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Performance of hybrid anaerobic reactors for treatment of dairy effluent using different commercial packing media

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ABSTRACT : The anaerobic treatment process escorted with the development of several high rate reactors has earned more feasibility to cope up with the variability in effluent and its treatment against rapid rate of its production. Looking to the advantages of these high rate reactors, an attempt was made at laboratory scale to employ the benefits of both, the anaerobic fixed film reactor and upflow anaerobic sludge blanket (UASB) type reactors in a single reactor and to check whether that would yield better treatment efficiency. Two such reactors were developed following general design considerations for anaerobic fixed film reactor and UASB reactor. Two reactors were identical in every aspect but had different commercial packing media. The reactors were fed with the diluted cheese whey at different hydraulic retention time (HRT) in a semi-continuous mode. The performance data were collected and analyzed for COD removal, biogas production, specific biogas yield, specific methane yield and COD and pH profiles across the height of the reactors. The results showed that the reactors performed satisfactorily at all the HRTs with an average COD removal of up to 83 % and average specific biogas production of 0.63 l/g of COD removed at a COD load of 6800 mg/l. The reactors showed good stability against shock loadings and showed good performance at lower HRTs.

KEY WORDS : Anaerobic fixed film reactor, UAS B, Dairy effluent, Biogas, COD, Methane

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Effluent treatment is not only a legal requirement but is also the social responsibility of an industry (Boghra *et al*., 2003). The dairy industry generates about 2.0 - 2.5 L of wastewater per litre of milk processed (Kumar and Desai, 2011). The key pollutants in the dairy wastewater include organic compounds like fat, proteins, dissolved sugars and possibly residues of additives. The waste load equivalents of specific milk constituents in terms of chemical oxygen demand (COD) are: 1 kg of milk fat = 3 kg COD; 1 kg of lactose = 1.13 kg COD; and 1 kg protein = 1.36 kg COD (Kumar and Desai, 2011). The dairy effluent is biodegradable in nature; and therefore, biological treatment processes - either aerobic or anaerobic - are used for its treatment.

Anaerobic processes require very less energy for their operation, generate energy in the form of biogas and produce sludge which is at least five times less than that produced in aerobic process (Takiguchi, 2004 and Alileche *et al.*, 2008). These three advantages make them very attractive effluent treatment options for any industry. Moreover, anaerobic processes have evolved in a faster treatment process with the development of several high rate reactors such as UASB, sequential bed reactors, membrane reactors, multiple phase reactors, anaerobic fixed film reactors, etc. that can handle wastes at a high organic loading rate and high flow rate at a lower hydraulic retention time (HRT) (Saleh and Mahmood, 2004).

Mostly UAS B type reactors are employed in the treatment of dairy effluent. These reactors are based on suspended growth of the biomass inside the reactors and have some limitations such as wash-out of the culture at higher flow rate, poor stability, long restoration period after any disturbance etc. The fixed film reactors are based on attached growth of anaerobic microorganisms on a support media that reduces the risk of escaping out of microflora from the outlet of the reactor. It also offers distinct advantages such as simplicity of construction, elimination of mechanical mixing, better stability at higher loading rates, and capability to withstand shock loads with an early recovery if the alkalinity is high enough to maintain the pH above 6.2.

In the present study, two hybrid reactors were fabricated with a view to combine benefits of UASB and anaerobic fixed film reactors, operated on dairy effluent and at different HRTs. Commercial packing media were placed in the fixed film portion of the reactors as they have the advantages of higher surface-to-volume ratio, durability and the availability in various shapes, sizes and material of construction. The media were similar in shape and size but the material of construction was different. The objective was to see whether material of construction of media results in any significant difference in the performance of the reactors.

■ METHODOLOGY

Reactors:

Two laboratory scale reactors were developed using the general design consideration followed for the anaerobic fixed film reactors and UASBs which were practiced by earlier research workers. They were fabricated using PVC fittings, valves and the accessories looking to the low cost of construction and easy fabrication and maintenance. The reactors were in cylindrical shape to avoid the formation of dead spaces inside the reactor. The reactors were designed as upflow reactors and hence inlet port was positioned at the bottom of the reactor and the outlet port towards the top. A gas cap was provided at the top and arrangement was made for the collection and measurement of the biogas produced. Four sampling ports were provided at different heights in the reactor to analyze the COD removal at each level and these data were used to create COD and pH profiles across the height of the reactor. The schematic diagram is given in Fig. A.

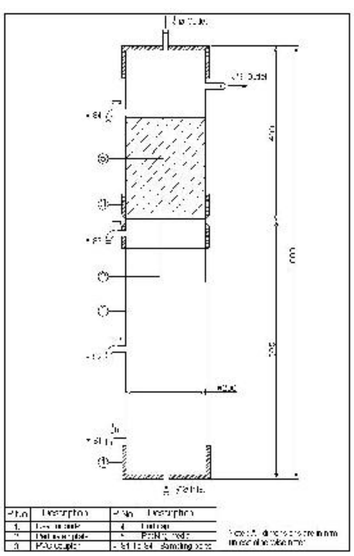

Fig. A : Schematic diagram of reactors

The packing media was supported inside the reactor with the help of a perforated plate. The packing media was placed in 20 % of the total volume of the reactor (Wu *et al.*, 2000). The perforated plate was placed at a height of 60 cm thereby providing a portion of 40 % height to the upper body and 60 % height to the lower body of the reactor. The lower portion was expected to work as UASB while the upper portion as fixed film reactor. The porosity of both the packing media was calculated to know the void space of media per unit volume of reactor (Tembhurkar and Mhaisalkar, 2006). A provision of recirculation of effluent was provided in the reactor as it would aid in degradation as it keeps the solids in suspension (Cheenicharo, 2007). The feeding of reactor was done through a peristaltic pump with a flow rate of 57.1 l/h. The specifications of the reactors are given in Table A.

Table A : Specifications of the reactors

	Height (cm)	Diameter (cm)	Effective volume (l)	Actual volume* (l)
Reactor A	100	20	26.59	27.11
Reactor B	100	20	24.10	25.96

* Actual volume of the reactor is measured upto the top of packing media

Two different packing media were used inside the reactors *viz.*, polypropylene saddles and ceramic saddles having the specifications as given in Table B. The reactors were named as reactor A for polypropylene saddles and reactor B for ceramic saddles.

The reactors were completely filled with filtered mixture of cow dung slurry and digested slurry from an operating anaerobic reactor for culture development and early start up. They were observed for a few days for any gas production. The feeding of dairy effluent in the reactors was started when combustible biogas production started in these reactors.

Operation and data collection:

The reactors were operated for a period of six months and five HRTs *i.e.* 15d, 10d, 5d, 3d and 2d were tested during the period. Final three HRTs were selected for the statistical analysis of reactor performance. The measurements of pH, COD, TDS and biogas produced were taken on daily basis. A pH meter was used for recording pH. Estimation of TDS was done through standard gravimetric method and COD was analyzed using the standard technique as per Bureau of India Standards; IS: 3025 (Part 58): 2006, (ASTM, 1995). The quantification of biogas generated was done through water displacement method and also using gas flow meters. Methane content was analyzed through Orsat apparatus. The data were analyzed and also evaluated through statistical analysis.

The statistical analysis was done through the Factorial Complete Randomized Design (FCRD) model of statistics as given by Steel and Torrie (1980) in which each experimental

Table B : Specifications of the packing media

Specifications	Packing media	
	 Polypropylene saddles	 Ceramic saddles
Size (mm)	25	25
Surface area (m^2/m^3)	210	255
Bulk density (kg/m^3)	100	660
Voidage (%)	90	73

Source: SPRERI Report

unit has an equal chance of receiving a certain treatment. The packing media had two different levels and HRT had three levels (as data at 2, 3 and 5 d retention time were used). Six treatment combinations *viz*., R_1H_1, R_1H_2, R_1H_3, R_2H_1, R_2H_2 and R_2H_3 arising from these two factors were subjected to this model in which the mean value of each attribute obtained from three replications of each treatment was tested for significant difference in COD removal and biogas generation.

RESULTS AND DISCUSSION

The experimental findings obtained from the present study have been discussed in following heads:

Performance evaluation of the reactor:

The reactors exhibited consistent performance and high treatment efficiency at all the HRTs. Almost no problem of clogging was observed when the rectors were fed at an average COD load up to 6800 mg/l reactor volume. The overall TDS removal during the study was 54.33 % and 61.85 % in reactor A and reactor B, respectively. Average COD removal during overall study period was good and nearly the same for both the reactors *i.e.* 83.52 % in reactor A and 83.01 % in reactor B. Amongst the test HRTs (5, 3, 2 days), considering their individual performance, reactor A achieved highest COD removal *i.e.* up to 87.69 % at HRT of 3 d, similarly the HRT of 2 d achieved highest COD removal *i.e.* up to 89.42 % for reactor B as shown in Table 3. The average biogas production achieved at tested HRTs was 25.95 l/d for reactor A and 26.56 l/d for reactor B as shown in the table. Biogas generation increased with a decrease HRT as the organic loading of the reactor increases.

Methane content in biogas produced met the general standards quoted by many research workers. It ranged between 55 to 75 % for the studied reactors. The average methane content (v/v) was 62.59 % and 66.53 % for reactor A and reactor B, respectively and was in the range offered by the other high rate anaerobic reactors. Banu *et al*. (2007) operated two stage hybrid UASB reactors and achieved similar methane content in biogas *i.e.* about 63-70 % in first stage and 63-66 % in second stage.

The average specific methane yield was measured for both the reactors. It was found to be 0.39 l/g COD removed for reactor A and 0.45 l/gCOD removed for reactor B. Bodkhe (2008) reported a specific biogas yield of 0.35 l CH_4/ g COD removal with 70% of CH_4 content obtained using anaerobic filter reactor for treatment of municipal wastewater. Alileche *et al*. (2008) reported that dairy wastewaters are likely to produce specific biogas yield of 0.4 l CH_4/ gCOD removal.

Table 1 : Results of operation at different HRTs (Average)

HRT (Days)	COD removal (%)		Biogas production (l/d)		Methane content (v/v) (%)		Specific biogas yield (l/gCOD removed)		Specific methane yield (l/gCOD removed)	
	A	B	A	B	A	B	A	B	A	B
5	84.47	86.68	20.46	20.00	62.61	63.60	0.67	0.70	0.42	0.44
3	87.69	89.42	28.64	28.84	59.15	65.00	0.73	0.80	0.43	0.52
2	87.16	89.99	28.75	30.83	66.00	71.00	0.50	0.57	0.33	0.40
Avg.	86.44	88.70	25.95	26.56	62.59	66.53	0.63	0.69	0.39	0.45

The COD profile was studied and a consistent decrease in COD was observed across the height of the reactors in which most of the COD was removed below the packing media and the remaining was further reduced across the packing media as shown in Fig. 1. Similar profile graphs were reported by Ittisupornrat *et al*. and Escudie *et al*. (2005) in their study for three completely filled anaerobic fixed film reactors with three different packing media *viz*., sea shell, bamboo sticks and plastic pall rings.

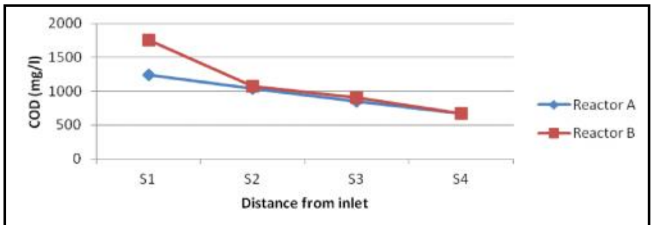

Fig. 1 : Average COD profile in reactors

The pH profile showed that there was an increase in pH across the height in both the reactors as shown in Fig. 2a and 2b. This increase in pH may be due to the digestion of effluent in progress with time. Good buffering capacity of the reactors also indicates presence of well-developed microbial biomass inside the reactors.

Significant difference was observed in COD removal at various HRT; all the treatments and their interaction effects were found at par; indicating the consistent COD removal throughout the tested HRTs. The reactors performed consistently over the different HRTs in respect to COD removal. The FCRD analysis showed that in HRT of 2 days, rector B was found significant from other HRTs at the 5 % level of significance for reactor B with respect to biogas production in which the critical difference (CD at 5%) was found to 1.19 for individual and 1.68 for the interaction effect for reactor B at HRT 2d. The co-efficient of variance (CV) was 6.32 %. The results are shown in Table 4.

The effect of shock loadings was observed while shifting to a lower HRT. A decrease in COD removal in combination with lower methane content in the biogas was observed till the reactors again stabilized themselves due to their buffering capacities. However, reactor B got stabilized earlier than reactor A in majority of the cases. This might be due to less biomass fixed on the surface of polypropylene media compared to ceramic media. Though both the reactors performed well, Reactor B with ceramic saddles showed little better performance in all respect.

Conclusion:

The benefits offered by several high rate anaerobic reactors can be employed to cope up with the problems of treatment and disposal of effluent. The hybrid reactors developed with a combination of two or more reactors suits best for this purpose. The results obtained in the study support the adoption of anaerobic reactors for the treatment of dairy effluent at commercial scale. The design of anaerobic reactors used in the study can offer the advantages of hybrid reactors in which the mechanism of UASB and anaerobic fixed film

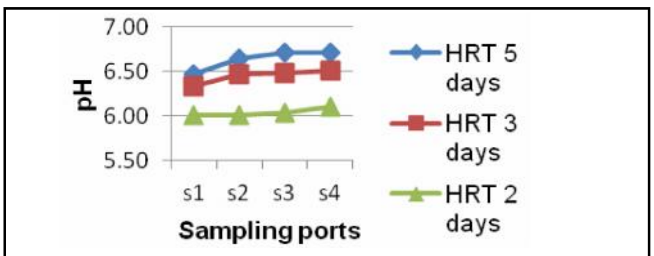

Fig. 2 a : pH profile in Reactor A

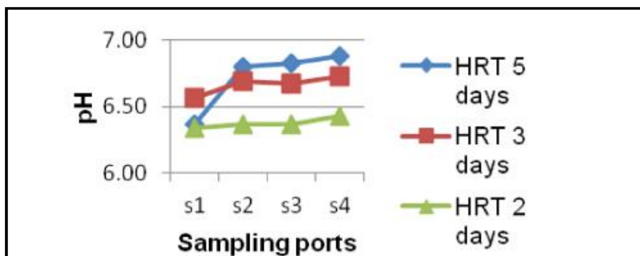

Fig. 2 b : pH profile in Reactor B

Table 2 : FCRD Analysis on performance evaluation of the reactors

Treatments	COD Removal (%)			Biogas Production (l/d)		
	R1	R2	Mean	R1	R2	Mean
H1	87.15	89.98	88.56	28.75	30.82	29.78
H2	85.97	87.58	86.78	27.95	28.6	28.27
H3	83.64	86.29	84.96	22.06	20.5	21.28
Mean	85.59	87.95	86.77	26.25	26.64	26.44
C.D. (P=0.05)	R	H	R X H	R	H	R X H
	NS	NS	NS	NS	1.19	1.68
CV %		5.67			6.32	

*R1-Reactor A, R2-Reactor B, H1- HRT of 2d, H2-HRT of 3d, H3-HRT of 5d NS=Non-significant reactor can be combined together to get better efficiency. Two different packing media were used and both of them gave satisfactory results in terms of pH regulation, COD removal, biogas production and methane content. If shape and size of the packing media are same, the material having lower specific weight can be preferred from the point of ease of handling and requirement of lighter supporting structure. The constructional material of packing media has a definite role in adherence of biomass on its surface which influences the overall performance of the reactors.

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