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Separation of swine wastewater into solid fraction, concentrated slurry and dilute liquid and its influence on biogas production

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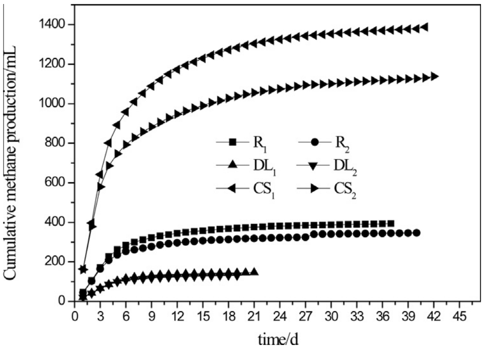
HIGHLIGHTS

- The separation offered a more effective option for swine wastewater treatment.
- Wastewater was separated into concentrated slurry and dilute liquid by sedimentation.
- The methane production kinetics of separated productions have been investigated.
- The components and methane distribution in products of separation were evaluated.

GRAPHICAL ABSTRACT

Cumulative methane production of raw wastewater, separated slurry and their separation products: R_1-raw wastewater, R_2-separated slurry, DL_1-dilute liquid from raw wastewater, DL_2-dilute liquid from separated slurry, CS_1-concentrated slurry from raw wastewater, CS_2-concentrated slurry from separated slurry.



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ABSTRACT

Swine wastewater was separated into a solid fraction and a liquid fraction in a biogas plant using a separator with hydraulic wedge-shaped sieve. The liquid fraction (separated slurry) was further separated into concentrated slurry and dilute liquid by gravity sedimentation in the laboratory. Components and methane production of the solid fraction accounted for about 15% of those of the raw wastewater. The majority of the organic matter and phosphorus (more than 60%) were distributed in the concentrated slurry. The concentrated slurry represented 15% of the volume of initial wastewater but produced more than 70% of the total methane production. The condensation of the pollutants and nutrients in the concentrated slurry can facilitate land application of digestate. The dilute liquid with less organic matter and nutrients can be treated easily using less expensive and easier treatment options.

1. Introduction

Anaerobic digestion is becoming increasingly attractive as a way to treat swine wastewater since it produces renewable energy (methane), and valuable digested residues. However, in China and

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some other Asian countries, a large amount of water is used in pig production to cool the pigs and to clean solid floors [25,24]. Thus, swine wastewater is produced in large volumes [24] with a low concentration of nutrients and low total solids concentration of around 1–2% [10]. The average dry matter (DM) content in slurry from finishing pigs is six times greater in European slurry than in Asian slurry [24]. Because of the low concentration in swine wastewater, it is difficult to recover the energy and nutrients. The biogas yield from anaerobic digestion of swine wastewater is often too low to make biogas production economically viable. In addition, maintenance of digestion temperature is very difficult owing to the low biogas yield, which would lead to poor treatment efficiency in winter [6]. Digestion is only economically feasible in large-scale co-digestion plants if swine wastewater is co-digested with wastes containing high organic matter concentrations [19]. If a dry matter rich fraction can be produced by solid–liquid separation, digestion of the solid portion might improve the economic performance of plants. Thus, separation of swine wastewater has been deemed an effective method to increase biogas yields [14]. Pre-treatment of slurry by separation to produce a highly-concentrated solid fraction has been shown to significantly increase the biogas potential per waste volume [16,17]. However, separation of the solid fraction from the wastewater using mechanical screens resulted in low effectiveness, with removal of 5–15% being observed for suspended solids [26]. In comparison, decanting centrifuges were very efficient at removing DM and TP. Specifically, 37–68% of DM, 50–83% of TP, and 8–33% of TKN could be separated into solid fractions. Additionally, chemical treatment of swine wastewater could enhance the removal of organic solids and nutrient elements from the liquid manure. Overall, 55–87% of DM, 72–91% of TP, and 16–45% of TKN were separated into the solid fraction by chemical precipitation with coagulants and flocculants [17]. Even though highly efficient separation was achieved using decanting centrifuges or chemical treatment, the cost was expensive. Indeed, treatment of slurry with a decanting centrifuge is five times more expensive than using a mechanical screen separator [14]. More attention was paid to utilization of the solid fraction derived from pre-separation of slurry than to the liquid fraction. The solid fraction generated from pre-separation of slurry is easier to dispose of because it can be composted or applied directly as fertilizer. However, the liquid fraction contains a low concentration of organic matter and nutrients, necessitating that it be further treated by evaporation, membrane filtration or ammonia stripping to obtain the desired end-products. Nevertheless, low-maintenance and/or cost-efficient methods for these post-treatments have not yet been demonstrated [11].

In our previous study, a new swine wastewater treatment technology was developed in which the swine wastewater was separated into supernatant (dilute liquid) and bottom sediment (concentrated slurry) through gravity sedimentation. The volume of the concentrated slurry, which accounted for 18.3% of that of the raw wastewater, could produce about 60% of the total biogas production potential [6]. During winter, the efficiency of methane fermentation of swine wastewater could be improved if concentrated slurry was heated using the surplus heat from the electric generator. Following separation, the digestate of the concentrated slurry contains nearly three times the total nutrient content as that of raw slurry, and can therefore be readily used as fertilizer.

Preliminary solid–liquid mechanical separation is usually employed prior to biological treatment [15]. Some solid organic matter can be removed from wastewater during solid–liquid separation. However, it is unclear if the separated slurry would be further separated or what the efficiency of the system would be.

This study was conducted to investigate the influence of removal of the solid fraction from raw wastewater on the post-separation of dilute liquid and concentrated slurry. The components and methane production distribution in the solid fraction, concentrated slurry and dilute liquid were also evaluated.

2. Materials and methods

2.1. Solid–liquid pre-separation

This experiment was performed in a biogas plant treating swine wastewater. Specifically, a separator with hydraulic wedge-shaped sieve (Model LK-120, Huizhou Lian Sheng Machinery Co., LTD, China) used for solid–liquid separation has a capacity of 40–80 $m^3\ h^{-1}$. The clearance of the hydraulic wedge-shaped sieve ranged from 0.3 to 0.5 mm. During solid–liquid pre-separation, swine wastewater was separated into a solid fraction and a liquid fraction (referred to as separated slurry). Samples of separated slurry and raw wastewater were taken from the adjusting tank and collecting tank and sent to the laboratory for a follow-up experiment.

2.2. Experiments regarding post-separation of dilute liquid and concentrated slurry

Post-separation of dilute liquid and concentrated slurry was conducted in the laboratory in a settling column composed of a cylinder made of transparent, rigid Plexiglas tubing with an internal diameter of 15 cm and a height of 280 cm, giving a total volume of 44 L and an effective volume of 43.2 L. A schematic diagram of the settling column is available elsewhere [6].

A dividing line was drawn in the settling column before the post-separation experiment. The volume below the dividing line accounted for 15% of the total effective volume, while that above the dividing line accounted for 85%. The separated slurry was pumped into the settling column and subjected to 3 h of sedimentation. The supernatant above the dividing line was discharged, which was referred to as the dilute liquid (DL_2). The sediment below the dividing line was then collected and referred to as the concentrated slurry (CS_2). The raw wastewater was also separated into dilute liquid (DL_1) and concentrated slurry (CS_1) as a control experiment. The raw wastewater, separated slurry, dilute liquid, and concentrated slurry were stored at 5 °C until used for characteristics analysis and the biogas fermentation experiments.

2.3. Biogas fermentation experiments

Anaerobic digestion experiments were carried out in an Automatic Methane Potential Test System (AMPTS; Bioprocess Control Sweden AB) as shown in Fig. 1.

The digester was filled with 338 mL raw wastewater, 369 mL DL_1, 221 mL CS_1, 342 mL separated slurry, 371 mL DL_2, and 226 mL CS_2, respectively, then adjusted to a total volume of 400 mL with incubated sludge. The TS and VS of the sludge were 5.92% and 3.98% respectively, while the VS/TS was 67.23%. To distinguish the amount of biogas produced by the inoculum itself, a control experiment was performed in digesters containing sludge alone. All experiments were conducted in triplicate. The digester was closed with rubber stoppers, after which the headspace was flushed with pure nitrogen (with 99% purity) for 2 min to remove the oxygen. Finally, the sample incubation unit, CO_2-fixing unit and the gas volume measuring unit were connected. The biogas fermentation experiments lasted 44 days at 35 °C. To monitor the methane yield, the experimental data were exported at the same time each day.

2.4. Analytical methods

TS and VS were measured using the weighting method. COD was determined by the potassium dichromate method. NH_3–N