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Hydrodynamic behaviour of a laboratory scale hybrid upflow anaerobic sludge blanket reactor

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A laboratory study has been conducted to assess the performance of Hybrid Upflow Anaerobic Sludge Blanket (HUASB) Reactor in treating paper mill effluent. The hydraulic retention time (HRT) is maintained at 12 h. The organic loading rates (OLR) are calculated on the basis of COD inlet in the reactor for different flow rates and the maximum OLR is found to be 12 kg COD/m^3.d. The maximum reduction of TCOD and SCOD is found to be 92 and 88% respectively. The maximum biogas production is 4.85m^3/m^3.d. The hybrid up flow anaerobic sludge blanket reactor is found to be develop granules in two different inoculum sludges in early granulation and start-up has been studied. The study reveals that earlier start-up and granulation of biomass can be achieved using mixed sludge (cow dung and effective microorganisms (EM)). Scanning electron microscope (SEM) study of the granules shows predominance of Methanosarcina and Methanothrix type of species on the surface of granules. The process efficiency and biogas production is found to be increased with an increase in the organic loading rate. Methanobacterium and Methanosaeta bacteria were dominant at the end of start-up whereas Methanosarcina, cocci and rods are predominant at the end of performance studies. The size of the granules is 1 to 3 mm and exhibit good settleability. Residence time distribution (RTD) study show mixed regime flow behaviour at the end of performance study. Dispersion numbers greater than 0.2 show the reactor attained ideal mixed flow regime.

Keywords: HUASB reactor, COD Reduction, RTD study

Pulp and paper industry is listed one of the seventeen most polluting industries by the Central Pollution Control Board (CPCB) of Indian Government. Huge amount of water is used in the manufacture of pulp and paper. The utilized water finally leaves as waste water unless it is appropriately recycled. The effluent carries 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[1]. Several such small and medium sized mills discharge their effluent (appropriately called black liquor) along with bleach effluent directly into the local water bodies. Considering that each ton of paper produced consumes nearly 200-350 cubic meter of water[2], it is not difficult to perceive the magnitude of pollution being caused to the water bodies receiving these untreated effluents. The paper mill effluent could be treated with anaerobic treatment rather than aerobic treatment[3]. It has been realized that anaerobic treatment is not only a 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[4]. When using HUASB reactors for the treatment of waste water, it is important to limit the applied surface speed, in order to avoid the washout of the sludge. The surface speeds of the UASB reactors are 0.5-0.7 m/ h [(5)].The effects of hydraulic retention time (HRT), solids retention time (SRT), BOD removal and COD removal on the anaerobic treatment of kraft pulp effluent at mesophilic temperatures (41 to 50°C) were observed[6]. The technology of effective microorganisms (EM) was developed during the 1970s at the University of Ryukyus, Okinawa, Japan[7].

The hydrodynamic character of the system complicates the nature of anaerobic processes in biogas generation and bio mass accumulation. The inherent mixing action of biomass and biogas also distorts the flow pattern and affects both substrate and bio mass distribution within the reactors. Residence time distribution (RTD) studies are used to evaluate the flow characteristics inside the reactor[8,9]. Mixing characteristics of anaerobic reactors depend on the reactor geometry, the type of substrate, inlet and outlet design, the amount of biogas produced, upflow velocities of the feed and the effluent recycle and any other artificial mixing provided.

The overall hydrodynamic behaviour of HUASB depends on several factors, such as the gas production within the sludge bed, the influent distribution system, as well as advection and dispersion effects. All these determine the final performance of the reactor.

Objective of the study

Overall objective

- Assessing the hydrodyanamic behaviour of pilot scale HUASB reactor treating paper mill wastewater

Specific objectives

- Examination for the presence or otherwise of microorganisms.
- Study the effect of using different organic loading rates maintaining the HRT at 12 hrs.
- Study the variation of biogas production and methane yield with respect to time.
- Study on the macro mixing behaviour and process performance of the reactor and quality of the sludge produced.

Materials and Methods

The laboratory scale reactor was fabricated using plexi glass with an internal diameter of 95 mm and overall height of 610 mm (Fig. 1). Total volume of the empty reactor is 4.32 L; a gas headspace equivalent to 1 L (about 140 mm height) was maintained above the effluent line. A screen was placed at a height of 295 mm to arrest the floating packing material. The material used as packing media was PVC rings. A peristaltic pump (Make: Miclins pp20) 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[10]. 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 h. 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 and 32°C.

In order to study hydro dynamic behavior, a pulse of sodium chloride tracer (25 mL of solution in 300 g/L) was introduced into the bottom of the reactor along with the feed inlet. The sodium chloride was measured at the outlet of the reactor. Sodium chloride was selected as a tracer because it is non-biodegradable and non-toxic in the anaerobic digestion process and its molecular diffusibility is low. Effluent samples were collected at intervals of 4 hrs and centrifuged to remove suspended solids and filtered through millipore microfilter assembly before the analysis. Sodium was estimated using spectrophotometer.

Preparation of sludge for measuring the granular biomass was carried out as per requirements for scanning electron microscopy (SEM).

Results and Discussion

SEM Study of the Granules

Visual examination of granular biomass revealed a black colour with a spherical shape. Slight irregular projections were also seen on the surface of granules. SEM photographs of the granules showed that the surface of granules was rough and uneven. In an earlier study the shape granules varied widely

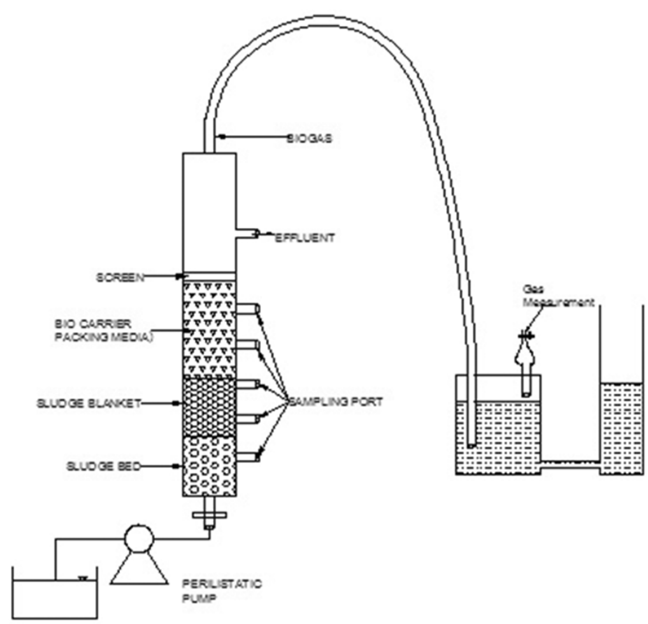

Fig. 1 — Schematic diagram of hybrid up flow anaerobic sludge blanket reactor

depending on the operating conditions but they usually had a spherical shape[11]. The size of the granules was 1 to 3 mm and exhibited good settling tendency. The size of the granules was found to be between 1.32 mm and 1.47 mm in hybrid UASB reactor[12]. Morphology of the granules demonstrated the presence of heterogeneous bacterial population on the surface of the granules. Cluster cocci- shaped and rod shaped microorganisms were dangling on the surface of granules. The predominance of both cocci and rod shaped organism in sludge acclimatized for anaerobic digestion of distillery-spent wash[13]. Figures 2, 3 and 4 show the enlarged view of the cluster of cocci shaped Methanosarcina type of bacteria and rod shaped Methanothrix type bacteria, respectively on the surface of the granules. The various types of well settling Methanogenic sludges grew in HUASB reactors[14].

Reactor performance

After granulation, at constant HRT of 12 h, the variation in TOLR ranged from 1 kg COD/m^{3}d to 12 kg COD/m^{3}d by increasing the feed concentration (days 127-215). Before granulation, effluents VFA was maintained less than 500mg/L. Figure 5 shows the performance of the reactor was decreased with

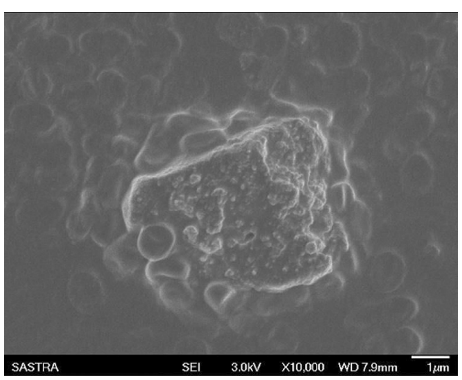

Fig. 2 — Cluster of cocci shape (Methanosarcina) bacteria

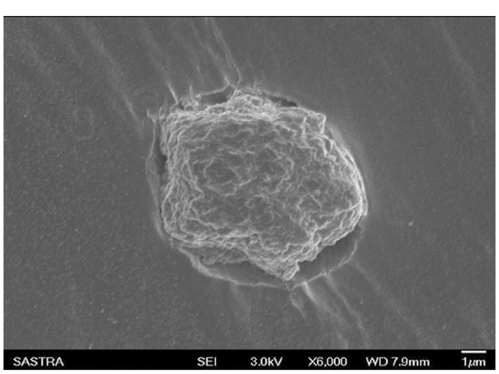

Fig. 3 — Cocci shape (Methanosarcina) bacteria

increase in organic loading rate in terms TCOD removal beyond 8 kg COD /m^{3}day. The 15 day HRT was the best for biogas production from cattle dung in south and central region of India, where the ambient temperature are around 28°C[15]

Methane % and Biogas

The variation of biogas production and methane yield with respect to time in HUASB reactor is shown in Fig. 6. The gas production rates are found to be increase with respect to increase of the OLR. After start up process the increase in TCOD from 500 to 6000 mg/L increased the gas production to 4.85 m^3/ m^3 d and

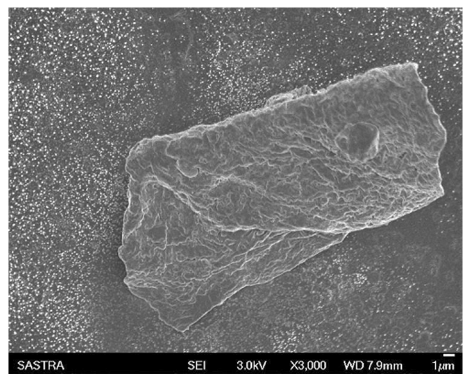

Fig. 4 — Rod shaped (Methanothrix) bacteria

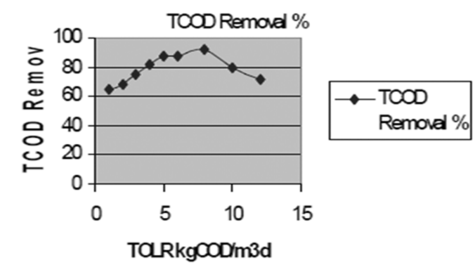

Fig. 5 — Removal of COD at Various OLR.

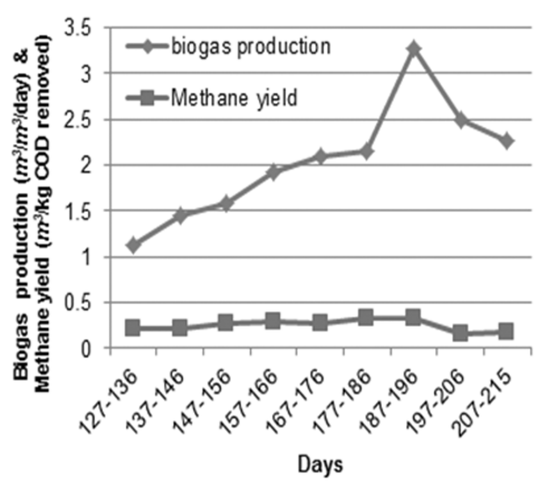

Fig. 6 — Variations of biogas production and methane yield.

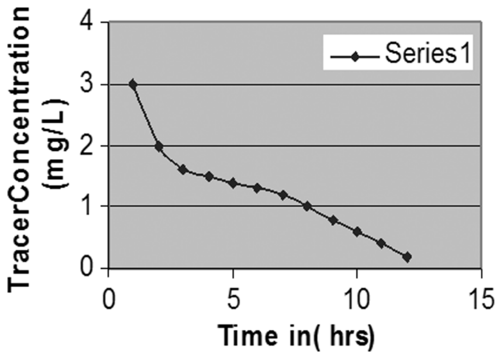

Fig. 7 — The residence time distribution curve for the reactor at the OLR of 5kg COD / m^3.d

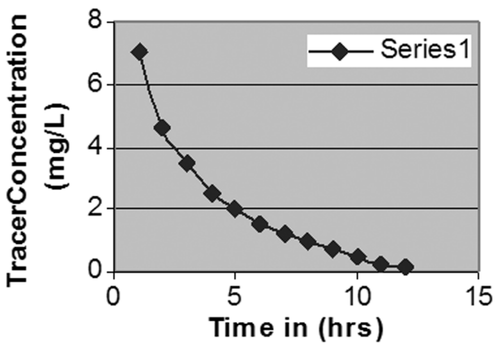

Fig. 8 — The residence time distribution curve for the reactor at the OLR of 8kg COD/m^3.d

methane content was 72%. The methane content varied between 65 and 75% during the treatment of slaughterhouse wastewater using flocculants sludge HUASB reactor. The decreasing methane content indicates reduced quantity/activity of methanogens in the reactor[16]. 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. The theoretical methane yield is 0.35 lit CH_4 / g COD removed upto an OLR of 16.02 kg COD/ m^{3}d[17]. 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. 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[18].On day 106 in HUASB reactor the removal efficiencies of TCOD and SCOD reached around 83%, 80% at a TOLR of 1.4 and SOLR of 0.52 respectively. The COD removal efficiencies increased with increasing OLR. Finally, the HUASB reactor achieved the removal efficiencies of 75 and 72% in terms of TCOD and SCOD, respectively[19]. The ratio of VFA/ Alkalinity was in the range of 0.39 to 0.88. The OLR values increased and reached a maximum of 0.88. This exceeded the lower limit of 0.4 in order to avoid system failure[20].

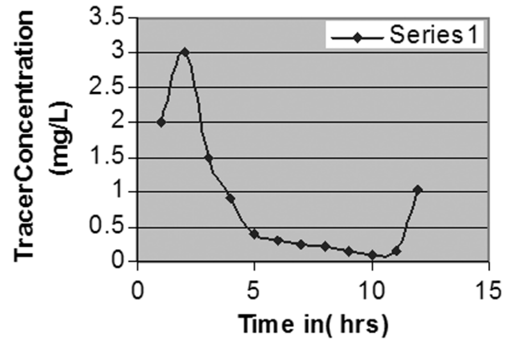

Fig. 9 — The residence time distribution curvefor the reactor at the OLR of 12kg COD/m^3.d

Table 1 — Tracer statistical parameters

OLR of kg COD / m^{3}d	t (hours)	σ^2 (hours^2)	D/UL
5	4.60	9.24	0.230
8	3.55	12.60	0.275
12	3.98	12.03	0.379

Hydraulic characteristics

The tracer curves are depicted at various OLR in Figs 7, 8 and 9. If the D / UL value is 0.2 or less than the reactor is approaching plug flow, whereas greater than 0.2 it is considered as mixed flow pattern[8]. Referring to Table 1, it is seen that at the end of performance study, the dispersion number D/UL values are 0.230, 0.275, and 0.379 respectively, indicating mixed flow pattern. This could be attributed to better mixing in sludge bed zone, increased gas production with reduced dead zones. As the OLR increased the dispersion values were also increased. Hence it is recommended that the media depth may be reduced by modifying the reactor to avoid clogging, channelling problems and to increase the removal efficiency.

Conclusions

The following conclusions are reached from the results obtained in this study.

- The maximum TCOD & SCOD removal efficiency of 92 and 88 % was achieved with HRT of 12 h 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.
- SEM 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.

- Study revealed the behaviour of HUASB reactor more closely to ideal mixed flow with certain degree of dispersion. This is evident from the values of the dispersion number 0.230, 0.275 and 0.379 from varying OLR. As the OLR increased the dispersion values were also increased with constant HRT.
- The HUASB reactor proved to be efficient for the treatment of pulp and paper mill effluent. However it is recommended that the media depth may be reduced for better efficiency.

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