Cheese factory wastewater treatment by anaerobic semicontinuous digestion

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ABSTRACT

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The processing of wastewater from a cheese factory in a semicontinuous anaerobic digester was studied. The experimental set-up consisted of six thermostatically-controlled digesters in a bath at $35 \pm 1\,°C$, and magnetically stirred at 100 rpm. The best feeding for the culture medium was 0.633 g l^{-1} day^{-1}. The minimum hydraulic retention time was nine days. The efficiency of treatment varied between 90 and 78%. The composition of biogas was of high quality, with 67% of methane, and no trace of H_2S.

INTRODUCTION

One of the most important motives for the development of wastewater treatment is to control the environmental problem. The wastewater of a cheese factory contains large amounts of dissolved whey, which cause problems in disposal as the cheese whey has a high chemical oxygen demand.

In the literature there are few data concerning the utilization of these wastewaters. De Haase and co-workers [1] used a downflow fixed-bed reactor, and they found it successful for the anaerobic digestion of diluted cheese whey. Recently, Lo and Liao [2] and Lo et al. [3] used a laboratory-scale anaerobic rotating biological reactor in the processing of a cheddar cheese whey. They concluded that two-state anaerobic fermentation was a suitable method for treating whey. Rouleau et al. [4] and Yan et al. [5]] have also built two types of reactors in parallel, i.e., the downflow fixed film, and the upflow sludge blanket for these wastewater anaerobic treatment.

In the present study we have chosen the wastewater from a cheese factory in order to apply the anaerobic treatment method. This wastewater is easy to handle, does not contain large solid particles in suspension, and probable good

digestibility, owing to the absence of polymers of difficult degradation. The subject of this study is as follows:
- physicochemical characterization of the wastewater;
- check of its digestibility and degree of its transformation into biogas;
- study of the treatment, quantity, and composition of gas and effluent produced in this process.

MATERIALS AND METHODS

Wastewater from a cheese factory was used. Samples were taken according to the standard methods [6], from a sewer that collected wastewater from all the factory processes. The wastewater was taken every six minutes over five hours in the central period of a working day (Wednesday). Seventy-five litres of sample were collected and, after characterization, were stored at $-20°C$.

Experimental processes

A battery of 6 anaerobic digestion reactors, each of one litre, was used. The digesters were inserted in a thermostatic water bath at $36 \pm 1°C$ and were stirred by means of a magnetic stirring bar at 100 rpm. Figure 1 shows a diagram of the anaerobic digestion unit.

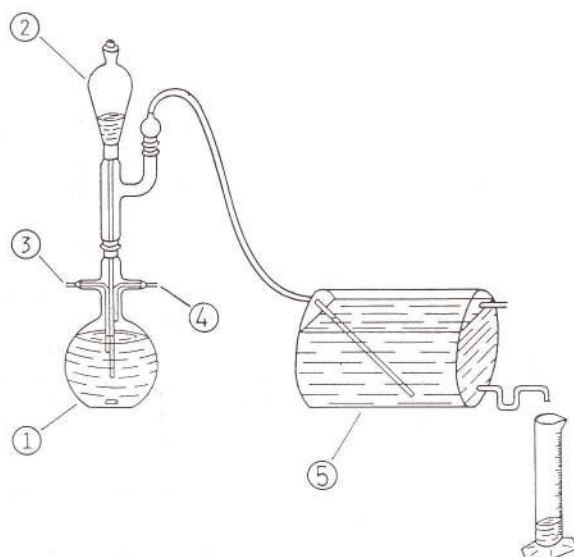The digesters were inoculated with biomass from an anaerobic reactor that

Fig. 1. Anaerobic digester reactor. *1*: Digester, *2*: feeding input, *3*: effluent output, *4*: N$_2$ injection, *5*: gasometer.

processes piggery wastewater, which contained the methanogenic flora. On the eighth day there was started the change of feeding, adding wastewater from the cheese factory to the pig manure. The content of cheese wastewater was increased daily by 2%; thus, after fifty days in the feeding liquid, only this wastewater was present. The sample of effluent was removed from the digester by over pressure of nitrogen injection. The feeding was performed from the top through a decantation funnel. The gas production was measured daily by the displacement of water in a Mariotte bottle.

Analyses

Before and after the process of digestion the following analyses of the wastewater by the standard methods for examination of water and wastewater [6] were carried out: density, viscosity, calorific capacity, content of total solids, mineral solids, volatile solids, conductivity, pH, free ammonium, volatile acidity and chemical oxygen demand (COD).

Nitrogen and total phosphorus were determined by the Kjeldahl method, with the Nichols modification for digestion with hydrogen peroxide without a catalyst. Nitrogen was determined as free ammonium by a vapour stream and phosphorus by colorimetry of the phosphomolybdate formed.

Biogas composition was analysed with an Orsat apparatus, and H_2S with a multigas detector.

RESULTS AND DISCUSSION

According to data supplied by the factory, the wastewater contained 80% washing water and 20% whey, with a daily output of 50 000 l. The wastewater was analysed and results are shown in Table 1.

After the adaptation of the biomass to the wastewater from the cheese factory, it was fed at daily rate of 30 ml, until the biogas production in the digester was stabilised at about 300–320 ml day^{-1}. The following step was to evaluate the optimum feeding amount, within a range of 30 to 50 ml, for water with about 17 000 mg l^{-1} COD [7].

Digesters 1 and 2 were fed at a constant feeding rate of 30 ml day^{-1}. In the other four digesters this was increased stepwise. The highest biogas production, 370 ml, corresponded to 37 ml day^{-1}, decreasing for higher feeding rates. This optimum amount of feeding (37 ml day^{-1}) contained 633 mg of organic matter, and corresponded to a hydraulic retention time (HRT) of 27 days.

The critical HRT was calculated by adding to the optimum feeding (37 ml) increasing amounts of water, immediately after removing equal volumes of the effluent from the digester. One retention time was changed to another when the gas production stabilised.

The point at which the biogas production suddenly decreased was the crit-

TABLE 1

Wastewater characterization from cheese factory

COD (ppm)	17 120
Density ($kg\,l^{-1}$)	1.05
Viscosity ($g\,m^{-1}\,s^{-1}$)	1.10
Calorific capacity ($cal\,g^{-1}\,{}^{\circ}C^{-1}$)	0.9
Total solids (ppm)	16 800
Mineral solids (ppm)	6200
Volatile solids (ppm)	10 600
Total solids in suspension (ppm)	6200
Mineral solids in suspension (ppm)	1000
Volatile solids in suspension (ppm)	5200
Conductivity (mS)	56.4
pH	4.1
Free ammonium (ppm)	50
Volatile acidity (ppm)	700

TABLE 2

Biogas production under standard conditions

HRT (days)	27	25	20	15	9	8
Gas (ml)	387	307	259	218	207	47

ical HRT or "wash out" point, where the growing biomass is less than the biomass lost in the effluent daily.

The digesters operated with continuous stirring, and under these conditions the critical HRT was nine days, as shown in Table 2.

The gas production rate was within a range of 380–207 ml day^{-1}. The feeding rate and effluent composition for each HRT are shown in Table 3. The gas yield was 0.11 $g\,l^{-1}$ COD day^{-1}.

It can be seen that COD removal efficiency reaches values of between 78 and 90% for each HRT.

The self-regulation of pH at 7–7.4, optimal for this digestion process, for each HRT was observed due to formation of CO_3HNH_4 from CO_2 and NH_3 make-up in the process, which increases the alkalinity. Thus, any variation of volatile acids does not affect the pH (Table 4).

The biogas composition is shown in Table 5.

The composition of biogas is of a high quality, with 67% of methane, and no traces of H_2S were detected.

In order to compare the results obtained in this paper with the data from the bibliography, Table 6 shows the gas yields and hydraulic retention time (HRT) for different types of digesters and residues. Marshall and Timbers [8] and Switzenbaum and Dankin [9] obtained 0.27 and 0.23 $g\,l^{-1}$ COD

TABLE 3

Feed (F) and digested effluent (E) composition (mg l^{-1}) for various HRTs

	HRT=27 days (F)	(E)	HRT=25 days (F)	(E)	HRT=20 days (F)	(E)	HRT=15 days (F)	(E)	HRT=10 days (F)	(E)	HRT=9 days (F)	(E)	HRT=8 days (F)	(E)
TS	16 800	7100	15 540	5100	12 432	4700	9240	5500	6300	4010	6216	3600	4973	3000
MS	6200	2900	5735	2000	4588	1900	3424	2400	2420	1580	2294	1500	1835	1200
VS	10 600	4200	9805	3100	7844	2800	5830	3100	3880	2430	3922	2100	3137	1800
TSS	6200	2100	5735	1900	4588	1600	3410	1570	2600	1520	2294	1700	1835	1200
MSS	1000	900	925	750	740	600	550	600	590	780	370	800	296	700
VSS	5200	1200	4810	1150	3848	1000	2860	970	2010	740	1924	900	1539	500
COD	17 120	1600	15 836	1500	12 669	1400	9454	1400	7037	1548	6334	4450	5100	5100
Depuration efficiency (%)	90		90		89		85		78		29		0	

TS, total solids; MS, mineral solids; VS, volatile solids; TSS, total suspended solids; MSS, mineral suspended solids; VSS, volatile suspended solids; COD, Chemical oxygen demand.

TABLE 4

Values of pH and some related parameters for wastewater and effluents at various HRTs

Parameter	Wastewater	Effluent HRT=27	25	20	15	10	8 days
pH	4.1	7.3	7.2	7.4	7.0	7.3	5.9
Conductivity (mS)							
Volatile acidity (ppm)	56.4	86.5	81.0	78.0	79.0	76.9	84.0
Free ammonium (ppm)	716.0	370.0	530.0	800.0	800.0	900.0	1500.0
Alkalinity (ppm)	–	530.0	500.0	500.0	470.0	460.0	460.0
	–	600.0	500.0	500.0	550.0	600.0	400.0

respectively, less than the 0.35 of the theoretical study of McCarty [10]. These values are greater than those obtained in this paper (0.11). The better gas yields from these authors are possibly due to their using whey from a cheese factory, instead of wastewater, which is less concentrated, and less suitable for the anaerobic digestion.

Lo and Liao [2], in the treatment of whey, obtained good results using two stages, fermentative and methanogenic.

The lower results obtained in this paper can be also attributed to the type of digester causing daily loss of biomass in the effluent.

TABLE 5

Biogas composition (%)

CH_4	67
H_2	5
CO_2	22
O_2	1
N_2	5
Total	100

TABLE 6

Gas yields and hydraulic retention times for different types of digesters and residues

Waste	Digester type	Hydraulic retention time	Gas yields $(g\,l^{-1}\,COD\,day^{-1})$	Reference
Theoretical study	–	–	0.35	McCarty [10]
Domestic sewage	Semicontinuous stirring	6 days	0.19	Lebrato [11]
Whey	Fixed film	5 days	0.27	Marshall and Timbers [8]
Whey	ANRBC, two stage	5 days	0.42	Lo and Liao [2]
Whey	Expanded bed	9 hours	0.23	Switzenbaum and Danskin [9]
Cheese factor wastewater	Semicontinuous stirring	8 days	0.11	This study
Domestic sewage	Rotatory fixed film	–	0.11	Noyola et al. [12]

The digesters with fixed or expanded bed have higher process speeds, so the HRTs are lower than for the shaken reactors.

CONCLUSIONS

(1) This type of waste from a cheese factory is digestible and it has good conditions for fluid transport in a plant, because it has no large particles in suspension. This makes its pretreatment unnecessary.
(2) The minimum HRT is nine days.
(3) The biogas composition is of high quality with 67% of methane, and no trace of H_2S.
(4) The efficiency in depuration is high, 78% for a minimum HRT, reaching 90% for higher HRTs.

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