Rest methane potential in digestates from farm scale biogas production plants.

K. Ahlberg-Eliasson*, A. Schnürer**, S. Bergström Nilsson*

* Swedish Rural Economy and Agricultural Society, Box 5007, SE-514 05 Länghem, Sweden
(E-mail: *karin.eliasson@hushallningssallskapet.se, sara.nilsson@hushallningssallskapet.se)*
**Department of Molecular Sciences, BioCenter, Swedish University of Agricultural Sciences, Box 7025, SE-750 07 Uppsala, Sweden
(E-mail: *anna.schnürer@slu.se*)

Abstract
Biogas plants at farm scale level digesting agricultural waste i.e. manure, represent an important approach to both produce fossil free energy and to reduce GHG emissions from the agriculture. In these processes a high degree of degradation of added substrates is essential in order to reach high methane yield and to minimize risk for methane leakage from the digestate produced. Insufficient degradation of organic matter leads to more degradable matter in the digestate storage tank. The aim of this study was to further investigate the relationship between the rest methane potential (RMP) in the digestate and the efficiency of the biogas plant. To highlight this question the RMP were determined for digestates from 11 Swedish biogas plants. The gas production in the digester was also determined, expressed as volumetric gas production and specific methane production, and used as a measure of the efficiency of the biogas plant. The result showed RMP values from 48 to 145 mL CH4 * g VS^{-1} and a positive correlation between RMP and the volumetric gas production was found. Furthermore, relating the rest methane potential to the specific methane potential (RMP/SMP) showed a positive correlation with the organic loading rate. Overall the results showed that measurement of rest methane potential can be a useful tool for evaluation of both the degradation efficiency in biogas plants as well as the risk for GHG emissions during digestate storage.

Keywords
Rest methane potential, agricultural waste, anaerobic digestion

INTRODUCTION

Biogas production at farm scale level allows *i*) production of fossil free energy, *ii*) recycling of nutrients, *iii*) reduction of GHG emissions from the agricultural sector. However, there is also a potential risk of GHG emissions during digestate storage and handling, caused by for example insufficient digestion, operating complications or problems according to the technical design of the biogas plant (Kaparaju & Rintala 2011; Monlau *et al.* 2015).

One way to evaluate risk of GHG emissions are to measure the rest methane potential (RMP) from the digestate. This measure also gives information about the substrate degradation efficiency and how much of the energy bound in the substrate still being available for biogas production (Liebetrau *et al.* 2013). Swedish farm scale biogas production has been under hard economic pressure, but since 2015 a subsidy system is in service, giving economical support to biogas plants using manure as a substrate. The overall aim of the subsidy is increase the amount of manure being treated in a biogas processes and consequently reduce risks for GHG emissions from the agricultural sector. The level of subsidy relates to the amount of manure digested at the biogas plant and the level of gas produced (Swedish Board of Agriculture 2015). The efficiency of the plant in regard to level of organic matter degraded (degree of degradation), or the rest methane potential is however not taken into account.
The main objective in this study was to evaluate the rest methane potential in the digestate from agricultural biogas plants and to investigate the relationship between this potential and the overall gas production at the biogas plant. An additional aim was to compare obtained results with data collected from the same biogas plants at an earlier occasion and by doing so further investigate relationships between RMP and operational parameters such as OLR and/or HRT. The hypothesis was RMP may

be a useful parameter to evaluate the efficiency in the biogas plant i.e. degradation of organic matter and biogas production.

MATERIALS AND METHODS

Process data from 11 Swedish farm scale biogas plants were collected during 2015. Methods for sampling and measurements were according to a previous study (Ahlberg-Eliasson *et al.* 2017). To enable comparison, the biogas plants were coded by the same ID numbers as used in the previous study.

Bio-methane potential and rest methane potential

The bio-methane potential (BMP) of substrates and the rest methane potential from digestates (RMP) were determined by continuous measurement of methane using the AMPTS equipment of Bioprocess Control AB. The inoculum used for the BMP analyses was taken from a co-digestion plant. The substrate to inoculum ratio in the tests were set to 1:3 on VS basis and the load of the substrate corresponded to 3 g VS* L^{-1}. The active volume in the bottles was 400 mL.

To evaluate the rest methane potential (RMP) in the digestate the AMPTS batch bottle were filled with 400 mL of digestate from the biogas plant and directly, under normal temperature conditions nonstop transported to the biogas laboratory. All samples for BMP and RMP were analysed in triplicate and were incubated for 30 days at 38 °C.

The methane content in the biogas produced at the biogas plant was determined by using a gas analyser *Multitec 540* (*Sewerin Multitec 540; PPM Mätteknik, Industriell Gasmätning AB, Hisings Backa*). The average value of methane content from three samplings points was used to calculate SMP (specific methane potential), RMP and BMP. The gas volume was adjusted to standard pressure and temperature.

Calculations and statistics

The specific methane production (SMP) was defined as the yearly average methane gas production at the biogas plant divided by yearly incoming amounts of volatile solids (VS) in substrates. The ratio RMP/SMP was calculated to express the level of RMP in relation to SMP. The difference between the VS content in the digestate versus the substrate was calculated to get the reduction of VS (VS_red).

In SAS 9.4 the CORR procedure was used to evaluate the Pearson partial correlation coefficient (n=11). Significance levels determined for linear correlations were: $P<0.001$, $P<0.01$ and $P<0.05$.

Table 1. RMP, BMP and SMP (mL CH_4 * g VS^{-1}), OLR (Ton VS * m^3 day^{-1}) and MP_V (m^3 CH_4 * m^3 day^{-1}) for the 11 investigated biogas plants.* Not Analysed

ID	VS_red (%)	RMP	BMP	SMP	OLR	HRT Days	RMP:SMP (%)	MP_V
2	37	58	136	227	2.4	29	26	0.5
13	44	52	132	125	4.3	22	42	0.5
14	50	56	246	314	2.4	46	18	0.8
15	38	49	250	250	1.8	30	20	0.4
17	25	90	514	450	1.0	26	20	0.5
18	68	70	266	293	1.2	19	24	0.4
20	57	54	163	246	2.0	35	22	0.5
21	38	56	455	461	1.5	33	12	0.7
24	44	145	394	462	2.3	19	31	1.1
25	36	48	NA*	409	1.1	25	12	0.5
27	53	117	325	379	2.8	23	31	1.1

RESULTS AND DISCUSSION

The specific methane production (SMP) for the biogas plants in the study varied between 125 to 462 mL CH_4 * g VS^{-1} and the bio-methane potential (BMP) varied from 132 to 514 mL CH_4 * g VS^{-1} (Table 1). Only two biogas plants (no 13 and no 17) showed lower SMP values compared to BMP values. These results suggest that the majority of the plants operated at relatively good efficiency. The rest methane potential (RMP) in the digestate were 48 to 145 mL CH_4 * g VS^{-1}, results in line with previous studies, showing a wide variation of RMP from 20 to 240 mL CH_4 * g VS^{-1} (Seppala et al. 2013; Thygesen et al. 2014; Ruile et al. 2015).

The statistical evaluation showed a positive correlation ($P<0.01$) between RMP:SMP and OLR. This correlation indicate that a high organic load lead to a decrease in SMP or an increase of RMP. A negative correlation ($P>0.05$) between OLR and SMP was also found. This result is in line with earlier studies showing that OLR as well as retention times affect the RMP (Lindorfer *et al.* 2008; Thygesen *et al.* 2014; Ruile *et al.* 2015). However the dataset in this study show no correlations for HRT. Interestingly, RMP had a positive correlation with the volumetric methane production MP_V ($P<0.01$), suggesting that digesters with high efficiency expressed as MP_V have a comparably high risk for methane production from the digestate (Figure 1). Plants, no 17, 18, 24 and 27, all had comparably high RMP (> 70 CH_4 * g VS^{-1}). Plant no 24 and 27 also had high MP_V, obtained by addition of energy rich materials as co-substrate to the manure (Table 2). In contrary, no 17 and 18, had a high RMP but relatively low MP_V. These plants use mono-digestion with swine manure as the only substrate. Both these two biogas plants had operating problems, probably explaining the less effective biogas production process. Additional plants with high MP_V and low RMP are no 14 and no 21. No 14 is a co-digestion plant adding high energy rich food waste and no 21 is also a typical co-digestion plant. Conclusively, high RMP was found among plants using both mono- and co-digestion.

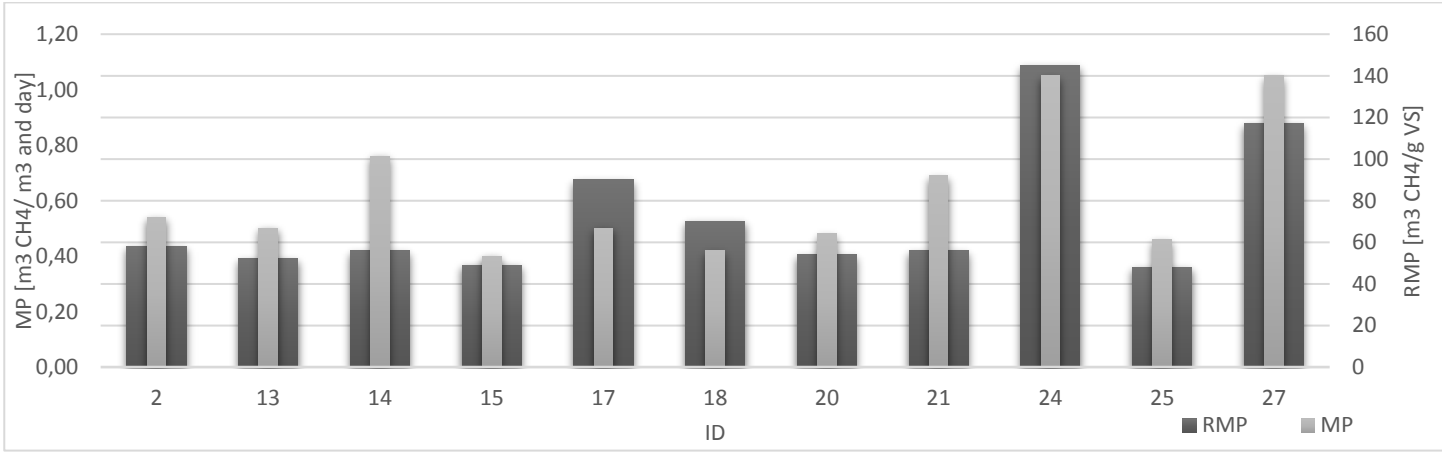

Figure 1. Rest methane potential RMP (black bars) expressed as m^3 CH_4*ton VS^{-1} of the digestate and volumetric methane production MP_V (grey bars) expressed as m^3 CH_4*m^3 day^{-1}

Compared to data collected one year earlier the efficiency, measured as both volumetric methane production (MP_V) and as well as specific methane potential (SMP), at the majority of investigated biogas plants had increased (Table 2). That can be explained by an increase in OLR, using more manure but also to some extent substrates having a comparably higher energy content than manure. For seven of the plants a lower VS reduction (VS_red) was seen compared to the previous period, probably caused by the increase in OLR, giving a shorter HRT. Only plant no 13 and no 24 showed an improvement of VS_red compared to the previous measurement. This development, that is and increased load of manure, maybe driven by the principles in the subsidy system supporting high load of manure.

Table 2. The change in (%) for different operating parameters between the results from Ahlberg-Eliasson et al. 2017 compared to the data collected 2015.

ID	VS_red	HRT	SMP	OLR	MP_V
2	-8	-15	21	26	42
13	93	-4	5	10	9
14	-24	-19	-8	4	4
15	-22	3	18	-14	0
17	-27	0	19	-13	92
18	14	0	38	-33	5
20	9	-3	-4	100	-9
21	-20	-11	57	23	97
24	17	0	66	45	139
25	-30	-36	72	-45	2
27	-21	-4	80	33	36

The farm scale biogas branch is in need of new tools to evaluate relationships between operating parameters and performance of the biogas plant. The relatively simple test of RMP could be an interesting option to get a measure of the efficiency at the biogas plant and to evaluate risks for emissions. To take into consideration when comparing results of RMP is that the methods used varies in different studies, for example in regard to incubation temperature and time (Monlau *et al.* 2015). The RMP can also be measured as a common BMP test using an inoculum and the digestate as the substrate (Thygesen *et al.* 2014). The earlier study of 27 Swedish biogas plants showed the importance to use energy rich substrates in order to reach high gas production and degree of degradation of organic matter, i.e. VS removal, as well as nutrient concentration in the digestate (Ahlberg-Eliasson *et al.* 2017). Compared to the former result this study show that the evaluated biogas plants had increased the gas production as well as the OLR. This approach might result in reduced HRT and as a consequence also decreased VS reduction and an increased RMP and increased risk for GHG emissions from digestates. This development needs to be further followed up especially as the Swedish subsidy system tend to favour plants using a high amount of manure. We therefore suggest that the Swedish Board of Agriculture, responsible for the subsidy system, take this development under consideration when the subsidy system are under assessment. Considering the results in this project, methods to improve the farm scale biogas production are important, specifically methods contributing to improve the degradation as well as the gas production. Strategies can for example include change of digester temperature, and/or prolonged retention time or enhancement of microbial activity.

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