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Performance of an aerobic granular sequencing batch reactor fed with wastewaters contaminated with Zn^{2+}

Ana P.G.C. Marques, Anouk F. Duque, Vânia S. Bessa, Raquel B.R. Mesquita, António O.S.S. Rangel, Paula M.L. Castro*

CBQF – Centro de Biotecnologia e Química Fina, Laboratório Associado, Escola Superior de Biotecnologia, Universidade Católica Portuguesa/Porto, Rua Dr. António Bernardino de Almeida, 4200-072 Porto, Portugal

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A B S T R A C T

The main aim of this study was to investigate the performance of an aerobic granular sludge sequencing batch reactor (AGS-SBR) receiving water streams supplied with different loads of Zn^{2+} (50 and 100 mg L^{-1}) during an operation of 866 cycles (ca. 109 days). When the metal was not fed, chemical oxygen demand (COD), PO_4^{3-} and NH_4^+ were efficiently removed, with efficiencies of 56, 23 and 72% respectively. DGGE profiles showed that Zn^{2+} supply negatively affected the bacterial diversity and community structure of the granules. Consequently, the shock loadings with Zn^{2+}, particularly at the higher levels (100 mg L^{-1}), affected the nutrient removal in the AGS-SBR, although the reactor still generally complied with admissible legal values concerning organic matter, nitrogen and Zn. Simultaneous removal of PO_4^{3-} and TSS in such conditions needs further refining but the application of aerobic granular SBR in the treatment of Zn^{2+} contaminated wastewaters seems viable.

1. Introduction

The selection of a wastewater treatment process depends mainly on the type of contaminants present in the wastewater. Wastewaters, especially those from industrial sources, may contain not only organic matter but also inorganic pollutants. Mining (production of acid mine drainage) and industrial (electroplating, metal processing, paint, plastics, alloys, batteries, etc.) activities are amongst the main processes of heavy metals (HM) contamination of water (Xu et al., 2004). The treatment of HM contaminated wastewaters before its release to the environment is very important as these pollutants are toxic, bioaccumulating in plants and animals, and contaminating the food chain. Conventional treatment of metal containing wastewater, generally involves physic-chemical processes, such as coagulation, flocculation and sedimentation (Lim et al., 2002). However, bioremediation of such contaminated wastewaters is a potential alternative, as it has been reported that a number of microorganisms can adsorb HM from water (Sirianuntapiboon and Hongsrisuwan, 2007). Additionally, the application of a biological treatment offers the opportunity to remove not only metals but the simultaneous degradation of the present organic matter.

Aerobic granules are used as a novel technique for the biological treatment of wastewaters, and have confirmed to be more proficient for water treatment than the use of suspended activated sludge (de Bruin et al., 2004). Their compact and strong microbial structure, excellent settleability, due to better control of filamentous growth (Yu and Gu, 1996), as well as their high biomass retention, and tolerance to high organic loadings and to toxicity, allows their development in sequencing batch reactors (SBR) and renders their use an important tool for organic and inorganic pollutants removal from wastewaters (Adav et al., 2008). Aerobic granular sludge (AGS) is able to perform simultaneously diverse biological processes such as COD, P and N removal (de Kreuk et al., 2005).

Only few studies focused on metal decontamination of wastewaters using aerobic granular sludge (Liu et al., 2002; Xu et al., 2004). There are reports on the use of anaerobic granular sludge in upflow anaerobic sludge blanket (UASB) (Mu et al., 2012) or flocular SBR (Sirianuntapiboon and Hongsrisuwan, 2007; Sorour and Sayed-Ahmed, 2003). Zheng et al. (2011) studied the effect of Zn in the characteristics of the granules of an aerobic granular sludge sequencing batch reactor (AGS-SBR), however, up to date and to our knowledge, there are no reports concerning the

* Corresponding author. Tel.: +351 22 558 00 59; fax: +351 22 509 03 51.
E-mail addresses: amarques@porto.ucp.pt (A.P.G.C. Marques), anoukduque@gmail.com (A.F. Duque), vbessa@porto.ucp.pt (V.S. Bessa), rmesquita@porto.ucp.pt (R.B.R. Mesquita), arangel@porto.ucp.pt (A.O.S.S. Rangel), plcastro@porto.ucp.pt (P.M.L. Castro).

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performance of AGS-SBR with simultaneous removal of Zn^{2+}, organic matter and nutrients from contaminated wastewaters.

The main aim of this study was to investigate the influence of a heavy metal, Zn, on the performance of AGS-SBR towards different loads of Zn^{2+} in inlet streams. Chemical oxygen demand (COD), N and P concentrations in the treated effluent and Zn^{2+} removal were assessed. Diversity of microbial communities within the granules was also followed.

2. Materials and methods

2.1. AGS-SBR set up and operation

A 2.5 L SBR with 110 cm height and an internal diameter of 6.5 cm was used. Before starting this experiment, the reactor was maintained for 15 months fed with acetate, as described in Duque et al. (2011). The system was operated in cycles using an automatic timer (Siemens Logo! 230RC) to start and stop pumps for influent, aeration (4 L min^{-1}) and effluent withdrawal. The operating conditions tested in the reactor are described in Table 1. Dissolved oxygen (DO) and pH were measured online. DO was measured as percentage of the oxygen saturation concentration. The oxygen saturation level was not controlled, resulting in a DO of 100% (9.1 mg L^{-1}) during aeration. The pH was maintained at 7.0 ± 0.8 by dosing 1 M NaOH or 1 M HCl.

The reactor was operated in successive cycles of 3 h, consisting of 60 min influent feeding (which was introduced in the bottom of the reactor), 112 min aeration, 3 min settling and 5 min effluent withdrawal. The settling time was chosen such that only particles with a settling velocity larger than 6 m h^{-1} were effectively retained in the reactor. The composition of the reactor influent media – synthetic wastewater – was as described by de Kreuk et al. (2005). From each media – medium A (63 mM Na–Ac, 3.6 mM $MgSO_4.7H_2O$ and 4.7 mM KCl) and B (4.2 mM Na_2HPO_4, 2.1 mM KH_2PO_4, 35.4 mM NH_4Cl and 10 ml L^{-1} of Vischniac trace element solution)- 89 ml per cycle were dosed together with 772 ml of tap water to compose the influent synthetic wastewater with a Zn^{2+} concentration of 10 mg L^{-1} (Table 1). Medium A was supplemented with Zn^{2+} in order to obtain the influent extra loadings of 50 mg L^{-1} (to a final Zn concentration of 60 mg L^{-1}) during phases II, IV, VI, VIII and X, and of 100 mg L^{-1} (to a final Zn concentration of 110 mg L^{-1}) during phases XII, XIV, XVI, XVIII and XX.

Samples were daily collected (1 cycle/d) from the influent (after 60 min influent feeding) and from the effluent. During Zn^{2+} shocks samples were taken from all cycles, including the immediately subsequent cycle without Zn^{2+}. Wastewater samples were analysed for COD, NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}, total suspended solids (TSS), volatile suspended solids (VSS) and Zn.

Granules were taken at the beginning of the experiment (t_0) and at the end of phases XI (t_{50}) and XXI (t_{100}) and analysed for total Zn content and for microbial analysis (denaturing gradient gel electrophoresis (DGGE)).

2.2. Wastewater analysis

Total suspended solids (TSS) and volatile suspended solids (VSS) were determined according to Standard Method 2540 (APHA et al., 1998). Chemical oxygen demand was determined according to Standard Method 5220 (APHA et al., 1998).

Ammonia, NO_3^- and NO_2^- were measured by sequential injection analysis (SIA) as described by Segundo et al. (2011) and Mesquita et al. (2009), respectively; PO_4^{3-} concentration of filtered samples was determined by flow injection analysis (FIA) according to Torres et al. (2007).

The Zn content of the wastewater samples was determined using flame atomic absorption spectroscopy (FA-AAS) in an UNICAM 960® spectrophotometer (Waltham, USA) (Houba et al., 1995).

2.3. Metal accumulation in the granules

Granule samples collected at the end of stages XI (t_{50}) and XXI (t_{100}) were filtered and oven dried at 70 °C for 48 h. Samples were

Table 1
Summary of the operating conditions and performance of the SBR for Zn removal.

Phase	Length of operation (cycles)	Zn^{2+} fed/cycle (mg L^{-1})	Inlet carbon source concentration (g L^{-1})	Zn mass balance (mg)		
			Acetate	Zn fed	Zn in the outlet	Zn adsorbed to the granules
I	1–59	10	0.36	570	175	395
II[a]	60–62	60	0.36	171	17	154
III	63–99	10	0.36	351.5	207	144.5
IV[a]	100–102	60	0.36	171	13	158
V	103–115	10	0.36	123.5	70	53.5
VI[a]	116–118	60	0.36	171	16	155
VII	119–155	10	0.36	351.5	173	178.5
VIII[a]	156–158	60	0.36	171	15	156
IX	159–171	10	0.36	123.5	57	66.5
X[a]	172–174	60	0.36	171	14	157
XI	175–619	10	0.36	4227.5	2991	1236.5
XII[b]	620–622	110	0.36	313.5	28	285.5
XIII	623–659	10	0.36	351.5	303	48.5
XIV[b]	660–662	110	0.36	313.5	36	277.5
XV	663–675	10	0.36	123.5	141	−17.5
XVI[b]	676–678	110	0.36	313.5	32	281.5
XVII	679–715	10	0.36	351.5	389	−37.5
XVIII[b]	716–718	110	0.36	313.5	34	279.5
XIX	719–731	10	0.36	123.5	133	−9.5
XX[b]	732–734	110	0.36	313.5	39	274.5
XXI	735–866	10	0.36	1254	894	360
				Total from phase I to XXI		
				10374	5777	4597

[a] Zn^{2+} shock loadings of 50 mg L^{-1} Zn^{2+} applied in 3 continuous cycles.
[b] Zn^{2+} shock loadings of 100 mg L^{-1} Zn^{2+} applied in 3 continuous cycles.