BIOMASS AND BIOENERGY 34 (2010) 1321–1329

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Biogas production from co-digestion of a mixture of cheese whey and dairy manure

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ARTICLE INFO

Article history:
Received 2 April 2008
Received in revised form
19 March 2010
Accepted 12 April 2010
Available online 15 May 2010

Keywords:
Cheese whey
Co-digestion
Dairy manure
Biogas
Acidifying

ABSTRACT

In this study, daily amount of biogas of different mixtures of cheese whey and dairy manure, rates of production of methane, removal efficiencies of chemical oxygen demand (COD), total solid (TS) matter and volatile solid (VS) matter from the mixtures were investigated at 25 and 34 °C. In the experimental studies, two different solid matter rates (8% and 10%) were studied. The hydraulic retention times (HRTs) were 5, 10 and 20 days. Removal efficiencies and amount of biogas produced in each HRT were determined. Maximum daily biogas production was obtained as 1.510 $m^3\ m^{-3}\ d^{-1}$ at HRT of 5 days in the mixture containing 8% total solid matters at 34 °C and the methane production rate was around 60 ± 1% in all experiments. Maximum removal efficiencies for TS, VS and COD were found as 49.5%, 49.4% and 54%, respectively at HRT of 10 days in the mixture containing 8% total solid matters at 34 °C.

1. Introduction

Cheese whey is a by-product of the dairy industry in which the principal components are lactose, proteins and mineral salts [1]. The composition of cheese whey depends on a lot of parameters like the composition and quality of evaluated milk, techniques of production of cheese, the amount of yeast or acid which used coagulation and their quality, the period of coagulation and temperature.

Approximately 47% of the 115 Mt of whey produced worldwide every year are disposed of in the environment [2–4]. This represents a significant loss of resources and causes serious pollution problems. Particularly, for medium size cheese factories, that have growing disposal problems and cannot afford high investment costs for whey valorisation technologies, physico-chemical and/or biological treatment of this effluent is imperative.

In Turkey, cheese whey is being generated in enormous quantities as a result of increased production of cheese. It is estimated that about 1.5–2 Mt of whey is produced from 20% of the 11.1 Mt of milk produced in Turkey in 2005 [5]. During the last few decades, this production has increased very rapidly with the development of the dairy industry. Thus, the problem of whey disposal will worsen. Indeed, the continuous discharge of whey onto land can endanger the chemical and physical structure of the soil, reduce crop yields and lead to serious groundwater pollution problems [6].

The whey has a high COD which very often causes a problem of disposal. However, it also represents a potential energy source, and its anaerobic digestion offers an excellent approach in terms of both energy conservation and pollution control [6,7].

The biogas produced can be used for the generation of heat and electricity. Co-digestion results in liquid and solid effluents are valuable, as they retain all their nutrient constituents (nitrogen, phosphorous, trace elements, etc.) and so they can be used as fertilizers and soil improvers [8,9].

The high organic content of cheese whey renders the application of conventional aerobic biological treatment

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0961-9534/$ – see front matter
doi:10.1016/j.biombioe.2010.04.006

Table 1 – Data on anaerobic treatment of cheese whey.

Reactor type[a]	HRT (days)	Influent COD concentration (kg m^{-3})	Organic loading rate (kg COD m^{-3} d^{-1})	Removal efficiency (%)	Reference
UFFLR	5	79	14	95	[17]
DSFFR	5	13	2.6	88	[21]
FBR	0.4	7	7.7	90	[22]
FBR	0.1–0.4	0.8–10	6–40	63–87	[23]
AAFEB	0.6–0.7	5–15	8.2–22	61–92	[24]
SDFA	–	69.8	16.1	99	[25]
UASB	1.5	11	7.1	94	[26]
UASB	5	5–28.7	0.9–6	97–99	[27]
DUHR	7	68	10	97	[28]
AP	8	4.4	0.55	63	[29]
UASB	2.3–11.6	5–77	1–28.5	95–99	[18]
UASB	5.4–6.8	47–55	7–9.5	90–94	[18]
ASBR	0.33	(0.6–4.8) 10^{-3}	1.5–12	90	[15]

a UFFLR, upflow fixed-film loop reactor; DSFFR, downflow stationary fixed-bed reactor; FBR, fluidized-bed reactor; AAFEB, anaerobic attached-film expanded-bed reactor; SDFA, semi-continuous digester with flocculant addition; UASB, upflow anaerobic sludge blanket reactor; DUHR, downflow–upflow hybrid reactor; AP, anaerobic pond; ASBR, anaerobic sequencing batch reactor.

Table 2 – The composition of cheese whey and dairy manure.

	TS (%)	pH	VS (%)	Organic carbon (%)	Nitrogen (%)	Phosphorus (%)	C/N (%)
Dairy manure	20 ± 0.4	7.1 ± 0.1	83 ± 0.19	48 ± 0.16	1.2 ± 0.15	0.51 ± 0.05	40 ± 0.37
Cheese whey	5.9 ± 0.2	6.6 ± 0.2	71.5 ± 0.27	41.5 ± 0.24	19 ± 0.38	0.56 ± 0.02	2.2 ± 0.04

The percentages of volatile solid matter, organic carbon, nitrogen and phosphorus are rates in solid matter.

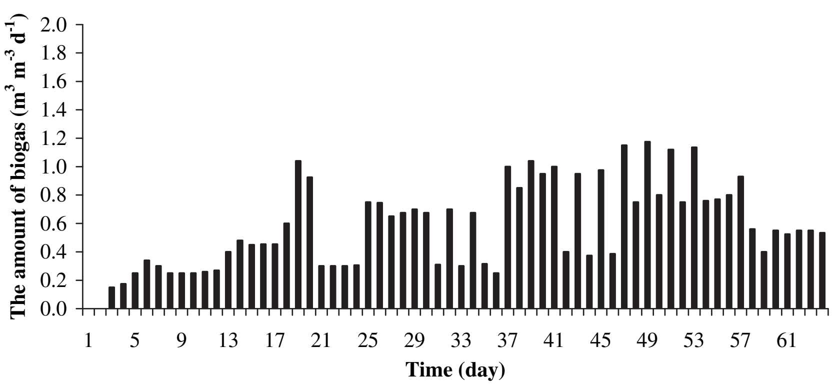

Fig. 1 – Daily biogas production rates at 34 °C and 10% TS.

costly, mainly due to the high price of oxygen supplementation. Anaerobic treatment requires no oxygen supplementation and generates a significant amount of energy in the form of methane gas [10].

It has stated, however, that raw cheese whey is a quite difficult substrate to treat anaerobically because of the lack of alkalinity, the high chemical oxygen demand (COD) concentration and the tendency to acidify very rapidly [11].

Cheese whey, which is a protein and lactose rich by-product of the cheese industry, is very biodegradable (≈99%) with very high organic content (up to a COD of 70 kg m^{-3}) and low alkalinity content (2.5 kg m^{-3} as $CaCO_3$) [12,13]. These may impair biomass granulation during biological treatment. This would in turn result in biomass wash-out. Anaerobic treatment of whey has therefore frequently encountered difficulties in maintaining stable operation [11,14,15]. Because of low bicarbonate alkalinity supplemental alkalinity is required so as to avoid anaerobic process failure [16,17]. This alkalinity supplementation can be minimized by using operation conditions directed at obtaining better treatment efficiency, such as using higher hydraulic residence times or dilution of the influent [14,18,19].

It has been reported that co-digestion of whey with manure was proved to be possible without any need of

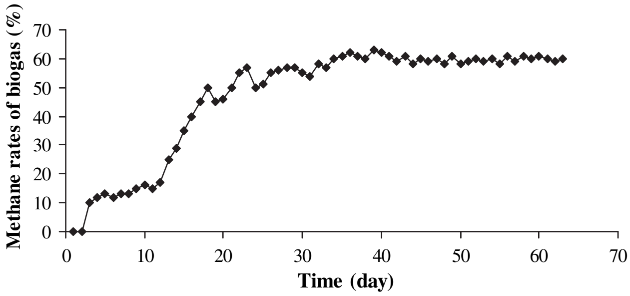

Fig. 2 – Daily methane rates of biogas at 34°C and 10% TS.

chemical addition up to 50% participation of whey (by volume) to the daily feed mixture. At whey fractions 50%, the reactor turned to be unstable [20].

There are many laboratory and pilot-scale studies in the literature on the anaerobic treatment of cheese whey. Their literature data and references are summarized in Table 1.

It has been stated that for COD > 2 kg m^{-3} when amount of dilution decreases, removal efficiency of COD decreases, too. Because, when undiluted cheese whey is directly treated in anaerobic reactors, stability problems arise [15].

In this study, anaerobic co-digestion of cheese whey and dairy manure which is rich in nutrient was studied. Experiments were carried out in a specially designed anaerobic reactor at different HRTs and at 25 and 34 °C. Optimum experimental conditions were investigated to obtain maximum COD removal and methane yield.

2. Materials and methods

2.1. *Equipments*

Experimental studies were performed in a cylindrical metallic anaerobic reactor made from austenitic stainless steel (type 316) with a total volume of 26.6 L (working volume is 20 L). The reactor was heated up by circulating warm water equipped with a thermostat. The temperature of the liquor in the reactor was monitored by a metallic thermometer located at the mid-depth and adjusted to 25 or 34 °C. Agitation, provided by a motor agitator, was at 0.3 Hz. The reactor was fed from its upper part and the discharge port was located below. The reactor was tested at 5, 10 and 20 days of hydraulic retention times.

In the reactor, there was a continuous stirring to circulate the liquid content to ensure secure uniform temperature conditions and to prevent sedimentation of suspended solids within the reactor. The reactor was insulated with glass wool to prevent heat loss. After dairy manure was filled to the reactor, entrance of the reactor was closed to prevent against the air leakage. Biogas collection from the reactor was made via a tedlar bag.

2.2. *Characterization of cheese whey and dairy manure*

The whey and dairy manure used in this study were obtained from the Milk Plant and the Animal Farm of the Agricultural Faculty of Ondokuz Mayis University in Samsun city located on

Table 3 – The average biogas and methane rates at different HRTs, 34°C and 10% TS.

	HRT (day)	Biogas (m^3 m^{-3} d^{-1})	Methane rate (%)	Influent content	
Daily feedings				DM (kg)	1.60
	5	0.968 ± 0.073	60 ± 1.22	CW (L)	1.12
				BM (L)	0.28
				Water (L)	1.00
				DM (kg)	0.80
	10	0.699 ± 0.043	59 ± 2.55	CW (L)	0.56
				BM (L)	0.14
				Water (L)	0.50
				DM (kg)	0.40
	20	0.540 ± 0.014	60 ± 1.00	CW (L)	0.28
				BM (L)	0.07
				Water (L)	0.25
Two daily feedings				DM (kg)	3.20
	5	0.948 ± 0.038	60 ± 1.20	CW (L)	2.24
				BM (L)	0.56
				Water (L)	2.00
				DM (kg)	1.60
	10	0.662 ± 0.060	59.5 ± 2.10	CW (L)	1.12
				BM (L)	0.28
				Water (L)	1.00
				DM (kg)	0.80
	20	0.505 ± 0.028	59 ± 2.60	CW (L)	0.56
				BM (L)	0.14
				Water (L)	0.50

DM: dairy manure, CW: cheese whey, BM: basal medium.

Table 4 – The analyses results of initial mixture and last product at 34 °C and 10% TS.

	Initial mixture (%)	Last product (%)	Efficiency (%)
TS	10	5.6	44
pH	7	7.2	–
VS	76	40	47
Organic carbon	44.1	23.2	47.3
Nitrogen	7.4	9.15	19
Phosphorous	0.54	0.75	28

Initial mixture: 8 kg dairy manure + 5.6 L cheese whey + 1.4 L basal medium +5 L water.

Table 5 – COD removal efficiency at different HRTs, 34 °C and 10% TS.

HRT (day)	Initial COD (kg m^{-3})	Final COD (kg m^{-3})	Removal efficiency (%)
5	33.75 ± 0.420	22.500 ± 0.230	33
10	25.25 ± 0.250	14.392 ± 0.150	43
20	28.00 ± 0.301	15.600 ± 0.181	44

The initial COD values are the values obtained just after feeding. The final COD values are the values obtained after 1 day of treatment.

the Black Sea coast in northern Turkey (36° 18′ 81″ E, 41° 36′ 59″ N). The whey samples were drained directly from cheese vats, collected in 10 L tanks and transported to the laboratory. Fresh cheese whey was taken two times every week and stored at 4 °C for up to 4 days. Dairy manure was taken daily and transported to the laboratory before feeding. The chemical composition of cheese whey and dairy manure was determined according to the standard methods [30] (Kjeldahl Method for nitrogen, stannous chloride method for phosphorous, method 209A for TS and method 209D for VS) and is shown in Table 2.

2.3. Basal medium

The composition of the basal medium (BM) used in the experiments is as follows (concentrations of the constituents are given in parentheses as kg m^{-3}):

Calcium chloride (0.2), magnesium sulfate (0.098), potassium chloride (0.4), sodium chloride (6.8), sodium phosphate monobasic (0.122), LL-arginine·HCl (0.021), LL-cystine·2HCl (0.01565), LL-glutamine (0.292), LL-histidine (0.008), LL-isoleucine (0.026), LL-leucine (0.026), LL-lysine·HCl (0.0365), LL-methionine (0.0075), L-phenylalanine (0.0165), LL-threonine (0.024), L-trytophan (0.004), LL-tyrosine·2Na·2H_2O (0.026), L-valine (0.0235), D-biotin (0.001), choline chloride (0.001), folic acid (0.001), myo-inositol (0.002), niacinamide (0.001), D-pantothenic acid (0.001), pyridoxal·HCl (0.001), riboflavin (0.0001), thiamine·HCl (0.001), D-glucose (1.0), phenol red [sodium] (0.011).

This BM contained all the necessary micro and macronutrients required for an optimum anaerobic microbial growth.

2.4. Experimental procedure

Experiments were realised in three different forms as at 34 °C, 10% TS, at 34 °C, 8% TS and at 25 °C, 8% TS. All experimental studies were performed in HRT of 5, 10 and 20 days and biogas production, methane content of biogas, COD, TS and VS removal rates were determined.

Before each experiment, manure was diluted with tap water up to a total solid (TS) content of 10%. Then it was screened for removal of the gross inert material and blended for homogenization to avoid spoiling of the agitator.

Preexperimental studies, realised by us, showed that the production of biogas was diminished in 2–3 days and the process collapsed after feeding the reactor by the mixture of cheese whey and fresh manure. Hence, the reactor was filled with diluted manure only and run until maximum biogas production conditions (18 days) were achieved. Then co-digestion process was started.

In the first experiment, the rate of TS was 10%. On 18th day 10 L of manure was discharged and a mixture of whey and manure of the same rate was fed to the reactor. After 24th day, the feedings were semi-continuously with various amounts of mixtures according to each HRT, but TS rate of feedings was the same. The temperature was kept at 34 °C. HRT of 5, 10 and 20 days was maintained by feeding 4 L, 2 L and 1 L of substrate and removing 4 L, 2 L and 1 L of effluent daily, respectively and by feeding 8 L, 4 L and 2 L of substrate and removing 8 L, 4 L

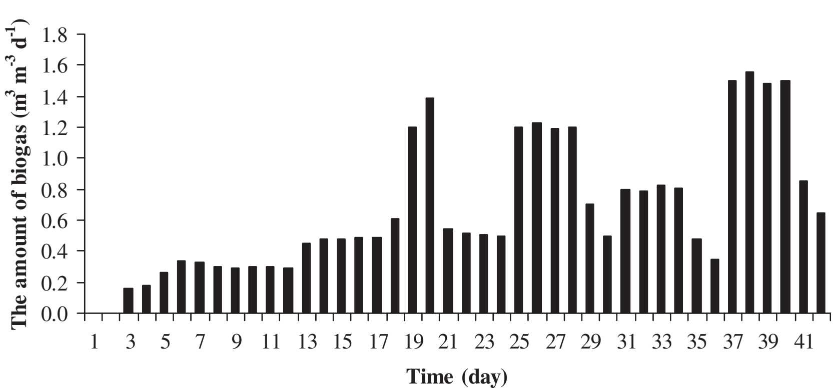

Fig. 3 – Daily biogas production rates at 34°C and 8% TS.

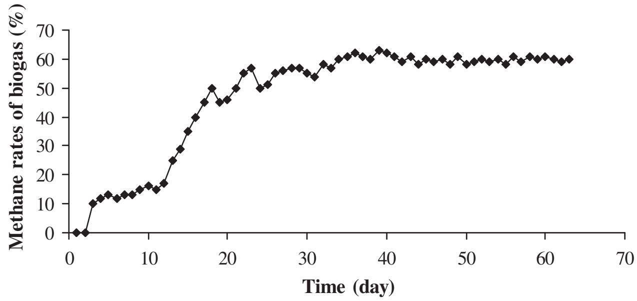

Fig. 4 – Daily methane rates of biogas at 34 °C and 8% TS.

and 2 L of effluent one time in 2 days, respectively. This experiment was performed with or without BM.

In the second experiment, 10 L of manure was discharged and 10 L of whey was fed instead (again on 18th day), so that the mixture in the reactor comprised a TS of 8% at 34 °C. The hydraulic retention times were 5, 10 and 20 days and the reactor was fed daily only.

In the third experiment, the same experimental variables were kept constant as in the second one except the temperature which was kept at 25 °C in order to investigate its effect.

While feeding the digesters with these mixtures and during the experiments, the pH value of the liquid content was kept within the optimal range for methanogenesis (6.5–7.5).

2.5. *Chemical analyses*

Standard methods [30] were applied for pH measurement and the determination TS, VS, COD, ammonia nitrogen, total nitrogen and phosphorous. Methane content of biogas was determined by Gas Chromatography (GC/FID) using helium as the carrier gas. A 30 m of capillary column was used to separate gases. The injector, detector and oven temperatures were 150, 200 and 225 °C, respectively. The volume of biogas was measured using a gas-meter.

3. Results and discussion

3.1. *The results of analyses at 34 °C, 10% TS*

This experiment was completed in 64 days. As mentioned before, the experiment started with diluted manure of 10% TS only. In the first 2 days, no biogas production was observed. As known from batch processes the gas production increased in following days and reached maximum values on 18th day. Then a volume of 10 L of mixture was discharged and 3 kg manure + 5.6 L cheese whey + 1.4 L BM mixture was fed to the reactor; so that the rate of TS remained constant (10 wt%). By semi-continuous process, the replaced volumes of the mixture were 4 L, 2 L and 1 L for the HRT of 5, 10 and 20 days, respectively. The reactor was fed daily from 24th to 28th day for HRT of 10 days, from 36th to 40th day for HRT of 5 days and from 59th to 63rd day for HRT of 20 days. Two daily feedings were realised from 29th to 34th day for HRT of 20 days, from 42nd to 45th day for HRT of 10 days and from 46th to 53rd day for HRT of 5 days. The experiment with HRT of 20 days (from 29th to 34th day) was repeated without BM from 55th to 58th day. On other days (35th, 41st, 54th and 64th day), the reactor was not fed.

Daily biogas production rate was measured and is presented in Fig. 1. The results of the amount of biogas obtained by daily feeding of the reactor and one times in 2 days were compared and the better result was obtained by daily feedings.

Experimental results showed that there is no beneficial effect of BM addition into the reactor. To determine the effect of this, on 55th and 57th day, the mixture of 2 L was added to the reactor and BM wasn't added to the mixture. All in all, a significant difference wasn't observed.

Table 6 – The average biogas and methane rates at different HRTs, 34 °C and 8% TS.

HRT (day)	Biogas ($m^3\ m^{-3}\ d^{-1}$)	Methane rate (%)	Influent content	
5	1.510 ± 0.033	59.75 ± 1.00	DM (kg)	1.0
			CW (L)	2.0
			Water (L)	1.0
10	1.205 ± 0.021	59.5 ± 2.38	DM (kg)	0.5
			CW (L)	1.0
			Water (L)	0.5
20	0.805 ± 0.015	60 ± 1.41	DM (kg)	0.25
			CW (L)	0.50
			Water (L)	0.25

DM: dairy manure, CW: cheese whey.

Table 7 – The results obtained at different HRTs, 34 °C and 8% TS.

HRT (day)	TS ($kg\ m^{-3}$)	VS ($kg\ m^{-3}$)	COD ($kg\ m^{-3}$)	Ammonium–nitrogen ($kg\ m^{-3}$)	Phosphorous ($kg\ m^{-3}$)
Influent					
5	54.720 ± 0.367	43.030 ± 0.069	28.750 ± 0.250	0.128 ± 0.005	0.268 ± 0.005
10	60.710 ± 0.102	48.910 ± 0.086	28.750 ± 0.275	0.207 ± 0.007	0.352 ± 0.005
20	46.940 ± 0.265	36.840 ± 0.150	31.875 ± 0.150	0.234 ± 0.004	0.337 ± 0.004
Effluent					
5	40.096 ± 0.267	31.913 ± 0.120	22.125 ± 0.150	0.186 ± 0.004	0.362 ± 0.006
10	30.641 ± 0.120	24.727 ± 0.069	13.125 ± 0.085	0.300 ± 0.005	0.461 ± 0.004
20	28.776 ± 0.098	25.422 ± 0.096	17.775 ± 0.102	0.288 ± 0.004	0.370 ± 0.005

The influent values are the values obtained just after feeding.
The effluent values are the values obtained after 1 day of treatment.

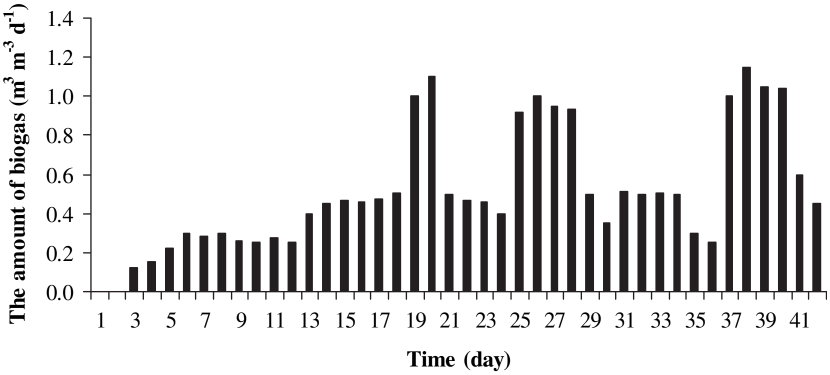

Fig. 5 – Daily biogas production rates at 25°C and 8% TS.

Biogas production rate was measured and is presented in Fig. 1. When the amounts of biogas obtained by daily feeding and feeding in 2 days of the reactor were compared, it can be seen that the better result was obtained by daily feedings. Experimental results showed that there is no significant difference between the biogas produced with BM or without BM. It can be said that there is no beneficial effect of BM addition into the reactor.

The amount of methane in gas mixtures was measured daily and is given in Fig. 2. It can be seen from Fig. 2 that methane percentage does not change much at different HRTs.

Daily biogas production and methane rate of biogas produced at different HRTs are given in Table 3. Because daily biogas production showed some little variations, in each period of HRT, average daily biogas production and its standard error were calculated for every HRT. According to the Table 3, it becomes obvious that the biogas production decreases from 0.968 to 0.540 m^3 m^{-3} d^{-1} as HRTs are increased from 5 to 20 days.

As can be seen, the best biogas productivity was approximately 0.968 m^3 m^{-3} d^{-1} and contained about 60% of methane. It was obtained at an HRT of 5 days.

Removal efficiencies of TS, VS, nitrogen and phosphorous were calculated from the difference of their amounts in influent and effluent and the results are given in Table 4. According to Table 4, TS and VS decreased, while nitrogen and phosphorous increased.

The differences between COD concentrations of influents and effluents are given in Table 5 for different HRTs. For every HRT, average COD removal efficiency and its standard error were calculated. As can be seen from Table 5, the best COD removal efficiency was 44% obtained at an HRT of 20 days. The removal efficiency of COD increased by increasing HRT.

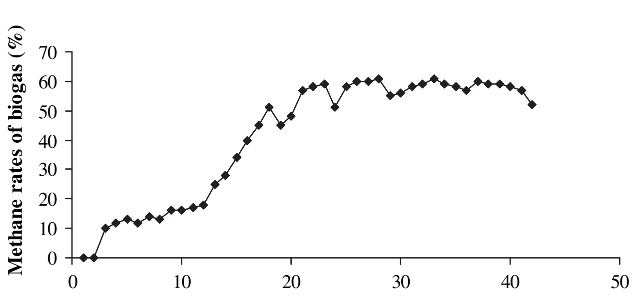

Fig. 6 – Daily methane rates of biogas at 25°C and 8% TS.

3.2. *The results of analyses at 34 °C, 8% TS*

The aim of this experiment was to investigate the effect of increasing amount of cheese whey on biogas production. It was completed in 42 days. It started again with diluted manure of 10% TS only as in first experiment. During feedings by semi-continuous process after 24th day, it was paid attention to keep unchanged the composition of mixture (8%). Therefore, the mixture of cheese whey, fresh manure and water were fed to the reactor at rates of 50%, 25% and 25% respectively. It was fed on 24th, 30th and 36th day for HRT = 10, 20 and 5 days, respectively. Because in the first experiment daily feedings were more effective than two daily feedings and adding BM had no beneficial effect, the reactor was fed daily only and operated without BM.

The amount of daily biogas production is shown in Fig. 3. As can be seen from the figure, the amount of biogas production decreased by the increase of HRT like in the previous experiment with 10% of TS. Higher biogas yield obtained by the addition of increasing extent of cheese whey to dairy manure could be attributed to the higher biodegradability of cheese whey.

Methane rate of biogas produced using mixture including 8% of TS is presented in Fig. 4. It is seen obviously from the

Table 8 – The average biogas and methane rates at different HRTs, 25 °C and 8% TS.

HRT (day)	Biogas (m^3 m^{-3} d^{-1})	Methane (%)	Influent content	
5			DM (kg)	1.0
	1.055 ± 0.064	59 ± 1.41	CW (L)	2.0
			Water (L)	1.0
10			DM (kg)	0.5
	0.950 ± 0.034	59.75 ± 1.29	CW (L)	1.0
			Water (L)	0.5
20			DM (kg)	0.25
	0.502 ± 0.007	59.25 ± 1.29	CW (L)	0.50
			Water (L)	0.25

DM: dairy manure, CW: cheese whey.

Table 9 – The results obtained at different HRTs, 25 °C and 8% TS.

HRT (day)	TS (kg m^{-3})	VS (kg m^{-3})	COD (kg m^{-3})	Ammonium–nitrogen (kg m^{-3})	Phosphorous (kg m^{-3})
Influent					
5	61.360 ± 0.350	46.020 ± 0.102	33.125 ± 0.075	0.168 ± 0.005	0.246 ± 0.005
10	67.330 ± 0.275	50.600 ± 0.203	32.500 ± 0.095	0.129 ± 0.004	0.354 ± 0.006
20	60.090 ± 0.351	45.067 ± 0.153	29.375 ± 0.063	0.196 ± 0.004	0.321 ± 0.003
Effluent					
5	46.633 ± 0.253	36.355 ± 0.234	26.168 ± 0.098	0.207 ± 0.007	0.316 ± 0.004
10	37.031 ± 0.102	28.925 ± 0.195	18.850 ± 0.075	0.172 ± 0.003	0.442 ± 0.005
20	39.659 ± 0.185	31.997 ± 0.210	16.743 ± 0.059	0.223 ± 0.005	0.336 ± 0.003

The influent values are the values obtained just after feeding.
The effluent values are the values obtained after 1 day of treatment.

figure that the methane rates do not show much difference by changing HRTs.

Daily biogas production and methane rate of biogas produced at different HRTs are given in Table 6. The amounts of TS, VS, COD, nitrogen and phosphorous in influent and effluent are given in Table 7.

The average value of daily amount of biogas yield was 1.205 m^3 m^{-3} d^{-1} at an HRT of 10 days, 0.805 m^3 m^{-3} d^{-1} at an HRT of 20 days and 1.510 m^3 m^{-3} d^{-1} at an HRT of 5 days. Although the maximum biogas production of 1.510 m^3 m^{-3} d^{-1} occurred at an HRT of 5 days, the maximum reduction of TS, VS and COD occurred at an HRT of 10 days. The amount of TS, VS and COD decreased, while nitrogen and phosphorous increased (Table 7). Decreasing of COD and VS shows that the anaerobic treatment is quite effective.

3.3. *The results of analyses at 25 °C, 8% TS*

The aim of this experiment is to observe biogas production by decreasing temperature. Moreover, the aim is also to investigate the cost of methane production without heating. The experiment was completed in 42 days as previous experiment. The reactor was fed on 24th, 30th and 36th day for HRT = 10, 20 and 5 days, respectively. The amount of daily biogas production is shown in Fig. 5. As can be seen from the figure, the amount of biogas decreased, while HRT increased. The amount of biogas produced at 25 °C is less than that obtained at 34 °C.

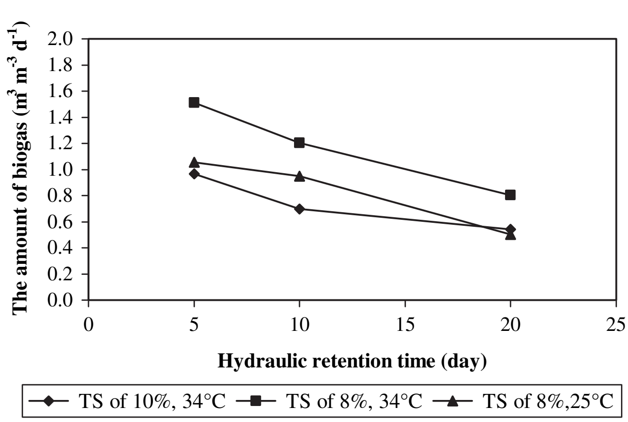

Fig. 7 – Biogas production rates for the mixtures including 8% and 10% TS at different HRTs.

Methane rate of biogas produced at 25 °C is presented in Fig. 6. From the figure it is seen obviously that methane rates don't show significant difference with HRT.

Daily biogas production and methane rate of biogas produced at different HRTs are given in Table 8. The amounts of TS, VS, COD, nitrogen and phosphorous in influent and effluent were measured and are presented in Table 9.

The average of daily amount of biogas produced was 0.950 m^3 m^{-3} d^{-1}, 0.502 m^3 m^{-3} d^{-1} and 1.055 m^3 m^{-3} d^{-1} at HRTs of 10, 20 and 5 days, respectively. Although the maximum biogas production occurred at HRT of 5 days, the maximum reduction of TS, VS and COD occurred at an HRT of 10 days.

3.4. *Comparison of the results depending on different HRTs*

The amounts of biogas, methane rate, COD, TS and VS removal efficiencies of three different experiments were compared for the different HRTs and are presented in Figs. 7–11.

The effect of HRT on biogas productivity is shown in Fig. 7. As can be seen from Fig. 7, the biogas yield decreases with the increase of HRT for both TS concentrations and temperatures. The maximum biogas production of 1.510 m^3 m^{-3} d^{-1} occurred at 8% of solid matter and 34 °C. The amount of biogas produced decreased as the amount of cheese whey and temperature decreased.

Fig. 8 shows the methane rates of biogas. From the figure becomes obvious that methane rates didn't show a significant difference with HRT and temperature. Rates of methane in biogas were found around 60 ± 1% in all steady experiments.

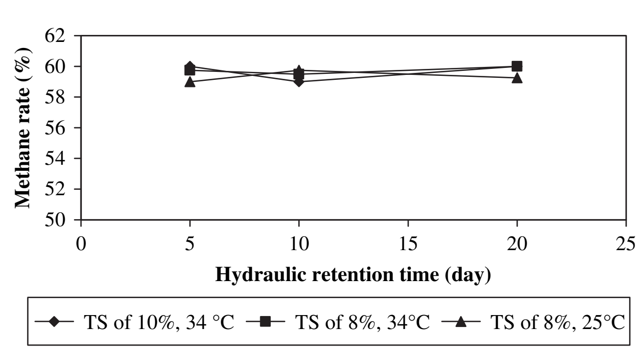

Fig. 8 – Methane rates of biogas for the mixtures including 8% and 10% TS at different HRTs.

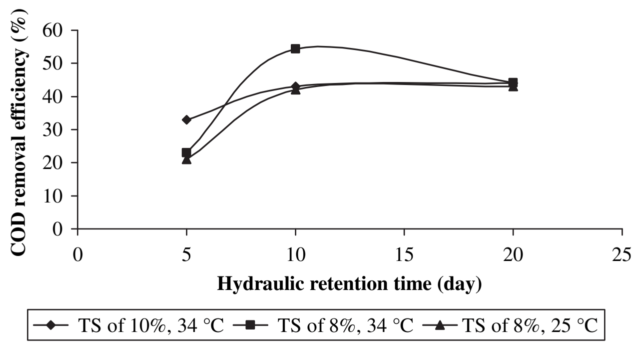

Fig. 9 – COD removal efficiency for the mixtures including 8% and 10% TS at different HRTs.

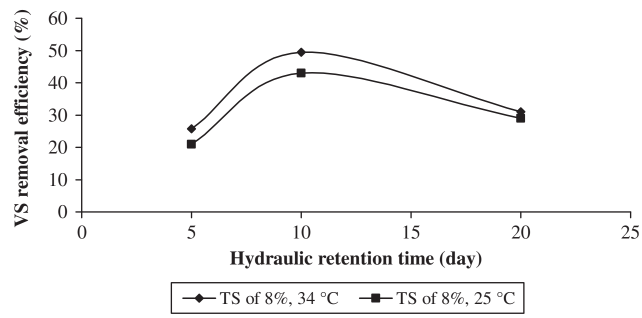

Fig. 11 – VS removal efficiency for the mixture including 8% TS at different HRTs and temperatures.

Fig. 9 represents the COD removal efficiency versus the HRT. A maximum COD reduction of 54% occurred at the optimum solid matter rate of 8% and at 34 °C. COD removal efficiency increased as the amount of cheese whey and temperature increased. It is seen that the COD removal rate is lower at 10% of solid matter in the mixture than 8% at the same temperature; because the cheese whey is lower in the mixture which comprises 10% of solid matter. It was found that the maximum reduction of COD (%54.3) occurred at an HRT of 10 days.

Fig. 10 shows the TS removal efficiency versus the HRT. Because the activities of microorganism were more effective at mesophilic temperature, the maximum reduction degree of TS occurred at 34 °C in all HRTs. The maximum TS removal efficiency was 49.5% at an HRT of 10 days and at 34 °C.

Fig. 11 shows the VS removal efficiency versus the HRT. VS is an important parameter for measuring biodegradation which directly indicates the metabolic status of some of the most delicate microbial groups in the anaerobic system. The reduction of VS denotes the process stabilization. The maximum reduction degree of VS occurred at 34 °C in all HRTs. The maximum VS removal efficiency was 49.4% at an HRT of 10 days and at 34 °C.

A VS removal efficiency exceeding 49% has been obtained, which however cannot be fully justified by the biogas production rates obtained. A possible reason for this disagreement could be the considerable loss of organic matter with the thick foam which had been formed, at high rate, above the liquid surface in the reactor. Unfortunately, foam was not analyzed for TS and VS content.

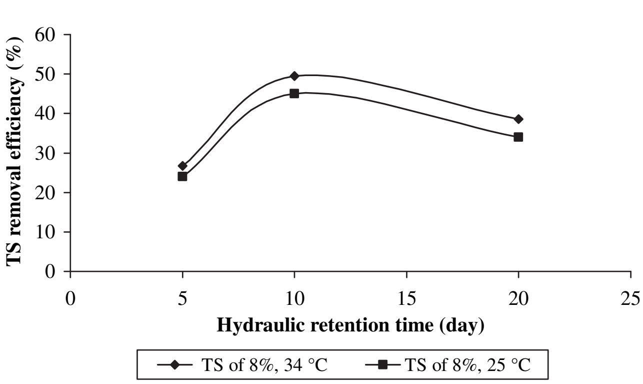

Fig. 10 – TS removal efficiency for the mixture including 8% TS at different HRTs and temperatures.

4. Conclusions

This study shows that a combined treatment of different waste types like manure and cheese whey gives the possibility of treating waste, which cannot be successfully treated separately. Whey was quantitatively degraded to biogas when co-digested with diluted manure without addition of any chemicals. Manure had a high content of lipids, while whey had a high content of easily biodegradable carbohydrates. It could be concluded that co-digestion of these two wastes is advantageous than processing each one separately. But to reach this goal, it is useful or necessary to start the co-digestion process with a mixture of the whey and digested manure. Otherwise to start the co-digestion with a mixture of the whey and fresh manure can lead to fall down the process because of acidifying.

The following conclusions can be drawn from the present study. The hydraulic retention times (HRTs) were 5, 10 and 20 days in all experiments. The biogas yield decreased with the increase of HRT for both TS concentrations (8–10%) and temperatures (25 and 34 °C). Methane rates didn't show a significant difference with HRT and temperature. The best biogas yield from the co-digestion of cheese whey with manure at HRT = 5 days, was 1.510 $m^3\ m^{-3}\ d^{-1}$ with methane content of 60%. The maximum COD reduction of 54% occurred at the optimum solid matter rate of 8% at 34 °C. The maximum TS and VS removal efficiencies were 49.5% and 49.4% at an HRT of 10 days at 34 °C.

Due to high organic content and biodegradability of cheese whey, the most appropriate treatment method for whey is anaerobic digestion and it can be applied to existing facilities, already used for manure digestion alone. As a result, co-digestion of cheese whey together with local agricultural residues, such as manure, is a sustainable and environmentally attractive method.

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