A R C H I T E C T U R E C I V I L E N G I N E E R I N G E N V I R O N M E N T
The Silesian University of Technology No. 1/2012

POSSIBILITY OF SEWAGE SLUDGE AND ACID WHEY CO-DIGESTION PROCESS

Ewa ZIELEWICZ [a], Malwina TYTŁA [b*], Gabriela LISZCZYK [c]

[a] DSc; Faculty of Energy and Environmental Engineering, The Silesian University of Technology, Konarskiego 18, 44 -100 Gliwice, Poland

[b] MSc; Faculty of Energy and Environmental Engineering, The Silesian University of Technology, Konarskiego 18, 44 -100 Gliwice, Poland

* E-mail address: *malwina.tytla@polsl.pl*

[c] MSc; Faculty of Energy and Environmental Engineering, The Silesian University of Technology, Akademicka 2A, 44 -100 Gliwice, Poland

Received: 15.11.2011; Revised: 18.01.2012; Accepted: 30.01.2012

Abstract

In this study the possibility of acid whey and municipal sewage sludge co-digestion as well as biogas production were investigated. The experiment was conducted in static conditions in co-digestion installation for 32 days. In order to determine the influence of acid whey addition on methane fermentation, the following acid whey doses 0; 20; 40; 50; 60 ml in 400 ml of final mixture volume were applied. Process efficiency was determined based on volatile solids reduction and biogas production. The results indicate that acid whey doses do not improve co-digestion process. Despite of high volatile solids reduction (from 36.8 to 42.9%) and desirable pH values (6.9-7.5), other parameters: chemical oxygen demand (COD), volatile fatty acids (VFA), total phosphorus (P_{TOT}) concentrations did not achieve required values. Biogas production rate also confirmed that the applied whey doses do not allow for high co-digestion process effectiveness. Therefore, to enhance co-digestion, smaller doses of acid whey or longer process duration should be used.

Streszczenie

Celem pracy było zbadanie możliwości kofermentowania serwatki kwaśnej z miejskimi osadami ściekowymi oraz ilości wytworzonego w procesie biogazu. Eksperyment prowadzono w instalacji do kofermentacji w warunkach statycznych przez okres 32 dni. Udziały serwatki w kofermentowanym osadzie wynosiły kolejno: 0; 20; 40; 50; 100 ml w 400 ml badanej próby. Efektywność procesu była określana na podstawie redukcji suchej masy organicznej (36.8-42.9%) i ilości wydzielonego biogazu. Pomimo wysokiego stopnia redukcji suchej masy organicznej oraz pożądanych wartości pH po procesie (6.9-7.5), wartości innych parametrów tj. chemicznego zapotrzebowania na tlen (ChZT), lotnych kwasów tłuszczowych – (LKT), fosforu ogólnego (P_{og}), a także stopnia produkcji biogazu wykazały, że fermentacja metanowa przy zastosowanych dawkach serwatki nie przebiegała efektywnie. W związku z tym w celu zwiększenia efektywności procesu kofermentacji konieczne jest zastosowanie mniejszych dawek serwatki kwaśnej lub wydłużenie czasu trwania procesu.

Keywords: **Sewage sludge, Acid whey, Methane fermentation, Co-digestion, Biogas.**

1. INTRODUCTION

The process of wastewater treatment is connected with generation of waste whose disposal is necessary. The significant problem pose sewage sludge from different part of wastewater treatment plant containing high amount of organic matter, nitrogen and phosphorus compounds, as well as heavy metals, micropollutants and pathogens. The sewage sludge are stabilized mainly in the methane fermentation process. One of the process products is to obtain stabilized and devoid of most pathogenic organisms sludge. The second fermentation product is biogas which could be used as source of energy for wastewater treatment plants and it would reduce plant operation costs. Because of the financial aspects, the enhancement of biogas production is advisable. One of the alternative methods of fermentation is co-digestion (fermentation of at least two components from different sources). In this process apart from sewage sludge, industrial waste, liquid waste from agricultural and food sectors (acid whey from cheese production), animal waste (manure), organic waste (grass) or energy crops (corn) can also be used [1]. Therefore, it is expected that means of co-digestion process the following is obtained: dilution of toxic substances contained in the substrates that undergo the process, increasing the amount of nutrients and biodegradable organic substances, high degree of the process and biogas production [2]. Application of this technology results in considerable environmental and economical benefits by which the acquisition of biogas and waste disposal is meant. Furthermore, the acquisition of biogas means of co-digestion, is also a very significant aspect in the context of compliance with the applicable provisions of law i.e. directive of the European Parliament and Council 2009/28/EC on the promotion of utilizing the energy from renewable sources [3].

On the other hand cheese whey, the by-product of dairy processing characterized by high contents of organic components is refractory substrate to anaerobic fermentation due to the high acidity [4]. The utilization or disposal of cheese whey is becoming increasingly significant due to high amount of produced whey, around 3 billion liters of liquid whey arises in Poland [1, 2, 5-9]. In view of high amount of organic matter content in whey-approximately 7-10%, it could have suitable application as substrate to co-digestion. In contrast, sewage sludge contain from 3-4% of organic matter, although fats (cooking oil, margarine) up to 90% [2].

It was confirmed in several studies, which demonstrated that dairy waste are the ideal raw material for biogas production in the fermentation process due to the large amount of easily degradable organic contaminants [10-17].

Significant for co-digestion technology is selection of the most proper sludge and the determination the optimal ratio of sludge and whey dose, permitting to improve biogas production process. The aims of the study were: (1) the investigation of the possibility of sewage sludge and acid whey co-digestion (2) determination of co-digestion performance on the basis of process variables.

2. METHODS

Experimental studies were conducted for 32 days in tightly sealed glass flasks with a capacity of 500 ml and put in a water bath maintaining a constant temperature of 37°C. The installation was equipped with a kit to collect and to measure volume of the released biogas according to standard of DIN 38414, part 8 [18]. Two kinds of substrate were co-digested: acid whey and sewage sludge (primary, excessive, and as an inoculum sludge from fermentation chambers). The sludge, was mixed in proportion of: 200 ml-primary, 200 ml-excessive and 100 ml inoculum sludge. Acid whey was charged from the District Dairy Cooperative. The tested samples were marked as: 0; I; II; III; IV for 0; 20; 40; 50; 100 ml of acid whey respectively. Total volume of each tested samples were 400 ml. The physicochemical characteristics of process were examined by means of certain parameters: pH, chemical oxygen demand (COD), volatile fatty acids (VFA), total nitrogen (N_{TOT}), total phosphorus (P_{TOT}), total solids (TS), volatile solids (VS), fixed solids (FS). The values of the parameters COD, VFA, N_{TOT}, P_{TOT}, were marked in accordance with the method described by Hach Lange (DR5000 spectrophotometer). Cationic polyelectrolyte (Zetag 7633) concentration used in dewatering test (sieve filtration method) was 0.2%. The effects of the process was based on organic matter reduction evaluation (38% and above), the quantity of evolved biogas and fermented sludge dewatering.

3. RESULTS AND DISCUSSION

Studies on co-digestion of sewage sludge with acid whey allowed to compare intensity of biogas secretion from sludge with or without varying participation of waste from cheese production. Sewage sludge and acid whey parameters before and after co-digestion are shown in Table 1 and 2.

Obtained results confirmed that whey doses do not improve outcomes of co-digestion process. It indicate that total volume of biogas together with biogas production rate were lower compared to sludge fermented without whey (control sample). The highest intensity and amount of biogas production was recorded in the following samples: 0; III; IV; I; II. The biogas production intensity was on the level: 0-0.35; I-0.25; II-0.16; III-0.28; IV-0.27 [l/d from kg sample]. The values of biogas production coefficient were on the level: 0.013; 0.001; 0.007; 0.011;

Table 1.
Sewage sludge and acidic whey parameters before co-digestion

parameter	unit	0	I	II	III	IV	acid whey
COD	gO_2/l	54.67	56.77	59.68	56.90	62.10	72.84
VFA	g/l CH_3COOH	0.79	1.08	1.08	1.68	1.74	3.02
N_{TOT}	gN_{TOT}/l	2.93	3.04	2.72	2.39	2.13	1.39
P_{TOT}	gP_{TOT}/l	0.42	0.43	0.44	0.45	0.45	0.35
pH	-	6.7	6.6	6.6	6.5	6.5	4.6
TS	g/kg	42.60	43.10	42.88	43.52	44.21	67.15
FS	g/kg	11.47	11.15	11.05	10.82	10.91	7.53
VS	g/kg	31.13	31.95	31.83	32.70	33.30	59.62
hydration	%	95.7	95.7	95.7	95.7	95.6	93.3

COD – chemical oxygen demand; VFA – volatile fatty acids; N_{TOT} – total nitrogen; P_{TOT} – total phosphorus; TS – total solids; FS – fixed solids; VS – volatile solids

Table 2.
Sewage sludge and acid whey parameters after co-digestion

parameter	unit	0	I	II	III	IV
COD	gO_2/l	37.70	42.80	48.90	43.30	61.20
VFA	g/l CH_3COOH	0.83	1.70	5.40	4.60	4.78
N_{TOT}	gN_{TOT}/l	1.45	1.82	1.97	1.99	2.05
P_{TOT}	gP_{TOT}/l	0.98	1.41	1.60	1.58	1.67
pH	-	7.5	7.45	6.9	7.0	6.9
TS	g/kg	29.35	31.90	30.25	30.12	30.10
FS	g/kg	11.57	11.71	11.38	11.04	10.88
VS	g/kg	17.79	20.18	18.87	19.09	19.22
hydration	%	97.1	96.8	97.0	97.0	97.0

0.010 [m^3/kg VS] for: 0; I; II; III; IV samples respectively. Moreover, between 10th and 18th day an increase in biogas production intensity was observed in control sample (maximum in 13th day). While in case of the tested samples the increase of biogas production intensity was between 11th and 19th day of experiment. It was also observed that between 1st and 9th day there was a significant increase of biogas production in sewage sludge, while for the other samples process runs with a very low intensity. In contrast, between 19th and 32th day of experimente opposite situation was observed. These findings indicate that sewage sludge fermentation duration is shorter compared to co-digestion with acid whey. Total amount and intensity of biogas production are shown in Figure 1 and 2.

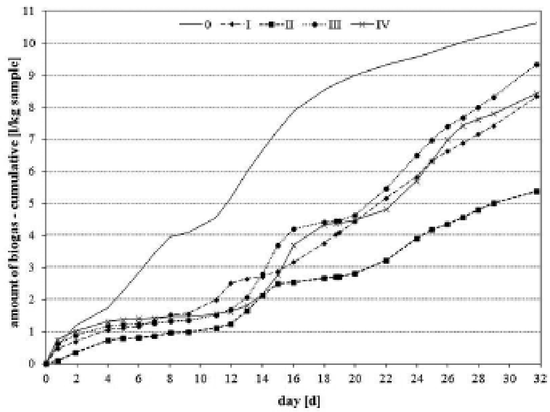

Figure 1.
Amount of biogas production rate during co-digestion process

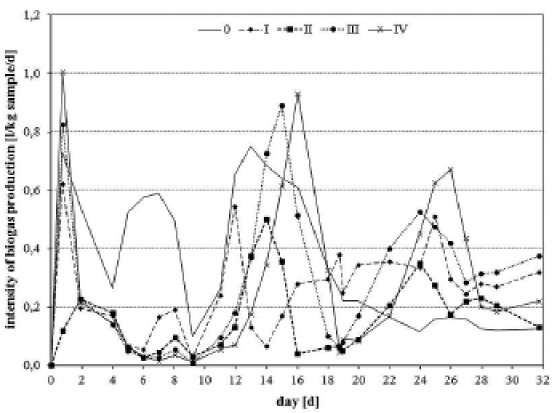

Figure 2.
Intensity of biogas production rate during co-digestion

Final content of volatile solids in sludge samples fermented with acid whey was slightly higher than without it. Furthermore at the same time the efficiency of process was at the level of: 0-42.9%; I-36.8%; II-40.7%; III-41.6%; IV-42.3%. The results of volatile solids reduction (over 38%) meet the requirements for sanitary clean sludges Class B, except for sample number I [19,20] (Figure 3). Nevertheless the COD values after the process were quite high. COD reduction was: 0-31.0%; I-24.6%; II-18.1%; III-23.9%; IV-1.4% (Figure 4).

An increase in total phosphorus concentration from 2 to 4 times in relation to output value was also reported. Increase in VFA concentration after process was probably inhibitive factor during process. It could be due to microbiological degradation of organic matter in the simple compounds. In anaerobic condition the phosphate bacteria take a VFA as a source of organic carbon to produce

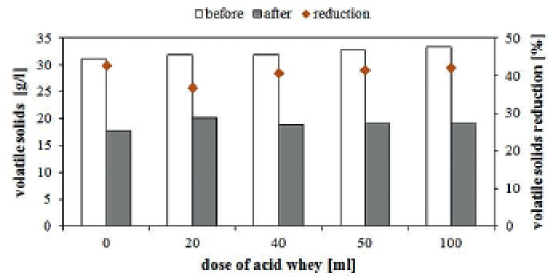

Figure 3.
Volatile solids before and after co-digestion process

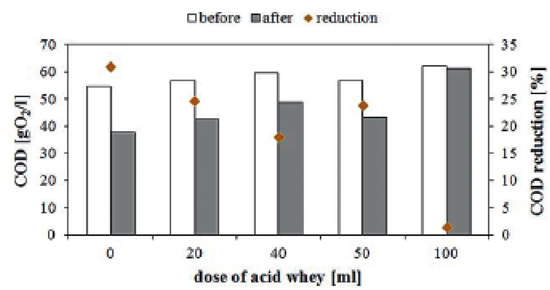

Figure 4.
COD before and after co-digestion process

polihydroxybutyrate. Energy necessary for this process is obtained from intercellular hydrolysis of phosphates. Therefore, the concentration of total phosphorus increase [21]. After the process there has been also reported total nitrogen decrease in range 3.9-50.5%. This could be caused by incomplete proteins hydrolysis present in acid whey or other compounds containing this element. Sludge hydration after the process was within the range 96.8-97.1%. It can be concluded that the sludge and whey mixture was poorly digested [22]. Whey chemical characteristic could have negative influence on process parameters characterized by high COD and VFA. Paradoxically pH values were close to desirable. Low efficiency of the process may also result from inhibitors presence, for example metal ions or sewage sludge sensitivity. Those factors could have significant impact on the amount and intensity of biogas production during the process. Results from dewatering, indicate that before and after this process parameters were comparable (Table 3).

Control sample dewatering ability was slightly worse than in tested samples. Therefore it cannot be concluded that acid whey dosage negatively affects sewage sludge dewatering ability.

The results of biogas production and physicochemical characteristics of tested samples indicate that acid whey addition affects acid phase of fermentation elongation. In that case, process duration should be

Table 3.
The results of sludge dewatering test (volume of feed 0.1 l)

Sample number	Zetag dose [g/kgTS]	Filtration time [min]	Volume of filtrate [l]	Filtration rate [l/min]	Effect of floccultaion	Quality of the filtrate
0	4.09	10.5	0.040	0.0039	The sludge is well linked by the polyelectrolyte	– yellow filtrate. individual particles of sludge in the filtrate
I	3.76	6.5	0.046	0.0077	The sludge is lightly linked by the polyelectrolyte	– yellow filtrate. many particles of sludge in the filtrate
II	3.97	2.5	0.047	0.0189	The sludge is medium linked by the polyelectrolyte	– light-yellow filtrate. few particles of sludge in the filtrate
III	3.98	3.5	0.047	0.0134	The sludge is well linked by the polyelectrolyte	– light-yellow filtrate. few particles of sludge in the filtrate
IV	3.99	2.3	0.045	0.0195	The sludge is medium linked by the polyelectrolyte	– yellow filtrate. few particles of sludge in the filtrate

extended, although it will involve higher costs and is economically inefficient. Obtained results could also be due to wastewater characteristic which was inflowing to the treatment plant (urban-industrial basin area). The average content of individual pollutant indicators in the wastewater flowing to the treatment plant is shown in Table 4.

Table 4.
Characteristics of wastewater

Parameter	Unit	Wastewater
COD	mgO_2/l	681.2
BOD_5	mgO_2/l	202.7
$N\text{-}NH_4$	$mgN\text{-}NH_4/l$	54.7
N_{TOT}	mgN_{TOT}/l	84.5
P_{TOT}	mgP_{TOT}/l	8.2
suspended solids (SS)	mg/l	381.1
chlorides	$mgCl^-/l$	232.5
sulfates	$mgSO_4^{-2}/l$	174.3
pH	-	7.2

There is necessity to check the possibility of sewage sludge co-digestion at lower doses of whey. If the results of further research are similar to discussed in the paper, it might mean that selected sewage sludge is not suitable for conducting the co-digestion process with acid whey. It might be caused by the presence of high concentrations of industrial contaminants accumulated by sewage sludge, as well as the nature of wastewater flowing into wastewater treatment plants.

4. CONCLUSIONS

The objective of sludge fermentation is to turn bulky odorous, sludges into relatively inert material that can be dewatered without burdensome odorous [19]. Obtained results showed that sewage sludge and acid whey co-digestion faces many problems. Despite the relatively high reduction of volatile solids (from 36.8 to 42.9%), the value of other parameters after the process does not meet satisfactory requirements. It could be due to process inhibition caused by improperly chosen whey doses. However, it should be emphasized that co-digestion could be the way to waste disposal (which is acid whey), despite of the fact that this process was not completely effective. Therefore, it is necessary to carry out the process with smaller doses of acid whey.

ACKNOWLEDGE

The research was financed by BK-324/RIE-4/2011.

REFERENCES

[1] *Bień J., Worwąg M., Neczaj E., Kacprzak M., Milczarek M., Gałwa-Widera M.*; Fatty waste and sewage sludge co-digestion. Engineering and Environmental Protection, No. 1, 2008; p.73-82

[2] *Lebiocka M., Pawłowski A.*; Biomethanization sustainable method of waste disposal. Middle-Pomeranian Scientific Society of Environmental Protection Lublin University, No.11, 2009; p.1257-1266

[3] European Parliament and Council 2009/28/WE of 23th April 2009 on the promotion of energy from renewable sources amending and subsequently repealing Directives 2001/77/WE and 2003/30/WE

[4] *Malaspina F., Cellamare CM., Stante L., Tilche A.*; Anaerobic treatment of cheese whey with a downflow-upflow hybrid reactor. Bioresource Technology, No.55, 1996; p.131-139

[5] *Zieliński M., Dębowski M. Krzemieniewski M.*; The possibility of anaerobic biodegradation of pollutants in permeate after acid whey nanofiltration. Yearbook of Environmental Protection, No.9, 2007; p.199-210

[6] *Kowalczyk-Juśko A.*; Efficiency of biogas production from agricultural waste and agricultural and food processing. South-Eastern Branch of the Ecological Engineering Polish Society, Polish Society of Soil Science, Branch in Rzeszów, Scientific Papers, No.11, 2009; p.149-154

[7] *Zielewicz-Madej E., Fukas-Płonka Ł, Gil B.*; New meaning of methane fermentation in sewage sludge stabilization. Silesian University of Technology Scientific Papers, Environmental Engineering, No.48, 2003; p.181-191

[8] *Jędrzejewska-Cicińska M., Kozak K., Krzemieniewski M.*; Innovative technology for conversion of biodegradable waste from the dairy industry (whey) to high-energy fuel gas (hydrogen, methane). Energy and Ecology, No.4, 2007; p.296-299

[9] *Szczurek W.*; Whey processing products and their use in broiler chickens feed – nutritional and physiological aspects. Zootechnical News, R. XLVI, 2008; p.41-52

[10] *Mockaitis G., Ratusznei S.M., Rodrigues J.A.D, Zaiat M., Foesti E.*; Anaerobic whey treatment by a stirred sequencing batch reactor (ASBR) effects of organic loading and supplemented alkalinity. Journal of Environmental Management, No. 79, 2006; p.198-206

[11] *Zhang, Xinyuan*; Anaerobic co-digestion of municipal primary sludge and whey; Massey University Palmerston North, New Zealand, 2010

[12] *Ghaly A.*; A comparative study of anaerobic digestion of acid cheese whey and dairy manure in a two stage reactor. Bioresource Technology, No.58, 1996; p.61-72

[13] *Kavacik B., Topaloglu B.*; Biogas production from co-digestion of a mixture of cheese whey and dairy manure. Biomass and Bioenergy, No.34, 2010; p.1321-1329

[14] *Klyuzhnyi S. V., Martinez E.P., Martinez J.R.*; Anaerobic treatment of high strength cheese whey wastewaters in laboratory and pilot UASB reactors. Bioresource Technology, No.6, 1997; p.59-65

[15] *Denac M., Dunn I.J.*; Packed and fluidized-bed biofilm reactor performance for anaerobic wastewater treatment. Biotechnology and Bioengineering, No.32, 1988; p.159-173

[16] *Switzenbaum M.S., Danskin S.C.*; Anaerobic expanded bed treatment of whey. Agricultural Wastes, No.4, 1982; p.411-426

[17] *Barford J.P., Cali R.G., Callender I.J., Floyd E.J.*; Anaerobic digestion of high-strength cheese whey utilizing semicontinuous digesters and chemical flocculant addition. Biotechnology and Bioengineering, No.28, 1986; p.1601-1607

[18] DIN 38414-8 German standard. sludge and sediments (group S)-Determination of the fermentation behavior (S8)

[19] *Hammer M.J., Hammer M.J.Jr.*; Water and Wastewater Technology, Sixth Edition, Prentice Hall, 2008

[20] EPA (1979). Process design manual for sludge treatment and disposal. Techn. Transf. US Environmental Protection Agency, EPA 625/1-79-011, MERL-ORD, CERI

[21] *Miksch K., Sikora J.*; Sewage Biotechnology, PWN, 2010

[22] *Podedworna J., Umiejewska K.*; Sewage sludge Technology, Warsaw University of Technology Printing House, 2008