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Efficient sewage pre-concentration with combined coagulation microfiltration for organic matter recovery

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HIGHLIGHTS

- CCM improved the filtration performance in direct sewage concentration.
- CCM achieved sewage concentrate around 16,000 mg COD/L.
- 70% organic matter recovery was realized within 295-h continuous concentration.
- Anaerobic biodegradability of concentrate was 56.5%, similar to blackwater.
- An energy production of 0.0098 kW h/m^3 could be achieved by CCM system.

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ABSTRACT

This study proposed an efficient way of direct sewage pre-concentration by a combined coagulation microfiltration (CCM) system and an optimal operational strategy of aeration. Compared to two typical technologies for sewage pre-concentration, i.e. direct sewage microfiltration (DSM) and continuous aerated sewage microfiltration (ASM), the CCM system under optimal aeration strategy showed higher concentration efficiency and slower permeability decline (i.e. better control of membrane fouling), and easier collection of retained organic matter (OM). A lab-scale CCM reactor was running continuously for 295 h, and a concentrate of about 16,000 mg COD/L was produced at an average net flux of 13.3 L/(m^2 h) and an influent OM recovery of nearly 70%, which was higher than the concentrate produced by a high-loaded membrane bioreactor (MBR) with one day solids retention time. The use of chemical coagulant was found to have little impact on the following anaerobic digestion (AD) process, for anaerobic biodegradability of the concentrate is 56.5% (close to the typical value for blackwater). The integration of the CCM and AD processes could achieve a net energy production of 0.0098 kW h/m^3 after deduction of 0.0919 kW h/m^3 required for the operation of the CCM system, thus showing promise as an effective OM concentration method for energy recovery from sewage.

1. Introduction

Activated sludge process is currently the dominant sewage treatment process, mainly because of its stable performance in providing an effluent quality that meets the discharge standards. However, to carry out enough mineralization of organic matter (OM) in sewage, this process demands an extensive use of aeration, leading to huge amount of energy consumption in terms of electricity [1]. In addition, large volume of sewage sludge and greenhouse gas emission also render problems of sustainability, especially under the circumstances of global energy crisis and climate change.

This explains recent attention in sewage treatment to minimizing energy consumption or even achieving net energy production, recovering the nutrients like phosphorus and nitrogen and reclaiming treated water. As an example, microbial fuel cells (MFCs) are able to directly convert organic chemical energy in sewage into electricity or hydrogen. However, MFCs remain far from practical application [2]. Among many choices, methane production by anaerobic digestion (AD) is regarded as a more mature technology for sewage energy recovery [1]. Meanwhile, the left digestate after AD can be also reused as agricultural fertilizer in

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many areas, e.g. in China. So AD is considered a potential practical way for maximizing sewage resource recovery.

One of main bottlenecks in direct anaerobic sewage treatment is the low temperature and the low strength organic loading in raw sewage, which will cause the ineffectiveness and the energy waste in AD process. Thus, an appropriate sewage pre-concentration step would allow subsequent economical AD with limited sewage volume at easier-controlled elevated temperatures [3]. Conventional physicochemical pre-treatment steps including precipitation and flotation were tested, but high chemical consumption and increased salinity of the effluent were identified as two major bottlenecks [4]. Membrane concentration technologies were also studied, including a high-loaded membrane bioreactor (MBR) system, a dynamic membrane system, a submerged vibrated membrane filtration system and a direct membrane filtration system in dead-end process with chemically enhanced backwash [5–8]. This indicates that the idea of membrane-based sewage pre-concentration has been widely accepted. Although these processes have proven to be technologically feasible, they still require further study for scaling-up and optimization in order to minimize the energy and chemicals consumption for membrane fouling control and alleviate bio-mineralization of OM. Consequently, a pre-concentration step was proposed in this study by means of a combination of coagulation and membrane filtration together with optimal aeration strategy. Although coagulants have been extensively used in water and wastewater treatment, e.g. MBRs, tertiary sewage treatment, drinking water pre-treatment, their application in direct membrane filtration for sewage OM pre-concentration has not yet been investigated. Coagulation can result in the aggregation of small particles and colloidal OM, and hence mitigate membrane fouling and facilitate the pre-concentration efficiency [9]. It is also expected that the combination of coagulation and membrane filtration can assist the aeration strategy optimization to reduce the aeration energy consumption which comprises the majority in commercial MBRs [10].

In this study, the performance and feasibility of combined coagulation microfiltration (CCM) were tested in sewage OM pre-concentration. Three lab-scale sewage concentration systems, including direct sewage microfiltration (DSM), continuous aerated sewage microfiltration (ASM) and CCM, were compared in short-term batch experiments. Commercial coagulant polyaluminum chloride (PAC) was selected according to its best chemical oxygen demand (COD) removal in preliminary batch tests [11]. Long-term continuous CCM was also implemented to achieve higher COD concentration and examine its technological feasibility, where emphasis was given to filtration and COD recovery performance. The energy balance of CCM and AD processes were primarily estimated.

2. Materials and methods

2.1. System configuration and operation

2.1.1. Membranes

Three sets of submerged commercial hollow-fiber polyvinylidene fluoride (PVDF) membranes were applied for DSM, ASM and CCM, supplied by Origin Water Co. Ltd., China, with an effective surface area of 1 m^2 and a nominal average pore-size of 0.1 μm. The inner and outer diameter of the hollow-fiber were 0.95 mm and 2.45 mm, respectively. The PVDF membrane modules were stored in tap water before use.

2.1.2. Single-cycle pre-concentration performance

In preliminary tests, DSM, ASM and CCM systems were operated only for a single-cycle to examine the respective effect of coagulation and aeration on membrane fouling control and on raw sewage pre-concentration. The configurations of all three systems are presented in Fig. 1. Three rectangular Perspex reactors with a working volume of 28 L were used. DSM system (Fig. 1a) was operated without coagulant addition and aeration. ASM system (Fig. 1b) was operated with continuous aeration at an air flowrate of 0.6 m^3/h without coagulant addition. CCM system (Fig. 1c) adopted both coagulation and intermittent aeration with a normalized air flowrate of 0.12 m^3/h because of intermittent air blowing of 3 min every 15 min. Apart from providing necessary scouring to save the coagulant consumption during membrane fouling control, the intermittent aeration was also designed to conserve more OM and energy by reducing the aeration time. The raw sewage for preliminary test was picked from a 20,000 t/d local municipal wastewater treatment plant in Xiaojiahe, Beijing (China) after screening. PAC (analytical level, Al_2O_3 content of 27%, Guangfu, China) dosing was implemented in connection tubes by peristaltic pumps (Longer, USA) before sewage mixture fed into the reactor. The feeding PAC concentration was 10 g/L, and the flow ratio of the influent pump to the dosing pump was fixed to keep a PAC dosage of 30 mg/L during the experiment due to its balanced COD removal performance in previous study [11]. Piston pumps (Seko, Italy) were used to intermittently draw permeate from membrane modules, with 12-min permeation followed by a 3-min relaxation, when intermittent aeration occurred. The volumes of concentrates in all three reactors were controlled by a liquid-level-pump control system, which started or stopped peristaltic or piston pumps according to a liquid level sensor (Changjiang, China) and a time delay relay (Symore, China). The initial filtration flux was set at 20 L/(m^2 h) in all three reactors. A paperless recorder connected with pressure sensors and metal tube rotameters was set to monitor and record the flowrate and the transmembrane pressure (TMP) data. The preliminary test would stop when the TMP of any two of these three concentration systems reached around 700 mbar.

2.1.3. Continuous CCM operation

For continuous test by CCM, the same membrane module and reactor configuration were used. Table 1 compares the operation conditions in continuous CCM test with those in high-loaded MBR [12]. The raw sewage for continuous test was directly pumped from the equalization tank in Xiaojiahe plant. Off-line physical membrane cleaning by a soft sponge was carried out when TMP rose up to around 700 mbar. Continuous CCM operation was stopped when the COD concentration of the concentrate reached 15,000 mg/L, which is the economical level for OM energy recovery by AD [13]. COD mass balance and CCM process efficiency were calculated according to COD concentrations in the influent, concentrate and permeate, including the flowrate data.

2.2. Analytical procedures

2.2.1. Sewage, concentrate and permeate characteristics

COD, total nitrogen (TN), total phosphorus (TP), Ammonia (NH_4^+-N) and total suspended solids (TSS), were all determined according to the Chinese National Environmental Protection Agency (NEPA) Standard Methods [14]. Particulate, colloidal and soluble COD were fractionated according to van Nieuwenhuijzen's method [15]. Turbidity was measured using a turbidity meter (Hach 2100Q). Particle size distributions of raw sewage and the concentrate were measured by a laser diffraction spectroscopy (Beckman Coulter LS13320). Average values of these parameters for raw sewage during the whole experimental period are listed in Table 2. Biochemical methane potential (BMP) tests were used to determine the anaerobic biodegradability of the concentrate [16]. Methane specific production expressed in mL CH_4/g COD was calculated from the