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Turf soil enhances treatment efficiency and performance of phenolic wastewater in an up-flow anaerobic sludge blanket reactor

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HIGHLIGHTS

- Turf soil was novel used in a UASB reactor for phenolic wastewater treatment.
- Turf soil improved performance and resilience to impact loading.
- Bigger granules were formed with better settling property with turf soil.
- Humic substances in turf soil facilitated phenol biodegradation.
- Rough surface and mesopores provided habitat for bacteria growth.

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ABSTRACT

Phenols are industrially generated intermediate chemicals found in wastewaters that are considered a class of environmental priority pollutants. Up-flow anaerobic sludge blanket (UASB) reactors are used for phenolic wastewater treatment and exhibit high volume loading capability, favorable granule settling, and tolerance to impact loads. Use of support materials can promote biological productivity and accelerate start-up period of UASB. In the present study, turf soil was used as a support material in a mesophilic UASB reactor for the removal of phenols in wastewater. During sludge acclimatization (45–96 days), COD and phenols in the treatments were both reduced by 97%, whereas these contents in the controls were decreased by 81% and 75%, respectively. The phenol load threshold for the turf soil UASB reactor was greater (1200 mg/L, the equivalent of COD 3000 mg/L) in comparison with the control UASB reactor (900 mg/L, the equivalent of COD 2250 mg/L) and the turf soil UASB reactor was also more resistant to shock loading. Improved sludge settling, shear resistance, and higher biological activity occurred with the turf soil UASB reactor due to the formation of large granular sludge (0.6 mm or larger) in higher relative percentages. Granular sludge size was further enhanced by the colonization of filamentous bacteria on the irregular surface of the turf soil.

1. Introduction

Phenols are intermediate chemicals found in contaminated wastewater generated from industrial processes, e.g., coking, oil refining, and plastic and textile manufacturing (Veeresh et al., 2005). Phenols are considered priority pollutants by the US Environmental Protection Agency (Office of the Federal Registration, 1982). Physical, chemical and biological methods and combinations of them are used for the treatment of phenolic wastewaters (Jiang et al., 2016; Khaksar et al., 2017). Physical and chemical processes using solvent extraction and activated carbon adsorption are especially attractive for the treatment of wastewater having high phenol concentrations. Environmentally friendly and cost effective biological treatment processes are feasible for concentrations of phenol having a range between 5 and 500 mg/L (Patterson, 1975). Aerobic biological removal of phenols have been successfully applied in an activated sludge system (Cozma et al.,

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2012) and biofilm reactors to achieve a high phenol and COD removal efficiency (above 95%) (Bajaj et al., 2008). Anaerobic biological processes are preferred as they require no aeration, consume low energy, exhibit a high operational efficiency and are strongly resistant to loading impacts (Fang et al., 1996). Many studies for the treatment of phenolic wastewater using anaerobic bioreactors have been performed (Suidan et al., 1983; Chou and Huang, 2005; Scully et al., 2006; Subramanyam and Mishra, 2007; Chen et al., 2009; Wang et al., 2017a,b).

Up-flow anaerobic sludge blanket (UASB) reactors have favorable performance characteristics when compared with other reactors. UASB reactors are able to accept high volume loads, have favorable granule settling, and are more resistant to impact shock. An existing problem for UASB reactors are long start-up times and slow granule formation. Anaerobes would be sensitive to phenols at the initial stages. The addition of support materials has been shown to promote biological productivity and reduce start-up time (Schmidt and Ahring, 1996; Pol et al., 2004). Support substrates that have been successfully used to facilitate the formation of biologically active granular sludge include; zeolite, oyster shell, activated carbon, ceramsite and fly ash (Schmidt and Ahring, 1996; Milán et al., 2010).

In this study, turf soil was investigated for use as a novel support material in a UASB reactor for the treatment of phenolic wastewater. Turf soil is a widely available natural material that has an irregular surface area. This irregular surface provides a nucleation point promoting sludge granulation. Furthermore, humic substances contained in turf soil can promote biodegradation process. The utilization of turf soil as a substrate in a USAB reactor and its effect on sludge granulation and strength, organic removal, methane production, and system stability were investigated. Changes in microbial community structure within the granules was also determined.

2. Materials and methods

2.1. Turf soil and seed sludge

Turf soil was purchased from Xingtong Trading Company (Baishan, Jilin, China). It was oven dried at 105 °C and ground in a quartz mortar. The ground turf soil was then sieved through a 60-m mesh and then a 200-m mesh sieve to collect particles having diameters 0.076–0.25 mm. Total organic carbon (TOC) and the chemical oxygen demand (COD) from the turf soil was shown in Fig. s1 (supplementary material).

Sludge used for seeding was obtained from a hydrolytic acidification tank in the wastewater treatment plant at Liaohe Petrochemical Company (Panjin, Liaoning, China). The total suspended solids (TSS), volatile suspended solids (VSS), sludge settling ratio (SV), and sludge volume index (SVI) of the seed sludge was 57.07 g/L, 98 and 12.78 mL/g, respectively. The low SMA of 0.0642 g CH_4-COD/gVSS•d suggested low methanogenic activity.

2.2. Synthetic phenolic wastewater

Phenolic wastewater was prepared by dissolving different amounts of phenol in water. The salts NH_4Cl and KH_2PO_4 were used to prepare solutions having ratios of COD: N: P range from 350:5:1 to 500:5:1. Trace elements were added to a final concentration of $FeCl_2$, 1275 μg/L; $CoCl_2$, 1091 μg/L; EDTA, 994 μg/L; $MnSO_4$, 888 μg/L; $ZnSO_4$, 60 μg/L; $NiCl_2$, 32 μg/L; $(NH_4)_6Mo_7O_{24}$, 47 μg/L; H_2BO_3, 49 μg/L; $CuCl_2$, 19 μg/L. Finally, $NaHCO_3$ was added to maintain $CaCO_3$ alkalinity between 0 and 1000 mg/L. The initial influent pH was adjusted to 6.5–8.0.

2.3. UASB configuration and experimental procedure

Two identical UASB reactors were constructed using Plexiglass, having an internal diameter of 74 mm, a height of 1195 mm, and a total volume of 4.715 L. The experimental reactor contained 0.15 L of turf soil (R1), and the control reactor (R0) did not include any support materials. The phenolic wastewater was introduced through the bottom of each reactor using peristaltic pumps and flow moved upward through the granular sludge. Samples of produced biogas were collected from the top of the reactor using a three-phase separator and a 15 L gas collection bag. The biogas volume was measured using a 150 mL syringe. The experiment was performed using thermostatic conditions (36 ± 2 °C) maintained with a circulating water jacket. A schematic diagram of the UASB reactor was shown in Supplementary Fig. s2.

The UASB reactors were continuously operated for 180 days. The influent composition and COD concentrations were shown in Fig. 1. To initially enhance heterotrophic bioactivity, glucose (Beijing Chemical Reagents Co., China) was added with newly introduced sludge during the reactor startup. The experimental timeline periods are defined as; start-up (the first 45 days), acclimatization (day 45–96), steady state (day 96–127) and shock and recovery (day 127–180). During the start-up period, the influent COD was gradually increased to 2000 mg/L and the volume load (OLR) to 1.8 kg-COD/m^3•day. During the acclimatization period, the influent glucose concentration was reduced to zero, and the phenol concentration simultaneously increased to 800 mg/L. After 70 days additional turf soil (1.5% of the total volume) was added to reactor R1. During the steady-state period, influent phenol concentration was gradually increased until the COD removal rates decreased. This point was defined as the phenol load threshold. The R1 reactor was operated at an influent COD of around 3000 mg/L (completed phenolic wastewater, equivalent to 1200 mg/L of phenol), while the R0 reactor had a maximum of 2250 mg/L (phenol 900 mg/L). After the reactor was again stabilized, as indicated by its COD removal rates. Shock exposure included changes in temperature, pH and the addition of high concentrations of phenol. To test for low-temperature resilience, at day 127 the temperature was decreased to 17 °C for 24 h. To determine how the influx of high concentrations of phenol impacts its productivity, influent having concentrations of 1500 mg/L and 2000 mg/L were added to R0 and R1, respectively, at day 133. At day 139, the pH was decreased to 2.2 and then increased to 9.45 at day 146 to investigate the impacts of exposure to acid/alkaline conditions. The recovery time and the performance of the two reactors were determined after exposure to the variables. The pH, COD, biogas production and composition were measured throughout the experiment.

2.4. Analytical methods

Standard methods of the American Public Health Association were used to determine COD, total suspended solids (TSS), volatile suspended solids (VSS), mixed liquid suspended solids (MLSS), concentration of phenol and volatile fatty acid (VFA) (APHA, 2005). Sludge settling ratio (SV_{30}) was the sludge volume after 30 min of settling in a 100 mL graduated cylinder. The SVI was calculated as follows: $SVI = \frac{SV_{30} \times 10}{MLSS}$.

The pH was measured with a Mettler Toledo MP220 m. Humic substances (HS) from soil, including humic acid and fulvic acid contents, were determined according to a previously described method (Aivalioti et al., 2012).

The composition of biogas was analyzed on a gas chromatograph (GC 7806, Wenling, China) having a thermal conductivity detector (TCD) and a Porapak Q packing column. The inlet, analyzer