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Moving Bed Biofilm Reactor Performance in Phenol Removal from Wastewater

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Abstract

Background: Phenolic compounds are found in wastewater of many industries such as pulp and paper, textile, petrochemical, oil refineries, production of phenolic resins, plastics, coal furnace, tannery, rubber reclamation plant, fertilizers, coke, paints, rubber, decolorizer, resins, rubber and phenol- formaldehyde resin industries. This study aimed to evaluate Moving Bed Biofilm Reactor (MBBR) performance in phenol removal from wastewater.

Methods: The MBBR with Hydraulic Retention Time (HRT) of six hours was operated for 105 days. The effect of phenol concentration (0-500 Mg/L) on the MBBR performance was assessed in three phases of 0-100, 100-300 and 300-500 Mg/L phenol concentration.

Results: In this study, at phenol concentration of 100 Mg/L, phenol and COD removal efficiencies were 95.5-97% and 94%, respectively. The removal efficiencies for phenol concentrations of 300 Mg/L and 500 Mg/L were 94.5-96.5% and 92-94.5%, respectively.

Conclusion: Moving Bed Biofilm Reactor (MBBR) is a promising method for phenol removal from wastewater.

developed in the left eye. Two patients had no family history suspicious for keratoconus.

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Introduction

Phenol and its derivatives are of the most common organic compounds found in wastewaters and industries such as olive oil factories, oil refineries and petrochemical industries (1, 2). Although phenolic compounds are rarely found in urban wastewater, they are abundant in some industrial wastewaters like those of pulp, textile, petrochemical industries and oil refineries (3). Phenol is used in producing a great number of compounds including chemical fertilizers, coke, paints, rubber, detergents, decolorizers, drugs, caoutchouc and phenol-formaldehyde resin. Therefore, phenol can be found abundantly in industrial wastewaters like oil refineries, phenolic resin products, plastics, coal furnace, tannery, textile, rubber reclamation plants and fish processing (4- 6).

Phenol found in the wastewaters of oil refineries, petrochemical industries, olive oil factories, pesticide production and oil field activities is usually accompanied with total dissolved solids (TDS) (7); olive oil factories produce acid wastewater with high salt and 0.1-1% phenol (8). There are different methods to remove phenol from wastewater. The wastewater can be treated via various physicochemical methods including absorption, solvent extraction and chemical oxidation. These methods are often expensive and have dangerous side effects (4, 5, 7).

Nevertheless, biological methods have priority over other methods due to ease of operation and preservation, reasonable cost, efficiency, environmental friendliness and degradation of pollutants with little adverse effects (9,10). For biological treatment of phenol, different methods have been proposed including aerobic and anaerobic methods, suspended growth and attached growth. Although phenol can be degraded both in aerobic and anaerobic conditions with the presence of acclimated biomass, usually anaerobic methods are less adopted due to phenol inhibitory effect in concentrations higher than 10 g/L (1,11).

Packed bed reactors show more resistance to high phenol concentration and lead to more removal as compared with suspended growth reactors (12). Packed bed reactor is an attached growth sort of aerobic method with unique advantages including better control of biofilm thickness, less tendency to clog, and low pressure drops (12). Therefore, today, wastewater treatment plants utilize MBBRs (13). MBBRs were developed in the end of 1980s and beginning of 1990s in Norway (14). MBBRs are usually filled with low-density polyethylene carriers with 10 mm diameter, 8 mm height and 500 m^2 m^{-3} actual specific surface area (15).

The main idea behind MBBRs is continuous operating of a biofilm reactor with a high density of biomass without the need for backwashing and sludge return (16). Peyton et al (2002) reported that bacterial media with high salinity environments are able to degrade phenol from 50 to 2 mg/l in 10% (w/v) NaCl (17). Aloui et al (2008) revealed that fish processing saline wastewater with salt concentration=2.5%, CODi= 2400 mg/l, HRT= 1 day and OLR=1710 Mg/L.d and using Vibrio fischeri, which tolerates the used salt concentrations, can remove COD to 78% (18). Dosta et al (2010) also demonstrated that treatment of industrial wastewater characterized by low phenol concentrations (8–16 mg L^{-1}) and high salinity (150–160 mS cm^{-1}) is operated in Membrane Biological Reactor (MBR). During the operation of this reactor, the phenol loading rate was increased and less than 1 mg phenol L^{-1} was detected even at very low HRTs (0.5–0.7 days) (3).

Investigating the previous works done in Iran and around the world showed that although there have been appropriate studies on phenol removal from industrial wastewater and polluted water via biological methods with attached growth and biological moving bed, few studies have been carried out on saline wastewater containing phenol despite its considerable importance. Hence, the present study was conducted to determine the efficiency of Moving Bed Biofilm Reactor (MBBR) in removing phenol from wastewater.

Materials and Methods

Introducing the Reactor

In order to achieve the objectives of this study, a pilot of MBBR as well as a settling tank, with the descriptions presented in tables 1 and 2was designed for the treatment of saline wastewater containing phenol under laboratory conditions. They were later installed and utilized after sealing steps. MBBR is made up of polyoxy glass with total column volume of 9.5 liters [inner diameter (D) × height (H), 13.5 cm × 63.5 cm] and effective volume of 6.3 liters. Fifty percent of the volume of the reactor was filled with polyethylene filler material. The wastewater entered the reactor through storage tank and by means of a peristaltic dosing pump. The reactor was aerated by a compressor. In order to supply oxygen for the system and move beds in the reactor, the intake air entered the reactor via three diffusers at the bottom. A mesh was embedded on the top of the reactor exit to keep the beds within. Figure 1 represents the attached growth biofilm reactor with moving bed used in this study.

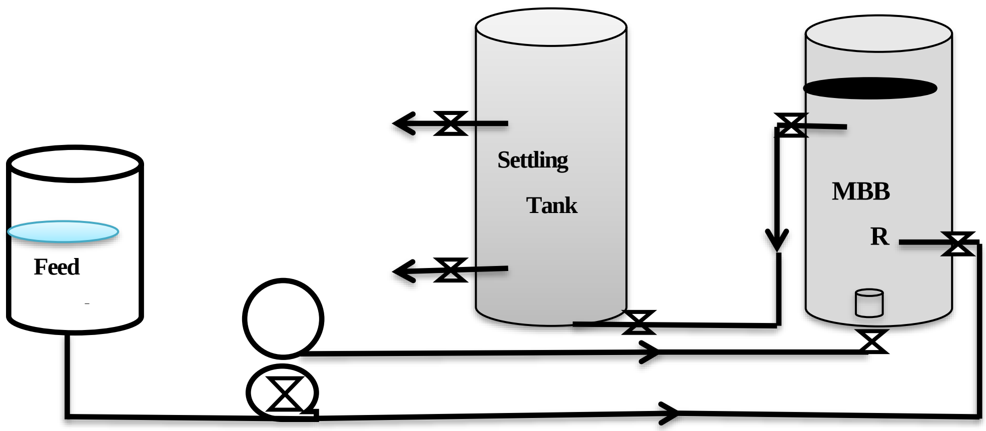

Figure1. The schematic of the MBBR experimental set up

Table1. Description of the MBBR reactors used in the pilot- scale

Outer diameter (mm)	160
Inner diameter (mm)	135
Wall thickness (mm)	25
Total Height (external) (mm)	650
Internal height (from bottom to head) (mm)	635
Effective height (mm)	440
Total volume (l)	9.5
Volume occupied by bed (l)	3.2
Effective volume (l)	6.3

Table 2. Description of the settling tank used in the pilot- scale

Outer diameter (mm)	165
Inner diameter (mm)	135
Wall thickness (mm)	25
Total Height (external) (mm)	350
Internal height (from bottom to head) (mm)	325
Effective height (mm)	210
Total volume (l)	9
Effective volume (l)	3

Reactor Operation

In this stage, the reactor started to work using 3 liters of activated sludge of Choneybe, wastewater treatment plant in Ahvaz. It was fed with synthetic wastewater containing acetate and required nutrients (dipotassium monohydrogen phosphate, potassium dihydrogen phosphate, sodium bicarbonate, ammonium chloride, magnesium sulphate, calcium chloride, boric acid, ferric chloride, copper sulfate, potassium iodide, manganese chloride, zinc sulfate, cobalt chloride, manganese thiosulfate) through a batch process. The total volume of beds used in the reactor was 3 liters. After a thin biofilm was formed on beds to enhance the biofilm and prepared the system to start loading, the trend carried on continuously.

The hydraulic retention time in this study was 6 hours. For acclimation of microorganisms, the acetate was reduced daily and instead phenol was used as the only source of carbon in wastewater. After increasing phenol to 100% desired level and providing stability in the reactor, the operation of system continued with the increase in concentration of phenol Mg/L (100-500) through three stages 0-100, 100-300 and 300-500 Mg/L. Since nitrogen and phosphorus are among the most essential nutrients in the biological process, ammonium chloride and potassium dihydrogen phosphate were used to express C:N:P ratio as 100:5:1. In order to prevent the decrease in pH, alkalinity was increased by adding sodium bicarbonate and the pH value was maintained within the appropriate range for aerobic biological process (7-7.5).

Moreover, the oxygen in the solution was kept at minimum value of 1-2 mg in the reactor. The criterion for achieving stability was lack of statistically significant changes in criteria parameters of wastewater effluent for 7 days. With taking the variable of inlet phenol concentration (100-500) Mg/L into consideration and defining the number of levels of this variable, three stages of study were designed in HRT of 6 hours. The tested parameter in stability condition of phenol and pre-stability condition was COD.

Synthetic Wastewater Composition

In order to prepare synthetic wastewater, dipotassium monohydrogen phosphate, potassium dihydrogen phosphate, sodium bicarbonate, ammonium chloride, magnesium sulphate, calcium chloride, boric acid, ferric chloride, copper sulfate, potassium iodide, manganese chloride, zinc sulfate, cobalt chloride and manganese thiosulfate (Merck Co,. Germany) were used.

Analysis

To evaluate the performance of MBBR, samples were taken from inlet, settled effluent and the content of the reactor. The inlet samples were analyzed for phenol, COD, pH and TDS. Mixed liquor samples were analyzed for phenol, COD and suspended solids and wastewater effluent samples were also analyzed for phenol and COD. Phenol concentrations were measured spectrophotometrically by means of the chlorimetric 4-aminoantipyren method elaborated in the book entitled "Standard Methods for the Examination of Water and Wastewater" (19) as well as a DR 5000 UV/VIS Spectrophotometer (made by HACH CO., USA.). MLSS, DO and COD of mixed liquor were also measured as per the methods explained in Standard Methods for the Examination of Water and Wastewater with codes of 2540 D, 5220D and 4500 B, respectively. The pH of samples was determined by a pH meter (Eutech Co., Singapore).

Results and Discussion

In this period, with the gradual increase in phenol concentration, it was attempted to adapt microorganisms to high phenol concentrations. For this purpose, phenol was gradually increased from 0 to 500 Mg/L in the synthetic wastewater. As phenol concentration increased, the acetate was reduced daily and phenol was used as the only source of carbon in wastewater. As depicted in figure 2, suspended MLSS had an increasing trend by the 30^{th} day of operation and was increased from 1200 to 2890 Mg/L; the concentration of outlet COD was decreased and the removal efficiency was changed from 27% to 87% demonstrating an appropriate and desirable condition for operation and proper growth of microorganisms in the system. From the 30^{th} day onwards, suspended MLSS was gradually decreased from 2890 to 1310 Mg/L and COD removal efficiency was increased from 87% to 94%. Indeed, as the concentration of inlet COD increased, the concentration of attached growth biomass was gradually increased and that of suspended growth biomass was reduced.

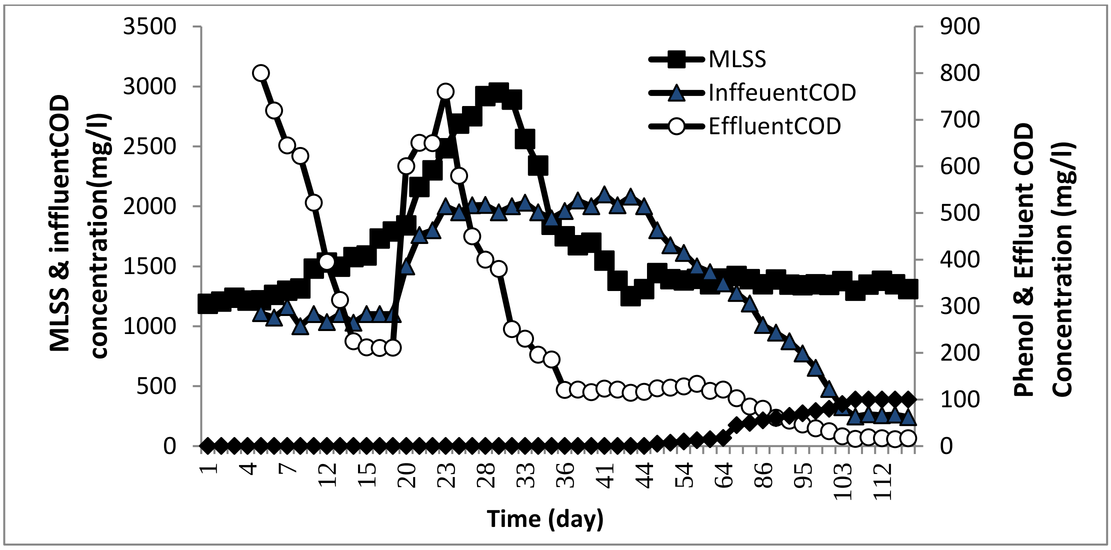

Figure2. Performance of MBBR rector on COD Removal

The effects of phenol concentration of 0–500 Mg/L on the performance of MBBR in phenol and COD removal were evaluated in three stages within 105 days. The reactor operated in every concentration till a stable performance in phenol removal was resulted. Changes of phenol removal efficiency in accordance to the time of operation in every stage of the study have been represented in Figure 3. In the first stage, when phenol was fed to the reactor up to the concentration of 100 Mg/L, removal efficiency was observed as 95.5-97%. Lack of lag phase in phenol removal can be due to the presence of biomass acclimated to phenol.

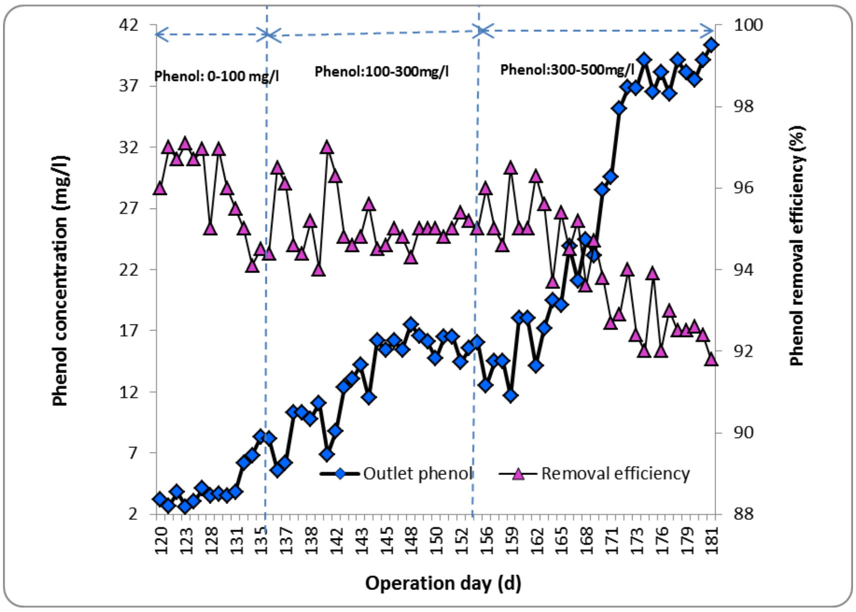

Figure 3. The effect of phenol concentration on phenol removal by MBBR

The effects of phenol concentration of 100-300 Mg/L on the performance of MBBR in phenol removal were not considerable. Nevertheless, more increase in the concentration of phenol up to 500 Mg/L resulted in a slight decrease in removal efficiency. With the increase in the concentration of phenol up to 300 Mg/L and 500 Mg/L, removal efficiency was changed to 94.5-96% and 92-94%, respectively. The reactor returned immediately to normal conditions after each stage; these conditions were resulted from the presence of acclimated biomass in MBBR which can absorb load fluctuations (7).

COD removal efficiency was also evaluated in different inlet concentrations and is presented in Figure 4. This chart indicates that COD removal efficiency was not considerably influenced by the inlet concentration of up to 100 Mg/L. When phenol reached 500 Mg/L (equal to COD concentration of 1150 Mg/L), COD removal efficiency decreased more than that of phenol. By the increase in COD, removal efficiency reduced at first and then returned to the stable state. When phenol was utilized as the only source of inlet carbon in MBBR, each decrease in COD, except the degree combined in new cells, was an indicative of mineralization of compounds (7).

MBBR is able to effectively remove phenol from synthetic wastewater in inlet concentration of 100 Mg/L. The increase in COD concentration up to 714 and 1150 Mg/L leads to the decrease in COD removal efficiency to 90% and 88%, respectively. Therefore, MBBR can effectively remove phenol and COD from synthetic wastewater. It has also been demonstrated in the studies by other researchers that MBBR can be effective in removing phenol from wastewater. Li et al (2011) showed that maximum removal efficiencies for phenol and COD from coal gasification wastewater using Moving Bed Biofilm Reactor (MBBR) in HRT of 48 hours were obtained as 89% and 81%, respectively (16).

In this study, the average of COD removal efficiency in HRT of 6 hours was acquired as 85% (inlet CDO concentration: 1000Mg/L) and 94% (inlet CDO concentration: 2000 Mg/L). The efficiency achieved in this study was higher than that of the study by Li et al (2011), which might be due to better conditions of operating MBBR and more acclimation of microorganisms.

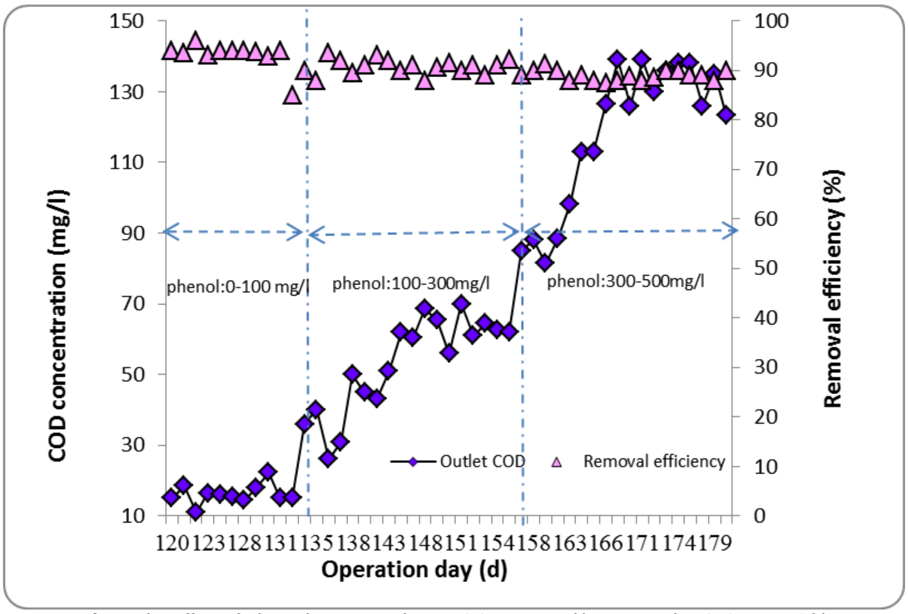

Fig.4. The effect of Pheno l concentration on COD removal by MBBR (TDS: 0, HRT: 6 h)

Garcia et al (2007) treated olive mill wastewater using a two-stage biological system including aerobic treatment and anaerobic digestion. This system operated with an Organic Loading Rate of 0.3 KgCOD/L.d, leads to biogas production of 1.25 Lbiogas/L.d and total COD reduction in excess of 93%. Fifty-four percent of the phenol was degraded during the aerobic treatment stage, and biogas was produced during anaerobic digestion with 68-75% methane (20).

Mousavi et al (2010) concluded that MSCR could remove more than 99% of phenol and formaldehyde for concentrations up to 1300 Mg/L (equal to the loading rate of 1.54 kg/m3.d and COD concentration of 4800 Mg/L) within 6 hours (7). It can be concluded from these studies that phenol in wastewater inlet in concentrations higher than the optimal, had no toxic effects on biomass activities. Such great performance can be attributed to the presence of a biomass containing high concentrations of active and acclimated microbial population in the reactor which is required for phenol degradation (21-23).

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