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Short Communication

Utilization of solid and liquid waste generated during ethanol fermentation process for production of gaseous fuel through anaerobic digestion – A zero waste approach

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HIGHLIGHTS

- Feasibility study on biogas production from solid and liquid waste.
- Comparative performance at thermophilic and mesophilic temperatures.
- Solid residues from TR_1 andTR_2 yielded more biogas than MR_1 and MR_2.
- The waste generated during ethanol fermentation were amenable for biomethanation.

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ABSTRACT

Preliminary investigations were performed in the laboratory using batch reactors at 10% solid concentration for the assessment of the biogas production at thermophilic and mesophilic temperatures using solid residues generated during ethanol fermentation process. One kg of solid residues (left after enzyme extraction and enzymatic hydrolysis) from thermophilic reactors (TR_1 and TR_2) produced around 131 and 84 L of biogas, respectively, whereas biogas production from mesophilic reactors (MR_1 and MR_2) was 86 and 62 L, respectively. After 20 and 35 days of retention time, the TS and VS reductions from TR_1, TR_2 and MR_1, MR_2 were found to be 39.2% and 35.0%, 67.3% and 61.0%, 21.0% and 18.0%, 34.7% and 27.8%, respectively. Whereas the liquid waste was treated using four laboratory anaerobic hybrid reactors (AHRs) with two different natural and synthetic packing media at 15–3 days HRTs. AHRs packed with natural media showed better COD removal efficiency and methane yield.

1. Introduction

Renewable resources have now become important primarily due to the depletion of oil resources and the devastating effects of burning fossil fuels on climate change. Many alternative, potentially sustainable sources of energy exist however; there are limited choices for replacement of the liquid fossil fuels. One of these possibilities is production of fuels from lignocellulosic biomass. While developing an integrated process technology for transport fuel production from lignocellulosic material, it is important to extract as much energy contents of the material as possible.

The high rate anaerobic treatment is one of the most effective ways of minimizing the concentration of organic matter in the wastewater. The most efficient and quite flexible designs available is an anaerobic hybrid reactor (AHR) which combines advantages of both anaerobic filter and up flow anaerobic sludge blanket designs. The other most important aspects in the AHR design is the selection of appropriate support material. As a result, a hybrid treatment system has been chosen in this work, because of its potential to reduce investment costs through the use of cheaper local media and also its flexibility to deal with almost all kinds of wastewater (Narra et al., 2014).

Solid-state anaerobic digestion (SS-AD) has also been successfully used to convert various lignocellulosic biomass feedstocks to biogas. SS-AD provides many benefits over liquid AD in digesting lignocellulosic biomass such as treating more organic solids in the same size digester and producing a compost like finished organic material that is easier to handle and can be applied to agricultural land for fertilizer (Martin et al., 2003; Li et al., 2011). The SS-AD system also features lower energy inputs needed for heating and mixing (Li et al., 2011).

The conversion of crop residues like rice straw (RS) into bioethanol generates huge amount of liquid and solid residues and which

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could be used for biogas generation. Thus, as an attempt to utilize energy generation potential of the biomass as far as possible, studies were carried out towards the utilization of liquid fraction (wastewater/influent) generated after alkali pretreatment and solid biomass left after enzyme production and enzymatic hydrolysis. Four laboratory AHRs with two different natural and synthetic packing media were operated for treating liquid fraction. The efficacy of different packing media in terms of minimum hydraulic retention time (HRT) achievable, chemical oxygen demand (COD), biological oxygen demand (BOD), total solids (TS), volatile solids (VS) removal efficiencies and methane yield (YM) were assessed and reported earlier (Narra et al., 2014), whereas batch reactors were operated for treating solid residues at 10% total solid concentration at mesophilic and thermophilic temperatures, respectively.

2. Methods

2.1. Substrate and chemicals

RS was procured from a local farm. Physically pretreated RS was used for enzyme production and mild alkali pretreatment as described previously (Narra et al., 2012). The influent to four AHRs was the wastewater generated during mild alkali pretreatment of RS and it was produced in Institute's lab as described in the earlier studies (Narra et al., 2014). The solid residues obtained after enzyme extraction and enzymatic hydrolysis were used as solid substrate for operating solid state bioreactors. All chemicals and media components were obtained from commercial sources and were of analytical grade.

2.2. Chemical pretreatment of substrate

Based on the optimized data RS was pretreated with 0.5% NaOH in the solid: liquid ratio of 1:20 at room temperature (RT) for 24 h (Narra et al., 2012). The mixture was filtered through double layered muslin cloth and the solid residue was neutralized with 1 N HCl. The solid residue was dried at 60 °C till constant weight and was either used immediately for hydrolysis studies or stored at 4 °C in air tight bags. The wastewater collected was used as substrate and fed to the AHRs through a peristaltic pump. After chemical treatment, weight loss, total solids (TS) and the contents of lignin, hemicellulose and cellulose of the liquid and solid biomass were determined.

2.3. Solid biomass separation during enzyme extraction and after enzymatic hydrolysis

Crude cellulases were produced using in-house isolated strain *Aspergillus terreus* under solid state fermentation at 45 °C using modified Mandels and Weber media as a moistening agent (Narra et al., 2012). The content of each flask was extracted using twice with 30 mL of 0.05 M sodium acetate buffer (pH 4.8) and filtered through a double layered wet muslin cloth by thorough squeezing. The extract was centrifuged at 10,000×*g* for 10 min at 4 °C and the clear supernatant was used as the crude enzyme source for further analysis and the solid residue left after enzyme extraction was used as a substrate for anaerobic digestion. Enzymatic hydrolysis was carried out with pre-treated rice straw at 50 °C in 250 mL capacity Oakridge wide mouth bottles with a total system of 50 mL (0.05 M citrate buffer, pH 4.8) (Narra et al., 2012). After 40 h incubation period the contents of the flask were squeezed and the solid residue was used as a substrate for anaerobic digestion. Physico-chemical characteristics of substrate and inoculum were shown in Table 1.

2.4. Description and start up of laboratory AHRs and solid state bioreactors

2.4.1. Laboratory AHRs

The experimental set-up consisted of four bioreactors (combined UASB + anaerobic filter) named as R1, R2, R3 and R4 and fabricated using rigid PVC material in the Institute workshop. For startup, all the four reactors were inoculated with filtered, diluted, digested cattle dung slurry. The reactors were operated at four different HRTs (15, 10, 8, 5 and 3 days) for at least 4 cycles under ambient conditions. Detailed description and start-up of AHRs was described earlier (Narra et al., 2014).

2.4.2. Laboratory solid state bioreactors

One liter borosil glass bottles sealed with rubber stopper were used as solid state bioreactors. Total solids concentration maintained was 10%. The batch reactors of solid residue available from the enzyme extraction were named as TR_1, MR_1 and from the enzymatic hydrolysis were named as TR_2, MR_2. Thermophilic reactors (TR_1 and TR_2) were incubated at 50 °C in a temperature controlled waterbath and mesophilic reactors (MR_1 and MR_2) were incubated at ambient conditions. Composition of TR_1, TR_2 and MR_1, MR_2 were shown in Table 2. Natural inoculum (compost) collected from a core of compost pit (where the temperature was in the range 45–50 °C) and cattle dung slurry was collected from an operating biogas plant were used as inoculum to initiate the fermentation process for thermophilic and mesophilic reactors, respectively. Substrate to inoculum ratio of 1:1 was maintained on dry weight basis. Retention time periods were 20 and 35 days for thermophilic and mesophilic conditions, respectively. C/N ratio was in the range of 27–30. Separate bioreactors for the cultures (compost and digested slurry) alone were also set-up and gas production from the bioreactors was deducted from the gas generated from each of the corresponding bioreactors to arrive at net gas production values. All treatments were set-up in duplicate and average values have been reported.

2.5. Analysis

The performance of AHR was checked daily by measuring biogas production, influent and effluent pH and COD, whereas analyses of TS, volatile solids (VS) of effluent samples were done in alternative days. The solid bioreactor performance was checked daily by measuring biogas production by water displacement method after the mixture being stirred manually, while biogas composition was analyzed using gas chromatograph (Perkin Elmer, Clarus 500) with Thermal Conductivity Detector (TCD). The stainless steel column used was packed with Porapak Q. Injector, oven and detector temperatures were 100, 50 and 200 °C, respectively. Nitrogen was used as a carrier gas and flow was maintained at 30 ml min^{-1}. Physico-chemical characteristics (TS, VS, C, N and P) of solid residues before and after anaerobic digestion were done according to the Standard Methods for Examination of Water and Wastewater (APHA, 1997). All the analyses were carried out in duplicates.

3. Results and discussion

3.1. Performance monitoring of AHRs

Comparative study of different packing materials for AHR shows the superiority of the pumice stone over gravel, polypropylene saddles and ceramic saddles sustaining the biomass within the closed system. Higher COD removal efficiency (69.2%) and methane yield (0.153 L CH_4 g^{-1} COD_{added}) were achieved in reactor R2