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UASB biomethanation reactor performance in fruit processing industrial wastes

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ABSTRACT : An upflow anaerobic sludge blanket (UASB) reactor was successfully developed and field tested for energy production from biomethanation of fruit processing industry wastes. The performance of the reactor in terms of reduction in pollution, total biogas production and quality of biogas were evaluated by monitoring physico-chemical characteristics of the influent and effluent, daily biogas production, COD removal efficiency and methane content. The organic loading rate and HRT were optimised based on the maximum values of total biogas production, COD removal efficiency and specific biogas production. The optimum organic loading rate observed to be 2.67 kg of COD/m^3/day, when the reactor was operated at three days HRT. The specific gas production was 0.577 m^3/kg of COD removed per day and the COD removal efficiency was 70 per cent.

KEY WORDS : UASB reactor, Fruit wastes, Biomethanation, COD removal, Biogas

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The food processing industry is one of the largest industries in India – it is ranked fifth in terms of production, consumption, export and expected growth. There are over 18,550 food processing industries in India, producing large quantities of wastes (Viswanath *et al.*, 1992). Papaya and pineapple are the fruits which are widely being processed for manufacturing the finished products such as jam, jelly, etc. Utilization of these commodities results in 30 to 35 % of waste generation (Vimal and Adsule, 1976). These wastes are either uneconomically utilized or disposed of as such, thereby causing serious pollution problems.

In recent years, attention is being given to treating the fruit wastes and waste water chemically or biologically to obtain useful by-products before the final disposal. Of the many alternatives, biomethanation of fruit wastes is the best suited treatment, as the process not only adds energy in the form of methane, but also results in a highly stabilized effluent which is almost neutral in pH and is odourless (Bardiya *et al*., 1996). Fruit-processing wastes are highly biodegradable as they are rich in organic matter and have a high (above 50%) moisture content. It has been established that bio-conversion processes are more suitable than thermo-conversion processes. So, there exists a vast scope for the energy recovery as well as waste management, through establishment of proper design of biomethanation plants for the fruit industries.

Anaerobic digestion experiments were carried out on organic food-market wastes. Alvarez *et al.* (1992) have shown that bio-methanation of food-market waste resulted in a production of 0.64 m^3 biogas kg^{-1} total solids (TS) added. Chauhan (2009) reported that biomethanation generation potential from papaya fruit processing wastes was 0.357 m^3 kg^{-1}of VS added. Nand *et al.* (1991) studied the biogas yield from canteen wastes, which was a mixture of fruit and vegetable wastes, when subjected to anaerobic digestion produced 0.82 to 0.9 m^3 of biogas per kg of VS added. Mohan and Sunny (2008) studied the anaerobic digestion of wastewater from jam industries, the specific methane production was found to be 0.28 m^3 kg^{-1} of COD removed per day.

Biomethanation of fruit waste is an economically viable option in terms of energy generation and reduction in greenhouse gas emission. Hence, this investigation has been taken up to study the biomethanation of papaya fruit solid waste and wastewater through UASB reactor.

METHODOLOGY

An upflow anaerobic sludge blanket reactor was designed to handle 8,800 litres per day of the influent, developed and installed in Vee Yel Fruit Processing Industry, Mettupalayam, Coimbatore, India. The reactor has the total height of 5.4 m and diameter of 1.6 m. Effective volume and total volume of the reactor are 8.84 m^3 and 10.8 m^3, respectively. The wastewater from the fruit processing industry was collected in a collection tank and was pumped to the bottom of the UASB reactor using a sludge pump.

The performance of the reactor was evaluated at different HRTs after an initial stabilization period of 40 days. A minimum of 3 turnovers at different HRTs was allowed and the steady state observations were recorded. Parameters like pH, total solids (TS), volatile solids (VS), total suspended solids (TSS), volatile suspended solids (VSS) and chemical oxygen demand (COD) were analyzed as per the APHA (1998) methods.

RESULTS AND DISCUSSION

The physico-chemical characteristics of the fruit wastewater and mixtures of solid wastes and waste water were analysed. The pH of the fruit wastewater was observed to vary from 4.02 to 5.9. The BOD of the fruit wastewater was observed to vary between 1250 and 1610 mg/L and the COD varied between 3000 and 3800 mg/L. The BOD: COD ratio was determined and it was found to vary between 0.41 and 0.42.

Performance of the UASB reactor:

The COD load of the influent and HRT are two independent variables and the performance analyses have been carried out and they are optimized for maximum biogas production.

The COD load of fruit wastewater from the selected industry was in the range of 3000 to 3800 mg/L and the COD load of the influent was very less for biomethanation. In order to increase the COD load of the influent, the solid waste was mixed with wastewater in different proportions. As the per cent of addition of solid wastes in the influent is increased beyond 15%, the COD removal efficiency get reduced at the temperature of 25 - 30°C (Lettinga and Hulshoff Pol, 1991). Hence the values of 5, 10 and 15% of fruit solid waste are chosen for this study. The characteristics of the mixtures of solid and liquid wastes were analyzed and furnished in Table 1.

For stabilization, seeding with digested effluent from a sago industry was filled in the reactor progressively both on batch mode and continuous mode, for a period of 40 days.

After stabilization for a period of 40 days, feeding the raw waste water along with solid wastes was carried out with 5 days HRT (41^{st} day to 85^{th} day), 3 days HRT (86^{th} day to 112^{th} day) and 1 day HRT (113^{th} day to 121^{st} day) for each of three COD loads of 5000, 8000 and 11,000 mg / L. Performance of the reactor under different OLRs and HRTs is depicted in the Table 2.

Table 1 : Characteristics of the mixtures of solid and liquid wastes

Sr. No.	Parameters	Solid wastes composition		
		5%SW + W	10%SW + W	15%SW+ W
1.	pH	6.7-6.8	6.7-6.9	6.5-6.7
2.	Total Solids (TS), mg/L	4580-4675	8224-8235	11780-11827
3.	Volatile solids (VS), mg/L	3750-3800	6770-6790	9660-9685
4.	TSS, mg/L	2910-2945	5364-5388	7693-7742
5.	VSS, mg/L	2745-2759	4685-4724	6912-6930
6.	COD, mg/L	4950-5010	8010-8040	10890-11055

SW-Solid Waste, W – Wastewater

Table 2 : Performance of the UASB reactor with varying OLRs and varying HRTs

HRT, days	Influent COD load, (mg L^{-1})	OLR (kg COD. m^{-3} day^{-1})	COD loading, (kg COD. day^{-1})	COD removal efficiency, (%)	Specific gas production, (m^3 kg^{-1} of COD_d)	Mean daily gas production,m^3	Volumetric biogas production, (m^3/ m^3 reactor)	Methane content of biogas, (%)
5	5000	1.00	8.80	80.67	0.597	4.237	0.481	72
5	8000	1.60	14.73	76.07	0.582	6.240	0.709	68
5	11000	2.20	44.01	65.10	0.384	4.839	0.550	65
3	5000	1.67	14.12	75.77	0.581	6.457	0.734	70
3	8000	2.67	23.52	70.33	0.577	9.519	1.082	72
3	11000	3.67	70.46	57.90	0.357	6.678	0.759	63
1	5000	5.00	19.35	58.00	0.338	8.593	0.976	65
1	8000	8.00	32.24	53.00	0.219	8.188	0.931	63
1	11000	11.00	96.80	45.00	0.189	8.194	0.931	62

Effect of different HRT on COD of 5000 mg/L of the influent :

The COD load of the influent was maintained at 5000 mg/L for the HRT of 1, 3 and 5 days, respectively. The influence of the COD load of the influent of 5000 mg/L of the influent on COD removal efficiency and methane content is shown vividly in Fig. 1.

When the COD of 5000 mg/L of influent was used, the volumetric loading rates (organic loading rate) in terms of COD varied from 1.0 kg/m^3/day at 5 days HRT, 1.67 kg / m^3/ day at 3 days HRT to 5.0 kg / m^3/day at 1 day HRT. The COD reduction varied from 80.67 % (at 5 day HRT), 75.77 % (at 1 day HRT) and 58% (at 1 day HRT). The maximum mean daily biogas production varied from 4.237 m^3 (at 5 days) HRT, 6.457 m^3 (at 3 days HRT) to 8.593 m^3 (at 1 day HRT). The methane content of biogas varied from 72.3 % (at 5 day HRT), 68 % (at 3 day HRT) to 66 % (at 1 day HRT). The maximum specific biogas production of 0.597 m^3/kg of COD removed/day was obtained for the COD load of 5000 mg/L of the effluent at 5 days HRT.

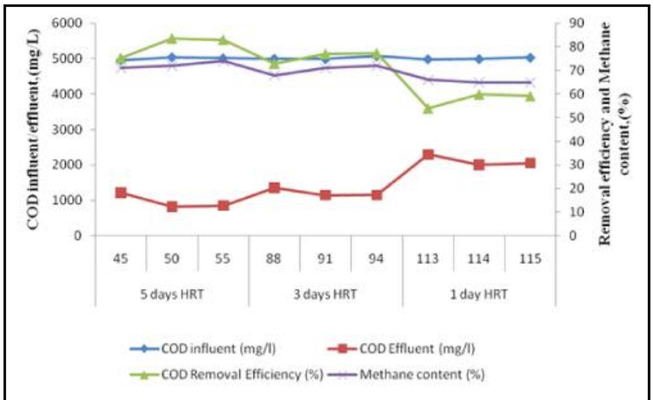

Fig. 1 : Effect of different HRT on COD of 5000 mg/L of the influent

At 5000 mg/L COD influent, the optimum volumetric loading rate was 1 kg COD/m^3 of the reactor volume/day when it was operated with five days HRT. The maximum removal efficiency of COD was found to be 80.6 %. The specific gas production was 0.597 m^3/kg of COD removed/day. Hence, it can be concluded that the maximum specific biogas was obtained at 5000 mg/L of COD load of the influent at 5 days HRT.

Effect of different HRT on COD of 8000 mg/L of the influent :

When the COD load of 5000 mg/L of influent was used, the volumetric loading rate of COD varied from 1.60 kg / m^3/ day (at 5 days HRT), 2.67 kg / m^3/day at (at 3 days HRT) to 8.0 kg / m^3/day (at 1 day HRT). The influence of the COD load of the influent of 8000 mg/L of the influent on COD removal efficiency and methane content is shown vividly in Fig. 2.

The COD reduction varied from 76.07 % (at 5 day HRT), 70.33 % (at 3 day HRT) and 53 % (at 1 day HRT). The maximum mean daily biogas production varied from 6.240 m^3 (at 5 days) HRT, 9.519 m^3 (at 3 days HRT) to 8.188 m^3 (at 1 day HRT). The methane content of biogas varied from 70.3 % (at 5 day HRT), 72.3 % (at 3 day HRT) to 70 % (at 1 day HRT). The specific gas production in terms of COD varied from 0.582 m^3/ kg of COD$_{destroyed}$ at 5 days HRT, 0.577 m^3/ kg of COD$_{destroyed}$ at 3 days HRT to 0.219 m^3/ kg of COD $_{destroyed}$ at of 1 day HRT.

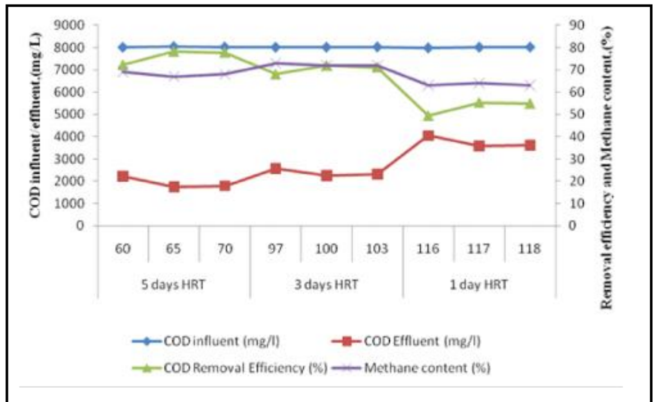

Fig. 2 : Effect of different HRT on COD of 8000 mg/L of the influent

At 8000 mg/L COD influent, the volumetric loading rate was 1.6 kg COD/m^3 of the reactor volume/day when it was operated at five days HRT. The maximum removal efficiency of COD was found to be 76.07 %. The Specific gas production in terms of COD was 0.582 m^3/kg of COD removed/day. Despite the values of removal efficiency, specific gas production at 5 days were maximum, the mean daily biogas production was high (9.519 m^3) in 3 days HRT because of high volumetric loading rate (2.67 kg COD/m^3/day).

Effect of different HRT on COD of 11000 mg/L of the influent:

When the COD of 11000 mg/L of influent was used, the volumetric loading rate of COD varied from 2.2/ kg / m^3/day (at 5 days HRT), 3.67 kg / m^3/day (at 3 days HRT) to 11.0 kg / m^3/day (at 1 day HRT). The influence of the COD load of the influent of 11000 mg/L of the influent on COD removal efficiency and methane content is shown vividly in Fig. 3.

The COD reduction varied from 65.10 % (at 5 day HRT), 57.9 % (at 1 day HRT) to 45 % (at 1 day HRT). The maximum mean daily biogas production varied from 4.839 m^3(at 5 days) HRT, 6.678 m^3 (at 3 days HRT) to 8.194 m^3 (at 1 day HRT). The methane content of biogas varied from 66 % (at 5 day HRT), 69.6 % (at 3 day HRT) to 61.67 % (at 1 day HRT). In

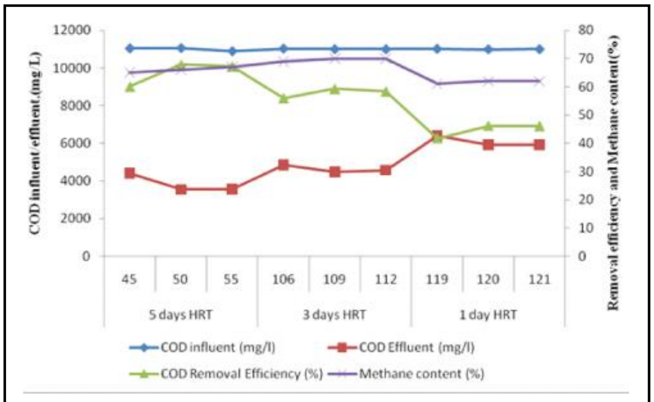

Fig. 3 : Effect of different HRT on COD of 11000 mg/L of the influent

11000 mg/L COD, the removal efficiency was very low. Therefore, the operation of 11000 mg/L COD is not recommended.

Optimisation of the operating parameter of the reactor:

The volumetric biogas production for the COD load of 5000 mg/L of the influent was 0.734 m^3/m^3 of the reactor volume at 3 days HRT and 0.481 m^3/m^3 of the reactor volume at 5 days HRT. The volumetric biogas production for the COD load of 8000 mg/L of the influent was 1.082 m^3/m^3 of the reactor volume at 3 days HRT and 0.709 m^3/m^3 of the reactor volume at 5 days HRT. From above discussion it can be concluded that 3 days HRT is optimized against the 5 days HRT.

The COD removal efficiency for the COD load of 5000 mg/L of the influent was 75.77 % at 3 days HRT and 80.67 % at 5 days HRT. The COD removal efficiency for the COD load of 8000 mg/L of the influent was 70.33 % at 3 days HRT and 76.07 % at 5 days HRT. Even though the COD removal efficiency for the COD load of 8000 mg/L was higher by 5.66 % (the difference of 76.07 and 70.33) for 5 days HRT, the volumetric biogas production for the COD load of 8000 mg/L was higher for 3 days HRT (1.082 m^3/m^3 of reactor volume). Hence, COD load of 8000 mg/L of the influent at 3 days HRT is optimized and recommended for adoption.

Conclusion:

A Pilot-Scale UASB reactor was successfully operated at the organic loading rate of 1- 11 kg COD /m^3 /day. The optimum organic loading rate has been found to be 2.67 kg COD/m^3per day, when the reactor is operated at three days HRT. The COD removal efficiency was found to be 70 per cent. The specific biogas production was 0.577 m^3/kg of COD removed per day. The results obtained on biomethanation of papaya fruit processing wastes reveal that the anaerobic treatment of papaya fruit wastes is technically feasible. The economics of biomethanation of fruit processing wastes indicate that it is economically viable also. The energy generated in the form of methane, when utilized efficiently, not only improves the overall economy of these fruit processing industries, but also provides onsite solutions to waste management problems.

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