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Recovery strategies for tackling the impact of phenolic compounds in a UASB reactor treating coal gasification wastewater

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ABSTRACT

The impact of phenolic compounds (around 3.2 g/L) resulted in a completely failed performance in a mesophilic UASB reactor treating coal gasification wastewater. The recovery strategies, including extension of HRT, dilution, oxygen-limited aeration, and addition of powdered activated carbon were evaluated in batch tests, in order to obtain the most appropriate way for the quick recovery of the failed reactor performance. Results indicated that addition of powdered activated carbon and oxygen-limited aeration were the best recovery strategies in the batch tests. In the UASB reactor, addition of powdered activated carbon of 1 g/L shortened the recovery time from 25 to 9 days and oxygen-limited aeration of 0–0.5 mgO_2/L reduced the recovery time to 17 days. Reduction of bioavailable concentration of phenolic compounds and recovery of sludge activity were the decisive factors for the recovery strategies to tackle the impact of phenolic compounds in anaerobic treatment of coal gasification wastewater.

1. Introduction

In China, coal gasification technology is developed because China is rich in coal and poor in oil and gas (Chen and Xu, 2010). In the next few decades, the strategy adjustment of energy structure would make the coal gasification industry play a key role in the new clean and renewable energy market (Attwood et al., 2003). However, the coal gasification wastewater (CGWW) from coal gasification process contained high concentrations of phenolic compounds, ammonia, cyanide, and other toxic pollutants (Wang et al., 2010). For a typical case, the content of phenolic compounds and ammonium in the raw wastewater ranged from 4500 mg/L to 7500 mg/L and 4500 mg/L to 13,000 mg/L, respectively at a coal gasification plant located in the Northeast of China (Yu et al., 2010). The treatment of CGWW had become a bottleneck for the development of coal gasification industry. Now, the treatment of CGWW could be classified into physico-chemical method (e.g. ammonia stripping, phenol solvent extraction and coagulation) and biological method (e.g. anoxic–oxic process and conventional activated sludge process) (Feng et al., 2009; Marañón et al., 2008; Wang et al., 2002; Yang et al., 2006; Zhao et al., 2010). However, these methods still had several problems to be solved, such as poor stability in the solvent extraction process, unsatisfactory effluents and high handling costs in the biological processes. Especially, the instability of solvent extraction process often caused a sudden increase of concentration of phenolic compounds in the effluent. The impact loading of phenolic compounds could reach above 3000 mg/L immediately and result a completely failed performance in the biological processes. Thus, it was very important to find an appropriate way for the quick recovery of the failed reactor treating CGWW.

With the continuous development of anaerobic biotechnology, anaerobic digestion was considered as an effective way for the treatment of CGWW (Kindzierski et al., 1991; Kuschk et al., 2010; Ramakrishnan and Gupta, 2006). However, the efficiency of the conventional anaerobic process for treating CGWW was low due to the toxicity of phenolic compounds. In the previous studies, the removal efficiency of COD and phenolic compounds of CGWW was both only around 30% at organic loading rate of 2.5 kg COD/(m^3 d) and HRT of 24 h by a mesophilic UASB reactor (Wang et al., 2011a). The thermophilic anaerobic process and the two-continuous UASB process could enhance organic removal at some extent, but the removal efficiency of phenolic compounds

Abbreviations: BOD, biochemical oxygen demand; CGWW, coal gasification wastewater; COD, chemical oxygen demand; DO, dissolved oxygen; GAC, granular activated carbon; HRT, hydraulic retention time; MIBK, methyl isobutyl ketone; OLR, organic loading rate; PAC, powdered activated carbon; SS, suspended solids; SUR, sludge utilization rate; UASB, upflow anaerobic sludge blanket; VSS, volatile suspended solids.

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was still less than 65% even at a prolonged HRT of 48 h (Wang et al., 2011a,b). Recently, anaerobic granular activated carbon (GAC) bioreactor, such as anaerobic filter and expanded-bed GAC reactor, was considered as the best way for reducing the toxicity and enhancing the anaerobic biodegradation of CGWW (Fox et al., 1990; Kindzierski et al., 1991; Nakhla and Suidan, 1995). Nakhla et al. (1990) treated CGWW at 30% and 60% strength of raw wastewater by the anaerobic GAC reactor and the removal efficiency of phenolic compounds exceeded 95% at organic loading rate of 33.8 kg COD/(m^3 d). Suidan et al. (1983) reported a 97.4% removal in total COD from 10% dilution of CGWW by anaerobic filter. Because anaerobic digestion could significantly improve the aerobic biodegradability of CGWW, more and more anaerobic technologies were proposed and applied on the treatment of CGWW in the engineering application. However, anaerobic technology had its disadvantages. For example, the impact of phenolic compounds could result a completely failure for the anaerobic reactor treating CGWW. Therefore, the strategies to reduce the toxicity of phenolic compounds and to recover reactor activity were very important for the stable operation of CGWW treatment plants.

Among the phenolic constituents of the CGWW, phenol, methyl phenols, ethyl phenols and binary phenols constituted above 80% of the phenolic content. These phenolic compounds inhibited the activity of anaerobic microbes even at low concentrations. Although the sludge acclimatization for enhancing the degradation of phenolic compounds had been reported, alkyl phenols were more persistent from biological treatment and inhibitory to anaerobic microbes than phenol (O'connor and Young, 1996). Therefore, bioaugmentation methods such as addition of co-substrates, GAC or filter media, had been used for enhancing the removal of phenolic compounds. Previous studies mainly focused on the degradation and inhibition of phenolic compounds, and few attentions had been paid to the recovery strategies for the anaerobic process after the impact of phenolic compounds. The aim of this work was to evaluate the recovery strategies including extension of HRT, dilution, oxygen-limited aeration, and addition of powdered activated carbon (PAC), on the quick recovery of anaerobic bioreactor impacted by phenolic compounds using batch tests. The most appropriate recovery methods of oxygen-limited aeration and addition of PAC were investigated in the UASB reactor shocked by 3.2 g/L of phenolic compounds. Further, these two methods were compared and evaluated.

2. Methods

2.1. Experimental setup and inoculum

The UASB reactor was constructed of cylindrical plexiglass column with an internal dimension of 5 cm and a working volume of 1 L. The reactor was maintained at mesophilic temperature of 35 ± 2 °C and had been operating for treating CGWW over 120 days. The seed sludge was obtained from a full-scale anaerobic reactor at a coal gasification plant located in the Northeast of China. The suspended solids (SS) and volatile suspended solids (VSS) added to the reactor were around 35.7 g/L and 25.0 g/L, respectively.

2.2. Wastewater characteristics

The organic composition of CGWW after ammonia stripping and phenol extraction with methyl isobutyl ketone (MIBK) was presented in the previous work (Wang et al., 2011b). Phenolic compounds were the major organic constituents, accounting for about 40% of the total COD. The actual CGWW had a complicated composition and the wastewater characteristics with their constituent concentrations expressed in mg/L were as follows: COD (2723 ± 280), BOD_5 (805 ± 96), phenolic compounds (545 ± 61), ammonia nitrogen (109 ± 12), oil (57 ± 9), thiocyanate (64 ± 10), cyanide (0.9 ± 0.5) and pH (7.6 ± 0.3). The macro- and micro-nutrients were added to the reactor as described in the previous study (Wang et al., 2011a).

2.3. Recovery strategies for tackling the impact of phenolic compounds in the batch tests

The recovery strategies, including extension of HRT, dilution, oxygen-limited aeration, and addition of PAC were investigated by five glass bottles (1.0 L working volume) closed with rubber stoppers. Feeding was applied once a day in the batch experiments. All the bottles were fed with CGWW with a normal phenolic concentration of around 0.5 g/L and a HRT of 3 days. This was done for achieving a stable performance before shock load with the phenolic compounds of around 3.2 g/L. A control bottle (R_0) was run with the normal loading during the whole experimental period. No feeding was applied to other four bottles after phenolic loading for a HRT. The recovery strategies were applied to other four bottles after the impact of phenolic compounds. The detailed recovery strategies were described as follows: (1) extension of HRT (R_a): reduction of 80% of the CGWW feeding daily and corresponding to a HRT of 15 days. (2) dilution (R_b): replacement of 80% of the CGWW feeding daily with tap water corresponding to the phenolic concentration of around 100 mg/L. (3) oxygen-limited aeration (R_c): aeration with a low DO level of 0–0.5 mg/L. (4) addition of PAC (R_d): addition of PAC of 1 g/L of the CGWW feeding. For all the experiments, the recovery strategies tested were applied at 3 HRTs periods (9 days except R_a) after the impact of phenolic compounds and then the bottles were operated at the normal load.

2.4. Recovery strategies for tackling the impact of phenolic compounds in the UASB reactor

Operation of the reactor was begun with the COD and phenolic concentrations of around 2500 mg/L and 500 mg/L at a HRT of 24 h. After 37 days of operation, influent COD and phenolic concentrations were rapidly increased to 10,362.5 mg/L and 3215.5 mg/L, respectively on day 157, and then the corresponding concentrations were reduced to the initial concentrations of around 2500 mg/L and 500 mg/L on day 158. The reactor was allowed to recover fully from the impact effect of phenolic compounds and the recovery time was defined as the time between the initiation of recovery action and the time when the removal of phenolic compounds achieved above 40%. After the recovery of reactor performance, the reactor was continuously operated at a pseudo-steady state for two weeks. On day 197, the phenolic loading rate of around 3.2 kg/(m^3 d) was shocked on the UASB reactor for 1 day time and the normal phenolic loading rate of around 0.5 kg/(m^3 d) was resumed at the next day. The PAC of 1 g/L was added into the UASB reactor for 3 days on days 198–200 and then the reactor performance was gradually recovered without the addition of PAC. After the reactor performance achieved a pseudo-steady state, the phenolic load of around 3.2 kg/(m^3 d) was shocked on the reactor for 1 day time on day 217, and the normal phenolic loading rate of around 0.5 kg/(m^3 d) was resumed on day 218. The oxygen-limited aeration of 0–0.5 mgO_2/L was carried out in the reactor for 3 days on days 218–220 and then the reactor performance was gradually recovered without aeration.

2.5. Analytical methods

COD, BOD_5, SS, VSS, phenols, oil, thiocyanate, cyanide, and ammonia nitrogen were determined according to Standard Methods (Wei et al., 2002). pH value was analyzed by a pH meter