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EXPERIMENTAL STUDY TO DEVELOP A CONTROL SYSTEM FOR SUBMERSIBLE MIXERS IN BIOGAS PLANTS

BADANIA DOŚWIADCZALNE NAD ROZWOJEM SYSTEMU STEROWANIA MIESZADEŁ W INSTALACJACH BIOGAZU

Abstract

For developing a control system for these agitators, the analysis focused on the rheological characteristics of digestates, the open jet in non-Newtonian fluids and the flow conditions in a biogas reactor. In addition to a clearly visible shear-thinning effect, the viscoelastic proportion of these substrates was also determined. Depending on the stirrer speed and the rheology, the angle of spread varies and a reverse flow can occur directly at the stirrer. Therefore, not only can the position of the stirrer be used to optimise the flow field. The conical spreading of the liquid jet also enhance the mixing process. By using thrust measurements, their suitability as controlled process variables could be demonstrated.

Keywords: biogas, viscoelastic behaviour, open jet, thrust

Streszczenie

W pracy przedstawiono możliwość sterowania mieszadłami w oparciu o analizę charakterystyki reologicznej odpadów pofermentacyjnych, przepływu w płynach nienewtonowskich oraz warunków przepływu w reaktorach biogazu. W zależności od szybkości mieszania i reologii zmienia się kąt rozprzestrzeniania i możliwy jest przepływ wsteczny bezpośrednio przy mieszadle – oprócz położenia mieszadła również stożkowe rozprowadzanie strumienia cieczy może wzmacniać proces mieszania. Potwierdzono przydatność pomiarów tensometrycznych do kontroli zmiennych procesowych.

Słowa kluczowe: biogaz, własności lepkosprężyste, napór

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1. Introduction

The mixing of large storage tanks was studied in a thorough and comprehensive manner between 1960 and 1985. At that time, the focus was on homogenising mineral oils of different densities [1, 2, 3]. Fermenters with a similar geometry are used in biogas plants and the submersible mixers also resemble those used for the stirring technique in the petrochemical industry. By installing them inside the tank, their height, the azimuth direction angle and their pitch angle can be adjusted; therefore, it is possible to respond to changes in the substrate mixture and therefore, the flow behaviour. However, the positioning of stirrers is usually done only at the first commissioning process. The plant operator has often no information about the rheology and the flow field.

The published results of research from the mixing of large storage tanks cannot be transferred to the biogas process as the structure of the digestates is much more complex than the crude oil. The stirred medium in the fermenter is fibrous and has a large number of coarse components. This leads to a more complicated rheology and support the formation of floating and sinking layers. During the operation of the stirrers, the distinctive shear thinning and viscoelastic behaviour of the substrates must be considered; therefore, knowledge about the rheology, the open jet and the impact from the stirrer position on the fluid flow in the biogas reactors is necessary for developing a control system.

The simultaneous deployment of up to four stirrers in one fermenter offers a wide range of variables.

2. Setup

Investigations on the flow fields, the effects of scale and the development of a process control system for the submersible mixers were performed by using two pilot plants with a diameter of 635 mm and 1,300 mm (Fig. 1 and 2); these are geometrically similar to large-scale biogas digesters. The thrust is determined in accordance with ISO 21630 [4] by using strain gauges. For the description of the open jet by using particle image velocimetry (PIV), a rectangular tank was employed (Fig. 3). The design was set up in a way that no interaction between the open jet and the wall could occur. According to the specifications of biogas plants, the stirrer is in a horizontal position.

Solutions of carboxymethylcellulose and xanthan gum in distilled water were used as model substance systems. The rheology of these could be adapted to the flow curves of the digestate by varying their concentrations [5].

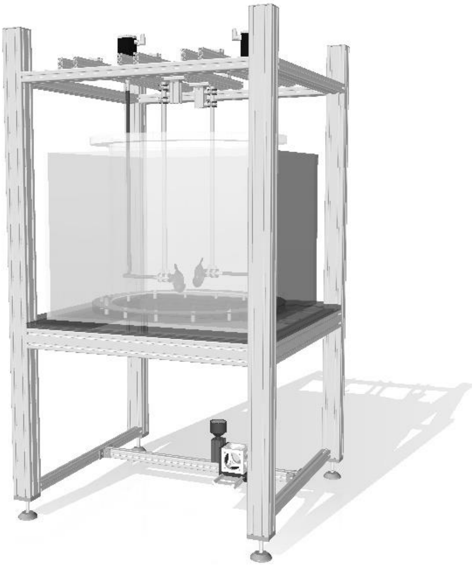

Fig. 1. The pilot plants with a diameter of 635 mm for studying the flow field by using PIV

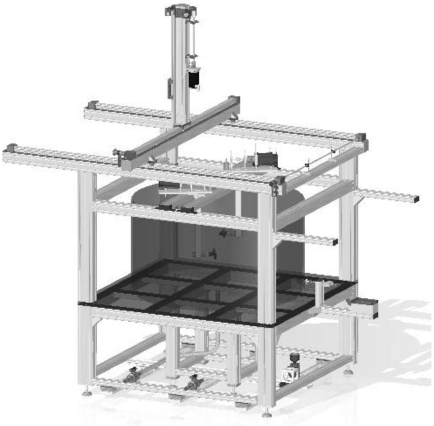

Fig. 2. The pilot plants with a diameter of 1,300 mm for studying the flow field and measuring the thrust

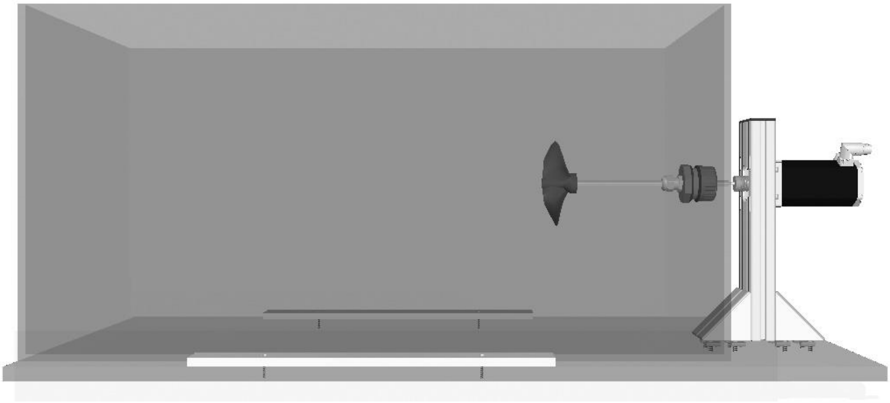

Fig. 3. The pilot plants for studying the open jet in viscoelastic fluids

3. Results

3.1. Rheological characterisation

The rheology of digestate either cannot be determined or can only be insufficiently determined with standardised rheometers [6]. Therefore, to characterise the substrate, the Metzner-Otto method [7] as well as a tube viscosimeter was used. The description is based on the Ostwald and de Waele equation

$$\mu_{eff} = K \cdot (\partial u_x / \partial y)^{n-1} \tag{1}$$

where

μ_{eff} – apparent or effective viscosity,
K – Ostwald coefficient,
n – shear rate exponent,
y – y-coordinate,
u_x – velocity in x-direction.

In Figure 4, the parameters of the power law equation are presented. Taking the example of corn silage, significant fluctuations can be observed during the year. The shear rate exponent lies in the range of 0.06 and 0.18 and the Ostwald factor from 6 to 44. In contrast, there are only low fluctuations in the dry matter.

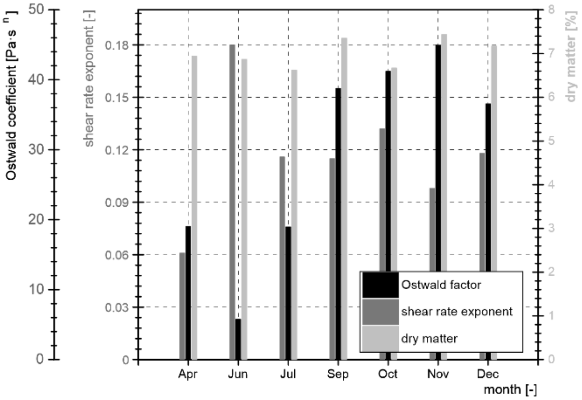

Fig. 4. Rheological parameter for corn silage during the year

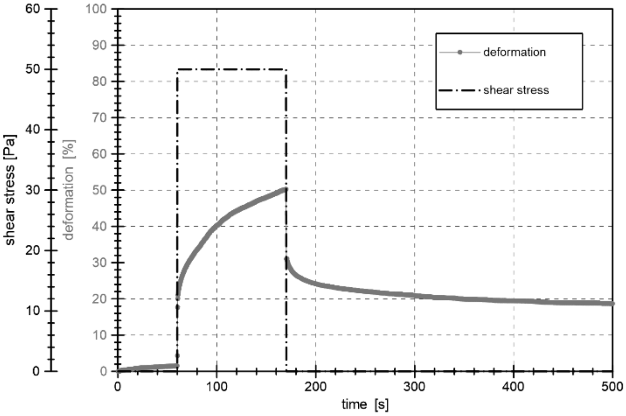

Fig. 5. Determining the viscoelastic part of corn silage

In addition to the shear thinning character, a viscoelastic portion of this substrate could also be detected in creep tests. The deformation was measured during stress- and relaxation periods (Fig. 5) by using a blade stirrer. Here, the viscoelastic portion was 65% and is in the same range as xanthan gum with a concentration above 3 g/kg.

Due to the fact that the range and characteristics of the open jet is essential for the positioning of the stirrers, the viscoelastic effects of the fluid must be considered while stirring a biogas reactor.

3.2. Open jet

The angle of spread at the stirrer was characterised for various non-Newtonian media and different stirrer speeds in a rectangular tank. Figures 6 to 11 show the open jet of a stirrer in different model substance systems. Solutions with Carboxymethylcellulose (CMC) in a concentration of 2 g/kg$_{H2O}$ and 5 g/kg$_{H2O}$ as well as xanthan gum of 1g/kg$_{H2O}$ were used. The description of the flow curves can be carried out according to Equation 1 as follows:

Xanthan gum of 1 g/kg: $$\mu_{eff} = 0.26 \cdot (\partial u_x / \partial y)^{0.4-1} \tag{2}$$

CMC of 2 g/kg: $$\mu_{eff} = 0.06 \cdot (\partial u_x / \partial y)^{0.74-1} \tag{3}$$

CMC of 5 g/kg: $$\mu_{eff} = 0.67 \cdot (\partial u_x / \partial y)^{0.56-1} \tag{4}$$

The angle of spread of the liquid jet clearly depends on the rotation speed. In the case of an angle greater than zero the flow direction along the rotation axis turns around, as also known for viscoelastic fluids [8]. However, an explicit viscoelastic behaviour of the CMC or xanthan gum solution with 1 g/kg could not been detected, neither with an air bearing oscillating rheometer nor with the Giesekus experiment [9]. The range of the open jet is substantially reduced by the reverse flow – this affects the correspondence of the stirrers in the biogas plant and therefore, the flow field.

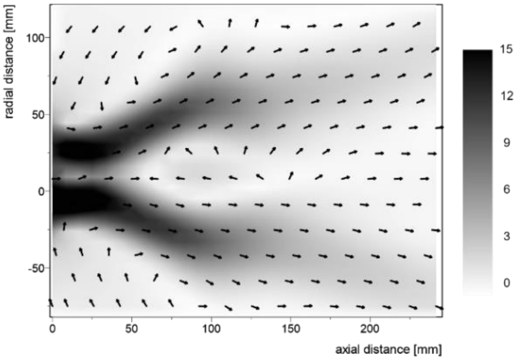

Fig. 6. Open jet of a propeller in a carboxymethylcellulose solution of 2 g/kg (stirrer speed: 300 rpm)

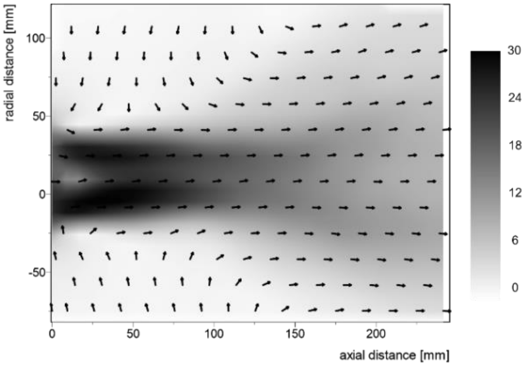

Fig. 7. Open jet of a propeller in a carboxymethylcellulose solution of 2 g/kg (stirrer speed: 1000 rpm)

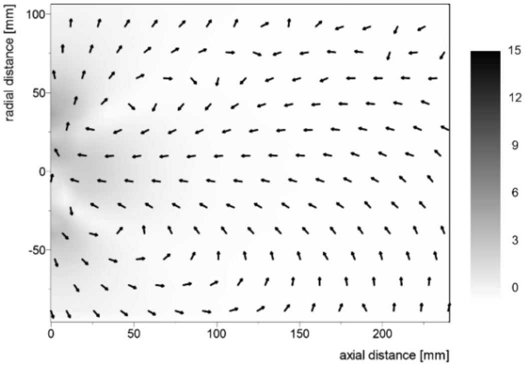

Fig. 8. Open jet of a propeller in a carboxymethylcellulose solution of 5 g/kg (stirrer speed: 300 rpm)

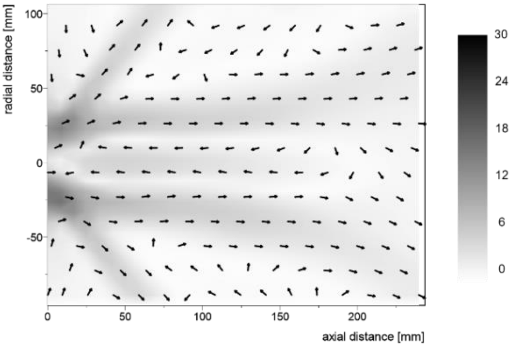

Fig. 9. Open jet of a propeller in a carboxymethylcellulose solution of 5 g/kg
(stirrer speed: 1000 rpm)

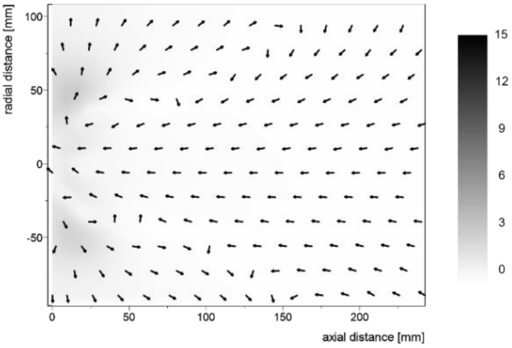

Fig. 10. Open jet of a propeller in a xanthan gum solution of 1 g/kg
(stirrer speed: 300 rpm)

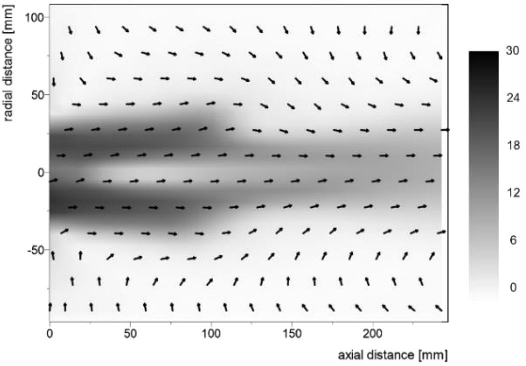

Fig. 11. Open jet of a propeller in a xanthan gum solution of 1 g/kg
(stirrer speed: 1000 rpm)

3.3. Flow conditions in a fermenter

By using a tracer, the flow field in the pilot plant can be visualised and the mixing time determined. As shown in Figures 12 and 13, there is a clear dependence on the viscosity, the azimuth angle and the stirrer speed. However, a higher viscosity does not always lead to lower-mixed volumes. Due to the spreading of the liquid jet, it is possible that the fluid flow reach the centre of the reactor. The classic stagnation zone in the centre reduces or completely disappears.

As expected, interactive stirrers also decrease the thrust; therefore, by measuring the thrust, conclusions about the interaction of the stirrers and the flow field can be drawn.

Fig. 12. Flow field at a xanthan gum of 2 g/kg (stirrer speed: 3000 rpm; azimuth angle: 65°)

Fig. 13. Flow field at a xanthan gum of 3 g/kg (stirrer speed: 3000 rpm; azimuth angle: 65°)

4. Conclusion

According to rheological studies, the digestates show a distinctive pseudoplastic behaviour. Due to the varying feeding of the fermenter, these viscosity values fluctuate considerably during the year. Furthermore, viscoelastic effects must be considered for the positioning and operation of the agitators. Based on measurements of the open jet by using particle image velocimetry, there are huge dependencies of the stirrer speed, the rheology and the propeller geometry on the open jet (especially the angle of spread) the range and the field of return flows. These results provide the basis for determining the optimal positioning of the stirrers in the fermenter. The ideal operation could be quantified by measuring the mixing time and visualising the flow field. Classical stagnation zones are avoided in the reactor centre, or at least reduced. However, for all adjustments, the interaction of the agitators was important to achieve an adequate flow field. This interaction could be detected by measuring the thrust. In addition to the viscosity, the thrust is a second parameter for a control system for submersible mixers in biogas plants.

Acknowledgement

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