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Effects of rising biogas bubbles on the hydrodynamic shear conditions around anaerobic granule

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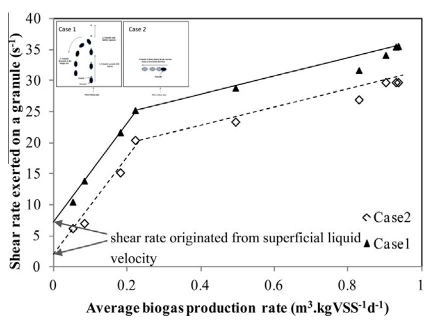
HIGHLIGHTS

- *In situ* biogas production in a reactor was studied using a high-speed camera and PIV.
- Shear rate exerted on granules in typical motions was studied at first time.
- 56.8–96.6% shear rate exerted on a granule stems from the generated biogas bubbles.
- Shear rate exerted on granule linearly correlates with specific bubble population.
- The study could facilitate understanding hydrodynamic conditions around sludge.

GRAPHICAL ABSTRACT



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ABSTRACT

Anaerobic reactor is one of gas–liquid–solid three-phase bio-reactors and has attracted high attentions worldwide due to biogas, a renewable energy. As is well-known, hydrodynamic conditions play crucial roles in the performance of the three-phase reactors. But the knowledge about the hydrodynamic conditions around sludge (microbial aggregates) is limited. The hydrodynamic shear force exerted on sludge derives from the liquid flow and rising biogas bubbles nearby. The *in situ* investigation in a two-dimensional micro anaerobic reactor shows that 56.8–96.6% shear rate exerted on one piece of granular sludge (major axis of 2 mm and minor axis of 1.5 mm) in typical motions stems from the rising bubbles when biogas production rate is greater than 0.1 m^3 $kgVSS^{-1}$ d^{-1} and the superficial liquid velocity of reactor was fixed at 6.48 mh^{-1} in this study. Furthermore it linearly correlates with specific bubble population with R^2 of superior to 0.95. The specific bubble population plays more important roles in the shear rate on granules than the bubble diameter. Liquid flow is also important for the shear rate exerted on moving sludge in term of the relative velocity between sludge and liquid flow rather than the superficial liquid velocity. Thus the shear rate derived from liquid flow would be significantly lower than that part originated from bubbles. A high-speed digital camera and a particle image velocimetry (PIV) system were used to *in situ* quantify the bubbles and their behavior in reactor. This study could facilitate understanding and improving the hydrodynamic conditions in three-phase bio-reactors.

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1. Introduction

Gas–liquid–solid three-phase bio-reactors are widely used in chemical engineering and environmental engineering including various aerobic and anaerobic reactors. Anaerobic reactor is one of the most important three-phase reactors. It could utilize the organics in wastewater or wastes to produce biogas and has been used for decades [1–3]. At present, the interest to recover biogas as the fuel from industrial and agricultural wastewater and wastes seems to be increasing at the condition of fossil fuel shortage. Upflow anaerobic reactors are currently the most high-efficiency anaerobic reactors, including upflow anaerobic sludge blanket (UASB) reactor, internal circulation anaerobic (ICA) reactor and expanded granular sludge blanket (EGSB) reactor. They all are granule-based reactors. Some of relative research focuses on the granulation process, especially the formation, disruption, structure and metabolism of granular sludge in anaerobic reactors [2,4–13]. Other studies are devoted to dynamic effects of hydraulic and organic loadings, temperature, nutrients, inhibitors, pH and alkalinity on the performance of reactors [3,14–16].

Hydrodynamic conditions play important roles in the performance of anaerobic reactors [4,7,13,17–20], but the control is challenging. Generally, the global hydrodynamic conditions in terms of superficial liquid velocity or gas velocity are used in practice. But this method is invalidated when the contributions of both gas and liquid phases to the hydrodynamic force become almost equally important and none can be ignored [21]. Then the average hydrodynamic shear rate of reactor is proposed [21,22]. In fact, the actual shear force exerted on moving sludge in reactor is significantly different from the average shear rate of reactor. And the former would be more important because the bio-reaction is processed in the sludge. However, to our best knowledge, little related information about the shear rate of the moving sludge in reactor is available so far in the literature. The hydrodynamic shear force exerted on sludge derives from the liquid flow and rising biogas bubbles nearby, especially the latters. But it seems that the quantitative information about the contribution of the two phases to the shear force is limited. In the previous works [23–25], shear rate around static sludge stemmed from liquid flow were characterized. But there is no information about the effects of the rising biogas bubbles.

The objectives of this study include two points: firstly, to understand how the hydrodynamic conditions around moving sludge is formed; secondarily, to understand proper approaches to control he hydrodynamic conditions of the reactors. A particle image velocimetry (PIV) system and a high-speed digital camera were employed to characterize biogas bubbles and their behavior in flow field to facilitate understanding the hydrodynamic conditions around the moving sludge in three-phase bio-reactors. Changing superficial liquid velocity is still one of widely-used approaches to control the hydrodynamic conditions in practice to this date. But this study shows that this method might not be proper because the shear rate exerted on moving sludge might be determined by the relative velocity between sludge and liquid flow rather than the superficial liquid velocity. This would be very important for the performance of the reactors. In a word, this study would be of great importance of both science and engineering.

2. Materials and methods

2.1. Experimental setup and operating conditions

The experimental setup is shown in Fig. 1. The 2 dimensional (2D) upflow reactor at mesoscale was made of polymethylmethacrylate with a cross section of 30 mm × 5 mm and a height of 250 mm (Fig. 1). 2D reactor is of small thickness and is designed for the measurement of flow field because the targeted flow field cannot be reached by the high-speed camera when the thickness is big. It was fed from the bottom and was discharged from the top. The synthetic feed was stored in an airtight reservoir with total volume of 17 L during the experiment. It was pumped into the reactor by a peristaltic pump after being heated to 30 °C *via* a water thermal bath.

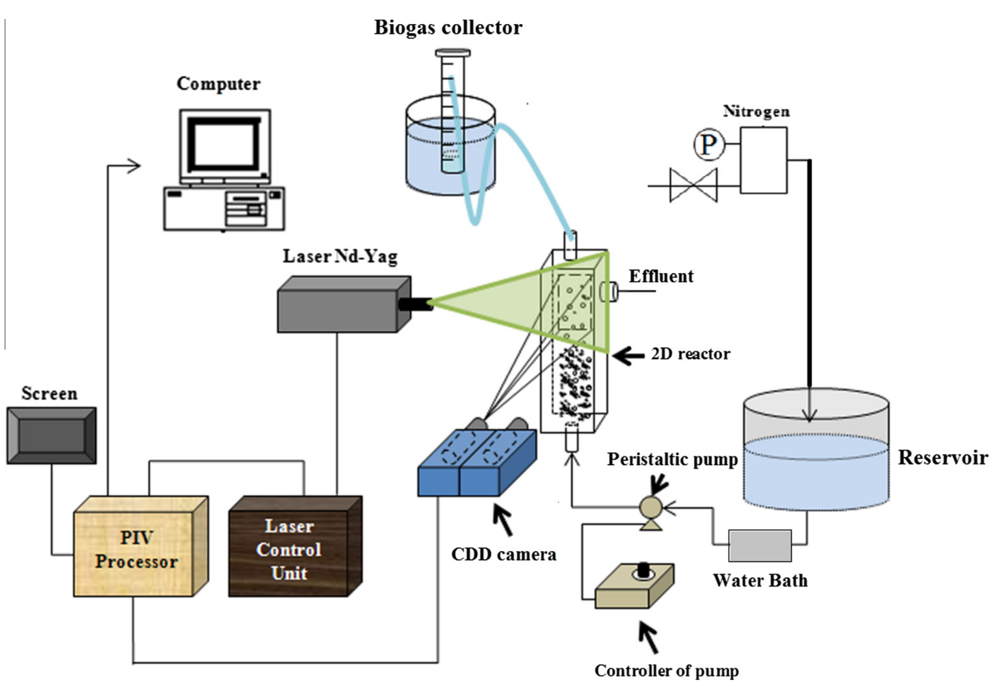

Fig. 1. Diagram scheme of the experimental setup including PIV system.