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Treatment of waste water from a multi product food-processing company, in upflow anaerobic sludge blanket (UASB) reactors: The effect of seasonal variation

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Abstract: We have investigated the treatment of waste waters from a multi product food-processing company using a UASB reactor concept. The company Frigodan processes over the season: peas, carrots, celery roots and leeks, resulting in four different types of waste waters. Four lab-scale UASB reactors were started with the individual waste waters. The biomass was characterized after the reactors were adapted to the individual waste water streams and steady state had been reached. Significant differences in both the activities of the different metabolic groups and the numbers of bacteria in the different metabolic groups were found, indicating that problems could occur when changing from one waste water to another. To investigate this further, the waste waters were changed between the different UASB reactors to allow as many different combinations of changes to be tested as possible. Significant decreases in the overall efficiency were observed in the following cases: (1) When changing from celery waste water to any other waste waters due to a significant increase in the organic loading rate of the reactor. (2) When leek waste water with high content of lipids and protein was fed to the reactor. Criteria for treating of waste waters with seasonal variations were developed.

Keywords: UASB reactors, Co-digestion, Seasonal variation

INTRODUCTION

Food processing industries typically generate waste waters with a high organic content that can be treated successfully in Upflow Anaerobic Sludge Blanket (UASB) reactors. However, the food processing industries often process raw material such as various fruit and vegetables that are of seasonal nature. Some industries have a specific product that is seasonally produced, while others vary their production during the year. Consequently, the waste waters generated from these industries can vary significantly throughout the year in quantity and characteristics. Such variations can have a great influence on the overall performance of the anaerobic waste water treatment (ref.1).

Codigestion is a waste treatment method where different types of waste are treated together (refs.2,3,4). The application of codigestion as an intelligent raw material management strategy offers economical, technical and environmental advantages. Codigestion of waste waters from food processing industries offers a treatment method that could solve many problems associated with the treatment of their waste waters. The company, Frigodan, produces frozen vegetables during the summer and fall. Typically, the vegetables are washed, then cooked, frozen, mixed and finally packed before shipping. The company processes in turn: peas, carrots, celery roots and leeks, resulting in four different types of waste waters. Frigodan generates a large amount of waste water (600.000 m^3) of variable quality depending on the vegetable processed (see Table 1).

We have investigated the treatment of waste waters from a multi product food-processing company using UASB reactors. Furthermore, the effect of combining the four waste waters was investigated and strategies for optimal waste water managements were developed.

TABLE 1 Production pattern of vegetables processing at Frigodan Factory in 1993.

	Week no.																				
	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
Pea	▨	▨	▨	▨	▨	▨	▨							▨	▨	▨	▨	▨	▨	▨	▨
Carrot					▨	▨	▨	▨	▨	▨	▨										
Celery													▨								
Leek												▨									

MATERIAL AND METHODS

Waste waters. The waste waters were collected during a period of 3 hours in a reservoir at Frigodan in the summer and fall of 1993. The content of the reservoir was distributed in 10 litres plastic containers and immediately frozen (-20°C).

Source of inoculum. The granular sludge originated from a full-scale UASB reactor treating waste water from a paper mill in the Netherlands (Eerbeek). The granular sludge was stored at 4°C before use.

UASB reactors. Four glass UASB reactors with 200 ml volumes were used. To retain the sludge in the reactors, a round wire gauze made of stainless steel (1 mm mesh size, 39 mm in diameter) was placed 135 mm from the bottom of the reactor as previously described (ref.5). During start-up each of the four reactors was inoculated with 50 ml granular sludge. Bottles with the waste water were placed in a water bath at 2-3°C, to prevent microbial growth. The waste water was pumped to the bottom of the reactor with a peristaltic pump with a waste water, recirculation ratio of 1:4. The reactors were run under mesophilic conditions (37°C). The reactors were started at a hydraulic retention time (HRT) of approx. 24 hr. The organic loading rate (OLR) was increased when the COD reduction efficiency was more than 90% by decreasing the HRT.

Activity tests. Determination of the specific methanogenic activity (SMA) of the granular sludge was done as previously described (ref.6). The test was run in triplicate. Five different substrates, acetate, propionate, butyrate, glucose and formate in a final concentration of 2 $gCODl^{-1}$ were used. Hydrogen was added in 0.5 atm overpressure. Controls without any addition of substrates were included. No significant accumulation of methane was observed in the controls. The specific methanogenic activity was calculated as the initial rate of methane accumulation per gram volatile suspended solids (VSS).

Most probable number (MPN) test. A three-vial MPN test was used to determine the number of bacteria in the various trophic groups. Six different substrates were used: acetate, propionate, butyrate, glucose and formate in a final concentration of 2 $gCODl^{-1}$ and hydrogen (0.5 atm overpressure). Controls were run without any addition of substrates. BA-medium (ref.7) was used, without addition of cysteine. To vials with butyrate or propionate as substrate 1 ml of a hydrogen/formate utilizing methanogen was added. This methanogen was isolated from the inoculum. After 2 month of incubation at 37°C the content of methane in the head space of the vials was measured. Vials were scored positively if the methane content was higher than the mean methane (+3 x standard deviation) produced in corresponding control vials with no added substrate.

Analytical procedures. CH_4/CO_2 and volatile fatty acids (VFA) were quantified using gas chromatography with, respectively, thermal conductivity (ref.7), and flame ionization detection (ref.8). Total solids (TS), volatile solids (VS) and VSS contents were determined using standard methods (ref.9). Chemical oxygen demand (COD) was determined using the dichromate method (ref.9) and potassium phthalate was used as a standard.

RESULTS AND DISCUSSION

Analysis of the waste waters. Celery waste water had a significantly lower COD content than the other waste waters (see Table 2). For the carrot waste water in particular, a high amount of inorganic material was contributing to the total solids. These large differences in composition could result in problems when changing from one waste water to another. The high gCODg^{-1}VS ratio of leek processing wastes indicated that this waste water had a high amount of protein and lipids while celery waste water with a COD/VS ratio close to unity mainly contained carbohydrates (see Table 2). The differences in composition of organic matter could be expected to result also in problems when treating the different waste waters, e.g., when changing to leek waste water from another waste water due to the high gCODg^{-1}VS ratio in the leek waste water.

TABLE 2 Characteristics of the waste waters[1]

	Pea	Carrot	Celery	Leek
COD (gl^{-1})	5.8 (0.4)	7.7 (0.6)	1.4 (0.3)	4.1 (0.8)
TS (gl^{-1})	4.5 (0.2)	11 (3)	1.7 (0.3)	2.1 (0.8)
VS (gl^{-1})	3.8 (0.2)	6 (1)	1.2 (0.2)	1.6 (0.7)
gCODg^{-1}VS	1.5 (0.2)	1.4 (0.3)	1.1 80.2)	2.6 (0.9)

[1] In parenthesis standard deviation

Start-up and operation of UASB reactors with individual waste waters. The UASB reactors were inoculated with granular sludge from a full-scale UASB reactor. The reactors were started with a HRT of approx. 24 hr. The treatment of pea, leek and celery waste water proceeded without any problems. The OLR was increased when the COD reduction efficiency exceeded 90-95%. Increasing the OLR resulted in an increased methane production (data not shown). However, the UASB reactor treating carrot waste water showed several operational problems. The COD reduction decreased from 60% to 25% in the first 20 days. From day 20, pH of the influent was adjusted to 7, resulting in increased efficiency. However, after 20 days of operation the efficiency dropped and VFA accumulated. At day 55, 2 g $NaHCO_3l^{-1}$ were added to the influent and the OLR was decreased. This resulted in an increase of the efficiency to around 95-99%. The OLR was then increased to around 10 gCODl^{-1}d^{-1} without any further problems (data not shown).

Satisfactory treatment of carrot waste water could only be achieved after $NaHCO_3$ was added. However, the addition of alkalinity during treatment of the waste water in a pilot-plant or full scale plant would be expensive and other solutions must be found. A possible solution could be co-digestion with another waste with a high buffer capacity such as household waste or manure.

The results show that the main problems associated with treatment of the different waste streams in the same reactor are the differences in COD and composition. To investigate this further the activity and composition of the microbial biomass were estimated.

TABLE 3. Differences in SMA[a] and MPN[b] between the different granules.

	Acetate		Propionate		Butyrate		Glucose		Hydrogen		Formate	
	MPN	SMA	MPN	SMA	MPN	SMA	MPN	SMA	MPN	SMA	MPN	SMA
Pea			h	h					h		h	h
Carrot		h					h	h	h			
Celery		l										
Leek			h		h				h		h	h

a: Specific Methanogenic Activity
b: most Probable Number Index
h: a higher MPN number of bacteria or a higher activity than all other granules tested.
l: The SMA lower than the rest of the granules.

Characterization of the microbial biomass. The Specific Methanogenic Activity (SMA) test and MPN tests were preformed with granules from the four different reactors (data not shown). When comparing the results obtained from the activity measurements and the counts of bacteria significant changes were found between the different types of waste waters (see Table 3). The results can be summarized as follows:

a) Changes in the activity of the metabolic groups of bacteria when changing from one waste water to the other, i.e., the activity of the acetate degraders increased when changing from celery to carrot waste water

b) The numbers of bacteria in a metabolic group changed, i.e., the number of hydrogen utilizers increased when changing from celery to leek waste water

c) Both activity and number of bacteria belonging to a metabolic group changed, i.e., both the activity and the number of formate degraders increased when changing from carrot to leek waste water.

Operation of UASB reactors with varying waste waters. The waste waters were changed between the different UASB reactors according to Table 4. Reactors U1 (adapted to pea waste water) and U2 (adapted to carrot waste water) followed the same seasonal variations as normal during a production in the Frigodan factory. In U2, half of the biomass was removed from the reactor, during the period when celery waste water was being treated. The waste waters fed to U3 (adapted to celery waste water) and U4 (adapted to leek waste water) followed different schemes, to allow as many different combinations of changes to be tested. The waste waters were fed to the reactors at a rate comparable to that produced by the factory.

Reactor U1. A change from pea to carrot waste water had no significant influence on the overall efficiency of the reactor. However, when leek waste water was fed to the reactor a significant decrease in the efficiency of 33% was observed. After changing to celery waste water the efficiency increased approx. 25%, but decreased again approx. 47% when pea waste water was fed to the reactor (see Table 5).

Reactor U2. To reduce the decrease in efficiency by changing the waste stream from celery to pea waste water, reactor U2 was fed in the same pattern as U1, but half of the biomass was removed during the period the reactor was fed with celery waste water. No significant decrease in the overall efficiency was observed when the waste water was changed from celery to pea waste water, when this procedure was followed. A decrease in the overall efficiency was observed (approx. 19%) when changing from carrot to leek waste water (see Table 5).

TABLE 4. Changes in the waste waters fed to the different reactors.

Week	1	2	3	4	5	6	7	8	9	10	11
U1[1]	P.W.	P.W.	P.W.	P.W.	Ca.W.	Ca.W.	Ca.W.	L.W.	Ce.W.	P.W.	P.W.
U2[2]	Ca.W.	Ca.W.	Ca.W.	Ca.W.	L.W.	Ce.W.*	P.W.	P.W.			
U3[3]	Ce.W.	Ce.W.	Ce.W.	Ce.W.	Ca.W.	Ca.W.	P.W.	L.W.	P.W.	Ce.W.	
U4[4]	L.W.	L.W.	L.W.	L.W.	Ca.W.	Ca.W.	Ce.W.	L.W.			

[1] Adapted to pea waste water; [2]Adapted to carrot waste water; [3] Adapted to celery waste water; [4] Adapted to leek waste water; [5] half of the biomass removed from the reactor in this period.
P.W.: Pea waste water, Ca.W.: Carrot waste water, Ce.W.: Celery waste water, L.W.: Leek waste water

Reactor U3. To investigate the influence of seasonal variation of the performance of the UASB reactors, other patterns of changes were tested. Significant decreases were observed in the overall efficiency when changing the feed from either celery to carrots or from pea to leek waste water (see Table 5).

Reactor U4. This reactor was adapted to leek waste water. When the waste water fed to the reactor was changed to carrot waste water, a decrease of the efficiency of 67% was observed. The efficiency increased when celery waste water was fed to the reactor, but decreased again when leek waste water was fed to the reactor (see Table 5).

Problems with decreases in the overall efficiency were observed in the following instances:

1. When changing from celery waste water to any other waste water. The significanly lower COD content in celery waste water indicated that this result was due to an increase in OLR when changing from celery waste water to any other waste water.

2. When leek waste water was fed to the reactor. The higher lipid content in leek waste water induced inhibition thus reducing efficiency.

The first problem could be overcomed by removing half of the granules in the period when celery was being fed to the reactor. In this way the remaining granules had a higher organic loading with celery waste water comparable to the organic loading obtained with the other waste waters. When changing to a new waste water, these remaining granules were very active, and the performance of the reactor did not change significantly.

The second problem was solved by introducing granules adapted to the leek waste water to the reactor two or three days before the leek waste water was introduced. Previously it was shown that addition of active long chain fatty acids degrading cultures could prevent the accumulation of long chain fatty acids (ref.10). The granules with the ability to degrade a specific waste water containing lipids and proteins would be introduced to the system, ensuring the effective degradation of these compounds. However, this procedure needs to be further investigated.

A buffer tank with prestorage capacity corresponding to a waste water production of two days could be placed before the reactor to reduce the sudden changes in OLR and waste water composition. However, depending of the amount of waste water produced this solution could be economically unrealistic.

TABLE 5. Changes in efficiency after the different changes of waste water.

Reactor	Change of waste water	Change in efficiency (%)
U1	P.W → Ca.W	5%
	Ca.W → L.W.	-33%
	L.W → Ce.W	25%
	Ce.W. → P.W.	-47%
U2	Ca.W. → L.W.	-19%
	L.W → Ce.W.	5%
	Ce.W. → P.W.	6%
U3	Ce.W. → Ca.W.	-17%
	Ca.W. → P.W.	20%
	P.W. → L.W.	-22%
	L.W. → P.W.	15%
	P.W. → Ce.W.	1%
U4	L.W. → Ca.W.	-67%
	Ca.W. → Ce.W.	133%
	Ce.W. → L.W.	-43%

* half of the biomass removed from the reactor in the period where celery waste water is fed to the reactor
P.W.: Pea waste water; Ca.W.: Carrot waste water; Ce.W.: Celery waste water; L.W.: Leek waste water.

CONCLUSION

Our results show that problems will occur when treating waste waters exhibiting seasonal variations, if no special precautions are taken, indicating that a strategy for co-digestion is important in such cases.

The following criteria were developed for co-digestion waste water showing seasonal variations:

- When changing between waste waters with high and low OLR, the reactor should be stopped during the period of low OLR and reopened at the end of the period.
- When changing between waste waters with high and low content of lipids and proteins, granules adapted to waste with high lipids and protein content should be introduced to the reactor some days before the new waste water.
- a buffer tank with a capacity that equals the volume of up to two days of waste water production should be placed in front of the UASB reactor to reduce any sudden changes in waste characteristics.

These criteria will ensure effective and stable treatment of seasonally varying waste waters.

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