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Anaerobic Co-Digestion of Fats, Oils and Grease (FOG) with Waste Activated-Sludge

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Two mesophilic batch digestion runs were set-up in which a FOG is co-digested with waste activated sludge. FOG loadings range from 0 to 50 % of the VS. This co-digestion of FOG and activated sludge successfully increased the biogas production up to 400 % when the FOG loading consisted around 50 % of the VS. An inhibition effect was observed in one of the tests when the FOG loading was over 25 % of the VS, apparent from a drop in methane yield per VS. Additionally, a beneficial co-digestion effect was observed at FOG loading of 25 % of the VS when the measured biogas production was compared to the maximum predicted biogas production. This indicates a possible enhancing effect on the sludge degradation.

1. Introduction

The mitigation of CO_2 emissions and related global warming necessitates the exploitation of renewable forms of energy to reduce the dependency on fossil fuels. In this regard, anaerobic digestion is generally considered as one of the most promising technologies for the energetic valorisation of various types of biomass and solid organic wastes, and it is predicted to play a crucial role in the future of renewable energy production (Buffière et al. 2008; Appels et al., 2011).
Wastewater treatment plants (WWTP) generate sludge as a by-product of the physical, chemical and biological processes used during treatment. Anaerobic digestion has shown to be an excellent technology to treat this sludge, since it has the ability to reduce the overall load of biosolids to be disposed with a theoretical production of 0.590 m³/kg per kg volatile solids (VS) (Appels et al., 2011).
Fats, oils and greases (FOG) commonly refer to the lipid-rich material skimmed from wastewater originating from food processing such as restaurants. This kind of waste is detrimental for collection systems (i.e. drains, pipes) as it sticks to walls and causes clogging. Furthermore, direct disposal in the environment is considered harmful to the aquatic environment. FOG is theoretically suitable for anaerobic treatment due to its high methane production potential, i.e. 0.9-1.4 Lg^{-1} at 65-70% CH_4 (Alves et al., 2009; Long et al., 2012).
The degradation of FOG, however, leads to a significant increase of long chain fatty acids (LCFA), which are assumed to cause inhibition of the methanogenesis with digester failure as a result. Several mechanisms are held responsible for the inhibitory effect of LCFA. First of all, they are believed to be toxic to methanogenic bacteria. The exact mechanism behind this toxicity is not yet fully known, however, a surfactant effect of the LCFA on cell membranes with cell lysis as a result, seems to be most likely.Additionally, adsorbed LCFA on cell membranes may further impede mass transport over the membrane (Long et al., 2012). It is assumed that the impact of LCFA is correlated with the degree of unsaturated fats in the substrate (Kim et al., 2004). There is some dispute regarding the

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irreversibility of the inhibition due to the ooccurrence of temporary lag phases in the methane production (Angelidaki et al., 1992; Pereira et al., 2004; Long et al., 2012).
To overcome these problems, FOG is often co-digested with other substrates such as sludge or manure. Interesting for this co-substrate is the abundance of buffering components such as bicarbonate and micro-nutrients (e.g. S, P, N...) necessary for cellular activity and growth. Numerous reports on co-digestion of sludge and FOG are available for lab, pilot and full scale such as Kabouris et al. (2008), Kabouris et al. (2009a), Kabouris et al. (2009b) and Wan et al. (2011) who report biogas production increases up to 200 %. The results of Kabouris et al. (2009a) even suggests that the near ideal mixing conditions, the increase in biogas production exceeds the theoretical value, indicating some sort of synergistic effect, although it is not clear what the cause for this effect might be.
In this research, the influence of fatty co-substrates on anaerobic digestion is evaluated through the addition of vegetal oil. Various topics have been addressed: (i) the possible inhibition of the used oil in a co-digestion with sludge, (ii) the occurrence of a lag phase, (iii) a possible beneficial co-digestion performance on the degradation of the vegetal and the waste activate sludge

2. Materials and methods

2.1 Samples

The FOG used is purchased vegetal cooking oil of the brand 'Everyday (Belgium). This choice has the advantage of being a homogenous waste without particulates and with constant composition. According to the manufacturer it consists of 15 % saturated fats, 44 % monounsaturated fats and 41 % polyunsaturated fats. Because it is of vegetal origin (sunflower oil, palm kernel oil, canola oil), it contains no trans-fats. In comparison with other reports as shown in Table 1, it has a relatively high concentration of polyunsaturated fats.

Table 1: Fat composition of the used oil and compared with other research (n.d. = not determined).

	sample	Saturated fat (%)	Polyunsaturated fat (%)	Monounsaturated fat (%)	Trans fat (%)
'Everyday' oil	Vegetal cooking oil	15	41	44	-
Kabouris et al. (2009a)	Brown grease	37.9	7.4	39.5	15.2
Suto et al. (2006)	Restaurant waste	48.6	15.3	36.10	n.d.
Canacki (2007)	Brown grease	37.03	12.91	45.49	n.d.

The sludge used originates from the municipal water treatment plant of 'Mechelen-Noord' (Belgium). The inoculum or seed sludge for the batch digestion is effluent from a full-scale sludge digester located at the municipal wastewater treatment plant of 'Antwerpen-Zuid' (Belgium).
In the following, the combination of sludge and oil, i.e. the substance that is converted to biogas, is referred to as the substrate.

2.2 Batch digestion set-up

Two runs of 5 sludge mixtures were set up, each mixture in triplicate. Each run consisted of one sample with only the seed to account for substrate remnants in the anaerobic biomass, one sample with 250 mL of sludge and 250 mL of inoculum and three samples with 250 mL sludge, 250 mL inoculum and a selected amount of oil. The batch digesters consisted of 1 L bottles which were connected to a water displacement system to measure the biogas production. The bottles were kept in heated water bad to attain mesophilic digestion (37 °C). The digestion bottles were linked to 2.5 L bottles filled with acidified water. The biogas accumulated at the top of these bottles and pushes the acidified water via separate tubing in a receiving bottle. The amount of biogas produced was determined by weighing these bottles daily. The used water is acidified (0.05 M H_2SO_4) to prevent CO_2 dissolution.

2.3 Analytical methods

The total solids (TS) and volatile solids (VS) were measured according to standard methods (APHA, 1998). The lipid content was determined with a soxhlet extraction, also according to standard methods (APHA, 1998).

3. Results and discussion

Different concentrations of FOG were added to the digestion mixtures. In the first run concentrations of 0 %, 24.5 %, 38.4 % and 49.5 % of the VS of the substrate. In the second run they were 0 %, 34.2 %, 40.2 % and 45.5 % of the VS of the substrate. The first and second runs were stopped after 29 and 24 days respectively, after biogas production ceased. The results of the analysis are given in Table 2 and the produced biogas is shown in Figure 1.

Table 2: TS, VS and lipid fraction of the sludge and seed. The lipid fraction of the seed and sludge of the second run were not determined (n.d.), however, it is expected that they are of the same order as the values of run 1.

	TS (g / kg sample)	VS (g / kg sample)	Lipid fraction (% VS)
Run 1 - sludge	37.8	25.8	2.9%
Run 1 - seed	46.7	24.5	1.3%
Run 2 - sludge	19.1	13.4	n.d.
Run 2 - seed	32.0	15.4	n.d.

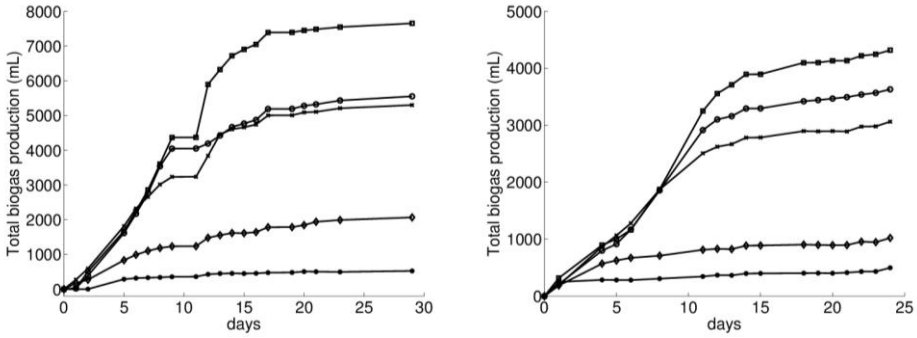

Figure 1: Total biogas production in time. Left: run 1 for the seed (-●-) and sludge-oil mixtures with an FOG fraction of 0% VS (-♦-), 24.5 % VS (-x-), 38.4 % VS (-o-) and 49.5 % VS (-■-). Right: run 2 for the seed (-●-) and sludge-oil mixture with an FOG fraction of 0 % VS (-♦-), 34.2 % VS (-x-), 40.2 % VS (-o-) and 45.5 % VS (-■-).

It is clear from Table 2 that the TS and VS content of the sludge in the second run is much lower. As a result of the lower organic content, the total biogas production was about 40-50 % less in the second run. The lipid fraction of sludge and seed was relatively low compared to the added FOG. In both runs, no lag in the biogas production was observed. In fact, the digestion of the FOG-loaded, took about the same time to reach 90 % of the final or ultimate biogas production, i.e. 13-16 days.

Adding the FOG clearly had a beneficial effect on the total biogas production. For instance an increase of the VS with 100 % through the addition of oil, corresponding to a FOG content of 50 % of the VS of the substrate, increased the total biogas production with about a factor 4. The addition of 32 % of VS, corresponding to 24.5 % of the resulting VS content of the substrate, increased the total biogas production with a factor 2.5 - 3.

The lipid or oil content of the batch tests and the VS values before and after the digestion are depicted in Table 3. From these values, the VS degradation and the substrate VS degradation can be calculated. The latter is based on the assumption of an equal degradation of the seed in all samples, i.e. 5.8 % and 0.6 %. For all batch tests, the degradation of VS increased with increasing FOG content,

yielding similar final VS values for all batches, i.e. around 20 g/kg sample for the first run and 11.5 g/kg for the second. The measurement of the lipid content after digestion, unfortunately, was rather unreliable as evident from the large standard deviations.
The increase in biogas production compared to the sludge digestion, i.e. an oil fraction equal to 0.0 %, is also shown in Table 3 and is compared with a theoretical estimate of the increase in biogas production. The latter is done by assuming a full conversion of the added oil to biogas, according to a conversion rate of 1.42 Lg^{-1} (Alves et al., 2009). For both runs, the difference between the measured and the theoretical biogas production increased with an increasing FOG content to about 40 % for a FOG fraction of 49.5 %. The result in the first run for an oil fraction at 24.5 % is, however, remarkable. For this mixture, the biogas production exceeded what would theoretically be predicted, indicating that the digestion of the other substrate, i.e. the sludge, is stimulated and enhanced.

Table 3: Overview of the FOG fraction and VS values before and after digestion, the measured VS degradation, the calculated VS degradation of the substrate and the measured and theoretically predicted increase in biogas production in comparison with the digestion of the sludge (oil fraction equal to 0.0 %). (n.d. = not determined)

	FOG fraction before digestion (% VS)	initial VS (g/kg sample)	FOG fraction after digestion (% VS)	Final VS (g/kg sample)	VS degradation (%)	Substrate VS degradation (%)	Increase in biogas production (mL)	Theoretical increase in biogas production (mL)
	seed	24.5	4.3% ± 3.2%	23.1	5.8	-	-	-
	0.0%	25.2	3.7% ± n.d.	19.6	22.0	37.3	-	-
1	24.5%	29.3	4.1% ± n.d.	19.5	33.4	53.2	**3233**	**2980**
	38.5%	33.2	3.9% ± 2.5%	20.1	39.6	59.3	3485	5740
	49.5%	37.8	3.6% ± 0.6%	20.5	45.7	64.8	5586	9001
	seed	15. 5	n.d.	15.4	0.6	-	-	-
	0.0%	14.4	n.d.	11.7	18.9	40.0	-	-
2	34.2%	17.9	n.d.	12.2	32.0	55.7	2042	2487
	40.2%	19.0	n.d.	11.7	38.2	64.1	2608	3219
	45.6%	20.1	n.d.	11.2	44.2	71.5	3296	4003

The results are presented more clearly in Figure 2, showing the methane production per g VS of substrate in function of the FOG fraction of the substrate. These results are also compared to reports of Kabouris et al. (2008) and Davidsson et al. (2008) who performed similar batch tests using grease from grease traps with a VS content of 313 g/kg FOG and 173 g/kg respectively. The presented volumes are corrected in reference to the inoculum, i.e. the biogas production of the inoculum is subtracted. The produced volumes are normalised to a temperature of 25 °C. The methane fraction is about 65 %. In the first run at an oil fraction of 24.5 % of the VS of the substrate, equivalent to a FOG to biomass ratio of 0.34 g/gVS, the methane yield dropped, probably due to some inhibition effect. However, from the measurements it is not possible to reveal underlying reason for this effect and why it was not manifested in the second run.

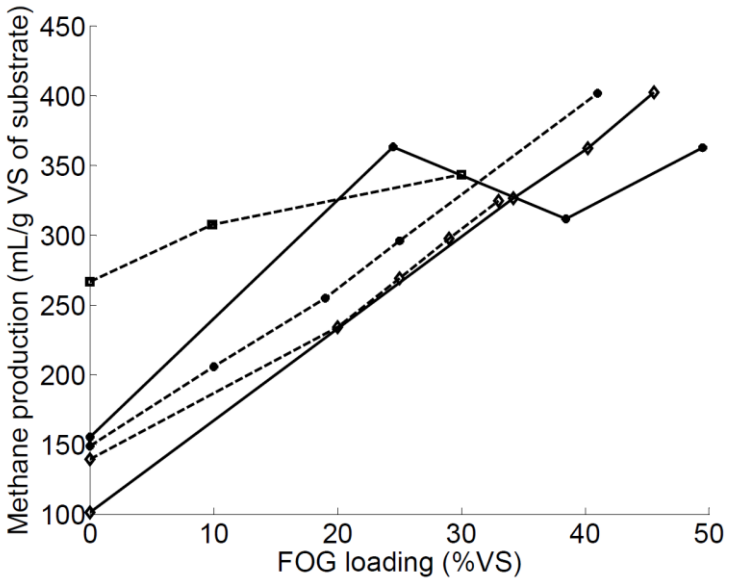

Figure 2: Methane production in co-digestion of sludge and FOG: the first batch run (-●-) and the second run (-◊-) are compared with the results of batch-tests done by Kabouris et al. (2008) with normal seed sludge (- -●- -) and acclimatised seed sludge (- -◊- -) and Davidsson et al. (2008). All results volumes are corrected in reference to the inoculum and are normalized to 25°C. The methane fraction is about 65 %.

4. Conclusions

Co-digestion of FOG and activated sludge successfully increases the biogas production, with almost a quadrupling of the biogas yield for a FOG loading around 50 % of the substrate VS. In the tests, using vegetal oil as FOG, no lag in the digestion was observed. In one run, however, an inhibition effects was observed in a drop in methane production per g VS. At a FOG loading of about 25 % an enhancement in the degradation of the sludge was seen, revealing a beneficial co-digestion effect.

References

Alves M., Pereira M., Sousa D., Cavaleiro A., Picavet M., Smidt H., Stams A., 2009, Waste lipids to energy: how to optimize methane production from long-chain fatty acids (LCFA), J. Microbial Biotech. 2 (5), 538-550.

American Public Health Association (APHA)/American Water Works Association/Water Environment Federation, 1998, Standard Methods for the Examination of Water and Wastewater, 20th edition, Washington DC, USA.

Angelidaki I., Ahring B., 1992, Effects of free long-chain fatty acids on thermophilic anaerobic digestion, Appl. Microbiol. Biotechnol. 37 (6), 808–812.

Appels L., Lauwers J., Degrève J., Helsen L., Lievens B., Willems K., Van Impe J. and Dewil R., 2011, Anaerobic Digestion in global bio-energy production: Potential and research challenges. Renew. Sust. Energ. Rev. 15 (9), 4295-4301.

Buffière P., Mirquez L.D., Steyer J.-P., Bernet N., Delgenes J.P., 2008, Anaerobic digestion of solid wastes needs research to face an increasing industrial success. Int. J. Chem. React. Eng., 6.

Davidsson A., Lovstedt C., Jansen J.C., Gruvberger C., Aspegren H., 2008, Co-digestion of grease trap sludge and sewage sludge. Waste manage. 28 (6), 986-992.

Kabouris J.C., Tezel U., Spyros G., Pavlostathis S.G., Engelmann M., Todd A.C., Gillette R., 2008, The anaerobic biodegradability of municipal sludge and fat, oil and grease at mesophilic conditions, Water Environ. Res. 80 (3), 212-212.

Kabouris J.C., Tezel U., Spyros G., Pavlostathis S.G., Engelmann M., Dulaney J.A., Todd A.C., Gillette R., 2009a, Mesophilic and thermophilic anaerobic digestion of municipal sludge and fat, oil and grease. Water Environ. Res. 81 (5), 476-485.

Kabouris J.C., Tezel U., Spyros G., Pavlostathis S.G., Engelmann M., Dulaney J., Gillette R.A., Todd A.C., 2009b, Methane recovery from the anaerobic codigestion of municipal sludge and FOG, Bioresour. Technol. 100, 3701-3705.

Kim S.H., Han S.K., Shin H.S., 2004, Kinetics of LCFA inhibition on acetoclastic methanogenesis, propionate degradation and beta-oxidation, J. Environ. Sci. Health A: Toxic/Hazard. Subst. Environ. Eng. 39 (4), 1025-1036.

Long J.H., Aziz T.N., de los Reyes III F.L., Ducoste J.J., 2011, Anaerobic co-digestion of fat,oil and grease (fog): a review of gas production and process limitations, Process Saf. Environ. Prot. 90, 231-245.

Pereira M., Sousa D., Mota M. Alves M., 2004, Mineralization of LCFA associated with anaerobic sludge: kinetics, enhancement of methanogenic activity and effect of VFA, Biotech. Bioeng., 88 (4), 503-511.

Suto P., Gray D.M.D., Larsen E., Hake J., 2006, Innovative anaerobic digestion investigation of fats, oils and grease. In: Proceedings of the Water Environment Federation, 858-879.