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Performance and microbial community of a membrane bioreactor system — Treating wastewater from ethanol fermentation of food waste

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A B S T R A C T

In this study, a lab-scale biological anaerobic/anaerobic/anoxic/membrane bioreactor (A^3-MBR) was designed to treat wastewater from the ethanol fermentation of food waste, a promising way for the disposal of food waste and reclamation of resources. The 454 pyrosequencing technique was used to investigate the composition of the microbial community in the treatment system. The system yielded a stable effluent concentration of chemical oxygen demand (202 ± 23 mg/L), total nitrogen (62.1 ± 7.1 mg/L), ammonia (0.3 ± 0.13 mg/L) and total phosphorus (8.3 ± 0.9 mg/L), and the reactors played different roles in specific pollutant removal. The exploration of the microbial community in the system revealed that: (1) the microbial diversity of anaerobic reactors A_1 and A_2, in which organic pollutants were massively degraded, was much higher than that in anoxic A_3 and aerobic MBR; (2) although the community composition in each reactor was quite different, bacteria assigned to the classes *Clostridia*, *Bacteroidia*, and *Synergistia* were important and common microorganisms for organic pollutant degradation in the anaerobic units, and bacteria from *Alphaproteobacteria* and *Betaproteobacteria* were the dominant microbial population in A_3 and MBR; (3) the taxon identification indicated that *Arcobacter* in the anaerobic reactors and *Thauera* in the anoxic reactor were two representative genera in the biological process. Our results proved that the biological A^3-MBR process is an alternative technique for treating wastewater from food waste.

Introduction

Food waste comes from the kitchens of households, restaurants and public catering rooms, and contains high moisture and high concentrations of organic pollutants. Anaerobic fermentation is an attractive method for food waste treatment, compared to landfills that may cause serious odor and nuisance, highly polluted leachate wastewater and excessive land occupation (Tawfik et al., 2015; Xie et al., 2014). In anaerobic fermentation, complicated organic substrates are converted into biofuels by bacteria in reactors through hydrolysis, acidogenesis, acetogenesis and methanogenesis (Byun, 2012; Yirong et al., 2015). Recently, anaerobic ethanol fermentation has been considered to be the most effective

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way to obtain renewable energy from food waste (Wu et al., 2015). However, the ethanol fermentation of food waste generates huge amounts of wastewater, which contains high concentrations of inorganic and organic pollutants, such as suspended solids, ammonia, sulfate, phosphorus, saccharides and proteins. The discharge of this wastewater without appropriate treatment would cause serious eutrophication of water bodies. Therefore, it is a critical issue to find an environmentally and economically sound way to treat this wastewater during the application of ethanol fermentation of food waste.

Previous studies on food waste fermentation have mainly focused on the efficiency of biofuel production and the optimization of fermentation processes, but gave little attention to the treatment of fermentation wastewater. The wastewater from food waste fermentation shares many features with distillery wastewater from corn, sorghum or cassava fermentation, but contains more complicated components than the distillery wastewater (Kamalaskar et al., 2010; Wicher et al., 2013). Nowadays, many studies have explored technology for distillery wastewater treatment. However, few have addressed the treatment of wastewater from food waste fermentation. The high loading of multiple organic and inorganic pollutants may cause adverse effects on the treatment efficiency of the fermentation wastewater. Therefore, it is necessary to investigate the properties of the wastewater and design the treatment processes accordingly.

Biological wastewater treatment, which employs microorganisms to degrade pollutants under anaerobic or aerobic conditions, is usually considered a feasible and cost-effective treatment method for both domestic and industrial wastewater. In biological treatment processes, organic and inorganic compounds are transformed into H_2O, CO_2, N_2, etc., achieving the complete mineralization of wastewater pollutants. Researchers have successfully applied biological processes in the treatment of distillery wastewater (Nadia et al., 2015). According to previous research, a combined process involving both anaerobic and aerobic processes is suitable for the treatment of wastewater with high concentrations of organics, such as fermentation wastewater (Shin et al., 2010; Zerrouki et al., 2015). The anaerobic unit can recover bioenergy when it removes the loading of organic pollutants, and the aerobic unit treats the effluent of anaerobic wastewater to reduce the level of organic pollutants further and to remove nitrogen and phosphorus from the wastewater.

The membrane bioreactor (MBR), which relies on the membrane separation of biomass from effluent, is widely used in aerobic biological wastewater treatment. A long sludge retention time and high sludge concentration can be achieved simultaneously in MBRs (Zhao et al., 2009). Therefore, the MBR has a rich microbial community, and the presence of plenty of microorganisms is favorable to the removal of nitrogen and phosphorus and the degradation of organic pollutants. Pretreatment is also necessary, since the fermentation wastewater usually contains high concentrations of suspended solids. Coagulation is the most effective method for the removal of solids, color, and some organic pollutants. The initial pH and dosage of coagulants, which affect the coagulation efficiency, need to be optimized (Ahmad et al., 2006; Fang et al., 2012).

In this study, an anaerobic/anaerobic/anoxic/aerobic-membrane bioreactor (A^3-MBR) system was employed to treat food waste fermentation wastewater, and the influence of operation parameters on the efficiency of pollutant removal was investigated. The composition of the microbial community in each reactor of the A^3-MBR system was studied by 454-pyrosequencing technology in order to provide useful information relating to the biological treatment process.

1. Materials and methods

1.1. Wastewater

The wastewater used in the research was obtained from a food waste fermentation process described in previous studies (Thallinger et al., 2009; Ma et al., 2014). In this process, Q2 Q3 food waste was collected from the dining room of a university in Beijing. The ethanol fermentation of food waste was carried out at pH 4 after the addition of some strains isolated for ethanol production. The ethanol was distilled out after the fermentation. The remaining water discharged from the reactor was called food waste fermentation wastewater. In this study, the water qualities of the raw wastewater were as follows: pH, 4.0 ± 0.5; SS (suspended solids), 1050 ± 150 mg/L; COD (chemical oxygen demand), 15,000 ± 1000 mg/L; TOC (total organic carbon), 5500 ± 1500 mg/L; NH_3–N (ammonia), 225 ± 30 mg/L; TN (total nitrogen), 350 ± 50 mg/L; TP (total phosphorus), 85 ± 25 mg/L.

1.2. Coagulation

Coagulation was employed as the pretreatment process and conducted before the biological treatment of the wastewater. The pH and coagulant dosage were optimized using 0.5 L of raw fermentation wastewater under uniform magnetic stirring at room temperature of 23–25 °C. The initial pH was adjusted to the desired values using 1 mol/L HCl and 1 mol/L NaOH solutions. After 2 min premixing, polyaluminum chloride (PAC, purity (Al_2O_3) = 18%) was added to the wastewater. Then the tested samples were mixed rapidly at 200 r/min for 0.5 min, followed by slow stirring at 50 r/min for 8 min, and finally settled for 30 min. After coagulation, the supernatant (50 mL) was collected to determine the residual turbidity and TOC.

1.3. Reactor set-up

A laboratory-scale anaerobic/anaerobic/anoxic/aerobic MBR ($A_1/A_2/A_3$/MBR, or A^3-MBR) treatment system was applied to treat the coagulation-treated wastewater (Fig. 1). The anaerobic reactors, A_1 (working volume, 0.628 L) and A_2 (working volume, 0.628 L), and the anoxic reactor, A_3 (working volume, 0.314 L), were all packed with soft hydrophilic fibers for microorganism adhesion. The aerobic MBR (working volume, 0.628 L) employed a submerged polyvinylidene fluoride hollow fiber membrane module with pore size of 0.02 μm. The maximum flux of the membrane module was 9.72 L/m^2/hr in this study. Air was supplied by a compressor and dispersed at the bottom of the MBR to provide oxygen for the microorganisms and generate continuous stirring. A part of the MBR effluent was returned to

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