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Performance Evaluation of Paper Mill Effluent in a Granular Bed Hybrid Up-flow Anaerobic Sludge Blanket (HUASB) Reactor

A. Sangeetha, R. Ambalavanan, J. Santhosh and G. Thirumal Murugan
Department of Civil Engineering, Periyar Maniammai University, Thanjavur - 603413, Tamilnadu, India

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ABSTRACT

A laboratory study was conducted to assess the performance of a Hybrid Upflow Anaerobic Sludge Blanket (HUASB) Reactor in order to treat the effluent from a paper mill. The maximum organic loading rate (OLR) is 12 kg COD/m^3.day. The OLR was calculated on the basis of COD inlet in the reactor for different flow rates. A hydraulic retention time (HRT) of 12 hrs was maintained in the reactor. The maximum TCOD and SCOD reduction was 92% and 88% respectively. The maximum biogas production was 3.27 m^3/m^3.day. Development of granulation with two different inoculums in early start-up was also studied. The study revealed that earlier start-up and granulation of biomass could be achieved using mixed sludge (cow dung and effective microorganisms). Scanning Electron Microscope (SEM) study of the granules showed predominance of *Methanosarcina* and *Methanothrix* type of species on the surface of granules. The process efficiency and biogas production were found to be increased with an increase in the organic loading rate. The size of the granules was 1-3 mm and exhibited good settling tendency.

INTRODUCTION

The pulp and paper industry is one of the seventeen most polluting industries listed by the CPCB (Central Pollution Control Board) of India. Huge amount of water is used in the manufacture of pulp and paper. The utilized water finally leaves as wastewater unless it is appropriately recycled. The effluent carries the high pollution load in terms of COD, BOD, absorbable organic halides (AOX) and is dark brown in colour, mainly due to lignin and lignin derivatives (Kulkarni 2003). Several such small and medium sized mills discharge their effluents, namely black liquor and bleach effluent directly into the local water bodies. Considering that each ton of paper produced consumes nearly 200-350 m^3 of water (CPCB report 1986), it is not difficult to perceive the magnitude of pollution being caused to the receiving water bodies by these untreated effluents. Muna Ali et al. (2000) have reported that the paper mill effluent could be treated with anaerobic treatment rather than aerobic treatment. It has been realized that anaerobic treatment is not only a very cost effective alternative, but it can also offer a payback on investment through generation of biogas. Among the different types of reactors, the HUASB reactor is one with high loading capacity. The UASB process is a combination of physical and biological processes. The main feature of physical process is separation of solids and gases from the liquid and that of biological process is degradation of decomposable organic matter under anaerobic conditions (Bal & Dhagat 2001). When using HUASB reactors for the treatment of wastewater, it is important to limit the applied surface speed, in order to avoid the washout of the sludge. Lettinga et al. (1996) adopted average surface speeds of the order of 0.5-0.7 mh^{-1} in their UASB reactors.

Barr et al. (1996) investigated the effects of hydraulic retention time (HRT), solids retention time (SRT) and temperature of the anaerobic treatment of kraft pulp effluent. BOD removal was observed at mesophilic temperatures (41°C to 50°C) and a higher COD removal was reported.

The technology of effective microorganisms (EM) was developed during the 1970s at the University of Ryukyus, Okinawa, Japan (Sangakkara 2002). EM is a group of organisms that has a reviving action on human wastes, animal wastes and natural biomass. EM technology finds a number of applications including agriculture, livestock, gardening, landscaping, composting, bioremediation, cleaning septic tanks, algal control and household uses (EM Technology 1998). The important microorganisms involved in the EM solution are *Bacillus* species (25%), *Pseudomonas striata* (25%), *Pseudomonas fluorescence* (25%) and *Trichoderma viridae* (25%), and are expected to act as inoculant in the reactor. The gas phase (constituted by the gases formed during the anaerobic digestion process) is composed predominantly of CH_4 and small quantities of CO_2 and H_2S. The gas formed, together with upward effluent flow strips with it particles of sludge to the top of the reactor.

The main aim of this work is to evaluate a new configuration of the solid-liquid-gas separation system in a HUASB reactor. The assessment would be based on the monitoring of a HUASB bench scale reactor under laboratory environment. The present paper describes the treatment studies conducted in HUASB reactor, along with the results with respect to organic removal efficiency and biogas production.

MATERIALS AND METHODS

The laboratory scale reactor was fabricated using plexi glass. Internal diameter was 9.5 cm and overall height was 61 cm (Fig. 1a & 1b). The total volume of the empty reactor was 4.32 litres. Gas headspace equivalent to 1 litre (about 14 cm height) was maintained above the effluent line. A screen was placed at a height of 29.5 cm to arrest the floating material. The material used as packing media was PVC rings. A peristaltic pump was used for feeding the influent (wastewater) into the reactor. The effluent pipeline was connected to a water seal to prevent the escape of gas. The gas outlet was connected to water displacement jar. The EM solution was procured locally. The paper mill effluent was stored at 4°C until the experiment was started. The influent and effluent wastewater was tested in terms of pH, VFA, TCOD, SCOD (APHA 1995). The biogas production from the HUASB reactor was measured using water displacement method. The TCOD concentration of wastewater as collected from the paper mill was in the range of 2000 to 8000 mg/L. It was diluted and concentration in this study varied between 500 to 6000 mg/L. Hydraulic retention time was 12 hours. Organic loading rates used, ranged between 1 kg COD / m^3 day and 12 kg COD /m^3 day. The experiment was carried out at ambient room temperature that varied between 27°C and 32°C.

Preparation of sludge for measuring the granular biomass was carried out as per requirements for scanning electron microscopy (SEM). Studies were made in Research Department, Research laboratory, Sastra University, Thanjavur.

In the startup study, the HRT was varied from 4 to 36 hrs keeping the OLR range between 500 and 6000 mg/L. The gas production was measured and optimum HRT was found to be 12 hrs. The granular biomass obtained was examined both visually and through SEM. Based on the results, performance of HUASB reactor was studied using different OLR ranging from 1 kg COD/m^3d to 12 kg COD/m^3d. The study was continued between 127 and 215 days after startup. Before increasing the loading, care was taken to ensure that effluent VFA is less than 500 mg/L. The pH, VFA and alkalinity are very important variables in the HUASB process. These parameters were also measured. Most of the samples were analysed and pH values found to be more than 6. Some samples indicated a pH value of 5.35 on 187th day. So $NaHCO_3$ was added to increase the pH values so as to increase the biogas production and COD removal efficiency.

RESULTS AND DISCUSSION

Visual examination of granular biomass revealed a spherical shape and black colour. Slight irregular projections were also seen on the surfaces of granules. SEM photographs of the granules showed that the overall surface of granules was rough and uneven. Hulshoff et al. (1986) have reported that the granules vary widely in shape depending on the operating conditions, but they usually have a spherical shape. The size of the granules was 1 to 3 mm and exhibited good settling tendency. Gupta (2005) has reported that the average size of the granules was between 1.47 mm and 1.32 mm in hybrid UASB reactor. Morphology of the granules demonstrated the presence of heterogeneous bacterial population on the surface. Clusters of cocci-shaped and rod shaped microorganisms were dangling on the surface of granules. Shin et al. (1992) have also reported the predominance of both cocci and rod shaped organisms in sludge acclimatized for anaerobic digestion of distillery spent wash. Figs. 2, 3 and 4 show the enlarged views of the cluster of cocci shaped *Methanosarcina* type of bacteria and rod shaped *Methanothrix* type bacteria, respectively on the surface of the granules. Dolfing (1986) has reported the growth of various types of well settling methanogenic sludge in UASB reactors.

After granulation, with a constant HRT of 12 hrs, it was observed that the increase in organic loading rate was followed by a decreased reactor performance in terms of TCOD removal as shown in Fig. 5. This can be attributed to the fact that increase in feed concentration built-up the higher VFA levels in the system, which would stress and inhibit the biomass.

The variations of pH, VFA and alkalinity with respect to time are shown in Figs. 6 and 7. Bolle et al. (1986) have reported that when the pH in the reactor is too low (<6.0), the consumption of fatty acids get strongly inhibited. If the pH is too high (>8.0), the bacteria are limited in their growth by the low concentrations of unionized fatty acids. Lettinga & Hulshoff Pol (1991) have reported that the pH determined the growth of both methanogens and acidogens. On the 127th day the inlet and outlet pH were 6.05 and 7.25, while it was 6.15 and 7.49, 6.22 and 7.53, 6.25 and 7.58, 5.96 and 7.62, 6.24 and 7.67, 5.35 and 7.29, 5.99 and 7.32, 6.32 and 7.48 in the 137th, 147th, 157th, 167th, 177th, 187th, 197th and 215 days respectively.

The substrate degradation was faster at the initial stage and most of the substrate was utilized by microorganisms nearby the granular surface. The UASB system can withstand high volatile fatty acids than the other anaerobic sys-

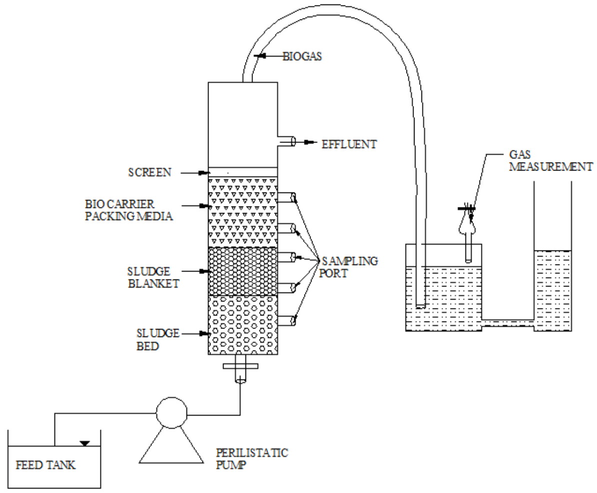

Fig.1a: Schematic diagram of HUASB reactor.

Fig.1b: Bench setup of HUASB reactor.

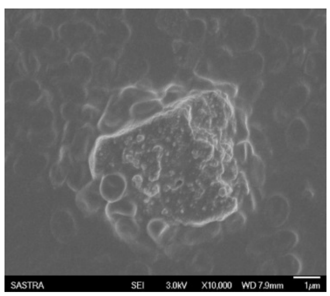

Fig. 2: Cluster of cocci shape (*Methanosarcina*) bacteria.

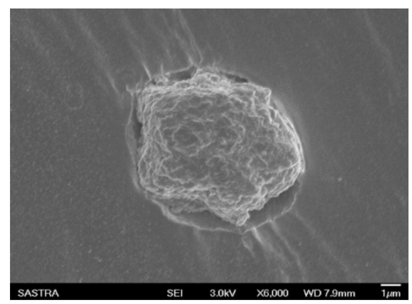

Fig. 3: Cocci shape (*Methanosarcina*) bacteria.

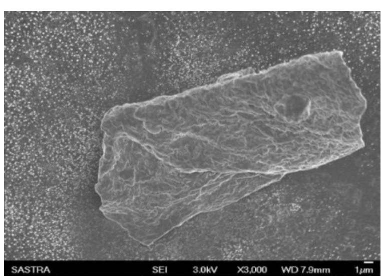

Fig. 4: Rod shaped (*Methanothrix*) bacteria.

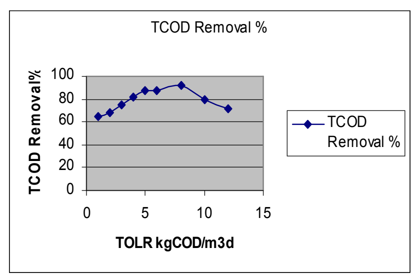

Fig. 5: Removal of COD at various OLR.

tems of wastewater treatment and also sudden changes of HRT does not hamper the process efficiency (Jayantha et al. 1994). It was observed that the available alkalinity was sufficient to counteract volatile fatty acids (VFA) to maintain near neutral pH. Alkalinity is required for buffering the eventual accumulation of VFA produced during the anaerobic metabolism of the substrate and thus avoid drop in pH. The alkalinity of the influent was between 317 mg/L and 357mg/L. The alkalinity of the effluent was found in the range of 425 mg/L to 468 mg/L. After granulation, the alkalinity increased in the outlet and this indicates the stable condition of the anaerobic digester. The alkalinity was mainly based on the pH of the substrate. Alkalinity in the form of sodium bicarbonate was available as a result of the anaerobic biodegradation of the substrate in the reactor (Simpson et al. 1960). The ratio of VFA/alkalinity was in the range of 0.39 to 0.88. The OLR values were increased and reached a maximum of 0.88. Behling et al. (1997) have reported a limiting value of 0.4 in order to avoid the system failure.

The COD removal efficiency strictly depends upon the

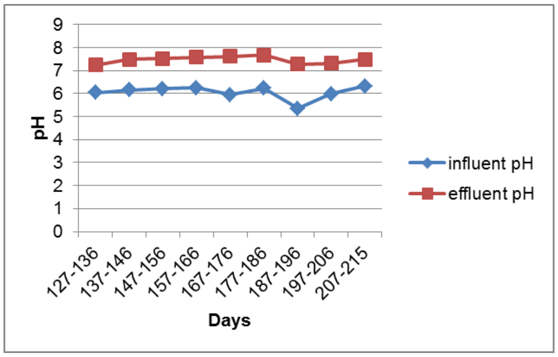

Fig. 6 Variations of in pH and out pH.

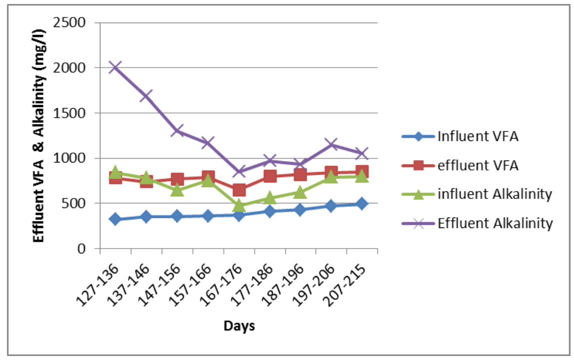

Fig. 7 Variations of VFA and alkalinity.

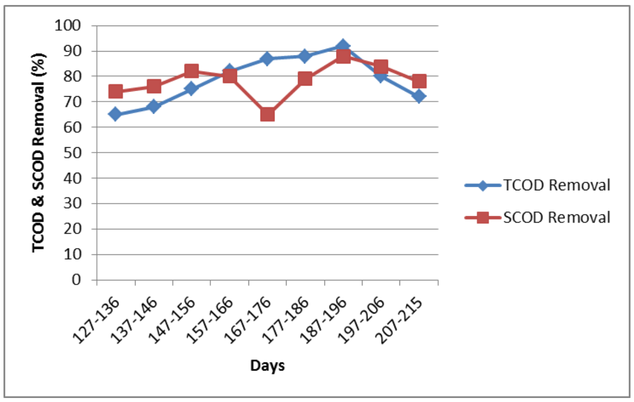

Fig. 8: Variations of TCOD% and SCOD%.

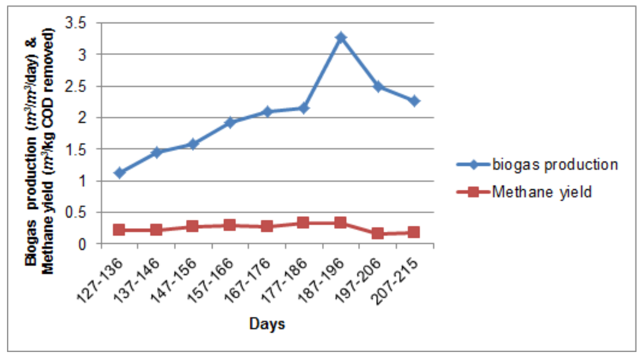

Fig. 9: Variations of biogas production and methane yield.

organic loading rate in terms of TCOD and SCOD. The initial TCOD and SCOD levels were maintained at 500 mg/L and 160 mg/L, until the COD reduction reached 92%, 88%, at a TOLR of 8 kg COD/m^{3}d in terms of TCOD and SCOD respectively. Borja et al. (1998) have reported that the applicable OLR of HUASB reactor in their study was around three times higher than the hybrid reactor using polyurethane as packing media, applied to cattle and hog slaughter house effluent. The COD reduction as observed at different periods is shown in Fig. 8. The maximum TCOD, SCOD removal of 92% and 88% in paper mill effluent is due to the formation of well settling granules. Fang (1995) has reported that the substrate degradations were faster at the initial stage and most of the substrate was consumed by bacteria near the biogranules surface.

The variation of biogas production and methane yield with respect to time in HUASB reactor is shown in Fig. 9. The gas production rates are increased with respect to increase of the OLR. After the startup process, the increase in TCOD from 500 to 6000 mg/L increased the gas production to 3.27 m^3/m^3 of reactor volume per day and methane content was 72%. Sayed et al. (1984) reported the methane content varied between 65 and 75% during the treatment of slaughter house wastewater using flocculants sludge UASB reactor. The decreasing methane content indicates reduced quantity/activity of methanogens in the reactor. At an optimum OLR of 8 kg COD/m^{3}d the highest specific methane yield of 0.32 m^3/kg COD removed was observed. Lawrence & McCarty (1969) have reported that the theoretical methane yield is 0.35 L CH_4/g COD removed up to an OLR of 16.02 kg COD/m^{3}d .

The specific methane yield also gradually reduced and reached the lowest value of 0.18 at an OLR of 12 kg COD/m^{3}d. Kavitha et al. (2007) have reported that the reduction of biogas production is mainly because of the sulphate reduction and in addition to that some quantity of gas escaped along with the effluent.

CONCLUSIONS

The following conclusions can be made from the results obtained in this work:

- The maximum TCOD and SCOD removal efficiency of 92% and 88 % was achieved with HRT of 12 hrs for OLR of 8 kg COD/m^3·day.
- The highest specific methane yield of 0.32 m^3/ kg COD

removed was observed also at an optimum OLR of 8 kg COD/m^{3}d.

- Scanning electron microscope analysis of the granules showed spherical and rod shaped colonization of bacteria-like organisms. These bacteria are identified as *Methanosarcina* and *Methanothrix* known to have methanogenic property.
- The HUASB reactor proved to be efficient for the treatment of pulp and paper mill effluent.

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