Journal of Environmental Chemical Engineering 1 (2013) 233–240

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Chemical Engineering

journal homepage: www.elsevier.com/locate/jece

Effect of Ni^{2+} and Pb^{2+} on the efficiency of packed cage rotating biological contactor system

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ARTICLE INFO

Article history:
Received 27 February 2013
Accepted 30 April 2013

Keywords:
Adsorption
Ni^{2+}
Pb^{2+}
Packed cage rotating biological contactor (packed cage RBC)
Hydraulic retention time (HRT)

ABSTRACT

The research aimed to study the effects of Ni^{2+} and Pb^{2+} on the efficiencies of the packed cage rotating biological contractor (packed cage-RBC) system with synthetic industrial wastewater (SIW) containing various concentrations of Ni^{2+} or Pb^{2+} (SIW-Ni^{2+} or SIW-Pb^{2+}) of 10, 20, 30, 40, 50 mg/L at various hydraulic retention times (HRT) of 4, 6 and 8 h. The results showed that the system efficiencies decreased with the increase of heavy metal (HM) concentrations or loadings. However, Ni^{2+} and Pb^{2+} concentrations of up to 10 mg/L did not affect the system efficiencies. The COD, BOD_5, TKN and Ni^{2+} or Pb^{2+} removal efficiencies of 89 ± 1% and 93 ± 0%, 87 ± 1% and 87 ± 1%, 80.2 ± 0.3% and 80.0 ± 0.8% and 85.7 ± 0.7% or 89.8 ± 1.5%, respectively, were obtained with SIW-10Ni^{2+} and SIW-10Pb^{2+}, respectively, at a HRT of 8 h. According to the increase of HM, the numbers of aerobic heterotrophic, nitrifying and denitrifying bacteria decreased while facultative heterotrophic bacteria dominated. Moreover, Ni^{2+} gave a greater repression effect than Pb^{2+} on the growth and activity of bio-film.

Introduction

Normally, the industrial estate park was designed for single type industries such as food processing, automobile, chemical or textile industrial estate parks according to their easy operation and control [1–4]. However, several industrial estate parks in Thailand consist of various types of industries as a result of economic problems and the size of the industrial park. The wastewater from such industrial parks contains various types of pollutants including both organic and inorganic pollutants (heavy metals: HM) [3,5,6]. So, the selection of a wastewater treatment system should be carefully considered [1,4,7,8]. Theoretically, a biological wastewater treatment process is suitable for organic wastewater, but inorganic wastewater is usually treated by a chemical treatment process [1,4]. Furthermore, it is well documented that Ni^{2+} and Pb^{2+} at high concentrations are toxic to the microorganisms (bio-sludge) of the biological treatment process, especially nitrifying and denitrifying bacteria [5,6,9]. The application and operation of the biological treatment process to treat organic wastewater contaminated with HM is a very interesting issue for wastewater technologists and engineers. Two types of aerobic-biological treatment systems, suspended growth (activated sludge system) and attached growth (rotary biological contractor: RBC and packed cage-RBC), are normally applied for the treatment of organic wastewater containing some toxic substances such as chlorine, surfactants, phenolic compounds and so on [5,9]. The advantages of the RBC and packed cage-RBC systems are low energy consumption and high nitrogen removal efficiency [4,7,8]. However, the growths and activities of nitrifying and denitrifying bacteria are repressed by HM as mentioned above [5,6,9]. So, the effects of the types and concentrations of HM on the nitrogen removal efficiency of the packed cage RBC system should be investigated. Our previous works [8,10,11] reported that the packed cage RBC system showed high nitrogen removal efficiency with low energy consumption as a result of the high populations of nitrifying and denitrifying bacteria [8]. The system was also applied for wastewater containing surfactants, especially sodium dodecyl sulfate and triton X-100, without any effects on the bio-film growth and performance (the bio-film was not peeled off by the effect of the above surfactants during operation) [10].

From the information above, the packed cage RBC system should be applied for treating the wastewater from such industrial estate parks according to the high nitrogenous and carbonaceous compound removal efficiencies with low energy consumption and easy operation [1,2,4]. However, HM contamination in the wastewater might affect the system efficiency and performance [7,10,11]. In this study, the effects of Ni^{2+} and Pb^{2+} concentrations and loadings on the packed cage RBC system efficiency and performance were carried out. The effects of hydraulic retention time (HRT) on the system efficiency and performance were also investigated.

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http://dx.doi.org/10.1016/j.jece.2013.04.019

Nomenclature

BOD_5	biochemical oxygen demand
COD	chemical oxygen demand
HM	heavy metals
HRT	hydraulic retention time
Ni^{2+}	nickel
Pb^{2+}	lead
NH_4^+	ammonium
NO_3^-	nitrate
NO_2^-	nitrite
RBC	rotating biological contractor
SIW	synthetic industrial wastewater
SS	suspended solids
TKN	total kjeldahl nitrogen
SIM-HM	systhetic industrial wastewater containing heavy metals.
TN	total nitrogen

Materials and methods

Synthetic industrial wastewater containing heavy metals (SIW-HM)

SIW-HM was prepared according to the chemical properties (organic matter, TKN and Ni^{2+} and Pb^{2+}) of industrial estate wastewater (SIW) collected from Ladkrabang industrial estate in Bangkok, Thailand as shown in Table 1. Two types of SIW-HM, SIW containing Ni^{2+} (SIW-Ni^{2+}) and SIW containing Pb^{2+} (SIW-Pb^{2+}), were used in this study. The SIW-HM contained various HM (Ni^{2+} or Pb^{2+}) concentrations of 10, 20, 30, 40 and 50 mg/L. $PbCl_2$ and $NiCl_2.H_2O$ were used to generate Ni^{2+} and Pb^{2+}, respectively, in the wastewater.

Packed cage RBC system

The packed cage RBC system [7,8,10,11] is an aerobic moving bio-film reactor, modified from the original RBC system [4] to increase both the surface area of the bio-drum and bio-film mass of the system as shown in Fig. 1A. The packed cage RBC system used in this study consisted of a 42 cm × 90 cm × 46 cm tank (working volume of 43 L) and a 755.7 cm^3 cylindrical packed cage drum (31 cm in diameter, 62 cm in length) as shown in Fig. 1B. 436 pieces of square ring polypropylene media (each square ring media was 68 mm in diameter with 90% porosity and 190 m^2/m^3 specific surface area) were packed inside the drum as shown in Fig. 1B. The total surface area of both the media and drum was 12.67 m^2. Approximately 40% of the drum was submerged in wastewater during operation. The speed of the packed cage drum was approximately 3 rpm. The flow diagram of the system is shown in Fig. 1C.

Acclimatization of bio-sludge

The bio-sludge used to start up the packed cage RBC system was collected from the sedimentation tank of the Bangkok municipal sewage wastewater treatment plant (Sipaya sewage treatment plant). The bio-sludge (10,000 mg/L in concentration) was cultivated in SIW without HM, as shown in Table 1, for 1 week before being used as the inoculum of the packed cage RBC system in the start up process.

Start up of the packed cage RBC system

A 21.5 L of acclimatized bio-sludge suspension (10,000 mg/L) was inoculated into the packed cage RBC reactor and 21.5 L of tap water was added into the reactor (final volume of 43 L). The packed cage drum was rotated at 3 rpm for 3 days without feeding of the fresh wastewater. After that, SIW without HM was continuously fed at a flow rate of 50 L/day for 1–2 weeks. The red-brown bio-film was fully built up on the surfaces of the media and drum. This meant that the bio-film was grown under aerobic conditions [4]. The bio-film on the media and drum was 3–4 mm in thickness as shown in Fig. 1-B.

Operation of packed cage RBC system with various types of SIW-HM under various HRT

The system was operated with various types of SIW-HM, as shown in Table 1, and under various hydraulic retention time (HRT) operations of 4, 6 and 8 h (organic loadings of 10.18, 6.79 and 5.09 g BOD_5/m^2 d), as shown in Table 2.

Chemical analysis

The BOD_5, COD, TKN, ammonia (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), Ni^{2+}, Pb^{2+} and suspended solids (SS) of both the influents and effluents were analyzed in accordance with the standard methods for waste and wastewater examination [12].

Statistical analysis method

Each experiment was repeated at least 3 times. All the data were subjected to two-way analysis of variance (ANOVA) using the statistical analysis system (SAS) [13]. Statistical significance was tested using the least significant difference (LSD) at the $p < 0.05$ level and the results are presented as the mean ± the standard deviation.

Table 1
Chemical composition and properties of synthetic industrial wastewater containing heavy metals.

Substance	Chemical composition		Properties	Chemical properties	
	Concentration, mg/L			Concentration, mg/L	
	SIW-Ni^{2+}	SIW-Pb^{2+}		SIW-Ni^{2+}	SIW-Pb^{2+}
Glucose	720	720	COD	731 ± 11	735 ± 5
$PbCl_2$	–	13.4, 26.9, 40.3, 53.7, 67.1	BOD_5	510 ± 10	510 ± 8
$NiCl_2.6H_2O$	40.5, 81.0, 121.5, 162.0, 202.5	–	Ni^{2+}	10, 20, 30, 40, 50	–
Urea	108	108	Pb^{2+}	–	10, 20, 30, 40, 50
KH_2PO_4	22	22	TKN	34 ± 1	34 ± 1
$FeSO_4.7H_2O$	12.5	12.5	NH_4^+	8.0 ± 0.6	8.0 ± 0.7
			NO_2^-	0.2 ± 0.0	0.2 ± 0.0
			NO_3^-	0.2 ± 0.0	0.2 ± 0.0
			pH	6.7 ± 0.0	6.7 ± 0.0

SIW-Ni^{2+}: synthetic industrial wastewater containing various concentrations of Ni^{2+}; SIW-Pb^{2+}: synthetic industrial wastewater containing various concentrations of Pb^{2+}.