Effect of total solids contents on the performance of anaerobic co-digestion of pig manure and food waste

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Introduction

It is estimated that 743 kilotonnes of biodegradable municipal waste, primarily comprising food waste (FW), was produced in Ireland in 2016, in addition with an annual production of 3.19 million m^3 of liquid pig manure (PM). There is a need to call for effective technologies for management of organic wastes (Jiang et al., 2019). Anaerobic digestion is a well-established biotechnology which can reduce and stabilise biodegradable organic fraction of wastes under anaerobic conditions by consortia of bacteria and archaea, and produce a renewable energy in the form of biogas. It is widely adopted, with the configurations of wet and dry anaerobic digestion; wet digestion has a total solids (TS) contents of substrate less than 10% while dry digestion has a TS content higher than 15%. Though wet AD is matured technologically, it has low organic loading rates that lead to high energy requirement for heating water and a large space for digesters (Liu et al., 2016). In addition, as a by-product of AD system, the dilute digestate requires extensive post treatment before using as an organic fertilizer on the land or discharged into the environment, which definitely increases the operation cost of AD (Masebinu et al., 2019). In comparison with wet AD, dry AD seems to be a more promising technology due to its several advantages, such as higher volumetric methane productivity, smaller reactor volumes, reduced energy requirement for heating, less digested residual, and a low moisture digestate that is easier to handle (Jiang et al., 2018). However, dry AD suffers from biological and technological drawbacks mainly due to the excessive content in solids and the poor mass transfer efficiency due to low water content (Benbelkacem et al., 2015). According to the literature, it is difficult to make a clear conclusion on the influence of TS contents on AD of solid waste, and few studies have been conducted so far to investigate the performance of anaerobic co-digestion of pig manure and food waste at different TS contents. The aim of the study presented herein was to assess the impact of the TS content on the performance of anaerobic co-digestion of pig manure. In addition, through the analysis of the microbial community structure, it was expected to clarify the specific microbial or metabolic characteristics being responsible for the enhanced resistance capacity in high-solid AD, and facilitate the development of more efficient and cost-saving full-scale dry AD systems.

Material and Methods

The batch assays were conducted using a series of 2-L glass bottles sealed with rubber stoppers as bio-reactors. The blending ratio between PM and FW was established by 50:50 based on VS with ISR (inoculum to substrate ratio) of 1:1. Sufficient mixture of substrates and inoculum was well prepared and then diluted to the TS content of 5% (R1-5%), 10% (R2-10%), 15% (R3-15%) and 20% (R4-20%) with tap water, and were placed in bio-reactors after fully mixing. After that, these lab-scale digesters were placed in an incubator with a constant temperature of 37.0 ± 1.0 °C. The volume of biogas generated was measured with a volumetric flow meter and then adjusted to the biogas volume under standard temperature and pressure conditions. The methane (CH_4) content in the biogas was determined by a gas chromatography equipped with a thermal conductivity detector. The digestate from each reactor was sampled regularly in order to measure pH, soluble chemical oxygen demands (SCOD), NH_4^+-N and volatile fatty acids (VFAs) concentrations in the digestate. After a digestate sample (1 or 2g) was taken from digesters, 19 parts of deionized water (w/w) was added to dilute 1 part of digestate sample and then fully blended to obtain a 20-fold dilution. The pH was measured with a portable pH meter. The dilution was centrifuged at 13,500 rpm for 5 min and the supernatant was filtered via a syringe filter. The obtained filtrate was used for determination of SCOD, total VFA and TAN concentrations. Total VFA concentration was analyzed by high performance liquid chromatography equipped with an ion exclusion column. TAN was analyzed using a Konelab nutrient analyzer. Each TS content test was conducted in triplicate.

Results and Discussion

The evolution of main parameters for digesters operated at different TS contents is shown in Fig.1. Overall, all the digesters gained a good performance. The profiles of pH value showed globally an identical tendency that pH decreased in the first several days, and then increased gradually until reached a constant value. Especially, digesters with TS of 20% had a lower pH value around 7.5 in comparison to the other three bioreactors, which were around pH 8.0. This was most likely attributed to the accumulation of VFAs though partly counteracted by gradually increasing ammonia concentration. Herein, these pH values were all within the acceptable range for AD 6.5-8.5.

Higher total ammonium (TAN) concentrations were observed in the digesters with high TS contents. According to Fig.1c, the maximum concentrations of free ammonia (FAN) in digesters with TS contents of 5%, 10%, 15% and 20% were 110.7±9.8, 498.6±14.4, 1025.1±31.3 and 1264.4±112.0 mg/L, respectively. It has been reported that the FAN concentrations above 200-1100 mg/L can exert inhibitory impact on the anaerobic system (Hansen et al., 1998). Therefore, the inhibitory impact of FAN concentrations might occur in the digesters with TS contents ranging from 10% to 20%. With increasing TS contents, higher VFAs concentrations were obtained in the digesters. VFAs in digesters of R1-5%, R2-10% and R3-15% were gradually degraded, with an exception that the concentration of propionic acid in digesters of R4-20% was still high at the 60th day.

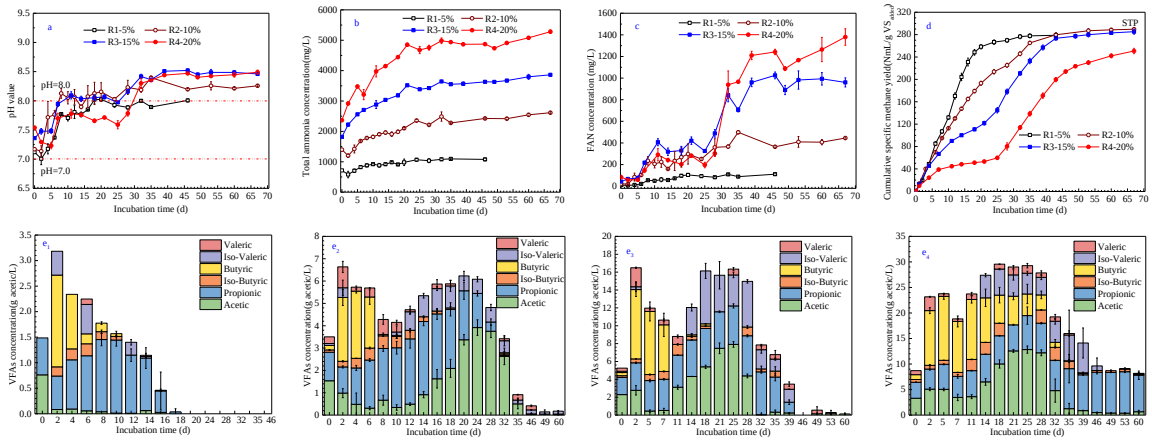

Fig.1. Evolution of pH, TAN, FAN, SMY and VFAs in digesters at the four different TS contents. (a. pH; b. TAN; c. FAN; d. SMY;e$_1$-e$_4$, VFAs)

The cumulative specific methane yields at different TS contents are shown in Fig. 1d. The cumulative specific methane yield (SMY) (based on added VS) of R1-5%, R2-10%, R3-15%, and R4-20% at the end of experiments were 278.8±3.9, 289.6±2.5, 285.3±4.6 and 250.7±4.9 NmL/g $VS_{added,}$ respectively. It turned out that the maximum SMY of digesters did not showed a decreasing trend with increasing TS contents from 5% to 15%, while the 20%-TS digesters obtained a slightly low SMY. The reason for this result was likely to link with the microbial community structures in the digesters. Moreover, the lag phase was extended with increasing the TS contents. Specifically, the lag phase of R2-10% digesters was very short and not significantly different to that of R1-5%. Technically and economically, 15%-TS content was preferable operation condition when established a full-scale dry AD of pig manure and food waste under mesophilic condition.

Conclusion

All the digesters with TS contents ranging from 5% to 20% gained a good performance. The inhibitory impact by FAN concentrations might occur in the digesters at TS contents over 10% but the inhibition was reversible. The maximum SMY of 15%-TS digesters was almost identical with that of 5%-TS and 10%-TS digesters, while the 20%-TS digesters obtained a slightly lower SMY.

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