Chemical Engineering Journal 352 (2018) 855–862

Contents lists available at ScienceDirect

Chemical Engineering Journal

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

Effect of flocculation pre-treatment on membrane nutrient recovery of digested chicken slurry: Mitigating suspended solids and retaining nutrients

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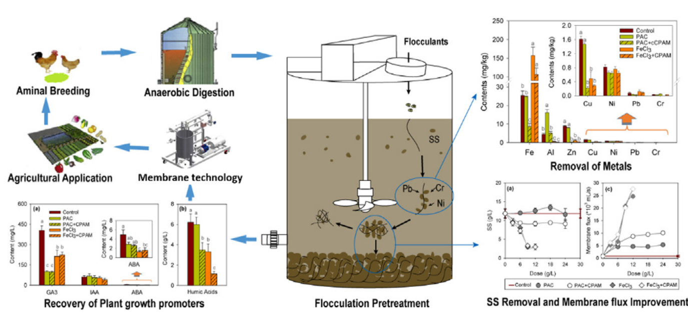
HIGHLIGHTS

- Flocculation pre-treatment effectively improved membrane flux by solids mitigation.
- High dosage of flocs reduced PO_4^{3-}-P, humic acids, and some phytohormone content.
- Limited influence of flocculation was seen on N and indoleacetic acid contents.
- Metals were significantly removed during flocculation due to binding effect of flocs.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Anaerobic digestion
Membrane filtration
Flocculation pre-treatment
Heavy metals
Organic fertilizer

ABSTRACT

Use of membrane filtration is attracting increasing attention for nutrient recovery from anaerobically digested slurry. However, the challenge is to reduce membrane fouling by effective solids mitigation, while maintaining valuable nutrients. In this study, the effects of several flocculation pre-treatments using polyaluminium chloride, iron chloride, and flocculant aid at various dosages were investigated. The results showed significant improvement in membrane flux from 0.8 to 27.6 mL/m^2/s due to solid migration (up to 75% removal). Significant loss of PO_4^{3-}-P (99%) and humic acids (40–80%) was observed. However, the content of NH_4^+-N and indoleacetic acids was largely maintained in the treated slurry. Moreover, toxic metals were significantly removed through flocculation, making the final product risk-free of heavy metals for agricultural application.

1. Introduction

Prominent fluxes in livestock breeding have occurred globally, especially over the past six decades. A major consequence of intensive or industrialized livestock production is the generation of a large amount of wastes [1]. Therefore, there is an urgent need for efficient and affordable treatment alternatives to handle excess manure. Anaerobic digestion (AD) is a suitable technology for livestock manure management due to its low maintenance cost and high treatment efficiency [2]. Moreover, AD technology could transform livestock waste into bioenergy (biogas), which eases the fossil energy crisis, as well as greenhouse gases emission [3].

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https://doi.org/10.1016/j.cej.2018.07.097
Received 17 May 2018; Received in revised form 11 July 2018; Accepted 13 July 2018
1385-8947/

The digestates generated in the AD of livestock manures are often rich in macronutrients, such as N, P, and K, and micronutrients, such as Zn, Fe, Mo, and Mn [4–6]. According to the sustainable concept of converting waste into useful products that enhance food security [7], these digestates have substantial potential to be used as organic fertilizers and soil amendments in agricultural land. However, the surrounding farmland is not sufficient in many regions to completely consume such large quantity of digestates. Thus, large storage capacity requirements and/or high transportation costs would arise, because a majority of the digestate is presented as liquid digested slurry with high water content (up to 95%) and relatively low nutrient level (around 4% of NH_4^+-N) [8]. Therefore, a feasible utilization method ought to be adopted to enrich nutrient concentrations and reduce the volume of digested slurry so that the pre-treated digested slurry could be easily transported and applied as a fertilizer in regions of high demand [9]. This nutrient enrichment strategy might also help reduce the environmental pollution risk of nutrient run-off and leaching by the surplus application of digested slurry [10].

So far, flocculation treatment coupled membrane technology has been well investigated in the water treatment area for suspended solid removal [11]. The concept for nutrients enrichment and recovery from digested slurry has just been attracting increasing interest [12]. However, clogging (or fouling) is well recognized as a major challenge in this membrane concentrating technology, inhibiting its large-scale implementation. Pre-treatment of slurry by decreasing the suspended solids through flocculation has been proposed as a feasible solution to this problem [13]. Due to the advantages of easy-operation and low cost, the flocculation-sedimentation pre-treatment prior to membrane filtration process have added value in decentralized installations of small size anaerobic plants where other expensive technologies are not feasible.

Flocculation involves the destabilization and aggregation of particles in suspension [14], and thus the effect of flocculants is highly dependent on the physicochemical properties of particle suspension in specific wastewaters. Various commonly used flocculants and flocculant aids exist in the industrial sector [15], such as trivalent aluminium salts and iron salts. From a traditional point of view of wastewater treatment, flocculation is fairly effective as a pre-treatment for membrane technology, because it removes not only suspended solids, but also other pollutants from the water [11]. However, the results from these studies cannot be transferred directly to digested slurry, due to its specific physicochemical properties. If we take the recovery of the nutrients from the wastewater and their retention in concentrated liquor as the main target of this technology, removal of suspended solids by flocculation may also result in the loss of nutrients through floc formation [16]. Besides the macronutrients, plant growth promoters, such as humid acid and phytohormones, are also commonly present in the slurry [17,18]. To best of our knowledge, the available information from literature on the dynamics of plant growth promoters from digested slurry through flocculation and membrane treatment is still limited. Considering the value of these nutrients as fertilizers, it is crucial to determine a suitable flocculation strategy that balances the conflict between increasing the membrane flux by the removal of suspended solids and retaining the nutrients.

To address this knowledge gap, various combinations of the two commonly used flocculants, polyaluminium chloride (PAC) and iron chloride ($FeCl_3$), and the flocculant aid, cationic polyacrylamide (CPAM), were selected to evaluate the flocculation effect on digested chicken slurry in this study. The effect of various flocculation strategies on the membrane filterability of digested chicken slurry were initially investigated by determining the content of suspended solid (SS), distribution of particle size, as well as membrane flux. Secondly, the corresponding influence of the flocculation process on the macronutrients (NH_4^+-N and PO_4^{3-}-P), plant growth promoters (phytohormones and humic acids), and metals (Fe, Al, Zn, Ni, Cu, Pb, and Cr) has been evaluated. With these results, this study aims to introduce a low-cost and easy-operated technology for digested chicken slurry pre-treatment, so that the nutrients can be effectively enriched by followed membrane technology.

Table 1
Characteristics of anaerobically digested slurry from digestion of chicken manure (n = 4).

Parameters	Symbol	Unit	Value
Physicochemical characteristics			
pH	/	/	8.44 ± 0.09
Electrical conductibility	EC	mS/cm^3	33.3 ± 0.3
Suspended solids	SS	g/L	11.9 ± 1.2
Macronutrients			
Ammoniacal nitrogen	NH_4^+-N	mg/L	4481 ± 269
Ortho-phosphate	PO_4^{3-}-P	mg/L	121.6 ± 2.7
Plant growth promoters			
Gibberellin III	GA_3	mg/L	404.1 ± 33.8
Indoleacetic acid	IAA	mg/L	59.9 ± 9.9
Abscisic acid	ABA	mg/L	4.9 ± 1.0
Humic Acids	/	g/L	6.2 ± 0.8
Plant essential metals			
Ferrous Iron	Fe	mg/kg	25.37 ± 2.56
Aluminum	Al	mg/kg	4.52 ± 0.46
Zinc	Zn	mg/kg	8.92 ± 0.46
Nickel	Ni	mg/kg	0.82 ± 0.06
Copper	Cu	mg/kg	1.61 ± 0.08
Plant non-essential metals			
Lead	Pb	mg/kg	0.08 ± 0.02
Chromium	Cr	mg/kg	0.03 ± 0.01

2. Materials and methods

2.1. Experimental materials

Digested chicken slurry was found to contain more plant growth nutrients than digested mammal manure slurry [19]. Therefore, it was selected as the target slurry to recover nutrients by flocculation pre-treatment in the present study. Anaerobically digested chicken slurry was collected from Deqingyuan biogas plant located in a suburb of Beijing, China. The biogas plant was operated under mesophilic condition (37 °C), with a hydraulic retention time (HRT) of approximately 28 days. The fresh effluent of the anaerobically digested slurry was collected and transported to laboratory within 4 h. The anaerobically processed chicken slurry was analysed for physicochemical characteristics, nutrients, plant growth promoters and metals prior to the experiment (Table 1).

2.2. Batch experiments

Two commonly used flocculants, polyaluminium chloride (PAC) and iron chloride ($FeCl_3$), were selected in this study, and cationic polyacrylamide (CPAM) was chosen as the organic flocculants aid in this study [20]. According to previous studies [21,22], as well as industrial practice, the dosage for PAC was determined to be 6, 12, 18, and 24 g/L, while for $FeCl_3$, it was 3, 6, 9, and 12 g/L. For the combined treatment with flocculant and flocculant aid, the dosage of CPAM was kept constant at 0.2 g/L (Table 2). For the flocculation treatment, 0.5 L of digested slurry was placed into a 1-L beaker and treated with various dosages of PAC and $FeCl_3$, with and without the aid of CPAM. Each treatment beaker was stirred rapidly (300 rpm) for 1 min, followed by slow stirring (75 rpm) for 12 min, using an overhead stirrer with four impellers (JJ-4, Baita Xinbao Instruments, China). The same value of slurry, which was stirred without adding flocculants and flocculant aid, was considered as the control after settling. All the treatments and control were conducted in triplicate.

Immediately after stirring, 10 mL of the sample was collected from