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The Anaerobic Treatment of Soft Drink Wastewater in UASB and Hybrid Reactors

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ABSTRACT

The anaerobic treatment of soft drink wastewater (SDW) was studied in two laboratory reactors—a 1.8-L UASB reactor and a 3-L hybrid reactor-sludge bed containing a layer of polyurethane in the upper part, at 35°C. The highest organic loading rates (OLR) achieved were 13 and 16.5 g COD/L · D for hybrid and UASB reactors, respectively, with the treatment efficiency of about 80% for both reactors. Despite the higher treatment productivity achieved for the UASB reactor, its lower ability to generate a sufficient level of alkalinity led to difficulties in maintaining a stable operation performance. Therefore, the hybrid reactor seems to be indicated for OLR higher than 10 g COD/L · d and HRT lower than 1 D, from the point of view of reliability of these two systems.

Both reactors can treat the SDW with pH influent up to 11.0. The feeding of reactors with higher pH influent values led to their quick failure because of alkali shock. The duration of the recovery period after alkali shock was about 1.5–2 mo.

Index Entries: UASB reactor; hybrid reactor; soft drink wastewater; performance; alkali shock.

INTRODUCTION

Typical wastewaters from soft drink industries are mainly composed of washing waters from production lines. For this reason, they have a mod-

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Table 1
Comparison of OLRs and Treatment Efficiencies Achieved in Various Anaerobic Treatments of Soft Drink Wastewaters

Reactor type (temp., °C)	OLR, g COD/l·day	Treatment efficiency, %	Reference
Semicontinuos batch with suspended support	(0.66*)	78	(3)
Anaerobic filter in series with UASB	0.88	75	(4)
UASB in series with			
anaerobic filter:	1.22	87	(5)
UASB	2.78	73	(5)
anaerobic filter	0.88	87	(5)
UASB	7.5	78	(6)
Herding Anaerobic	6-8	80	(7)
Biofilter Systems	6-10	85-95	(7)
UASB	16.5	80	this study
Hybrid	13.0	82	this study

*Apparent (calculated from feed data).

erate concentration of pollutants (usually not more than 10 g COD/L), the composition of which is derived from the ingredients used in the final product and high pH (up to 13.0). Owing to the nature of the main ingredients, like fruit syrups, sugars, flavorings, colorants, and so forth, the organic pollutions are soluble and easily biodegradable *(1–3)*. In practice, many soft drink wastewaters (SDW) are frequently treated together with beer wastewaters, but little research has been reported regarding the application of modern high-rate anaerobic digestion technologies for the treatment of SDW only. Some features of recent studies *(3–7)* are summarized in Table 1. Treatment productivities and organic loading rates (OLR) achieved in these studies were relatively low in comparison with those usually observed for sugar-containing wastewaters *(8–10)*. The possible explanation can be related to low sludge activities caused, in turn, by nutrient deficiency, for example, by nitrogen, and so forth.

This article deals with the treatment of SDW in two modern high-rate anaerobic reactors, the upflow anaerobic sludge blanket (UASB) reactor *(8, 11, 12)* and the so-called hybrid reactor-sludge bed combined with anaerobic filter *(13)*, which we consider to be the most appropriate reactor systems for treatment of SDW in Mexican conditions from the economic point of view. The aim of this work was to (1) compare treatment efficiency (TE) of these two reactors under elevated OLR and (2) investigate an effect of high pH value of influent SDW on performance of both reactors as well as their recovery after alkali shock.

METHODS

Reactors

The UASB reactor of 2.1 L was made from glass (internal diameter—6 cm, total working volume—1.8 L). The temperature (35°C) in the reactor was thermostatically controlled by pumping water from the thermostat through the jacket surrounding the reactor. A relatively small (60-mL) conical gas separator was installed in the upper part of the reactor.

The hybrid reactor (UASB in the down part and anaerobic filter in the upper part with a 5.5-cm layer of polyurethane) of 4.24 L was made from plastics (internal diameter—11.4 cm, total working volume—4 L). During the experiments the reactor was placed in a thermostat (35°C).

No recycling or mixing facilities were provided for both reactors, which were fed by pumps.

Wastewater

The SDW used was obtained from a continuous soft drink processing factory located in Saltillo, Coahuila (Mexico). The daily stream of wastewaters from this factory was on the average about 400 m^3. The main characteristics of SDW were very variable because of different production regimes of the factory. The range of variation of these characteristics during the period of execution of our experiments (January–September 1995) is shown in Table 2.

Because of a very low proportion of nitrogen/COD and low buffer capacity, the SDW was supplemented by 0.5–1 g/L NH_4Cl and 1–6 g/L sodium bicarbonate (when previous neutralization of SDW was necessary).

Seed Sludge and Start-up of Reactors

The hybrid reactor was seeded with 1 L of sludge originating from an anaerobic lagoon (Toluca, Mexico) treating beer industry wastewater. The concentration and specific methanogenic activity of this sludge were 12 g

Table 2
Main Characteristics of SDW Used

COD_{total}, g/l	1.1–30.7
$COD_{soluble}$, g/l	1.0–27.4
TS, g/l	0.8–23.1
VS, g/l	0.6–15.7
pH	4.3–13.0
Alkalinity, g $CaCO_3$/l	1.25–1.93
Nitrogen, g N/l	0–0.05
Phosphate, g P/l	0.01–0.07
Temperature, °C	20–32

VSS/L and 0.03 g CH_4-COD/g VSS · d, respectively. For the reactivation of the sludge, the mineral medium (pH of 7.3) previously described *(15)* with the addition of sacharose (1 g/L) and potassium acetate (1 g/L) was used. After 1 mo of continuous feeding of the reactor with this medium, the specific methanogenic activity of the sludge increased to 0.35 g CH_4-COD/g VSS · d. Beginning from this moment, the hybrid reactor was transferred and operated on SDW.

The UASB reactor was seeded with 0.5 L of sludge (20 g VSS/L) originating from a UASB reactor treating potato-maize wastewater (PMW) *(14)*. The specific methanogenic activity of this sludge was 0.4 g CH_4-COD/g VSS · d. Because of the similar (mainly carbohydrate) nature of SDW and PMW, the preliminary adaptation/reactivation of the sludge was not necessary in this case and the reactor was directly started up with SDW.

Analysis

Volatile fatty acids (VFA), methane, and carbon dioxide concentrations were measured using gas chromatography as previously described *(15)*. The volume of methane produced was determined by the liquid displacement method after removing CO_2 by adsorption into NaOH solution *(8)*. All other analyses were performed according to standard methods *(8, 16)*.

RESULTS AND DISCUSSION

Running Period

The generalized results of running period for both reactors are shown in Figs. 1–3. It is seen that the influent COD concentration applied was subject to sharp variation (Fig. 2), because we tried to work in the conditions close to the real conditions in the factory. Concerning the applied OLR (Fig. 1), the general strategy consisted of its stepwise increasing (without sharp variation) for both reactors. For this reason, applied HRT also varied significantly in the first month of running period.

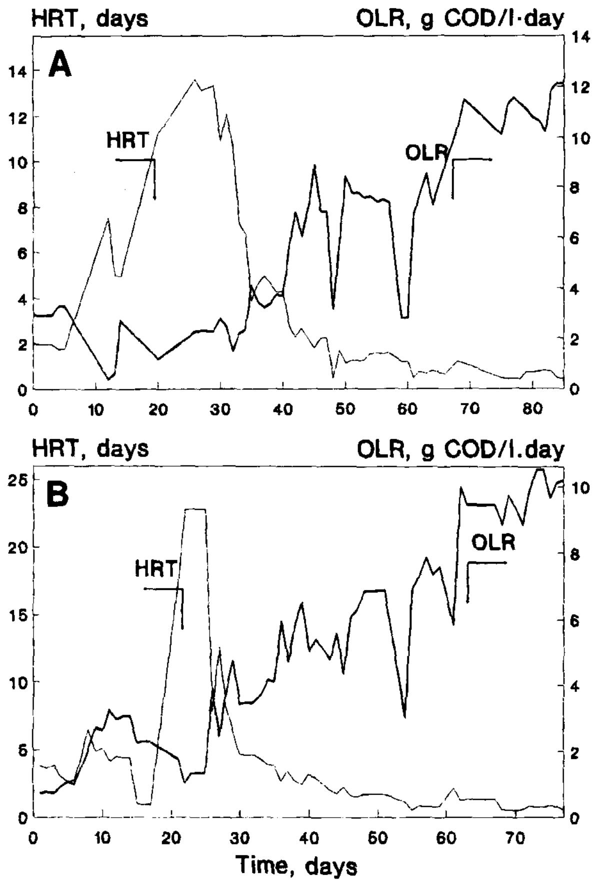

Fig. 1. Applied HRT and OLR for the UASB **(A)** and hybrid **(B)** reactors treating SDW at 35°C during running period.

The results obtained show that during gradual increase of the OLR up to 8 g COD/L · d (first 2 mo of the experiment), both reactors demonstrated good operational performance with the TE on the total COD usually higher than 80% (Figs. 1, 2). In this time, the formation of good settling granules was detected visually as well as by light microscopic examination of samples taken from the sludge bed zone of both reactors. On further gradual increase of the OLR up to 10–12 g COD/l · d, the hybrid reactor continued to maintain the TE, on the average, higher than 80% (Fig. 2B), but the TE of the UASB reactor decreased to 60–70% (Fig. 2A). The effluent COD concentrations were, on the average, 1 (Fig. 2B) and 2 g COD/L (Fig. 2A), respectively. The relatively worse performance of the UASB reactor at elevated OLR and shorter HRT (<1 d) can be mainly attributed to increased biomass washout, which was observed on this stage of the experiment (effluent COD insoluble varied from 0.3–0.5 g COD/L). On the contrary, the biomass washout from the hybrid reactor was not as noticeable (efflu-

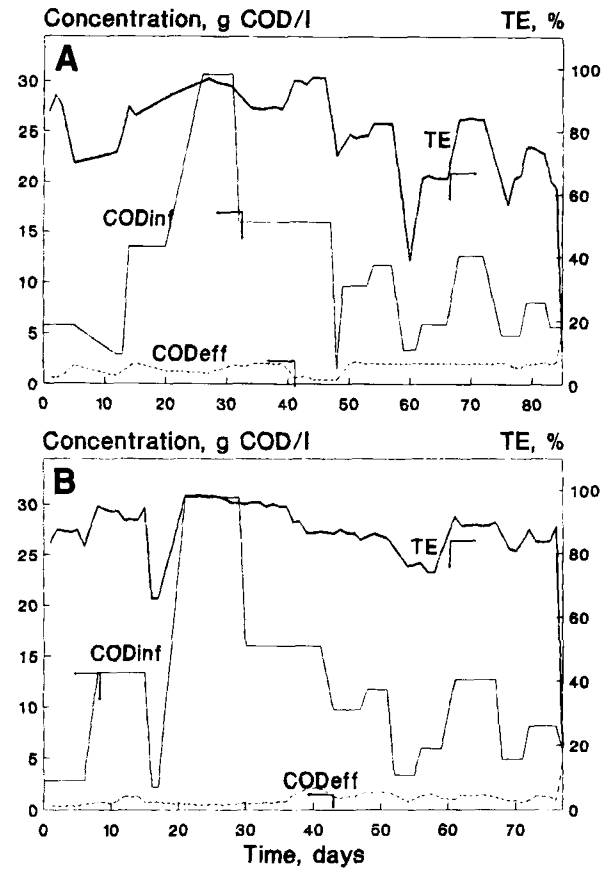

Fig. 2. Influent and effluent COD concentrations and treatment efficiency for the UASB **(A)** and hybrid **(B)** reactors treating SDW at 35°C during running period.

ent COD insoluble was 0.1–0.2 g COD/L) because of more effective retention of biomass aggregates by polyurethane layer.

The biogas content was sufficiently stable (CH_4—60–65%; CO_2—35–40) for both reactors as well as methane yield (0.32–0.33 nL/g COD consumed). During the last week of running period, the sludge taken from the bed zone of hybrid reactor had the following characteristics: concentration—18–20 g VSS/L of bed zone, specific methanogenic activity—0.54–0.56 g CH_4-COD/g VSS · d. The analogous parameters of the sludge taken from the bed zone of UASB reactor during the last week of the running period were slightly higher: concentration—22–24 g VSS/L of bed zone, specific methanogenic activity—0.61–0.63 g CH_4-COD/g VSS · d. Meanwhile, determination of sludge profile in the both reactors performed in the same time showed that the mean sludge concentration (per total working reactor volume) was slightly lower for the UASB reactor (8–9 g VSS/L of total reactor volume) than for the hybrid reactor (10–11 g VSS/L

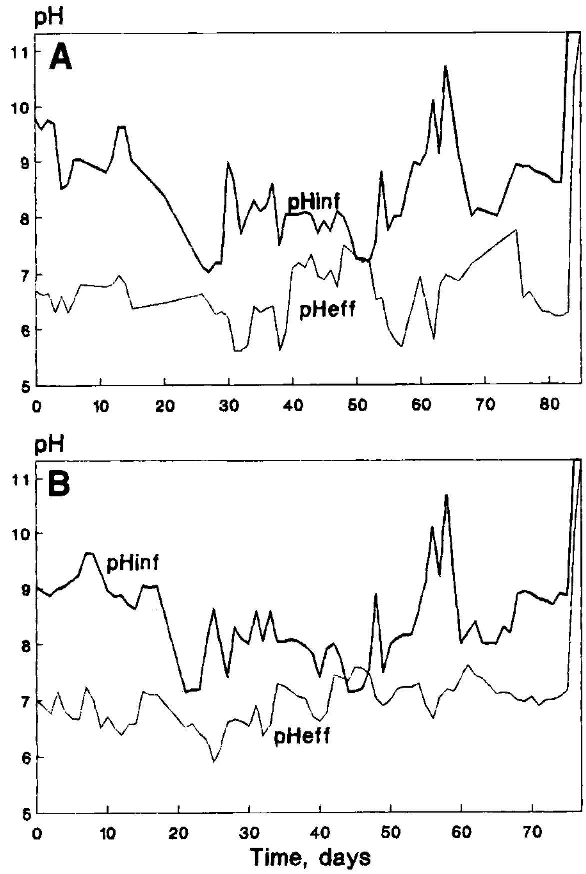

Fig. 3. Influent and effluent pH for the UASB (**A**) and hybrid (**B**) reactors treating SDW at 35°C during running period.

of total reactor volume). Thus, the mean sludge loading rates (SLR) during the last week of the running period were 1.29 and 0.95 g COD/g VSS · d for the UASB and hybrid reactors, respectively.

Taking into account low alkalinity of the fresh SDW (Table 2), special attention was paid to prevent acidification of the reactor media by addition of bicarbonate to the influent. In spite of the fact that the quantity of bicarbonate added was usually higher for the UASB reactor than for the hybrid reactor, the effluent pH was usually lower in the first case (compare Figs. 3A and B) because of the higher concentration of VFA (C_2-C_4) generated (on the average, the effluent VFA concentrations were 1 and 0.5 g COD/L for the UASB and hybrid reactors, respectively). Though the UASB reactor was able to cope even with the medium pH of about 5.5 (Fig. 3A) without noticeable decrease in the TE (Fig. 2A), the observed low medium alkalinity was a subject of continuous worries owing to the danger of an acidification collapse of the system. The above-mentioned problems were less

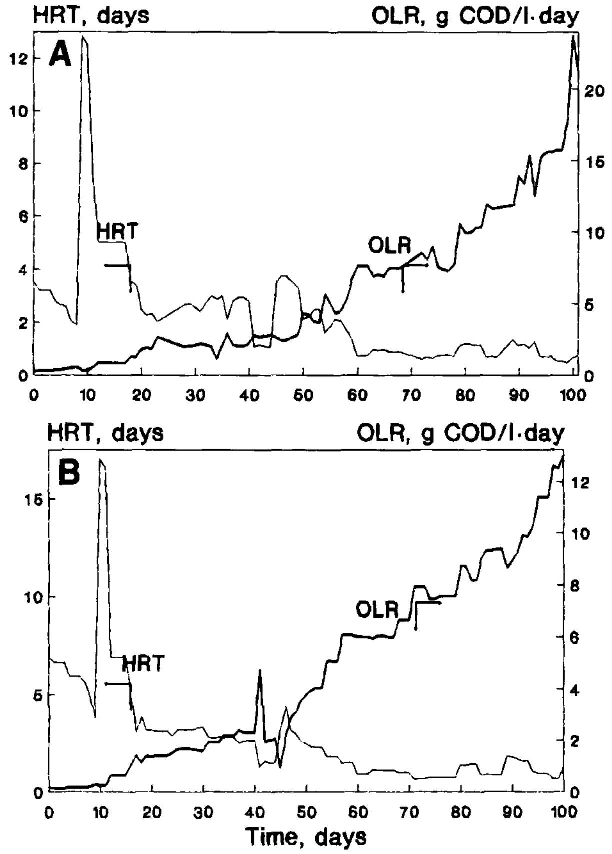

Fig. 4. Applied HRT and OLR for the UASB **(A)** and hybrid **(B)** reactors treating SDW at 35°C during alkali shock recovery period.

characteristic for the hybrid reactor because of the lower SLR applied (*see* previous paragraph).

Alkali Shock Recovery Period

Because of peculiarities of the production regime in the factory (periodic discharge of NaOH), the fresh SDW had sometimes very high pH values—up to 12. We checked the possibility of direct utilization of such SDW for anaerobic treatment (without preliminary decrease of pH). Both reactors easily coped with the SDW having the influent pH up to 11.0 (Fig. 3), but once, when the influent pH was higher than this level, the quick failure of both reactors occurred owing to alkali shock. Further experiments were directed to the recovery of both reactors from this state. The generalized results of these experiments are shown in Figs. 4–6. It is seen that the operation performance during the recovery period was similar for both reactors. Namely, in spite of the very hard shock and that a significant part of biomass was undoubtedly dead, the TE of about 60% was already

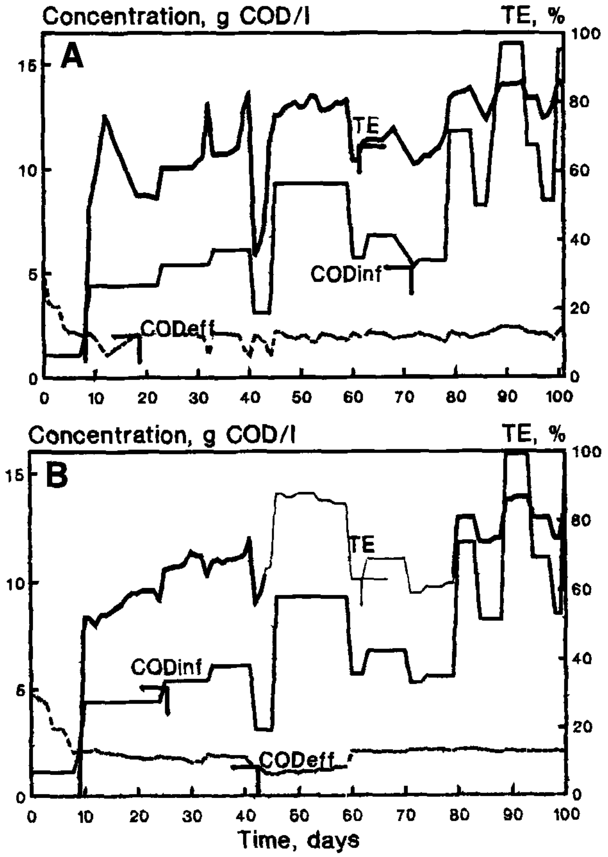

Fig. 5. Influent and effluent COD concentrations and treatment efficiency for the UASB (**A**) and hybrid (**B**) reactors treating SDW at 35°C during alkali shock recovery period.

restored at day 10 after the shock (Fig. 5). Further on, the slow stepwise increase of the OLR up to 2.5 g COD/L · d led to the increase of the TE higher than 80% at days 45–50. Thus, the recovery period of 1.5 mo seems to be necessary for restoring the sludge bacterial activity after the alkali shock. This is comparable with the duration of the start-up procedure usually observed for anaerobic reactors inoculated by disperse sludge *(8,17)*.

After termination of the recovery period (day 50), the OLR were increased more rapidly and reached 13 and 16.5 g COD/L · d for hybrid and UASB reactors, respectively (Fig. 4). The average TE was about 80% for both reactors (Fig. 5). The formation of new granules was observed in both reactors at this stage of the experiment. The higher OLR achieved for the UASB reactor after the shock were a surprise, and can be explained by higher specific methanogenic activity (0.7–0.73 g CH_4-COD/g VSS · d) detected in this reactor (day 99) in comparison with that (0.55–0.61 g CH_4-COD/g VSS · d) for the hybrid reactor. The reactor medium pH oscillated

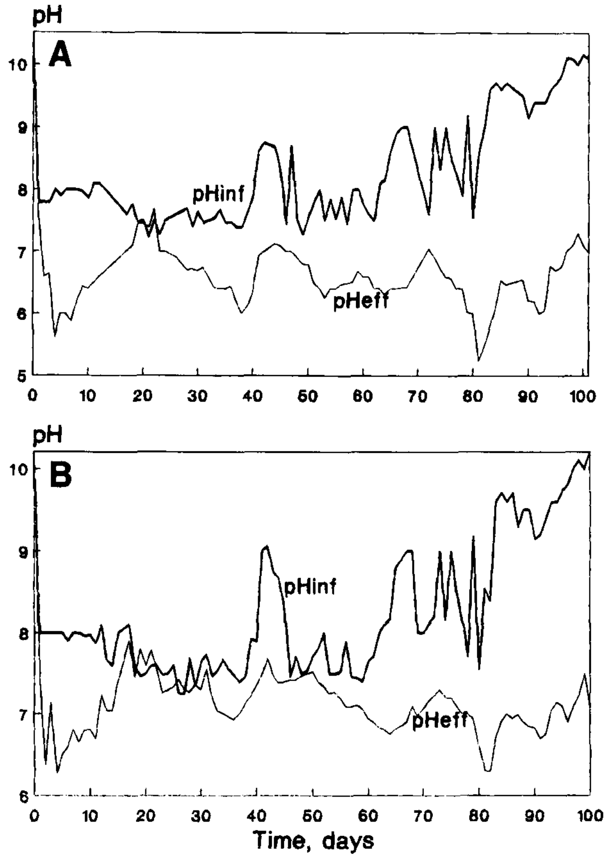

Fig. 6. Influent and effluent pH for the UASB (**A**) and hybrid (**B**) reactors treating SDW at 35°C during alkali shock recovery period.

about 7.0 and 6.0 for hybrid and UASB reactors, respectively (Fig. 6). The last fact can potentially lead to disturbing the operation performance of the UASB reactor. Further increase of the OLR led to decreasing the TE for both reactors (more sharply for the UASB reactor). Therefore, the experiments were stopped.

A comparison of the OLR and the TE achieved with those reported for other anaerobic treatment systems for the SDW (Table 1) indicates that our results are comparable with the best ones from the point of view of the TE and exceed at least two times the reported data on the OLR applied.

CONCLUSIONS

1. This study showed that, on the whole, the UASB and hybrid reactors have demonstrated satisfactory TE and operation performance under anaerobic treatment of SDW. The highest OLR achieved were

13 and 16.5 g COD/L · d for hybrid and UASB reactors, respectively, with the TE of about 80% for both reactors.

2. In spite of a higher OLR achieved for the UASB reactor, its lower ability to generate a sufficient level of alkalinity can potentially lead to difficulties in maintaining stable reactor operation. Therefore, the hybrid reactor seems to be preferential with the OLR higher than 10 g COD/L · d and the HRT shorter than 1 d from the point of view of reliability of these two systems.
3. Both reactors can treat the SDW with pH influent up to 11.0. The feeding of reactors with higher pH influent values led to their failure because of alkali shock.
4. The duration of recovery period after alkali shock was about 1.5–2 mo.

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