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ISBN 978-3-941785-37-3

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Stirring and Hydraulic Retention Time in Biogas Plant Digesters

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INTRODUCTION

The quality of the mixing affects directly the hydraulic residence time of the feed substrates in the digester, homogeneity of the agitated material, biogas yield and total energy consumption of biogas plants. In practice, in most of the biogas plants the own energy demand is 4-10 % of the total produced electric energy. The majority of this energy (>60%) is needed only for running the agitators.

Generally two basic types of stirrer systems are used in agricultural biogas plants. The high speed stirrers (typically propeller–stirrers) are applied for digesters with lower total solids content. Common application is for substrates like maize silage and manure. If the total solids content in the biogas slurry rises (e.g. over 10% TS) or if substrates with fibrous material and a tendency to form a surface layer are used it is preferable to install slow speed stirrers (typically paddle–stirrers) with a horizontal or vertical axis of rotation. In practice, both types are often combined to get a larger range of operating possibilities.

Operating experiences showed that slow speed stirrers are less energy demanding than high speed stirrers (Laaber et al., 2007).

The objective of this study is to investigate the real retention time of substrate material in anaerobic digesters by two biogas plants using different stirring systems, substrates, operation temperatures and total solids content (TS) in the biogas slurry.

MATERIAL AND METHODS

The investigated biogas plants use each two serial organised digesters. Both digesters are operated as continuously stirred tank reactors. The experiments and measurements were realized only in the first stage digesters (D1), because only there the stirring problems occurred. Second stage digesters (D2) were not investigated. In the monitored biogas digesters the operation data like quantity and

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Viscosity measurement

The viscosity of the digester material was measured using the process viscometer Hydramotion XL/7-101 at digester operation temperature (see Table 1) and laboratory temperature (by constant shear rate). Also a self designed and developed Macro-Viscosimeter was used to determine the shear rate dependent viscosity of the biogas slurries (data not shown). This viscosity values were used for CFD simulations. It was found that the rheological properties of the slurry fit to a power-law fluid (Pohn et al., 2010).

Tracer tests

Lithium hydroxide monohydrate was used for tracer tests. It was dissolved in 150L water and added together with input substrates in the time t_0 into the biogas digester. At the BGP A the dosed concentration was 47.1 mg Li^+/kg TS, at BGP B 46.6 mg Li^+/kg TS. In the first 48 hours the sampling intervals were as follows: 24 hours after adding every hour, in following 12 hours every 2 hours, next 12 hours every 4 hours and then every 6 hours until 60 hours in total. In the next days the frequency was one sample per day. The lithium tracer samples were analysed using inductively coupled plasma optical emission spectroscopy (ICP-OES) according to recommendation of FMENCNS (2007). The tracer tests data of two hydraulic retention times ($\Theta = 2$) were analysed following the work of Levenspiel (1972).

RESULTS

Operating and substrate parameters

The process operating data by BGP A and BGP B were analysed. By the focused parameters the most important differences can be seen in Table 1. It can also be seen that digester material coming from BGP B showed decisively higher viscosity. The total energy self-consumption at both plants is near to 4% of the produced electric energy. Herein the largest part is consumed for mixing in the digesters (68.0% and 82.7%). In the Table 1 is also shown that BGP B has higher energy consumption for mixing than BGP A.

Table 1. Operating parameters by investigated biogas plants

	BGP A (D1)	BGP B (D1)
Installed power capacity [kW$_{el.}$]	526	526
Operating Temperature [℃]	39	49
Digester active volume [m^3]	2000	1500
Input material – Average [t/d]	34.4	57.1
Feeding Intervals per Day	24x	48x
Calculated HRT [d]	58.1	26.3
Average TS [%]	8.6	11.0
Average VS [%]	6.8	8.2
Digester material viscosity at 20℃ [mPas]	190.6	580.6
Digester material viscosity at 39℃/49℃ [mPas]	54.1	145.2
Paddle - Stirrer	1 (vertical axis)	2 (horizontal axis)
Propeller – Stirrer	1	1
Installed Stirrer Power [kW$_{el}$]	25 (15 + 10)	26 (5.5 + 5.5 + 15)
El. Energy used for Stirring [kWh/d*m^{-3}]	0.15	0.17

By the feed substrates data (Table 2) it can be observed that the liquid input in BGP A makes 42.2 % and in BGP B 48.0 % of daily doses. This helps to hold the digester at stable total solids content. Inputs into digester BGP B are 52 % solid substrates, where 51.3 % of this falls on grass silage. Compared to other biogas plants the ratio is very high. Common biogas plants do not usually use such high grass silage content for the reason that stirring problems are expected. Mixing problems and the creation of a swimming layer are evoked because of particle size and grass silage characteristics.

Table 2. Feed substrates at BGP A and BGP B

	BGP A		BGP B	
	[t/d]	%	[t/d]	%
Manure	14.5	42.2	-	-
Recirculation liquid	-	-	27.4	48.0
Maize silage	8.5	24.7	13.3	23.3
Grass silage	3.6	10.3	15.2	26.6
Other substrates (mostly corn)	7.8	22.7	1.1	2.0
Total	34.4	100	57.1	100

Residence time distribution in biogas digesters – Tracer tests

Tracer test data from $\Theta = 0$ until $\Theta = 2$ are displayed for each digester in Figure 1. There is to observe that the tracer concentration in the out flow from BGA B rose compared to BGP A very slowly. In the BGP A digester the tracer concentration after attainment of the maximal concentration stayed up to 140 hours ($\Theta = 0.1$) nearly stable by $C = 0.9$. Than the Li^+ concentartion in the outflow started slowly and continuously to sink. In the BGP B digester the Li^+ concentration reached in the time

Θ = 0.1 (72 hours) only C = 0.44. At Θ = 0.1 the tracer concentration in BGP B digester outflow started to rise again and at Θ = 0.27 (7 days) the Li^+ quantity in outflow showed its maximum. In the case of BGP B the calculated tracer concentration in the outflow was not reached. At Θ = 0.53 (14 days) the Li^+ concentration in the outflow started to fall continuously.

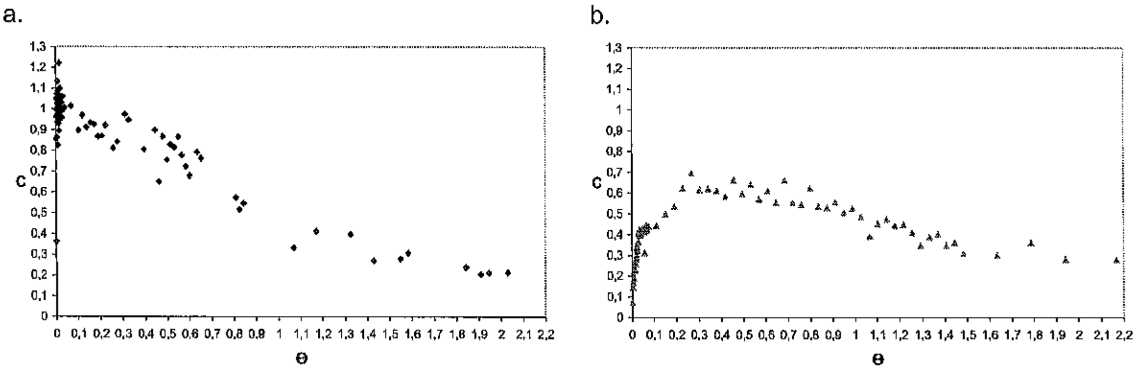

Figure 1. Tracer concentration in the digester outflow (C-curve) between Θ = 0 and Θ = 2 at a) BGP A and b) BGP B

We can see totally different hydraulic characteristics in the investigated digesters. At BGP A nearly 67 % of the tracer was washed out at Θ = 1, and 51 % of added tracer in BGP B at the same time. At Θ = 2 from BGP A digester was washed out nearly 80% totally of dissolved tracer in comparison to BGP B where about 70 % of Li^+ left the digester.

Residence time distribution in biogas digesters – CFD Methods

These measured data will be compared to results from CFD simulations. To do so first a numerical model had to be implemented. This model was solved with the commercial solver FLUENT^{TM}. The simulation was performed using the moving mesh method with an unsteady iteration scheme. Initialised with zero velocity the iterations were carried out until a stationary flow-field was achieved.

a. b. c.

Figure 2: Contour plot of the velocity magnitude in [m/s]

The non-Newtonian properties of the slurries were considered with a user-defined subroutine (Maier et al., 2010). As soon as the stationary flow-field is achieved the DPM method was used to track the tracer to obtain the residence time in the digesters. The calculations for the particle tracking (in progress) were not available for this publication.

Figure 2a shows the stationary velocity magnitude in digester BGP A, Figure 2b presents the velocity magnitude around the propeller stirrer in BGP A. And finally 2c shows the flow field in BGP B. In the very right picture it can be seen clearly that the flow field is very homogenous. In BGP A the slow moving stirrer and the propeller stirrer are not capable to ensure a complete homogenous flow field in the digester.

DISCUSSION

In the BGA A digester the tracer was distributed very fast and the calculated tracer concentration was achieved in 4 hours. This behaviour is near to complete mixing. BGA A digester seems to be mixed perfectly in spite of that according to CFD modelling the slow moving stirrer and the propeller stirrer are not capable to ensure a complete homogenous flow field in the digester. The installed vertical paddle stirrer has due to CFD model very good characteristic and the tracer results confirmed this. The slow rising concentration in the BGP B results gives a hint on „dead water“ in the system what means that a considerable fraction of the fluid is trapped in eddies and spends more than average time in the vessel, while most of the flow takes place through a restricted channel, as Danckwerts (1953) describes. This corresponds to calculated dead space volumes up to 80 % in the first hours. On the contrary the CFD model showed that the installed paddle-stirrers form a very homogenous flow field and a good mixing. The results from BGP B are not directly in conflict with the CFD model but it was assumed that the homogenising in the digester happens much faster. The longer time is caused by the very high viscosity of the mixed biogas slurry containing grass silage (longer particles compared to maize silage) and higher TS. These facts are also the reason for higher stirring energy consumption at BGA B. The tracer results clearly showed that the used stirrer combination in BGP A reaches faster the slurry homogeneity in digester than in BGP B. Nevertheless, in BGP B no short streaming to the outflow was detected and the HRT was not shortened. This is an interesting effect which prolongs compared to BGP A at least until $\Theta = 1$ the real hydraulic retention time of substrate in the digester. This showed also the calculated cumulative outflow rate. The relatively high rest tracer concentration at $\Theta = 2$ in the BGP B is caused by big amount of recirculation liquid (from D2 to D1) in the daily material input. Because of this since nearly $\Theta = 1.5$ the tracer concentration decreased very slowly. The “tail” i.e. the portion of the C-curve that lies beyond $\Theta =$

2 is a major parameter which affects the calculated dead space and the tracer recovery rate (Grobicki and Stuckey, 1992). It is quite possible that this distortion of obtained results appeared in both performed tracer tests.

The results showed that the residence time distribution is in BGP B digester despite of higher input rate and shorter theoretic retention time good comparable to BGP A. The grass silage characteristics and its high amount in the substrate can cause stirring problems and swimming layer formation on the slurry surface (observed in the past). At the BGA A similar problems were not registered. The selected stirrer types at BGP A and BGP B seem to be suitable for the used substrates.

CONCLUSIONS

In both cases there was not detected any strong short streaming to the outflow. The usage of grass silage brings risks of swimming layer formation, higher biogas slurry viscosity and higher requirements on the mixing system. The biogas slurry in BGP B had strong non-Newtonian behaviour. For such materials and higher TS (>10%) it is preferable to use paddle-stirrers.

Tracer tests showed better hydraulic characteristics for the anaerobic digester which was operated with combined stirring system (propeller-stirrer and slow moving stirrer) at lower slurry viscosity, lower grass silage content and lower TS.

Acknowledgement

This work was funded by Klima- und Energiefonds KLI.EN.

REFERENCES

Danckwerts, P.V., (1953), Continuous flow systems: Distribution of residence times, *Chemical Engineering Science* 2, 1-13.

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (FMENCNS, 2007), Amendment of the BioAbfV Appendix 2, Status 19.11.2007 (not aligned), Germany.

Grobicki A. and Stuckey D.C. (1992) Hydrodynamic characteristics of anaerobic baffled reactor. *Water Research* **26**, 371-378

Laaber, M., Madlener, R., Brachtl, E., Kirchmayr, R. and Braun, R. (2007), Aufbau eines Bewertungssystems für Biogasanlagen – „Gütesiegel Biogas", Projektnummer 807742, Endbericht, 35.5. 2007, Tulln, Austria.

Levenspiel O. (1972) Chemical Reaction Engeneering, 2nd ed. *John Wiley & Sons*, New York

Maier, C., Schlerka, M., W. Weichselbaum and M. Harasek. (2010) Scale-up of biogas plants by investigation of the mixing process using computational fluid dynamics. *In JSC*, April 2010.

Pohn, S., Kamarad, L., Kirchmayr, R. and Harasek, M. Design (2010) Calibration and numerical investigation of a macroviscosimeter. Conference Proceedings CHISA Prague, August 2010