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Projekt BIOFEGG

Biogas for Future Electric and Gas Grids

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1 Introduction

The BIOFEGG project enables flexible future use of biogas by developing an efficient and cost-effective cleaning solution for biogas. The main aspects of the project are the micro-impurities siloxane and terpenes which appear in biogas after the degradation of specific organic feedstocks. The removal of micro-impurities is becoming an increasingly vital development aspect with regard to new and stricter regulations. A novel siloxane removal solution and upgrading method for biogas was developed in the project, as well as a method for terpene analysis from biogas. The impurities were cleaned by adsorption on novel geopolymer adsorbents. The same material can also be used to upgrade the biogas by pressure swing adsorption (PSA). It was aimed at achieving gas qualities of standardized quality for direct insertion into the gas grid or biomethane filling stations. This report is to the Austrian National Funding Agency, for this reason the report mainly focusses on the Austrian contribution to the BIOFEGG project.

2 Methodological approach

2.1 Investigation of terpene formation

Terpenes are known as an antimicrobial agent which affects the biogas production and have been shown to be the main organic pollutants when biogas is produced from food waste mainly containing residues of citrus fruits. Especially limonene is in the focus of current research as it is the major component of citrus essential oils. The aim of the experiments was to develop and test a method to quantify terpenes in biogas. In addition, anaerobic degradation tests were carried out to provide terpene-rich biogas and to evaluate the effect of terpenes on the biogas process.

2.1.1 Development of a method for the detection of terpenes in biogas

Limonene and cymene were identified as target terpenes, with limonene originating mainly from citrus peels and cymene being a conversion product of limonene. Terpenes are generally sampled with adsorption tubes filled with Tenax and then measured with GC-MS systems after thermal desorption from the loaded tube. At IFA-Tulln a GC 6890N (Agilent Technologies, US) equipped with a 5975B series inert XL MSD from Agilent Technologies and a CTC PAL COMBI-xt (CTC Analytics AG, Switzerland) with the ITEX-2 option was used for the analysis of terpenes in biogas. For ITEX (In Tube Extraction), the Tenax coating is attached to the walls of the sampling needle of the syringe, thus providing sample surface for a repeated enrichment of terpenes on the adsorptive surface of this trap. The system is shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. Available trap materials are Tenax TA, Carbotrap/Carbopack and Carbosieve/Carboxen. Tenax was the material of choice in case of terpene determination.

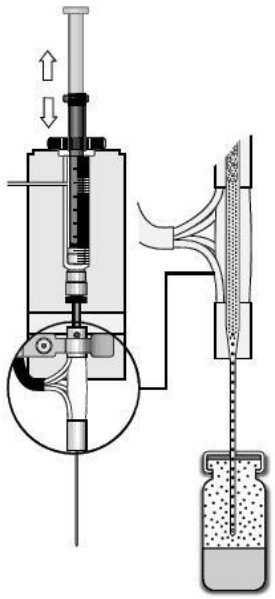


Figure 1 Schematics of the ITEX-system

2.1.2 Biogas batch degradation tests

The aim was to produce terpene containing biogas which can be sampled and analysed for terpenes and to monitor inhibitory effects of terpene on the degradation process. For these experiments, terpene concentrations much higher than normally occurring in biogas plants were applied.
A large number of batch tests had to be carried out. Two different systems, eudiometer and incubation room (Figure 2) were used to compare them concerning sampling, handling and performance. The batch tests were carried out both with cellulose as carbon source spiked with different limonene concentrations as well as with various orange peel concentrations since orange peels have a high limonene content.
The eudiometers are placed in a tempered water bath to control the reactor temperature. The produced biogas streams through the gas transport tube into the head space. There it spreads and displaces the barrier liquid. The amount of produced biogas can be read directly from the scale on the eudiometer tube. Gas sampling takes place via a valve in the headspace.
The measuring principle for the batch tests in the incubation room is similar to that in the eudiometers. Instead of a water bath, the reactors are placed in a heated room to adjust the temperature. If only methane is to be measured the biogas produced in the fermenter (1) bubbles through a bottle (2) filled with sodium hydroxide (NaOH) to capture the CO_2 and streams into the displacement bottle (3). Otherwise, if biogas is to be measured, the NaOH bottle may be omitted. The displaced barrier liquid (4) is measured with a measuring cylinder and is equivalent to the produced methane or biogas. Gas sampling takes place via a septum and a gas syringe.

a) Eudiometer (EUM)

b) Incubation room (IR)

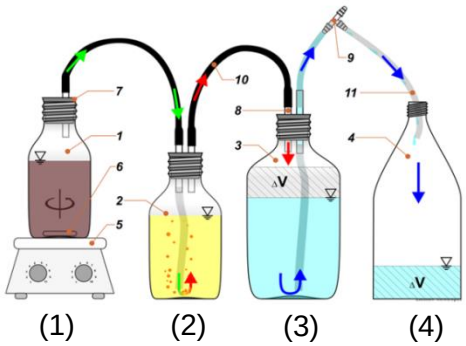


Figure 2 a) Eudiometer batch tests; b) Batch tests in the incubation room; fermenter (1), bottle filled with sodium hydroxide (NaOH) (2), displacement bottle (3), bottle that collects the displaced liquid (4).

2.1.3 Biogas continuous degradation tests

The continuous tests are carried out in 2L Schott bottles which are placed in a tempered water bath by 39°C (see Figure 3). The reactors are mixed continuously with the aid of a magnetic stirring plate. The produced biogas flows over a gas counter and is collected in 30L gasbags. Three reactors are operated. Reactor one serves as a reference and is charged with pig manure and maize silage. Reactors two and three are fed with the same organic dry matter (ODM) ratio as the reference but with pig manure and orange peels. During the start-up of the continuous tests, the organic loading rate (OLR) was increased slowly in order to adapt the microbes to the operating conditions. The trials were conducted over a period of 100 days. The following analyses were performed at regular intervals: pH, dry matter and organic dry matter, ammonium, volatile fatty acid (VFA), gas composition (CH_4, CO_2, O_2 and N_2) and limonene concentration.

Due to the continuous gas flow, sampling could be optimized. A bypass ensured that the produced biogas flows directly through the headspace vial (see Figure 3b). Compared to the batch tests, it was possible to ensure that the biogas has no possibility to condense before sampling. This is important because it is presumed that the terpenes accumulate in the condensate.

a) b)

Figure 3 a) water bath for the continuous tests with orange peels as substrate; b) Terpene sampling point with bypass

2.2 Siloxane removal by adsorption on geopolymers

The main research part on the utilisation of geopolymers for the removal of siloxanes has been done by the Finnish Coordinator KAMK (Kajaani University of Applied Sciences) and is therefore not part of this national report. They have been carrying out lab optimisation trials and have set up a pilot plant to test the geopolymers in industrial biogas plants. This plant was then shipped to Austria and tested at an Austrian biogas plant.

2.2.1 Pilot-scale tests at a wastewater treatment plant in Austria

The wastewater treatment plant in Tulln, Lower Austria, was selected as the location to set up the pilot plant. First it was checked whether the pilot plant could be connected to the biogas tube. Requirements were that the biogas should be dry, which means that the gas had to be taken after the condensate trap. On the other hand, the gas should not be filtered so that no pre-cleaning affects the siloxane load. Another requirement was that the biogas should be fed back into the system after the cleaning process. The following flow chart shows the regular gas pathway from digester to CHP (combined heat and power plant) with the chosen connection points to the pilot plant.

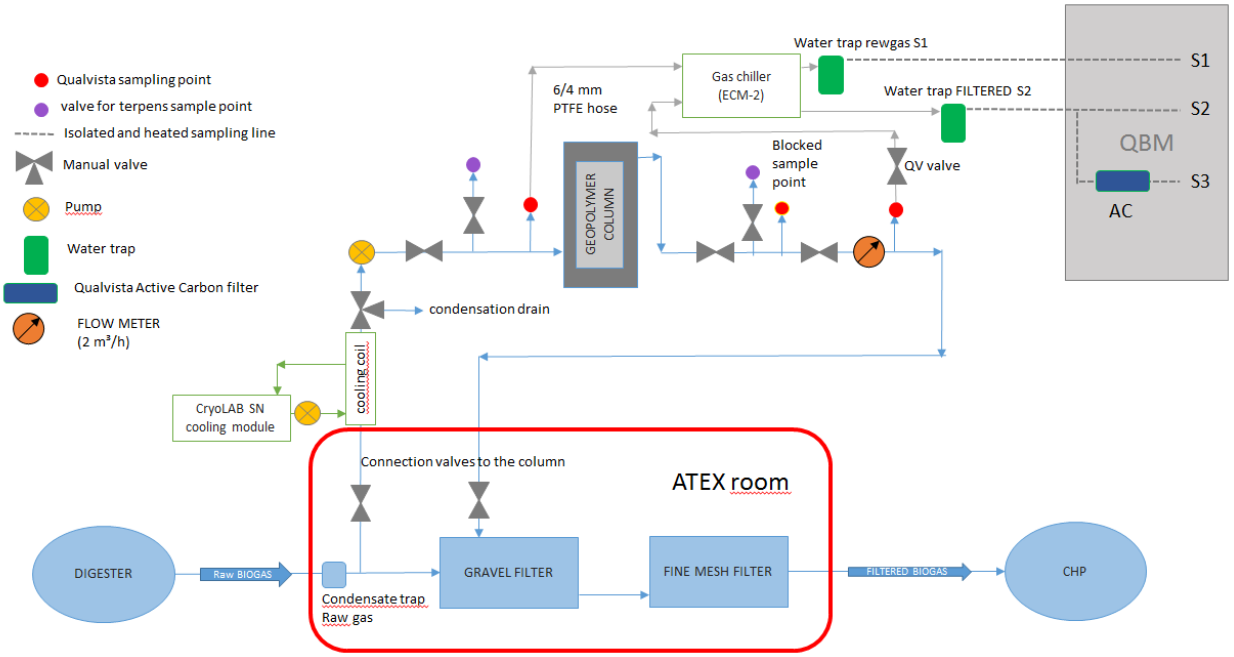


Figure 4 Process diagram from the pilot plant in Tulln

The gas is cooled by the CryoLAB condenser to minimize condensation in the column. In front of the gas pump there is a condensate separator. The pump sucks in the gas and presses it through the column and back into the gas network at constant volume flow. There is a sampling point both upstream and downstream of the column where gas is introduced into the Qualvista online siloxane measuring device. To ensure that no moisture enters the instrument, it is cooled down to 5°C by a gas chiller (ECM-2). In addition, two sampling points for terpenes are installed before and after the column. Figure 5 shows the complete pilot plant.

Figure 5 Pilot plant for siloxane removal on the wastewater treatment plant in Tulln

2.3 Regulation and policy assessment, socio-economic assessment and environmental sustainability analysis

In order to give an assessment of the status quo of policies that are related to biogas, an overview to appropriate regulations on EU and on national level for the partner countries was established. Policies and regulations related to the production, cleaning and upgrading of biogas were mapped and evaluated. Furthermore, national incentives in biogas production were analysed. The social acceptance and socio-economic impacts of biogas production and biogas upgrading technologies, as well as the whole value chain, were investigated. Explorations on previous and ongoing projects as well as on available literature have been carried out. In order to assess the social acceptance and to identify possible measures to increase it, a survey was provided to key actors in the partner countries. Contacts for the survey were discovered through existing networks as well as by reaching out to networks to share the survey or name organizations that might be interested in responding to the survey. Some biogas related associations also posted the survey on their social media, website or newsletter. In addition, a strategy of direct contacts was applied in the data collection. The partners contacted possible participants directly and actively searched for respondents. This was done primarily through telephone contacting. This also gave a good opportunity to tell the potential respondent more about the project itself and present some of the results so far, as well as to introduce the survey in a meaningful manner. If the respondent was interested in the survey a description of the project and the survey as well as the survey link was sent to him/her. In total, 33 stakeholders from Austria, Finland and Sweden participated in the survey.

3 Results and Conclusions

3.1 Investigation of terpene formation

3.1.1 Developed method for terpene detection in biogas

The ITEX sampling procedure comprises 4 steps i.e. sample conditioning, adsorption, desorption and trap cleaning. For each step, specific parameters need to be optimised during method development. Method parameters established for terpene analysis are given in Table 1:

Table 1 ITEX parameters

Incubation temperature	80°C
Shaking speed	500 rpm
Incubation time	5 min
Extraction volume	26,000 µL
Extraction speed	100 µL/s
Desorption temperature	200°C
Desorption speed	50 µL/sec
Clean temperature	280°C
Flush time	420 s

The GC system was equipped with a DB-WAXetr column (30mx0,25mmx0,25µm, Agilent Technologies, US). GC and MSD parameters for the separation and determination of limonene and cymene are listed in Table 2:

Table 2 Parameters of the GC-MS system

Front inlet	230°C
Oven program	40°C, hold 1,5min, 10°C/min up to90°C, 35°C/min up to 150°C
Constant flow	1.1 mL/min
MS Transfer line temperature	300°C
MS source temperature	230°C
MS quadrupole temperature	190°C

Standards were prepared in methanol (LC Grade) with concentrations ranging from 1 ng/µL up to 100 ng/µL. Standard solution (1µL) was pipetted with a Hamilton syringe into a 20 mL head space vial. The vials were instantly closed and transferred into the autosampler.
Calibrations were accomplished in selected ion mode of the MS detector. Fragments with an m/z of 69 and 93, and 119 and 134 were selected for the determination of limonene and cymene, respectively. Linear calibration curves were established in the chosen working range (see Figure 6).

a) b)

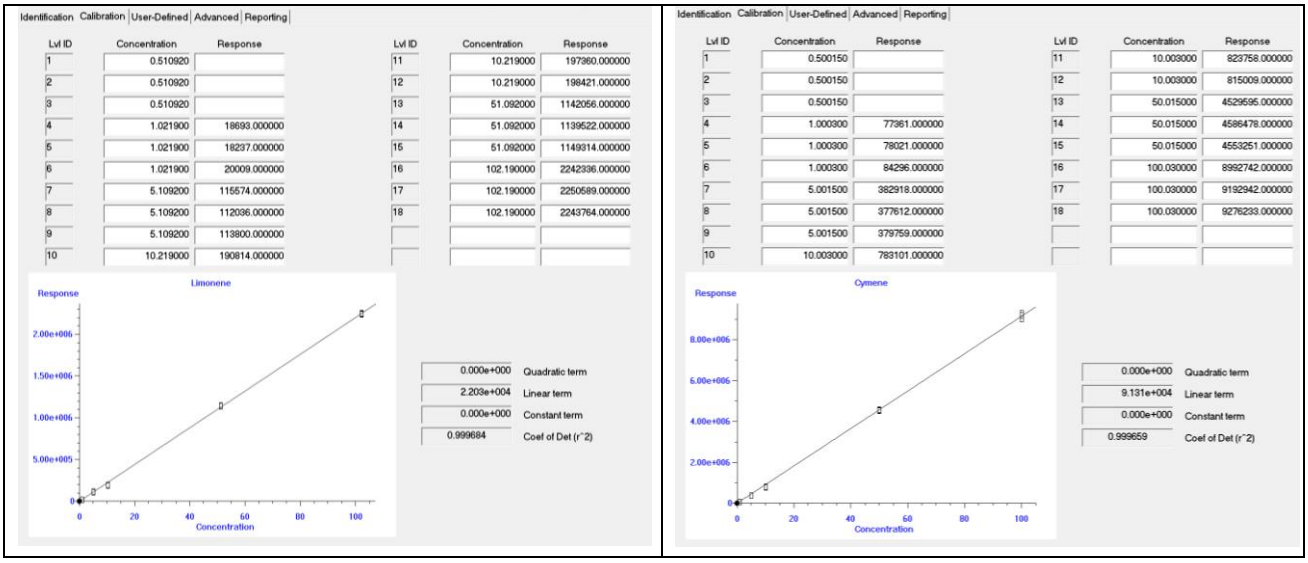


Figure 6 Calibration curve of a) limonene and b) cymene

Based on the gas volume inside the vials, determination limits amounted to 0.016 µg/L gas for limonene and 0.07 µg/L gas for cymene, which were sufficiently low for analysing samples from accomplished experiments.

To prevent high water contents in samples, 2 g of dried sodium sulphate were filled into all vials prior to gas sampling. In order to evaluate the influence of sodium sulphate on the measurement, standards were prepared with and without sodium sulphate.

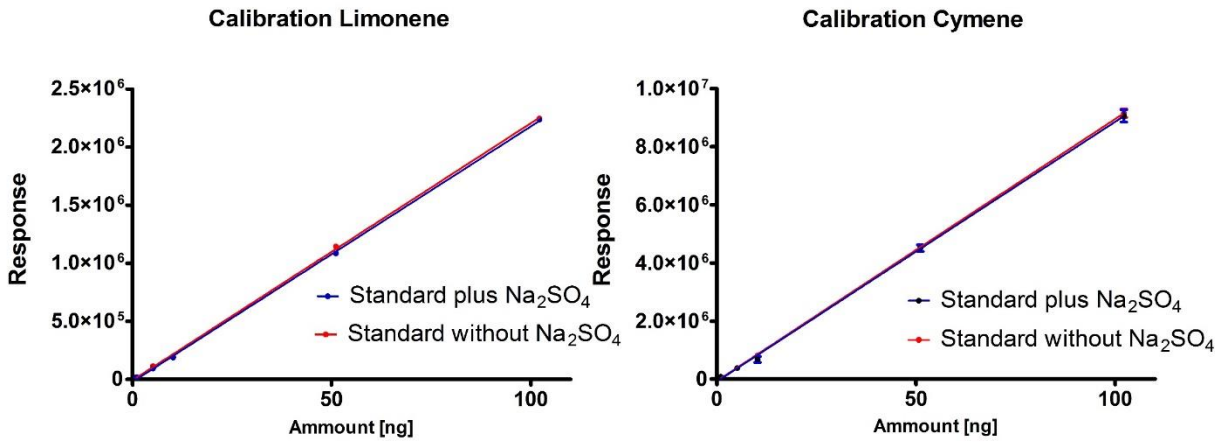


Figure 7 Calibration curve of limonene and cymene with and without Na_2SO_4 as drying agent

Calibration curves showed no relevant differences for both standard preparations (see Figure 7). Limonene gave an r^2 of 0.9997 for both calibration curves whereas r^2 values for cymene were nearly identical (0.9997 and 0.999).

To determine whether this method is suitable to analyse sludge samples, standards were also prepared in a biogas sludge matrix.

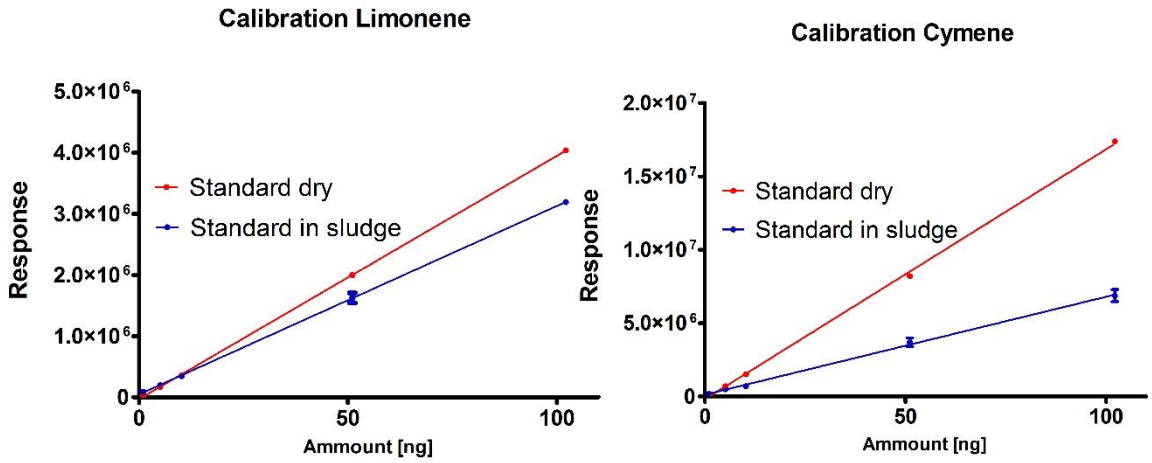


Figure 8 Calibration curve of limonene and cymene for sludge samples

For both terpenes the influence of the matrix is obvious (see Figure 8). Terpenes in sludge yielded a lower abundance than measured without matrix. Yet, linearity was still given, but the slope decreased for limonene from 39790 to 30840 (f=1.29) and for cymene from 170300 to 66730 (f=2.6). Consequently, when analysing sludge samples, calibration has to consider matrix effects.

3.1.2 Biogas batch degradation tests

The tested limonene concentrations of the first experiments were 0, 200, 500 mg/kg. The cumulative biogas production curves, after subtraction the biogas production of the inoculum, are shown in Figure 9.

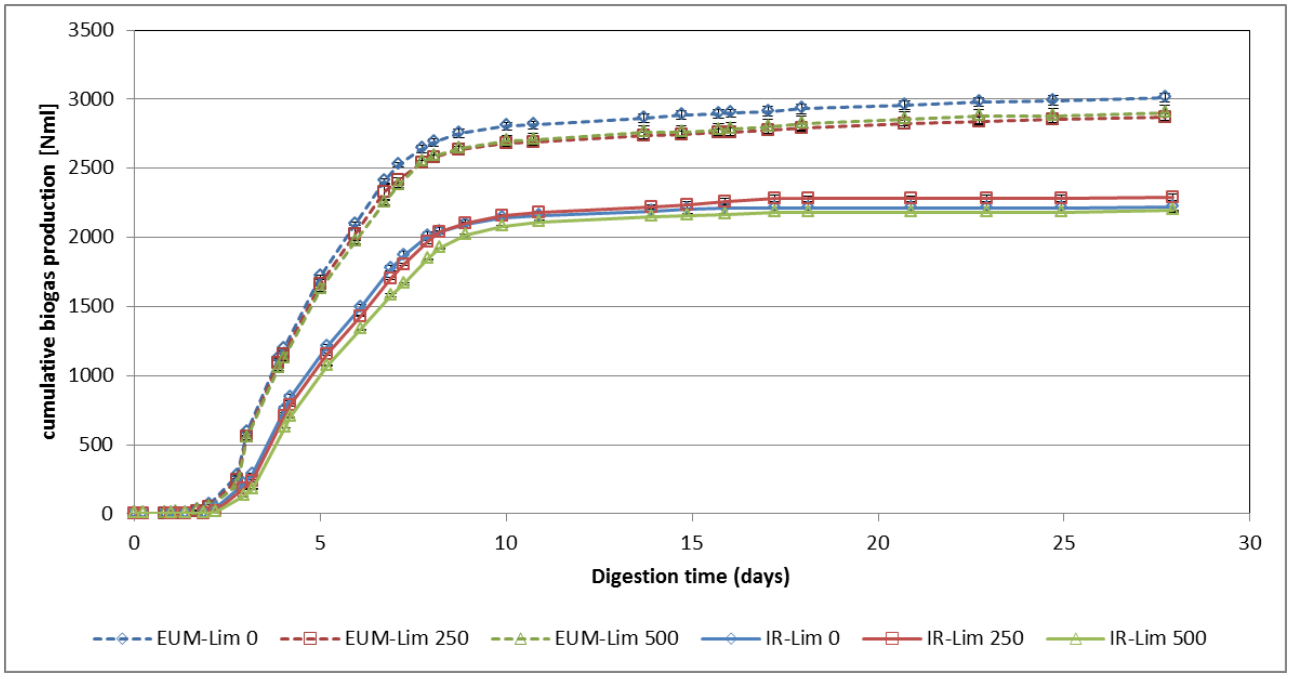


Figure 9 Comparison of eudiometer (EUM) and incubation room (IR) batch tests with different limonene (Lim) concentrations (0, 250, 500 mg/kg).

After a three-day lag phase, the accumulated biogas production increases linearly. From day 10, the stationary phase is reached. There are no significant differences between the various limonene concentrations (0, 250 and 500 mg/kg) neither in the experiments in the eudiometer nor in the incubation room. However, the biogas production in the incubation room is 23,6 % lower than in the eudiometer.

In order to find out which limonene concentrations cause an inhibition effect to the biogas production, experiments with higher limonene concentrations were carried out. To be able to compare them, the experiments took place in both systems again. This time, the barrier liquid was acidified in the incubation room and thus adjusted to the same pH value as in the eudiometer. In each case, triplicates were performed. Figure 10 shows the cumulative biogas production at different limonene concentrations (0, 1000, 2000 mg/kg).

As can clearly be seen in Figure 10, the biogas production decreases with increasing limonene concentration. Also the lag phase increases with increasing limonene concentration. The test series with 1000 mg/kg limonene in the end approaches the blank. However, the stationary phase starts much later and consequently the degradation rate is significantly lower. The strongest inhibition can be seen with 2000 mg/kg limonene. The cumulative biogas production is here roughly 45% of the blank. The deviations between the eudiometer and the incubation room could be minimized by the acidification of the barrier liquid.

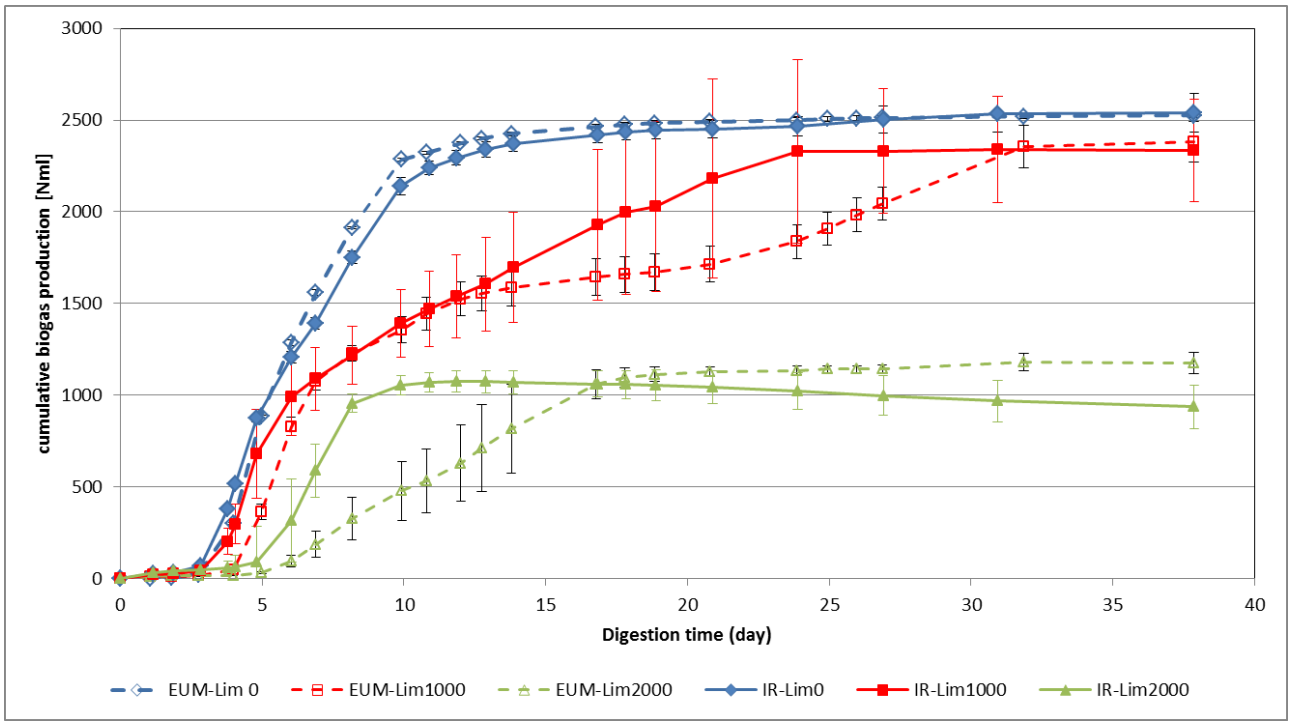


Figure 10 Cumulative biogas production depending on various limonene concentration (0, 1000, 2000 mg/kg). EUM = eudiometer, IR = incubation room.

In the previous experiments, cellulose was used as carbon source and the batches were spiked with pure limonene. To see how a natural substrate which contains limonene behaves, experiments with orange peels were carried out. A methanol extraction was used to determine the limonene concentration in the orange peels. With the GC-MS analysis developed a limonene concentration of 0.062 mg/g orange peel was determined. Per batch, 25 g orange peels were added which in sum corresponds to a concentration of 1.55 mg limonene. In comparison, in the trials with 1000 and 2000 mg/kg limonene, 400 or 800 mg pure limonene were added.
Figure 11 shows the cumulative biogas production for the experiments with orange peels (OP) and orange peels spiked with 2000 mg/kg limonene as substrate in both, eudiometer and incubation room.

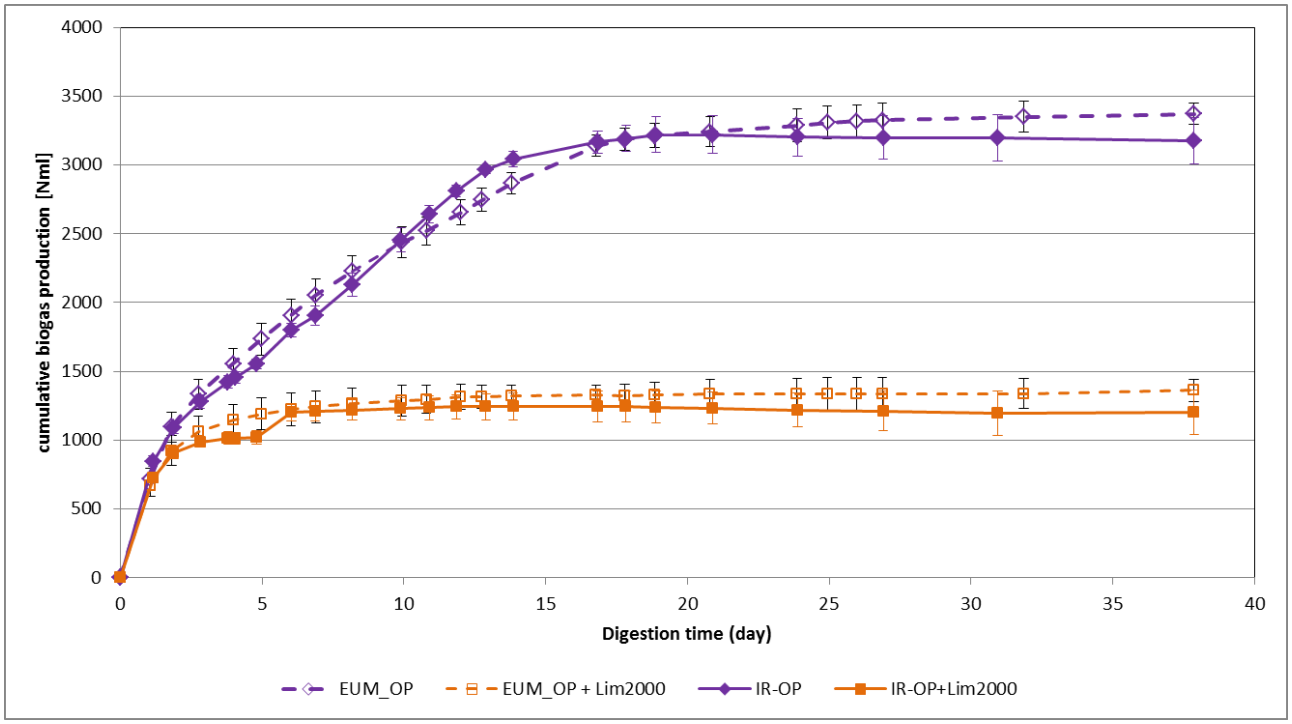


Figure 11 Cumulative biogas production from orange peels (OP) spiked with limonene. EUM = eudiometer, IR = incubation room.

To enable the comparison of the experiments with cellulose and orange peels, the biogas production is related to the added organic dry matter (VS/oTS) (Figure 12).

It can be clearly seen that the experiments with orange peel as a carbon source in comparison to those with cellulose differ significantly in their behaviour. The lag phase in the experiments with orange peels is significantly shorter or even absent. This suggests that the orange peels (OP) are very readily available. If one takes a look at the maximum biogas production, it can be seen that both the EUM-OP and EUM-OP + Lim2000 series are below the comparison series (EUM-Lim 0 and EUM-Lim2000) to the same extent. That meets the expectations, since the orange peels itself have a limonene content.

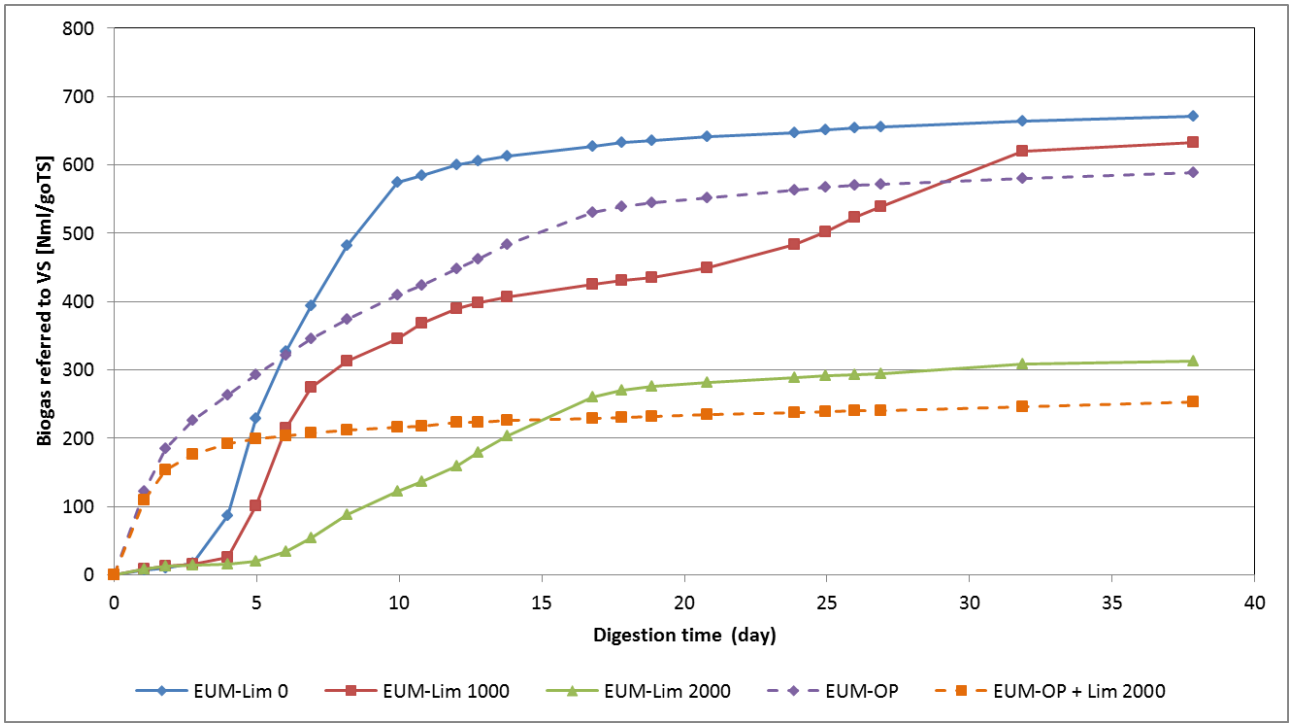


Figure 12 Biogas production referred to VS

In addition to the daily produced amount of biogas, the biogas composition was analysed by GC (see Figure 13). The biogas was analysed for the content of methane, carbon dioxide, nitrogen, oxygen and hydrogen. All readings were normalized to 100%. The analysis was carried out using the gasbag method. Since a minimum amount of gas is necessary for this method, the experiments with orange peel spiked with 2000 mg/kg limonene could not be analysed every day (see Figure 13 b).

a) b)

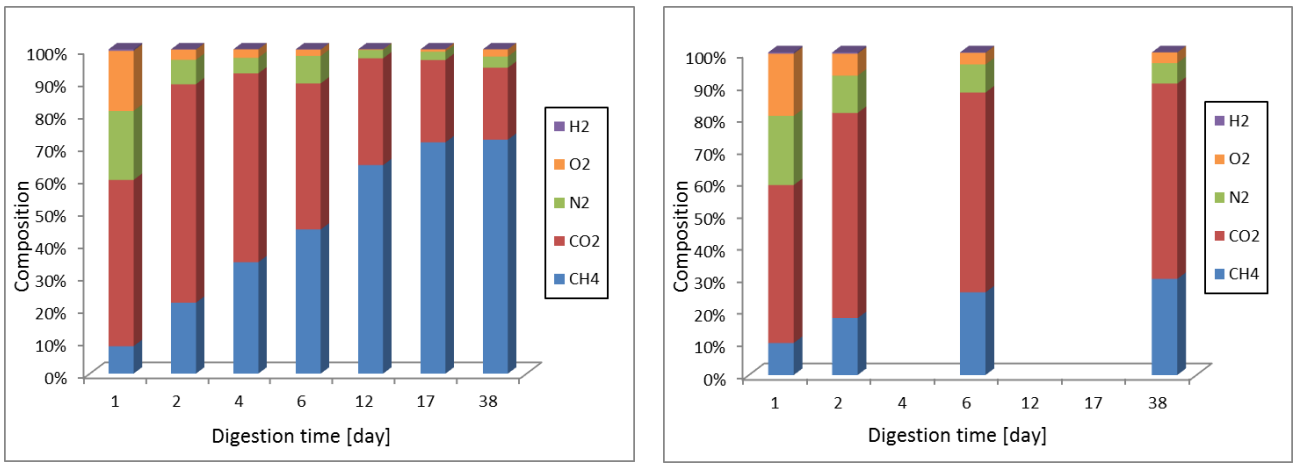


Figure 13 Biogas composition from the batches a) with orange peels; b) with orange peels spiked with 2000 mg/kg limonene in the eudiometer.

The relatively high oxygen and nitrogen concentration (40% in total) on the first day of measurement are due to inoculation. The methane concentration in the biogas is still very low at 10%. In the course of the next days it increases steadily until it approaches a CH_4/CO_2 ratio of 70/20.
A comparison of Figure 13 a and b shows that the methanogenic microorganisms are already clearly inhibited after the second day and hardly produce any more methane. In addition to the significantly lower biogas production (see Figure 11), the methane concentration is also significantly lower with a CH_4/CO_2 ratio of 30/60.

Further batch tests were carried out to find out if the microorganisms get accustomed to the terpene concentration. The batches were fed a second time with the same limonene concentration. Since up to this time the limonene was not detectable in the biogas or only in very small amounts near the limit of determination, it should additionally be examined if doubling the terpene concentration in the substrate cause the concentration in the gas to change similarly.

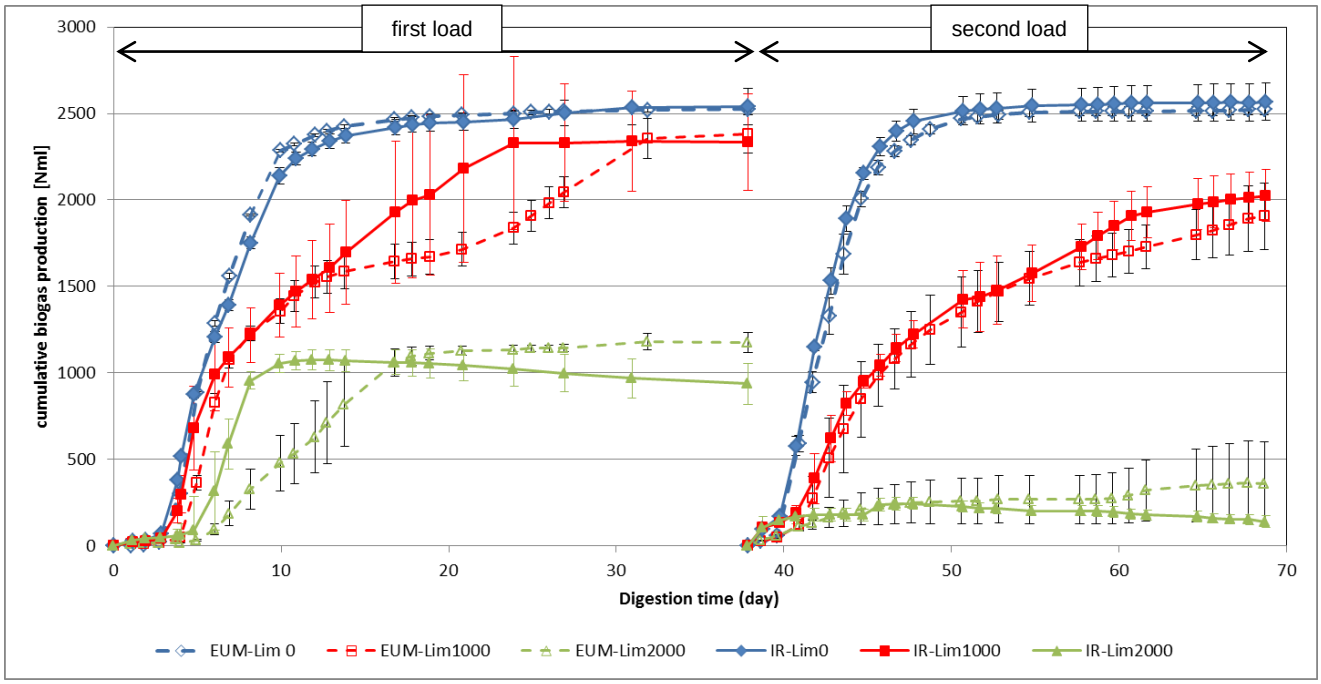


Figure 14 Cumulative biogas production depending on various limonene concentration for the first and second load. EUM = eudiometer, IR = incubation room.

By adapting the microbes to the test conditions, it was possible to shorten the lag phase by one day in all test series. As expected, the gas production in the experiments without limonene reaches the same total quantity as in the first loading. However, the gradient in the exponential phase is somewhat steeper at the second loading, which also suggests that the microbes got used to the conditions. In the test series with 1000 mg/kg limonene, the renewed loading results in a slight reduction of the total amount of biogas. In the test series with 2000 mg/kg limonene, the limonene concentration in the second feed is so high that practically the entire biogas production is inhibited. The biogas production is only 10% of the reference level without limonene.

Table 3 shows the limonene concentrations in the biogas on different days. The detection limit of the used method is 0.016 µg/L. Most of the values are in this range. It can be clearly seen that there is no significant difference between the tests with 1000 and 2000 mg/kg limonene neither in the eudiometers nor in the incubation room.

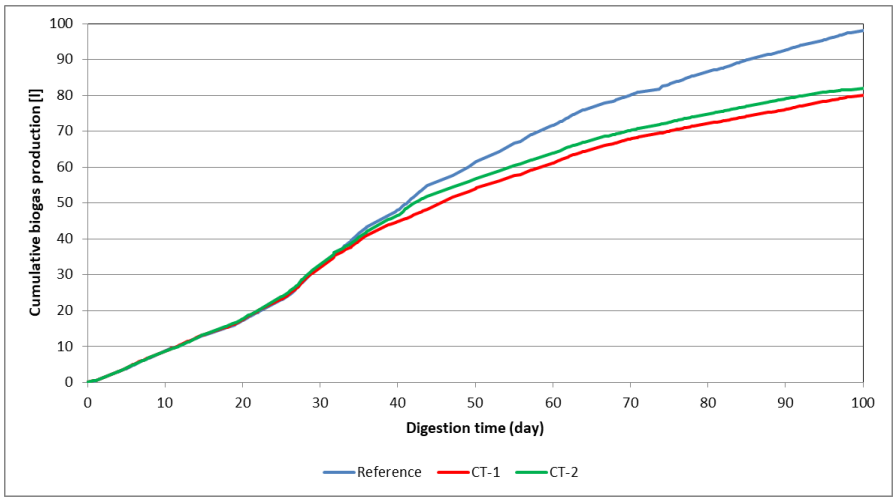
Table 3 Limonene concentration in biogas from the first and second load of the batch tests measured with the ITEX.

	EUM		IR		
day	LIM 1000	LIM 2000	LIM 1000	LIM 2000	unit
12	0.01	0.02	0.02	0.03	[µg/L]
17	-	0.02	-	0.02	[µg/L]
43	0.12	0.10	-	-	[µg/L]
46	0.01	0.01	0.02	0.01	[µg/L]

3.1.3 Biogas continuous degradation tests

Figure 15 shows the cumulative biogas production, the OLR and the total VFA formation in the continuous biogas degradation tests.
The biogas production of the three reactors is congruent until day 30. It can be seen that, with increasing OLR, the biogas production increases. From day 30 onwards, the biogas production of the reactors fed with orange peel decreases compared to the reference. This is even clearer when looking at the VFA production. The VFA formation in the CT-1 and CT-2 reactors increases significantly from day 30 whereas the VFA production of the reference decreases steadily. In order to counteract the increasing acidification, the feeding of orange peel was reduced and proportionally replaced by maize silage from day 34 onwards.

a)



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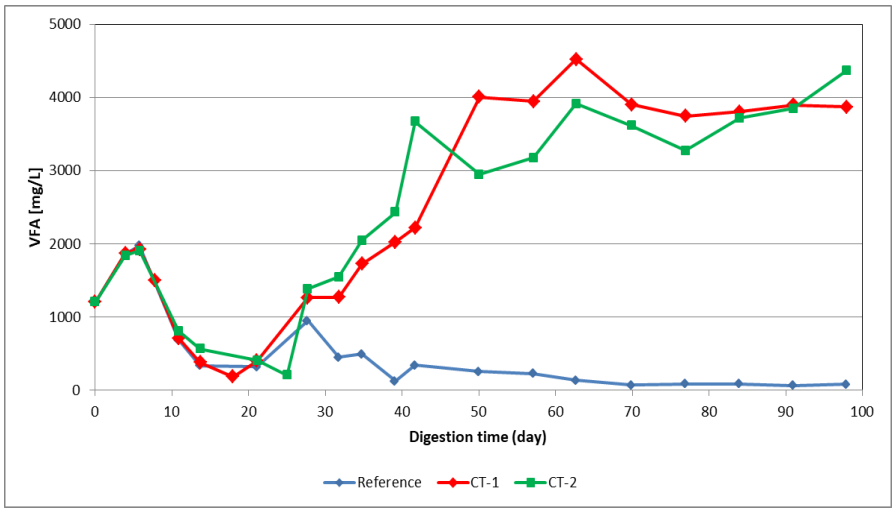

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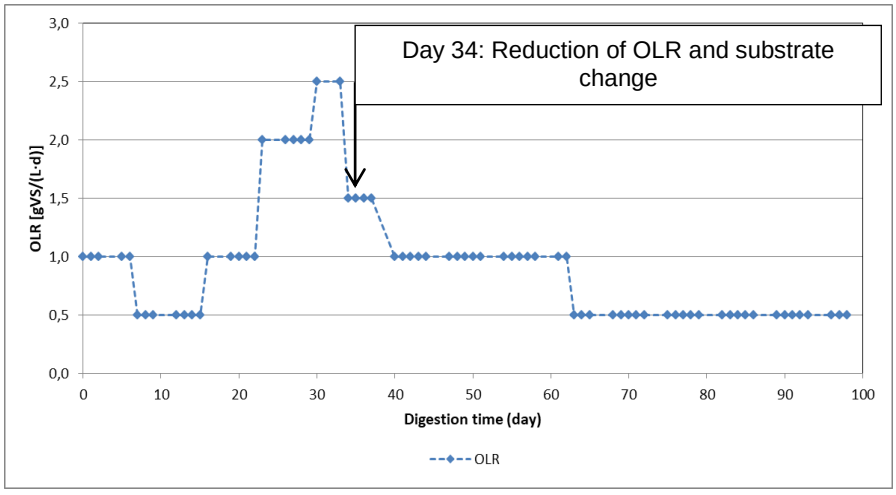
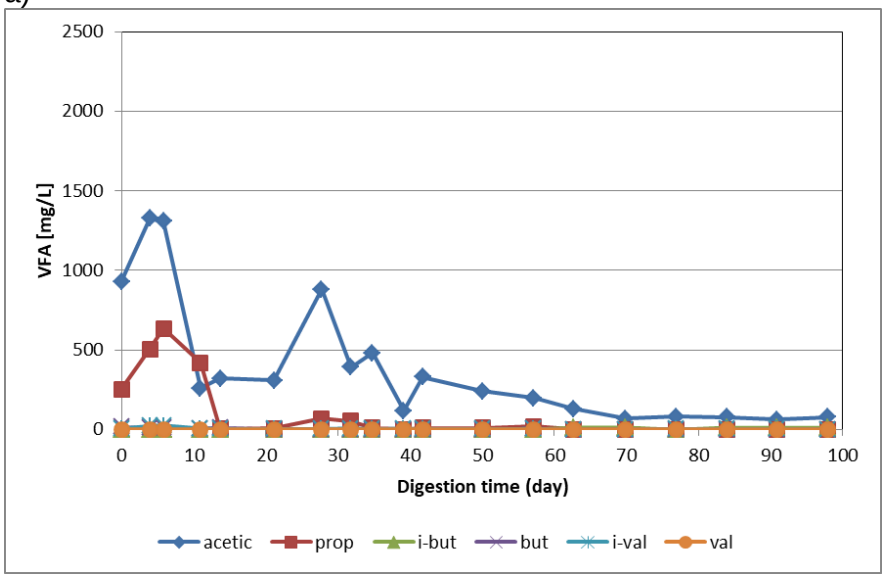


Figure 15 Demonstration of the continuous tests over the entire test period a) cumulative biogas production in [L], b) total fatty acid formation in [mg/L], c) organic loading rate in [gVS/(L*d)]

a)



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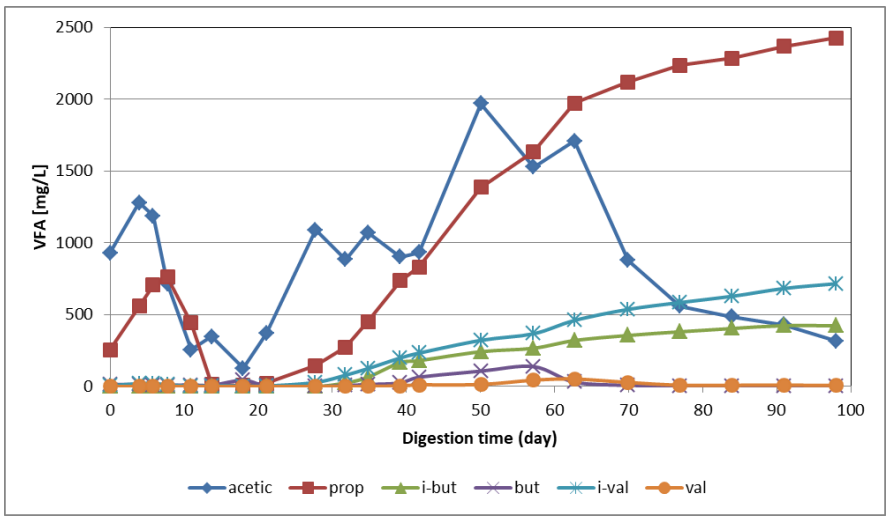

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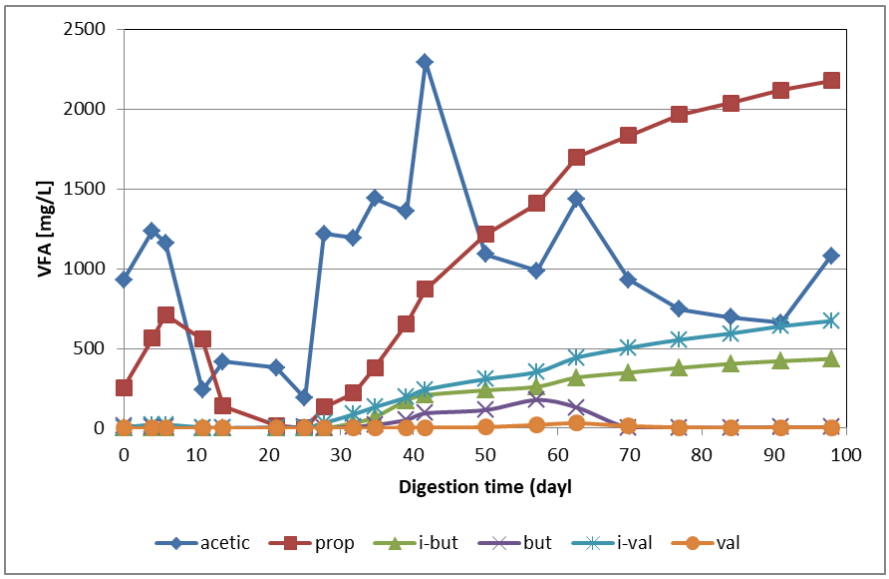


Figure 16 Volatile fatty acid concentration in mg/L of the three test series a) reference, b) CT-1, c) CT-2

Figure 16 shows the following fatty acid concentrations over the entire test period of 100 days: acetic acid, propionic acid, iso-butyric acid, butyric acid, iso-valeric acid and valeric acid. Figure 16a shows the reference. It can be seen that the fatty acid concentration of acetic acid and propionic acid decreases after the adaptation phase. Otherwise, no other fatty acids were detected during the entire test period. Figure 16 b and c (CT-1 and CT-2) show a similar course. The first 10 days coincide with the reference. Subsequently, the acetic acid concentration and the propionic acid concentration increased significantly. Apart from this also the iso-butyric acid and the iso-valeric acid concentration increased. The strong increase of VFAs shows that a pure orange peel feed proved to be problematic by causing instabilities in the anaerobic digestion process.

The following Figure 17 shows the limonene concentration in the biogas in µg/L measured with the GC-MS method developed by BOKU. With the increase of the OLR the limonene concentration in the produced gas rose from 1,88 µg/L to 12,30 µg/L. From day 34 onwards, the OLR was reduced and at the same time the loading of orange peel was reduced. It can be clearly seen that this has also significantly reduced the limonene concentration in the gas. During the experiments, there was an outlier with a limonene concentration of more than 80µg/L at day 42. Due to the very high deviation to the other measured values, it was not included in the evaluation.

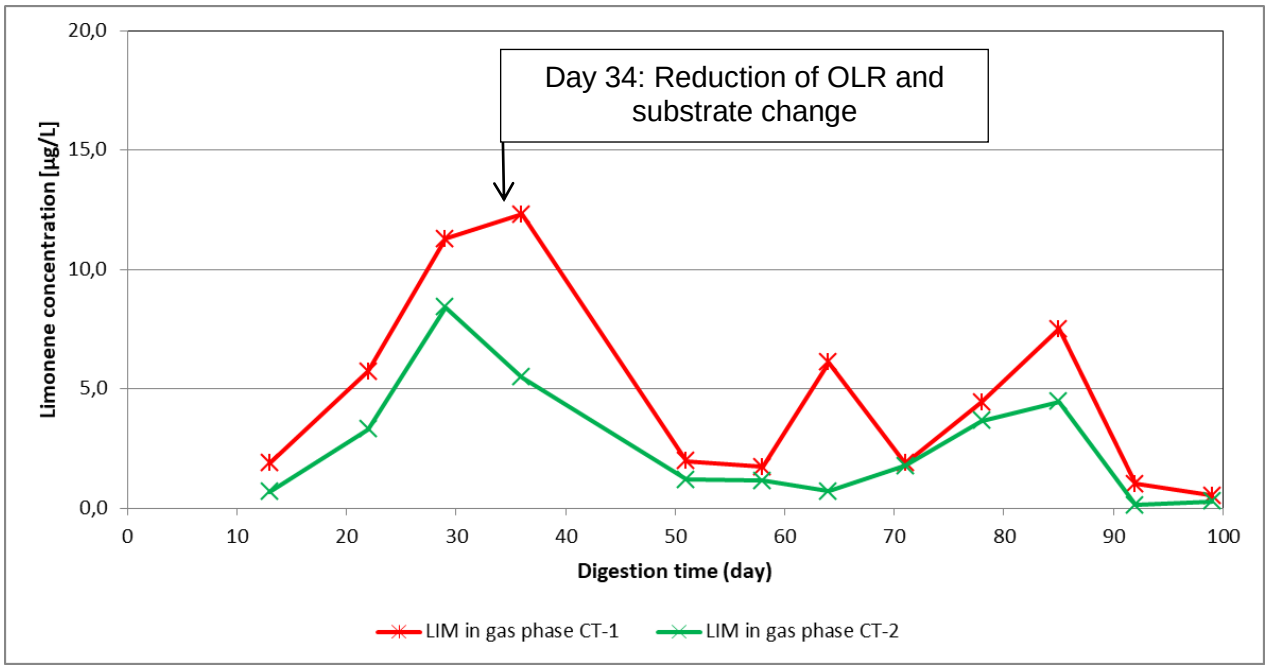


Figure 17 Limonene concentration in µg/L over the entire test period measured with the developed GC-MS method

3.1.3.1 Determination of terpenes in continuous biogas trials

Continuous experiments showed a direct correlation between feed concentration (orange peels) and limonene content in biogas samples (see Figure 18).

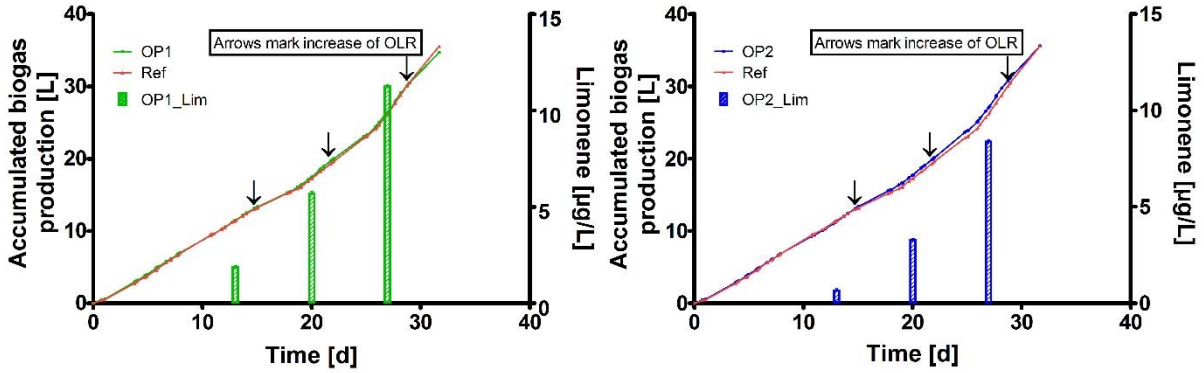


Figure 18 Correlation between OLR and limonene content in biogas samples of the continuous trials (left CT-1, right CT-2)

Limonene was dominant at the beginning of the experiment, which was paralleled by minor traces of cymene. This picture changed in the course of the experiment, when various peaks appeared in the chromatogram, which were eventually identified as terpenes (Figure 19 and Figure 20, Table 4). Subsequently, chemicals of identified terpenes were ordered to prepare standards. Identity of analytes was confirmed by matching retention time and mass spectrum.
For this lager range of terpenes, the method still needed improvement regarding SIM settings and chromatographic separation before calibration of analytes (see Figure 21).

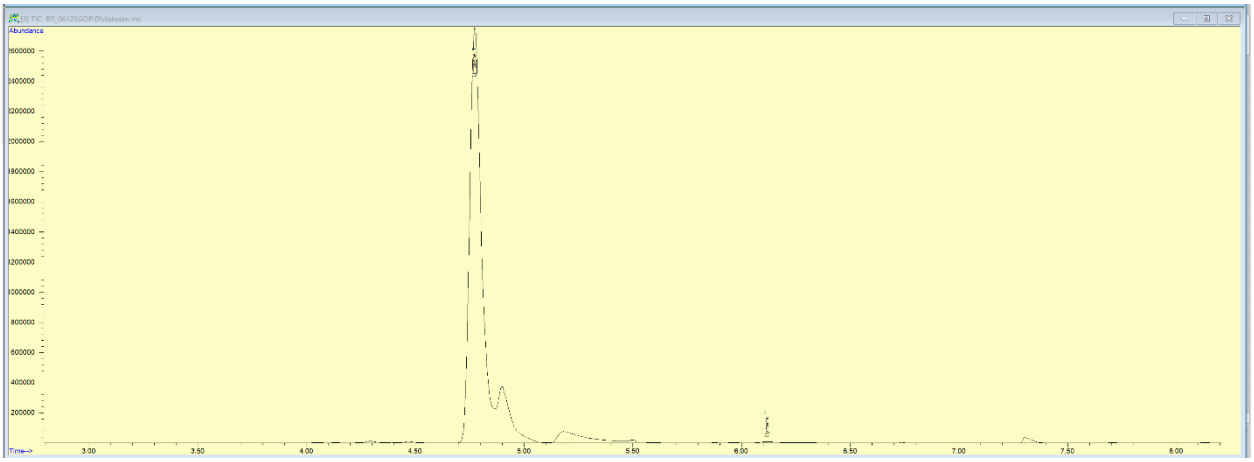


Figure 19 Chromatogram of the sample from the continuous experiment taken on day 28 (6.12.2018)

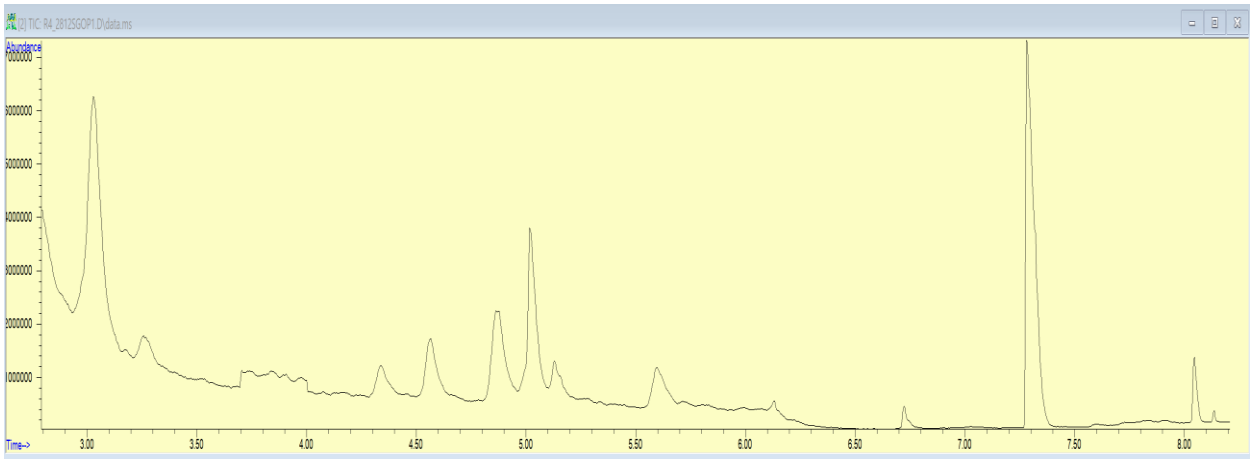
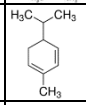
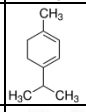
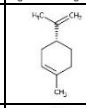
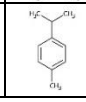


Figure 20 Chromatogram of the sample from the continuous experiment taken on day 50 (28.12.2018)

Table 4 Terpenes identified in biogas samples from continuous experiments.

		Molar weight	**Boiling point**	**Mass to charge ratio (m/z)**
		[g/mol]	[°C]	
Sabinene (Thujene)		136.23	163-165	**93**, 136
Phellandrene		136.24	171-172	**93**, 136
alpha-Terpinene		136.24	174	**121**, 93
Limonene		136.24	175	**68**, 93
gamma-Terpinene		136.24	174	**93**, 136
Cymene		134.21	177	**119**, 134

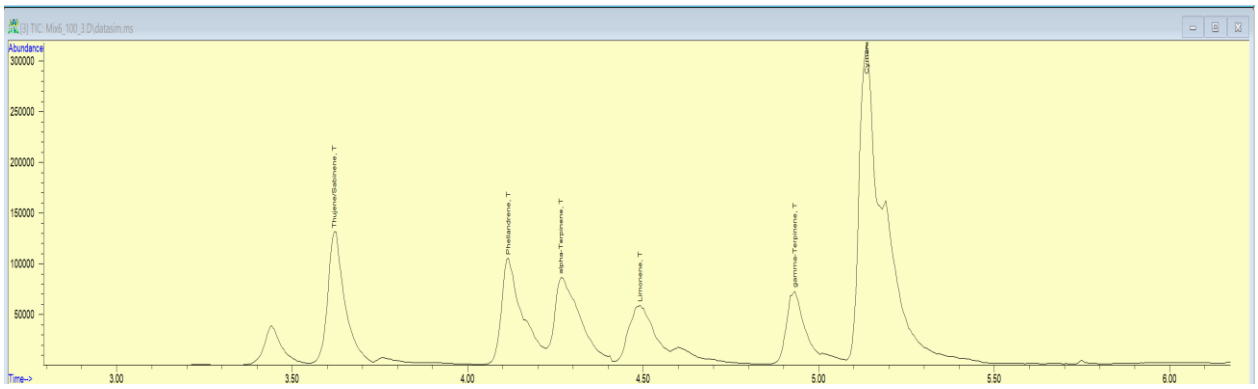


Figure 21 Chromatogram of standard mixture comprising 6 terpenes

3.2 Piloting siloxane removal by geopolymers in Austria

At the wastewater treatment plant three test series with different running times and column fillings were performed in the pilot plant.

Table 5 Set up of the experiments in the pilot plant at the wastewater treatment plant in Tulln.

Test	Fillings	Running time
A	90 kg Geopolymer	160 h
B	60 kg Geopolymer	260 h
C	50 kg Geopolymer + 25 kg activated carbon	400 h

Experiment A:

Figure 22 shows the limonene concentration and siloxane concentration over the test period. The solid line shows the raw gas, the dashed line the purified gas. In the first 48 hours the siloxane and limonene removal was about 60%. For safety reasons, the plant was not operated over the weekend. It is clearly visible that, after restarting the plant, the measured values fluctuate strongly. As a result, it was decided that no interruption of operation would be made in the following test series.

Figure 23 shows the hydrogen sulphide and methane concentration over time. It can be seen that the methane content is not affected by the geopolymers. Over the whole test period the range of variation is between 61% and 64%. The H_2S purification is about 40% after the first 24 hours and decreases to almost 20% after 48 hours.

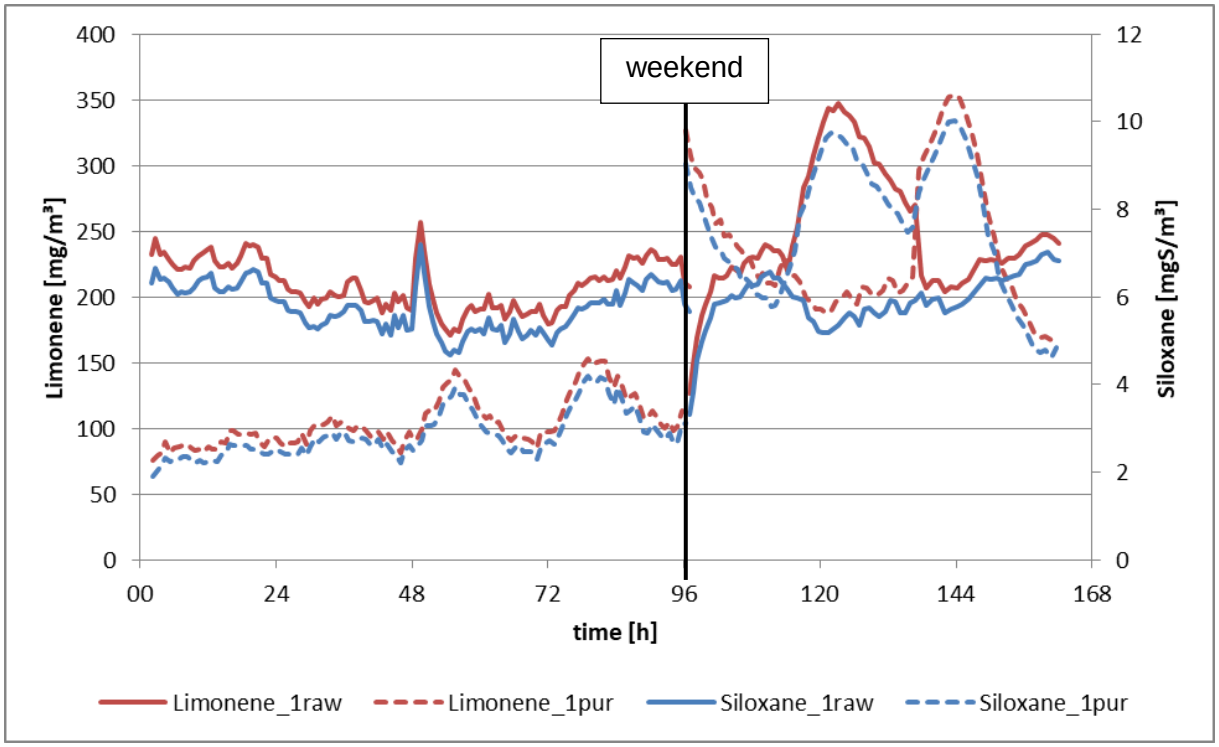


Figure 22 Limonene and siloxane concentration over time at test series A

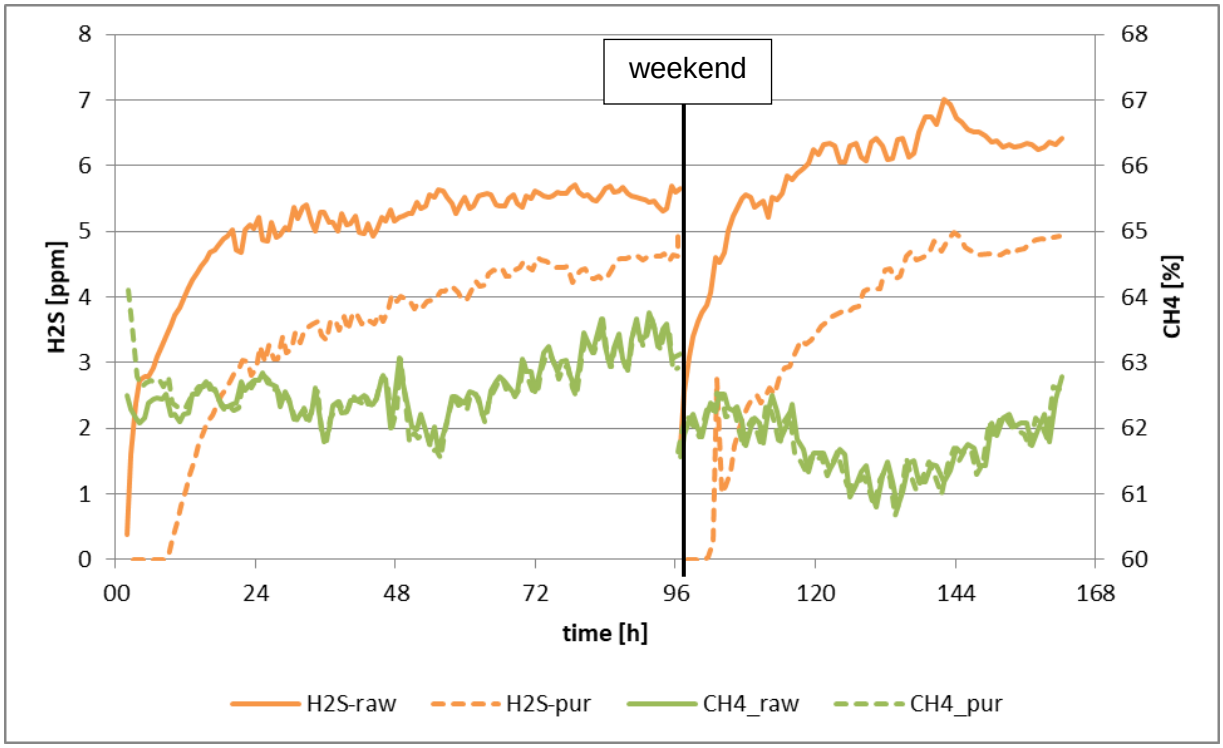
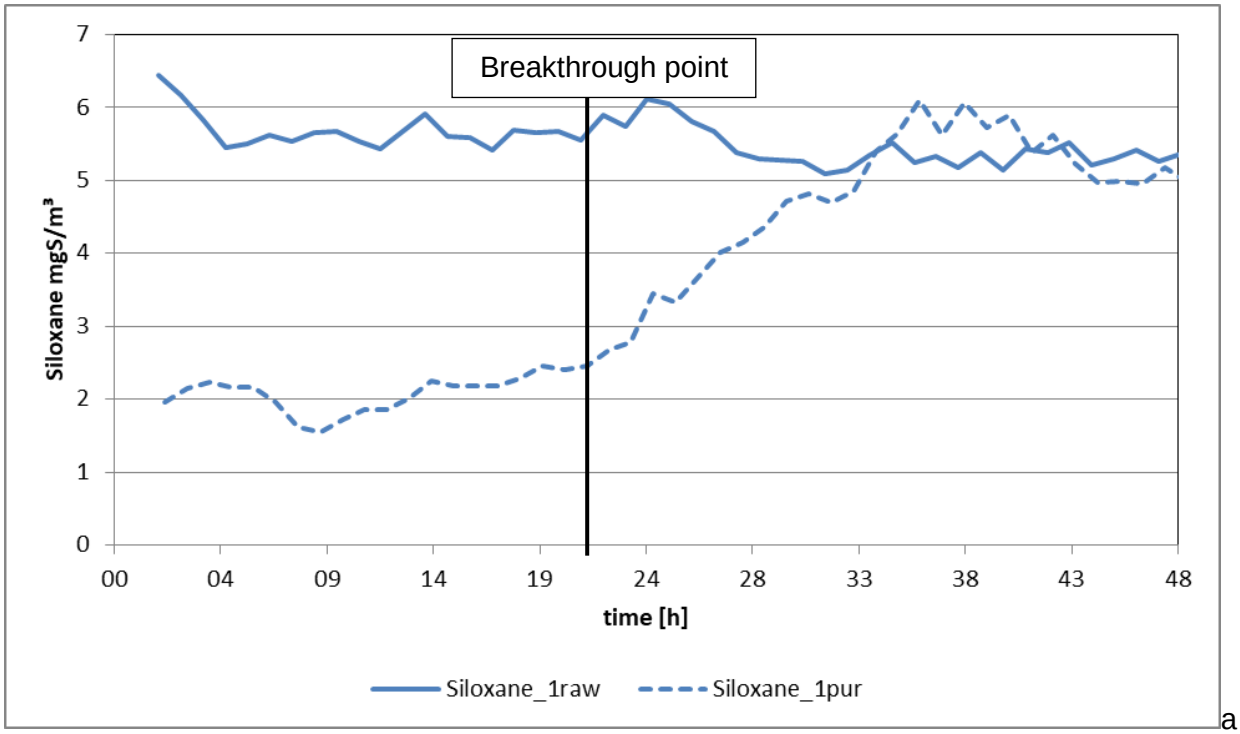


Figure 23 Hydrogen sulphide and methane concentration over time at test series A

Experiment B:

Test series B ran for 11 days without interruption. A purification of the biogas was only carried out in the first 30h. The breakthrough point was after 21h (see Figure 24) when the removal for both siloxanes and limonene was about 60%. In total 50 m³ of gas were purified.



a

Figure 24 Siloxane concentration during the first 48h at test series B

From day 2 to day 4 the concentration of limonene and siloxane in purified gas and raw gas was identical. From day 4 on there were significant fluctuations in the measured values of the purified biogas. It could not be completely clarified until now where these deviations come from.

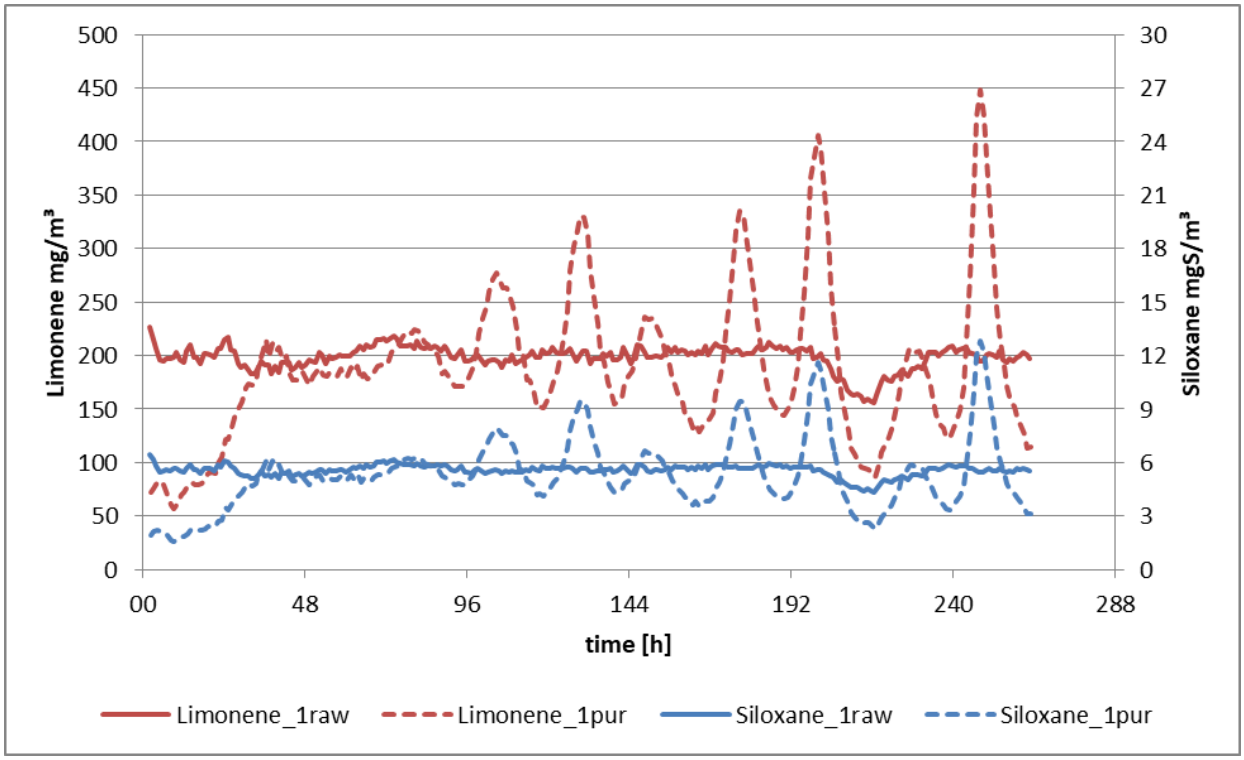


Figure 25 Limonene and siloxane concentration over time at test series B

Figure 26 shows the hydrogen sulphide and methane concentration. The methane content was between 60 and 64% over the entire test period. The hydrogen sulphide removal was about 20% over the whole test period.

Figure 26 Hydrogen sulphide and methane concentration over the time at test series B

Experiment C:

The third test series ran the longest with 17 days. The siloxane removal was almost 100% over the entire test period. Due to the high adsorption capacity of the activated carbon no breakthrough point was reached. A total of 1000 m³ biogas was purified. The following Figure 27 shows the limonene concentration in mg/m³ and the siloxane concentration mgS/m³ over the test period.

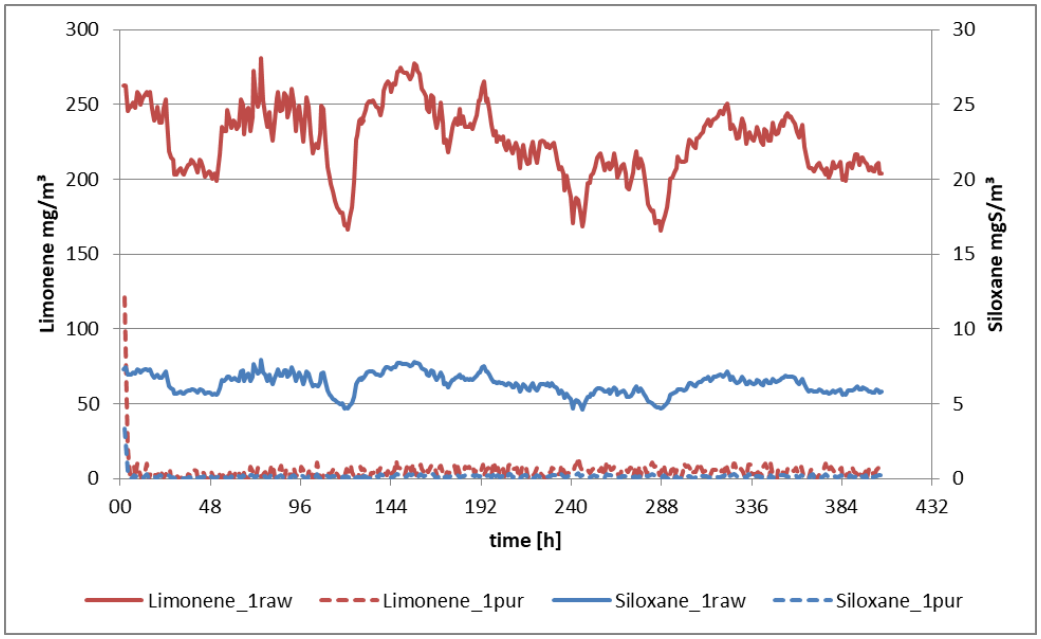


Figure 27 limonene and siloxane concentration mg/m³ over the test period

Figure 28 shows the hydrogen sulphide concentration in ppm and the methane concentration in %. In contrast to the limonene and siloxane removal, the removal of hydrogen sulphide was a bit less with 70 to 80%. The methane content was again in the range between 60 and 64%.

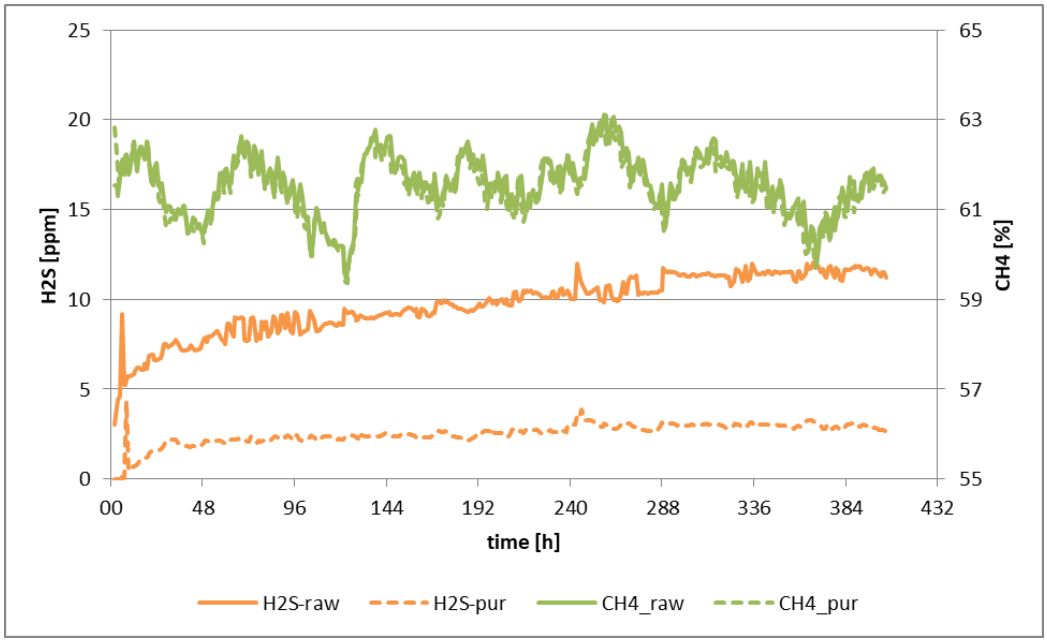


Figure 28 Hydrogen sulphide and methane concentration over the time at test series C

3.3 Regulation and policy assessment, socio-economic assessment and environmental sustainability analysis

By evaluating socio-economic issues, regulations, incentives and standardization the work contributed to the goal to integrate the developed solutions into existing systems in the market. For a successful market integration, it is important to identify and evaluate policies and regulations related to the production, cleaning and upgrading of biogas. In general, the Renewable Energy Directive (RED), published in 2009 and its successor RED II, published in 2018, are the most important EU regulations driving bioenergy and thereby the biogas deployment. RED II is certainly a positive step towards the large-scale take up of renewable gas in the next decade. EU policy measures have to be accompanied by a series of national regulations. All three partner countries (Austria, Finland, Sweden) have national policies that favour climate protection and have implications on the biogas sector. The specific regulations on the production, cleaning and upgrading of biogas vary between the countries. Also, the regulations on subsidies and feed-in tariffs differ. In Austria, the sector would profit, e.g., from an alignment in the rules for methane content in biogas if it is fed into the gas grid. In Austria it must reach 98% whereby in Sweden the average methane content is 90 %.
Furthermore, it is crucial to identify social implications of deploying technologies, at various levels. By enhancing social acceptance, better conditions for increasing the market share of bioenergy production systems can be achieved. Hence, it was focused on the social acceptance including socio-economic and environmental aspects of biogas and biogas upgrading. Apart from the legal framework, market constraints and the economics, social acceptance is essential for enlarging user groups and utilization. Based on the results of the conducted survey, the overall social acceptance of bioenergy/biogas is quite high. However, particularly in Austria, some problems concerning the social acceptance of bioenergy and in particular biogas could be identified:

- Competition with other uses - the food vs. fuel debate has caused some biogas feedstocks to lose acceptance
- Lack of knowledge about technologies & the ecological benefits
- Policy use is incorrectly communicated
- Lack of support from politicians
- Policy regulations: in part heavily regulated and not sufficiently harmonized throughout Europe
- High prices (compared to fossil fuels)
- Environmental impact of the digestate
- Under-developed distribution infrastructure

Results of the socio-economic and environmental evaluation show that biomethane supports the development of circular economy models and favours the decarbonisation of energy systems. However, since economic feasibility can only be demonstrated in some scenarios, support measures such as subsidies are still crucial. Therefore, the implementation of adequate support measures is essential for the further development of biomethane.

Results of the survey show that in Finland and Sweden, stakeholders are quite optimistic that the social acceptance of biogas can be increased by improving technical systems such as biogas upgrading

methods and by intensifying communication and dissemination activities. Furthermore, biogas/biomethane demand could be encouraged if the distribution network is improved.
The Austrian stakeholders also identified barriers for the increase of social acceptance of biogas:

- Austrian policy stakeholders focus on hydrogen, but not on already existing biogas/biomethane
- Lack of communication through policy stakeholders and biogas associations
- Too high production costs
- Biogas sometimes has a bad reputation among the population (odour emissions & food vs. fuel)
- Currently, biogas production is not being promoted, and thus is not in the minds of the population. Due to the funding landscape it is also difficult to operate economically

4 Contact information

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