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RESEARCH PAPER

High rate anaerobic bioreactors for treatment and energy conversion of organic effluents from agro processing industries

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SUMMARY :

Many food-processing industries cause pollution of air and water if the organic effluents are let out without proper treatment. At the same time, these industries face acute energy shortages. Biomethanation of agro-industrial effluents using high rate bioreactors with cell immobilization techniques is an environment friendly way to combat both these problems. Up-flow anaerobic hybrid reactors (UAHR) for treatment of Cassava Starch Factory Effluent (CSFE) were designed and fabricated with preprocessed coconut shells and PVC pall rings as media. The hybrid design incorporated the UASB and UAF concepts. The performance of the reactors in their ability for pollutant reduction and energy (biogas) production were evaluated by operating the system at different hydraulic retention times (HRT). Similar lab scale bioreactors with coconut shells as well as rubber seed outer shells as matrix could be successfully used for rice mill effluent (RME). Even though a slight inhibitory effect was observed in the case of coconut shells during the start-up the developed UAHRs were found to be effective in pollutant reduction and energy conversion of CSFE as well as RME. A pilot scale UAHR was also installed for biomethanation of waste coconut water from a coconut mill. The cost reduction achieved by replacement of synthetic media with locally available natural materials and the simple design coupled with high treatment efficiency and biogas production ability offers great scope for energy conversion of agro-industrial effluents.

KEY WORDS : Biomethanation, Cell immobilization, Upflow anaerobic hybrid reactor, Agro-industrial effluent

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Biological systems for energy production are gaining worldwide appreciation in recent years due to the concern on depleting fossil fuel reserves as well as on the environmental impact of their use. For a country like India where energy continues to be precious, with international oil price hikes continue to threaten the economy, homemade energy has far greater relevance than it has to many other regions of the world. The pollution caused by effluent discharge from many agro-processing industries pose serious threats to the environment. At the same time, these industries face acute energy shortages. In addition to ability to produce energy, the modern anaerobic bioreactors are capable of treating biological wastes at much lesser costs than the energy-intensive aerobic digestion processes. High rate anaerobic digestion of organic effluents is an environment friendly way to combat these problems. The up flow anaerobic filter (UAF), up flow anaerobic sludge blanket (UASB) reactor, anaerobic fluidized bed (AFB) reactor and upflow anaerobic hybrid reactors are widely used high rate bio-reactors for energy production from organic effluent (James and Kamaraj, 2002).

Cassava Starch Factory effluent (CSFE) is a low strength high volume waste for which anaerobic treatment is possible only using high rate anaerobic bioreactors. The wastewater is organic in nature and on an average, these industries generate 30 to 40 l of effluent per kg of sago produced (Nandy *et al*., 1996). The effluent is acidic with a pH in the range 4.5–5 and BOD in the order of 500-3500 (James, 2000). Similar is the case with rice mills in Kerala where parboiling of paddy results in the production of a highly organic effluent (Bovas and James, 2010). Rice mill effluent (RME) is often not properly treated and results in air and water pollution. At the same time, thermal energy produced from fire wood is used for drying moist parboiled paddy to bring down its moisture content before milling. The anaerobic treatment of RME has the twin advantages of pollution control and production of energy as biogas. Bio-reactors such as up-flow anaerobic filters (UAF) and up-flow anaerobic sludge blanket (UASB) reactors utilize immobilized cell technology to retain the bacteria in the reactor for longer periods resulting in shorter hydraulic retention times. Hence, it was attempted to develop environmentally benign high rate anaerobic bioreactor for energy conversion of both CSFE and RME. A pilot scale bioreactor was also fabricated and installed in a coconut oil mill to assess the developed system in actual field conditions with another effluent *viz*., waste coconut water (WCW).

EXPERIMENTAL METHODS

Upflow anaerobic hybrid reactors (UAHRs) in which two cell immobilization techniques *viz*., UAF and UASB are hybridized were developed for CSFE. Field scale UAHRs were designed and fabricated with coconut shells as packing media and the performance was evaluated in comparison with a similar reactor with PVC media at various hydraulic retention times (HRTs). The reactors were started up by operating in the batch mode using supernatant effluent from an anaerobic lagoon as inoculum and were operated in a semi-continuous mode by feeding daily with well mixed CSFE directly taken from the effluent collection tank of the starch factory by a gear pump at a start up HRT of 15 days. The start-up process is described in detail elsewhere (James and Kamaraj, 2007). Then the reactors were evaluated by reducing the HRT step by step to 11, 8, 6, 4, 2.5, 1.67 and 1 day. They were allowed to reach a pseudo steady state (PSS) condition (Guiot *et al*., 1989) at each HRT by operating the reactors at that HRT for a minimum of three volume turnovers. The performances of the bioreactors were studied by monitoring the influent and effluent characteristics and daily biogas production. Further, lab scale UAHRs with a design HRT of 1 day were designed and fabricated for RME and evaluated at different HRTs. The upper halves of the reactors were filled with media for cell immobilization where as the lower half was intended for sludge bed. The evaluation comprised of 4 treatments *viz*., reactors R_1, R_2 and R_4 with rubber seed outer shell as media, and R_3 having polyurethene rings (inert media). The inoculum was cow dung in reactors R_1 (volume 20%) as well as R_3 and R_4 (volume 50%). Sludge from semi-continuous digesters used for preliminary studies was used as inoculum in R_2 (volume 20%). A computer controlled peristaltic pump was used for feeding at different HRTs. The UAHRs were evaluated from the volume and methane content of biogas as well as pH, TS, BOD and COD of influent and effluent by operating them at different organic loading rates (OLR) and hydraulic loading rates (HLR) corresponding to HRTs of 10, 5, 3, 2, 1 and 0.8 day. The pH, total solids (TS), volatile solids (VS), chemical oxygen demand (COD) and biochemical oxygen demand (BOD) were determined by the procedures outlined by APHA (1989). The daily biogas outputs were measured using a calibrated water displacement meter and a wet gas flow meter. Methane content of biogas was measured using a sacharometer filled with an aqueous saturated solution of KOH. A pilot scale UAHR of hydraulic capacity 400 litres was then fabricated and installed at a coconut oil mill in Pattambi, Kerala.

EXPERIMENTAL FINDINGS AND ANALYSIS

The results of the present study as well as relevant discussions have been presented under following sub heads:

UAHRs for CSFE :

The general characteristics of CSFE during the period of study for different parameters are shown in Table 1. The polluting nature of the effluent is evident from the high values of BOD, COD and the low pH. The fairly high BOD:COD ratio indicated a high biodegradability of the CSFE.

Performance of UAHR's at different HRTs:

As the CSFE was directly pumped to the reactors from the effluent collection tank of the factory, the pH of the influent varied from 4.7 to 5.3 during the study. No pH control using alkali addition was attempted as it was aimed to evaluate the performance in the actual field condition. The variation in pH of the influent CSFE did not affect the performance and the bioreactors and the effluent pH values remained almost neutral (pH 6.8-7.4) during the entire period of investigation. This is an indication of the stability of operation of the bioreactors. It could be noted that the sharp changes in the influent TS and VS did not produce corresponding sharp changes in the effluent characteristics. This shows the ability of the UAHRs in adjusting to the sharp changes in influent concentration. Gas production rates are the most important indicators of reactor performance for anaerobic bioreactors. A maximum specific gas production of 1108 and 1030 *l*/kg VS were obtained for reactors 1 and 2, respectively at the longest HRT of 15 days (Table 2). The corresponding minimum values were 725 and 703 l/kg vs at the shortest HRT of 1 day. The VS reduction corresponding to the maximum specific gas production (reactor 1 at 15 day HRT) was 76.2 per cent as the CSFE was a highly biodegradable material. The maximum biogas production obtained per litre of CSFE was 4.24 l/l of feed material and 4.16 l/l (at 8 day HRT) for reactors 1 and 2, respectively. The corresponding minimum values were 2.04 l/l and 1.98 l/l at 1 day HRT. The volumetric gas production (l/m^3 of reactor volume) steadily increased from 260.4 at 15 day HRT to the maximum values of 2038 and 1975 l/m^3 (1 day HRT) for reactors 1 and 2, respectively.

The organic pollutant reduction at various HRTs measured in terms of TS, VS, BOD and COD are given in Table 2. The maximum TS reduction of 60 per cent and 59.3 per cent occurred at 15 day HRT, for reactors 1 and 2, respectively. The minimum TS reductions were 33.8 per cent and 32.4. The maximum VS reductions were 76.2 and 75.9 % at 15 day HRT for reactors 1 and 2, respectively. The minimum values were 49.5 and 48 % at 1 day HRT. A very high BOD reduction of 99 and 98.9 % for reactors 1 and 2, respectively, were obtained at the longest HRT of 15 days. The lowest reductions of 78.9 and 77.4 % BOD and 77.4 and 76 % COD occurred at 1 day HRT. Reactor 1 was found superior to reactor 2 in BOD and COD reduction at all HRTs.

The superiority of reactor 1 as evidenced by increased performances might be due to the favourable surface configuration of the media even though coconut shells caused some inhibition during the start up period. Within a short time, reactor 1 picked up good performance and overtook reactor 2. One reason is that, the actual surface area made available by the micro structure of coconut shell surface would have been quite larger than the measurable area.

UAHRs for RME:

RME was observed to be an acidic organic waste water with average TS, BOD and COD values 3090, 3599 and 4100 mg/l, respectively with a pH of 3.8. The carbon: nitrogen (C:N) ratio was 22.4:1 with a BOD:COD ratio of 0.88 which indicated good biodegradability and suitability for anaerobic digestion (James and Kamaraj, 2004). The C:N ratio is in the optimum range of 20-30:1 for biomethanation recommended by Mathur and Rathore (1992) and there was no possibility of nitrogen deficiency.

Out of the three different media used, the specific surface area of the rubber seed inner shell was the highest (412.2 m^2/m^3) and was nearly 3 and 3.6 times higher than that of rubber seed outer shell and coconut shell, respectively. The surface of the rubber seed inner shell was very smooth on both inner and outer sides, where as the rubber seed outer

Table 1 : Characteristics of CSFE

Sr. No.	Parameters	Range
1.	Total solids (TS), mg/*l*	2100 – 4650
2.	Volatile solids (VS), mg/*l*	1700 – 3740
3.	Biochemical oxygen demand (BOD), mg/*l*	556 – 4025
4.	Chemical oxygen demand (COD) mg/*l*	1110 – 7060
5.	Threshold odour number (TON)	65 – 140
6.	pH	4.5 - 5.3
7.	BOD : COD ratio	0.5 - 0.57

Table 2 : Reactor performance at PSS of different HRTs for CSFE

Parameters		HRT							
		15	11	8	6	4	2.5	1.67	1
TS reduction, %	Reactor 1	60	57.2	56.7	55.5	50.5	46.1	40.3	33.8
	Reactor 2	59.3	56.8	55.6	55.1	49.5	44.9	38.1	32.4
VS reduction, %	Reactor 1	76.2	75.3	75.9	70.6	65.7	59.9	53.8	49.5
	Reactor 2	75.9	74.7	75.4	69.9	64.5	58.6	52.4	48
BOD reduction, %	Reactor 1	99	98.6	98.8	98.6	95.6	87.5	83	78.9
	Reactor 2	98.9	98.3	98.3	98.2	94.4	85.8	82.4	77.4
COD reduction, %	Reactor 1	96.2	96.4	96.2	96.1	93.2	86.3	81.8	77.4
	Reactor 2	96	96.3	95.8	95.2	92	85	80.5	76
CH_4 content of biogas, %	Reactor 1	70	71	72	72	70.5	68	66	65
	Reactor 2	72	73	74	73	71	68.5	65	64

shell had a porous and rather rough surface. A rough and porous surface enhances the biofilm development compared to smooth media surface (Acharya *et al*., 2008). All these media had a specific surface area of more than 100, which is the minimum requirement for the effective biofilm formation (Young, 1991).

Due to the favourable physical characteristics, rubber seed outer shell was selected as the material for lab-scale bioreactors. The lab scale UAHRs designed and fabricated had a total height of 60 cm and a diameter of 20 cm. The media was placed at the upper half of the reactor, retained at the proper position by dispersion plates and had a height of 28 cm for the media filled portion. The sludge bed zone consisted of lower 28 cm height of the cylindrical reactor and the base cone of 10 cm height.

The bioreactors took 23 to 25 days after charging for production of biogas. Feeding was commenced on the 25^{th} day. The influent pH was low (3.8) but the system performed without any problem as experienced by Acharya *et al.* (2008) while treating distillery spent wash having a pH of 4.5, without neutralization. The reactors were operated at the start up HRT of 10 day with the respective HLR of 100 l/m^3.d, TS loading rate of 0.164 kg/m^3.d and BOD loading rate of 0.36 kg/m^3.d. All the reactors exhibited good gas production performance during the start-up and the highest specific gas production of 1299 l /kg TS and 591 l /kg BOD were observed in the UAHR with rubber seed outer shell as media.

The evaluation of the reactors conducted by operating them at HRTs 10 day, 5 day, 4 day, 3 day, 2 day, 1 day and 0.8 day further confirmed the stability of operation and high performance of the UAHRs. The effluent pH values were in the range 7.0 – 8.6 during the entire period of operation even though the influent had a low pH in the range 3.8 – 3.9. The performance of the reactors with respect to TS and BOD reductions were in the range of 58.5 to 61.1 and 81.7 to 82.9 %, respectively.

The effluent TS was found to increase with the reduction of HRT for all reactors. The minimum effluent TS was seen at 10 day HRT in R_1 (638.19 mg/ l), while the maximum was noted at the shortest HRT of 0.8 day in R_4 (1143.21mg/ l). The BOD also exhibited a similar trend. The TS and BOD reductions followed a decreasing trend with shortening of HRT. The maximum reductions were 61.1 % TS by R_1 and 82.9 % BOD for R_4, respectively, both at 10 day HRT. The minimum values were observed at 0.8 day HRT *i.e.* 34.1 % TS (R_4) and 77.1 % BOD (all reactors).

The specific gas productions in terms of TS and BOD for all reactors were found to decrease with the reduction of HRT. A maximum specific gas production occurred at the longest HRT of 10 day for all reactors and the minimum values were obtained at 0.8 day HRT. The biogas productivity (l/l of RME fed) also followed a similar trend of specific gas production. The maximum biogas production obtained per litre of RME was 1.40 l/l (at 10 day HRT) in R_2 and the minimum (0.67 l/l) at 0.8 day HRT in R_4. The volumetric gas production increased with the decrease of HRT in all reactors. The methane content of biogas varied in the range of 65 to 75 % and the peak value of 75 % was observed at 4 day HRT in reactor 1.

Thus, it was evident that the UAHR with rubber seed outer shell as media is very effective in reduction of BOD and production of energy as biogas.

Pilot scale UAHRs for waste coconut water:

A pilot scale UAHR of hydraulic capacity 400 litres with broken coconut shells as matrix was installed in the coconut oil mill and was successfully started up. The slurry from a biogas plant operating on diary cattle manure was used as inoculum. The waste coconut water collected in a storage tank was pumped to the UAHR daily at a start-up HRT of 10 days. The influent waste coconut water was highly acidic having a pH in the range of 4.5-5 during the study period. In order to start-up the system fast the influent was neutralized using sodium hydroxide. The start-up could be achieved within 20 days and the system could be operated at a HRT of 5 days. The hydraulic loading rate was $0.2m^3/m^3$. The volumetric gas production was 0.25 m^3/m^3 reactor volume.

Conclusions:

The study with CSFE confirmed the stability of operation and high performance of the developed UAHRs, especially the one with coconut shells as matrix. The effluent pH was almost neutral (6.8 - 7.4) during the entire period of operation. As the reduction of HRT results in the increase of HLR as well as OLR, the effluent TS, VS, BOD and COD were found to increase with the reduction of HRT for both reactors. The specific gas productions in terms of TS, VS, BOD and COD for both reactors were also found to decrease with the reduction of HRT. The maximum biogas productivities, *l/l* of effluent were 4.24 and 4.16 (8 day HRT) for reactors 1 and 2, respectively. Both UAHRs exhibited high pollutant reduction performance during the above period. The TS, VS, BOD and COD reductions followed a decreasing trend with shortening of HRT. The high performance of both the reactors could be accounted to the high degree of cell immobilisation obtained by the hybrid design. The reactor with coconut shell media was found to perform marginally better than the PVC media reactor.

High performance accountable to the high degree of cell immobilisation obtained by the hybrid design which incorporated the sludge blanket concept along with media peaking of the developed bioreactors could be established in the study on RME also. The use of the developed high rate bioreactor, *viz*., UAHR can be economically operated at an

HRT of 2 days considering the aspects of energy production. At this HRT, 1litre of biogas with 65-70 % methane content can be produced from 1 litre of RME. The computed energy equivalence revealed that 1 tonne of firewood could be replaced by 200 m^3 of biogas produced from RME. Thus, on an average 2 tonnes of firewood could be saved daily in a medium scale rice mill. This has a tremendous effect on the pollution aspects and these findings have high relevance in the context of the present commitments of the country on carbon emission reduction.

The UAHRs with coconut shell as well as rubber seed outer shell media were found to perform better than the reactor with PVC and poly urethane media, possibly due to the favourable micro structure of these shell surfaces which facilitated biomass attachment. Use of costly synthetic media for cell immobilisation can be avoided if these natural materials, which is regarded as agricultural wastes is used in bioreactors. Thus the study could establish that the overall cost of installation of UAHRs can be reduced by the use of coconut shells and rubber seed outer shells as media and it could pave way for better utilization of this agricultural wastes.

LITERATURE CITED

Acharya, B.K., Mohana, S. and Madamwar, D. (2008). Anaerobic treatment of distillery spent wash – A study on upflow anaerobic fixed film bioreactor. *Bioresource Technol.*, **99** (11) : 4621–4626.

APHA (1989). *Standard methods for the examination of water and wastewater*. American Public Health Association, Washington (U.S.A.).

Bovas, Joe Joe L. and James, P.S. (2010). Development of a hybrid anaerobic reactor for treatment and energy conversion of rice mill effluent. Proc. of the Kerala Science Congress, KSCSTE, Trivandrum (KERALA) INDIA.

Guiot, S.R., Podruzny, M.F. and McLean, D.D. (1989). Assessment of Macro energetic parameters for an anaerobic up-flow biomass bed and filter reactor. *Biotechnol. Bioengg.*, **34** : 1277-1288.

James, P. Shaji (2000). Development of a high rate anaerobic reactor for biomethanation of cassava starch factory effluent. Ph.D. Thesis, Department of Bioenergy, College of Agricultural Engineering, Tamil Nadu Agricultural University, Coimbatore, T.N. (INDIA).

James, P. Shaji and Kamaraj, S. (2002). Immobilised cell anaerobic bioreactors for energy production from agro-industrial waste waters – An introduction. *Bioenergy News*, **6** (3): 10-15.

James, P. Shaji and Kamaraj, S. (2004). Preliminary investigation on the use of coconut shells as media for cell immobilization in anaerobic bioreactors. *SESI J.*, **14**(2): 35-40.

James, P. Shaji and Kamaraj, S. (2007). Start-up of a hybrid anaerobic bioreactor for energy production from cassava starch factory effluent. In: *Root and tuber crops- Post harvest management and value addition*, ICAR, Central Tuber Crops Research Institute, Thiruvananthapuram. pp. 235-241.

Mathur, A.N. and Rathore, N.S. (1992). *Biogas production, management and utilization*. Himanshu Publishers. New Delhi (INDIA).

Nandy, T., Kaul, S.N. and Shastry, S. (1996). Waste management in tapioca based sago industry. In: *Green book of tapioca*, Sago Serve, Salem. Vol. II. pp. 1-15.

Young, J.C. (1991). Factors affecting the design and performance of upflow anaerobic filters. *J. Water Sci. Technol.*, **24** (8) : 133-155.