Bioresource Technology 245 (2017) 1139–1147

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Impact of shear stress and impeller design on the production of biogas in anaerobic digesters

Aline Lebranchu[a,b], Stéphane Delaunay[a,b], Philippe Marchal[a,b], Fabrice Blanchard[a,b], Stéphane Pacaud[c], Michel Fick[a,b], Eric Olmos[a,b,*]

[a] CNRS, Laboratoire Réactions et Génie des Procédés, UMR 7274, 2 avenue de la forêt de Haye, TSA 40602, Vandœuvre-lès-Nancy F-54518, France
[b] Université de Lorraine, LRGP, UMR 7274, 2 avenue de la forêt de Haye, TSA 40602, Vandœuvre-lès-Nancy F-54518, France
[c] ENSAIA, Université de Lorraine, 2 avenue de la forêt de Haye, TSA 40602, Vandœuvre-lès-Nancy F-54518, France

A R T I C L E I N F O

Keywords:
Mixing
Helical ribbon
CFD
Biogas
Anaerobic digestion

A B S T R A C T

Today, intensification of anaerobic digestion is still a scientific and technical challenge. The present study proposed combined experimental and computational fluid dynamics simulations to characterize the impact of shear stress and impeller design on the biogas production after sequential additions of substrate. Liquid phase (cattle manure digestate) rheological law was experimentally determined and input in numerical simulations. The results showed that the original use of a double helical ribbon in digester allowed a significantly faster dispersion of fresh substrate than the use of a classical Rushton turbine, leading to a 50% higher methane production rate. However, with both impellers, too high agitation rates entailed a clear slow-down of production rate and a decrease in CH_4 content. To avoid this loss of productivity, it was shown that the maximal value of shear stress, determined by numerical simulations, was a consistent parameter to set the upper agitation conditions in digesters.

1. Introduction

Anaerobic digestion of wastes or substrates is a complex bioenergy production process as the involved biochemical and physical mechanisms are not yet clearly understood, making bioreactor design, set-up and control still not fully optimized. For instance, the rheology of the substrates, such as cattle manure, is generally considered as non-newtonian which addresses the real mixing performance of the digesters today available, *a fortiori* of large-scale systems. Indeed, an inadequate mixing may promote temperature or concentration gradients (pH, substrates, and dissolved gases) within the digester that may possibly impact biological reactions, substrate availability, dissolved gases stripping, the spatial distribution of microbial populations and *in fine* the performance of biogas production (composition, flow rate). Therefore, the characterization of mixing in digesters is of key importance to establish reliable and robust relationships between mixing performance and the efficiency of biogas microbial synthesis.

Several studies dealing with the impact of mixing on the biogas production rate have been published these last years, using various designs of impellers and vessels or process scales. Nevertheless, as the different results obtained in these articles do not systematically agree one with each other, it remains difficult to draw generalizable trends regarding this impact. For instance, Hoffmann et al. (2008) used a 4.5 L digester equipped with an axial flow impeller. They showed that a high agitation, obtained by increasing the agitation rate only, had no effect on biogas production in steady-state regime, while intense mixing (1500 rpm) had a negative impact on the digester performance during initial startup. Lastly, Kaparaju et al. (2008) used a 3.6 L digester equipped with impellers whose geometry was not specified and also demonstrated that minimal intermittent mixing of liquid phase (10 min mixing prior to feeding) enabled a higher biogas production than a continuous mixing.

Rheological behavior and bioreactor hydrodynamics are key parameters to characterize when mixing effects are studied. Cattle manure, which is the substrate used in the present study, is a relatively viscous feedstock which is often used for anaerobic digestion, especially in farm facilities. This fluid is known to reveal a complex rheological behavior (Chen, 1986) entailing that dramatic viscosity gradients are likely to occur in digester if the shear rate distribution is not sufficiently homogeneous. Rheology of cattle manure is non-newtonian, with a shear-thinning behavior (Achkari-Begdouri and Goodrich, 1992; Chen, 1986; El-Mashad et al., 2005). To model cattle manure rheology, a power-law model ($\mu = K\cdot\dot{\gamma}^{n-1}$) relating the liquid viscosity μ (Pa s), the shear rate $\dot{\gamma}$ (s^{-1}), the flow index n (–) and the consistency index K

* Corresponding author at: CNRS, Laboratoire Réactions et Génie des Procédés, UMR 7274, 2 avenue de la forêt de Haye, TSA 40602, Vandœuvre-lès-Nancy F-54518, France.
E-mail address: eric.olmos@univ-lorraine.fr (E. Olmos).

http://dx.doi.org/10.1016/j.biortech.2017.07.113
Received 20 June 2017; Received in revised form 20 July 2017; Accepted 22 July 2017
Available online 23 July 2017
0960-8524/ © 2017 Elsevier Ltd. All rights reserved.

(Pa s^n) is thus often used. In parallel to the determination of the liquid phase rheology, it is also necessary to develop and use robust approaches allowing the prediction of the spatial distribution of velocity gradients and thus viscosities and shear stresses. Mixing and hydrodynamics characterization of anaerobic digesters and more generally of bioreactors operating with non-newtonian fluids have been previously studied using Computational Fluid Dynamics (CFD) simulations. This approach relies on the 3D simulation of the liquid velocity fields with possible complex rheology, homogenized by moving parts or not. In most of the anaerobic digesters involving cattle manure or sludge digestion, a mechanical agitation is generally preferred. One or several propellers can be used to stir the liquid phase at different frequencies (Bridgeman, 2012; Wu, 2012a, 2012b). With this choice of stirrers, caverns may also be observed around it due to stress gradients (Low et al., 2012), which entail the formation of dead-zone whose volume could reach almost 50% of total volume (Bridgeman, 2012). All these studies have thus suggested that classical stirrers, such as Rushton turbine or even axial flow impellers, may probably not be the best choice to obtain an adequate mixing of the broth.

Finally, it is noticeable that studies describing biogas production performance in characterized digester hydrodynamics are still seldom in literature as these two approaches were generally used separately**.** In the present study, anaerobic digestions were performed to (i) highlight the impact of mixing on the biogas production using cattle manure as bacterial consortium and cellulose as substrate, (ii) to determine the transient behavior of the digester after substrate feeding. For this purpose, the biogas productions (total gas flow rate and composition) obtained after sequential additions of cellulose were measured in a 2 L digester mixed either by a Rushton turbine or a double helical ribbon and compared. To get further insight the differences obtained between both systems, the rheological behavior of the cattle manure and digestate were determined and CFD simulations were conducted to finely characterize the liquid phase hydrodynamics.

2. Material and methods

2.1. Biogas production

Two 2 L digesters (liquid height: 130 mm; total height: 200 mm; diameter: 136 mm) were designed and built to compare biogas production with different mixing devices (experimental set-up is described in Fig. 1). The first one is mixed with a non-standard double helical ribbon (height 130 mm/step 130 mm/width 11.6 mm) equipped with two scrapers at its bottom. The second digester was mixed by a standard 6-bladed Rushton turbine with height and width of the blades: 12 × 12 mm and total diameter D of 45 mm. These reactors were equipped with a pH-rH probe (Mettler, Ohio, USA) and a manometer (Leo Keller-druck, Winterthur, Schweiss) to measure the reactor pressure. The gas exit was equipped with a condenser to remove water vapor, a gas-counter for the measurement of total biogas production (Ritter, Bochum, Germany) and an online micro-gas-chromatography (SRA, Lyon, France) containing 2 modules with 2 columns and 2 thermal conductivity detectors (TCD). The first column is a molecular sieve preceded by a divinyl benzene ethylene glycol-dimethylacrylate polymer column (poraplotU) with a backflush system avoiding the introduction of CO_2 in the molecular sieve. This first module determined H_2, O_2, N_2, CH_4 concentrations while the second one is a single poraplotU measuring CO_2 and H_2S concentrations.

During the biogas production, the temperature was regulated at 40 °C by a heated jacket. The broth was mixed at agitation rates of 10, 50 or 90 rpm for the helical ribbon and 22, 66 or 110 rpm for the Rushton turbine to independently study, for each agitator, the impact of this parameter on biogas production. The raw matter was composed of 2 L of digestate from cattle manure digestion obtained from the 'La Bouzule' farm (Laneuvelotte, France). After grinding, the TS content of the digestate was 8.8%. A mass of 14 g of cellulose was also regularly added each time the biogas flowrate became lower than 30 mL h^{-1}. During the culture and for each cellulose addition, several parameters were measured: the delay time τ between addition time and the beginning of the induced biogas production, the production duration, the maximal production flowrate and biogas composition. The time-averaged biogas flowrate between two additions of cellulose $\overline{Q}$ and the total volume of biogas produced V were also determined.

2.2. Rheological study

The rotational rheometer used during this work consisted in a helical ribbon placed in a cylindrical vessel with a volume of 785 mL (height: 100 mm; diameter: 100 mm) made in Plexiglas. The ribbon was connected to a motor with a rotation frequency (Lamy Rheology, Lyon, France). The helical ribbon used had the following dimensions: height 100 mm; diameter 980 mm; width of ribbon 10 mm and step 100 mm.

The first step of the rheological study was to determine the stirrer characteristics (power dissipation and shear rate). In laminar regime

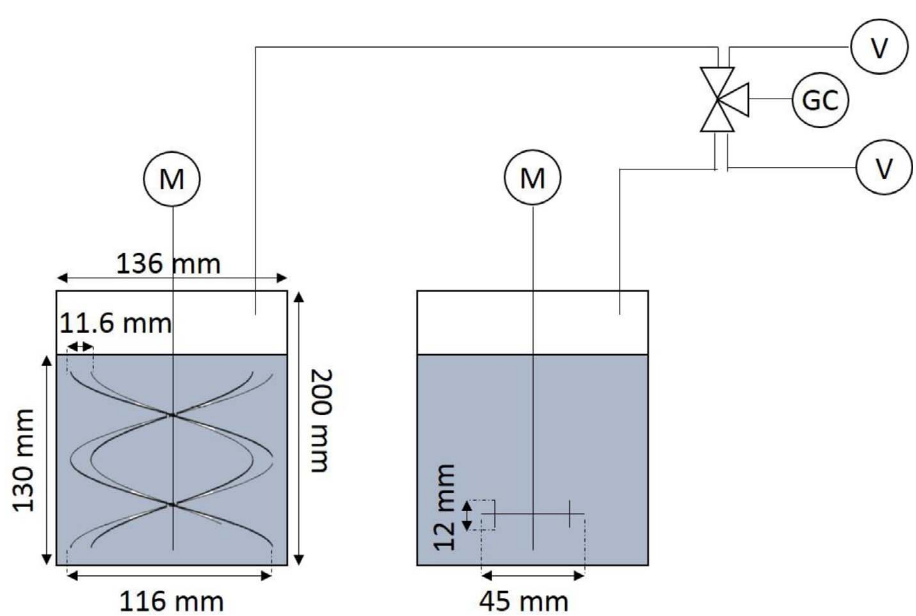

Fig. 1. Experimental setup. Digester equipped with the helical ribbon (on the left) and with the Rushton turbine (on the right). M: Motor; GC: Gas chromatography; V: Gas Counter.

Download English Version:

https://daneshyari.com/en/article/4996839

Download Persian Version:

https://daneshyari.com/article/4996839

Daneshyari.com