BENCHMARKING COMMERICAL BIOGAS PLANTS TO IMPROVE PERFORMANCE

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1 INTRODUCTION

Each European country has been assigned to produce about 20% renewable energy by 2020. To achieve this goal would meet the current Kyoto agreement on reducing GHG emissions that effect climate change. Biogas production from livestock sources in particular can contribute a considerable fraction of the reduced amount with agriculture targeting 6% based on 2008 emission levels by 2020. In order to improve the effectiveness of agro biogas production an EU project was funded targeting "Innovative approaches to improving the yield of medium to large scale biogas plants" http://www.eu-agrobiogas.net/.

The main objective was to benchmark those processes involving feedstock treatment, fermentation and mechanical aspects of the digester performance for all 13 biogas plants. Additionally we investigated the specific costs per kilowatt hour produced. Weak point analysis was also performed to determine the concerns of the operators. To ensure an efficient technology transfer into demonstration activities at full scale commercial agricultural biogas plants, selected operators (SMEs) of medium to large scale agricultural biogas plants agreed to collaborate and provide access to their plants.

2 MATERIALS AND METHODS

2.1 Scope of methods

The assessment of the biogas industry today has to be considered from a multidisciplinary perspective as real world biogas production implies the potential to generate conflicts as well as win-win situations. Therefore, biogas production cannot be assessed from an economic perspective only but also has to account for environmental impacts. To include environmental aspects requires the development of a modified financial perspective which should include the technical and human resource concerns. In a difficult economic market the biogas plant has to integrate production from feedstock sources with outputs locally to maximise what is considered to be a marginal profit from biogas alone. Due to the large volume of data gathered only data selected by the authors will be presented here.

2.2 Benchmarking and weak point analysis of biogas plant capacity

To improve the performance of the biogas plants requires that we first devise methods to assess performance by a range of observation methodologies to determine important monitoring parameters and criteria of evaluation. We adopted benchmarking criteria as defined by the most recognised approach as that of W.E. Deming's to quality control which consists of five stages - 'plan, measure, analyse, recommendations and implementation and monitoring and reviewing'. Perhaps the most notable output is that benchmarking, which is the collection of information that can overcome common ideas and concepts that are accepted as normal but may hamper progress. The stages of benchmarking can be a means of assessing a process or identifying best practice and improving processes.

Further discussions occurred at the initial meeting in Vienna in 2007 and partners clearly recognised and required sufficient information for quality data for this report. Partners also recognised that parameters often influenced each other. The best outcome was identified to acquire data from each biogas plant in the form of:

- Questionnaire to be completed by the biogas plant operator in the presence of the scientific partner for economic and social analysis

- Weak point analysis of each biogas plant by the biogas plant operator and the scientific partner
- Database of defined parameters from recent biogas operations up to 2007.

The questionnaire should include requests for information on the most influential parameters which have an impact on the biogas yield in an unbiased procedure. These were identified as the following parameters:

TABLE 1 **Influential parameters which have an impact on the biogas yield**

Benchmarking	Weak point concerns
Biogas plant technology and design	
Feedstock or substrate processing prior to the feeding of the digester	Loading rate
Pre-treatment of biomass (thermo-chemical, enzymes, etc.)	Hydraulic retention time
Hydraulic retention time and loading rate	Methanogenesis failure due to
Biogas utilisation	-Volatile fatty acids
Fermentation temperature	-Ammonium concentration
Biogas yield	-pH value
Methane and hydrogen sulphide content of the biogas	calorific value of biogas and effect on biogas engine
Degree of heat utilisation	Economics of using heat from CHP unit
Utilisation of digested sludge	Land spreading
Plant management costs	Biogas production economics
Personnel cost and personnel requirement	

3 RESULTS AND DISCUSSION

3.1 Description of biogas plants

Benchmarking data was collected from 13 biogas plant sites (BP1 to BP13). These biogas plants differ in both construction and use. Firstly, all biogas plants were operating at about 5 to 12% dry solids, which classify them as 'wet' biogas plant systems. Out of these, 7 plants had pre-treatments and post digesters, two had fermentation tanks that were within the outer hydrolysis tank. There were two biogas plants that were operating at thermophilic temperatures (55^{o}C). The other systems were either single or two process operating systems that may or may not have parallel tanks in the same stage (e.g. 2 methanogenesis stage tanks). Livestock slurry from cattle and pigs dominated the feedstock for 8 biogas plants, energy crops a further 4 biogas plants and fat and glycerol 1 biogas plant. Averaged outputs for the 13 plants were; 16 MWh d^{-1} electricity from 4428 m^3 of methane from 103 t fresh weight of feedstock. Specific methane yield of the feedstock was 0.44 m^3 kg VS $^{-1}$ with a methane productivity of 1.3 $m^3.CH_4.m^{-3}.d^{-1}$. Clearly with such a range of different approaches comparison will require careful consideration.

3.2 Comparing outputs from biogas plant

Weak point analysis identified that there were two main concerns: poor process monitoring and control as the lack of information and approaches for the pre-treatment of feedstock. The first relates to methane yield per amount of volatile solids (VS). VS are determined as the weight loss from heating the sample to constant weight from 105^{o}C to 550^{o}C. Surprisingly the differences between the plant were up to a factor of three as shown in Figure 1.

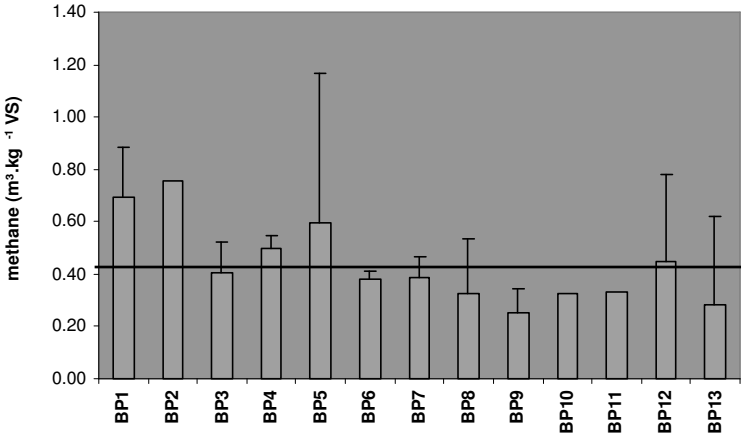

FIGURE 1 **Distribution of specific methane yield showing standard deviation error bars**

However this is not the only criteria for the assessment of the biogas plant performance. For example if some considerable capital investment has occurred for a large biogas plant then the economic return will be obtained more quickly by only utilising the easily convertible VS to biogas and then introducing more feedstock (i.e. undigested feedstock will pass through the digester). This measurement is known as methane productivity which is methane volume produced from 1 m^3 of digester volume per day ($CH_4.m^3.m^3.d^{-1}$). As expected high methane productivity reflects a low specific methane yield, however only a few biogas plants reflect this rationale as shown (Figures 1 and 2).

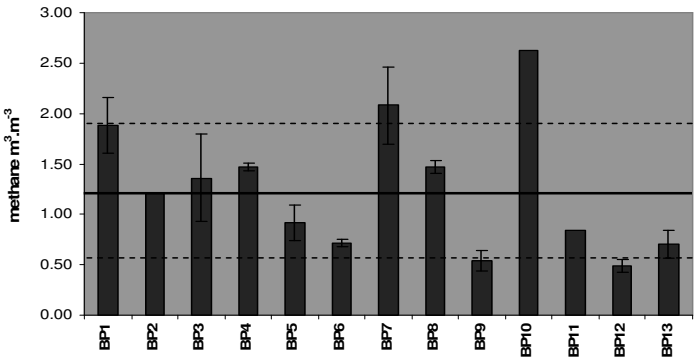

FIGURE 2 **Distribution of methane productivity per day for 13 commercial biogas plants**

Comparison of the hydraulic retention time (HRT) reveals that low HRT is the reason for the high methane productivity. Figures 2 and 3 suggest that variation maybe due to feedstock composition and/or co-digestion effects. For example BP10 has high methane productivity but a low loading rate and specific methane yield.

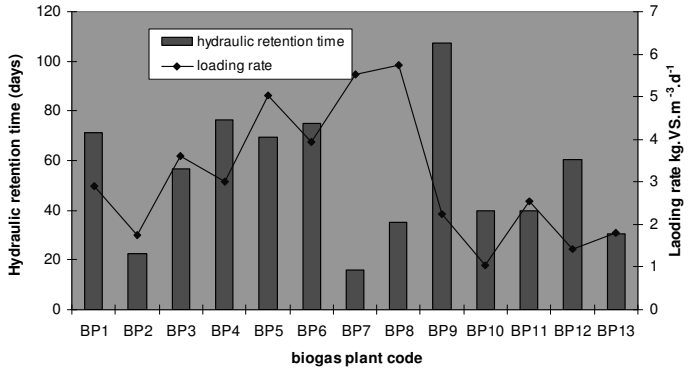

FIGURE 3 **Comparison of loading rate to hydraulic retention time**

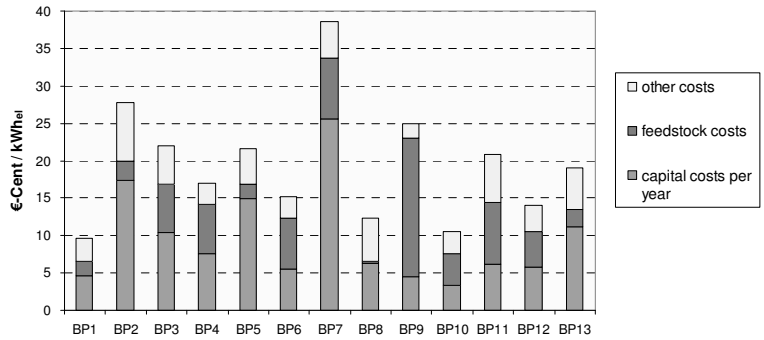

FIGURE 4 **Specific costs per kWh**

Similarly some biogas plants have a low HRT to remain viable in terms of the costs (Figure 4) of electric production. Both BP2 and BP7 having the lowest retention times and highest specific costs per kWh. The remaining

biogas plants seem to have more complex approaches to biogas production. Table 1 provides some summary information from this exercise highlighting the potential issues and means of improvement.

TABLE 2 **Concerns from collated benchmarking and weak point analysis from commercial biogas plants**

Measured parameter	**Able to improve**	**Comment**
Combined heat and power plants operating at capacity (7000hrs p.a.)	6/13	There are 8700hrs in one year
BP 7, 10, 11 and 12 have reduced methane conversion to electricity when compared to other biogas plant systems.	4/13	Performance could be increased by up to 25%
The average performance of biogas plants was 0.44 m^3 methane kg^{-1} VS.	na	The majority of these biogas plants were above the average value of 0,3 $m^3.kg^{-1}$ VS.
The fermentation stability expressed as standard deviations from the mean specific methane yield value demonstrated a 7 to 100% range	5/13	Process stability could be a function of inputs.
The methane productivity has a mean of 1.25 and a range from 2.62 to 0.5 $m^3.m^3$.	6/13	There will be feedstock type and economic dependencies.
The average degradation rate was 68% ranging from 48 to 89% of the VS. There was no relationship of measured fermentation parameters to the degree of VS degradation	3/13	Feedstock mixtures are complex, but there are design options such as 2nd digester.
High levels of manure feedstock produce about 3 times less biogas per ton of dry matter input	3/13	Transport and economic efficiency may be issues for these plants so alternative feedstock may provide profit
Collectively as the digester increases methane productivity the electricity produced per unit dry weight of feedstock increases	3/13	Suggests the digesters are not operating to full capacity.
There was an inverse relationship of methane productivity to the fraction of energy crop feedstock.	4/13	Maybe due to large HRTs necessary for energy crops

Very few biogas plants had means of monitoring any other fermentation parameters than pH, volume of biogas and temperature as a means of process control. As a consequence biogas plant owners cannot operate at full capacity, because one they are unsure of what it is a two the fear of fermentation failure due to organic overloading means that the plant may not operate to capacity.

4 CONCLUSIONS

Benchmarking and weak point analysis have rarely been performed on commercial biogas plants with only one in recent years from work by Braun et al. (2004). There was broad agreement with our findings except for our higher average specific methane yield. Data was collected by four means from the biogas plants: as periodic data, weak-point analysis from the plant operators; a questionnaire and a schematic of each plant. Analysis of this data revealed different approaches to biogas production and potential ways that may improve economic return. Weak point analysis identified the need for more pre-treatment of feedstock and monitoring and process control of fermentation processes in order to allow for better supported decision-making by the biogas plant operators.

ACKNOWLEDGEMENTS

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