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Performance evaluation of anaerobic hybrid reactors with different packing media for treating wastewater of mild alkali treated rice straw in ethanol fermentation process

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HIGHLIGHTS

- Biomethanation potential of liquid waste from pretreatment of RS was established.
- Performance of AHR with natural/synthetic media was compared for organics removal.
- AHR with pumice stone showed better COD removal efficiency and methane yield.

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ABSTRACT

Four anaerobic hybrid reactors with different packing media *viz.* gravel (R1), pumice stone (R2), polypropylene saddles (R3) and ceramic saddles (R4) were operated in semi-continuous mode. Biomethanation potential of the wastewater generated during alkali-treatment of rice straw in ethanol production process was investigated at ambient conditions. The reactors were operated with varying organic loading rates ($0.861–4.313\ g\ COD\ l^{-1}\ d^{-1}$) and hydraulic retention time (3–15 days). Higher COD removal efficiency (69.2%) and methane yield ($0.153\ l\ CH_4\ g^{-1}\ COD_{added}$) were achieved in reactor R2 at 15 days HRT. Modified Stover–Kincannon model was applied to estimate the bio-kinetic coefficients and fitness of the model was checked by the regression coefficient for all the reactors. The model showed an excellent correlation between the experimental and predicted values. The present study demonstrated the treatment of wastewater from alkali treated rice straw for production of biogas.

1. Introduction

Anaerobic treatment is a process where organic matters are digested to methane and carbon dioxide in the absence of oxygen. Although, anaerobic digestion process has been recognized for its ability to treat organic waste for decades, it is not until recently that a wide variety of industrial liquid wastes such as dairy wastewater (Anderson et al., 1994), poultry slaughterhouse wastewater (Debik and Coskun, 2009), pharmaceutical wastewater (Pandian et al., 2011) and domestic wastewater (Lopez et al., 2013) have been treated by using this process. Numerous designs and configurations of anaerobic systems have been developed for various purposes and different experiments. The high rate anaerobic treatment, however, is one of the most effective ways of minimizing the concentration of organic matter in the wastewater.

An anaerobic hybrid reactor (AHR) which combines advantages of both anaerobic filter and up flow anaerobic sludge blanket designs, operates with a sludge blanket in the lower zone and packing media forming a filter in the upper zone, was first developed by Maxham and Wakamiya in 1981. Since then, much work has been carried out on both laboratory and full-scale reactors in order to optimize the design and operating parameters (Tur and Huang, 1997). This type of reactor has been successfully and widely applied for the treatment of low to medium strength wastewater (Kumar et al., 2007).

The most important aspects in the AHR design are the selection of appropriate support material. A variety of natural materials such as smooth quartzite pebbles, shells, granite stones, wooden blocks, brick bats and synthetic materials like polyvinyl chloride sheets, rasching rings, tire rubber and other materials have been used for the attachment and growth of anaerobic biomass (Gourari and Achkari-Begdouri, 1997; Reyes et al., 1999; Show and Tay, 1999; Ahn and Forster, 2002; Michaud et al., 2005; Melidis et al.,

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2003; Rovirosa et al., 2004; Yang et al., 2004). It was reported that the reactors packed with high media porosity obtained better organic removal efficiency compared to that using non-porous support. It has also been reported that organic matter removal efficiency in anaerobic filter reactors is directly related to the characteristics of the support materials used for the immobilization of anaerobes. 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.

While developing an integrated process technology for transport fuel production from lignocellulosic material, it is important to extract energy potential of this material to the maximum extent. The process of de-lignifying rice straw (RS) using mild alkali treatment was optimized. The chemically pretreated substrate was divided into two fractions; one fraction contained only solids, functioning as substrate for fermentable sugars as described earlier (Narra et al., 2012) and the other was liquid fraction (wastewater/influent) used as substrate for anaerobic fermentation to produce biogas. Four laboratory AHRs with two different natural and synthetic packing media were used. 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 (Y_M) were assessed and reported in the present paper.

2. Methods

2.1. Substrate, packing media and chemicals

The influent to four AHRs was the wastewater generated during mild alkali pretreatment of RS and it was produced in Institute's lab. Natural and synthetic packing media were procured from local market. 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 (Narra et al., 2012) RS was pretreated with 0.5% NaOH in the solid: liquid ratio of 1:20 at room temperature for 24 h. 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.

2.3. Characteristics of the wastewater

The wastewater generated during NaOH pretreatment was characterized and analyzed for initial pH, COD, BOD, TS, VS, total dissolved solids (TDS), total suspended solids (TSS), total alkalinity (TA), total volatile fatty acids (TVFA), presence of chloride, sulphate and trace metals (Zn, Cu, Cr and Mn) according to the Standard Methods for Examination of Water and Wastewater (APHA, 1997) and total phenols (Bray and Thorpe, 1954). The reducing sugars were determined by dinitrosalicylic acid method (Miller, 1959). All the analysis was carried out in duplicates. Characteristics of wastewater have been shown in Table 1.

2.4. Characteristics of the support media

Four types of packing media-Gravel, Pumice stone, Polypropylene saddles and Ceramic saddles with voidage of 55%, 51%, 93% and 71%, respectively, were used as fixed film support. Reactors R1, R2, R3, and R4 were packed with gravel, pumice stone, polypropylene saddles and ceramic saddles and they have a bulk density of 1364,324,100 and 660 kg m^{-3}, respectively. Average size of the natural media was 20 mm while that of synthetic media was 25 mm (Table 2).

Table 1
Characteristics of wastewater.

Parameters	Values
Initial pH	7.20 ± 0.10
COD (g l^{-1})	12.95 ± 0.51
BOD (g l^{-1})	6.69 ± 0.89
Total solids (g l^{-1})	18.10 ± 0.01
Total volatile solids (g l^{-1})	9.91 ± 1.05
Total dissolved solids (g l^{-1})	8.30 ± 0.06
Total suspended solids (g l^{-1})	9.80 ± 0.07
Total phenols (mg l^{-1})	791 ± 5.51
Chloride (mg l^{-1})	4020 ± 7.23
Sulphate (mg l^{-1})	160 ± 9.40
Reducing sugars (g l^{-1})	0.55 ± 0.04
Zinc (mg l^{-1})	0.29
Copper (mg l^{-1})	Not detected
Chromium (mg l^{-1})	0.028
Manganese (mg l^{-1})	2.72

2.5. Description of laboratory AHRs

The experimental set-up consisted of four bioreactors (combined UASB + anaerobic filter) with necessary pumps and piping for feeding, recycling and draining of influent and effluent. Schematic diagram of the complete arrangement of AHR with necessary accessories has been shown in Fig. 1. The reactors were named as R1, R2, R3 and R4 and fabricated using rigid PVC material in the Institute workshop. Details of the reactors are given in Table 2. Two flexible PVC pipes fitted with valves and cocks were used for influent feeding and effluent removal. A pipe for the outlet of biogas was fitted at the top of each reactor. The reactors packed with different support media as described earlier were operated at identical conditions and were run in parallel. They were operated in up flow mode and the wastewater was fed in semi-continuous regime using peristaltic pump (Watson Marlow Ltd., Model 603 S). Biogas produced was measured daily using a wet type gas flow meter (Inserf, India).

2.5.1. Start up and acclimatization of the AHRs

For startup, all the four reactors were inoculated with filtered, diluted, digested cattle dung slurry. The characteristics of the inoculum used were: TS-8%; VS-55% of TS; and pH-7.0. Once the culture was developed, it was acclimatized with the wastewater. Feeding was carried out at five different HRT's (15, 10, 8, 5 and 3 days) in order to evaluate the effect of this parameter on the process performance of four bioreactors. With these values of HRT, the reactors were operated at volumetric OLR of 0.861, 1.295, 1.617, 2.59 and 4.313 g COD l^{-1} d^{-1}, respectively. Retention time was changed to the next lower level when steady state condition was achieved at one particular retention time (when the variation in the effluent characteristics was at a minimum and daily gas production in terms of quality and quantity was almost constant). The reactors were operated at each HRT for at least 4 cycles under ambient conditions. Steady state conditions were assumed when the quantity and quality of biogas produced and COD removal were remained practically constant with respect to time.