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ANAEROBIC TREATMENT OF RAW AND PRECLARIFIED POTATO–MAIZE WASTEWATERS IN A UASB REACTOR

Sergey Kalyuzhnyi[a,b]*, Lorenzo Estrada de los Santos[b] & Jesus Rodriguez Martinez[b]

[a]*Department of Chemical Enzymology, Chemistry Faculty, Moscow State University, 119899 Moscow, Russia*
[b]*Biotechnology Department, Chemistry Faculty, Autonomous University of Coahuila, 25000 Saltillo, Mexico*

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Abstract

The feasibility of the upflow anaerobic sludge bed process for the treatment of raw potato–maize wastewater (PMW) of chip-processing industry with a high concentration of suspended solids (up to 7 g/l), a high insoluble fraction of COD content (up to 60% of total COD) and significant quantities of potentially foaming substances, such as proteins and fats, has been demonstrated by operating a 1·8 litre reactor at 35°C. The influent waste strength was 5·3–18·1 g COD/litre, of which the soluble fraction was 3·2–7·4 g COD/litre. The organic loading rate (OLR) achieved in this laboratory-scale reactor was approximately 14 g COD/litre day with treatment efficiencies higher than 75 and 63% on the basis of centrifuged and total COD of the effluent, respectively. Some problems with excessive foaming and sludge flotation, as well as with accumulation of undigested ingredients that occurred at a high OLR (> 10 g COD/litre day) and moderate hydraulic retention times (HRT > 1 day), can be mostly eliminated by applying shorter HRT (< 1 day, e.g. by recycling some part of effluent) or temporarily decreasing OLR. The preclarification of raw PMW by applying a commercial flocculant led to a better reactor operation at an elevated OLR, though the effluent quality on the basis of centrifuged COD was practically the same as for the treatment of raw PMW. The UASB reactor showed a rapid adaptation to sharp changes in the OLR without significant losses in the treatment efficiency of both wastewaters.

Key words: reactor performance, potato–maize wastewater, sludge flotation, suspended solids, UASB reactor.

INTRODUCTION

Effective full-scale application of anaerobic wastewater treatment has been successfully demonstrated for a large variety of non-complex soluble wastewaters with relatively low concentrations of suspended solids (SS) (Lettinga, 1995). In the case of complex wastewaters (Lettinga & Hulshoff Pol, 1992), some undesired phenomena (such as inhibition of microbial activity, foaming, scaling and/or sludge flotation etc.) may take place and substantially affect performance of anaerobic reactors. Results are presented in this paper from studies on a laboratory-scale upflow anaerobic sludge blanket (UASB) reactor used for treating raw potato–maize wastewaters (PMW) from the chip-processing industry. These wastewaters can be considered as complex wastewaters because of a rather high concentration of SS (up to 7 g/l), a high content of insoluble fraction of COD (up to 60% of total COD) and significant quantities of potentially foaming substances, such as proteins and fats (Table 1).

The selection of the UASB reactor was based on its better suitability for the treatment of wastewater high in SS, which may clog reactors with packing material. However, the application of granular sludge UASB reactors can be difficult, because the poor segregation between granular (more settleable) and flocculant (less settleable) sludges may lead to sudden sludge flotation and reactor failure, especially at high organic loading rates (OLR). In addition, anaerobic digestion of such SS-rich wastewaters can be accompanied by a steady accumulation of slowly hydrolysing or inert substrate ingredients, which will lead to a dilution of the active biomass and, consequently, to its lower specific activity. In such cases, it is recommended to apply preclarification for the elimination of a significant part of SS from the influent (Lettinga & Hulshoff Pol, 1992). The goal of this work was to investigate the feasibility and the stability of the UASB process for the treatment of raw PMW at high OLR and to compare these data with those obtained on preclarified PMW.

*Author to whom all correspondence should be addressed

Table 1. Main characteristics of PMW used

COD_{tot} (g/litre)	COD_{cent} (g/litre)	TSS (g/litre)	VSS (g/litre)	pH	Nitrogen (g N/litre)	Proteins (g/litre)	Greases (g/litre)
Raw							
5·5–18·1	3·2–7·4	2·7–7·1	1·4–6·6	6–11	0·24–0·89	1·5–5·6	0·4–1
Preclarified							
3·6–9·0	2·4–6·1	1·1–2·6	0·8–2·4	6·6–9	0·15–0·37	0·9–2·3	0·2–0·.5

METHODS

Reactor

Experiments were performed in a 2·1-litre UASB-reactor made from glass (internal diameter 6 cm, total working volume 1·8 l). The temperature (35°C) in the reactor was maintained by pumping water from an external thermostat through a jacket surrounding the reactor. A relatively small (60 ml) conical gas separator was installed in the upper part of the reactor. Because of sufficiently high production of biogas, no additional measures were applied for stirring the reactor content. During feeding the reactor, the feed wastewater flask was continuously agitated to prevent sedimentation of SS.

Wastewater

The raw and preclarified PMW used (Table 1) were obtained from a continuous chip-processing factory located in Saltillo, Coahuila (Mexico). The daily wastewater flow from this factory was approximately 500 m^3. The raw PMW mainly consists of potato and maize juices (sometimes with admixture of peels), resting oils, greases and other ingredients, used in the chip production, diluted with the processing water. Preclarification of raw wastewater included treatment by commercial flocculant CT-5090 ('Chem Trea', USA), followed by sedimentation. The main characteristics of both types of wastewaters are shown in Table 1.

Seed sludge

The reactor was seeded with 300 ml (approximately 20 g volatile suspended solids (VSS)) of granular sludge obtained from a laboratory UASB reactor treating synthetic (glucose–acetate) wastewater (Kalyuzhnyi *et al.*, 1996).

Analyses

Volatile fatty acids (VFA) in the effluent, and methane and carbon dioxide in the headspace were measured using gas chromatography as described by Kalyuzhnyi & Davlyatshina (1997). The volume of methane produced was determined by the liquid displacement method after removing CO_2 by absorption into a NaOH solution (Lettinga & Hulshoff Pol, 1992). All methane measurements are expressed at 0°C and standard pressure (760 mm Hg). All other analyses were performed according to Standard Methods (APHA, AWWA, WPCF, 1975). The points shown in the graphs are the means of 2–4 sample sets. Statistical analysis of data was performed by the program 'Descriptive statistics' (Microsoft Excel).

RESULTS

After seeding, the reactor was fed by raw PMW with addition of 1–2 g/litre $NaHCO_3$ to prevent a drop in pH to <6.0 in the reactor medium. The initial OLR was 1.83 g COD/litre day. In a start-up period of 3 weeks, the reactor achieved steady-state with almost constant ($\pm$5%) effluent COD concentrations and methane production rates (Table 2). Later on, the reactor was fed only raw PMW without addition of sodium bicarbonate. The generalized results of these experiments with a stepwise increase of OLR for steady-state conditions (i.e. when the operation regime was maintained at not less than 3 HRT and methane production rates were constant$\pm$8%) are shown in Table 2 and Fig. 1. The influent COD concentration applied was subject to some variation (5·5–18·1 g COD/litre) because we tried to simulate actual conditions in the factory.

In general, the data of Table 2 and Fig. 1 show that the UASB process demonstrated treatment efficiencies (TE) higher than 63% on the basis of total COD for the treatment of raw PMW up to the OLR of about 14 g COD/litre day, though some difficulties in its operation were observed. The majority of these were caused by entrapment of the undigested part of SS of raw PMW in the reactor (the entrapped light aggregates, presumably starch granules and peels, were visually seen in the top of the sludge bed zone, beginning from the OLR of 4·37 g COD/litre day) and foaming. Both these phenomena gave rise to poor settling and consequently an increased washout of sludge. Foaming occurred not only at the gas–liquid interface in the gas separator, but sometimes in the sludge bed itself, followed by incidental lifting of parts of the bed and a pulse-like eruption of the gas from this zone. The heavy flotation of approximately a third part of the bed occurred under an OLR of 14·45 g COD/litre day. To prevent the possible development of this undesirable phenomenon, the feed supply of the

Table 2. Steady-state operation of UASB-reactor treating PMW*

OLR (g COD/ litre*day)	HRT (days)	Influent COD_{tot} (g/litre)	Effluent COD_{tot} (g/litre)	Effluent COD_{cent} (g/litre)	TE on COD_{tot} %	TE on COD_{cent} %	CH_4 %	CH_4 production (litre/litre per day)	Total VFA (g COD/litre)
					Raw				
1·83	5·0	9·1	1·71±0·25	1·60±0·26	81·3±2·7	82·5±2·9	67±1	0·44±0·02	0·79±0·04
2·21	2·5	5·5	1·27±0·14	0·97±0·16	77·0±2·5	82·4±2·8	65±1	0·4±0·03	0·48±0·04
3·0	6·0	18·0	3·50±0·49	2·49±0·45	80·6±2·7	86·2±2·5	64±1	0·91±0·06	0·55±0·04
4·37	1·9	8·3	1·74±0·22	1·29±0·22	79·±2·7	84·5±2·7	65±1	1·0±0·04	0·5±0·05
5·24	2·5	13·1	2·69±0·35	1·30±0·38	79·5±2·7	90·0±2·9	60±1	1·29±0·07	0·7±0·2
5·95	2·2	13·1	2·61±0·37	2·05±0·35	80·1±2·8	84·4±2·7	61±1	1·44±0·10	0·66±0·06
7·28	1·8	13·1	2·68±0·35	1·21±0·39	79·5±2·7	90·8±3·0	58±1	1·43±0·04	1·0±0·08
9·69	1·3	12·6	2·49±0·33	1·25±0·39	80·2±2·6	90·0±3·1	59±1	2·54±0·09	0·36±0·021
0·63	0·8	8·5	2·20±0·21	1·36±0·24	74·1±2·5	84·0±2·8	55±1	2·67±0·14	0·59±0·05
12·14	0·7	8·5	2·40±0·17	2·09±0·18	71·8±2·0	75·4±2·1	54±2	3·19±0·34	0·41±0·04
13·89	1·3	18·1	6·61±0·33	4·46±0·40	63·4±1·8	75·3±2·2	55±2	3·94±0·24	1·8±0.37
14.45	1·25	18·1	Sludge flotation						
3·01	6·0	18·1	3·50±0·47	2·37±0·54	80·6±2·6	86·9±3·0	66±1	0·91±0·04	0·59±0·04
11·31	0·75	8·5	2·20±0·18	1·50±0·23	74·1±2·1	82·3±2·7	54±1	2·81±0·15	0·59±0·05
12·47	0·68	8·5	2·40±0·17	2·10±0·20	71·8±2·0	75·3±2·4	55±2	2·84±0·12	1·12±0·1
13·08	0·65	8·5	2·80±0·16	1·36±0·22	67·1±1·9	84·0±2·6	54±2	2·86±0·40	0·89±0·08
					Preclarified				
5·02	1·79	9·0	0·58±0·36	0·48±0·35	93·6±4·0	94·7±3·9	65±1	1·67±0·05	0·35±0·02
6·98	1·29	9·0	1·45±0·41	1·43±0·39	83·9±4·6	84·1±4·3	64±1	2·16±0·16	0·6±0·14
8·41	0·66	5·6	0·7±0·38	0·66±0·39	87·5±4·2	88·3±4·3	62±1	2·22±0·06	0·7±0·05
13·64	0·66	9·0	1·56±0·44	1·34±0·41	82·7±4·9	85·1±4·6	60±2	3·89±0·07	0·86±0·06
15·0	0·6	9·0	2·60±0·40	2·18±0·41	71·1±4·4	75·8±4·6	59±3	3·96±0·03	1·07±0·23

*Results expressed as means ± standard errors (n = 3).

reactor was stopped for 3 days. During the unfed phase, the reactor continued to produce gas because of digestion of the entrapped suspended and coagulated ingredients of raw PMW.

After sedimentation of floating sludge, accompanied by its blackening caused by consumption of the entrapped components, the feed supply of the reactor was renewed at an OLR of 3 g COD/litre day, which was approximately four times less than the OLR applied before the unfed phase (Table 2). The reactor showed a rapid recovery in its performance and operational stability that allowed a rapid return to the high OLR (> 10 g COD/litre day). Excessive foaming and lifting of parts of the bed were rarely observed in this stage of the experiment, probably because of the shorter HRT and, consequently, the higher superficial upward liquid velocities (V_{up}) applied (~ 1 m/day) in comparison with those (~ 0·5 m/day) before the unfed phase. The higher V_{up} is believed to facilitate the separation of gas bubbles from the surface of biomass aggregates and reduce their excessive flotation into the upper part of the reactor (Hang & Byeong, 1990; Lettinga & Hulshoff Pol, 1992). The entrapment of the light aggregates from the raw PMW in the reactor bed was also less at higher V_{up}, probably because of better contact between substrates and microorganisms and, consequently, their better digestion. In addition, the increased V_{up} facilitated the washout of the flocculant entrapped substrate ingredients, which had worse settling characteristics in comparison with those of the granular sludge. Hence, an application of shorter HRT (< 1 day) at the OLR higher than 10 g COD/litre day (e.g. by recycling some part of effluent) seems to be preferable to prevent sludge flotation and accumulation of undigested ingredients in the reactor under UASB treatment of SS-rich wastewaters.

To investigate the influence of preclarification, the reactor was then transferred to feeding with preclarified PMW (Table 2). No noticeable difficulties in the reactor performance were observed under all the OLR applied, and the TE was always higher than 70% on the basis of total COD, even at the OLR of 15 g COD/litre day (Fig. 1a). The TE on the basis of centrifuged COD for anaerobically treated preclarified PMW was practically the same as for treatment of raw PMW at the comparable OLR (Fig. 1b).

pH of the effluent was between 6·5 and 7·5 during all the experiments, which indicates sufficient alkalinity of the reactor medium for both wastewaters. VFA gave approximately 60% impact to the centrifuged effluent COD concentration of the preclarified PMW and less than 50% to the centrifuged effluent COD of the raw PMW (Table 2). It was likely that some undigested colloidal ingredients from raw PMW were present in the effluent in the latter case.

Methane yield varied from 0·24 to 0·44 litre/g total COD removed for raw PMW and from 0·30 to 0·37 litre/g total COD removed for preclarified PMW. The deviation of these values from the theoretically expected value (0·35 litre/g total COD removed) can be attributed to temporary entrapment of undigested ingredients in the reactor (negative deviations), followed by their digestion or wash-out (positive deviations).

COD removal rates (COD-RR) on the basis of total COD increased with increasing OLR (Fig. 1d) but this dependence had a tendency toward saturation under the high OLR for both wastewaters. It was likely that COD-RR of about 9 and 11 g total COD removed/litre of reactor per day (for raw and preclarified PMW, respectively) were the maximum achievable for the laboratory set-up investigated.

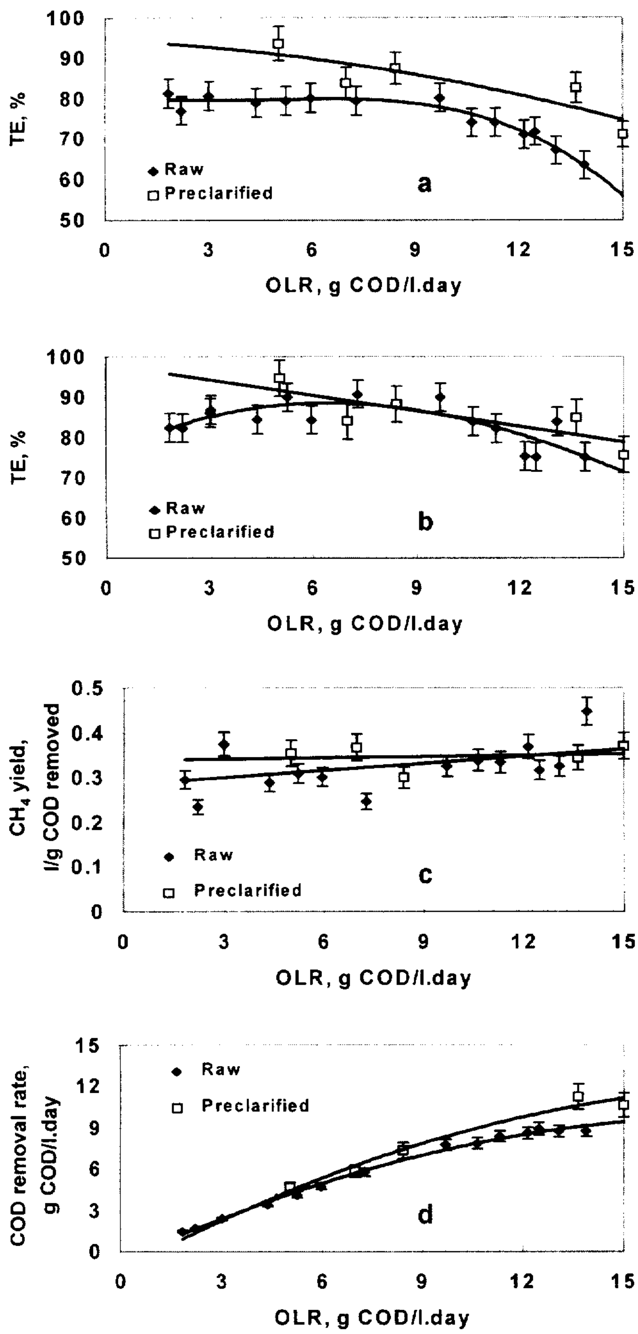

Fig. 1. Treatment efficiencies on the basis of (a) total COD, (b) centrifuged COD, (c) methane yield and (d) COD removal rates versus OLR ($n = 3$).

DISCUSSION

The experimental results described above clearly illustrate a feasibility of the UASB process for the treatment of raw SS-rich PMW up to the OLR of about 13–14 g COD/litre per day with satisfactory TE, though some problems with excessive foaming and sludge flotation as well as with accumulation of undigested ingredients can occur at high OLR (>10 g COD/litre per day) and moderate HRT (>1 day). These undesirable phenomena can be mostly eliminated by application of the shorter HRT (e.g. by recycling some part of the effluent) to enable better wash-out of accumulated ingredients that have worse settling characteristics than those of granular sludge, or by temporarily decreasing OLR for its digestion. Such a mode of functioning of the reactor was not detrimental to its performance, because the UASB reactor showed a quick adaptation to sharp changes in the OLR without significant losses in the TE (Table 2). Moreover, such a regime of feeding the reactor can be fitted with factory wastewater-producing regimes, which are usually characterized by frequent fluctuations in daily volume and COD concentration.

A comparison of the results achieved with those reported for other anaerobic treatment systems and for nearly similar wastewaters (Table 3) indicates that our results are close to optimal, though an actual comparison between various data sets can be based only on experiments where the same wastewater and reactors of comparable size with the same operation temperatures are used. In view of the clearly detrimental effect of the small diameter of our reactor, which contributes to a poor gas release and poor vertical mixing of the sludge, similar OLRs seem to be applicable at the scale-up of the process, provided the reactor is equipped with an appropriate feed inlet distribution system.

Elimination of a significant part of SS by preclarification led to a better reactor performance at elevated OLRs, though the effluent quality on the basis of centrifuged COD was practically the same as in the case of treatment of raw PMW. In this connection, the question arises of what process should be selected for scale-up: with preclarification or without it? Of course, the process with preclarification is more reliable but more expensive, taking into account the additional expenses on flocculant and disposal of the solids separated under preclarification. These additional expenses are eliminated in the process without preclarification and the additional gain is possible because of increased biogas production, but some operational problems can manifest. In order to make a correct choice

Table 3. Comparison of various anaerobic treatments of potato(maize)-processing wastewaters

Reactor[a]	Waste type	Temp. (°C)	HRT (days)	Influent (g COD/litre)	OLR (g COD/litre day)	TE %	Reference
UAFF	Raw[b]	21	9·5	11	1·16	96	1
UASB	Preclarified[b]	35	0·88	2·5	3	85	2
UASB	Raw[b]	20	3·6	18	5	75	3
UASB	Preclarified[b]	35	0·83	11·7	14	74	4
UASB	Preclarified[b]	31–35	0·29	1·954	7	83	5
UASB	Preclarified[c]	40	0·67	10	15	90–95	6
FFR	Preclarified[b]	NM[d]	NM[d]	0·4–11·4	0·64–1·25	NM[d]	7
FBCR	Preclarified[b]	37–42	0·67	16–18	24–27	38–72	8
AF	Preclarified[b]	20	1·5	0·43	0·27	56	9
UASB	Raw PMW	35	0·65–6	5·5–18·1	1·8–13·9	63–81	This study
UASB	Preclarified PMW	35	0·6–1·8	5·6–9	5–15	71–94	This study

[a]UAFF = unified anaerobic fermenter-filter; UASB = upflow anaerobic sludge bed (blanket); FFR = fixed film reactor); FBCR = fixed bed circulating reactor; AF = anaerobic filter.
[b]Potato; [c]maize; [d]NM, not mentioned.
1, Landine *et al.* (1983); 2, Christensen *et al.* (1984); 3, Koster & Lettinga (1985); 4, Nanninga & Gottschal (1986); 5, van Wambeke *et al.* (1990); 6, Lettinga & Hulshoff Pol (1992); 7, Austermann-Haun & Seyfried (1992); 8, Abeling & Seyfried (1993); 9, Viraraghavan & Varadarajan (1995).

between these two alternatives, pilot experiments are needed.

CONCLUSIONS

The following conclusions can be drawn based on the study: (1) the feasibility of the upflow anaerobic sludge bed process for the treatment of raw PMW was demonstrated up to an OLR of about 13–14 g COD/litre day, with the TE higher than 75 and 63% on the basis of centrifuged and total COD of the effluent, respectively; (2) some problems with excessive foaming and sludge flotation, as well as with accumulation of undigested ingredients, that occurred at elevated OLRs, can be mostly eliminated by application of the shorter HRT for better wash-out of accumulated ingredients, or by a temporal decrease of OLR; (3) the preclarification of raw PMW led to a better reactor performance at elevated OLRs, though the effluent quality on the basis of centrifuged COD was practically the same as for the treatment of raw PMW; and (4) the UASB-reactor showed a quick adaptation to sharp changes in the OLR without significant losses in the TE for both wastewaters.

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