ICMERE2019-PI-073

DEMAND BASED ENERGY PRODUCTION BRINGS A SUSTAINABLE CONDITION FOR BIOGAS ENERGY

Sharif Ahmed*, Kerstin Maurus and Marian Kazda

Institute of Systematic Botany & Ecology, Ulm University, Albert-Einstein-Allee 11, 89089, Ulm, Germany
sharif.ahmed@uni-ulm.de, kerstin.maurus@uni-ulm.de, marian.kazda@uni-ulm.de

Abstract*- The dynamic of energy consumption over the intraday has got an interest for biogas plant owners to generate energy when its demand is high. Sugar beet silage can be an option because it produces just-in-time biogas. In this study, the experiment was done at different ratios of maize silage (M) and sugar beet silage (S) in addition to a control reactor fed hourly with M alone. Beet silage was given every 12 hours (intermittent feeding). The hypothesis was that intermittent feeding could produce demand energy (i.e two-fold baseload) for 6 hours without requiring additional storage capacity. A model was performed using experimental data to prove the hypothesis. The results showed that gas production during intermittent feeding met demand energy without the necessity of additional storage capacity. The concept of demand energy production opens a new aspect for countries like Bangladesh, where biomass scarcity hinders continuous electrical energy production.*

Keywords: Sugar beet silage, Maize silage, Just-in-time biogas, Demand energy, Modelling

1. INTRODUCTION

Energy demand over the day differs due to dynamics of consuming electrical energy in industrial and residential sectors. In Germany, the average demand for electrical energy is increasing during the late morning (9-12 am) and at rush hours (5-8 pm) [1]. As a result, there is a divergence between energy demand and energy supply. The deviation of energy can be fulfilled by biogas energy since it is weather independent, unlike solar and wind energy. Furthermore, it has been interested by many biogas plant owners to generate electrical energy only at periods of high demand due to additional profit. Mostly, biogas plants have been designed to generate constant electricity (baseload) with a storage capacity of 25% of daily produced biogas [2]. In this context, flexible energy production in existing biogas plants might require additional storage capacity.

Flexible or demand energy production can be met by appropriate feeding management. Using easily degradable substrates such as sugar beet silage refers as suitable biomass because of its just-in-time biogas production characteristics. However, fermentation with only beet silage requires supplementation of external buffering agents to stabilize the process [3]. Such problems can be mitigated by adding buffer rich substrates such as maize silage or grass silage [4].

In this study, co-fermentations at different ratios of beet silage and maize silage were operated at the organic loading rate (OLR) 2 kgVS /m^3 /day under mesophilic temperature in wet anaerobic process. In co-fermentation, sugar beet silage was fed at 12 hrs interval (intermittent feeding) in parallel to hourly feeding of maize silage. A control reactor fed by maize silage alone was also maintained. Gas productions from this experiment were further modeled to understand the demand-based energy production and its effect on storage capacity. The hypothesis was that just-in-time biogas production by intermittent feeding of beet silage could increase the base load during the utilization phase without adding storage capacity. The model was performed using biogas for 12 hours period divided into (1) utilization phase (0-5 hours) when biogas was consumed to generate electricity and (2) storage phase (6-11 hours).

2. MATERIALS AND METHODS

The experiment started with the inoculum, which was sieved beforehand and kept at 40 °C under AD conditions for several days to avoid background methane production. Afterward, it began at low OLR of 0.5 kgVS /m^3 /day with the increment of the same OLR at every two weeks before reaching the final loading rate of 2 kgVS /m^3 /day. Furthermore, the final OLR equilibrium phase with hourly feeding of both feedstocks was also adapted before commencing the intermittent feeding with sugar beet silage. Total experimental period was 177 days, where intermittent feeding started on day 113. In this paper, data were considered for last 63 days to evaluate demand energy production by intermittent feeding.

The experiment was done in four identical continuously stirred tank reactors (CSTRs) (details in [5]) at 4 different ratios of maize silage (M) and sugar beet silage (S) (feedstock characteristics are given in [6]) operated at 40 °C with OLR 2 kgVS /m^3 /day. Mono fermentation of maize silage was conducted in control reactor R1, whereas, maize amount was substituted by beet silage at the share of 14%, 25% and 75% based on volatile solids, respectively, in reactors R2, R3, and R4 (Table 1). Sharing beet silage more than 75% was found to acidify the process causing instability, as mentioned in [7]. Sugar beet silage was fed at 12hrs interval (intermittent feeding) in parallel to hourly feeding of maize silage. Through the experimental period, online process parameters such as biogas volume and methane concentration were evaluated at 10 mins interval. Process stability was monitored weekly by off-line measurements in terms of pH, alkalinity ratio and volatile fatty acids (i.e. acetate, butyrate, and propionate) concentrations. Specific biogas and methane yields (Nl / kgVS) were calculated by dividing daily produced gas (Nl stands for norm liter) to the input amount of feedstocks in kgVS.

Table 1: Experimental design in four reactors at the organic loading rate (OLR) 2 kgVS /m3/day.

Reactors	M	S	HRT (days)	Data evaluation period (days)
	VS	VS		
R1	100%	0	173	63
R2	86%	14%	128	63
R3	75%	25%	108	63
R4	25%	75%	61	63

VS: volatile solids; HRT: hydraulic retention time.

To understand the demand energy production and its effect on storage capacity, a model was performed for virtual plants considering experimental feedstock ratios, as mentioned above. Gas storage capacity was presumed 25% of daily biogas from R1 (reactor with only maize silage) applicable for each reactor. Standardized electrical energy (i.e. baseload) was calculated empirically based on hourly gas production from R1 and realized for other reactors. The virtual plant at respective feedstock ratio was supposed to generate a two-fold baseload (referring as demand energy) using biogas during utilization time of 6 hours, resulting in a need to store the gas for the remaining 6 hours within 12 hours period. Modeling occurred with the target of demand energy production during utilization phase but no load during storage phase. The virtual storage level shown in percentage was computed by summing up the surplus biogas (subtracting produced gas to required gas) at hourly intervals.

3. RESULTS AND DISCUSSION

3.1 Process stability

pH and alkalinity ratio were within the optimal range in all reactors (data not shown) other than in R4. Reactor R4 with the highest share of beet silage showed a low pH value of 6.6 after 150 days with high alkalinity ratio of 0.5. Additionally, the ratio of propionate to acetate was 2.9 more than the value 1.4, a level to indicate process instability [8]. As a result, biogas production and methane concentration were decreasing simultaneously that led to cease the feedstock supply.

3.2 Biogas dynamic and methane concentration

Sugar beet silage contains a high amount of sugar that degrades promptly [6], thus biogas production increases immediately after feeding. As shown in Figure 1, the biogas production rate reached its maximum within 1 hr after feeding of beet silage and returned to its initial value after 4 hrs. However, the production rate in reactor R4 with 75% VS based share of beet silage reappeared to its initial value after 9 hrs. Maximum biogas production rates were 0.59, 0.68 and 1.03 lN/hr in R2, R3, and R4, respectively. Methane concentrations were constant in both reactors R1 and R2 but decreased after sugar beet silage was given from 63% to 60% and 57% in reactors R3 and R4, respectively. Methane percentage, however, recovered after 3 hrs and 6 hrs in R3 and R4. After feeding, both biogas and methane production rates reached their maximum at the same time, indicating adequate microbial adaptation to intermittent feeding.

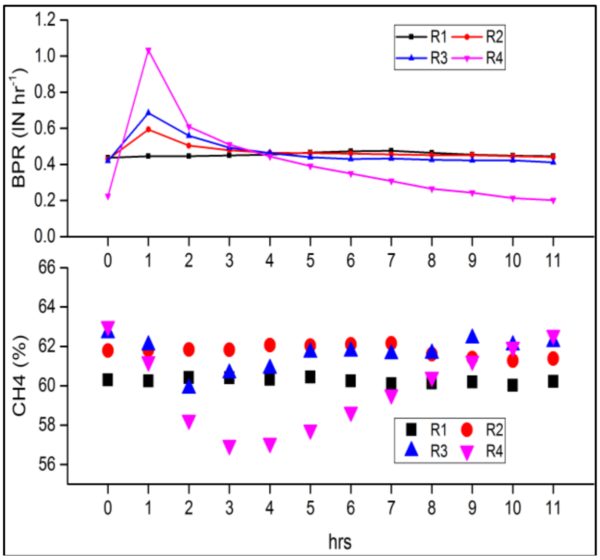

Figure 1: effects on biogas production rate (BPR) and methane concentration after intermittent feeding of beet silage. Maize silage was fed hourly and sugar beet silage feeding occurred at 0 hrs.

Substituting maize silage with beet silage did not increase significantly both biogas and methane yields, shown in Table 2. Moreover, sharing 75% VS based beet silage compared with mono fermentation of maize silage lowered the yields by 11 % and 13 %, respectively. High amount of beet silage could increase the kinetic of acidogenic microorganism resulted in the acidification of biogas fermenter, which inhibits the methanogenesis process. Hence, lower yields were produced while adding high amount of sugar beet silage with maize silage.

Table 2: Comparing biogas and methane yields of co-fermentation with respect to mono-fermentation of maize silage.

Reactors	Biogas yield (lN / kgVS)	Increment (%)	Methane yield (lN / kgVS)	Increment (%)
R1	546	-	329	-
R2	564	3	348	5
R3	560	2	345	4
R4	479	-11	285	-13

3.3 Model-based demand energy and its effect on storage capacity

A model was performed, based on experimental data from the previous chapter, to demonstrate demand energy production. It was presumed that biogas would be utilized to generate demand-based electrical energy (i.e. two-fold baseload) during the utilization phase of 6 hours and stored for the remaining 6 hours within 12 hours period (details in the chapter of materials and methods).

The model illustrated that producing demand-based energy was depending only on feedstock ratio and might ask for additional storage capacity (Figure 2). Considering a storage capacity of 25% from daily biogas of control reactor (R1) is not sufficient enough to meet demand energy by hourly feeding with maize silage. It exceeded more than 100% storage capacity for reactor R1. Whereas, adding a small portion of sugar beet silage (R2) energy could not only be produced on demand but also the storage level was kept under 100%. Further increment of sharing beet silage in R3 reduced the storage level to 93%. For reactor R4, with the highest share of beet silage, the storage level could be reduced to 63% but the energy produced during utilization phase was insufficient to meet demand energy goals.

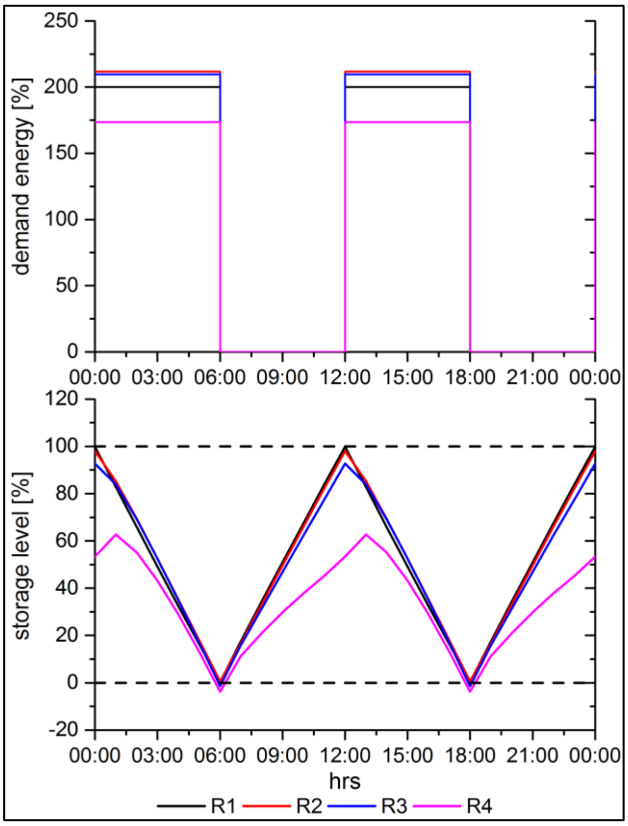

Figure 2: Storage level of different reactors to meet demand energy during utilization time. Dash lines represent the upper and lower limits of gas storage.

3.4 Evaluation of demand energy using typical biomasses in Bangladesh

Based on a survey in the energy sector of Bangladesh, low rate of electricity generation in comparison to its demand increased the rate of load shedding by 6.72 % per annum [15]. It was also demonstrated that the abundance of biomasses in Bangladesh could accommodate 73% of total energy[16]. The scenarios of typical biomasses are presenting in Table 3. It is also remarkable that the recoveries of certain biomasses are lower than their generations.

Table 3: Productions, recoveries and the yields of typical biomasses in Bangladesh.

	[a]Waste production (kiloton/year)	[b]Ratio of waste recovery (%)	Biogas / Methane yield (L/kgVS)	Ref.
Rice straw	56852	35	463 / 240	[9]
Maize cobs	278	100	481 / 250	[10]
Sugarcane bagasse	1354	100	-/236	[11]
Wheat straw	1701	35	220/125	[12]
Cattle manure	23978	60	466 / 233	[13]

[a]collected and [b]calculated based on data in [14].

Available typical biomasses in Bangladesh could play an important role in the energy sector in respect of demand-based energy production. For instance, methane yields from rice straw and sugarcane bagasse were 240 and 236 L/kgVS (Table 3), respectively. Kinetic rates, that characterize the decomposition speed, for these biomasses were, respectively, 0.078 day^{-1} [9] and 0.124 day^{-1} [11]. Whereas, a comparatively low kinetic rate of 0.032 day^{-1} was documented for maize silage [17]. Hence, with adequate feeding management, the biomasses with those kinetics might be an option to produce electrical energy during high demand hours. Moreover, co-fermentation of such feedstocks may have synergistic effects promoting a good perspective to produce such energy. However, required storage capacity and feeding management still need to be properly investigated before implementing in practice. Indeed, It can be presumed that demand-based energy production using typical biomasses might contribute to reduce load shedding rates in rural areas, where only 25% people have access to electricity.

4. CONCLUSIONS

This study illustrated that demand-based energy can be achieved by suitable substrates and adequate feeding management. Intermittent feeding with easily degradable substrate alters the methane and carbon dioxide concentration within acceptable ranges. Nevertheless, high share of acidic substrates could lead to an unstable process. Hence, lab-scale experiments for such substrates are highly recommended prior to implementing in practice. Demand-based energy production could bring a new prospect in the energy sector of Bangladesh. There such a concept could elucidate the problem of biomass scarcity as substrates would be required only at certain times. Local authorities could benefit by implying this concept in terms of economics and technical feasibility for energy supply during high-demand hours.

6. ACKOWLEDGEMENT

The authors would like to thank Fachagentur Nachwachsende Rohstoffe e.V. (agency for renewable resources) for providing financial support under the project no. FKZ 22402115.

7. REFERENCES

[1] https://www.epexspot.com/en/market-data/auction. (accessed on 15/08/2019)

[2] T. Braun *et al.*, "Optimized operation of flexible biogas plants," in *Conference preceedings of the 22nd European Biomass conference and Exhibition (EUBC&E), Hamburg, Germany*, 2014.

[3] B. Demirel and P. Scherer, "Production of methane from sugar beet silage without manure addition by a single-stage anaerobic digestion process," *Biomass and Bioenergy*, vol. 32, no. 3, pp. 203–209, Mar. 2008.

[4] S. Ahmed, D. Einfalt, and M. Kazda, "Co-Digestion of Sugar Beet Silage Increases Biogas Yield from Fibrous Substrates," *Biomed Research International*, vol. 2016, pp. 1–11, 2016.

[5] S. Ahmed and M. Kazda, "Characteristics of on-demand biogas production by using sugar beet silage," *Anaerobe*, vol. 46, pp. 114–121, 2017.

[6] K. Maurus, S. Ahmed, W. Getz, and M. Kazda, "Sugar beet silage as highly flexible feedstock for on demand biogas production," *Zuckerindustrie*, vol. 143, no. 12, 2018.

[7] R. Böttcher, M. Smieszek, C. Stollberg, and H. Gerath, "Biogas production by co-fermentation of fodder and sugar beet as part of a holistic energy concept in a new greenhouse generation," *Agricultural Engineering*, vol. 45, no. 1, pp. 28–32, 2013.

[8] I. H. Franke-whittle, A. Walter, C. Ebner, and H. Insam, "Investigation into the effect of high concentrations of volatile fatty acids in anaerobic digestion on methanogenic communities," *Waste Management*, vol. 34, no. 11, pp. 2080–2089, 2014.

[9] L. M. Contreras, H. Schelle, C. R. Sebrango, and I. Pereda, "Methane potential and biodegradability of rice straw, rice husk and rice residues from the drying process," *Water Science and Technololgy*, vol. 65, no. 6, pp. 1142–1149, 2012.

[10] M. Blandino, C. Fabbri, M. Soldano, C. Ferrero, and A. Reyneri, "The use of cobs, a by-product of maize grain, for energy production in anaerobic digestion," *Italian Journal of Agronomy*, vol. 11, no. 3, pp. 195–198, 2016.

[11] L. Janke *et al.*, "Biogas Production from Sugarcane Waste: Assessment on Kinetic Challenges for Process Designing," *Internatinoal Journal of Molecular Sciences*, vol. 16, no. 9, pp. 20685–20703, 2015.

[12] C. Zhong, C. Wang, F. Wang, H. Jia, P. Wei, and Y. Zhao, "Enhanced biogas production from wheat straw with the application of synergistic microbial consortium pretreatment," *RSC Advances*, vol. 6, no. 65, pp. 60187–60195, 2016.

[13] A. Lehtomäki, S. Huttunen, and J. A. Rintala, "Laboratory investigations on co-digestion of energy crops and crop residues with cow manure for methane production: Effect of crop to manure ratio," *Resources, Conservation and Recycling*, vol. 51, no. 3, pp. 591–609, 2007.

[14] A. S. N. Huda, S. Mekhilef, and A. Ahsan, "Biomass energy in Bangladesh: Current status and prospects," *Renewable and Sustainable Energy Reviews*, vol. 30, pp. 504–517, 2014.

[15] D. F. Barnes, S. R. Khandker, and H. A. Samad, "Energy poverty in rural Bangladesh," *Energy Policy*, vol. 39, no. 2, pp. 894–904, 2011.

[16] A. K. M. S. Islam, M. Islam, and T. Rahman, "Effective renewable energy activities in Bangladesh," *Renewable Energy*, vol. 31, no. 5, pp. 677–688, 2006.

[17] P. Mähnert and B. Linke, "Kinetic study of biogas production from energy crops and animal waste slurry: effect of organic loading rate and reactor size.," *Environmental Technology*, vol. 30, no. 1, pp. 93–99, Jan. 2009.

7. NOMENCLATURE

Symbol	Meaning	Unit
CSTRs	Continuously stirred tank reactors	-
M	Maize silage	-
S	Sugar beet silage	-
OLR	Organic loading rate	kgVS/m3/day
VS	Volatile solid	%
TS	Total solid	%
FM	Fresh mass	%
HRT	Hydraulic retention time	day