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DETERMINATION OF MIXING QUALITY IN BIOGAS PLANT DIGESTERS USING TRACER TESTS AND COMPUTATIONAL FLUID DYNAMICS

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Abstract

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The total electricity demand of investigated biogas plants (BGP) makes up 7–8 % of the total electricity produced. Nearly 40 % of this energy is consumed just for mixing in digesters and the energy demand for mixing in some biogas plants can be even higher. Therefore, optimal mixing in anaerobic digesters is a basic condition for efficient plant operation and biogas production. The use of problematic substrates (e.g. grass silage or other fibrous substrates), installation of unsuitable mixing systems or inconvenient mixing intervals may lead to mixing problems. Knowledge about mixing in biogas digesters is still insufficient, so the objective of this study was to fill the information gaps in the literature by determining the minimal retention time of substrates fed into anaerobic digesters and to describe substrate distribution and washing out rates from investigated digesters. Two full-scale biogas plant digesters (2000 m^3 and 1500 m^3) using different mixing systems and substrates were investigated. To characterize the substrate distribution, lithium hydroxide monohydrate solutions were used for tracer tests at concentrations of 47.1 mg Li^+ / kg TS and 46.6 mg Li^+ / kg TS in digester. The tracer concentration in the digester effluents was measured during two hydraulic retention times and compared. Although the tracer was detected in the digester effluent at nearly the same time in both cases, the tracer tests showed very different distribution curves. The tracer concentration in effluent B grew much slower than in effluent A and no significant short circuiting streams were detected. Although the data calculated by computational fluid dynamics methods (CFD) showed a very good agreement with the full scale results, full comparison was not possible.

mixing, digester, tracer tests, substrate distribution, CFD methods, biogas

Most agricultural biogas plants in central Europe were designed for using manure and maize silage as main substrates, but many biogas plant operators are interested in using alternative substrates (such as grass silage). A change in substrate can cause various problems in anaerobic digestion, particularly with mixing. A lot of research has been carried out on the biochemistry of anaerobic digestion, and good process monitoring can help control, optimise and evaluate the biogas process very well. However, there is little scientific literature available about the effect of different mixing arrangements. In particular, a new challenge is to optimize the mixing systems in biogas digesters for less common substrates and higher organic loading rates. The quality of mixing directly affects the hydraulic retention time of the fed substrates in the digester, the homogeneity of the mixed suspension, the biogas yield and the total energy consumption of biogas plants. In practice, biogas plants consume about 5–10 % of the total electricity they produce (FAL, 2005). If not considering the energy needed for CHP units, the majority of this energy (> 60 %) is used just for running the agitators. It is therefore important that these agitators are running efficiently.

Generally, two basic types of mixing systems are used in agricultural biogas plants. The high speed mixers (typically propeller mixers) are applied for digesters with lower total solids content (TS) in the suspension. This is very common for substrates like maize silage and manure. If the total solids content in the biogas slurry rises to a value over around 9 % or if substrates with fibrous material and a tendency to form a swimming layer on the suspension surface are used, it is preferable to install slow going agitators (typically paddle agitators) 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-going agitators are less energy demanding than fast-going mixers (Laaber *et al.*, 2007).

Most information about mixing systems in anaerobic digestion is obtained either from lab-scale experiments with model substrates, which only give very limited information about large-scale processes, or directly from the biogas plant manufacturers. Scientific publications on large-scale biogas plants digesting agriculturally-relevant substrates are rare because the systems are very complex. The objective of this study is to address the literature gap on mixing in real large-scale biogas plants. Specifically, this study aimed to investigate the minimal retention time of the fed substrate in anaerobic digesters with different mixing systems and to investigate the relation between the mixing quality, total solids content and used substrates.

Hydraulic retention time (HRT) and tracer tests

Theoretical background

The parameter HRT (or $\bar{t}$) is used to determine the average retention time (in days) of substrates in biogas plant digesters

$$HRT = \frac{V_{Digester}}{\dot{Q}_{Substrate}}, \qquad (1)$$

where $V_{Digester}$ [m^3] represents an active digester volume and $\dot{Q}_{Substrate}$ [m^3/d] an average daily substrate input flow.

The HRT is a simplified theoretical parameter which can be often different to the real values. Tracer tests are needed in order to find the real distribution of the retention time. The commonly used tracers for anaerobic digesters are lithium salts like $LiCl \cdot H_2O$, LiCl or $LiOH \cdot H_2O$. Several experiments with Li^+ tracer at biogas plants and waste water treatment plants have been carried out (USG, 2000; Zábranská *et al.*, 2000; DBU, 2004). Lithium is easy to detect in the biogas slurries and, in the applied concentrations, it has no negative effects on the biogas digestion (Anderson *et al.*, 1991). The tracer tests performed in this study confirmed this.

The investigated anaerobic digesters were continuously stirred tank reactors (CSTR). The normalized dimensionless tracer concentration in the digester outflow $C = f(\Theta)$ is given by:

$$C = \frac{c_i}{c_0}, \qquad (2)$$

where c_0 is the tracer concentration (when totally dissolved) and c_i concentration measured in the digester outflow. The parameter Θ for dimensionless time unit is proportional to the time point and inversely proportional to the ($\bar{t}$), given by:

$$\Theta = \frac{t_i}{\bar{t}}, \qquad (3)$$

where t_i represents the time point after the time when the tracer was added.

MATERIAL AND METHODS

Each of the investigated biogas plants uses two digesters arranged in series. Both investigated digesters were operated as continuously stirred tank reactors. The tests and analysis were only carried out on the first stage digesters (D1), because the mixing problems mostly occur there. Second stage digesters (D2) were not investigated. In the monitored biogas digesters, the operation data like quantity and quality of installed mixers, energy demand for mixing, quality and quantity of input material, output material quantity and digester slurry parameters (total solids, total volatile solids, viscosity and temperature) were taken into account. The investigated biogas plants are described in the text as BGP A and BGP B.

Viscosity measurement

The viscosity of the digester material was measured using the process viscometer Hydramotion XL / 7 - 100 at digester operation temperature (see Tab. I) and laboratory temperature (at constant shear rate 1000 1/s). Also a macro-viscometer, designed and developed in house, was used to determine the shear-rate-dependent viscosity of the biogas slurries (at shear rate 25 1/s). The macro-viscometer construction and calibration is described in Pohn *et al.* (2010). It could be confirmed that the investigated biogas slurries have non-Newtonian properties and can be characterized as shear-thinning fluids. The properties fit to a power-law fluid.

Tracer tests

Lithium hydroxide monohydrate was used for the tracer tests. It was added together with input substrates at time t_0 into the biogas digester. In the case of the BGP A, the lithium hydroxide monohydrate was dissolved in 0.15 m^3 water. This solution was dosed through the manure pipeline together with 5 m^3 of pig manure directly into the digester (pipeline outflow on the slurry surface). In the second case (BGP B), the lithium hydroxide monohydrate was dosed into the digester through feed screw together only with solid silage substrate below the suspension surface. In the BGP A digester the dosed concentration was 47.1 mg Li^+ / kg TS, in the BGP B digester 46.6 mg Li^+ / kg TS digested suspension. In the first 48 hours, the sampling intervals were as follows: every hour for the first 24 hours after adding, 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 sampling frequency was one sample per day. At the BGP B, the sampling interval was changed in the first 6 hours from 1 hour to 30 minutes interval. The tests were carried out according to recommendations of FMENCNS (2007). The samples were analysed using inductively coupled plasma optical emission spectroscopy (ICP-OES). As soon as the time $\Theta = 1$ was achieved, the samples from the digester were taken just once a week. The tracer tests data of two hydraulic retention times were analysed following the work of Levenspiel (1972).

RESULTS

Operating and substrate parameters

The process operation data from the last two years were obtained from BGP A and BGP B and analysed. The most important differences can be seen in Tab. I. It can also be seen that digester material coming from BGP B showed significantly higher viscosity. The total electric energy consumption (parasitic energy demand) at BGP A was 7.2 % of the produced electric energy and 7.8 % at BGP B. At investigated biogas plants, the largest part of electric energy is consumed by CHP units (37.8 % resp. 49.6 %) and for mixing in the digesters (38 % or 42 %, respectively). Tab. I also shows the energy demand for mixing just in D1.

In the data summary of fed substrates (Tab. II) it can be observed that the liquid input in BGP A makes up 42.2 % and in BGP B even 48.0 % of daily doses. This helps to hold the digester at stable total solids content. Input into digester BGP B makes up 52 % the solid substrate, 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 mixing problems are expected. The mixing problems and the creation of swimming layers are mostly caused by insufficient mixing and slurry characteristics (particle size, viscosity etc.).

Mixing set-up

BGP A: The paddle agitator mixed at 75 % average working load and maximal 14.5 rpm. The propeller mixer had intervals of 35 minutes mixing (at 475 rpm) and 90 minutes break.

BGP B: Here both paddle stirrers (rotation against each other), mixed permanently at 80 % average working load and maximal 7 rpm. The set-up of the propeller mixer was 10 minutes mixing (at 320 rpm) and 130 minutes break.

Residence time distribution in biogas digesters

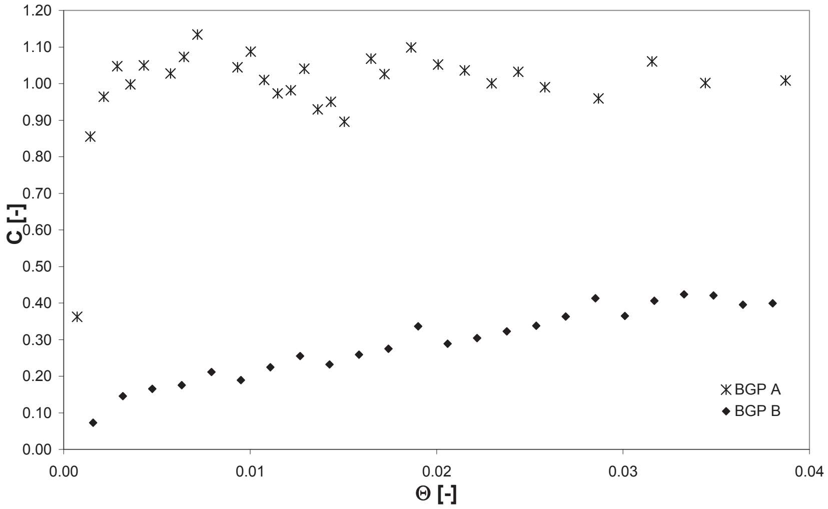
For better understanding, the tracer concentration results measured in the digester outflow are divided in two figures. The first hours of the tracer tests from time $\Theta = 0$ until time $\Theta = 0.04$ are shown in Fig. 1. Analysed data up to $\Theta = 2$ for each digester are displayed in Fig. 2.

I: *Operation parameters of investigated biogas plants*

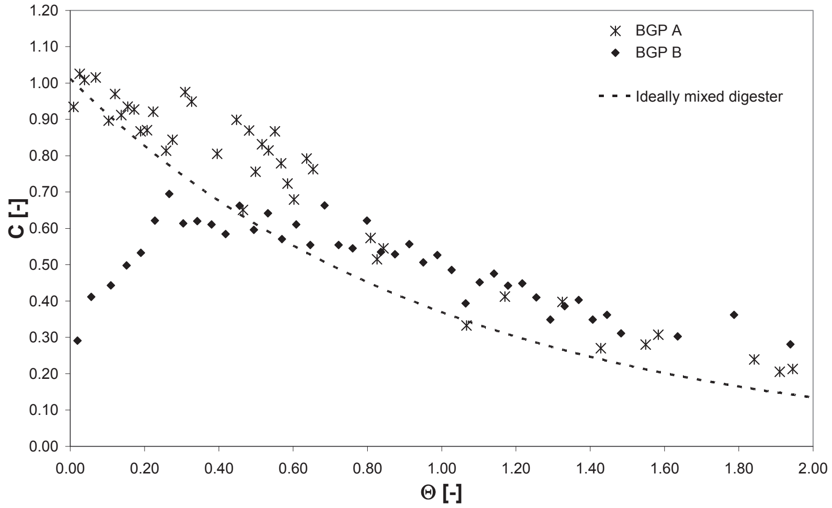
	BGP A (D1)	**BGP B (D1)**
Installed plant power capacity [kW$_{el.}$]	526	526
Operating temperature [°C]	39	49
Digester active volume [m^3]	2 000	1500
Input material – average [Mg/d]	34.4	57.1
Feeding intervals per day (solid / liquid inputs)	24/5	48/3
Calculated HRT [d]	58.1	26.3
Average TS [%]	7.86	11.4
Average TVS [%]	6.17	8.60
Average density at operating temperature [kg/m^3]	943	954
Average biogas slurry viscosity [Pas] at 20°C and shear rate 1000 1/s	0.19	0.58
Average biogas slurry viscosity [Pas] at operating temperature and shear rate 1000 1/s	0.05	0.15
Average biogas slurry viscosity [Pas] at operating temperature and shear rate 25 1/s	3.50	5.50
Paddle agitator	1 (vertical axis)	2 (horizontal axis)
Propeller mixer	1	1
Installed mixing power [kWh$_{el}$]	25 (15 + 10)	26 (5.5 + 5.5 + 15)
El. energy demand for mixing [kW$_{el}$/d] in D1	303	257
El. energy used for mixing of 1 Mg TS in D1 [kWh$_{el}$ / Mg TS .d^{-1}]	1.93	1.50

II: *Feed substrates at BGP A and BGP B*

	BGP A		**BGP B**	
	[Mg/d]	**[%]**	**[Mg/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



1: *Measured tracer concentration until dimensionless time Θ = 0.04 in the digester outflow at BGP A and BGP B*



2: *Measured tracer concentration in the digester outflow between Θ = 0 and Θ = 2 in BGP A and BGP B digester*

In Fig. 1 it is clear to see that in the BGP A digester the tracer concentration in the effluent grew much faster than in BGP B. The tracer was in the outflow after 1 hour (Θ = 0.00072) first time detected and its concentration reached after 4 hours (Θ = 0.0029) the calculated maximal value. In the case of BGP B the sampling interval has been shortened and the tracer was detected already after 30 minutes (Θ = 0.00079). Afterwards the tracer concentration grew compared to BGP A very slowly.

In the BGP B digester the calculated tracer concentration was not reached within the first

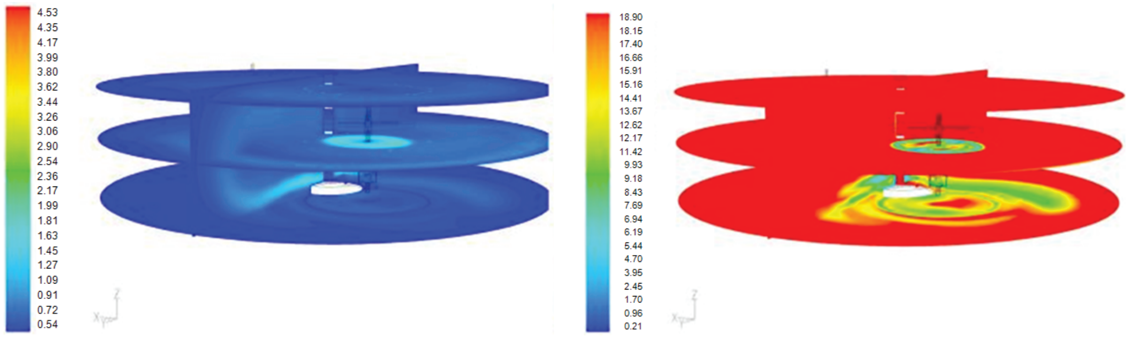
24 hours (Θ = 0.04). While in the BGP A digester at time Θ = 0.0014 (2 hours) the tracer concentration in effluent achieved nearly 90 %, in the BGP B digester at the same time Θ (1 hour) the tracer concentration made up just 10%. That means, the tracer in BGP A was nearly completely distributed in the whole digester while the substrate distribution in BGP B was very slow. Fig. 2 represents Li^+ concentration distribution in the digester outflows between Θ = 0 and Θ = 2. In the BGP A digester the tracer concentration after attainment of maximum stayed several hours nearly stable. After 140 hours (Θ = 0.1) at C = 0.9 the Li^+ amount in the outflow started to sink slowly and continuously. In the BGP B digester the Li^+ concentration reached only C = 0.44 at time Θ = 0.1 (72 hours). The tracer concentration in BGP B digester outflow rose again and at Θ = 0.27 (7 days) the Li^+ quantity in outflow reached its maximum too. Nevertheless the maximal calculated tracer concentration for BGP B was not achieved during the test. After reaching the time Θ = 0.5 (nearly 13 days), the Li^+ concentration in outflow started to fall.

The distribution of the tracer in the two investigated digesters was obviously totally different. In the BGP A digester nearly 67 % of the added tracer was washed out at Θ = 1 and just 51 % in the case of BGP B digester at the same time. That means 16 % difference. At time Θ = 2 were from BGP A digester nearly 80 % of dissolved tracer washed out in comparison to BGP B, where just about 70 % of Li^+ left the digester.

Computational Fluid Dynamics

The measured data were compared with results from CFD simulations. To do so first a numerical model had to be implemented. This model was solved with the commercial solver FLUENT™. 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. 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 (Discrete Phase Model) was used to track the tracer to obtain the residence time in the digesters.

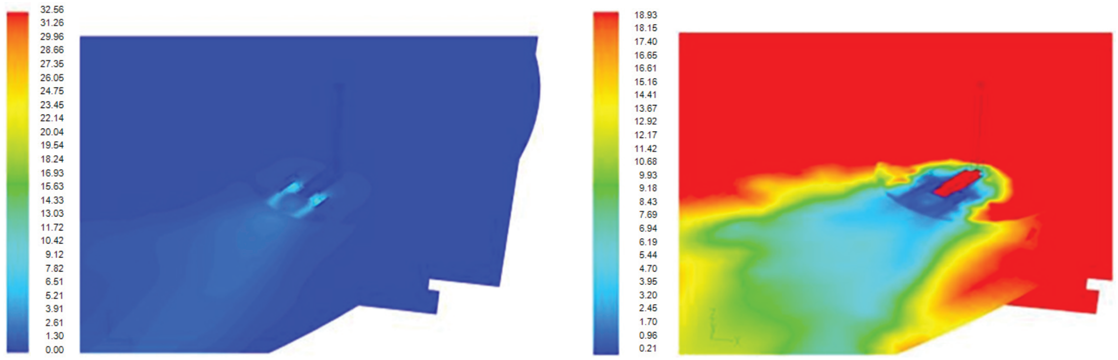
Fig. 3a shows the stationary velocity magnitude in digester A and Fig. 4a presents the velocity magnitude around the propeller mixer in digester A as well. And finally Fig. 5a shows the flow field in the BGP B digester. In this picture can be seen clearly that the flow field created by paddle agitator in digester B is very homogenous. In BGP A, the slow-going agitator and the propeller mixer are not capable of ensuring a complete homogenous



a.

b.

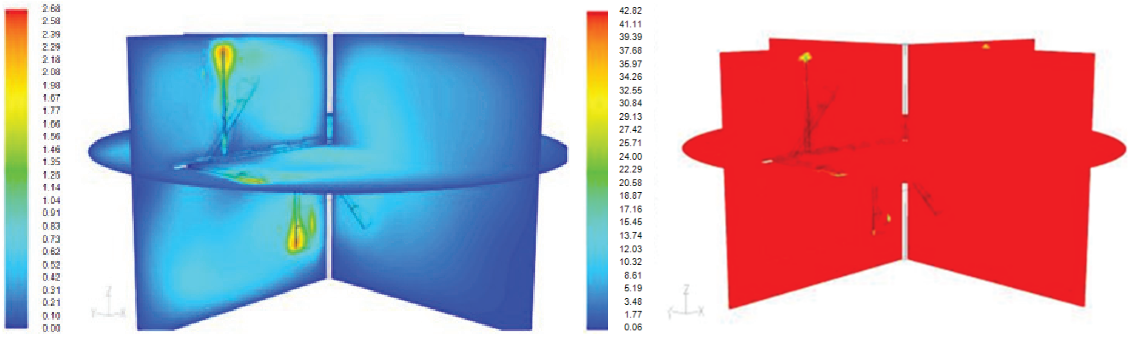
3: *Contour plot of the velocity (a) magnitude [m/s] and contours of viscosity [Pas] in digester A (b) for paddle agitator*



a.

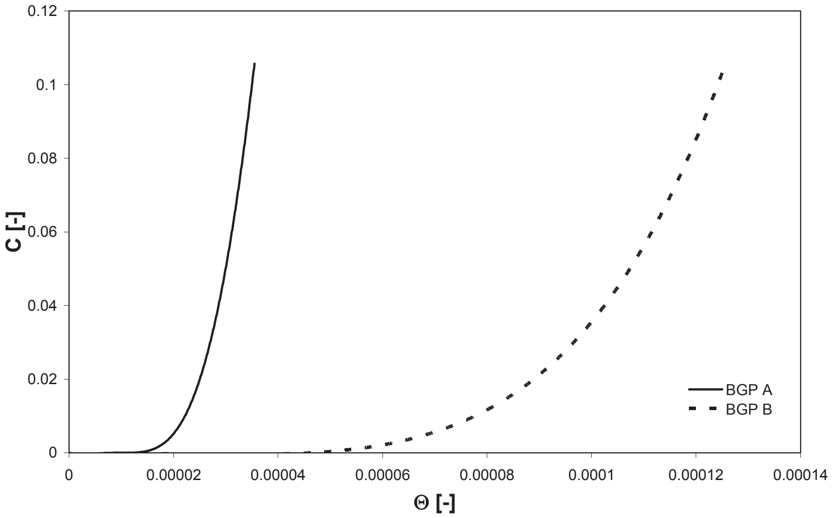
b.

4: *Contour plot of the velocity (a) magnitude [m/s] and contours of viscosity [Pas] in digester A (b) for propeller mixer*



a. b.

5: *Contour plot of the velocity (a) magnitude [m/s] and contours of viscosity [Pas] in digester B (b) for paddle agitator*



6: *Calculated tracer contentration (CFD model) in the effluent of digesters A and B*

flow field in the digester A. But the vertical paddle agitator in digester A forces the flow from the surface to the bottom, which is a very good mixing device characteristic considering prevention of creating swimming layers on the suspension surface. The propeller mixer induces very high velocities in the digester, which can be useful to break up particle coagulates.

Fig. 3b, 4b and 5b give a view of the non-Newtonian viscosity changes in the digesters. The power law describes a decreasing viscosity with an increasing shear rate.

The measured power law indices K and n for these two slurries are K = 18.9 Pas^n, n = 0.132 for BGP A and K = 6785.8 Pas^n, n = –1.21 for BGP B. The coefficients of BGP A show good agreement with values presented already in literature (El-Mashad *et al.*, 2005).

The coefficients of the suspension from BGP B digester are not comparable with literature data. This might come from reasons mentioned earlier in this work. The substrate used in BGP B contains mostly grass silage and the suspension in digester B has higher total solids content as well. This leads to very strong non-Newtonian behaviour where the viscosity only changes nearby the stirrer blades as is possible to see in Fig. 5b.

Fig. 6 shows the tracer concentrations in effluents of digesters A and B calculated by the computational fluid dynamics methods. It is clear to see that the tracer concentration in digester A effluent is rising faster than in case of digester B and the tracer could be detected even in the first minutes after addition. Because of high hardware requirements it was possible to calculate just a few minutes of the total tracer test duration (compare the scales in Fig. 1 and 6). This means the full-value comparison of practical tests with the model was, in this case, not possible.

DISCUSSION

The CFD simulation indicates that the main mass flow in the investigated biogas digesters is induced by slow-going agitators. The fast-going propeller stirrers only play a supporting role. The tracer tests showed that in the BGP A digester the tracer was distributed very fast and the calculated maximal tracer concentration was achieved within the first hours. This behaviour would be expected in an ideally-mixed digester. The BGP A digester, under the set conditions, seems to be mixed perfectly, despite that according to CFD modelling the slow-running agitator and the propeller mixer are not capable of ensuring a completely homogenous flow field in the digester. In this study, no significant short circuit streams (C > 1) were detected. Because of the tracer adding method (pre-dissolving the tracer in manure), lower TS and lower viscosity in the suspension from BGP A, a similar result was expected. Pre-dissolving the tracer in larger substrate volumes accelerates the tracer distribution in the digester. Another tracer test was carried out later in BGP A in the same digester with a different (biological) tracer and an alternative mixing set up (propeller stirrer turned against the main stream). The tracer was added together with the solid substrate through the feed screw below the liquid surface and the tendency was very similar to the first run but, additionally, short circuit streams were detected (Pohn *et al.*, 2011A). Kamarád *et al.* (2011B) describes the optimization potentials of the detection method and the weaknesses of the tests using the biological tracer. The vertical paddle agitator in digester A has, according to the CFD model, a good characteristic for slurries with lower total solids (TS < 9%) and the tracer test results confirmed this.

The slow rising concentration of tracer in the BGP B effluent hints at dead zones in the system where a considerable fraction of the fluid is trapped in eddies. However, as the tracer compounds measured in the effluent remained below 1, this indicated that there are no short circuit streams. This means that the material spends more than average retention time in the vessel, while by mixing most of the flow takes place through restricted area, as e.g. Danckwerts (1953) describes. The installed mixing system and set up does not technically allow much of unmixed areas in the digester. The CFD model showed that the installed paddle agitators form a very homogenous flow field and give a very good mixing performance. The results from BGP B are not in conflict with the CFD model but it was assumed that the homogenising in the digester happens much faster. As it is possible to see in Fig. 2, the tracer was totally distributed at time range Θ = 0.3–0.4 (8–10 days) when the highest and stabilized tracer concentrations in the effluent were achieved. Afterwards, the concentration started to sink. The much longer distribution time was very probably caused by mixing set up (rotation of agitators against each other), agitator geometry and consistency of the biogas slurry (high TS and viscosity). The results show the tracer was probably trapped in reach of the paddle agitators for relative long time and just slowly released in the remaining digester volume and to the effluent. The biogas slurry suspension B showed significantly higher viscosity and TS than suspension A in all measurements. In Tab. I it can be observed that the viscosity is strongly affected by shear rate, total solids content and temperature. The particle size plays an important role too. Grass silage contains significantly longer particles than maize silage and this can affect the homogeneity of these suspensions (Kamarád *et al.*, 2011A).

The agitator geometry and its suitability for mixed suspensions have a very big influence on the quality of mixing. The higher TS, suspension viscosity and tendency to form swimming layer is a main reason for higher energy consumption for mixing in the BGP B digester related to the mixed volume. Taking into account the energy demand needed for mixing of 1 Mg of total solids in the digester, the mixing system in digester B consumes for mixing of the same amount of TS about 20 % less energy than the mixing system in digester A (see Tab. I). Pohn *et al.* (2011B) reports that, in both cases, the energy demand for mixing could by even reduced up to 50 %. When focussing only on the fast homogeneity achieved in the digester, the results show that the mixing set-up in BGP A digester seems to work better than in BGP B. On another hand, the slower substrate distribution in digester B obviously prolongs the real hydraulic retention time of substrate in the digester of BGP B compared to BGP A, at least until the time Θ = 1, where the difference in the washed out tracer amount was 16 %. This could also be confirmed by the calculated cumulative outflow rate. The higher retained tracer concentration at time Θ = 2 in the BGP B could be partially caused by relatively high amount of recirculation liquid (from D2 to D1) in the daily material inputs. Because of nearly identical average retention times in both digesters at BGA B and irregularity in recirculation, this influence during the test time (Θ = 2) could be neglected. Nevertheless it is necessary to take into account that the "tail" i.e. the portion of the measured tracer concentrations lying beyond Θ = 2 is a major parameter which affects the tracer recovery rate (Grobicki and Stuckey, 1992). There is no doubt this distortion of obtained results appeared in both performed tracer tests. Because of this and variations in plant operation conditions, the tracer recovery rate could only be reliably calculated until time Θ = 1.

The measured minimal retention time was very similar in both digesters. The early tracer detection in the digester outflow, 30 minutes after its addition in the case of BGP B digester, is a relevant argument for recommendation to change sampling time intervals in the guidelines in first 6 hours from 1 hour (FMENCNS, 2007) to shorter intervals. The results showed that the residence time distribution was very good in BGP B compared to BGP A (nearly ideally mixed digester), despite higher input rate and shorter theoretical retention time.

The grass silage characteristics and its high concentration in the slurry can cause mixing problems and swimming layer formation on the biogas slurry surface (observed in the past). At BGP A, where less grass silage is used, similar intensive problems were not registered during the operation. The selected mixing systems in the digester A and digester B are suitable for the used substrates and mixed suspensions. If needed, the homogenising effect in BGP B could be partially improved by longer running periods of the propeller mixer. But higher energy demand for this increased mixing should be taken into account.

The tracer test results were compared with CFD simulations. Unfortunately, this comparison was only partially possible. Because of a high hardware and time severity it was only possible to simulate less than 10 minutes of the mixing process, which was insufficient for a full comparison with tracer tests taking several weeks. However, there is a considerable optimizing potential for the CFD methods in this area, the CFD simulation is a very strong and efficient method for investigating agitator and stirrer characteristics. In the first minutes the simulations showed a very good correspondence between the models and the practical tracer tests.

CONCLUSIONS

The use of grass silage and other fibrous substrates as a feed substrate is associated with risks of swimming layer formation and higher requirements for the mixing set-up and digestion technology. The tracer tests showed faster substrate distribution in the anaerobic digester that was operated at lower slurry viscosity, lower grass silage content and lower total solid content. The influence of temperature, in this case, is not considered as very relevant. In the case of BGP B, the combination of higher viscosity, different mixing set up and slower substrate distribution could prolong the retention time of substrates in the digester. That means, in the biogas digesters with higher TS it is not necessary to achieve a perfect substrate distribution. The suspension properties play an essential role for suitable mixing system selection and mixing set-up for each digester. The mixing system must be able to ensure an efficient release of biogas captured in the suspension and an adequate level of homogeneity. The experiences of the biogas plant operators confirmed that the slow-going paddle agitators are very suitable for suspensions with higher totals solids content (> 9%). The advantage is a lower energy consumption for achievement of mixing tasks and active prevention against the formation of swimming layers. That means, for an objective mixing system evaluation, a definition of the mixing tasks is necessary. Because of this, the aim does not need to be a perfectly mixed digester. It can also be concluded that lithium hydroxide monohydrate is applicable as a tracer for the determination of substrate outflow rates in full scale biogas plants. During the performed tests, no significant negative effects were observed by used tracer concentrations.

The tracer tests and CFD simulations showed the substrate can already leave the digester in the first minutes after its addition. The complete substrate distribution in the whole digester can take from just a few hours, in case of perfectly mixed digester, to as long as several days under specific conditions. Therefore, for elimination of short circuit streams, good synchronisation of the mixing, feed and pump intervals is necessary. The system and operation complexity, vessel and agitator geometry, suspension characteristic and the way of tracer addition are of crucial importance for the data quality and their interpretation. The same goes for an efficient substrate utilisation. This work presents results obtained under specific full-scale conditions and shows the specific system reactions. Therefore, for further investigation in this area the combination of the modelling and practical tracer tests can be recommend.

SUMMARY

Optimal mixing is a basic condition for efficient anaerobic digester operation and biogas production. The objective of this study was to investigate the mixing in digesters in two biogas plants. The total electric energy self-consumption by the investigated biogas plants was in the range of 7–8 % of the total electric energy produced. About 40 % of the consumed energy is needed just for mixing in digesters. Specifically, this study aimed to determine the minimal retention time of substrates fed into anaerobic digesters containing different types of mixing systems and to describe the intensity of substrates washing out from investigated digesters. Two full scale biogas plant digesters (2000 m^3 and 1500 m^3) using different mixing systems and substrates were investigated. To characterise the mixing quality, lithium hydroxide monohydrate solutions were used for tracer tests. The tracer concentration in the digester effluents was measured during two hydraulic retention times and compared with computational simulations. Although the tracer was detected in the digester effluent in both cases at nearly the same time, the tracer tests showed very different results. The tracer tests and CFD simulations showed the substrate can be detected in digester effluent already in the fist minutes after its addition. Biogas slurries with higher total solids content can be expected to have very strong non-Newtonian behaviour. In one case, the slow substrate distribution could even prolong the retention time of substrates in the investigated digester. Nevertheless, for an objective mixing system evaluation, a definition of mixing tasks is necessary. In practice, these tasks can differ depending on used operation and digester systems. During the performed tests, no significant negative effects were observed by used tracer concentrations. The full comparison of tracer tests and CFD model was only partially possible due to very high hardware requirements and time severity of modelling. Nevertheless, the CFD methods are very efficient for investigation of stirrer and agitator

characteristics. The application for supplying of practical tracer tests is very promising but because of a high hardware and time severity there is still a considerable optimizing potential in this area.

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