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Optimering av biogasproduktion från gödsel

Optimization of Biogas Production from Manure

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Summary Global Warming today is one of the main environmental problems caused by the release of greenhouse gases. In many countries, reduction of pollution and greenhouse gas emission are major political priorities to avoid global climate changes.

Biogas production is the result of anaerobic digestion of manure and slurries which include a wide range of organic contents. These substrates are converted into renewable energy and fertilizer for the agricultural area. Anaerobic digestion is a biological process which is accomplishable the decomposition of an organic substance in the absence of oxygen by fermentative bacteria. Produced gas consists of substantially methane, carbon dioxide and less amounts of other gases. Biogas, is combustible, and is commonly produced in airproof reactors called digesters.

In this study, two different parameters were studied using twelve batch reactors. All reactors containing cattle manure were placed in a water bath at 35 ^{0}C and left for 60 days. Reactors R1-R6 were used to study the shaking effect, where as, reactors R7-R12 were left for 63 days with silage as a codigestor. The effects of the first six reactors (R1-R6) were studied and the results showed that during the adaptation period of the microorganisms that shaken once and 5 times a week behaved similar. Between the second and forth week there was a small difference. Shaking five times a week gave a somewhat higher biogas production rate than shaking once a week during this period.

The other parameter was silage, mixed with the manure in two different proportions 1% and 3%. Addition of the plant waste it was affected the system positively in the total amount gas produced. Our first hypothesis was that, more silage would increase the yield of the process but after a while the 3% silage inhibited the system partially. This inhibition was caused by the degradability of the silage. So, more fatty acid might have been released into the system. The 3% co-digestion need a longer time to stabilize than the 1%.

Abstract (in English) In this study, the bioconversion of cattle manure and silage to biogas by an anaerobic digestion process in batch reactors was studied. Biogas is a valuable alternative energy source, mainly in rural areas. The main aim for the environment is to use biogas as a fuel instead of crude oil or natural gas. In this study, two different parameters were studied to observe the changes in methane productivity. The first three reactors were shaken once per week and the following three reactors were shaken 5 times per week. The results showed that mixing has no major effect on the methane production yield. In the second six reactors a mixture of 1% and 3% silage was added and the results were recorded. When the data from the reactors with just manure was compared to the reactors with 1% and 3% silage, it was seen that the silage increased the production rate and total gas produced. The process stabilization took a long time for digestion with the 3% silage possibly caused by release of too much fatty acids.

Key Words

Biogas, manure, silage, mixing

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1.0 INTRODUCTION

Biogas is the result of a natural bioconversion cycle and as such it is produced from organic material in an environment without oxygen. The product of anaerobic digestion is biogas, used as a brilliant fuel for heat, electricity, and transportation. Biogas is a renewable energy source that doesn't consume the earth's fossil fuel resources. The raw material in biogas production has usually been waste from municipal sewage treatment plants and the food industries. By creating stability in the supply of raw material, this makes way for a long lived energy source with high capacity. Moreover, the digestate might be an efficient fertilizer in the case that it does not contain toxic compounds and it might be replace chemical fertilizers. *(www.svenskbiogas.se)*

Anaerobic degradation is generated when microorganisms degrade organic material in an oxygen free environment. As a result of anaerobic degradation, methane is produced and from literature we can see that biogas contains other gases as well. *See Table1*.

Table 1. *Biogas composition, *: often 5 % of air is introduced for microbiological desulphurisation (Personal communication Ferhan Sami Atalay, Prof.Dr. Ege University Chemical Engineering Department İzmir-TURKEY)*

Matter	%
Methane, CH_4	50-75
Carbon dioxide, CO_2	25-50
Oxygen, O_2	0-2*
Nitrogen, N_2	5 -10*
Hydrogen, H_2	0-1
Hydrogen sulfide, H_2S	0-3

Manure is one of the substrates suitable for biogas production and its uncontrolled degradation is very undesirable because of its effect on global warming, which is caused by the released methane during storage. This is an important point that, methane is twenty times stronger than carbon dioxide as a greenhouse gas. However, by using controlled anaerobic digestion of animal manure, the methane emissions during storage can be decreased and the energy obtained from the manure can be used as a renewable fuel, therefore serving as a climate neutral energy source. This process is found in several anaerobic environments such as industrial and municipal wastewaters, agricultural industry wastes and plant residues. (Moller et al, 2003)

The anaerobic degradation process involves numerous steps and several groups of microorganisms are used for the process to convert organic substances into biogas. The digestion process can be explained in four steps (see *Figure1*);

Hydrolysis; The first step in the anaerobic degradation process is the enzymatic hydrolysis of particulate and soluble polymers into soluble products such as amino acids, carbohydrates, fatty acids***;*** (Seadi Teodorita Al et al, 2008)

Acidogenesis; Simple sugars, amino acids, and fatty acids are degraded into acetate, carbon dioxide, and hydrogen as well as into volatile fatty acids (VFA) and alcohols. "Seadi Teodorita Al et al, 2008"

Acetogenesis Products from acidogenesis are converted into methanogenic substrates during acetogenesis. Volatile fatty acids (VFA) and alcohols are oxidised into methanogenic substrates like acetate, hydrogen, and carbon dioxide. VFA, with carbon chains longer than two units and alcohols with carbon chains longer than one unit, are oxidized into acetate and hydrogen. The production of hydrogen increases the hydrogen partial pressure. During methanogenesis, hydrogen and carbondioxide is converted into methane. Acetogenesis and methanogenesis usually run parallel, as symbiosis of the two groups of organisms. "Seadi Teodorita Al et al, 2008"

Methanogenesis; The production of methane and carbon dioxide from intermediate products is carried out by methanogenic microorganisms. 70% of the formed methane originates from acetate, while the remaining 30% is produced from the conversion of hydrogen and carbon dioxide, according to the following equations:

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2H_2O$$
$$CH_3COOH \rightarrow CH_4 + CO_2$$

Methanogenesis is a critical step in the anaerobic digestion process, as it is the slowest biochemical reaction of the process. Methanogenesis is severely influenced by operating conditions. Composition of feedstock, temperature, pH, and feeding rate are examples of factors effecting the methanogenesis process. Digester overloading, temperature changes or a large influx of oxygen can result in termination of methane production. "Seadi Teodorita Al et al, 2008"

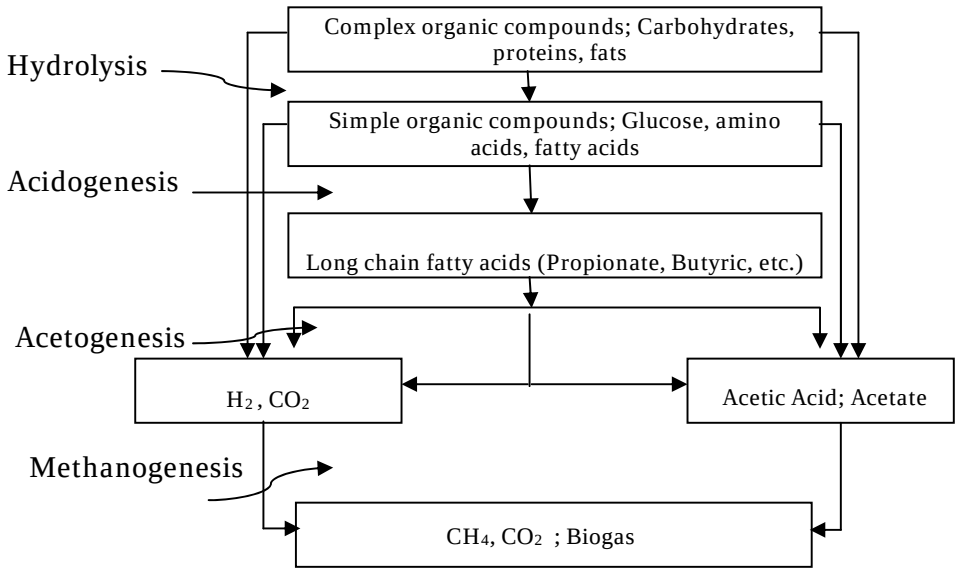

Figure 1. *Degradation of carbon in the anaerobic digestion process described by four steps; hydrolysis, acidogenesis, acetogenesis and methanogenesis.*
(http://www.schaumann-bioenergy.com/biogasproduktion/fermenterbio.php)
(http://pubs.ext.vt.edu/442/442-881/L_IMG_fig3.JPG)

There are some important parameters which directly affect the system such as; ***Humidity,*** bacteria can survive only in moist conditions. ***Temperature***, the optimum temperature for the psychrophilic, mesophilic, and thermophilic bacteria groups are in the range of 5-25^{o}C, 25-38^{o}C, and 50-60^{o}C, respectively (http://www.unienerji.com/?p=300). For some biogas plants the optimum temperature is 35^{o}C with working mesophilic bacteria. Some of these bacteria can be taken with manure from its natural environment. It is possible to work with thermophilic organisms at higher temperatures. ***Particle size***, as the particle size of the substrate gets smaller, decomposition becomes easier. ***Mixing*** is important not only to prevent floating and sedimentation but also for biogas extraction for that reasons mixers used to help bubbles rise in the digester.
(http://zorg-biogas.com/library/biogas-production-process)

2.0 AIM

The aim of this project was to observe the effect of two different parameters on the volume of biogas produced, methane percentage and production rate. The parameters are different shaking rates and silage as a co-mixture with manure. The optimum mixing point gives how much energy should be supplied for the process and also this parameter is important for process economy.

3.0 MATERIALS AND METHODS

Four batch experiments were performed in triplicate. The manure and silage, made from grass crops, were collected from a farm (Orraryd) in Sweden. Depending on the farm's production rate the manure was prepared as a mixture of 83% cow's and 17% bull's. Plant waste was mixed with the manure with two different percentages to observe its effect on the system efficiency. The amounts are given in *Table2* for each reactor.

Table 2. *Manure and plant waste amounts for four systems*

Reactors	Cow manure (g)	Bull manure (g)	Silage (g)	Manure(g)/silage(g)
R1-R6	415	85	-	-
R7-R9	411	84	5	99
R10-R12	403	82	15	32.33

Degradation of manure and mixture of manure with plant waste were tested in 1 liter bottles. For both systems, pH buffer solutions were prepared with $NaHCO_3$. By the consideration of the sodium hydrogen carbonate's solubility at 35 ^{0}C, 2g/20ml buffer solutions were added to reactors R1-6, R7-9, R10-12 which contain 500g, 495g and 485g manure, respectively. The bottles were closed with butyl rubber covers and incubated at 35^{0}C in water baths, after flushing for 2 minutes with nitrogen in each reactor to remove the O_2. Top of the bottles were then covered with a white elastic band approximately 3-4cm wide to prevent leakage.

The produced gas was collected in Teddlar bags. The duration of the experiment was 63 days. Collected samples were analyzed for CH_4 on a gas chromatograph (Varian Model 3700) equipped with a flame ionization detector (FID). Methane was isolated in a packed column of SUPELCO 5% CARBOWAX 20M. The carrier gas was N_2 at 2.7 bar and the temperatures of the injection part, column and detector was 120 ^{0}C, 40 ^{0}C, and 150 ^{0}C, respectively.

4.0 THEORY

A study was performed by Ward et al. 2008 on optimization techniques for anaerobic digestion and some possible areas for improvements were suggested, including basic design considerations of reactor configuration, the type, power and mixing regime for mixer types and also the retention time of microorganisms within the reactors. For these processes optimal environmental conditions such as temperature, pH buffering and fatty acid concentrations are discussed. (Ward et al, 2008)

The effect of mixing on biogas production was researched in lab scale and pilot scale studies at 55 ^{0}C by Kaparaju et al 2008. Three types of mixing were investigated in lab-scale continuous stirred tank reactors. They were continuously mixed (control), minimal (mixing for 10 min prior to extraction/feeding), and intermittent mixing (with holding mixing for 2h prior to extraction/feeding). During the comparison of intermittent with continuous mixing, pilot scale studies supported the lab scale results with an overall 7% increase in biogas efficiency during intermittent mixing compared to continuous mixing. At 55 ^{0}C, the effect of mixing in batch systems showed that when the process was overloaded by high organic matter to inoculumn ratio (40/60), gentle (35 times per minute) or minimal mixing (10 min mixing before feeding) was advantageous compared with vigorous mixing (110 times per minute). Alternatively, gentle mixing was the best under low organic matter to inoculum ratio. This study shows that, mixing intensities have some effect on anaerobic degradation of manures. (Kaparaju et al, 2008)

Anaerobic degradation of potato waste alone and in a mixture with sugar beet leaves was examined by Parawira et al. 2004. The effect of potato concentration was explained as a total solid percentage (TS) and initial inoculums to substrate ratio (ISR) was investigated on methane productivity. The ISRs studied were in the range of (0.25 to 9) with increased proportions of potato waste from 10% to 80% of TS. Up to 84% methane content was obtained at this proportion of potato waste and ISR. Moreover, Co-digestion improved the accumulated methane production and the methane yield compared with degredation of potato waste alone. (Parawira et al, 2004)

The effect of different mixing types on the performance of lab scale digesters were researched by Karim et al. 2005. The mixing types were biogas recirculation, impeller mixing, and slurry recirculation and they are compared with unmixed reactors. The digesters were fed 5% and 10% cow manure slurry at 8 W/ m^3.h constant energy supplied. The experiments were carried out in eight laboratory scale reactors, each having a 3.73 L volume, at a temperature of 35 ± 2 ^{0}C. The total solids (TS) loading rate of 3.08 g/Ld for 5% and 6.2 g/Ld for 10% manure slurry feeds.

At the end of the experiment, the results showed that the mixed and unmixed reactors performed fairly similar with 5% manure slurry and also produced biogas and methane at a rate of 0.84–0.94 L/Ld and 0.26–0.31 L CH_4/g volatile solids (VS), respectively. This similar behavior was because of the low solid content in the 5% manure slurry. However, the effect of mixing can be a major factor when the reactors are fed with thicker manure slurry (10%). Reactors fed with 10% cow manure slurry and mixed by slurry recirculation, impeller, and biogas recirculation produced around 29%, 22% and 15% more biogas than unmixed digester, respectively. Declaration of solids inside the reactors with 5% manure slurry was not observed, while it became significant in the reactors with 10% slurry. As a result of this, the mixing effect becomes important with thicker manure slurry. (Karim et al, 2005)

5.0 RESULTS AND DISCUSSION

5.1 The shaking effect

Six laboratory scale digesters were fed with a mixture of cow and bull manure and according to the dry substance analysis results; the volatile solids content was around 9.47% and 5.69% for bull and cow manure, respectively. The dry and volatile substance analysis results are given in *Table 3 and 4* and also all analysis results for the six reactors are in *Table 5 and 6.* In order to observe the effect of shaking, two different systems with three replicas were operated for approximately 60 days. The first three reactors were shaken once a week, (R1-R3) while the other three (R4-R6) were shaken five times in a water bath shaker with 100 U/min for 10 minute for each reactor.

Table 3 *Dry substance analysis results*

	Tare (g)	*Total weight (g)*	*After evaporation (g)*	*After combustion (g)*	*Volatile Substance %*
Bull Manure	18.24	30.80	19.67	18.48	9.47
Cow Manure	17.55	27.73	18.22	17.64	5.69

Table 4 *Volatile substance analysis*

	Volatile substance (%) Before degradation	*Volatile substance (%) After degradation*	*VS after degradation (g)*	*Used VS (g)*	*Total produced methane (l CH_4/g)*	*Total produced methane (ml)*
R1-3	6.33	4,14	20,71	10,99	0,57	6286,72
R4-6	6.33	4,40	22,02	9,68	0,66	6404,79

Initially there was not much methane production in both systems because of the adaptation period of the microorganisms. On the other hand, hydrolysis is the first biogas production step in which a high-molecular substance turns into monomers by the hydrolytic-fermentative bacteria. All six digesters behaved quite similarly as shown in *Figure 2 and Figure 3*. A similar finding was reported by Karim et al, 2005 for the start up period of the process. After this, the methane production rate and percentage increased which was related to the microorganisms' collaboration in parallel with small difference occurring between the five times a week and once a week shaken systems. Eventually, the shaking affected the methane production rate positively in this period (days of operation between 22 and 40), *Figure 3*.

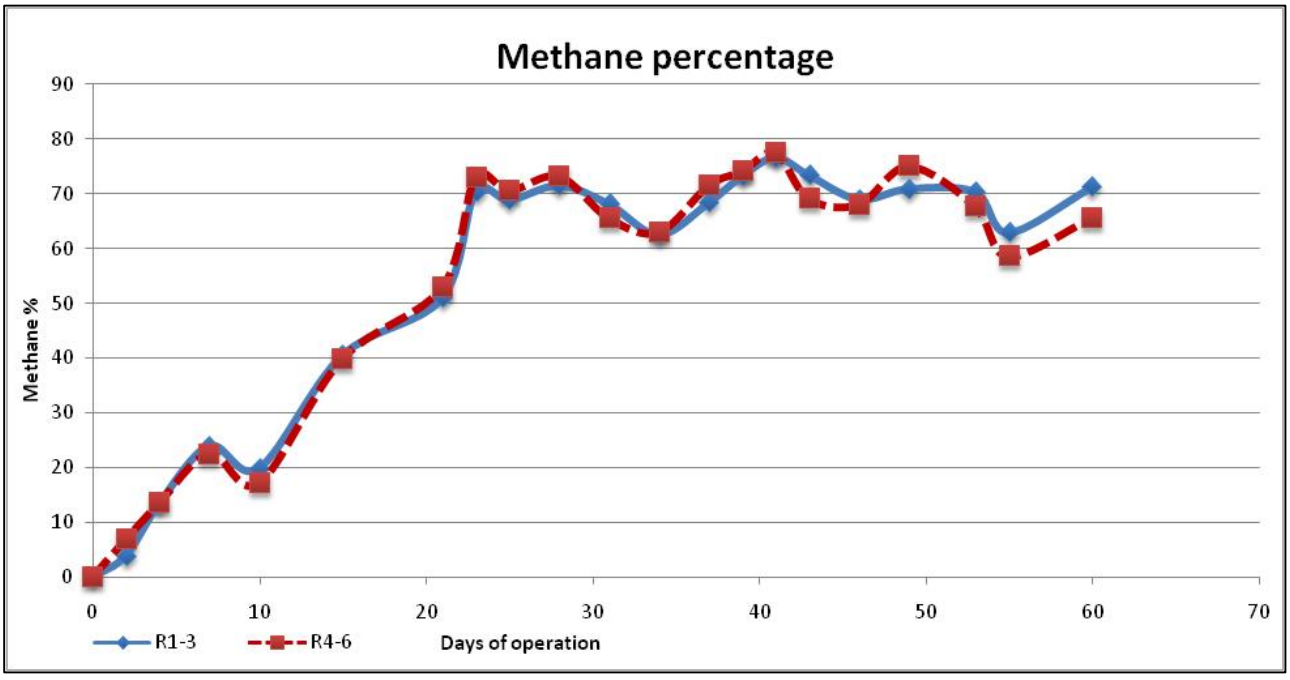

Figure 2 *Methane percentage*

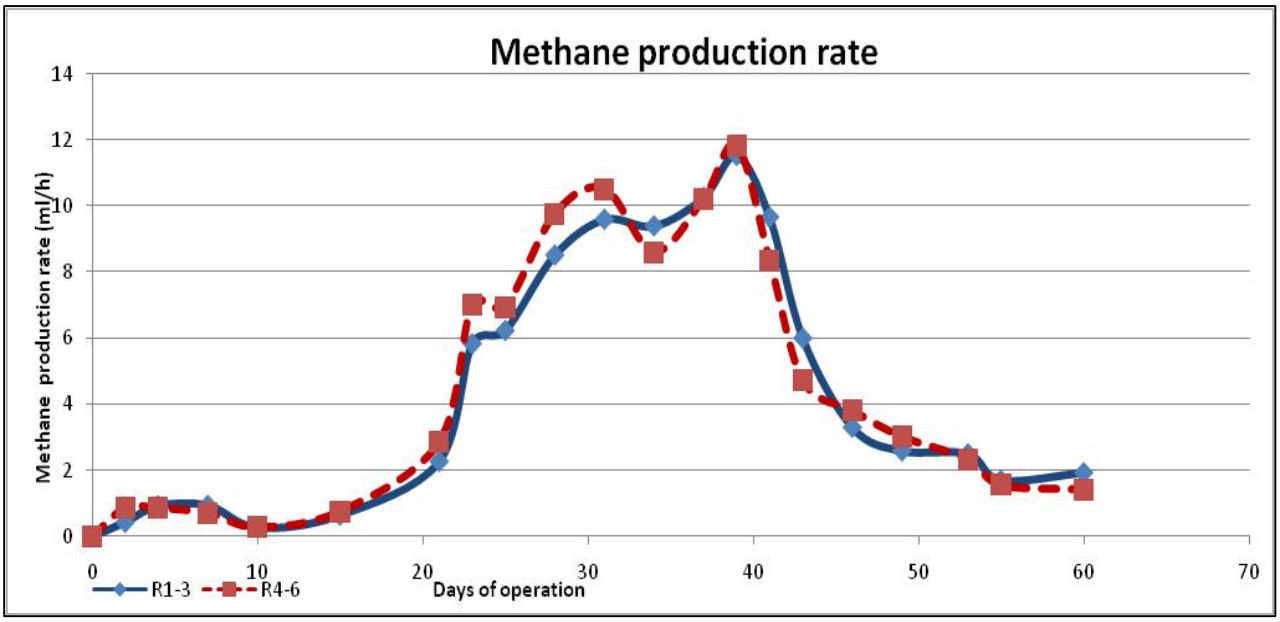

Figure 3 *Methane production rate*

The performance of the bacteria collaboration started to decrease at 38 day because of the limited substrate in each reactor. Based on the findings of this study, mixing did not improve the performance of the methane productivity to any larger extent which is also supported by previous studies mentioned in *section 4.0.*

Table 5 *Gas chromatography results for the reactors with manure*

	Calibration	*R1*	*R2*	*R3*	*R4*	*R5*	*R6*
09.07.2009	2865635	249593	209446,3	209685,33	378938	409528,3	396020
13.07.2009	2940228	795419,7	663994	910547	732744,7	801078	851318
15.07.2009	2543266	1158107	1198617	1301075,7	1254885	1079795	1105762
17.07.2009	3032103	1664275	720909	1235204	769619,7	1197476	1158511
21.07.2009	2137845,333	1396280	1789637	2016928	1492267	1900583	1725841
27.07.2009	2791660,667	2951976	2642446	2957046	2968029	3142134	2774504
29.07.2009	2794749,667	3791114	4035014	4003145,3	4244840	4017640	4004458
31.07.2009	2764762,667	3903896	3766458	3773339,7	3784347	4132366	3805624
03.08.2009	2804445,333	3932582	4110409	4005414,7	4051933	4163386	4120582

	Calibration	*R1*	*R2*	*R3*	*R4*	*R5*	*R6*
06.08.2009	2954625,667	4093123	4046074	3956707	3763237	3914264	3954761
09.08.2009	3185132	4093311	3983447,7	3889288,7	4095320	3933492	4024410
12.08.2009	2721422,667	3675998	3774974	3735444,7	3644324	3966124,3	4088725,3
14.08.2009	2705977	4047846	3894396,7	-	3924038	4024149,3	4099893,7
17.08.2009	2650337,333	3902494	4154518,7	4140964	3898243	4079193	4358515,7
19.08.2009	3132123,667	4704254	4517244,3	4596760	4392371	4385529	4218577,7
21.08.2009	2923708,667	4416141	3658045,3	4047284,7	3609241	4217046,7	4127343,7
24.08.2009	2953982,667	3934922	4307184,7	4342432,7	4223862	4499768,3	4589348,7
28.08.2009	3016754	4220690	4274216,7	4251829	4199202	3779358,7	4284449
30.08.2009	3021098,667	4548163	3275413	3596626,7	3311744	3497401,7	3819765
04.09.2009	2975996	4313300	4222407	4191651,3	3963900,7	3558534,3	4193617

Table 6 *Produced total gas and methane amounts for reactors with manure*

Reactors			R1-3			R4-6		
Analyses date (collected period)	Volume of total gas (ml)	Methane Percentage (%)	Methane amount (ml)	Methane rate (ml/h)	Volume of total gas (ml)	Methane Percentage (%)	Methane amount (ml)	Methane rate (ml/h)
09.07.2009 (45.5h)	508,33	3,89	19,77	0,43	570	6,89	39,30	0,86
13.07.2009 (46.25h)	326,66	13,43	43,03	0,93	296,66	13,52	40,15	0,87
15.07.2009 (77.25h)	306,67	23,97	72,99	0,94	245	22,55	55,34	0,72
17.07.2009 (69.5h)	95,67	19,90	19,08	0,27	115	17,18	19,91	0,29
21.07.2009 (116.5h)	186,66	40,56	75,54	0,65	225	39,90	89,15	0,76
27.07.2009 (143.75h)	639	51,05	326,31	2,27	773,33	53,04	411,67	2,86

Reactors			R1-3			R4-6		
Analyses date (collected period)	Volume of total gas (ml)	Methane Percentage (%)	Methane amount (ml)	Methane rate (ml/h)	Volume of total gas (ml)	Methane Percentage (%)	Methane amount (ml)	Methane rate (ml/h)
29.07.2009 (49.5h)	408,33	70,54	288,52	5,83	473,33	73,15	347,07	7,01
31.07.2009 (48.75h)	440	68,98	303,70	6,23	478,33	70,66	338,69	6,95
03.08.2009 (69.5h)	825	71,60	591,03	8,50	925	73,31	678,49	9,76
06.08.2009 (74.5h)	1046	68,23	714,40	9,59	1191	65,62	782,81	10,51
09.08.2009 (72h)	1080	62,61	676,46	9,39	985	63,07	620,09	8,61
12.08.2009 (70h)	1048	68,51	717,76	10,25	996	71,65	714,71	10,21
14.08.2009 (47.5h)	745	73,38	547,01	11,52	756	74,21	561,76	11,83
17.08.2009 (73,5h)	925	76,71	709,48	9,65	788	77,57	612,64	8,34
19.08.2009 (47h)	383	73,53	282,17	6,00	321	69,16	222,22	4,73
21.08.2009 (50h)	238	69,1	165,16	3,30	281	68,14	190,26	3,81
24.08.2009 (68.75h)	250	71	177,79	2,59	276	75,11	207,41	3,02
28.08.2009 (96.25h)	341	70,42	240,63	2,5	331	67,75	225,68	2,34
30.08.2009 (51h)	138	63	86,77	1,7	136	58,64	79,59	1,56
04.09.2009 (118.5h)	321	71,28	229,09	1,93	255	65,61	167,86	1,42

5.2 Silage as a commixture

Depending on the added amount of silage for co-digestion, methane production performance can be compared. Two systems with three replicas filled with 1% (R7-9) and 3% (R10-12) silage were analyzed. Dry substance and volatile substance analysis results are shown in *Table* 7 and 8 with all analysis values shown in *Table 9 and 10.*

Table 7 *Dry substance analysis results*

	Tare (g)	*Total weight (g)*	*After evaporation (g)*	*After combustion (g)*	*Volatile Substance of silage %*
Silage	17,67	19,1	18,49	17,71	54,54

Table 8 *Volatile substance analysis*

	Volatile substance (%)	*VS after degradation (g)*	*Used VS (g)*	*Total produced methane (l CH_4/g)*	*Total produced methane (ml)*
R7-9	4,37	21,85	12,25	0,59	7341,49
R10-12	4,68	23,4	15,52	0,52	8176,12

At the beginning of the process, there were no big differences. After a while, digesters with 3% silage gave a high methane production rate but it showed a rapid decrease as shown in *Figure 5*, meaning silage can easily degrade, so more fatty acids might have been released into environment. The system is a mixed culture and there are two kinds of bacteria directly affecting methane production. According to the Murto 2003, high fatty acid concentration decreases pH and may also be the cause of methanogenesis inhibition if the concentration exceeds a threshold level. Accumulation of volatile fatty acids and H_2 are due to the fact that methanogens could not metabolize the intermediates at the same rate as they were formed. This does not mean that the system was inhibited completely. This situation might be explained as that the bacteria collaboration was imbalanced. After a certain time, system reached a stable point but it took long time.

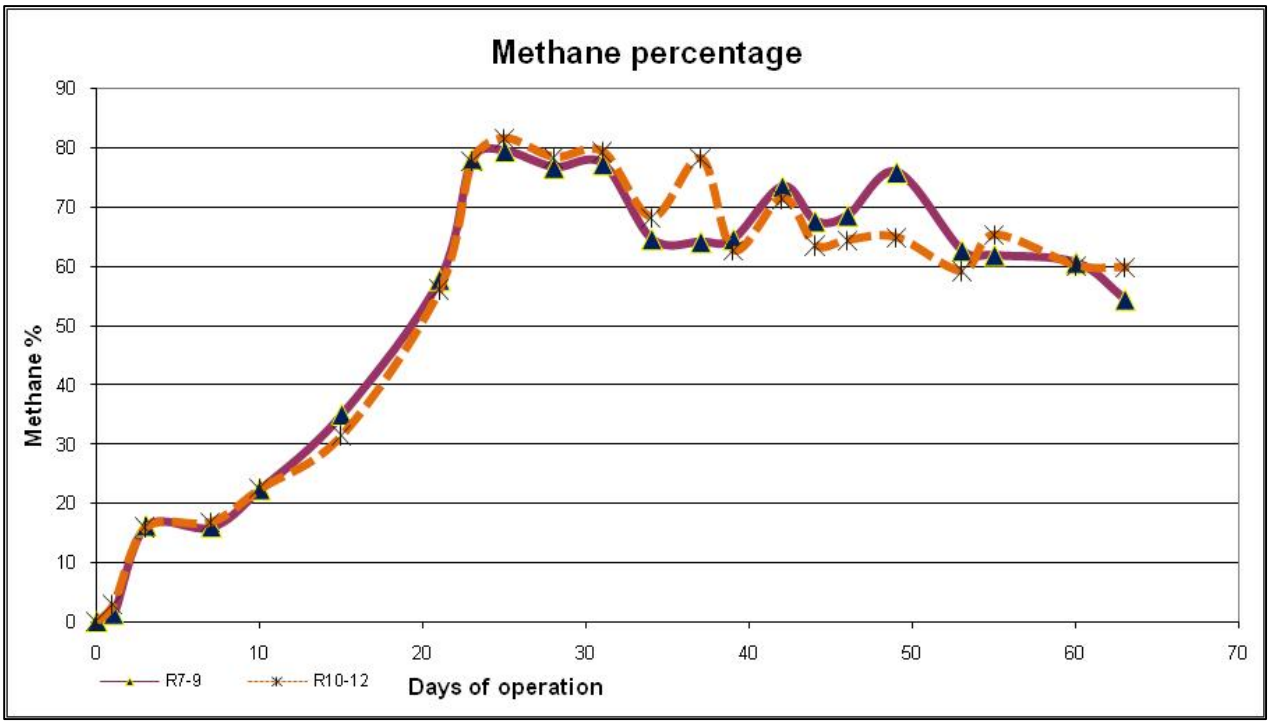

Figure 4 *Methane percentage*

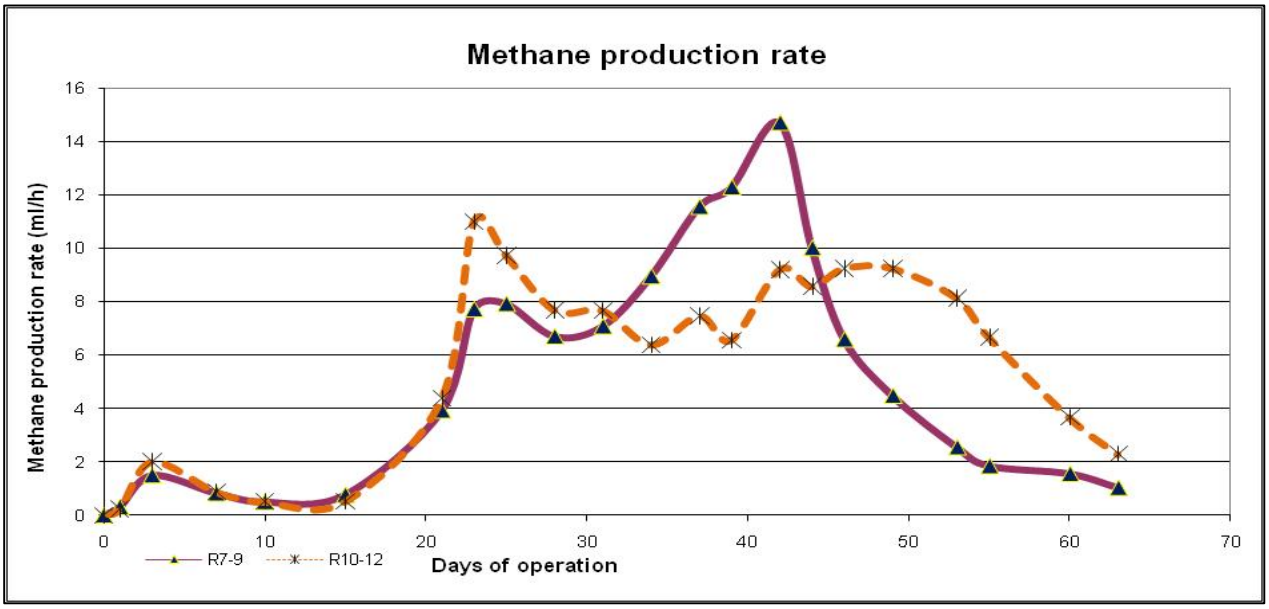

Figure 5 *Methane production rate*

A more stable methane production rate was obtained with a silage amount of 1%. After 55 days, there was a decrease in methane amount with the reactors with 3% silage because of limited substrate. With the similar reason, methane production rate decreased after 42 days with the reactors including less amount of silage.

Methane percentages for all systems are calculated and shown in *Figures 2 and 4*. When the process stabilized, the mean values of methane percentage were approximately 67% and 70% for the reactors without silage and with silage, respectively. By looking at the *Figure 4*, adding more silage has no important effect on biogas percentage. However, the reactors with 3% silage produced more methane in total methane amount especially comparing with *R1-6*. *(See table 4 and 8).*

Table 9 *Gas chromatography results for the reactors with manure and silage*

	Calibration	*R7*	*R8*	*R9*	*R10*	*R11*	*R12*
08.07.2009	2914440	66993	74063	82868	165221	166572	174374
10.07.2009	2853382	887231	942560	939065	929929	879545	904844
13.07.2009	2940228	1041909	808210	971214	922679	1085888	949312
16.07.2009	2478573	1059183	1139200	1120769	965082	1253342	0
22.07.2009	3057380	2302036	1960033	2155356	1927316	1669887	2164983
27.07.2009	2791660	3172865	3199860	3295680	3016951	3076466	3292745
29.07.2009	2794749	4635760	4208221	4256032	4251755	4324857	4443995
31.07.2009	2764762	4380866	4197330	4598629	4494960	4457313	4570277
03.08.2009	2804445	4377694	4205105	4318297	4368341	4324555	4492037
06.08.2009	2954625	4387527	4695018	4667926	4572605	4752530	4723852
09.08.2009	3185132	3937192	4281015	4118948	4522164	4170586	4694440
12.08.2009	3185132	3366591	3642247	3456961	4260368	4248420	4250285
14.08.2009	2705977	3621818	3398580	3465978	3700593	3807782	2662454
17.08.2009	2650337	3769342	3964587	3942163	3846232	3427464	4083565
19.08.2009	3132123	4308325	4096962	4303410	3610463	4186522	4140112
21.08.2009	2923708	3637992	4268267	4121041	3446212	3839580	4009407
24.08.2009	2953982	4411951	4558562	4474994	3887917	3512413	4088119
28.08.2009	3016754	4392009	3270580	3671115	3585188	3533366	3592002
	Calibration	*R7*	*R8*	*R9*	*R10*	*R11*	*R12*
30.08.2009	3021098	3102217	4138440	3971015	4023694	3673527	4130381

04.09.2009	2975996	4313418	2969942	3537082	3384916	3596551,3	3748465,7
07.09.2009	3318337	2906613	4304409	3613929	4030458	3583223	4286892

Table 10 *Produced total gas and methane amounts for reactors with manure and silage*

Reactors			R7-9			R10-12		
Analyses date (collected period)	Volume of total gas (ml)	Methane Percentage (%)	Methane amount (ml)	Methane rate (ml/h)	Volume of total gas (ml)	Methane Percentage (%)	Methane amount (ml)	Methane rate (ml/h)
08.07.2009 (17h)	416	1,28	5,34	0,31387	726	2,89	21,07	1,24
10.07.2009 (52h)	481	16,17	77,92	1,49	659	15,83	104,68	2,01
13.07.2009 (96h)	326	13,43	43,03	0,93	296	13,52	40,15	0,87
16.07.2009 (70.3h)	158	22,32	35,29	0,5	165	22,38	35,9	0,51
22.07.2009 (121.3h)	268	34,98	93,64	0,77	203	31,41	64,36	0,53
27.07.2009 (143.3h)	974	57,72	562,34	3,92	1118	56,04	626	4,37
29.07.2009 (45h)	445	78,12	347,41	7,72	636	77,65	494	10,98
31.07.2009 (49h)	488	79,43	387,95	7,92	585	81,52	476	9,73
03.08.2009 (73.25h)	640	76,67	490,69	6,69	718	78,36	562,86	7,68
06.08.2009 (70.25h)	633	77,56	491,29	6,99	680	79,25	538	7,66
09.08.2009 (72h)	1080	62,61	676,46	9,39	985	63,07	620	8,61
Reactors			R7-9			R10-12		
Analyses date	Volume of total	Methane Percentage	Methane amount	Methane rate	Volume of total	Methane Percentage	Methane amount	Methane rate

(collected period)	gas (ml)	(%)	(ml)	(ml/h)	gas (ml)	(%)	(ml)	(ml/h)
12.08.2009 (97h)	1343	64,55	868,13	8,95	905	68,23	619	6,39
14.08.2009 (47 h)	893	64,58	576,99	12,27	491	62,64	308	6,57
17.08.2009 (69h)	1381	73.42	1014	14,7	888	71,42	635	9,2
19.08.2009 (47h)	695	67,62	470	10,01	641	63,52	402	8,57
21.08.2009 (51h)	491	68,56	336	6,59	739	64,38	471	9,24
24.08.2009 (68.5h)	431	75,86	327	4,78	978	64,82	632	9,24
28.08.2009 (96.75h)	386	62,61	244	2,54	1316	59,17	778	8,14
30.08.2009 (54,75h)	163	61,85	101	1,85	560	65,25	364	6,66
04.09.2009 (113h)	290	60,59	175,85	1,56	678	60,09	413	3,66

6.0 CONCLUSION

The shaking effect and silage as a co-digestor were studied successfully for methane yield and methane production rate from cattle manure. Results from this experiment suggest that 1% silage content is a possible co-substrate for anaerobic digestion for biogas production and can supply more benefits to productivity in large scale biogas production plants. The addition 3% silage partially inhibited the system, so in the following studies of 2% silage content should be researched to compare with 1% and 3%. Mixing did not improve the performance of the digesters excluding a 2 week period. And finally, under the leadership of these results, this study may potentially be applied to continuous systems for lab scale studies or larger scale biogas production on batch reactors.

7.0 REFERENCES

Atalay Ferhan Sami, Prof.Dr. Ege University Chemical Engineering Department İzmir-TURKEY , ferhan.atalay@ege.edu.tr, +90 232 388 76 00-2284

Bilim ve Teknik, 2009 May, No 498, Tübitak

Demirel Burak, Scherer Paul, 2009, Bio-methanization of energy crops through mono-digestion for continuous production of renewable biogas, Renewable Energy 34 (2009) 2940–2945

Hoffmann Rebecca A., Garcia Marcelo L., Veskivar Mehul, Karim Khursheed, Al-Dahhan Muthanna H., Angenent Largus T., 2007, Effect of Shear on Performance and Microbial Ecology of Continuously Stirred Anaerobik Digesters Treating Animal Manure, Biotechnol. Bioeng. 2008;100: 38–48.

Karim Khursheed, Hoffmann Rebecca, KlassonThomas, Al-Dahhan M.H., 2005, Anaerobic digestion of animal waste: Waste strength versus impact of mixing, Bioresource Technology 96 (2005) 1771–1781

Kaparaju Prasad, Buendia Inmaculada, Ellegaard Lars, Angelidakia Irini, 2008, Effects of mixing on methane production during thermophilic anaerobic digestion of manure: Lab-scale and pilot-scale studies, Bioresource Technology 99 (2008) 4919–4928

Klocke Michael, Pia Mä hnert, Mundt Kerstin, Souidi Khadidja, Linke Bernd, 2006, Microbial community analysis of a biogas-producing completely stirred tank reactor fed continuously with fodder beet silage as mono-substrate, Systematic and Applied Microbiology 30 (2007) 139–151

Koch Konrad, Wichern Marc, Lübken Manfred, Horn Harald, 2009, Mono fermentation of grass silage by means of loop reactors, Bioresource Technology 100 (2009) 5934–5940

Lindorfer H., Corcoba A, Vasilieva V., Braun R., Kirchmayr R., 2007, Doubling the organic loading rate in the co-digestion of energy crops and manure – A full scale case study, resource Technology 99 (2008) 1148–1156

Møller, H.B., Sommer, S.G., Ahring, B.K., 2003, Methane productivity of manure, straw and solid fractions of manure, Biomass and Bioenergy, 26, 2004, 485-495

Murto Marika, 2003, Anaerobic Digestion Microbial Ecology, Improved Operational Design and Process Monitoring, Department of Lund University.

Parawira W., Murto M., Zvauya R., Mattiasson B., 2004, Anaerobic batchdigestion of solid potato waste alone and in combination with sugar beet leaves, Renewable Energy 29 (2004) 1811–1823

Prochnow A., Heiermann M., Plöchl M., Linke B., Idler C., Amon T., Hobbs P.J., 2009, Bioenergy from permanent grassland – A review: 1. Biogas, Bioresource Technology 100 (2009) 4931–4944

Seadi Teodorita Al, Rutz Dominik, Prassl Heinz, Köttner Michael, Finsterwalder Tobias, Volk Silke, Janssen Rainer, 2008, Biogas for Eastern Europe, Biogas Handbook, Published by University of Southern Denmark Esbjerg, Niels Bohrs Vej 9-10, DK-6700 Esbjerg, Denmark, ISBN 978-87-992962-0-0

Ward Alastair J., Hobbs Phil J., Holliman Peter J., Jones David L., 2008, Optimisation of the anaerobic digestion of agricultural resources, Bioresource Technology 99 (2008) 7928–7940

SUNDET, Växjö Municipality Sewage Prufication Plant, SWEDEN

http://zorg-biogas.com/library/biogas-production-process, September 2009

http://www.schaumann-bioenergy.com/biogasproduktion/fermenterbio.ph, September 2009

http://pubs.ext.vt.edu/442/442-881/L_IMG_fig3.JPG, September 2009

8.0 NOMENCLATURE

VFA : Volatile fatty acid

VS: Volatile substance

TS: Total substance

TDS: Total dry substance

R: Reactor

9.0 APPENDIX

9.1 Volatile substance content

For cow manure; *Ref.Table3*

$\text{Tare(g)} = 17.5\text{g}$

$\text{Manure} + \text{basin} = 27.73\text{g}$

$\text{Manure} = 27.73 - 17.5 = 10.23\text{g}$

$\text{After evaporation} = 18.22\text{g}$

$\text{Total dried substance} = 18.22 - 17.5 = 0.72\text{g}$

$\text{After combustion} = 17{,}64\text{g}$

$Ash = 17.64 - 17.5 = 0.14g$

$Total\ Volatile\ Subs\tan ce = 0.72 - 0.14 = 0.58g$

$$\%VS = \frac{(0.58 \times 100)}{10.23} = 5.66$$

For bull manure; *Ref.Table3*

$Tare(g) = 18.24g$

$Manure + ba\sin = 30.8g$

$Manure = 30.8 - 18.24 = 12.56g$

$After\ evaporation = 19.68g$

$Total\ dried\ subs\tan ce = 19.68 - 18.24 = 1.44g$

$After combustion = 18.49g$

$Ash = 18.49 - 18.24 = 0.25g$

$Total\ Volatile\ Subs\tan ce = 1.44 - 0.25 = 1.19g$

$$\%VS = \frac{(1.19 \times 100)}{12.56} = 9.47$$

For silage; *Ref.Table7*

$Tare(g) = 17.67g$

$Silage + ba\sin = 19.1 - 17.67 = 1.43g$

$After\ evaporation = 18.49g$

$Total\ dried\ subs\tan ce = 18.49 - 17.67 = 0.82g$

$After combustion = 17.71g$

$Ash = 17.71 - 17.67 = 0.04g$

$Total\ Volatile\ Subs\tan ce = 0.82 - 0.04 = 0.78g$

$$\%VS = \frac{(0.78 \times 100)}{1.43} = 54.54$$

Reactors 1-3, after degradation; *Ref.Table4*

$Tare(g) = 16.7g$

$Manure + basin = 31.51g$

$Manure = 31.51 - 16.7 = 14.81g$

$After\ evaporation = 17.51g$

$Total\ dried\ substance = 17.51 - 16.7 = 0.81g$

$After\ combustion = 16.9g$

$Ash = 16.9 - 16.7 = 0.2g$

$Total\ Volatile\ Substance = 0.81 - 0.2 = 0.61g$

$$\%VS = \frac{(0.61 \times 100)}{14.81} = 4.11$$

Reactors 4-6, after degradation; *Ref.Table4*

$Tare(g) = 17.54g$

$Manure + basin = 33.43g$

$Manure = 33.43 - 17.54 = 15.89g$

$After\ evaporation = 18.46g$

$Total\ dried\ substance = 18.46 - 17.54 = 0.92g$

$After\ combustion = 17.76g$

$Ash = 17.76 - 17.54 = 0.22g$

$Total\ Volatile\ Substance = 0.92 - 0.22 = 0.7g$

$$\%VS = \frac{(0.7 \times 100)}{15.89} = 4.40$$

Reactors 7-9, after degradation; *Ref.Table8*

$Tare(g) = 17.82g$

$Silage + basin = 33.6g$

$Silage = 33.6 - 17.82 = 15.78g$

$After\ evaporation = 18.72g$

$Total\ dried\ substance = 18.72 - 17.82 = 0.9g$

$After\ combustion = 18.03g$

$Ash = 18.03 - 17.82 = 0.21g$

$Total\ Volatile\ Substance = 0.9 - 0.21 = 0.69g$

$$\%VS = \frac{(0.69 \times 100)}{15.78} = 4.37$$

Reactors 10-12, after degradation; *Ref.Table8*

$Tare(g) = 18.17g$

$Silage + ba\sin = 35.9g$

$Silage = 35.9 - 18.17 = 17.73g$

$After\ evaporation = 19.27g$

$Total\ dried\ subs\tan ce = 19.27 - 18.17 = 1.1g$

$After combustion = 18.44g$

$Ash = 18.44 - 18.17 = 0.27g$

$Total\ Volatile\ Subs\tan ce = 1.1 - 0.27 = 0.83g$

$$\%VS = \frac{(0.83 \times 100)}{17.73} = 4.68$$

9.2The Recorded Reactor Values

Measurement Date	Changed time with date	Calibration % 50 methane	%1 Straw			Average Replicas	%3 Straw			Average Replicas
			R7	R8	R9		R10	R11	R12	
08.07.2009	06.07.2009 at 18.00-07.07.09 11.00	2950018	70111	71485	83409		169722	166500	164448	
Time (h)	17	2981356	68090	73631	85163		157650	167759	178263	
		2811947	62779	77074	80033		168292	165459	180411	
	average	2914440,333	66993,33	74063,333	82868,333		165221,33	166572,67	174374	
	Volume (ml)		420	410	420	416,67	665	725	790	726,67
	%Methane		1,149334	1,270627	1,4216852	1,28	2,8345294	2,8577128	2,9915521	2,89
	Methane amount (ml)		4,827205	5,2095708	5,9710778	5,34	18,84962	20,718418	23,633261	21,07
	Methane rate (ml/h)					0,31				1,24
			Once a week shaking				5 times a week shaking			
			R1	R2	R3		R4	R5	R6	
09.07.2009	06.07.2009 18.00-08.07.09 15.30	2778047	257890	215052	208829		377746	404497	391856	
Time (h)	45,5	2898188	256989	210884	210303		392135	413216	387317	
		2920670	233900	202403	209924		366933	410872	408887	
	average	2865635	249593	209446,33	209685,33		378938	409528,33	396020	
	Volume (ml)		510	495	520	508,33	560	600	550	570,00
	%Methane		4,354934	3,6544489	3,658619	3,89	6,6117632	7,1455076	6,9098123	6,89
	Methane amount (ml)		22,21016	18,089522	19,024819	19,77	37,025874	42,873046	38,003968	39,30
	Methane rate (ml/h)					0,43				0,86
			R7	R8	R9		R10	R11	R12	
10.07.2009	07.07.2009 at 11.00-09.07.09 15.00	2905188	831465	989936	928478		940124	869237	885155	
Time (h)	52	2731972	948241	940352	992653		922755	874488	917886	
		2922987	881989	897392	896065		926909	894910	911493	
	average	2853382,333	887231,7	942560	939065,33		929929,33	879545	904844,67	
	Volume (ml)		475	490	480	481,67	720	618	640	659,33
	%Methane		15,54702	16,516539	16,455302	16,17	16,295211	15,412323	15,855651	15,85
	Methane amount (ml)		73,84833	80,93104	78,985447	77,92	117,32552	95,248156	101,47616	104,68
	Methane rate (ml/h)					1,50				2,01
			R1	R2	R3		R4	R5	R6	
13.07.2009	08.07.09 15.30- 10.07.09 13.45	3030085	827278	640128	865836		747696	790299	839787	
Time (h)	46,25	2885389	811094	664611	909885		707648	794147	843453	
		2905210	747887	687243	955920		742890	818788	870714	
	average	2940228	795419,7	663994	910547		732744,67	801078	851318	
	Volume (ml)		300	400	280	326,67	285	310	295	296,67
	%Methane		13,5265	11,291539	15,484292	13,43	12,460678	13,622719	14,477075	13,52
	Methane amount (ml)		40,57949	45,166157	43,356019	43,03	35,512931	42,230429	42,70737	40,15
	Methane rate (ml/h)					0,93				0,87
			R7	R8	R9		R10	R11	R12	
13.07.2009	09.07.2009 at 15.10-13.07.09 15.00	2940228	1090499	849020	1046742		894377	1071246	934100	
Time (h)	96		1071686	781928	940832		941239	1086359	1079588	
			963541	793684	926069		932423	1100061	834248	
	average		1041909	808210,67	971214,33		922679,67	1085888,7	949312	
	Volume (ml)		478	580	450	502,67	455	512	548	505,00
	%Methane		17,71816	13,744014	16,51597	15,99	15,690614	18,466062	16,14351	16,77
	Methane amount (ml)		84,69281	79,715278	74,321864	79,58	71,392295	94,546239	88,466435	84,80
	Methane rate (ml/h)					0,83				0,88

			R1	R2	R3		R4	R5	R6	
15.07.2009 10.07.09 13.45-13.07.09 18.30		2409855	1109849	1194638	1168818		1270244	1146850	1162503	
Time (h)	77,25	2604574	1123471	1230038	1411357		1174225	1127958	1058072	
		2615369	1241001	1171176	1323052		1320186	964578	1096711	
	average	2543266	1158107	1198617,3	1301075,7		1254885	1079795,3	1105762	
	Volume (ml)		385	275	260	306,67	255	245	235	245,00
	%Methane		22,76811	23,564529	25,578836	23,97	24,670738	21,228517	21,739016	22,55
	Methane amount (ml)		87,65721	64,802456	66,504973	72,99	62,910383	52,009868	51,086687	55,34
	Methane rate (ml/h)					0,94				0,72
			R7	R8	R9		R10	R11	R12	
16.07.2009 13.07.2009 15.00- 16.07.09 13.20		2370452	1058199	1195194	1208885		1022491	1188801	0	
Time (h)	70,3	2544813	1010853	1099603	1016053		929602	1285843	0	
		2520455	1108497	1122804	1137371		943153	1285384	0	
	average	2478573,333	1059183	1139200,3	1120769,7		965082	1253342,7	0	
	Volume (ml)		170	165	140	158,33	200	130	165	165,00
	%Methane		21,36679	22,980969	22,609169	22,32	19,468498	25,28355	0	22,38
	Methane amount (ml)		36,32354	37,918599	31,652837	35,30	38,936996	32,868615	0	35,90
	Methane rate (ml/h)					0,50				0,51
			R1	R2	R3		R4	R5	R6	
17.07.2009 13.07.2009 at 18.30-16.07.09 16.00		3090005	1612261	670995	1181273		823042	1212831	1174548	
Time (h)	69,5	2939453	1731843	814266	1292176		743068	1168721	1273273	
		3066851	1648720	677466	1232163		742749	1210876	1027713	
	average	3032103	1664275	720909	1235204		769619,67	1197476	1158511,3	
	Volume (ml)		105	102	80		110	135	100	
	%Methane		27,44423	11,887937	20,368767	19,90	12,691186	19,746625	19,104089	17,18
	Methane amount (ml)		28,81644	12,125696	16,295014	19,08	13,960305	26,657943	19,104089	19,91
	Methane rate (ml/h)					0,27				0,29
			R7	R8	R9		R10	R11	R12	
22.07.2009 16.07.2009 at 13.20-21.07.09 15.00		3164532	2169429	1962814	2234168		1950486	1625885	2124166	
Time (h)	121,3	2970745	2568852	2026848	2159022		1916282	1641857	2226912	
		3036864	2167827	1890438	2072879		1915181	1741921	2143873	
	average	3057380,333	2302036	1960033,3	2155356,3		1927316,3	1669887,7	2164983,7	
	Volume (ml)		275	295	235	268,33	245	165	200	203,33
	%Methane		37,6472	32,05413	35,248417	34,98	31,51908	27,309126	35,405861	31,41
	Methane amount (ml)		103,5298	94,559684	82,83378	93,64	77,221747	45,060057	70,811722	64,36
	Methane rate (ml/h)					0,77				0,53
			R1	R2	R3		R4	R5	R6	
21.07.2009 16.07.2009 at 16.00-21.07.09 12.30		295433	1594613	1871601	2099593		1428223	1798902	1647571	
Time (h)	116,5	2990714	1354801	1820075	1936138		1470769	1983786	1723451	
		3127389	1239427	1677236	2015053		1577808	1919062	1806500	
	average	2137845,333	1396280	1789637,3	2016928		1492266,7	1900583,3	1725840,7	
	Volume (ml)		200	160	200	186,67	245	205	225	225,00
	%Methane		32,65625	41,856099	47,171981	40,56	34,901184	44,450908	40,364021	39,91
	Methane amount (ml)		65,3125	66,969759	94,343963	75,54	85,507901	91,124362	90,819047	89,15
	Methane rate (ml/h)					0,65				0,77

			R7	R8	R9		R10	R11	R12	
27.07.2009	21.07.09 at 15.00-27.07.09 14.20	2732479	3158663	3128998	3274920		2973892	2868651	3289041	
Time (h)	143,3	2794207	3133971	3205609	3327886		3124437	3177089	3190138	
		2848296	3225960	3264973	3284236		2952525	3183659	3399058	
	average	2791660,667	3172865	3199860	3295680,7		3016951,3	3076466,3	3292745,7	
	Volume (ml)		937	1067	920	974,67	1215	1025	1115	1118,33
	%Methane		56,82755	57,311049	59,027243	57,72	54,035065	55,101008	58,974676	56,04
	Methane amount (ml)		532,4741	611,50889	543,05064	562,34	656,52604	564,78533	657,56764	626,29
	Methane rate (ml/h)					3,92				4,37
			R1	R2	R3		R4	R5	R6	
27.07.2009	21.07.2009 at 12.30-27.07.09 12.15	2732479	2934322	2718993	2908758		2914130	3182061	2839248	
Time (h)	143,75	2794207	3071611	2500083	2902471		2995827	3211500	2831880	
		2848296	2849995	2708261	3059909		2994129	3032841	2652384	
	average	2791660,667	2951976	2642445,7	2957046		2968028,7	3142134	2774504	
	Volume (ml)		637	635	645	639,00	660	900	760	773,33
	%Methane		52,87133	47,327487	52,962132	51,05	53,158837	56,277148	49,692716	53,04
	Methane amount (ml)		336,7903	300,52954	341,60575	326,31	350,84832	506,49433	377,66464	411,67
	Methane rate (ml/h)					2,27				2,86
			R7	R8	R9		R10	R11	R12	
29.07.2009	27.07.2009 at 14.30-29.07.09 11.30	2611749	4566376	4323200	4274362		4190517	4297283	4483762	
Time (h)	45	2712023	4564191	4253319	4302482		4483340	4371510	4336008	
		3060477	4776714	4048144	4191254		4081410	4305779	4512215	
	average	2794749,667	4635760	4208221	4256032,7		4251755,7	4324857,3	4443995	
	Volume (ml)		435	445	455	445,00	635	660	615	636,67
	%Methane		82,93695	75,287977	76,143361	78,12	76,066843	77,374682	79,506137	77,65
	Methane amount (ml)		360,7757	335,0315	346,45229	347,42	483,02445	510,6729	488,96274	494,22
	Methane rate (ml/h)					7,72				10,98
			R1	R2	R3		R4	R5	R6	
29.07.2009	27.07.2009 at 12.15-29.07.09 13.45	2611749	3752622	3973041	3947579		4135664	4071114	4066658	
Time (h)	49,5	2712023	3874714	3942207	4048648		4332607	3951245	4017620	
		3060477	3746005	4189794	4013209		4266249	4030561	3929096	
	average	2794749,667	3791114	4035014	4003145,3		4244840	4017640	4004458	
	Volume (ml)		375	430	420	408,33	530	470	420	473,33
	%Methane		67,82564	72,189185	71,619032	70,54	75,943117	71,878352	71,642517	73,15
	Methane amount (ml)		254,3461	310,41349	300,79994	288,52	402,49852	337,82825	300,89857	347,08
	Methane rate (ml/h)					5,83				7,01
			R7	R8	R9		R10	R11	R12	
31.07.2009	29.07.2009 at 11.30-31.07.09 12.30	2590678	4417268	3915409	4459300		4547078	4568928	4476102	
Time (h)	49	2749114	4244438	4402213	4790294		4368841	4446240	4527126	
		2954496	4480892	4274369	4546293		4568961	4356773	4707603	
	average	2764762,667	4380866	4197330,3	4598629		4494960	4457313,7	4570277	
	Volume (ml)		435	515	515	488,33	610	580	565	585,00
	%Methane		79,2268	75,907607	83,164987	79,43	81,29016	80,609336	82,652248	81,52
	Methane amount (ml)		344,6366	390,92417	428,29968	387,95	495,86998	467,53415	466,9852	476,80
	Methane rate (ml/h)					7,92				9,73

			R1	R2	R3		R4	R5	R6	
31.07.2009	29.07.2009 at 13.45-31.07.09 14.30	2590678	3766349	3676412	3814917		3659500	3865832	3881376	
Time (h)	48,75	2749114	3894354	3849155	3798365		3940140	4136499	3816406	
		2954496	4050985	3773807	3706737		3753401	4394766	3719089	
	average	2764762,667	3903896	3766458	3773339,7		3784347	4132365,7	3805623,7	
	Volume (ml)		460	420	440	440,00	440	510	485	478,33
	%Methane		70,60092	68,115395	68,239848	68,99	68,438912	74,732738	68,823695	70,67
	Methane amount (ml)		324,7643	286,08466	300,25533	303,70	301,13121	381,13696	333,79492	338,69
	Methane rate (ml/h)					6,23				6,95
			R7	R8	R9		R10	R11	R12	
03.08.2009	31.07.09 at 12.30-03.08.09 13.45	2741229	4368626	4219381	4117615		4334732	4502291	4442428	
Time (h)	73,25	2739088	4295482	4338972	4454023		4378059	4087107	4432729	
		2933019	4468973	4056962	4383255		4392233	4384269	4600954	
	average	2804445,333	4377694	4205105	4318297,7		4368341,3	4324555,7	4492037	
	Volume (ml)		650	645	625	640,00	730	710	715	718,33
	%Methane		78,04919	74,972134	76,990227	76,67	77,882448	77,1018	80,087798	78,36
	Methane amount (ml)		507,3197	483,57026	481,18892	490,69	568,54187	547,42278	572,62775	562,86
	Methane rate (ml/h)					6,70				7,68
			R1	R2	R3		R4	R5	R6	
03.08.2009	31.07.09 at 14.30-03.08.09 12.00	2741229	3903221	4132793	4104367		4130191	4205068	4043831	
Time (h)	69,5	2739088	4001973	4217373	3791721		3957663	4204978	4190212	
		2933019	3892551	3981061	4120156		4067944	4080113	4127703	
	average	2804445,333	3932582	4110409	4005414,7		4051932,7	4163386,3	4120582	
	Volume (ml)		775	840	860	825,00	875	985	915	925,00
	%Methane		70,11336	73,283814	71,411887	71,60	72,241249	74,228338	73,465187	73,31
	Methane amount (ml)		543,3785	615,58404	614,14223	591,03	632,11093	731,14913	672,20646	678,49
	Methane rate (ml/h)					8,50				9,76
			R7	R8	R9		R10	R11	R12	
06.08.2009	03.08.09 13.45-06.08.09 12.00	2930515	4507189	4797509	4663058		4480422	4774039	4664354	
Time (h)	70,25	3029790	4258381	4647291	4580579		4627558	4665717	4868063	
		2903572	4397010	4640255	4760142		4609837	4817834	4639139	
	average	2954625,667	4387527	4695018,3	4667926,3		4572605,7	4752530	4723852	
	Volume (ml)		630	630	640	633,33	735	655	650	680,00
	%Methane		74,24844	79,451999	78,993532	77,56	77,380457	80,425247	79,939941	79,25
	Methane amount (ml)		467,7651	500,5476	505,5586	491,29	568,74636	526,78537	519,60961	538,38
	Methane rate (ml/h)					6,99				7,66
			R1	R2	R3		R4	R5	R6	
06.08.2009	03.08.09 12.00-06.08.09 14.30	2930515	4241419	3911380	3880488		3897764	3894878	3874095	
Time (h)	74,5	3029790	4136855	4153597	3893471		3637733	3896231	3879986	
		2903572	3901094	4073245	4096162		3754215	3951683	4110202	
	average	2954625,667	4093123	4046074	3956707		3763237,3	3914264	3954761	
	Volume (ml)		1110	1000	1030	1046,67	1100	1240	1235	1191,67
	%Methane		69,26635	68,470163	66,957839	68,23	63,683826	66,239592	66,924908	65,62
	Methane amount (ml)		768,8565	684,70163	689,66574	714,41	700,52209	821,37095	826,52261	782,81
	Methane rate (ml/h)					9,59				10,51
			R7	R8	R9		R10	R11	R12	
09.08.2009	06.08.09 12.00-10.08.2009 13.00	3112377	3987350	4179626	4313736		4742588	4448295	4639552	
Time (h)	97	3232943	3868120	4458662	3945969		4420721	4104845	4816135	
		3210076	3956105	4204757	4097139		4403183	3958618	4627633	
	average	3185132	3937192	4281015	4118948		4522164	4170586	4694440	
	Volume (ml)		1340	1450	1240	1343,33	980	830	725	905,00
	%Methane		61,80578	67,203102	64,658984	64,56	70,988643	65,469594	86,249741	68,23
	Methane amount (ml)		828,1975	974,44498	801,77141	868,14	695,68871	543,39763	625,31062	619,54
	Methane rate (ml/h)					8,95				6,39

			R1	R2	R3		R4	R5	R6	
09.08.2009	06.08.09 14.30-09.08.2009 14.30	3112377	4141834	4187125	3934774		4313376	3915403	3965174	
Time (h)	72	3232943	4013015	3736851	3545278		4148992	3871900	4167443	
		3210076	4125084	4026367	4187814		3823593	4013173	3940613	
	average	3185132	4093311	3983447,7	3889288,7		4095320,3	3933492	4024410	
	Volume (ml)		1120	1040	1080	1080,00	850	1120	985	985,00
	%Methane		64,25654	62,531909	61,053807	62,61	64,288079	61,747708	63,174933	63,07
	Methane amount (ml)		719,6732	650,33185	659,38111	676,46	546,44867	691,57433	622,27309	620,10
	Methane rate (ml/h)					9,40				8,61
			R7	R8	R9		R10	R11	R12	
12.08.2009	10.08.2009 13.00-12.08.2009 14.30		3312855	3596169	3541971		4290435	4274393	4327269	
Time (h)	49,5		3441281	3704840	3500947		4229048	4230605	4313002	
			3345637	3625733	3327965		4261623	4240264	4110586	
	average		3366591	3642247,3	3456961		4260368,7	4248420,7	4250285,7	
	Volume (ml)		825	960	885		500	430	490	
	%Methane		61,85351	66,918075	63,513857	64,10	78,27466	78,055142	78,089407	78,14
	Methane amount (ml)		510,2915	642,41352	562,09763	571,60	391,3733	335,63711	382,6381	369,88
	Methane rate (ml/h)					11,55				7,47
			R1	R2	R3		R4	R5	R6	
12.08.2009	09.08.2009 14.30-12.08.2009 12.30	2588158	3764508	3768625	3755900		3919557	4163018	3900076	
Time (h)	70	2721289	3498616	3705271	3517201		3566574	3663452	4199537	
		2854821	3764871	3851026	3933233		3446842	4071903	4166563	
	average	2721422,667	3675998	3774974	3735444,7		3644324,3	3966124,3	4088725,3	
	Volume (ml)		1130	990	1025	1048,33	940	1120	930	996,67
	%Methane		67,53817	69,356628	68,630366	68,51	66,956235	72,868584	75,121101	71,65
	Methane amount (ml)		763,1814	686,63062	703,46125	717,76	629,38861	816,12814	698,62624	714,71
	Methane rate (ml/h)					10,25				10,21
			R7	R8	R9		R10	R11	R12	
14.08.2009	12.08.2009 14.30-14.08.2009 13.30	2616203	3437173	3597007	3591688		3871956	3833748	387761	
Time (h)	47	2782572	3660557	3320073	3324502		3569295	3867346	3634088	
		2719156	3767725	3278662	3481745		3660530	3722254	3965513	
	average	2705977	3621818	3398580,7	3465978,3		3700593,7	3807782,7	2662454	
	Volume (ml)		880	860	940	893,33	525	470	480	491,67
	%Methane		66,92256	62,797664	64,043012	64,59	68,378143	70,35874	49,195799	62,64
	Methane amount (ml)		588,9186	540,05991	602,00431	576,99	358,98525	330,68608	236,13983	308,60
	Methane rate (ml/h)					12,28				6,57
			R1	R2	R3		R4	R5	R6	
14.08.2009	12.08.2009 12.30-14.08.2009 12.00	2616203	3989024	3676011	0		3982926	4000599	4222392	
Time (h)	47,5	2782572	3942068	4140944	0		3786634	4001799	4012333	
		2719156	4212447	3866235	0		4002555	4070050	4064956	
	average	2705977	4047846	3894396,7			3924038,3	4024149,3	4099893,7	
	Volume (ml)		770	720	765	745,00	720	785	765	756,67
	%Methane		74,79454	71,959161	0	73,38	72,506868	74,35668	75,756255	74,21
	Methane amount (ml)		575,918	518,10596	0	547,01	522,04945	583,69994	579,53535	561,76
	Methane rate (ml/h)					11,52				11,83

			R7	R8	R9		R10	R11	R12	
17.08.2009	14.08.2009 13.30-17.08.2009 10.30	2785801	3780849	4178810	3913465		3972196	3553328	4069450	
Time (h)	69	2632099	3661223	3747079	3866465		3655619	3579157	4002695	
		2533112	3865955	3967873	4046561		3910883	3149908	4178552	
	average	2650337,333	3769342	3964587,3	3942163,7		3846232,7	3427464,3	4083565,7	
	Volume (ml)		1400	1400	1345	1381,67	1065	810	790	888,33
	%Methane		71,11061	74,794014	74,370979	73,43	72,561191	64,660907	77,038602	71,42
	Methane amount (ml)		995,5486	1047,1162	1000,2897	1014,32	772,77668	523,75335	608,60496	635,04
	Methane rate (ml/h)					14,70				9,20
			R1	R2	R3		R4	R5	R6	
17.08.2009	14.08.2009 12.00-17.08.2009 13.30	2785801	4069587	4199579	4272750		3945576	4098740	4345218	
Time (h)	73,5	2632099	3842612	4310284	4098511		3854491	3753591	4378899	
		2533112	3795283	3953693	4051631		3894661	4385248	4351430	
	average	2650337,333	3902494	4154518,7	4140964		3898242,7	4079193	4358515,7	
	Volume (ml)		925	855	995	925,00	795	715	855	788,33
	%Methane		73,62259	78,377168	78,121452	76,71	73,542387	76,956109	82,225678	77,57
	Methane amount (ml)		681,009	670,12478	777,30844	709,48	584,66198	550,23618	703,02954	612,64
	Methane rate (ml/h)					9,65				8,34
			R7	R8	R9		R10	R11	R12	
19.08.2009	17.08.2009 10.30-19.08.2009 11.30	3099194	4450143	4025217	4356824		3632523	4295670	4209735	
Time (h)	47	3215710	4127347	4050888	4403413		3455704	4336685	3804563	
		3081467	4347485	4214781	4149995		3743163	3927211	4406040	
	average	3132123,667	4308325	4096962	4303410,7		3610463,3	4186522	4140112,7	
	Volume (ml)		790	645	650	695,00	810	585	530	641,67
	%Methane		68,77642	65,402303	68,697969	67,63	57,636028	66,832004	66,091143	63,52
	Methane amount (ml)		543,3337	421,84485	446,5368	470,57	466,85183	390,96722	350,28306	402,70
	Methane rate (ml/h)					10,01				8,57
			R1	R2	R3		R4	R5	R6	
19.08.2009	17.08.2009 13.30-19.08.2009 14.30	3099194	4616078	4512392	4632436		4080390	4327617	3919766	
Time (h)	47	3215710	4830891	4670593	4788896		4664235	4350883	4405322	
		3081467	4665793	4368748	4368948		4432487	4478087	4330645	
	average	3132123,667	4704254	4517244,3	4596760		4392370,7	4385529	4218577,7	
	Volume (ml)		420	360	370	383,33	375	240	350	321,67
	%Methane		75,09688	72,111526	73,380883	73,53	70,118091	70,008874	67,343728	69,16
	Methane amount (ml)		315,4069	259,60149	271,50927	282,17	262,94284	168,0213	235,70305	222,22
	Methane rate (ml/h)					6,00				4,73
			R7	R8	R9		R10	R11	R12	
21.08.2009	19.08.2009 11.30-21.08.2009 14.30	2996650	3421428	4192841	4215880		3304024	3793877	4030632	
Time (h)	51	2842757	3602889	4119645	4007066		3595336	3686692	4012080	
		2931719	3889658	4492315	4140177		3439276	4038172	3985509	
	average	2923708,667	3637992	4268267	4121041		3446212	3839580,3	4009407	
	Volume (ml)		520	465	490	491,67	890	700	627	739,00
	%Methane		62,21536	72,994055	70,476259	68,56	58,935626	65,662841	68,567143	64,39
	Methane amount (ml)		323,5199	339,42235	345,33367	336,09	524,52707	459,63989	429,91599	471,36
	Methane rate (ml/h)					6,59				9,24

			R1	R2	R3		R4	R5	R6	
21.08.2009	19.08.2009 14.30-21.08.2009 16.30	2996650	4552706	3720474	4084211		3898006	4093345	4027888	
Time (h)	50	2842757	4311743	3702852	4324236		3212384	4213170	4056395	
		2931719	4383974	3550810	3733407		3717334	4344625	4297748	
	average	2923708,667	4416141	3658045,3	4047284,7		3609241,3	4217046,7	4127343,7	
	Volume (ml)		250	228	237	238,33	320	268	255	281,00
	%Methane		75,52293	62,558308	69,21491	69,10	61,723683	72,118107	70,584045	68,14
	Methane amount (ml)		188,8073	142,63294	164,03934	165,16	197,51579	193,27653	179,98931	190,26
	Methane rate (ml/h)					3,30				3,81
			R7	R8	R9		R10	R11	R12	
24.08.2009	21.08.2009 14.30-24.08.2009 11.00	2850803	4284539	4734638	4393476		3922629	3629138	4191704	
Time (h)	68,5	2967226	4434073	4505414	4440912		3956876	3373070	4101340	
		3043919	4517240	4435635	4590596		3784246	3535033	3971315	
	average	2953982,667	4411951	4558562,3	4474994,7		3887917	3512413,7	4088119,7	
	Volume (ml)		420	430	445	431,67	1015	1010	910	978,33
	%Methane		74,67801	77,159599	75,745107	75,86	65,808054	59,452171	69,196744	64,82
	Methane amount (ml)		313,6476	331,78627	337,06573	327,50	667,95175	600,46693	629,69037	632,70
	Methane rate (ml/h)					4,78				9,24
			R1	R2	R3		R4	R5	R6	
24.08.2009	21.08.2009 16.30-24.08.2009 12.15	2850803	3888729	4327263	4284551		4274499	4281164	4472275	
Time (h)	68,75	2967226	4035430	4156940	4428742		4340501	4600435	4733784	
		3043919	3880608	4437351	4314005		4056585	4617706	4561987	
	average	2953982,667	3934922	4307184,7	4342432,7		4223861,7	4499768,3	4589348,7	
	Volume (ml)		235	280	235	250,00	310	220	300	276,67
	%Methane		66,60368	72,904704	73,501323	71,00	71,494354	76,164434	77,680697	75,11
	Methane amount (ml)		156,5186	204,13317	172,72811	177,79	221,6325	167,56175	233,04209	207,41
	Methane rate (ml/h)					2,59				3,02
			R7	R8	R9		R10	R11	R12	
28.08.2009	24.08.2009 11.00-28.08.2009 10.45	3014276	4307897	3299263	3863860		3562851	3453106	3566880	
Time (h)	95,75	3049324	4292273	3122476	3375603		3596194	3506071	3507590	
		2986662	4575858	3390002	3773883		3596521	3640923	3701538	
	average	3016754	4392009	3270580,3	3671115,3		3585188,7	3533366,7	3592002,7	
	Volume (ml)		425	370	365	386,67	1120	1455	1375	1316,67
	%Methane		72,79363	54,206945	60,845454	62,62	59,421296	58,562393	59,534232	59,17
	Methane amount (ml)		309,3729	200,56569	222,08591	244,01	665,51852	852,08282	818,59569	778,73
	Methane rate (ml/h)					2,55				8,13
			R1	R2	R3		R4	R5	R6	
28.08.2009	24.08.2009 12.15-28.08.2009 12.30	3014276	4112628	4392868	4308612		4409694	3818118	4368432	
Time (h)	96,25	3049324	4301679	3967276	4143162		3846625	3742753	4409417	
		2986662	4247762	4462506	4303713		4341287	3777205	4075498	
	average	3016754	4220690	4274216,7	4251829		4199202	3779358,7	4284449	
	Volume (ml)		335	350	340	341,67	400	285	310	331,67
	%Methane		69,95416	70,841319	70,470264	70,42	69,598018	62,63949	71,010911	67,75
	Methane amount (ml)		234,3464	247,94462	239,5989	240,63	278,39207	178,52255	220,13382	225,68
	Methane rate (ml/h)					2,50				2,34

			R7	R8	R9		R10	R11	R12	
30.08.2009	28.08.2009 10.45 30.08.2009 17.30	2846325	3146009	4190899	3961066		3972303	3774929	4096520	
Time (h)	54,75	3047298	3038848	4167386	3944678		4054858	3616922	4053644	
		3169673	3121794	4057037	4007303		4043922	3628732	4240980	
	average	3021098,667	3102217	4138440,7	3971015,7		4023694,3	3673527,7	4130381,3	
	Volume (ml)		160	190	140	163,33	500	600	580	560,00
	%Methane		51,34253	68,492312	65,721383	61,85	66,593229	60,797876	68,358928	65,25
	Methane amount (ml)		82,14805	130,13539	92,009937	101,43	332,96615	364,78726	396,48178	364,75
	Methane rate (ml/h)					1,85				6,66
			R1	R2	R3		R4	R5	R6	
30.08.2009	28.08.2009 12.30-30.08.2009 15.30	2846325	4545315	3079787	3628136		3307700	3522452	3904554	
Time (h)	51	3047298	4451347	3381386	3454184		3308209	3489638	3631532	
		3169673	4647827	3365066	3707560		3319323	3480115	3923209	
	average	3021098,667	4548163	3275413	3596626,7		3311744	3497401,7	3819765	
	Volume (ml)		130	135	150	138,33	170	115	125	136,67
	%Methane		75,27333	54,208971	59,525144	63,00	54,810259	57,882943	63,218144	58,64
	Methane amount (ml)		97,85533	73,182111	89,287716	86,78	93,17744	66,565385	79,02268	79,59
	Methane rate (ml/h)					1,70				1,56
			R7	R8	R9		R10	R11	R12	
04.09.2009	30.08.2009 17.30-04.09.2009 10.30	2970485	4223517	2773726	3473148		3359231	3440572	3946072	
Time (h)	113	2922649	4402857	3034899	3526977		3417379	3885630	3650215	
		3034854	4313879	3101201	3611121		3378138	3463452	3649110	
	average	2975996	4313418	2969942	3537082		3384916	3596551,3	3748465,7	
	Volume (ml)		300	300	270	290,00	315	800	920	678,33
	%Methane		72,47015	49,898286	59,426861	60,60	56,870305	60,426011	62,978338	60,09
	Methane amount (ml)		217,4105	149,69486	160,45252	175,85	179,14146	483,40809	579,40071	413,98
	Methane rate (ml/h)					1,56				3,66
			R1	R2	R3		R4	R5	R6	
04.09.2009	30.08.2009 15.30-04.09.2009 14.00	2970485	4357066	4061665	4284393		3994584	3549023	4216466	
Time (h)	118,5	2922649	4485150	4185816	4051713		3917787	3554177	4009446	
		3034854	4097685	4419740	4238848		3979331	3572403	4354939	
	average	2975996	4313300	4222407	4191651,3		3963900,7	3558534,3	4193617	
	Volume (ml)		300	300	365	321,67	365	200	200	255,00
	%Methane		72,46818	70,941073	70,424344	71,28	66,597883	59,787284	70,45737	65,61
	Methane amount (ml)		217,4045	212,82322	257,04886	229,09	243,08227	119,57457	140,91474	167,86
	Methane rate (ml/h)					1,93				1,42
			R7	R8	R9		R10	R11	R12	
07.09.2009	04.09.2009 10.30-07.09.2009 12.45	3224206	2807350	4535007	3477368		3851527	3404180	4353795	
Time (h)	74,15	3538063	2919201	4271932	3655967		4095452	3543840	4325371	
		3192744	2993288	4106288	3708454		4144395	3801651	4181511	
	average	3318337,667	2906613	4304409	3613929,7		4030458	3583223,7	4286892,3	
	Volume (ml)		140	145	140	141,67	225	270	350	281,67
	%Methane		43,79622	64,857911	54,453917	54,37	60,730076	53,991245	64,593974	59,77
	Methane amount (ml)		61,31471	94,043971	76,235484	77,20	136,64267	145,77636	226,07891	169,50
	Methane rate (ml/h)					1,04				2,29