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The removal of high concentrations of phenol from saline wastewater using aerobic granular SBR

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ABSTRACT

The treatment of saline wastewater containing phenol is a challenge faced in the application of biological pollution control technologies. Phenol-laden saline wastewater is generated from various industrial and manufacturing activities. The aerobic granular sequencing batch reactor (GSBR) was investigated in this work in order to assess its performance for the degradation and chemical oxygen demand (COD) removal of phenol as the sole substrate from saline wastewater. The effect of inlet concentration (100–2000 mg phenol/L), cycle time (14–24 h), filling cycle time (1–4 h), shock loading, and total dissolved solids (TDS) concentration (3–8%) were evaluated on the performance of a bench scale GSBR seeded with granules containing mixed phenol-degrading consortia acclimatized to salt. The results showed that the investigated reactor could remove more than 99% of phenol from the feed saline wastewater at inlet phenol concentrations of up to 1000 mg/L, total cycle time of 17 h (15.5 h aerating, 1 h filling, and 30 min settling, decanting and idle) and TDS concentrations up to 8%. A high percent of COD removal and phenol mineralization obtained at these operational conditions. The GSBR could also withstand and absorb the strong phenol shock. Furthermore, the granular biomass in the GSBR indicated high quality in terms of sludge settleability. Overall, the results of this work revealed that establishing a granular biomass containing high concentration of active mixed microbial populations in the GSBR system can achieve complete degradation of high concentrations of phenol in saline wastewater. This makes it a very efficient and flexible technology for treating such waste streams in full-scale applications.

1. Introduction

Industrialization has led not only to an increase in water demand, but also to an increase in water pollution due to industrial discharges. Many industries such as meat canning, olive oil mills, petroleum, petrochemical, agro-food, seafood processing, vegetable canning, pickling and cheese processing generate effluents with high salt content [1], most of which contain some amount of various organic compounds [2]. One common organic compound found in saline wastewater generated in industries like olive oil mills, petroleum refineries, petrochemical plants and oil field operations is phenol and its derivates [3]. For instance, olive oil mills, which are mostly concentrated in the Mediterranean area [4], produce an acidic wastewater with high salt and phenol content (0.1–1%). Furthermore, characteristics of olive oil mill wastewater vary widely and depend on the oil production method. In addition, concentrations of phenol in refineries and petrochemical plants are in the ranges of 6–500 mg/L and 2.8–1220 mg/L, respectively [5].

Phenol is listed as a toxic substance and is included in the priority list of hazardous substances as well, which demonstrates its serious health and ecological effects [6]. This makes it a major focus of environmental and health pollution control. In order to protect the environment against the adverse effects of phenol, wastewaters containing this toxic compound need to be treated in an effective and environmentally benign process before the wastewater can be discharged into the environment. Reviewing the literature indicated that most investigations reported on phenol removal has focused on its removal from fresh (low TDS) wastewaters using a range of processes [7]. Busca et al. [6] have recently published a short review on the separation and destruction techniques of phenol removal from wastewater. However, in spite of its importance, few works have been published on removal of phenol from saline wastewaters. This lack of published research is despite the fact that several industries such as olive oil mills, oil refinery, petrochemical, pharmaceutical, pesticides and oilfields [5,8] generate saline effluents containing several organic compounds such as phenol. Biological processes are considered to be environmentally benign, efficient, and cost effective treatment techniques in comparison to other processes [9] and offer effective removal of a wide range of contaminants in wastewater treatment. It is known that high salinity can seriously inhibit the effectiveness of aerobic and

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anaerobic biological treatment of wastewater [10]. Although using halophilic microorganisms such as *Halobacter halobium*, etc. is the best approach for the biological treatment of saline wastewater [1], a biomass acclimated to a desired salt concentration can also mitigate the detrimental effects of salinity on the overall bioprocess performance.

Woolard and Irvine [11] investigated the removal of phenol from synthetic wastewater containing 15% salt in a sequencing batch biofilm reactor inoculated with moderated halophilic bacteria. They observed a removal efficiency of higher than 99% for phenol at inlet concentrations of 120 mg/L. They repeated the experiment in 1995, with a sequencing batch reactor (SBR) seeded with pure halophil culture and found a removal efficiency of 99.5% for phenol [12]. Hinteregger and Streichsbier [13] reported almost 100% removal of phenol in wastewater containing 14% NaCl. Li et al. [14] evaluated the effect of nutrients on the rate of phenol biodegradation in synthetic saline wastewater in a sequencing batch biofilm reactor. They observed an important role for nutrient content on phenol removal. Other investigations that have dealt with biological treatment of saline wastewaters containing phenol are those reported by Freire et al. [15], Alva and Peyton [16], Gómez et al. [17], and Ramos et al. [18], who showed the effectiveness of biotreatment of phenol-laden saline wastewaters. However, most of these studies have involved either single microbial species or low inlet phenol concentrations; both of which may have limitations in field application due to the presence of different and/or high concentrations of contaminants in the targeted wastewater.

The primary objective of this work was to investigate the biological treatment of saline wastewater containing high concentrations of phenol using a mixed culture and improvement of the biomass separation. Among the bioreactors invented for biological wastewater treatment, the SBR confers greater advantages, including flexibility, robustness, single basin operation, better control of shock loads, simplicity of operation, relatively low cost, and no sludge loss in the reaction period (and hence no need to return activated sludge) [19,20]. Therefore, SBR is the most common type of bioprocess used for industrial wastewater treatment [21]. A recent advantage reported for SBR is the possible formation of granules of biomass without using media, which can improve the reactor performance and sludge settleability [22,23]. On the other hand, one of the most frequently encountered problems in biological treatment of saline wastewater is gravity separation of solid-liquid phases in sedimentation unit operation. This is caused by a difference in saline water and biomass density, cell plasmolysis, reduced quantity of the filamentous bacteria and lack of protosoans [1,12]. Exploring the granulation ability in SBR systems might be a solution to mitigate the settling problems encountered in conventional suspended biological processes in treating saline wastewaters for several reasons. In addition to settleability improvement, biomass granulation increases the concentration of the biomass into the reactor and improves the resistance to toxicity [23,24], resulting in an enhancement of bioreactor performance. Although the ability of aerobic granules to be effective in the removal of toxic compounds like phenol [24], p-nitrophenol [25] and 2-4,dichlorophenol [23] has been previously published, no report could be found on phenol removal from saline wastewaters. Accordingly, the basic aim of this parametric study is investigating the performance of an aerobic granular sequencing batch reactor (GSBR) to explore the above-mentioned benefits in the treatment of a synthetic saline phenolic wastewater. To achieve this goal, the effect of inlet phenol concentration, wastewater salt content, aeration cycle time, filling cycle time and contaminant shock loading was evaluated in the removal of phenol from saline wastewater in a bench scale GSBR. It will be indicated that the GSBR can efficiently remove the phenol from saline wastewater.

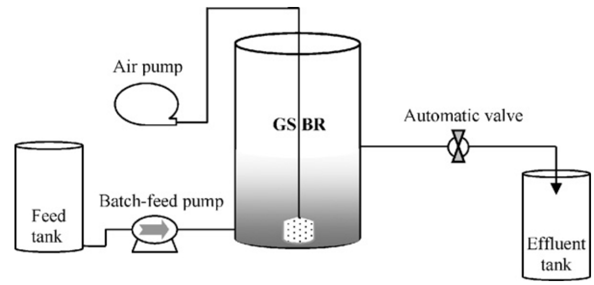

Fig. 1. The schematic of the GSBR experimental set up.

2. Materials and methods

2.1. Reactor setup

In this investigation, a cylindrical bench scale reactor, the schematic of which is shown in Fig. 1, was constructed and studied for the treatment of saline wastewater containing phenol under laboratory conditions. The reactor was made from glass and consisted of a 7 L total volume column (internal diameter (D) × height (H), 15 cm × 40 cm), 4 L of which served as the working volume. A peristaltic pump (WATSON MARLOW 101U/R) injected the synthesized wastewater into the reactor. The pumping rate of the wastewater to the reactor was regulated based on the fill volume and filling time. The reactor was aerated using an air pump (RESUN® AC-9908) and the air entered into the mixed liquor through two air stone diffusers placed at the bottom of the reactor. The inlet air flow rate to the GSBR was controlled by a valve mounted on the pump to meet the oxygen demand corresponded to the inlet organic loading rate. Two sampling ports were provided on the influent and effluent lines of the reactor for taking samples and monitoring the performance of the system in removal of phenol. In addition, a valve was located at the bottom of the reactor to withdraw the sludge and drain the reactor, as needed.

2.2. Reactor operation

The GSBR used in this work was operated in cyclic mode for 275 days, so that each operating cycle comprised of filling (with aeration), aerating, settling and decanting with various cycle times. The fill volume of the reactor was kept constant at 2 L during the entire course of the experiment, meaning that 50% of the full volume was replaced during the filling period with new synthetic wastewater in each cycle. Table 1 gives the operational conditions of the investigated GSBR. Following start up, the reactor was run to investigate the effects of operational variables on phenol removal and the corresponding chemical oxygen demand (COD) removal at steady state operational conditions. Table 2 illustrates the phases of the study and the purpose considered in each phase of the experiment along with the range of investigated variables. The steady state condition was assumed to have occurred at each operational run when change in the removal efficiency was within ±5% for 10–15 consec-

Table 1
Basic operation parameters of the GSBR.

Parameter	Unit	Value
Phenol concentration	mg/L	100–2000
COD concentration	mg/L	227–4540
Salt concentration	g/L	30–80
Cycle time	h	14–24
Filling	h	1–4
Aerating	h	9.5–19.5
Settling, decanting and idle	h	0.5