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# BOOSTING PRODUCTION OF METHANE FROM SEWAGE SLUDGE BY ADDITION OF GREASE TRAP SLUDGE

Feasibility and possible use of grease trap waste (GTW) as a co-substrate for improving biogas production in anaerobic digestion with sewage sludge has been established. Anaerobic co-digestion was studied in a semi-continuous experiment at 37 °C with hydraulic retention time (HRT) of 10 days. The grease trap sludge accounted for 20, 22, 24, 26, 28 and 30% of the mixture based on volatile solids. The results of the present laboratory study revealed that the use of GTW as a co-substrate is considered to be interesting option for digestion of sewage sludge due to increased methane production.

## 1. INTRODUCTION

The global energy demand is growing rapidly and it will increase during this century by a factor of two or three [1]. According to the International Energy Agency, fossil fuels accounted for up to 81% of the world's primary energy supply in 2007 whereas renewable energy sources only contributed 13% [2]. At the same time, concentration of greenhouse gases in the atmosphere quickly increases.

It is clear that renewable resources will play a crucial role in the $CO_2$ migration policy. The biogas from waste, residues, and energy crops can be used for replacement of fossil fuels in power and heat production. Anaerobic digestion (AD) is one of the most energy-efficient and environmentally beneficial technologies for bioenergy production [3]. AD is a widely used technology for the treatment of organic wastes including municipal, industrial and agricultural ones. Nowadays, the anaerobic sludge digestion has been increasingly developed in the waste water treatment plants (WWTPs). Municipal WWTPs generate sludge as a by-product of physical, chemical and biological processes used during wastewater treatment. About 4 million tons of

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sewage sludge per year can be hand handled by the anaerobic digestion in more than 120 full-scale WWTPs in Europe [4]. The production of biogas by anaerobic digestion offers significant advantages over other forms of generation of bioenergy.

Microorganisms within an anaerobic digester work synergistically to convert organic matter into biogas. Biogas has the energy content ranging from 18 630 to 26 081 kJ/m$^3$ depending on methane content. Anaerobic digestion of sewage sludge has the highest biogas production capacity worldwide. Efficiency of anaerobic digestion highly depends on waste characteristics in addition to reactor configurations and other operational parameters [5, 6]. Theoretically, methane yield obtained through anaerobic digestion should be around 0.59 m$^3$/kg ODS, and it strongly dependent on the sludge composition. However, reduction of organics from sewage sludge through digestion is limited to about 50%, even after a residence time of 20 days. Therefore, various filed can be identified in which more research is necessary to further optimize anaerobic digestion processes [7, 8].

Co-digestion is one of the optional methods used for the enhancement of anaerobic degradation and biogas production from waste with various characteristics [9]. Anaerobic co-digestion is simultaneous biodegradation of various wastes in a reactor to establish positive synergism in the digestion medium [10]. While co-digestion has been studied and practiced for a broad range of organic wastes, few studies have been conducted on the co-digestion of the sewage sludge from WWTPs with grease trap waste (GTW) as a co-substrate [11]. The primary components of grease trap waste are essentially spent fat, oil and grease with associated solids and other debris from food processing factories. GTW as a high-strength organic waste has high methane production potential. Theoretically, the methane potential of lipids is 1014 dm$^3$/kg volatile solids (VS), and it is much higher than carbohydrates and proteins. Lipid-rich wastes are known to combine high biodegradability and high biochemical methane potential (BMP), however they cannot be used for anaerobic digestion as a single substrate due to accumulation of inhibitory compounds, rapid acidification, and nutrient imbalance [12, 13]. These are the reasons making anaerobic co-digestion with sewage sludge a promising alternative of disposing this waste with many additional potential advantages. Due to problems with biomass washout and process inhibition by long chain fatty acids, the addition of grease trap sludge has to be carefully planned out in order to achieve complete biodegradation without increasing the volume of the digested material [14].

Based on previous study [11], the objective of this work was to evaluate the feasibility of GTW as an organic-rich co-substrate improving biogas production in anaerobic digestion with sewage sludge.

## 2. MATERIALS AND METHODS

*Materials*. Sewage sludge was collected from a municipal wastewater treatment plant (Silesia Region, Poland). Grease trap sludge was obtained from a meat processing plant (Silesia Region, Poland) specializing in meat cutting (cows and pigs) and production of various meat products. For anaerobic co-digestion experiment, waste was sampled weekly and stored at 4 °C. Feed mixtures of sewage sludge and grease trap sludge were prepared daily before feeding.

*Reactor experiment*. In the experiment, a glass reactor with a liquid volume of 5.5 $dm^3$ was used (Fig. 1) operating at a controlled mesophilic temperature of 37 °C. The temperature was controlled by a thermostatically regulated water bath. The reactor was constantly mixed (180 rpm) with a mechanical stirrer. Biogas was collected into a gas collector (PVC tube filled with water acidified to pH = 3) through lead-ins on the reactor top. The co-digestion process was conducted in semi-continuous regime with a hydraulic retention time of 10 days. Withdrawal of digested material and feeding were performed regularly once a day using 100 $cm^3$ syringe.

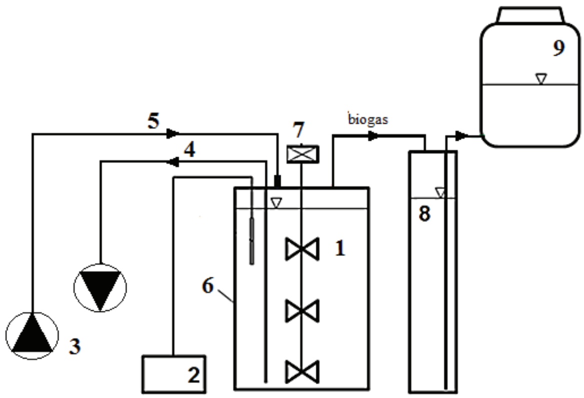


Fig. 1. Digester set-up: 1 – reactor, 2 – pH, redox meter, 3 – pump,
4 – effluent, 5 – influent, 6 - thermostatic heater,
7 – mixing equipment, 8, 9 – gas collector and gas metering unit

Addition of grease trap sludge in the feedstock was gradually increased from 20 to 30% (feed is calculated with respect to volatile solid basis). Mixture of co-substrate were introduced into the reactor, which were previously performed separate anaerobic digestion of sewage sludge (SS) as well as co-digestion of mixture with lower fat content in the feedstock.

*Analytical methods*. Total solids (TS), volatile solids (VS), pH (pH meter Cole Parmer Model No. 59002-00), alkalinity, total volatile acids (VFAs) (steam distillation BÜCHI K-355) and ammonium nitrogen were determined according to APHA standard methods [15].

Gas composition (methane and dioxide carbon) was analysed with a portable gas analyzer GA 2000, Geotechnical Instruments (UK), Ltd., and biogas volume was measured by the water displacement method. The biogas volume was expressed at standard temperature and pressure (STP).

## 3. RESULTS AND DISCUSSION

### 3.1. SUBSTRATE CHARACTERISTICS

Physicochemical properties of sewage sludge and grease trap waste are shown in Table 1. Significant differences between the two substrates were observed. Total solids content was in the range of 2.17–5.01% and 67% for sewage sludge and GTW, respectively. Grease trap waste was shown to have a considerably higher organic content than sewage sludge and could improve biogas production as a co-substrate in the anaerobic digestion process. The volatile fraction of the total solid of GTW was 0.99, while the VS/TS of the sewage sludge was only 0.64–0.75, indicating that grease trap waste contained more digestible organic matter than the sewage sludge.

Table 1

Characteristics of raw substrates and co-substrates mixtures used in the study

| Sludge | *VS* in feed [%] | *TS* [%] | *VS* [%] | *VS*/*TS* [%] | pH [%] |
|---|---|---|---|---|---|
| Sewage sludge | – | 2.17–5.01 | 1.62–3.45 | 0.64–0.75 | 5.11–5.67 |
| Grease trap sludge (GTS) | – | 66.96 | 66.36 | 0.99 | 5.21 |
| Feed 1 | 20 | 3.61–4.47 | 2.7–3.56 | 0.75–0.78 | 5.20–5.97 |
| Feed 2 | 22 | 3.83 | 3.03 | 0.79 | 5.44 |
| Feed 3 | 24 | 3.30 | 2.62 | 0.79 | 5.36 |
| Feed 4 | 26 | 5.66 | 4.11 | 0.73 | 5.25 |
| Feed 5 | 28 | 3.20 | 2.37 | 0.74 | 5.2 |
| Feed 6 | 30 | 3.19–4.33 | 2.53–3.46 | 0.79–0.8 | 5.06–5.2 |

### 3.2. ANAEROBIC DIGESTION EXPERIMENT

In order to evaluate the feasibility of GTW as an organic-rich co-substrate improving biogas production a semi-continuous anaerobic digestion in bioreactor was investigated. For this purpose, six greasy sludge ratios, from 20% to 30%, were evaluated based on volatile solids. Semi-continuous experiments were carried out with an increasing ratio of greasy sludge to allow biomass acclimation in the reactor. During 165–175 days, ammonia nitrogen concentration in the reactor increased from 605 to 762 mg/dm$^3$. In the next days the systematic decrease of $NH_4^+$ in the bioreactor was observed, while the value of pH was on the same level (Fig. 2).

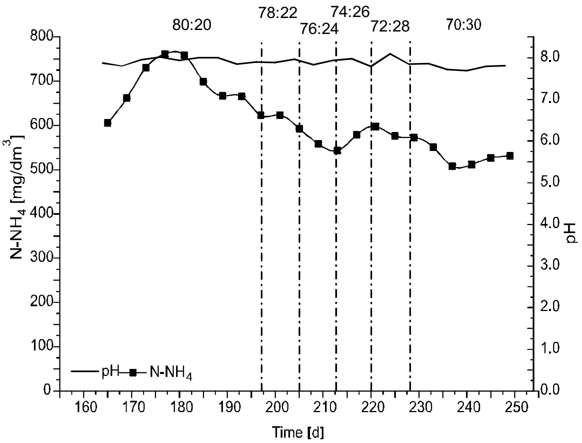


Fig. 2. Evaluation of ammonium nitrogen and pH in the effluent in a co-digestion process

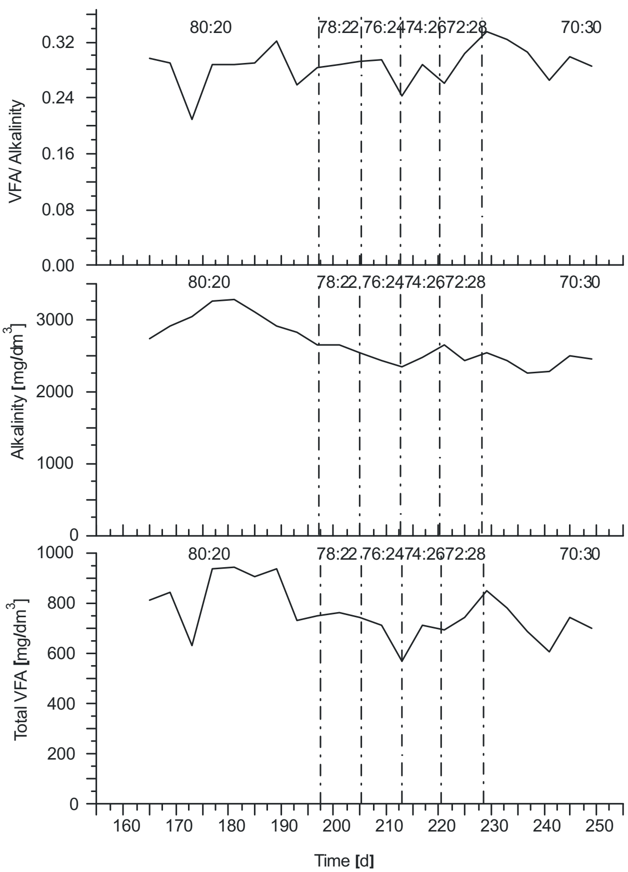


Fig. 3. VFA, alkalinity ratio, alkalinity and volatile fatty acids contents for various SS:GTW mixtures

One of the criteria for evaluating the digester stability is the ratio of VFA to alkalinity. Three critical ranges for this criterion may be distinguished [16]: <0.4 – the digester should be stable; 0.4–0.8 – some instability will occur; >0.8 – significant instability of the digester. During the whole experiment, the VFA:alkalinity ratio did not increase above the critical value of 0.4 (Fig. 3).

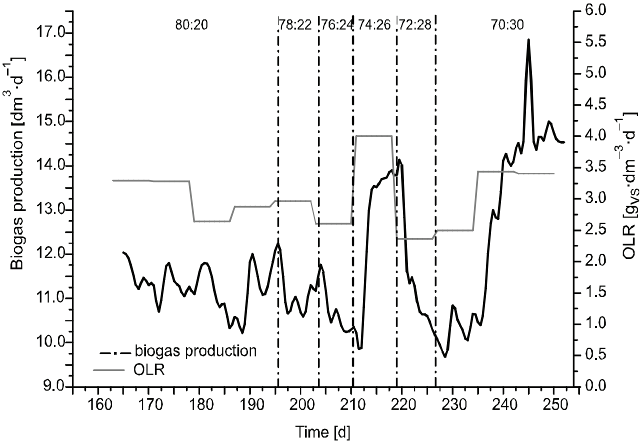


Fig. 4. Daily biogas production and OLR during co-digestion of sewage sludge and grease trap waste

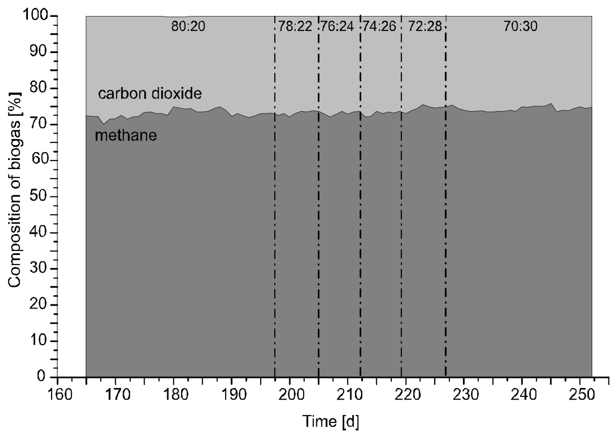


Fig. 5. The biogas composition during anaerobic co-digestion

The daily gas production (expressed in dm$^3$/d) together with the OLR (expressed in g VS fed/d) applied during semi-continuous anaerobic co-digestion is presented in Fig. 4. Variation of biogas production was due to fluctuation in OLR caused by changing the VS content in sewage sludge. Daily biogas production varied between 9 dm$^3$/d and 17 dm$^3$/d depending on the substrate composition, and the highest volume was

17 dm$^3$/d obtained for the last stage, with GTW addition of 30%. Generally the addition of GTW resulted also in both biogas production and methane content (Fig. 5).

A more accurate assessment of the process of digestion can be made by considering the quantity of gas produced per a unit of volatile solids fed, this parameter being known as biogas yield *Y*. Methane yields are presented in Fig. 6 for each period of grease trap waste with increasing concentration. Data in Fig. 6 for each period was analysed for statistical significance. Periods that are statistically different are shown in Fig. 6 with different letters. However, application of analysis of variances with one factor (one-way ANOVA at $\alpha = 0.05$) showed that only co-digestions with GTW addition of 28% and 30% presented a significant increase in the biogas yield.

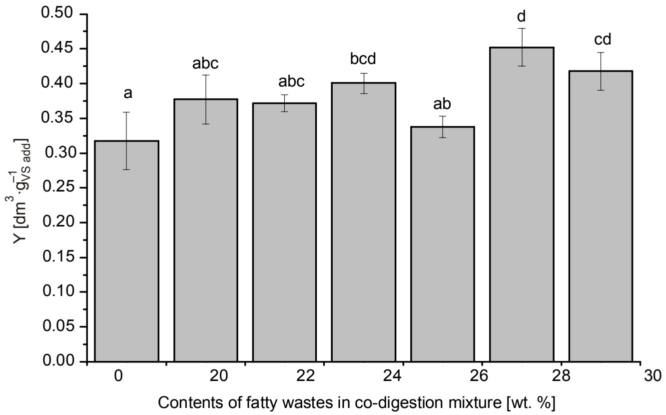


Fig. 6. Effect of grease trap sludge addition on the biogas yield of digested mixtures

Methane yield depends on substrate origin and composition, as well as on operational conditions, mainly temperature and HRT. Davidson et al. [17] reported increase of the methane yield lower to the one in this study with the GTW addition of 30%. The difference could be explained by different HRT and OLR, as well as by the scale of the study. Because Davidsson et al. [17] worked in a pilot scale, a full scale experiment should be performed in order to verify the present results. While Luostarinen et al. [18] for the 20% GTW content on a VS basis reported the specific methane yield higher (0.441 m$^3$·Mg$^{-1}$ VS$_{add}$) than in the present study but authors worked with higher HRT (16 d) and lower OLR (1.93–2.45 kg VS·m$^{-3}$·d$^{-1}$).

## 4. CONCLUSIONS

The potential of organic-rich GTW mixed with sewage sludge as a co-substrate in improving the anaerobic digestion process has been evaluated. Mesophilic anaerobic co-digestion of sludge from grease traps and sewage sludge was successfully performed in a laboratory continuous digestion test with hydraulic retention time of 10 days. The grease trap sludge accounted for 20, 22, 24, 26, 28 and 30% of the mixture on the volatile solids basis. It was found that co-digestion of sewage sludge and GTW improved both biogas production and methane content. It is also possible that a longer study period and higher GTW addition would have allowed for more biomass adaptation and restoration of higher methane production.

ACKNOWLEDGEMENT

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REFERENCES

[1] *IEA, World Energy Outlook*, International Energy Agency, Paris 2006.

[2] *IEA, World Energy Outlook*, International Energy Agency, Paris 2010.

[3] APPELS L., BAEYENS J., DEGRÈVE J., DEWIL R., *Principles and potential of the anaerobic digestion of waste-activated sludge*, Prog. Energ. Combust., 2008, 34 (6), 755.

[4] DE BAERE L., *Will anaerobic digestion of solid waste survive in the future?*, Water Sci. Technol., 2006, 53 (8), 187.

[5] ANGENENT L.T., KARIM K., AL-DAHHAN M.H., WRENN B.A., DOMÍGUEZ-ESPINOSA R., *Production of bioenergy and biochemicals from industrial and agricultural wastewater*, Trends Biotechnol., 2004, 22 (9), 477.

[6] HARTMANN H., AHRING B.K., *Strategies for the anaerobic digestion of the organic fraction of municipal solid waste: An overview*, Water Sci. Technol., 2006, 53 (8), 7.

[7] ZAWIEJA I., WOLNY L., *Generation of volatile fatty acids from thickened excess sludge subjected to the disintegration of high acoustic power ultrasonic field*, Pol. J. Environ. Stud., 2011, 20 (4A), 346.

[8] ZAWIEJA I., WOLSKI P., *Effect of thermal disintegration of excess sludge on the effectiveness of hydrolysis process in anaerobic stabilization*, Archiv. Environ. Protect., 2012, 38 (1), 103.

[9] BIEŃ J.B., GROSSER A., NECZAJ E., WORWĄG M., CELARY P., *Co-digestion of sewage sludge with different organic wastes: a review*, Pol. J. Environ. Stud., 2010, 2, 24.

[10] MALTA-ALVAREZ J., MACE S., LLABRÉS P., *Anaerobic digestion of organic wastes. An overview of research achievements and perspectives*, Bioresour. Technol., 2000, 74, 3.

[11] NECZAJ E., BIEŃ J., GROSSER A., WORWĄG M., KACPRZAK M., *Anaerobic treatment of sewage sludge and grease traps sludge in continuous co-digestion*, Global NEST Journal, 2012, 14 (2), 141.

[12] WANG Y.-S., ODLE W.S., ELEAZER W.E., BARLAZ M.A., *Methane potential of food waste and anaerobic toxicity of leachate produced during food waste decomposition*, Waste Manage. Res., 1997, 15 (2), 149.

[13] NAKHALA G., AL-SABAWI M., BASSI A., LIU V., *Anaerobic treatability of high oil and grease rendering wastewater*, J. Hazard Mater., 2003, 102 (2–3), 243.

[14] PALATSI J., LAURENI M., ANDRÉS M.V., FLOTATS X., NIELSEN H.B., ANGELIDAKI I., *Strategies for recovering inhibition caused by long chain fatty acids on anaerobic thermophilic biogas reactors*, Bioresour. Technol., 2009, 100, 4588.

[15] *APHA, Standard Methods for the Examination of Water and Wastewater*, 20th Ed., American Public Health Association, Washington, DC, 1999.

[16] CALLAGHAN F.J., WASE D.A.J., THAYANITHY K., FOSTER C.F., *Continuous co-digestion of cattle slurry with fruit and vegetable wastes and chicken manure*, Biomass Bioenergy, 2002, 22 (1), 71.

[17] DAVIDSSON A., LÖVSTEDT C., LA COUR JANSEN J., GRUVBERGER C., ASPERGEN H., *Codigestion of grease trap sludge and sewage sludge*, Waste Manage., 2008, 28, 986.

[18] LUOSTARINEN S., LUSTE S., SILLANPÄÄ M., *Increased biogas production at wastewater treatment plants through co-digestion of sewage sludge with grease trap sludge from a meat processing plan*, Bioresour. Technol., 2009, 100, 79.