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Anaerobic digestion of organic wastewater from chemical fiber manufacturing plant: Lab and pilot-scale experiments

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A B S T R A C T

Chemical fiber manufacturing wastewater (CFMW) usually contains high levels of organic materials. Anaerobic digestion of CFMW was evaluated by the lab and pilot scale experiments in the study. The CFMW used in the experiment characterized an inappropriate C/N ratio and acid pH for anaerobic digestion. The COD removal efficiency, pH and the methane yield were significantly decreased with 5.00 g COD/L day of OLR in the lab scale experiment. These results were thought to be due to the inappropriate C/N ratio and acid pH of CFMW. Thus, the addition of nutrients and neutralization for CFMW were conducted in the pilot scale experiment. Accordingly, the significant decreases in COD removal efficiency and pH were not observed although the OLR increased to 5.00 g COD/L day. The methane yield also increased above 25% compared to that of the lab scale experiment. In the case of 1,4-dioxane, the removal efficiency was not improved significantly at the higher HRT. It was considered that constant proportion of acetic acid was used in the degradation of 1,4-dioxane as a cosubstrate regardless of HRT.

1. Introduction

In the chemical fiber manufacturing process, a large amount of water is used for the various steps of the chemical fiber production. The two primary raw materials, terephthalic acid (TPA) and ethylene glycol (EG), are converted by a polycondensation reaction to polyethylene terephthalate (PET) resins or fibers. The water consumed in the manufacturing process is finally discharged as the wastewater which needs to be treated. Lin et al. [1] reported that over 5000 tons of wastewater could occur daily in a typical large chemical fiber plant. The wastewaters generated by chemical fiber plants are mainly characterized by their high chemical oxygen demand (COD). Some of the wastewaters also contain 1,4-dioxane produced from the polyester manufacturing process.

In order to treat these wastewaters, chemical fiber plants first use physicochemical treatment methods like neutralization and coagulation, followed by traditional activated sludge process as a secondary treatment. However, due to the expensive handling costs and production of secondary environmental pollutants such as chemical sludge, a better alternative for pre-treatment of organic wastewater before aerobic biological treatment is required.

Anaerobic digestion has been widely employed by many industries as their primary treatment of wastewater [2,3]. Anaerobic digestion is a complex biological process regulated by a bacteria consortium in which complex compounds are degraded into methane, carbon and other gases. Anaerobes are sensitive to the type of substrate, which is hydrolyzed to sugars, amino acids and fatty acids [4]. They are also degraded by acetogens into acetate, hydrogen and carbon dioxide, which are consumed readily by methanogens. Thus, anaerobic digestion of organic wastewaters enables not only the removal of pollutants regarding wastewater streams but also the production of renewable energy in the form of methane [5].

There are several types of reactors used in the field of anaerobic treatment processes such as a continuous stirred tank reactor, up-flow anaerobic sludge blanket reactor, up-flow anaerobic filtration, fluidized bed reactor and up-flow anaerobic sludge fixed-film reactor. An anaerobic contact digester is one of them. This process consists of a contact digester and a sedimentation tank where sludge from digester effluent is settled and the settled sludge is recycled into the contact digester. The anaerobic contact process is capable of reaching a steady-state quickly due to mixing. Ward et al. [6] reported that mixing enhances contact efficiency between

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the microorganisms and the substrate, reducing resistance to mass transfer and accumulation of inhibitory intermediates. In addition, the anaerobic contact process generally requires short hydraulic retention times and enables relatively high effluent quality. The successful study using this process includes ice-cream wastewater and fermented olive mill wastewater treatment [7,8]. Thus, organic wastewaters from a chemical fiber manufacturing plant can be treated by anaerobic contact digestion.

The aim of the study was therefore to evaluate the feasibility of anaerobic digestion for organic wastewater from a chemical fiber manufacturing plant. For this purpose, the lab and pilot scale experiments were conducted. Organic wastewater from the polyester manufacturing process was used and operated with the anaerobic contact process. In the lab scale experiment, the process was operated at four different phases with an organic loading rate of 0.63∼5.00 g COD/L day. Through the result of the lab scale experiment, we found better conditions for anaerobic digestion of organic wastewater and reflected them in the pilot scale experiment. The treatment performance of the reactor was monitored and evaluated in terms of pH, alkalinity, COD and biogas production. In addition, organic wastewater contained a high concentration of 1,4-dioxane and thus the removal efficiency of it was also evaluated.

2. Experimental

2.1. Characteristics of organic wastewater

The characteristics of chemical fiber manufacturing wastewater (CFMW) used in this study are presented in Table 1. The organic wastewater was collected from a chemical fiber manufacturing plant located at the city of Ulsan in Korea. The CFMW represented low pH, TN and TP concentrations, but it showed a high COD concentration. The optimum pH and COD:N:P ratio of anaerobic digestion for the enhanced yield of methane has been reported to be 7 and 100:2.5:0.5, respectively [9]. Thus, nutrients supplementation and neutralization for CFMW were considered for the stable anaerobic digestion treatment. CFMW also contains 1,4-dioxane and then removal efficiency of 1,4-dioxane was evaluated.

2.2. Anaerobic contact reactor

Experiments for the anaerobic digestion of CFMW were conducted by the lab and pilot scale anaerobic contact process, which consisted of an anaerobic contact reactor, sedimentation tank and gas holder as shown in Fig. 1. The contact digester and all the other tanks of the lab and pilot reactors were made of acryl and stainless, respectively. The contact digester was completely closed and mixed continuously with 80 rpm. The influent was fed into the anaerobic digester continuously with a peristaltic pump. The volumes of the lab and pilot scale contact reactor were 18 L and 3 m^3, respectively. Temperature of digester was maintained with 35 °C by a thermostatically controlled system. The sedimentation tank allows the flocculated solids to be settled and the sludge recycling was carried out continuously from the sedimentation tank to the anaerobic digester, ensuring a constant biomass concentration in the contact reactor.

Table 1
Characteristics of organic wastewater used in this study.

Item	CFMW
pH	4.51 ± 0.8[a]
SS (mg/L)	18.5 ± 3.3
COD_{Cr} (mg/L)	11,480 ± 820
BOD_5 (mg/L)	415 ± 25
TN (mg/L)	13.4 ± 1.5
TP (mg/L)	1.2 ± 0.2
1,4-Dioxane (mg/L)	252 ± 35

[a] Mean value ± standard deviation.

2.3. Operating condition

The operating conditions were separated based on the organic loading rate (OLR) and were given in Table 2. In the lab scale experiment (Run 1), the process was operated at four different phases with an organic loading rate of 0.63–5.00 g COD/L day. Through the result of the lab scale experiment, we concluded better conditions for anaerobic digestion of organic wastewater and reflected them in the pilot scale experiment (Run 2). In Run 2, the process was operated with an organic loading rate of 1.25–7.50 g COD/L day. In addition, nutrients supplementation and neutralization of CFMW were conducted. The addition of nutrients was carried out in order to achieve a COD:N:P ratio of 100:2.5:0.5 and thus the concentration of TN and TP in CFMW increased to about 300 and 60 mg/L, respectively. The pH of CFMW was neutralized by NaOH which caused the increase in alkalinity of CFMW about 800 mg $CaCO_3$/L. The OLR increased after reactors reached steady-state conditions.

2.4. Analytical methods

All samples under each set of conditions were tested within 7 days of sampling. For each sample, the COD_{Cr}, BOD_5, alkalinity, suspended solids, TN and TP concentrations were measured

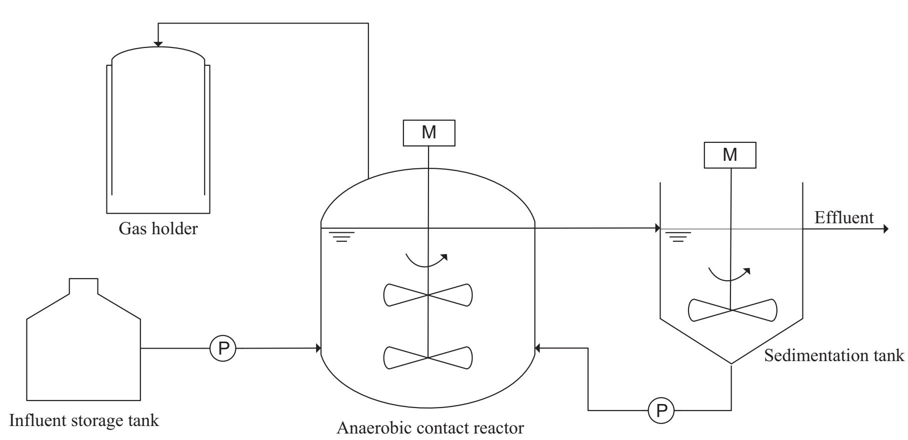

Fig. 1. Schematic diagram of the reactor setup.