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The Influence of intensity mixing on the digestion process

Abstract
The basics of convection, mechanical, hydraulic and bubbling mixing used in methane fermentation technologies are discussed. The impact of the intensity of mechanical mixing on the quality and quantity of biogas as well as the course of the fermentation process was evaluated. The influence of the paddle agitator speed rate on quasi-continuous fermentation was investigated. Fermentation was carried out under mesophilic conditions with a hydraulic retention time of 21 days. A 10% increase in biogas production was observed with the increase of the speed of mixing from 60 to 70 min^{-1} without a significant change in the composition of biogas and other process parameters.

Keywords: methane fermentation, mixing of fermentation bioreactor, mechanical mixing, efficiency of fermentation.

1. Introduction

Mixing is an important issue that should be taken into account in any chemical and biochemical process. Agricultural biogas plants are not an exception, although not so long ago mixing system was considered the least significant of the biogas plant. Wisely selected and efficient mixing system significantly affects biogas plant performance. Still, biomass mixing consumes energy, so choosing the adequate mixing method is important for reducing the costs of biogas plant operation (Buraczewski & Bartoszek, 1990; Hurtado et al., 2015).

The main role of mixing is biomass homogenization that enables equal speed of digestion process in the entire active volume of the bioreactor. Effective mixing allows to maintain the homogeneity of the batch, thus even distribution of biological material and increase the bioavailability of biomass for microorganisms. Moreover, it enables biogas release from the entire volume of the reaction mixture and even formation of post-fermentation products. Mixing allows for the relaxation of biomass in the bioreactor, which helps to release biogas bubbles retained in the reaction space. As a result of intensive biogas production, the so-called scum can accumulate on the surface of fermentation batch. Mixing also prevents stratification of the suspension, sedimentation of solid particles and settlement of agglomerates of acetic and methane bacteria, that would slow down the fermentation process. In addition, homogenization enables the transport of biocomponents between specific microenvironments existing within the bioreactor (Mata-Alvarez et al., 2000; Stroot et al., 2001; Sosnowski et al., 2003; Gómez et al., 2006; Holm-Nielsen et al., 2009; Aranowskiet al., 2010).

Mixing intensity must not have a negative impact on the formation of bacterial agglomerates, excessive shear forces can lead to the damage of bacterial colonies and disrupt the fermentation process. The fermentation process is based on the symbiotic effect of many strains of bacteria. Metabolites of one strain are used as feed by other species. By causing a disturbance in the bacterial system as a result of mixing, the fermentation process disruption occurs and persists until the dynamic balance is re-established.The best scenario is frequent or continuous mixing with very low intensity. In the case of standard paddle mixers, speed of several or dozens of rpm are used.

On the other hand, insufficient mixing leads to a significant reduction in the contact between organic matter and microorganisms, in consequence the decomposition process slows down and organic matter deposits in places where the biomass flow is the lowest.

2. Methods of bioreactors mixing

There are many mixing systems adapted to the fermentation method and substrates used:

1. Natural mixing — resulting from thermal convection, growth and release of biogas bubbles.
2. Mixing with rotary agitators — the basic and most commonly used solution in which biomass movements are forced by low-speed blades placed on a vertical or inclined shaft.
3. Hydraulic (pump) mixing — occurs as a result of transferring the digestion mass through the pump system, and also as a result of supplying the bioreactor with the raw material stream.
4. Screw agitators — in the central transport pipe there is a snail that keeps biomass in motion, most often in the vertical axis of the bioreactor.
5. Gas mixing — is caused by the flow of gas bubbles through the biomass bath.

Each method has some advantages and disadvantages that can significantly affect both the biogas production process and the energy consumption rate.

3. Influence of mixing intensity of anaerobic digestion

The influence of rotational speed of the paddle agitator in a stirred tank reactor on fermentation conducted in a quasi-continuous state was investigated. Fermentation was carried out in two reactors in mesophilic conditions with a hydraulic retention time of 21 days at 37°C (Fig. 1).

The twin reactors worked independently, enabling two measurements to be carried out simultaneously or determination the effect of changing the process parameters. The biomass was mixed with paddle agitators with an adjustable rotational speed in the range of 20–70 min^{-1}. Biogas flow was measured by a flow transducer and eudiometer. The installation was equipped with control and parameter acquisition systems. The feed biomass consisted of 47% bovine slurry, 44% water, 9% corn silage, crushed to a size of less than 3 mm. Bovine manure was used as the innoculum. Three fermentation experiments were carried out, with rotation speed of: 60, 65, 70 min^{-1}. Initially, fermentation at 60 min^{-1} was carried out in reactor 1, then fermentation at speeds of 65 and 70 min^{-1} in reactor 2 and 1, respectively.

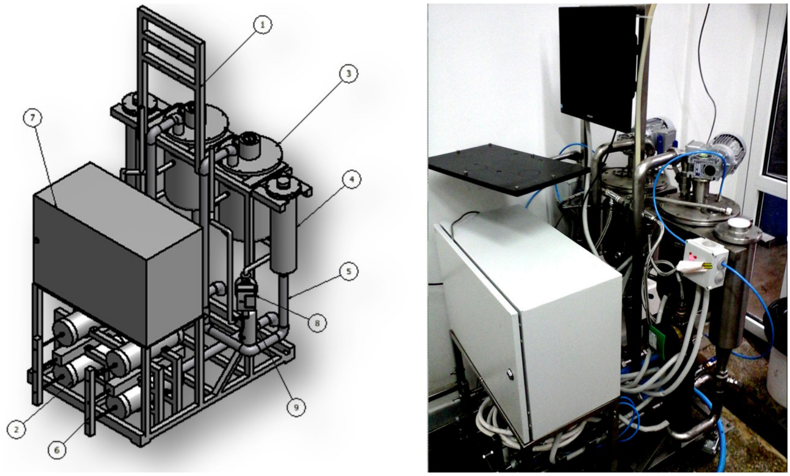

Fig. 1. Methane fermentation system: 1) frame, 2) dispenser, 3) fermentation reactor, 4) storage tank, 5) pipeline, 6) servomotor, 7) switching station, 8) circulation pump, 9) heater

The average load of fermentation chambers in the experiment with an agitator speed of 60 min^{-1} was 3.92±0.25 kgVS/m^3·d (Fig. 2) and for fermentation at 65 and 70 min^{-1} the average load value varied only by 0.3% and was 3.93±0.25 kgVS/m^3·d.

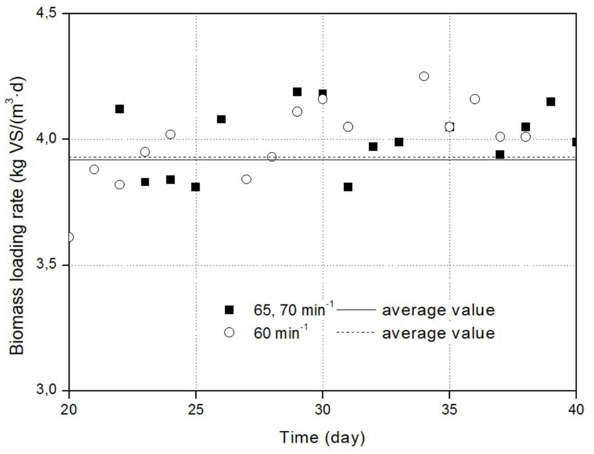

Fig. 2. Changes of volatile solids load at different agitator speeds

Daily biogas yield for the fermentation of maize silage with bovine manure for mixing intensity 60, 65, 70 min^{-1} measured in the period from 21 to 40 days of the process was 298±39, 329±18 and 329±11 m^3/kgVS·d, respectively (Fig. 3). The biogas obtained in the period of 16th to the 36th day of fermentation with agitator speed of 60, 65, 70 min^{-1} consisted respectively of CH_4: 54.9±1.9%, 51.4±8.0%, 54.0±3.2%, and CO_2 42.3±2.2%, 44.8±7.2%, 43.5±2%. Changes in the mixing intensity in the studied range did not affect the biogas composition significantly. The increase of biogas production by 10% for the process conducted at speed of 65 and 70 min^{-1} is noticeable, however, it fits within the limits of statistical error. Similar results were obtained by Kaparaj et al. (2008) during optimization of mixing in a thermophilic process fed with manure in a laboratory and pilot scale. They obtained an increase in production by 7 and 12%, when periodical mixing was applied, respectively in the pilot and laboratory scale, and by 1.3% using a minimum mixing speed (about 35 min^{-1}) in a laboratory scale. Lienen et al. (2013) stated that even a six-month mixing break does not affect significantly rheological parameters of biomass, however it can lead to sedimentation of mineral parts, and to the mixer damage during restarting.

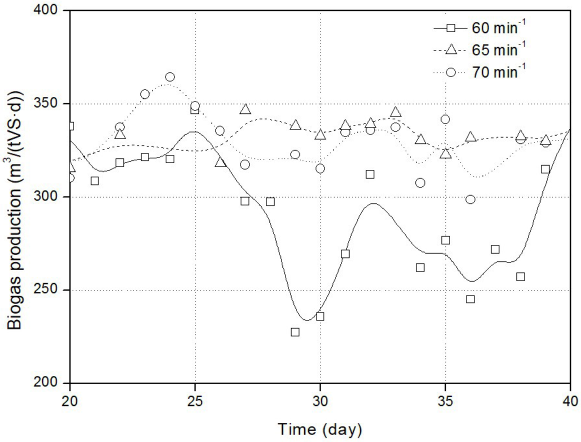

Fig. 3. Daily biogas production at different agitator speeds

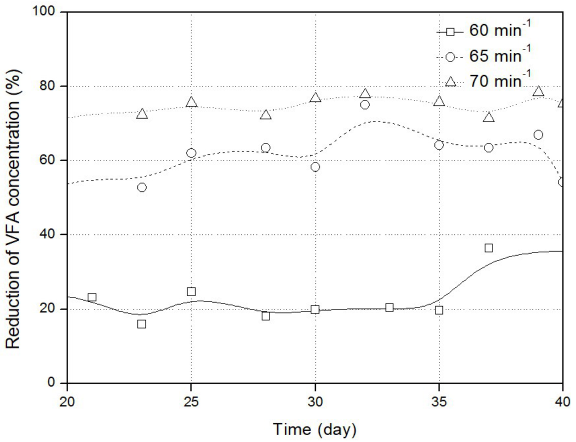

Fig. 4. VFA reduction rate at different agitator speeds

Significant changes were observed in the content of volatile fatty acids (VFA) while changing the rotational speed of the agitator (Fig. 4). For the process conducted at the rotational speed of the 60, 65, 70 min^{-1}, the concentration of VFA was 4.77±0.41, 2.79±0.88 and 1.55±0.27 g CH_3COOH/dm^3, respectively. Higher speeds of the agitator probably accelerated the release of volatile acids from the fermentation mixture. Similar effects were noted by Kaparaj et al. (2008) when using periodical interruptions in reactor mixing.

The change in mixing intensity in the studied range did not significantly affect the pH value, conductivity of the fermenting biomass, concentration of NH_4^+ ions, volatile fatty acids content or chemical oxygen demand (COD).

4. Summary

The basic aim of mixing is to ensure homogeneous fermentation mixture and, hence, uniformity of density and temperature in the entire volume of the bioreactor. Due to the heterogeneity of biomass and complex rheological nature this is not easy and requires individual approach and optimization. Insufficient effectiveness of mixing may result in reduced efficiency of fermentation through reduced availability of nutrients, as well as inhibition of release of biogas from the fermentation mixture (mainly carbon dioxide, which causes acidification of the fermentation mixture), which is caused by the inclusion of gas bubbles inside the bacterial flock.

The composition of the obtained biogas was not significantly influenced with the mixing intensity n examined range. The increase in biogas production by 10% for the rotational speed of 65 and 70 min^{-1} in comparison to the process carried out with the rotational speed of the 60 min^{-1} was not significant. According to Marchenko et al. (2017), with the relative difference in linear velocity of nutrients and bacterial flocks above 0.5 m/s, the absorption through the cell wall is limited and thus bacterial activity is reduced. In the examined range of mixing frequencies 60–70 min^{-1} the linear speed of the stirrer was respectively 0.18–0.21 m/s, which could not significantly influence the activity of microorganisms.

The influence of mixing on technical issues of the fermentation process was also found. In the case of a rotational speed of the agitator of 70 min^{-1}, wrapping of biomass fibres on the stirrer shaft was observed, and in the case of rotational speed of 60 min^{-1}, sedimentation of mineral particles at the bottom of the bioreactor occurred.

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