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Performance of Anaerobic Baffled Reactor for Biodegradation of Phenol

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Abstract: Effect of increase in phenol concentration on performance of anaerobic baffled reactor in terms of chemical oxygen demand (COD), phenol and COD removal efficiency and biogas productions was investigated. Furthermore, stability of the reactor with respect to the chemical shock load was monitored. The anaerobic baffled reactor was continuously operated with synthetic wastewater. The obtained results showed that adopted sludge improved the reactor performance. The start-up strategy used for this process has achieved to the targeted goals while the active microbial population was retained. For the initial stage of operation, there was no phenol present in the system. Then, the phenol concentrations were gradually and stepwise increased from 10 to 800 mg/L at hydraulic retention time (HRT) of 6 days. At loading rate of 0.5 g COD/L/day, maximum phenol removal efficiency of 96% was achieved. COD removal efficiency was quite high in the first compartment of baffled reactor, while the efficiency and the COD removal gradually dropped in the second and third compartments. In the bioreactor, low value of pH in the first compartment was due to acid generated by the acidogenic bacteria.

Key words: Phenol % Anaerobic baffled reactor % Acidogenic bacteria % Industrial wastewater % Biodegradation

INTRODUCTION

Phenols of anthropogenic origin exist in the environment due to various activities such as petroleum refinery wastes, coal conversion process, coke oven effluents, coal processing, metallurgic [1, 2] and pulp and paper mill effluents [3]. Due to the high toxicity and widespread penetration of the toxic and carcinogenic compounds to ecosystem, many research scientists have conducted investigations on preservation and control of environmental pollutants for the removal of toxic and hazardous compounds [2]. According to standards defined by the European Union (EU) Directive 2455/2001/EC, maximum allowable limit of phenol in drinking water is 0.5 µg/l. Phenols are reported to be highly toxic to fish at concentration of 5-25 mg/l [4].

Among various treatment methods for the removal of toxic compounds, biodegradation is the leading method which has high acceptance by public [4]. In biological treatment methods, phenols can be harmlessly degraded and this process is cost effective compared to physicochemical methods [5]. However, it must be noted that problems are arising from the antimicrobial feature and toxicity of these by-products such as cresols, resorcinol and hydroquinone. The disadvantages should be overcome by some skillful programming such as using co-substrate defined as glucose [6] for the bioaugmentation [7]. In addition, acclimatization method to save microbial cells from toxicity and inhibitory effects is well recommended [8].

Biodegradation of phenolic compounds can be accomplished by several biological processes such as up flow anaerobic sludge blanket reactor (UASB), anaerobic continuous stirred tank reactor (ACSTR) and anaerobic baffled reactor (ABR) [9]. These processes offer number of advantages over aerobic systems such as: generation of methane as fuel, no oxygenation demand, being compact and producing less biological sludge [10]. The use of anaerobic baffled reactor has been recommended in the literatures as a high rate system for industrial wastewater treatment [11].

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The ABR is extensively applied for treating heavy oil produced effluents [12], cassava wastewater [13], low strength complex discharge [14], wheat flour starch industrial disposal [15], acidic and zinc-containing effluents [16], palm oil mill effluent [17] and municipal wastewater treatment [18].

There was limited availability of literature regarding the use of ABR for phenol biodegradation [11, 19]. There is a relative lack of research on reactor start up, adoption period and microbial decomposition and effective parameters on reactor performance. Present study investigates the feasibility of an anaerobic baffled reactor for the biodegradation of phenol with supplementary substrate. Biomass washout, COD, phenol removal efficiency and acclimatization of the biomass along with phenol concentration changes was further investigated.

MATERIALS AND METHOD

Reactor Configuration: The reactor was fabricated by Plexiglas with a total volume of 36 and working volume of 28 L. The schematic representation of the experimental set up is shown in Fig. 1. The reactor consists of three compartments with dimensions of 15 cm width, 60 cm length and 40 cm depth. The up flow chamber width was designed with a ratio of 3.5:1 to down comer one. The lower section of the down comer baffles had a 4 cm separated space from the bottom of the reactor. The lower section was bent with an angle of 45E in order to lead the flow equally through the up flow chambers and also to obtain a better contact between feed and the retained biosolids. The upper portions of the risers were designed in a descending manner in order to overcome the problems rising from head depletion as the flow gently passes through the baffles. Sampling ports for collecting sludge samples and wastewater were located at 3 cm above the bottom of up flow chambers. A peristaltic pump was used to adjust the influent flow rate.

Acclimated Sludge Inoculation: The seed sludge was anaerobically acclimated with phenolic wastewater obtained from the pulp and paper wastewater treatment plant (Sari, Iran). The thickened sludge was introduced into the three compartments of reactor. The working volume in compartment 1, 2 and 3 were 9.9, 9.6 and 8.8 L, respectively. The volumes of acclimated sludge introduced into compartment 1, 2 and 3 were 3, 2 and 1 L, respectively.

Feed Composition: The ABR was initially fed with phenol as primary substrate and glucose as co-substrate. The phenol solution with a concentration of 3000 mg/L was prepared. In the course of investigation, favourable phenol concentrations were obtained by dilution of phenol stock solution with distilled water. Microelement solution was prepared at 600 times concentration. To avoid increasing VFA (volatile fatty acid), 1000-2000 mg/L $NaHCO_3$ was added to the reactor. Table 1 summarizes the synthetic feed composition of ABR [20].

Analytical Methods: COD of samples were determined using closed reflux colorimetric method and Phenol content in compartments and effluent was measured by 4-aminoantipyrine method; all in accordance with APHA and AWWA standard methods [21]. The biogas production was determined with volume displacement of biogas saturated water. The pH was measured with a digital pH meter electrode (HANNA, Germany).

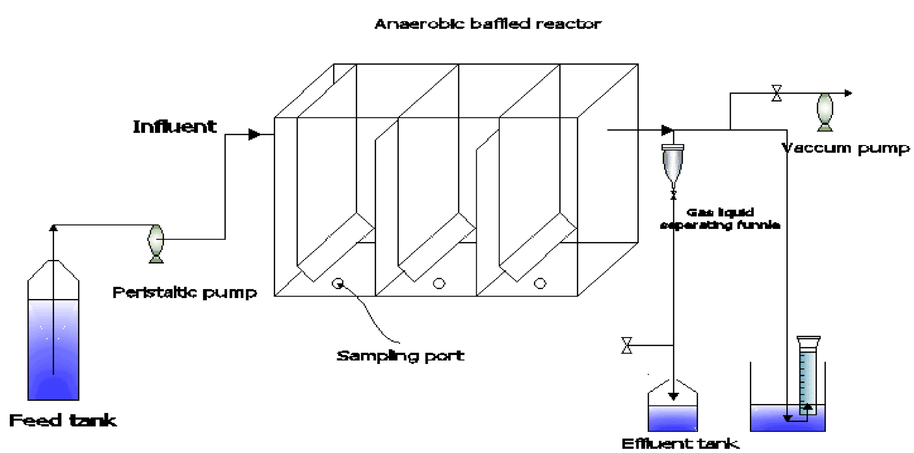

Fig. 1: Schematic representation of the anaerobic baffled reactor (ABR)

Table 1: Feed compositions

Feed composition	Concentration (mg/L)
COD components	
Phenol concentration	100-1000
Glucose concentration	1000
Equivalent COD	245-2300(phenol) / 950 (glucose)
Macro elements	
KCl	200
NH_4Cl	50
$NaHCO_3$	1000-2000
$CaCl_2.2H_2O$	150
$MgCl_2$	100
Microelements	
$FeCl_2.4H_2O$	10
$CoCl_2.2H_2O$	0.02
$NiCl_2.6H_2O$	0.02
$ZnCl_2$	0.02
$CuCl_2.2H_2O$	0.02
$MnCl_2.4H_2O$	0.02
$NaMoO_4.2H_2O$	0.05
H_3BO_3	0.02

Anaerobic Baffled Reactor Operation: In start-up period for duration of 17 days, the initial activity of the sludge was enhanced; initially the reactor was fed with glucose as the sole carbon source. After that, the reactor was fed with variable phenol concentration with initial phenol concentration of 100 mg/L; then the concentration was stepwise increased to 800 mg/L.

All the detailed information was gathered under steady state conditions which were attained when COD removal reached to 80-90 % of its efficiency. All collected data were replicated for precise and reliable results.

RESULTS AND DISCUSSION

Start-up of Anaerobic Baffle Reactor: It was reported that presence of an easy biodegradable substrate such as glucose has many advantages over systems which are treating inhibitory substances as single substrate. This can lead to an accelerated start up process and adaptation period also can improve the system stability [22]. Additional fact was the use of a co-substrate which may cause the methanogens remain in active phase while biomass is acclimatized to the xenobiotic substrate [1, 23].

Taking into consideration the importance of adaptation period, reactor was first inoculated with seed sludge in order to acquaint inocula with anaerobic condition of the ABR. The reactor was initially operated for 17 days with 1000 mg/L glucose as the single carbon source. Fig. 2 represents the COD removal efficiency in the rector for the start up period. All the data were collected after 3 days of the reactor operation. The COD removal efficiency on the third day of operation was 32%. The removal efficiency was significantly improved to 94 and 97% after 14 and 17 days, respectively. The reactor proved to be very stable after a few days of operation and after one week a steady state condition was easily achieved. At the end of the bioactive enrichment phase, the COD removal efficiency was maintained above 95%.

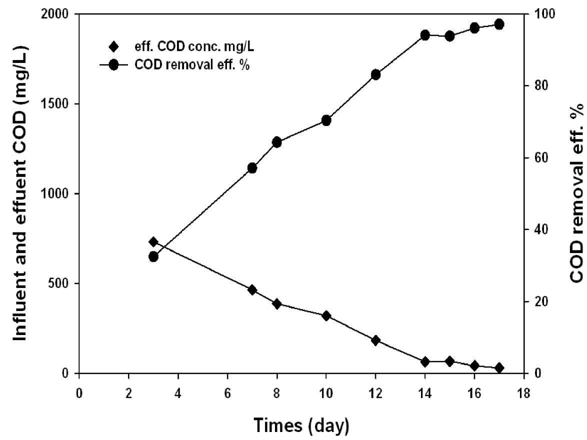

Fig. 2: COD variation for the reactor start up initially with glucose (1000 mg/L)

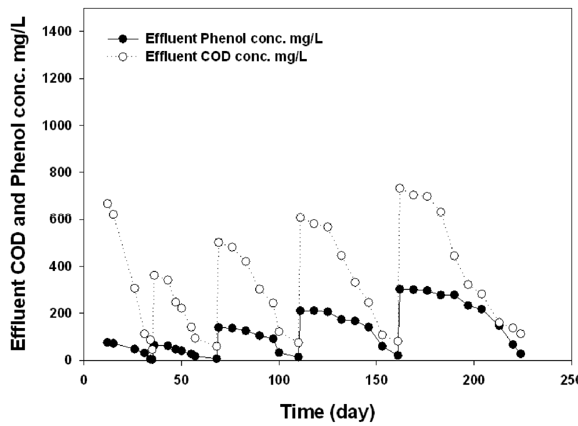

Fig. 3: COD and phenol profiles in the ABR

Performance of Anaerobic Baffled Reactor: After the initial stage of operation with glucose as the sole source of energy, the reactor was gradually fed with phenol as carbon source. The initial phenol concentration was 100 mg/L and once satisfactory phenol removal efficiency of 80-90% was achieved the phenol concentration stepwise increased to 200, 400, 600 and 800 mg/L (equivalent to 0.5 g COD/L/day) which resulted in organic loading rate (OLR) of 0.22, 0.26, 0.34 and 0.41, respectively.

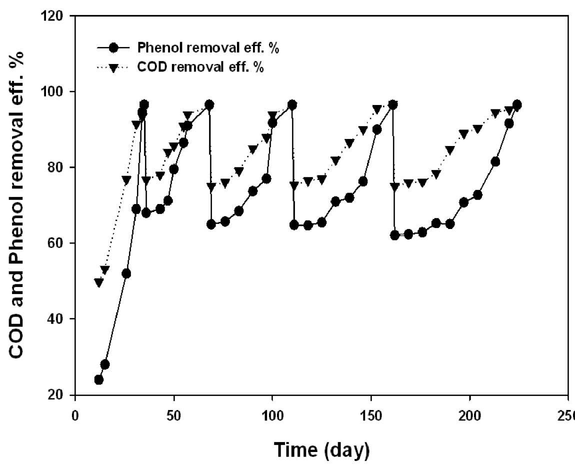

Fig. 4: Effect of phenol concentration on COD and phenol removal efficiencies in the ABR

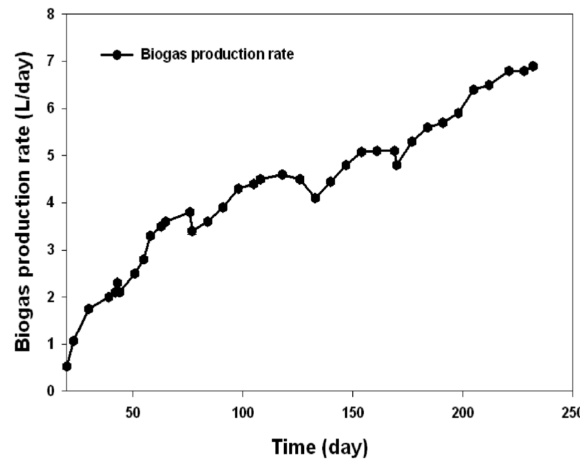

Fig. 5: Total biogas production rate (L/day)

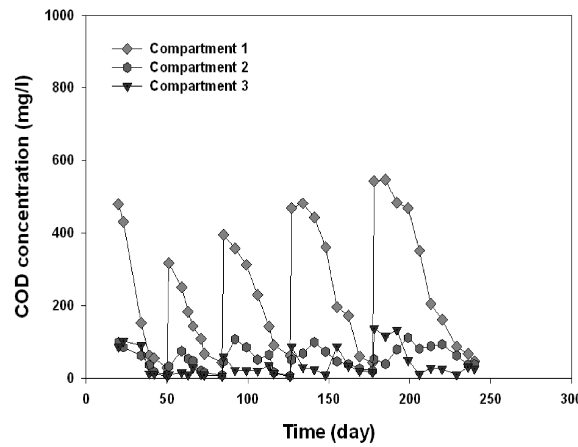

Fig. 6: The COD concentration in 3 compartments of the ABR (mg/L) and COD removal efficiency (%)

Figs. 3 and 4 show the reactor performance in response to elevated phenol concentration. Samples were withdrawn 3 days after adding phenol to synthetic wastewater with phenol and glucose concentrations of 100 and 1000 mg/L, respectively. The equivalent amount of organic level was 1329 mg/L of COD. At 20th day of operation, the removal efficiency of COD and phenol dropped to 49 and 24%, respectively. As the operation was prolonged to 42 days, the reactor recovered and gained its high removal efficiency of 89% and even reached to 96% at 50th day of the reactor operation. Once the stability of the reactor was confirmed after adaptation to phenolic compound, the concentration of phenol was gradually increased to 200, 400, 600 and 800 mg/L. The obtained data demonstrated that the degradation time noticeably increased when the phenol concentration was gradually increased. Reactor easily degraded 100 mg/L phenol with high efficiently within 24 days; while the influent phenol concentration increased to 800 mg/L degradation was prolonged to about 60 days and the removal efficiency enhanced to range of 80 to 90%.

Fig. 5 depicts biogas production rate from the 20th day of operation, while 100 mg/l of phenol was introduced to influent as additional carbon source. Initially, the rate of total biogas production was very low (0.5 L/d). Biogas production profile indicated that total gas production rate was gradually increased along with phenol increments in the feed solution. At the end of the first stage of adding 100mg/l phenol as the single substrate; the reactor had reached to 96% of removal efficiency, with biogas production rate of 2.3 L/d.

The COD concentration profile is shown in Fig. 6. Maximum COD removal efficiencies in the ABR compartments 1, 2 and 3 were 42-89, 6-35 and 4-24%, respectively. This indicated that the acidogenesis phase and VFA production occurred in compartment 1 while in the next stage, the methanogens populations were probably active for the accomplishment of anaerobic process.

Effect of Shock Loads: After steady state conditions were achieved the reactor was continuously operated for the duration of 224 days. The reactor OLR was raised to 0.85 g COD/L/day, with lowering HRT to the lowest value of 4h and increasing phenol concentration to 1000 mg/l as demonstrated in Fig. 7. The obtained results showed a collapse in phenol removal efficiency to 42%. On 262nd day, the shock load applied to the system was gradually recovered to 73%. When phenol concentration and HRT

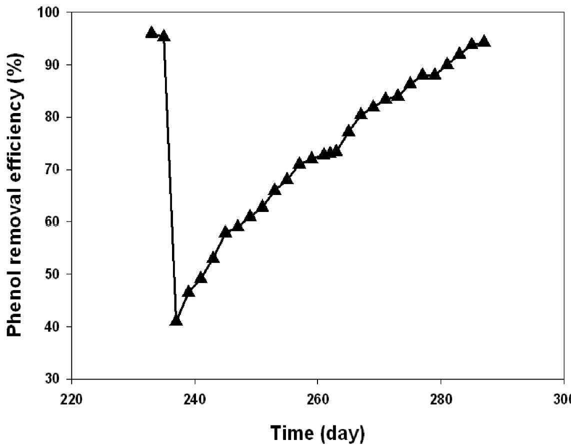

Fig. 7: Response of the ABR to chemical shock loads

was shifted back to its initial value of 800 mg/l and 6 days, system was successfully capable of recovering from the shock load. Therefore, the phenol removal efficiency reached to 93% on the 296th day. In fact, this result confirmed the inherent characteristic of the process stability, against organic shock loads owing to the compartmentalized structure of the reactor.

Treatability in this work (HRT of 6days) was higher than ABR which was treating *p*-nitrophenol (PNP) at hydraulic retention time of 10.38 days [11].

CONCLUSION

In this study, the biodegradation of phenol along with glucose as supplementary carbon source in an anaerobic baffled reactor was successfully accomplished. Use of glucose as a co-substrate and acclimated seed sludge had appreciably improved the biodegradation process by shortening the start up period and lowering the duration time. Maximum phenol concentration of 800 mg/L (equivalent to 0.5 g COD/L/day) was applied and 96% removal efficiency was achieved while the remaining phenol concentration in the effluent was 28 mg/L. It was concluded that prolongation HRT from 6 to 8 days, the reactor effluent can easily achieved the defined international standards. Lowering the pH values in the compartment 1 rather than compartment 2 and 3 indicated the high performance of the reactor in behaving as a two-phase system for the high achievement of anaerobic sequential stages such as hydrolysis followed by acidogenesis and methanogenis. ABR was completely able to recover from the shock load at 34 days after switching OLR to its initial value. This result showed the stability of the process against hydraulic and organic shock loads.

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