Bioresource Technology **37** (1991) 271–276

Anaerobic Treatment of Cheese-Production Wastewater using a UASB Reactor

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(Received 5 June 1990; revised version received 15 November 1990; accepted 25 November 1990)

Abstract

Dairy wastewater comes mainly from the washing of the installations, and due to its medium content of organic matter it is well suited for a biological treatment, especially an anaerobic treatment.

A laboratory scale (4 litres) UASB reactor was operated for more than a year, fed with wastewater from a cheese production industry. An organic loading rate (Bv) of 31 g COD/litre per day ($\bar{t}$ = 1·7 h) and a COD reduction near to 90% were reached, operating in steady-state conditions using a wastewater with a COD influent of 2050 mg/litre (BOD 1300 mg/litre). The effluent COD was 215 mg/litre (BOD 80 mg/litre). Organic loading rate peaks higher than 45 g COD/litre per day were sporadically reached with COD reductions of 70–80%.

The reactor operated with great stability once it had developed a mature microbial population. Prior to this it was necessary to add some alkali in order to maintain the buffer capacity of the system.

Biomass granulation occurred during the operation of the reactor after a sudden increase in organic loading rate. This allowed a more stable operation of the reactor.

Key words: Wastewater treatment, anaerobic treatment, cheese industry.

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INTRODUCTION

The aim of a dairy industry is the processing and exploitation of cows' milk. A diagram with the products that can be obtained in a dairy plant is shown in Fig. 1.

Looking at the process diagrams it can be deduced that the wastewaters produced in a dairy industry can be divided into two main groups; industrial waters and refrigeration plus condensation waters. The latter two do not have a high contamination and constitute between 60 and 90% of the total flow. They can be reused after the recovery of their calorific energy or be employed for washing and rinsing.

The industrial wastewaters are formed mainly from washing and rinsing waters produced in the reception of the milk, packaging, tanks, pumps or spillage during the processing. Water also comes from the washing of the plant and apparatus and sanitary wastewater. The components are mainly milk and cleaning agents.

Fresh wastewater is slightly alkaline (pH = 7·2–8·8), except for the wastewater from the casein plants and some kinds of cheese-making plants. These whitish wastewaters acidify rapidly due to the transformation of lactose to lactic acid, mainly in anaerobic conditions, and so the pH decreases below 5·0. This low pH value can produce precipitation of the casein and the production of suspended solids, while the fresh wastewater does not have suspended solids.

Bioresource Technology 0960-8524/91/$03.50

The effluents from the dairy industry are produced in an intermittent way, and the volume of wastewater changes from one factory to another depending on the kind of circuits and the method of operation. An average value, obtained by Vandamme and Waes (1979) is 1·63 litres wastewater/litre processed milk. However, other authors present higher values for small factories without recirculation of water (Viglianite, 1976). Pollution, expressed as kg of BOD_5 per m^3 of processed milk shows large differences for different factories and even from day to day in the same factory, with values between 0·6 and 2·6 kg BOD_5/m^3 milk. Typical values for the main characteristics of wastewater from a dairy industry are shown in Table 1 (Harper, 1974).

Wastewater from the dairy industry has a moderate concentration of easily biodegradable organic matter. For this reason biological processes are the most suitable if a choice has to be made among the different kind of processes that can be employed to treat these wastewaters. Aerobic processes have usually been used for the treatment of these wastewaters, although anaerobic processes can show some important advantages (Vandamme and Waes, 1980; Bull *et al.*, 1981; Méndez *et al.*, 1989; Rico *et al.*, 1989).

The COD of the wastewaters from the dairy industry varies between 2000 and 6000 mg/litre. This implies working with high hydraulic retention time when aerobic processes are used because the rate of oxygen supply is the limiting factor. Another disadvantage of aerobic processes is the large amount of sludge produced, which implies an expensive treatment for its stabilization and disposal. However, using an anaerobic process sludge production can be reduced to a tenth of sludge production for aerobic process. High COD removal efficiencies can be reached but some kind of post-treatment can be necessary depending on local discharge limitations.

METHODS

Equipment

A lab-scale UASB (upflow anaerobic sludge blanket) reactor was employed. The volume of the reactor was 4 litres. A diagram of the reactor employed during the experiments is shown in Fig. 2 (Rico, 1988). The reactor was cylindrical, made of methacrylate and divided in three zones, joined by clamps. The feed came into the lower zone (internal diameter of 7·1 cm and height of 16·8 cm), and a stone bed was provided to get a good distribution. The middle zone was jacketed to maintain the temperature of the reactor at 35 ± 1°C by recirculating warm water inside the jacket. This zone had a height of 51 cm and internal diameter of 9·3 cm. The upper part had a height of 23·5 cm and the same diameter as the middle zone, and on it there was a gas–liquid–solid separator similar to those described in the literature for UASB reactors (Van der Meer & De Vletter, 1982). The gas generated during the anaerobic process was collected through a wet gas

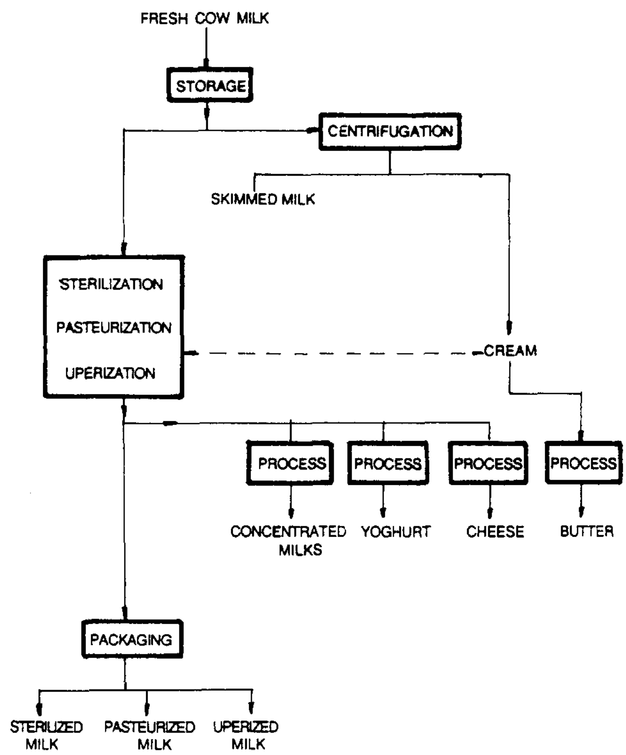

Fig. 1. Flow diagram of the dairy industry. Uperization is a Ultra High Temperature (UHT) treatment with direct contact between milk and vapour.

Table 1. Characteristics of wastewaters from the dairy industry in general

Characteristic	*Mean*	*Range*
BOD_5 (mg/litre)	2300	40–48 000
BOD_5 (g/kg processed milk)	5·8	0·2–71·0
COD (mg/litre)	4500	80–95 000
BOD_5/COD	0·53	0·11–0·90
pH	7·2	4·5–9·4
Total solids (mg/litre)	2540	135–85 000
Suspended solids (mg/litre)	816	24–4500
Volatile solids (mg/litre)	1093	6–5360
Total nitrogen (mg/litre)	56	15–180
Phosphorus (mg/litre)	33	12–132
Chloride (mg/litre)	200	48–559
Wastewater volume (litres/kg milk)	2·5	0·09–7·2
Temperature (°C)	32	18–52

meter. Treated wastewater left the reactor by means of an exit line at the top of the reactor. There was another exit line placed below the effluent exit in order to permit effluent recirculation when it was necessary.

Feed

The reactor feed was cleaning water from a cheese factory. The wastewater was kept refrigerated at 4°C between collection and use. This delay was no longer than 3 days. The characteristics of this wastewater are shown in Table 2. Sometimes the wastewater was polluted with whey coming from the manufacture process, leading to a large deviation from mean values.

Analytical methods

All parameters were determined according to *Standard Methods* (APHA, 1985). Volatile fatty acids (VFA) were determined by gas chromatography using a 5 ft 20% Carbowax 20 M + 2% H_3PO_4 over Chromosorb 100-120 column and a flame detector. Gas production was determined by water displacement and CO_2 percentage with an ORSAT.

Hydraulic retention time ($\bar{t}$) and organic loading rate (*Bv*) were based on working volume of the reactor (4 litres) although the sludge quantity present in it varied along the research programme.

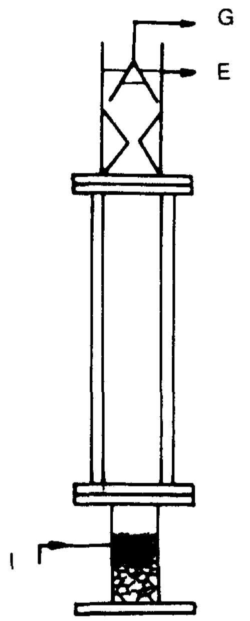

Fig. 2. UASB reactor used in the experiments. I, influent; E, effluent; G, gas outlet.

Table 2. Characteristics of cheese-production wastewater used in the experiments

	Mean	*Range*
COD (mg/litre)	2926	790–6550
pH	6·7	5·5–7·7
Alkalinity (mg $CaCO_3$/litre)	581	110–1812
TS (g/litre)	2·75	1·12–6·38
VS (g/litre)	1·88	0·89–4·16
Phosphorus (mg/litre)	21	6–47
Nitrogen (mg/litre)	36	10–82
Grease (mg/litre)	294	75–595
HAc (g/litre)	0·14	0·00–0·49
HPr (g/litre)	0·08	0·00–0·46
HBu (g/litre)	0·02	0·00–0·12

RESULTS AND DISCUSSION

Experimental results

The reactor was inoculated with 3 litres of anaerobic sludge from a sugar beet-wastewater anaerobic treatment plant that was operating with a *Bx* (mass loading rate/unit mass) of 0·5 g COD/g SVS per day. This sludge was a dispersed one (not granular), with a content of total solids (TS) of 68 g/litre, and volatile solids (VS) of 24 g/litre (35% volatile matter). The experimental reactor had been previously treating diluted whey, for 2 months. When the feed was changed to dairy wastewater, the organic loading rate applied initially was very low, with the aim of acclimatizing the sludge to the new feed. The initial hydraulic retention time (46 h) was quickly reduced because COD reduction was always higher than 98%. Organic loading rate was increased gradually by means of increasing the flow rate, with a consequent decrease in hydraulic retention time.

During the initial period the reactor showed some instability due to the low alkalinity of the influent: effluent alkalinity decreased gradually to 500 mg/litre, and pH was below 7·0 together with a volatile fatty acids accumulation. This forced an increase in alkalinity by addition of sodium bicarbonate (1 g/litre) to the feed. This amount was decreased as the reactor became capable of operating with feed alkalinity fluctuations without needing alkali addition.

The operation of the reactor can be divided into three periods. After each period the reactor was shut down and remained at room temperature until it was fed again. After each shut-down the reactor was restarted employing a *Bv* close to the maximum reached before the shut-down. In the first period the reactor was working for 97 days, and a *Bv* of 4·9 g COD/litre per day ($\bar{t}$ = 8 h) was reached. This period can be considered the start-up and acclimatization of the reactor.

After a shut-down of 50 days the reactor was restarted for the second period, and it operated continuously for 91 days, reaching a *Bv* of 10 g COD/litre per day ($\bar{t}$= 5·3 h). Alkali was added regularly. At the end of this second period *Bv* was decreased from the maximum value reached (10 g COD/litre per day, $\bar{t}$= 5·3 h) to a *Bv* of 4·6 g COD/litre per day ($\bar{t}$= 12 h) checking the stability of the anaerobic reactor without adding alkali. As can be observed in Table 3 there was a slight increment in COD reduction, together with a large gas production, and the reactor operated in a stable way for more than 10 days (more than 20 HRT).

The third period started after a shut-down of 1 month and lasted 140 days. The maximum *Bv* at which the reactor operated in steady-state conditions was 31 g COD/litre per day ($\bar{t}$= 1·7 h) and COD reduction was 88%.

During the third period the reactor operated without alkali addition. Effluent alkalinity was directly related to influent COD, except when wastewater was polluted with whey, because whey produced a COD feed increase without alkalinity increase and reactor alkalinity decreased dramatically. When wastewater was polluted with whey, influent COD increased and therefore also organic loading rate did, producing fluctuations in steady-state operation.

At the end of the reactor operation period sludge concentration was TS = 64 g/litre and VS = 44 g/litre (68% volatile matter). As can be seen, the total solids content was similar to the initial value, although volatile solids had almost doubled. The seed sludge was very mineralized and during operation lost a high percentage of non-organic material.

Figure 3 shows the behaviour of the reactor (influent and effluent COD, *Bv* and COD reduction for the whole period of operation) versus HRT. The maximum *Bv* at which the reactor operated was 31 g COD/litre per day ($\bar{t}$= 1·7 h) and the COD reduction was 88%. During the operation of the reactor it was not necessary to add nutrients to the feed in order to maintain the growth rate of the micro-organisms.

Figure 4 shows COD reduction versus $\bar{t}$. As can be observed for $\bar{t}$> 4 h, COD reduction is practically constant, with a value of 97%, whereas for $\bar{t}$< 4 h there is a linear relation between COD reduction and *Bv*. COD reduction is higher than 90% for $\bar{t}$> 2·5 h.

Methane production had an average value of 0·32 litres CH_4/g COD eliminated, and CO_2 percentage in the gas was between 12 and 20%. This percentage was directly related to *Bv*, increasing as *Bv* did. One fact that can be noted is that as the hydraulic retention time was decreased a slight decrease in the amount of CH_4 collected per g of COD eliminated was observed (Fig. 5).

BOD_5/COD ratio for the influent was quite constant with an average value of 0·65. This value indicates a good biodegradability of the wastewater. For the effluent, the BOD_5/COD ratio had an average value of 0·36, indicating that the wastewater had suffered a biological treatment. BOD_5 reductions are usually 2% higher than COD reductions, and effluent BOD_5 was less than 30 mg/litre, during normal operation conditions of the reactor.

Because of the small diameter of the reactor, when gas production was high it could not flow properly and accumulated to fill the whole section of the reactor, breaking up the bed, lifting it up and then dropping it down, with an increase of turbulence. When this phenomenon occurred higher values of total COD and suspended solids were observed in the effluent. This could be due to the breaking of the bed producing poorer contact between the micro-organisms and the wastewater, and the turbulence formed when the bed dropped down helped to wash out biomass from the reactor. This behaviour can also limit biofilm formation because of the high turbulence and shear forces.

This occurrence disappeared when the granulation of the biomass started. This occurred when the reactor was operating with a *Bv* of 22 g COD/

Table 3. Reactor behaviour with and without addition of alkali

Operation			*Influent*			*Effluent*			*Gas*	
$\bar{t}$ *(h)*	*Bv (g COD/litre per day)*	*Alkali (g/litre)*	*pH*	*Alk (mg/litre)*	*COD (mg/litre)*	*pH*	*Alk (mg/litre)*	*COD (mg/litre)*	*l CH_4/g COD*	*COD removal (%)*
8·6	4·9	0·5	7·3	670	1700	7·5	1045	50	0·33	97
5·3	10	0·5	7·2	630	2300	7·6	1140	90	0·29	96
12	4·6	0	7·3	780	2340	7·8	1250	65	0·33	97

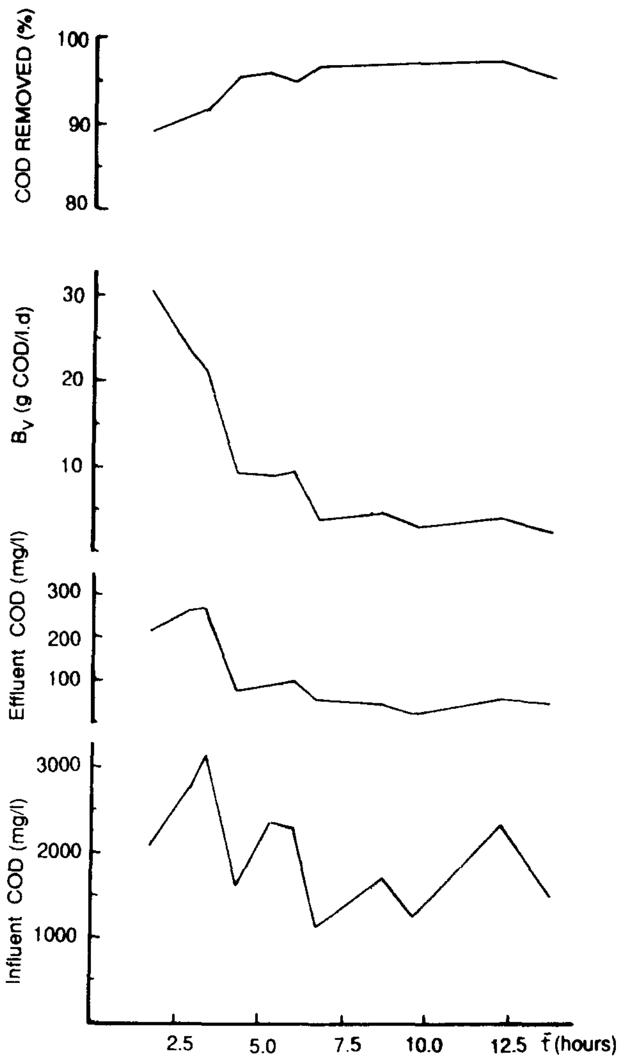

Fig. 3. Reactor behaviour at different HRT ($\bar{t}$).

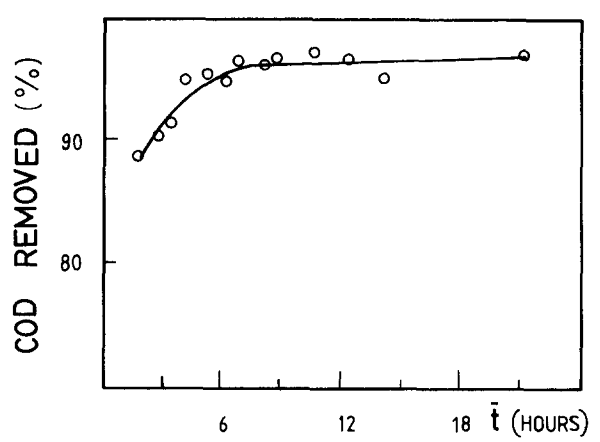

Fig. 4. COD reduction at different HRT ($\bar{t}$).

litre per day ($\bar{t}$ = 3·4 h) and after a period of time of sudden increase in the *Bv* to 45 g COD/litre per day produced by a rise of COD in the influent. These granules were egg-shaped, with a diameter up to 2 mm, like those described in the literature (Hulshoff Pol *et al.*, 1982; De Zeeuw, 1988). From the moment that the biomass granulated the wash-out of sludge with the effluent was much lower, although the reactor worked with higher organic loading rates.

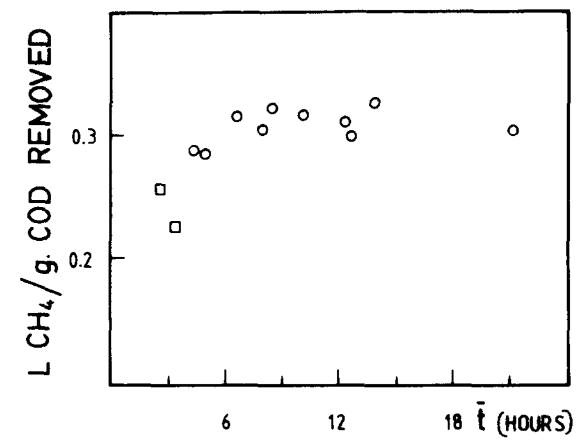

Fig. 5. Methane collected as a function of HRT ($\bar{t}$).

In the effluent the only VFA detected during the normal operation of the reactor were acetic and propionic acids in a concentration around 0·01–0·02 g/litre. When there was some instability of the reactor, values higher than 0·5 g/litre of acetic and propionic acids were obtained, and small amounts of butyric and valeric acids could also be detected. A quick recuperation of the reactor could be achieved by decreasing the organic loading rate applied, and sometimes increasing the alkalinity of the influent.

These results show that working with a lab-scale UASB reactor, and treating dairy waste-water it was possible to reach *Bv* of 25 g COD/litre per day ($\bar{t}$ = 2 h) together with COD reductions higher than 90%. The maximum *Bv* at which the reactor operated was 31 g COD/litre per day ($\bar{t}$ = 1·7 h) with a COD reduction near 90%.

The low alkalinity of the feed required addition of alkali during the start-up of the reactor, to produce stable operation. However, when the reactor was mature there was no necessity to add bicarbonate in order to maintain the alkalinity in a range high enough to ensure the buffer capacity of the reactor, when the wastewater had no whey. If the wastewater was polluted with whey the buffer capacity of the reactor was not high enough and VFA accumulated, due to the increase in feed COD.

Granulation of the biomass occurred after a sudden increase in the organic load due to influent COD increase.

The reactor was started up twice, after shutdown, with a high *Bv* and operated in steady-state.

ACKNOWLEDGEMENTS

This work was supported in part by a grant from the Dirección Regional de Medio Ambiente of the Diputación Regional de Cantabria.

REFERENCES

APHA-AWWA-WPCF (1985). *Standard Methods for the Examination of Water and Wastewater.* APHA, Washington DC.

Bull, M., Sterrit, R. & Lester, A. (1981). Some methods available for treatment of wastewater in the dairy industry. *J. Chem. Tech. Biotech.*, **31**, 579–83.

De Zeeuw, W. J. (1988). Granular sludge in UASB reactors. *Granular Anaerobic Sludge; Microbiology and Technology.* Puduc Wageningen, Wageningen, The Netherlands, pp. 132–45.

Harper, W. I. (1974). Implant control of dairy wastes. *Food Technol.*, **28**, 50.

Hulshoff Pol, L., De Zeeuw, W., Dolfing, J. & Lettinga, G. (1982). Start-up and sludge granulation in UASB reactors. In *Proc. Symp. Anaerobic Waste Water Treatment*, Amsterdam.

Méndez, R., Blazquez, R., Lorenzo, F. & Lema, J. M. (1989). Anaerobic treatment of cheese whey: start-up and operation. *Water Sci. Technol.*, **21**, 1857–60.

Rico, J. L. (1988). Comportamiento de reactores anaerobios UASB en la depuración de aguas residuales de industrias lácteas. Tesis Doctoral, Universidad de Valladolid.

Rico, J. L., García, P. A. & Fdz-Polanco, F. (1989). Valoración y tratamiento del lactosuero. Depuración anaerobia. *Alimentación, Equipos y Tecnología*, **8** (5), 103–10.

Vandamme, K. & Waes, G. (1979). Composition des eaux residuaires de laiterie, calcul de la pollution et de la perte de produits. *Revue de l'Agriculture*, **32** (6), 1453–60.

Vandamme, K. & Waes, G. (1980). Purification of dairy waste water in a two-stage treatment plant, including anaerobic pretreatment. *Milch-wissenschaft*, **35**, 11.

Van der Meer, R. & De Vletter, R. (1982). Anaerobic treatment of wastewater: the gas–liquid-sludge separator. *J. of Water Pollution Control Fed.*, **54** (11), 1482–92.

Viglianitei, E. (1976). La depurazion delle acque di scariso delle industrie lattiero-casaearie. *Mondo di latte*, **30** (5), 289.