Laboratory investigations on co-digestion of energy crops with industrial wastes in different configurations

A. Kacprzak, L. Krzystek and S. Ledakowicz

Department of Bioprocess Engineering, Faculty of Process and Environmental Engineering, Technical University of Lodz, 213 Wolczanska Street, 90-924 Lodz, PL
(E-mail: *krzystek@p.lodz.pl*; *stanleda@p.lodz.pl)*

Abstract
There is an increasing worldwide demand for energy crops for biogas production. This work examines the co-digestion of Rye (*Secale cereale L.*), Jerusalem artichoke (*Helianthus tuberosus L.*) from first (I) and second (II) swath, Sida (*Sida hermaphrodita L.*), Sorghum (*Sorghum Moench*) and cheese whey in different configuration together with glycerin fraction - the waste product of transestrification of oils (biodiesel production) in 25dm^3 bioreactor operated mesophically in quasi-continuous mode. The performed experiments showed that co-digestion of Sida with glycerol resulted in the highest yields (1.2 dm^3/dm^3/d) of methane-rich biogas.

Keywords
Anaerobic digestion, co-digestion, energy crops, glycerine, cheese whey, biogas

INTRODUCTION

Biological production of renewable energy from biomass has gained extreme importance during the last decade, although the anaerobic digestion process has been known for many centuries.

Anaerobic digestion process has found a wide application, in order to produce biogas from various sources of biomass, such as energy crops, agricultural wastes, organic fraction of municipal solid waste (OFMSW) and other types of degradable organic solid wastes (Burak, 2009). Energy crops, i.e. plants grown specifically for the purpose of producing energy, are a carbon-neutral source of domestic renewable energy. Economic biogas production depends on high biogas yields.

Co-digestion is a technology that is increasingly being applied for simultaneous treatment of different solid and liquid organic wastes (Bouallagui et al., 2009). It improves the biogas yields due to the positive synergism established in the digestion medium and the supply of missing nutrients by the co-substrates. Sometimes the use of a co-substrate can also help to establish the required moisture contents of the digester feed (Alvarez et al., 2008). Several studies have shown that multicomponent mixtures of agro-wastes and industrial wastes can be digested successfully, although with some mixtures a degree of both synergism and antagonism occurred (Alvarez et al., 2008; Ma et al., 2008; Bouallagui et al., 2009).

Cheese factories produce two streams of wastes: the washing water of the floor and equipment (mixed with detergents) and the cheese whey which actually is the liquid remaining after the precipitation and removal of milk casein during cheese-making process. Whey, although in much less volume (about 1/3 that of the wastewaters), is of high organic load and consequently, has very strong polluting potential to be allowed for direct disposal on land or water courses (Gelegenis et al., 2007).

Since whey has a very high chemical oxygen demand (COD) value of 60-100,000mg/dm^3, anaerobic digestion in the only viable biological method for treating (or at least pre-treating) this wastewater (Gelegenis et al., 2007).

Glycerol is an organic, readily-digestible substance which can be easily stored over a long period. In the past, the biodiesel industry considered glycerol a desirable co-product that could contribute to the economic viability of biodiesel production; nowadays glycerol is often regarded as a waste stream with an associated disposal cost. Recent research with co-digestion with applying glycerol have shown a significant increase in biogas yield. However, the amount of glycerol has a limiting concentration level (Fountoulakis et al., 2010).
The main objective of this work was to evaluate different configurations of co-substrates in order to boost biogas production during anaerobic digestion. The effect of glycerol supplementation was also investigated.

MATERIALS AND METHODS

Seven experiments in three series were conducted in this study. The substrates configurations in particular experiments are presented in table 1.

Table 1. Substrates configurations in performed experiments

	Series	Substrates configuration
Experiment 1	I	Sorghum + cheese whey + glycerol
Experiment 2	I	Jerusalem artichoke I + cheese whey + glycerol
Experiment 3	II	Jerusalem artichoke II + glycerol
Experiment 4	II	Jerusalem artichoke I + glycerol
Experiment 5	II	Sida + glicerol
Experiment 6	III	Jerusalem artichoke I + Sida + glycerol
Experiment 7	III	Rye + Sida + glycerol

All experiments conducted in this study were carried out in the bioreactor with the working volume of $25dm^3$, operated mesophically in semi-continuous mode at a hydraulic retention time (HRT) of 25 days.
Temperature was maintained to 37°C by thermostating system. Inoculum (sludge after anaerobic digestion) came from anaerobic digestion chambers of Municipal Wastewater Treatment Plant in Lodz, Poland.
The mixture of substrates with water was fed manually to the digester once a day, after withdrawing the same amount of fermentation broth until the steady state was obtained. Feed influent was prepared daily.
The characteristics of energy crops is shown in Table 2.

Table 2. General characteristics of energy crops

	TS [%]	VS [%]	COD [gO_2/g s.m.]	Total Nitrogen [% TS]	pH
Rye	29.6	93.9	1.02	1.22	4.1
Jerusalem artichoke	16.1	88.9	1.06	1.3	4.0
Sida	22.3	93.2	0.83	2.26	4.9
Jerusalem artichoke	20.7	84.7	1.06	1.88	6.8
Sorghum	23.4	93.5	1.36	1.32	4.4

Analytical methods

Mixed samples were daily drawn from the bioreactor and measured to determine: total suspended solids (TSS), volatile suspended solids (VSS), volatile fatty acids (steam distillation - BÜCHI B-324), chemical oxygen demand (COD) on centrifuged samples (Hach-Lange, method 435). Continuously – biogas flow rate (flow meter Ritter) and pH (pH-meter electrode WTW pH 540 GLP) were measured and biogas content (gas content analyzer LMS GAS DATA).

All analytical procedures were performed in accordance with Standard Methods (APHA, 1992).

RESULTS AND DISCUSSION

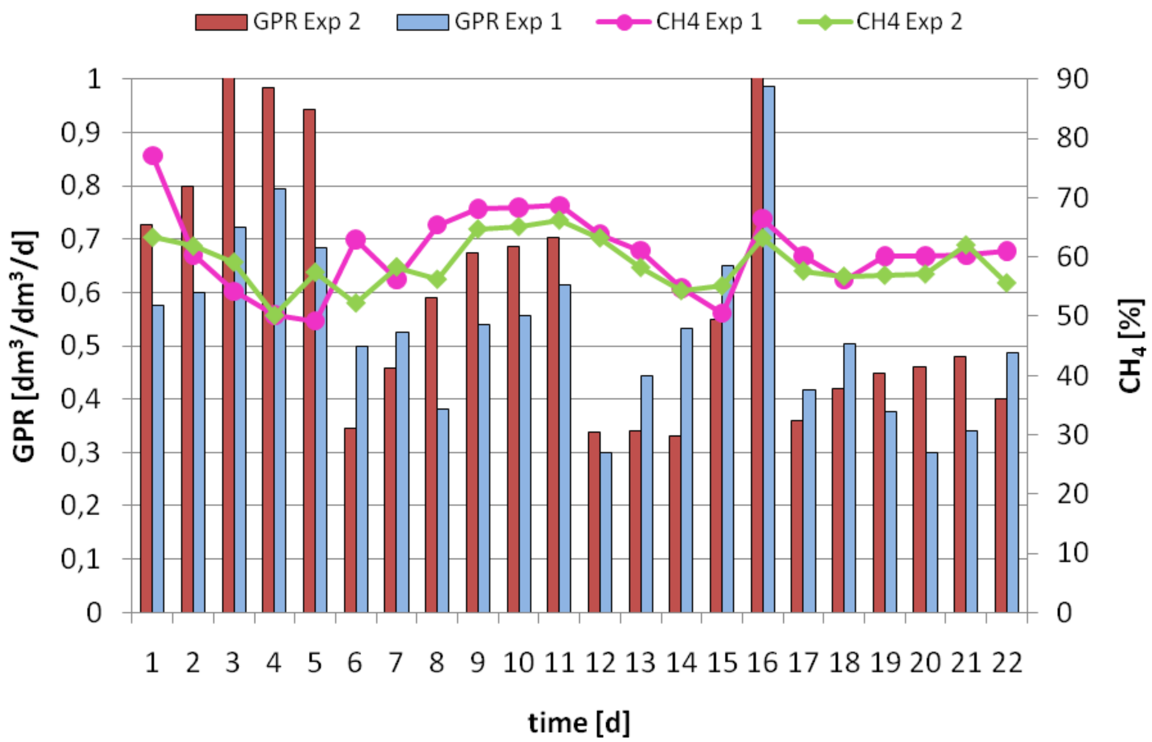
To optimize and compare co-digestion of several substrates in different configurations seven experiments were performed in order to obtain maximum productivity of biogas of high methane content, table 3.

Table 3. Mean values of the results obtained from performed experiments

		GPR [$dm^3/dm^3/d$]	CH_4 [%]	CO_2 [%]	COD [mgO_2/dm^3]	VFA [$mg_{CH3COOH}/dm^3$]
Serie 1	Exp. 1	0.53	59.9	39.3	2892	1044
	Exp. 2	0.6	55.6	38.9	1160	714
Serie II	Exp. 3	0.69	55.8	41.9	2222	1131
	Exp. 4	0.6	60	37.5	2100	911
	Exp. 5	1.2	62	37.6	1679	665
Serie III	Exp. 6	0.75	59.45	40	2949	1183
	Exp. 7	0.5	55.06	44.6	2656	870

In series I, Sorghum and Jerusalem artichoke (I) were co-digested with cheese whey and glycerol. In experiment 1, lower gas production rate (GPR) was obtained in comparison to experiment 2, however the methane content was slightly higher, reaching nearly 60 %, figure 1.

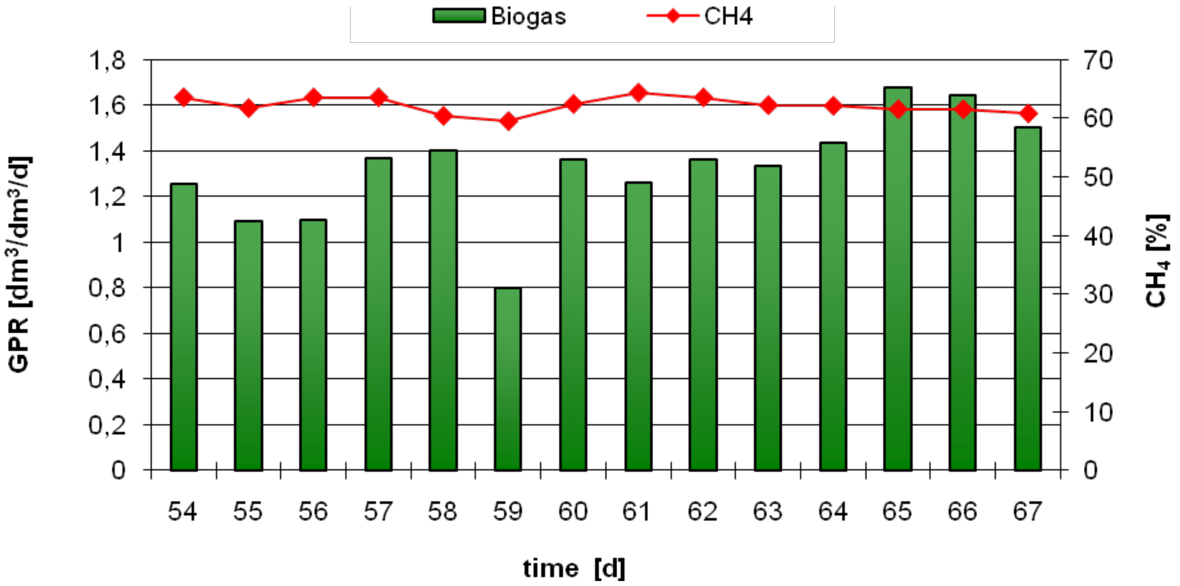
Figure 1. GPR and methane content in experiments 1 and 2 in series 1



Chemical oxygen demand (COD) in experiment 1 was more than twice higher. However, in both experiments, one obtained high COD reduction degree 51-54 %, figure 4.

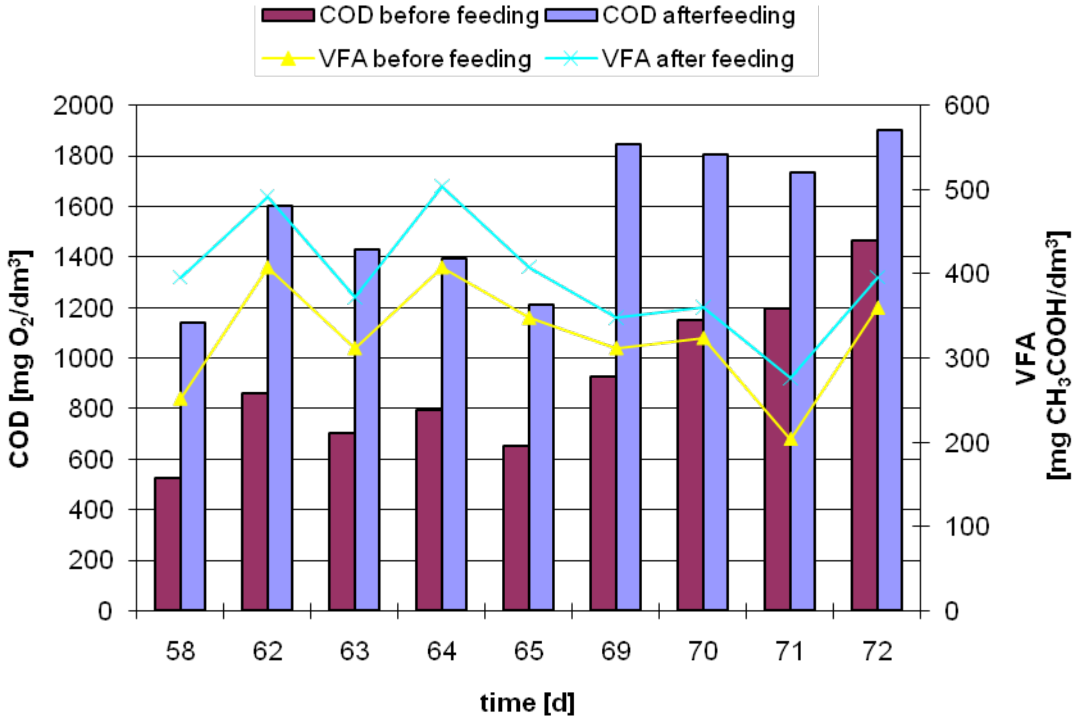
In series II, in three experiments Jerusalem artichoke (I), Jerusalem artichoke (II) and Sida were co-digested only with glycerol. Analyzing the obtained results, one can observe very little difference in the biogas and methane yields between first and second swath of Jerusalem artichoke. Sida proved to be the best of the three, resulting in GPR equal to 1.05 [$dm^3/dm^3/d$] and the highest methane content 61 %. Figure 3 presents the results obtained in stabilized state in experiment 5.

Figure 2. GPR and methane content in steady state in experiment 5



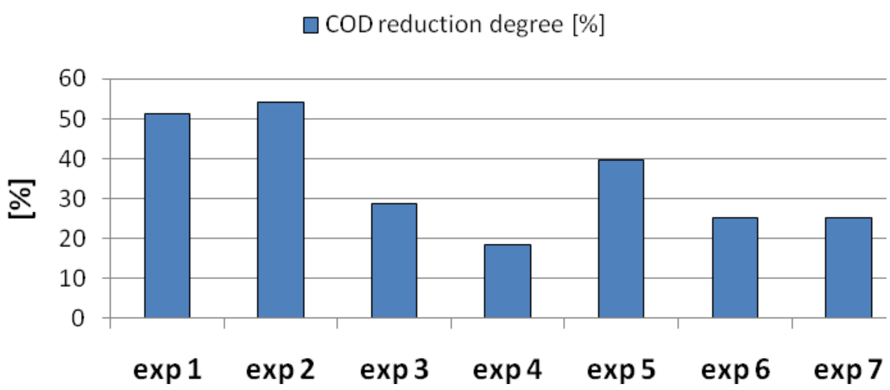
VFA concentration was in range from 204 to 504 $mg_{CH3COOH}/dm^3$ and chemical oxygen demand (COD) from 500 – 19000 mgO_2/dm^3, figure 2. COD reduction degree reached the value of 40 %, figure 4.

Figure 3. COD and VFA concentrations before and after feeding the bioreactor in stabilized state in experiment 5



Series III consisted of experiments 6 and 7, were two energy crops were mixed and co-digested with glycerol, table 1. The blend of Rye and Sida appeared to be the least effective. GPR was only 0.5 [$dm^3/dm^3/d$] and the methane content around 55 %.
In all experiments glycerol limiting concentration level was 1.3 % v/v and it avoided the risk of organic overloading. High stability of the bioreactor was confirmed by the presence of steady profiles of pH in the reactor

Figure 4. COD reduction degree in performed experiments



CONCLUSIONS

In the present study, the different configurations of co-substrates for effective anaerobic digestion process was investigated. It can be concluded that co-digestion of Sida with glycerol resulted in the highest yields of biogas production 1.2 $dm^3/dm^3/d$ and methane content of 62 %. When comparing the first and second swath of Jerusalem artichoke, no significant difference in biogas yields was observed.

References

Alvarez R., Lidén G. (2008) Semi-continuous co-digestion of solid slaughterhouse waste, manure and fruit and vegetable waste, Renewable Energy 33, 726-734.
APHA – AWWA, 1992. Standard Methods for Wastewater. 17th ed. American Public Health Association/American Water Works Association: Washington, DC, USA.
Bouallagui H., Lahdheb H., Romdan E. B., Rachdi B., Hamdi M. (2009) Improvement of fruit and vegetable waste anaerobic digestion performance and stability with co-substrates addition. Journal of Environmental Management 90, 1844-1849.
Burak D. (2009) Laboratory investigations on continuous bio-methanization of energy crops as mono-substrate without supplementation. Biomass and Bioenergy 33, 988-993.
Fountoulakis M.S., Petousi I., Manios T. (2010) Co-digestion of sewage sludge with glycerol to boost biogas production. Waste management 30, 1849-1853.
Gelegenis J., Georgakakis D., Angelidaki I., Mavris V. (2007) Optimization of biogas production by co-digesting whey with diluted poultry manure. Renewable Energy 32, 2147-2160.
Ma J., Wambeke M., Carballa M., Verstraete W. (2008) Improvement of the anaerobic treatment of potato processing wastewater in USAB reactor by co-digesting with glycerol, Biotechnology Letters 30, 861-867.