Biogas and struvite production from animal slurry in a novel pilot-scale reactor

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Methane production efficiency of anaerobic digestion (AD) process is limited under high ammonia conditions, causing significant economic and environmental consequences (Yan et al., 2021). Ammonia is mainly produced by nitrogen-rich substrates decomposition during hydrolysis step of AD process and it mostly remains in the produced digestate together with other valuable nutrients (i.e., phosphorus). Many strategies (e.g., temperature or pH adjustment, dilution of reactor content, addition of trace elements, etc.) have been used to alleviate ammonia toxicity in AD process with different levels of success (Braguglia et al., 2018). Fed-batch reactors have proven to provide a more robust AD process under high ammonia stress compared to batch and continuous reactors (Tian et al., 2017).

The AD produces digestate is predominately applied directly in farming land, instigating nutrients loss via runoff and volatilization with e.g., less than 40% ammonium nitrogen utilization (Manu et al., 2021). Thus, additional treatment of the digestate is necessary to achieve high efficiency nutrient recovery for a more economically and environmentally beneficial AD process (Styles et al., 2018). The biorefinery of struvite, which is a well-developed process for nitrogen and phosphorus recovery from the liquid digestate (after liquid- solid separation), has high potential compared to various ammonia recovery technologies (Al-Mallahi et al., 2020). Therefore, the aim of the current study was to create and assess an integrated strategy that promotes the overall efficiency of AD process under high ammonia levels coupled and efficiently recovers nutrients from the digestate. For this reason, an intergraded system consisted by a pilot-scale, fed-batch mesophilic (37±1°C) AD reactor (working volume: 7 m^3) fed with pig slurry (organic loading rate of ~0.90 g VS L^{-1}) and combined with a biorefinery reactor for struvite precipitation through ultrasonic frequency permeate, were set up and operated (Fig. 1). The produced digestate, biogas and struvite were assessed for all their respected physicochemical characteristics, while a pathogens analysis was also performed on the produced struvite (*Escherichia coli*, *Enterobacteriaceae* and *Salmonella*). The comprehensive data treatment, statistical analyses and illustrations were performed using the OriginLab program (OriginLab Corporation, Northampton, Massachusetts).

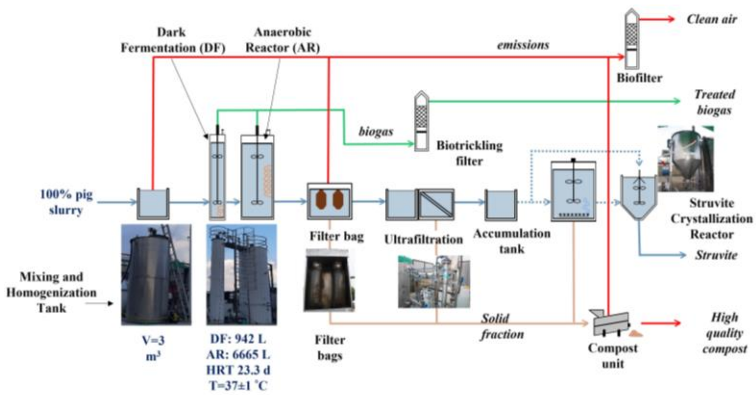

Figure 1. The overall integrated biomethanation-struvite pilot scale system

The results showed that methane production yield achieved was above 89% of the theoretical (based on COD) at the end of the experiment at increased levels of ammonia (>4.4 g NH_3-N L^{-1}). Additionally, VFA (20-220 mg HAc L^{-1}) accumulation and pH fluctuation (7.4-7.8) were inside healthy levels indicating an efficient AD process under increased ammonia stress (Fig.2) (Zhang et al., 2018). The precipitate production rate was 8 kg t^{-1} feedstock, while X-Ray Diffraction analysis revealed that purity of struvite crystals was 98% w/w. The nutrient recovery of nitrogen and phosphorus were above 48% and 68%, respectively. The chemical and sanitary indicators of the precipitate were in line with the European Union biofertilizer standards (Table 1).

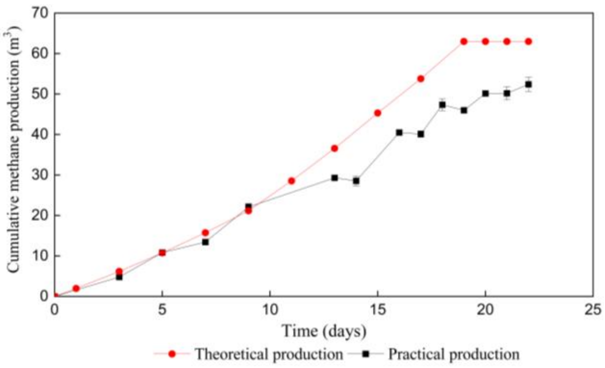

Figure 2. Methane production of the fed-batch reactor

Table 1. Characteristics of struvite and EU Requirements for compound solid inorganic macronutrient fertilizer

Parameters	Biofertilizer	EU Requirements
Total Nitrogen, TN (%)	4.46	At least 2 % w/w
Ammonium, NH_4^+ (%)	4.25	
Total Phosphorus, TP (%)	10.48	
Total phosphorus pentoxide, P_2O_5 (%)	24.04	At least 2% w/w
Phosphate Phosphorus, P-PO_4^{3-} (%)	6.60	
Organic carbon (%)	11.93	At least 7.5% w/w
Pathogens	Not Detected	

The obtained results indicate that it is possible to establish an integrated an efficient nutrient and energy recovery process for the simultaneous production of high-yield biogas and high-purity struvite fertilizer from pig slurry.

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