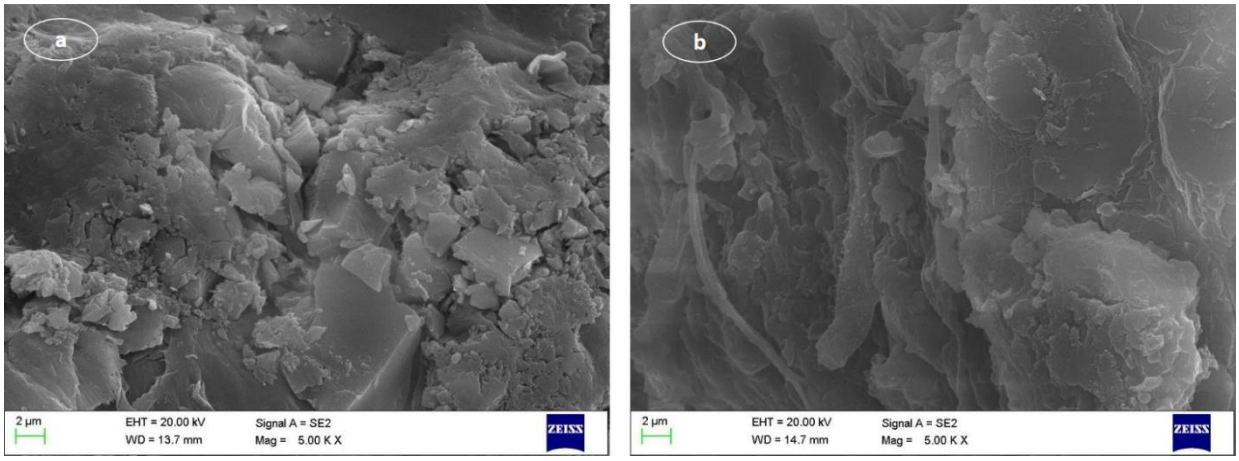

Figure 3: Scanning Electron Microscopic images of (a) Untreated rice straw, b) NaOH and thermally pre-treated rice straw

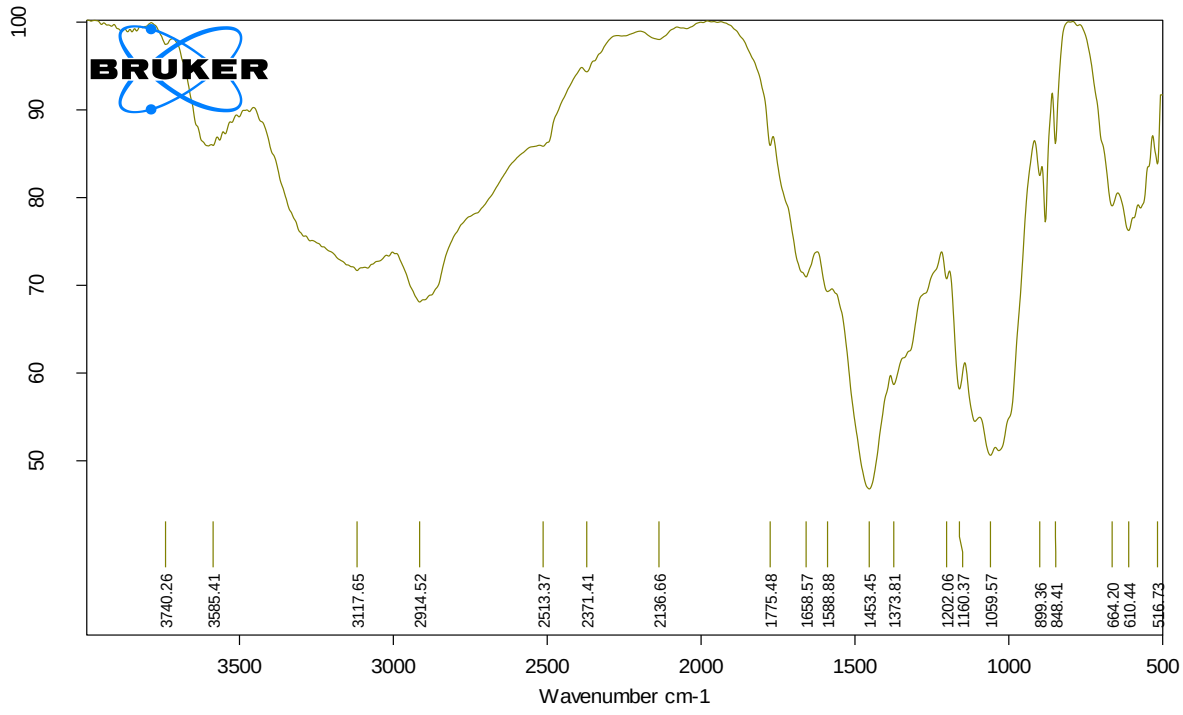

Figure 4: FTIR spectrum of NaOH thermal pre-treated rice straw

The reduction in peaks was observed in FTIR spectrum of pre-treated rice straw (Fig. 4). The O-H stretching in cellulose is represented by the bands at wavelength 3000-3500 cm^{-1} as reported by Shahinur et al[24] and Malik et al[12] which after the alkaline thermal pretreatment of rice straw showed weaker absorption due to cellulose digestibility[8]. The C-O stretching band near 1210 cm^{-1} confirmed delignification after alkali pretreatment[7]. The alkaline thermal pretreatment had a synergistic effect on microbial degradation in anaerobic co-digestion of rice straw and cattle dung and enhanced biogas production.

Conclusion

The pretreatment of rice straw with sodium hydroxide under heat treatment for a short duration had a great potential for enhancing biogas production. The delignification followed by degradation of cellulose and hemicellulose resulted in more biogas generation from anaerobic co-digestion of NaOH and thermally pre-treated rice straw and cattle dung. The structural modifications on lignin and cellulose by the pretreatment were confirmed by SEM and FTIR analysis.

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