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PILOT-SCALE THERMOPHILIC ANAEROBIC TREATMENT OF WASTEWATERS FROM SEASONAL VEGETABLE PROCESSING INDUSTRY

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ABSTRACT

Thermophilic anaerobic treatment of food industry wastewaters was studied using a 0.65 m^3 upflow anaerobic sludge bed (UASB) reactor. The reactor was operated at 55°C and placed on the premises of a factory manufacturing deep-frozen goods from vegetables. The hot (>80-90°C) and concentrated (COD 14-79 g/l) wastewater streams, deriving from steam peeling and blanching of carrot and potato were used.

The UASB reactor was inoculated with a small amount of granular sludge from a full-scale mesophilic UASB reactor. Prior to inoculation, the inoculum was acclimated to 55°C for 2 days. The reactor was fed with a mixture of wastewaters diluted to the desired COD. The reactor was started with loading rates of about 1.2 kgCOD/m^3d. After the initial acidification of the process, apparently due to insufficient buffer capacity, the COD removal started to improve and reached 60% within 35 days of inoculation. At the end of the 70 days run, more than 80% COD removal was achieved with loading rates of about 4 kgCOD/m^3d. The pilot-study run was limited due to the end of the seasonal production in the target factory.

The results of the pilot study together with the results from the intensive laboratory studies suggest the feasibility of thermophilic anaerobic treatment for the studied wastewaters. © 1997 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Anaerobic treatment; pilot-scale; thermophilic; UASB; vegetable processing wastewater.

INTRODUCTION

The processing of vegetables often includes high temperature unit operations, e.g., steam peeling and blanching. Thus, many of the generated wastewater streams are hot and concentrated due to an enhanced dissolution at elevated temperatures. Actually, most of the loads are generated in the high temperature units. In the traditional water systems, the concentrated and hot streams are combined with the cooler and more dilute streams. Also a significant part of the dissolved organics may be transferred together with the product to the next manufacturing unit, in which the load is then removed by flushing with a high volume of cool water. A more advanced separation of individual streams and improved removal of the dissolved load from the products will increasingly enable the treatment of specific streams applying most suitable means.

Anaerobic high-rate reactors, such as UASB reactors, have been widely studied and applied to the treatment of food processing wastewaters under mesophilic conditions. The thermophilic process has apparently not been applied for wastewater treatment, though it would be logical for the hot and concentrated wastewaters generated, e.g., in vegetable processing and in pulp and paper industries. For a long time thermophilic processes were considered unstable and ineffective. However, recent intensive laboratory-scale studies have shown the potential of the thermophilic anaerobic process for wastewater treatment (reviewed in Ahring, 1994; van Lier and Lettinga, 1995). Also a few pilot-scale studies on thermophilic anaerobic treatment of industrial wastewaters (vinasse (Souza *et al.*, 1992) and brewery (Ohtsuki *et al.*, 1994)) have suggested the feasibility of the process.

Besides the end of the pipe application, thermophilic anaerobic process could also have potential as an internal treatment process, combined, e.g. with membranes, when enhancing the re-use of process waters.

Treatment at high temperature could mean increased loading rates and redundancy of cooling before treatment as compared with the mesophilic process. Furthermore, the heat content of the stream would be available for post-treatment or re-use.

In previous laboratory studies, we demonstrated the feasibility of the thermophilic UASB reactor for treating vegetable processing wastewaters (Lepistö and Rintala, 1997). Loading rates of up to 5 $kgCOD/m^3d$ with more than 70% COD removals were obtained within two months of inoculation with mesophilic granular sludge. Subsequently loading rates up to 27 $kgCOD/m^3d$ were applied with COD removals above 90%.

The objective of this study was to evaluate the applicability of the thermophilic process for the treatment of vegetable processing wastewaters in pilot-scale and under mill conditions and subsequently to confirm the results obtained in laboratory-scale. The experimental period was limited to 70 days because of the end of the seasonal production. Thus, the pilot-scale study describes mainly the start-up of the thermophilic process with mesophilic inoculum, while the process performance was studied more intensively in preceding laboratory studies.

MATERIALS AND METHODS

Wastewaters

The wastewaters were from manufacturing deep-frozen goods from carrot and potato. The streams were collected from the steam peeling and blanching units. The main solids were removed with a short-term clarification (less than 1 hour) and a drum sieve of 1 mm poresize. The wastewater characteristics are summarised in Table 1.

Table 1. The characteristics of vegetable processing wastewaters after removing solids through clarification and drum sieve. The mean and range (in parentheses) are shown. Number of samples was 4 to 8 (partly from Lepistö and Rintala, 1997).

Unit operation	*Raw material*	*COD_{tot} (mg/l)*	*COD_{sol} (mg/ l)*	*COD_{sol}/COD_{tot} (%)*
Steam peeling	Carrot	19.4 (17.4-23.6)	17.8 (15.1-22.6)	91.4 (79-98)
	Potato	27.4 (13.7-32.6)	14.2 (11.7-17.5)	71.6 (36-93)
Blanching	Carrot	45.0 (26.3-71.4)	37.6 (22.1-45.8)	91.0 (84-100)
	Potato	39.6 (17.0-79.1)	31.3 (10.9-60.6)	74.3 (63-84)

The feed was prepared by mixing 2/3 (v/v) of steam peeling unit and 1/3 (v/v) of blanching unit wastewater and diluting the mixture with tap water to the desired COD. The feed consisted of wastewater from carrot processing (until day 49), 1/3 of potato processing and 2/3 of carrot processing wastewater (days 49 to 55), and potato processing for the rest of the run. Sodium bicarbonate (2 g/l until day 40 and 3 g/l from day 40 onwards) was added as buffer. From day 32 onwards, sodium hydroxide was added every or every other day into the feed to maintain a process pH above 7. No nutrients were added to the feed. The feed was stored unmixed in a 1.8 m^3 feed container in the factory at room temperature (10-15°C). The feed was prepared once or twice a week. The feed container was emptied and washed once a week to avoid the development of excessive acidifying microbial population.

In the feed tank, the feed was rapidly partly acidified. Immediately after preparation, volatile acids (VA) accounted for 3% of the soluble COD in the feed, while during storage the VA content increased to 14-21% of the soluble COD with no change in the COD value.

Experimental set-up

The experiment was performed using a thermostated and insulated UASB reactor with a liquid volume of 0.65 m^3. The reactor was placed at the mill at room temperature (10-15°C). The feed was heated with a heat exchanger adjusted through two thermometers situated at 10 and 50 cm height from the bottom of the reactor. The treated wastewater was recirculated at 20 cm beneath the liquid surface of the reactor at a flow rate of 1200-1800 l/d. Methane production was periodically measured with a wet-test gas meter (Ritter KG, model TG-1). Biogas samples were periodically obtained from gas tubes situated before the gas meter.

Inoculum

The reactor was inoculated with 45 l of granular sludge containing 78.7 g volatile solids (VS). The sludge was obtained from a full-scale 35°C UASB reactor (Neson Oy, Jokioinen, Finland) treating barley-starch processing wastewater. Before the experiments, the sludge was temperature acclimated in a batch digester at 55°C for two days, and then washed to remove the organic material dissolved due to the lysis of the mesophiles. On day 25, 12 l sludge (25.4 gVS/l) from a 44 l 55°C UASB reactor treating the same wastewater for 40 days was added into the 0.65 m^3 reactor.

Bioassays

The temperature response of the sludge grown in the pilot reactor was assayed in triplicate in 118 ml glass serum vials. 2 ml of granular sludge (23.2 gVS/l), taken at the end of the pilot run, was transferred directly to the vials containing sodium acetate (2.65 gCOD/ l), macro and trace nutrients (described in Lepistö and Rintala, 1997), sodium bicarbonate (3 g/l) and distilled water with a total liquid volume of 42 ml. The pH was adjusted to 7.0 with HCl and NaOH and the headspace of the vials was flushed with 80% N_2 - 20% CO_2. The vials were then sealed with butyl rubber stoppers and aluminium crimps. Sodium sulphide (Na_2S*9H_2O) was added to give a final concentration of 0.25 g/l. The vials were incubated in static cultures at the desired temperatures (20, 35, 50, 55, 58, 65, 70°C). The gas phase was sampled with a pressurised lock syringe.

Analyses

The VS was determined according to the Standard Methods (APHA, 1985), while COD (SFS 5504, 1988) and BOD_7 (SFS 3019, 1979) were determined according to the Finnish Standards, respectively. The VA was measured by direct titration (DiLallo and Albertson, 1961). The pH was measured with an Orion model SA 720 (Orion research, model SA 250 electrode) immediately after sampling in order to avoid pH changes. The samples for soluble COD, BOD, and VA were filtered using Whatman GF/A glass-fibre filters. The methane content in the biogas was determined as previously described (Lepistö and Rintala, 1997).

RESULTS

Reactor study

The loading rate was changed by adjusting both the feed COD concentration (by dilution of the wastewater) and the flow rate (hydraulic retention time (HRT)).

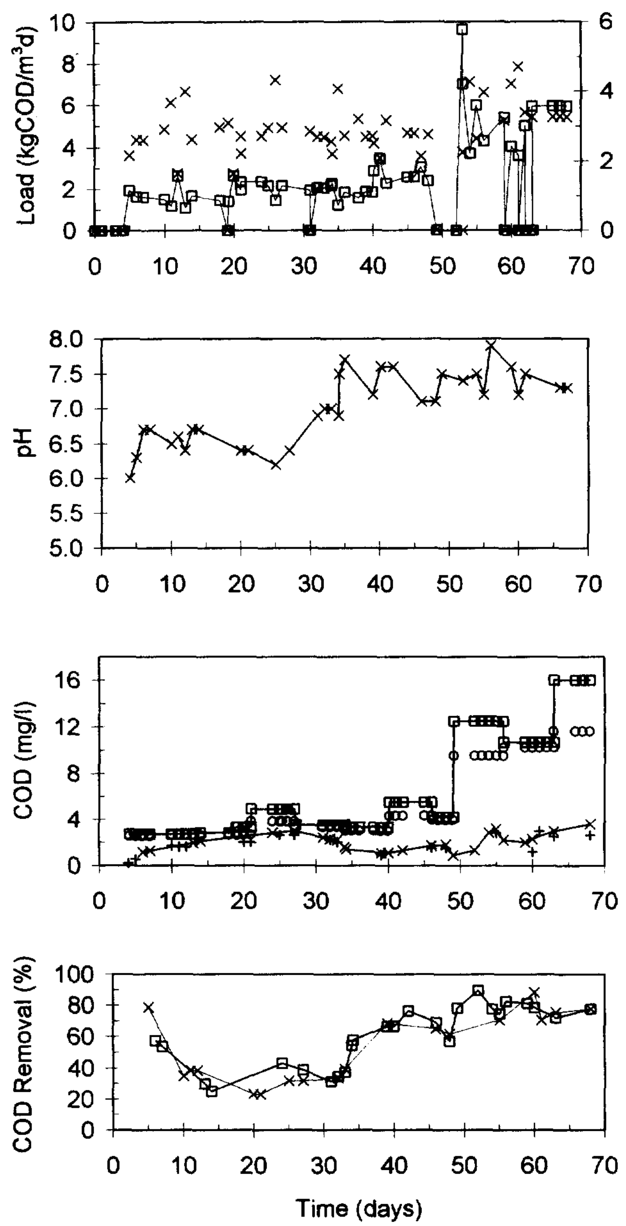

Figure 1. The loads (❑) and HRT (x), effluent pH, COD (❑, feed CODtotal; O, feed CODsoluble; x, effluent CODtotal; +, effluent CODsoluble), and COD removal (❑, CODtotal; x, CODsoluble) during the pilot study.

The reactor was kept unfed for 4 days after inoculation to initiate methanation. The continuous feeding was started on day 4 with a loading rate of about 1.2 kgCOD/m^{3}d (Fig. 1). A COD removal above 50% was obtained at the beginning of the run. However, between days 10 to 20 the COD removal decreased below 30% apparently because of the drop in the process pH. After the addition of the new inoculum (day 25) and the addition of NaOH (day 32), the process pH remained above 6.9 for the rest of the study. Coinciding with the pH increase, the COD removal started to improve and exceeded 60% within 35 days of the first inoculation. The change in the wastewater source (days 49 and 55) had no significant effect on the process performance.

At the end of the run, the COD concentration in the feed was increased up to 12 to 16 g/l, and the process showed COD removals above 80%. Soluble BOD_7 (sampled randomly six times during the run) contributed an average of 69% (range 57-79%) and 75% (range 64-87%) of the feed and effluent soluble COD, respectively. With the carrot feed the methane content averaged 60% in the biogas and the biogas production was 600 l/kgCOD. With potato feed vigorous biogas production was obtained but excessive foaming prevented reliable gas measurements.

The VA content in the feed was generally less than 0.5 g/l except with the more concentrated feed (from day 50 onwards). VA was periodically up to 1.8 g/l. The VA content in the effluent was less than 1 g/l for most of the study.

Temperature response

The temperature response of the sludge grown in the 55°C UASB pilot-reactor during the 70 day run was assayed. The maximum methane production rate was obtained at 55 to 58°C, while the rate was slightly lower at 50°C (Fig. 2). Methane production also started at 65 and 70°C, but slowed down and/or stopped. At 35°C, methane production was insignificant.

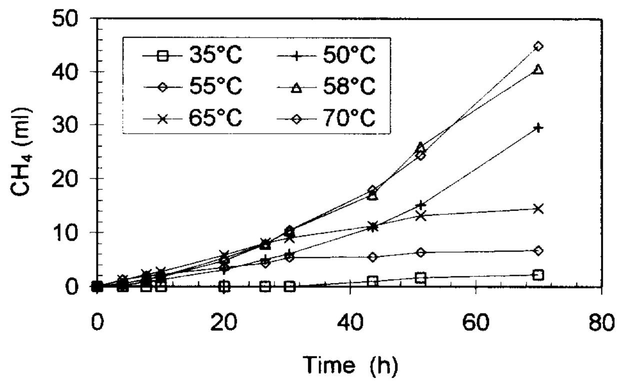

Figure 2. The effect of temperature on the methane production from acetate by the pilot-scale reactor sludge (obtained at the end of the pilot study).

DISCUSSION

The studied hot and concentrated wastewaters from vegetable processing were effectively treated by the thermophilic anaerobic process as indicated by the over 80 to 90% COD removals obtained in the present and in the previous laboratory studies (Lepistö and Rintala, 1997). The good amenability was apparently due to the high carbohydrate content of the wastewaters.

Several long term laboratory as well as pilot-scale studies on thermophilic anaerobic treatment of industrial wastewaters have shown that the process performance is stable, can withstand feed breaks (Ohtsuki *et al.*, 1992, 1994), and some temperature fluctuations (van Lier and Lettinga, 1995; the present bioassays). For example, the study by Souza *et al.* (1992) on thermophilic anaerobic treatment of vinasse proved the long term stability of a 75 m^3 UASB reactor after obtaining sludge granulation.

Laboratory-scale studies have demonstrated that thermophilic processes could stand extremely high loading rates (above 100 kgCOD/m^3d; reviewed in van Lier and Lettinga, 1995) as compared to mesophilic processes. On the other hand, some studies have shown that high loading rates were limited because of excessive washout of the granules at extreme loading conditions (Wiegant *et al.*, 1985). The pilot-studies have not revealed any obstacles that could affect the applicability of full-scale thermophilic anaerobic UASB reactors (Souza *et al.*, 1992; Ohtsuki *et al.*, 1994). Apparently higher loading rates could be applied in thermophilic full-scale processes than is commonly applied in mesophilic ones. However, to fully benefit from the extreme loading potential, a more advanced thermophilic reactor configuration than the available conventional UASB reactor may be needed (van Lier *et al.*, 1994).

The loading rates applied during the present pilot-reactor run were low. The low loading rates were mainly due to limited duration of the run, and partly because of the low amount of inoculum. The inoculum was less than 10% of the total reactor volume, while usually higher inoculum volumes are used. Also, the acidification of the process at the beginning of the run delayed the growth of thermophiles. However, in respect to achieved loading rates and COD removals, the results were similar to those obtained during similar periods in the laboratory studies with the same wastewaters (Lepistö and Rintala, 1997). When the laboratory studies were continued another 60 days, over 90% COD removals were obtained with loading rates of 24 to 27 kgCOD/m^3d.

Thermophilic inoculum is not currently commonly available for inoculation of new reactors. However, thermophilic UASB reactors can be started using sludge from a mesophilic process, e.g., granular sludge (e.g. Wiegant and Lettinga, 1985; Ohtsuki *et al.*, 1992; Rintala *et al.*, 1993). In 55°C UASB reactors loading rates of up to 20 kgCOD/m^3d have been reached within 60 days of inoculation with mesophilic inoculum (Ohtsuki *et al.*, 1994). On the other hand, the start-up may be delayed by excess organic load from the lysis of mesophilic bacteria (Ohtsuki *et al.*, 1994) and a tendency of the process to acidification because of a non-balanced anaerobic consortia. The present process start-up was evidently delayed by inadequate pH control at the beginning of the run.

The studied wastewaters, especially those from potato processing, contained some solids. Some of the solids settled in the feed tank and some were pumped into the reactor. The solids introduced into the reactor may either accumulate in the reactor, biodegrade, or wash out from the reactor with the effluent. In this study, no significant solids accumulation in the reactor was observed at the end of the run and no solids were found in the effluent. Thus, apparently the solids were methanised. Thermophilic anaerobic digesters are used to treat solids, e.g., from potato peeling (Trösch and Chmiel, 1988). However, in the long run solids may disturb the granular structure.

In the target mill, the thermophilic process could be applied to the studied hot streams, which constitute the majority of the total mill load. The treated wastewaters could be discharged to the sewer or post-treated, e.g., by a thermophilic aerobic process (Rintala and Lepistö, 1992).

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