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Pilot treatment of wastewater from *Dioscorea zingiberensis C.H. Wright* production by anaerobic digestion combined with a biological aerated filter

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ABSTRACT

An efficient combined system based on modified two-phase anaerobic digestion (MTPAD) combined with a biological aerated filter (BAF) is proposed to treat wastewater generated in the production of *Dioscorea zingiberensis C.H. Wright* (DZW). The pilot-scale experiments showed that both organics and sulfates at high concentrations could be removed satisfactorily due to the advantages of the MTPAD in eliminating the negative effects of sulfide inhibition to methanogens. Simultaneous nitrification and denitrification (SND) in the BAF resulted in efficient removal of COD and NH_4^+—N. UV–vis analysis showed that the organic compounds with aromatic structures were biodegraded effectively in the anaerobic process. GC–MS analysis revealed that furfural compounds in the influent were also biodegraded, leaving fewer compounds remaining in the final biological effluent. High efficiencies of COD removal (99.3%) and NH_4^+—N removal (93.7%) were achieved, and the quality of the final effluent met the National Discharge Standards of China for DZW wastewater.

1. Introduction

Dioscorea zingiberensis C.H. Wright (DZW) contains diosgenin which is used as a precursor for the synthesis of medical compounds such as contraceptives, steroids, cortisone, and hormones (Huang et al., 2008). The extraction of diosgenin from DZW is predominantly based on acid hydrolysis, resulting in the discharge of high-acid- and high-strength wastewater into the ecosystem. The DZW wastewater, deep brown in color, is characterized by low pH (<0.5), high level of COD (>60,000 mg L^{-1}), high level of total nitrogen (>650 mg L^{-1}), and high contents of sulfate (>35,000 mg L^{-1}) and chroma (>5000). DZW wastewater poses a major threat to the Danjiangkou Reservoir, which is the water source for the South to North Water Transfer Project (the largest water diversion project hitherto in China) aimed at alleviating water-shortage in northern China. So far, there have been few reports of the successful treatment of DZW wastewater. Therefore, the question becomes how to sustain the production and industrial processing of DZW without polluting precious water sources. The answer partly depends on the technological feasibility of DZW wastewater treatment.

Anaerobic digestion is an effective technology for the treatment of highly concentrated wastewater (Yamaguchi et al., 1999). In the conventional anaerobic process, acidogens and methanogens are retained together in a single reactor system (Zoetemeyer et al., 1982). DZW wastewater contains a high concentration of sulfate because much sulfuric acid is used in diosgenin production. In a single-phase anaerobic reactor, sulfate is reduced by sulfate-reducing bacteria (SRB) into sulfide, which inhibits and may even be toxic to the metabolism of methanogens, resulting in low COD removal efficiency (Pol et al., 1998). Pohland and Ghosh (1971) first proposed the physical separation of acidogens and methanogens using a pair of reactors, in which optimum environmental conditions for each group of organisms were provided to enhance the stability and control of the overall treatment process. Demirer and Chen (2005) and Ueno et al. (2007) found that the maximum allowable organic loading rate (OLR) achieved by the two-phase anaerobic digestion (TPAD) process was higher than that by a single methanogenic process. Moreover, sulfate reduction can occur in the acidogenic phase even at HRTs as short as 2 h (Mizuno et al., 1998). It is necessary to place a sulfate-reducing phase (acidogenic phase) ahead of the methane-producing phase to relieve the negative impact from sulfide. Sulfide produced in the sulfate-reducing phase can be partially oxidized biologically to elemental sulfur with a moderate dose of oxygen to elemental sulfur (Buisman and Lettinga, 1990; Janssen et al., 1999). A desulfurization reactor (DSR) has these features, stripping sulfide into the air and afterwards reducing sulfide into elemental sulfur.

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However, certain pollutants, especially ammonia nitrogen and some refractory organic compounds, still remain in the effluent from the anaerobic process. More effective treatment technology is needed to solve this problem. The biological aerated filter (BAF) is one type of immobilized-film reactor that is suitable for both secondary and tertiary treatment of wastewater including anaerobic effluent. BAF can achieve high hydraulic loading rates while retaining a high biomass concentration by using media with an elevated specific surface area (Stensel et al., 1988). BAF has been widely used in the treatment of many kinds of wastewater, especially those which contain high ammonia nitrogen (Yu et al., 2008) as well as toxic even refractory substances (Zhao et al., 2006; Jeong and Chung, 2006).

For the reasons above, a combination of BAF with the TPAD process was adopted to deal with DZW wastewater, which contains high levels of COD, sulfates and ammonia nitrogen. Based on an acceptable result obtained in an earlier laboratory-scale study (Zhao et al., 2008), the present pilot-scale study aims to assess the feasibility at an enlarged scale of the integration of modified TPAD (with a desulfurization capability) and BAF (using special carriers) for the treatment of DZW wastewater. UV–vis scan was used to examine the variations of the effluent contaminants at different stages in the treatment process. Gas chromatography/mass spectrometry (GC–MS) measurements were used to investigate the composition of organic compounds in the influent and the effluents at various stages during the treatment process. The main characteristic behavior of the carriers under operating conditions was revealed by an environmental scan electron microscope (ESEM).

2. Methods

2.1. Integrated system for DZW wastewater treatment

Fig. 1 shows the overall reactor system, which consists of a neutralization and precipitation tank, acidification reactor (AR), desulfurization reactor (DSR), methanogenic reactor (MR), and aerobic reactor (BAF). The acidification and methanogenic reactors, AR and MR, were constructed using a pair of cylindrical UASB reactors made of stainless-steel to resist corrosion by the anaerobic process. The AR was 1.5 m in inner diameter and 5.5 m in effective height. The MR was 2.5 m in inner diameter and 8.0 m in effective height. Each reactor has a three-phase separator on the top to prevent biomass washout. Situated between AR and MR, the stainless-steel DSR has a 50 cm inner diameter and 3 m effective height. The rectangular submerged BAF reactor was made of concrete given a special anti-seepage treatment and had an effective volume of 32 m^3, which included a sampling tube of dimensions 2 m × 4 m × 4 m on the outflow location. Air inflators (a roots blower, Shandong Zhangqiu Blower Co., Ltd., China) and air diffusers (Bifusheng Environment Protection Equipment Co., Ltd.) were used in the DSR with a volumetric ratio of gas to liquid flow (G/L) of 6 to supply dissolved oxygen (DO) at a concentration of 4.5–5.5 mg L^{-1}. Similarly, air inflation and diffusers, with G/L of 25, were used in the BAF to supply DO at a concentration of 4.5–6.2 mg L^{-1}. Metering pumps (Bosheng Water Pump Co., Ltd., China) were used to maintain a constant direct upflow of influent through the reactors. The carriers used to immobilize the microorganisms were Functional Polyurethane Foams (FPUFS) developed at Peking University (Zhao et al., 2006). Before use, the carriers were cut into cubes with each side length 15 mm. These carriers have a considerable affinity to microorganisms and pollutants since many active chemical groups are distributed on the carrier surface, such as –OH, $-NH_2$, –COOH, $-CH_2$, and $-CHOCH_2$ are found dispersed on their surfaces. When immersed in water, the carrier has a density of about 1.0 g cm^{-3} with a specific surface area of 35,000 $m^2\ m^{-3}$. In a previous study, Ye et al. (2002) observed that the biomass on the carriers can reach a density of 13–28 g L^{-1}, 80% volume of the DSR as well as of the BAF were filled with dry uncompacted carrier at the beginning of the treatment process. A similar procedure was undertaken in the present study. The temperatures inside the MTPAD and aerobic reactors were maintained at 33 ± 2 and 25 ± 2 °C, respectively, by employing preheating and heat preservation measures. The hydraulic retention times (HRT) of AR, DSR, MR and BAF were 10, 0.6, 40 and 32 h, respectively. The treatment capacity of the resulting system was approximately 8 m^3 of raw DZW wastewater per day.

2.2. Wastewater

The raw wastewater was collected from a DZW processing factory, located in Shiyan City, Hubei Province, Central China. The

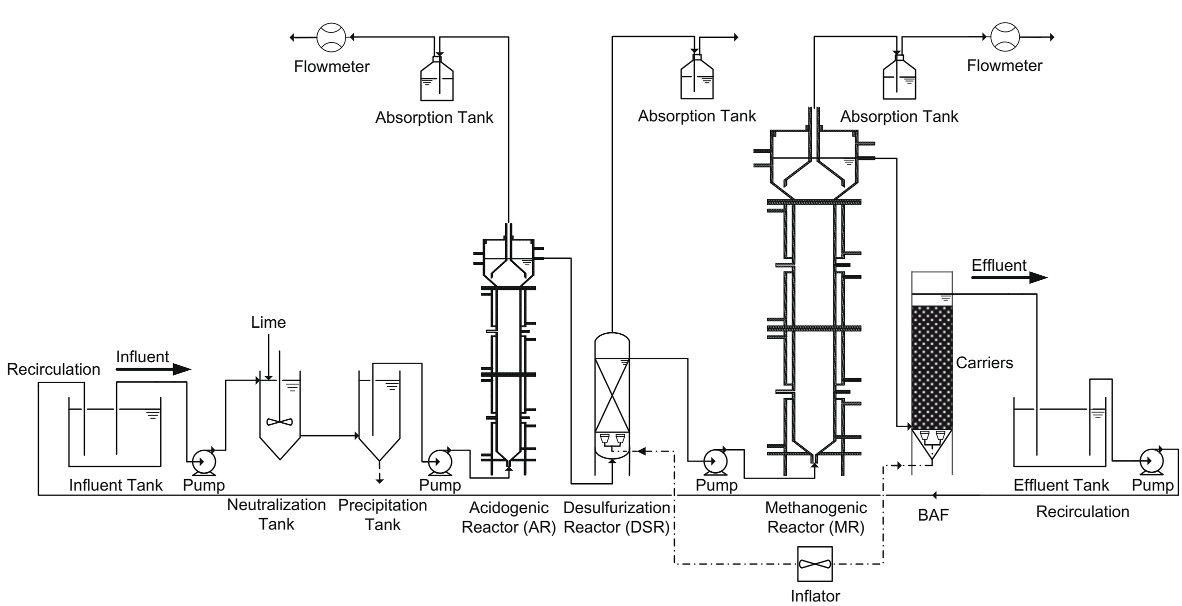

Fig. 1. The integrated process scheme of DZW wastewater treatment.