Biogas production from paper and pulp mill wastewater using Helical baffled bio-film reactor by methanogens

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Abstract

In thisstudy,paper and pulp millwastewater (Chemical oxygen demand, COD is 2055 ± 5 mg/L) collected from secondary clarifier istreated by Anaerobic helical baffle biofilm sequential batch reactor (AnHBBSBR). To improve the performance of the reactor Carbon fiber (CF) is used.The helical shape baffle in the reactor provides the microorganisms to utilize organics available in the entire capacity of the reactor and enhance biogas production with COD removal. Reactor was operated in a continuous mode for anaerobic biodegradation of wastewater effluent for 140 days. Results show that COD is reduced from 2055 ± 5mg/l to 232 ± 5mg/lwith the efficiency of 86 ± 2.0 % and the highest methane production (564ml-CH_4/g) by the effect of selected methanogens in AnHBBSBR compared to a normal AnSBR methane yield (264 ml-CH_4/g). Thermogravimetric analysis showed better combustion value and absolute oxidation of anaerobic treated sludge at 500 °C, with 10.14 MJ kg^{-1} heating value.

Keywords: Anaerobic treatment, helical baffle biofilm sequential batch reactor, Carbon fibre, biogas energy, Thermogravimetric analysis

1.INTRODUCTION

Pulp and paper mill industries produce tremendous volume of organic wastes that could be changed to source of energy in the form of methane.The pulp and paper industry is a water consuming industry, that creates a various types of wastewater with different qualities, at different stages of paper making process [1].The sludge biomass comprises of wood strands (lignin, cellulose and hemicellulose), paper making fillers like kaolin and calcium carbonate, pitch, lignin secondary products and ash

[2].Anaerobic treatment is routinely used to balance out various sludge in domestic wastewater treatment plants and furthermore progressively to create biogas, eco-friendly product, from biodegradable waste and compost and from energy crops [3].The biogas comprises of around 50-80% of CH_4, with the rest of predominantly CO_2 [4].Anaerobic treatment is a reasonable technique for higher COD wastewater focuses to minimize the organics and more advantageous when compared with activated sludge process[5].Stage reactors can give high treatment effectiveness to recalcitrants since stage partition, which produces separate conditions for acidogenesis and methanogenesis, additionally optimum condition to be provide for microbial cultures which are engaged with the decomposition of recalcitrants substance [6].Hybrid up flow anaerobic sludge blanket (HUASB) reactor showed COD removal of 87% at OLR of 0.71KgCOD/m3d ,during the reactor operated at OLR of 0.71KgCOD/m^3d [7].The study of anaerobic treatment was carried out to decrease the higher COD and AOX substance in agroresidue based pulp and paper wastewater[8].Researched the removal of COD, BOD and colour of textile wastewater utilizing a fluidized bed reactor with the activated carbon as additional supporting material which shows 98% COD, 95% BOD_5, and 65% color decrease were conceivable by an anaerobic FBR [9]. The application of moving bed sequencing batch biofilm reactor (MB-SBBR) for treatment of wastewater containing Acid Red 18 (AR18) which showed the color decolorization rate increase with expanding its concentration in the feed solution.[10].

The biodegradation of the date palm waste and examined the reuse of waste by following the biodegradation cycle during composting by considering different physico-synthetic boundaries (pH, TOC, TKN, C/N proportion) and the natural issue structure utilizing thermogravimetric and differential warm investigations (TGA/DTA) and FTIR[11]. At psychrophilic temperature (20 °C) dry anaerobic digestion (PDAD) for treating high solids (35%) dairy fertilizer in a consecutive clump reactor[12].For treatment of dairy-plant wastewater the following methods adopted at two precisely mixed, pilot-scale reactors, the Anaerobic Sequencing Batch Reactor and ASBBR [13].

A study of sequential anaerobic and aerobic treatment in two phases bioreactor for removal of color in the pulp and paper mill effluent with varying pH of the effluent and upsurge in biomass of microorganisms. [14].Based on the previous research work like anaerobic biofilm batch reactor (ABBR) and anaerobic baffled sequential batch reactor (ABSBR), in this present study an attempt have made to investigate the performance of AnHBBSBR for COD removal and biogas production. Further sludge particle size distribution was carry out to distinguish the sludge particle volume. Along with the thermogravimetric analysis is carried out to investigate the wastewater sludge characteristics.

2. MATERIAL AND METHODOLOGY

2.1. Sample water from paper mill plant

Wastewater collected from secondary clarifier of paper industry treatment plant and transported for laboratory study. Collected wastewater is stored at 4°C for further investigation. The characterization of wastewater carried out by standard method of examination of wastewater (APHA, 2005).

2.2. Culture isolationand identification

The methanogens are the bacterial culture which speedup or digest the organics to usable products this process is known as methanogenesis.The aggregates are mainly composed of methanogenic bacteria which accelerate acetate and H_2/CO_2 into methane. Temperature and pH ought to be kept up in the reach which is ideal for methanogenic microorganisms at 32to 50 °C and pH 6.5 to 7.5. The strain was continued utilizing potato dextrose agar (PDA) as medium, and cultivated for 6 days at 30°C to form the inoculants.The dimension of the microorganisms was approximately 2.5 μm.

2.3. Anaerobic Helical baffled Biofilm Sequencing Batch Reactor

The bench-scale AnHBBSBRreactor with 20 L (mixtures of substrate and inoculums) of working volumewere used in this study for treating pulp and paper mill wastewater. The reactor is made using acrylic plastic of 280 mm diameter, 600 mm height and 5 mm thick. The schematic view of experimental setup is shown in Fig. 1. Helical baffle is made of polyethylene material and 2 mm thickness carbon fiber (CF) is rolled over the baffle. A CF was washed in deionized water several times to completely remove a hydrophilic sizing agent (mainly hydrophilic surfactant and polyvinyl alcohol) before use for experiments. Helical baffle increases contact of sludge granules with wastewater by enhancing the internal recirculation of sludge biomass and thereby improves reactor performance due to better mixing. The lower end of helical baffle starts from 150 mm from the bottom and extended up to 450 mm.Low speed gear motor is used for driving the paddle shape impeller and maintained at a speed of 60 rpm to agitates the working volume. The influent from the feed tank (l) is injected into the reactor using a peristaltic pump. The pH meter and DO meter are attached with the reactor to monitor the pH value and dissolved oxygen concentration in the reactor. The batch reactor operation is performed under mesophilic conditions.

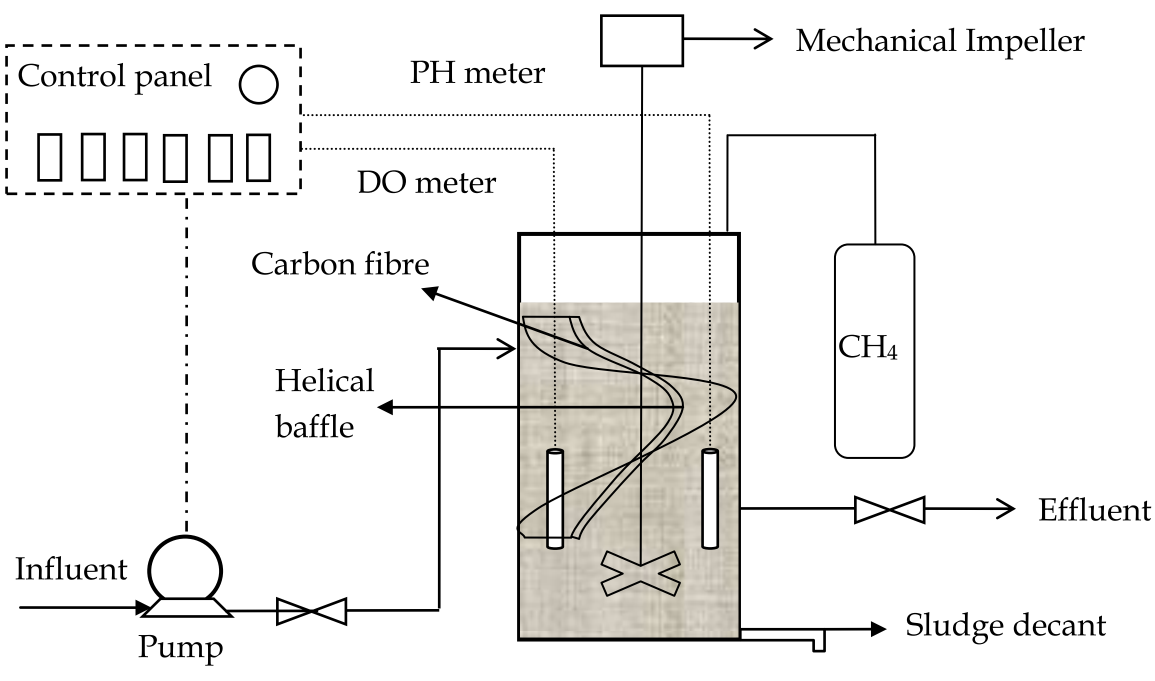

Fig. 1.Schematic setup of bioreactor

3. RESULTS AND DISCUSSION

Fig. 2 shows that sequential changes in the COD removal and fractional contribution by each stage of the reactor treating paper mill wastewater. The readings were monitored after 2 -3 days from the start of the anaerobic treatment. An early change was ascribed to technical issues with the peristaltic feed pump. From day 5, the reactor was fed with 100% paper mill wastewater with a microbe dosage of 55 ml/lit during the acclimatization period, the COD removal efficiency of the reactor system was around 84%. This indicated that there were no substantial reductions in the COD removal efficiency when the paper mill wastewater was present up to 90% of the feed. In addition, these results also indicated that there was not any substantial inhibitory effect to the methanogens when wastewater was introduced into the reactor system. It is observed from the figure that COD removal efficiency increases with increase in number of treatment days. The maximum COD removal efficiency of the developed AnHBBSER is 86 ±2%. The reactor shows continuous improvement in terms of COD removal when time was increased further. The average COD reduction efficiency was around 80%.

The effect of organic loading rate of biogas composition can be used as a direct indicator of the vitality of the anaerobic digester. Biogas production was scrutinized at all stages throughout the process of the reactor, particularly for the evaluation of methanogenic movement.Fig. 3. Shows the methane composition produced in each stage of the reactor system during the treatment of paper mill wastewater. The highest methane composition was produced in the earlier stage of the anaerobic treatment between (0-20 days) and the stable CH_4 production efficiency was observed after (40-50 days) of the treatment. From the biogas composition data, it can be concluded that, even high COD removal efficiency was observed during this period, the methane composition profile does not reflect the actual methane composition. This is probably due the problem of the gas measurement device. In actual fact, the methane composition should reflect the performance of the reactor system.

The flow and movement of the reactor content in the baffle region in AnHBBSBR was observed visually. It may be mentioned that mixing of AnHBBSBR reactor content (visual observation) was much better than that observed in AnSBR reactor. In AnHBBSBR, sludge biomass gets fluidized, and transfers through top end region of baffle and then moves on the other side of the baffle and gets deposited on the lower side of the baffle from where it gradually gets recirculated. There was some accretion of sludge biomass espied between lower end of the baffle and reactor wall which obviously indicated sludge biomass recirculation. Improved mixing in AnHBBSBR reactor improves the feasibility of contact of suspended particles in wastewater with sludge biomass, this possibly may lead to entrapment of suspended organics into sludge biomass. Biodegradable suspended organic substance existent in the wastewater should be effectually entrapped in sludge biomass in order to alter the organics into methane gas [15].

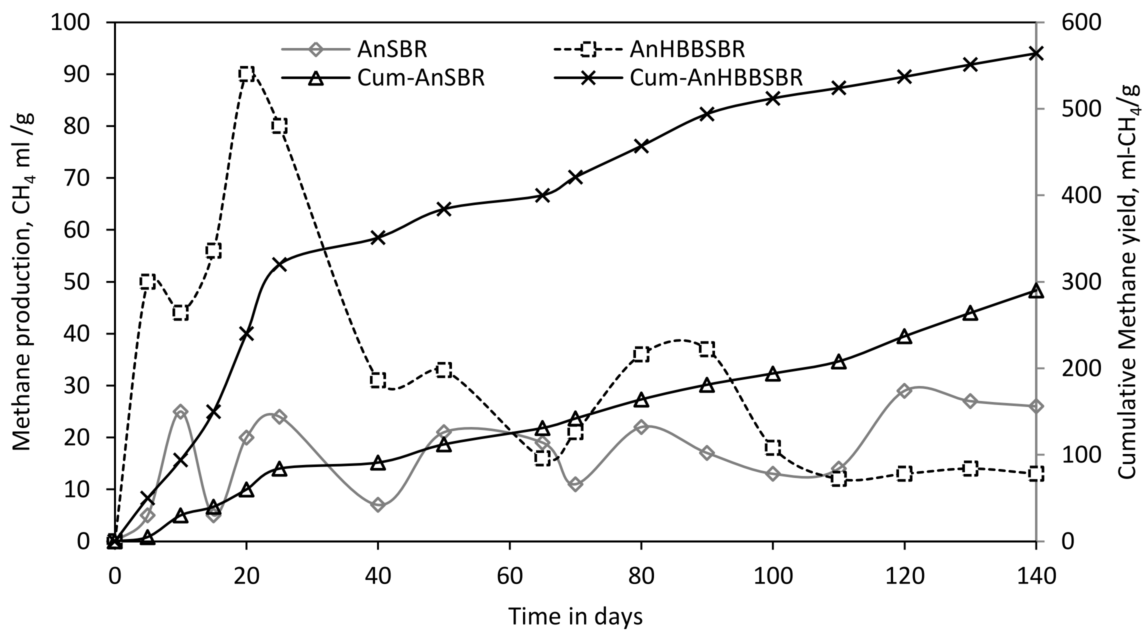

Fig. 2. Production of CH_4 (%) in AnSBR&AnHBBSBR

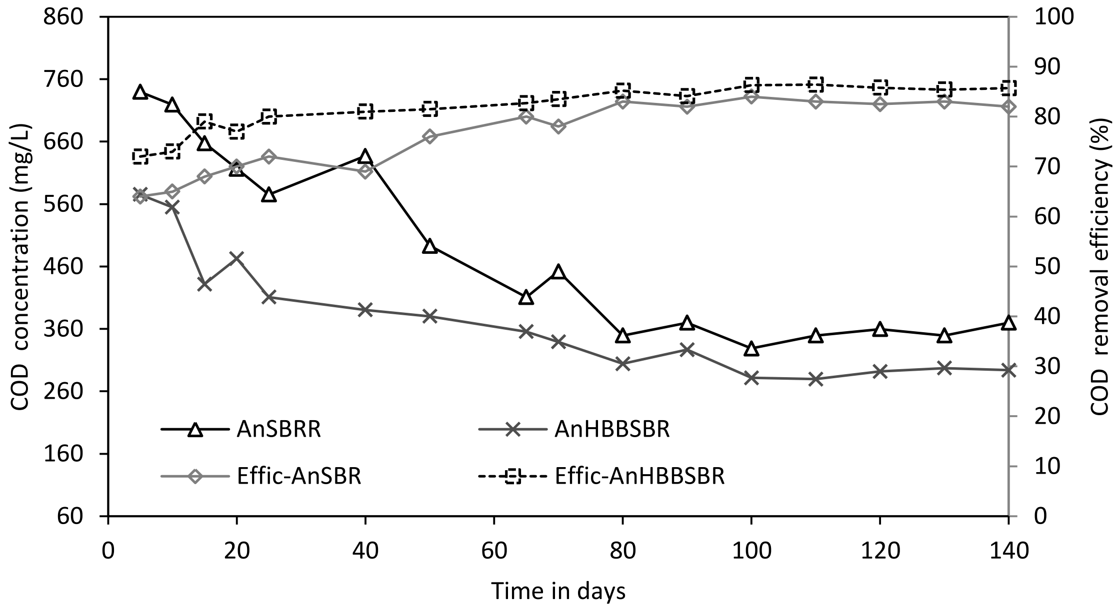

Fig. 3. COD removal efficiency

3.1. Particle size distribution

The 140 days of AnHBBSBR operated inoculum were deposited and dispersed on a glass slide and observed under a stereomicroscope (Metji- Stereo microscope, Chennai Metco Pvt. Ltd) equipped with a digital camera. Samples having 1000 mg of biomass were spread above petri dishes and a stereomicroscope captured the 2D particles shape. A 10 Petri dishes were required to evaluate the size distributions per sample, and with 10-30 pictures per Petri dish. In all petri dish, a minimum of 500 particles were totaled to confirm the depiction of size distributions with better statistical agreement. The images were focused to acquire a good description of the particle shapes. The mean anaerobic granule diameters were evaluated in samples from the inoculums and the biomass extracted at 10 days, 60 days and 140 days of AnHBBSBR operation as shown in Fig. 4. It is observed through particle size distribution analysis, the mean particle size get decrease and its density increases. This is because of pressure apply by the form of an AnHBBSBR operation along with sequential phases of feed; reaction; settling and discharge of the treated effluent. The augmented biomass density indications that was enough to uphold the biomass concentration needed to stimulate organic matter removal with evading reactor efficacy decay.

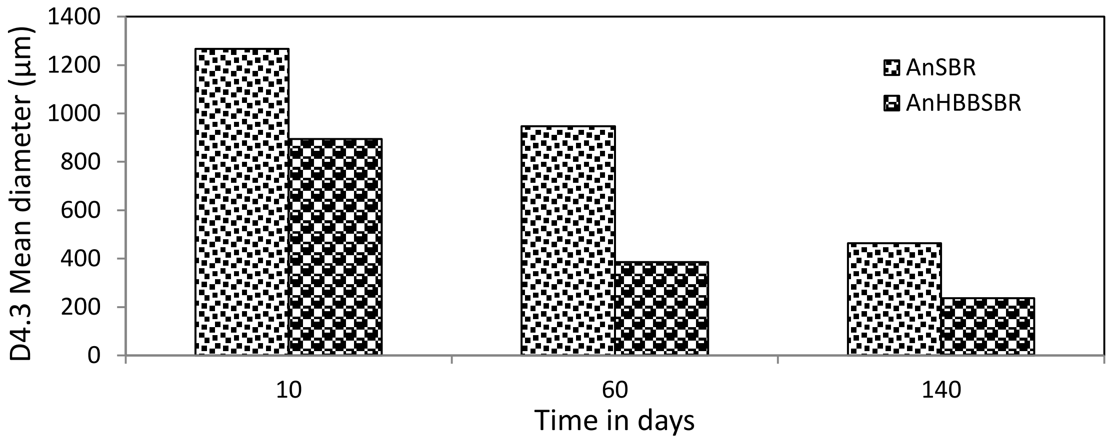

Fig. 4. Anaerobic granule size distribution after 10, 60 and 140 days of AnHBBSBR operation De Brouckere mean particle diameter (D4.3)

3.2. Thermal analysis and disposal of sludge

A thermal stability of sludge biomass is directly reliant on the disintegration temperature of its various organic substances. An anaerobic treated sludge biomass contains high amount of carbon and oxygen level. At high temperature, the organic substances existing in the sludge decompose, generating CO (200-600 °C), CO_2 (450-1000 °C) and water vapour and free hydrogen (500-1000 °C). The thermo gravimetric analysis curves (% of weight loss and derived weight %C) of treated paper mill wastewater sludge under air environment at a heating rate of 10 K/min are shown in Fig. 5. Three different degradation zones can be visualized in this figure, i.e. from room temperature to 200 °C, from 200 to 500 °C, and from 500 to 1000 °C. The major weight loss was recorded in the second region, whereas first and third region correspond to comparatively small weight losses. First region corresponds to removal of moisture, and light volatiles upto 200°C with a total loss of about 4.9%.

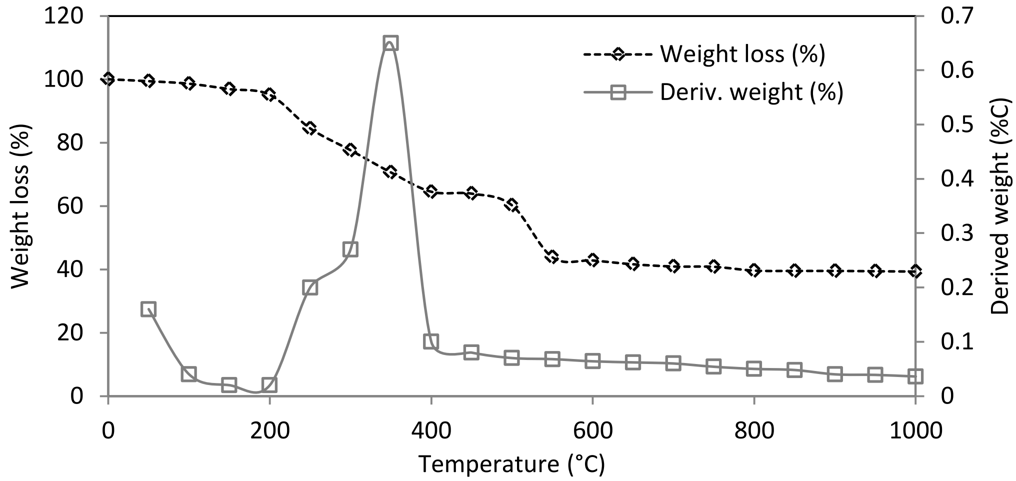

Fig. 5.Thermo gravimetric analysis of paper mill sludge

The active oxidation zone follows this initial zone from 200 to 500 °C with total degradation of 56.2% Subsequently, the sample weight decreased gradually with the total degradation of 4.5% up to 1000 °C. The residue left at 1000 °C is ash and is about 19.84% of the original sample weight. This sludge can be utilized for making blend fuel briquettes with other organics, that can be further used as a fuel in the furnaces. The ash content attained after its combustion can be merged with the cementitious mixture used in construction purposes, thus recuperating energy from the sludge biomass.

4. CONCLUSION

AAnHBBSBR shows the better performance over conventional anaerobic treatment process with the development of the mixing process by the implementation of helical baffle and carbon fibre layer. Better removal of COD and biogas production were observed on AnHBBSBR. Increases in microbe dosage and aeration time were found to induce a positive effect on effluent treatment efficiency. Results showed that COD is reduced from 2055 ± 5 mg/L to 232 ± 5 mg/L. Methane production (564 ml-CH_4/g) by the effect of selected methanogens in AnHBBSBR compared to a normal AnSBR methane yield (264 ml-CH_4/g). Thermo gravimetric analysis was performed for sludge it showed good combustion at characteristics and complete oxidation of the anaerobic treated sludge at 500 °C, with a heating value of

10.14 MJ kg^{-1}. The sludge biomass has lesser ash content, fixed carbon and higher volatile matter than that of Indian coal.

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