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Case Study

Simultaneous nitrogen and organic carbon removal in aerobic granular sludge reactors operated with high dissolved oxygen concentration

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HIGHLIGHTS

- The study offers information about the carbon and nitrogen removal in granular SBR.
- The SND process was discussed under high dissolved oxygen concentration conditions.
- Different organic and nitrogen loading rate have been applied.
- Results show that even with high DO concentration N and C can be removed.

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ABSTRACT

Simultaneous nitrification and denitrification (SND) together with organic removal in granules is usually carried out without Dissolved Oxygen (DO) concentration control, at "low DO" (with a DO < 30–50% of the saturation value, about 3–4 mg/L) to promote anoxic conditions within the aggregates. These conditions can sometimes be in detrimental of the stability of the granules itself due to a lack of shear force. In this work, the authors achieved SND without oxygen control with big sized granules. More specifically, the paper presents a experimentation focused on the analysis of two Sequencing Batch Reactors (SBRs), in bench scale, working with different aerobic sludge granules, in terms of granule size, and high DO concentration, (with concentration varying from anoxic conditions, about DO ~0 mg/L, to values close to those of saturation, >7–8 mg/L, during feast and famine conditions respectively). In particular, different strategies of cultivation and several organic and nitrogen loading rate have been applied, in order to evaluate the efficiencies in SND process without dissolved oxygen control. The results show that, even under conditions of high DO concentration, nitrogen and organic matter can be simultaneously removed, with efficiency >90%. Nevertheless, the biological conditions in the inner layer of the granule may change significantly between small and big granules, during the feast and famine periods. From point of view of granule stability, it is also interesting that with a particle size greater than 1.5 mm, after the cultivation start-up, the granules are presented stable for a long period (about 100 days) and, despite the variations of operational conditions, the granules breaking was always negligible.

1. Introduction

The *Sequencing Batch Reactor* (SBR) with aerobic granular sludge represents a good alternative to conventional activated sludge plants (Abdullah et al., 2013). In particular, granular SBR systems guarantee high sludge settle-ability and excellent performance, with small space demand. The phenomenon of bio-granulation involves cell–cell interaction and includes physical, chemical and biological factors (Liu and Tay, 2006a; Adav et al., 2008). The products of this process are the biomass aggregates formed through self-immobilization of micro-organisms. More specifically, the granules are constituted by dense clusters containing millions of organisms per gram, including within them different bacterial species that play different roles in wastewater treatment (Kim et al., 2008; Othman et al., 2013). Compared to conventional activated sludge flocs, the granules have a smooth texture, thick and very good settleability. Further, the granular sludge can efficiently operate with high levels of organic load, high Sludge Retention Times (SRTs) and variable operational conditions (Anuar et al., 2007; Yuan and Gao, 2010).

Another interesting aspect of this technology is the possibility of obtaining a successful removal of nutrients in a single reactor, because the conditions necessary for nitrification, denitrification and biological phosphorus removal are carried-out within the granules (Yang et al., 2003; Mosquera-Corral et al., 2005; de Kreuk et al., 2005; Chen et al., 2011; Coma et al., 2012). In fact, the

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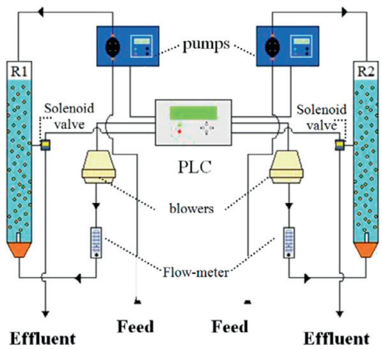

Geometric features of the reactors	SBAR	SBBC	Unit
cylinder height	860	860	mm
riser height	600	-	mm
water table level	690	640	mm
cylinder diameter	90	90	mm
riser diameter	54	-	mm
volumetric exchange ratio	50	50	%
Reactor volume	3.5	3.5	L

Fig. 1. The layout of the pilot plant and geometric features of SBAR/SBBC reactor.

structure of a stable granule can be characterized by different layers, that allow organic carbon and nutrient removal in the same reactor. The presence of heterotrophic population can be observed in the inner part of the granules and, due to oxygen diffusion limitation inside the granules, it is possible to establish a denitrification process; in the middle layer, autotrophic biomass is dominant; in the outer layer, where oxygen and organic substances are highly available, aerobic heterotrophic growth occurs (Jin et al., 2008; Wan and Sperandio, 2009). Nevertheless, the thickness of each layer depends on oxygen and substrate penetration within the granule. Thus, the Simultaneous-Nitrification–Denitrification (SND) process is regulated by the oxygen gradient within the granule (Yilmaz et al., 2008). This depends basically on two aspects (Coma et al., 2012): (1) the Dissolved Oxygen (DO) concentration in the bulk liquid; (2) the granule sizes.

In general, there appears to be a general consensus that SND process within the granules can be optimized when a limited oxygen concentration is applied or a specific anoxic phase is performed (Beun et al., 2001; de Kreuk et al., 2007). Unfortunately, granules may break with low oxygen concentration and often it is impossible to obtain stable granules (Liu and Tay, 2006b, 2008). In particular, de Kreuk and van Loosdrecht (2004) affirm that oxygen concentration reduced to 40% of the saturation value (DO < 3–4 mg/L) caused break-up of granules.

On the other hand, high concentrations of oxygen (with values close to those of DO saturation) may sometimes be required, especially when the granular sludge is used with other advanced technologies, for example with membranes bioreactor (Li et al., 2008). In this context, the granule sizes could have a more important role on the SND process, with reference to thickness variation of anoxic/aerobic zones within the granules. In particular, the different oxygen penetration inside a "big" granule, during feast and famine periods, can improve biological performance and reduce membrane fouling (Wei et al., 2011).

Bearing in mind these observations, the paper reports the analysis of the simultaneous organic and nitrogen removal obtained in two bench scale SBRs with different mean granule sizes (both greater than 1.5 mm after the cultivation period). The study aims to offer useful information about the optimization of nitrogen removal in an aerobic granular sludge reactor with "high" DO concentration.

2. Methods

2.1. Pilot plant description

Experiments were performed in two column-type aerobic granular sludge sequencing batch reactors. Actually, the granular sludge cultivation was carried-out with a Sequencing Batch Airlift Reactor (SBAR). Successively, after 102 days, the configuration of R1 and R2 was changed to Sequencing Batch Bubble Column (SBBC) reactor (Beun et al., 2002).

Both reactors had a working volume of 3.5 L and a filling height of 74 cm. The riser of SBAR configuration was 60 cm height with an internal diameter of 5.4 cm and was positioned at a distance of 3 cm from the bottom of the reactor. Other, geometric features were reported in Fig. 1, where a scheme of plant installation is reported.

The effluent was withdrawn using an electromagnetic valve located at 37 cm from the bottom of the reactor and so the volumetric exchange ratio was 50%. The Hydraulic Retention Time (HRT) was 6 h. The reactor operated in successive cycles of 3 h each. One cycle consisted of 5 min influent addition, 162–167 min aeration (depending on the settling time changing), 2–7 min settling (changing during the initial cultivation) and 6 min effluent withdrawal. Air was introduced in the reactor from the bottom, using a sparger, at a superficial air velocity of 2.25 cm/s (3 L/min). The air-flow was monitored using a flow meter but DO control was not applied. The operations were regulated by a PLC (*programmable logic controller*).

In order to accurately modify the Volumetric Loading Rate (VLR) and the *C*/*N* ratio, the experiment was carried-out with synthetic wastewater. The synthetic wastewater had the general composition described by Beun et al. (2002). In order to change the *C*/*N* ratio, the Sodium Acetate and/or NH_4Cl concentrations were changed.

2.2. Experimentation phases

The whole experimentation lasted 212 days and was divided into two different periods:

Table 1
Operational condition during the period 1 (cultivation).

Day	R1			R2		
	T_s min	VLR kg/m^{3}d	Configuration	T_s min	VLR kg/m^{3}d	Configuration
1st–7th	7	2.4	SBAR	5	2.4	SBAR
8th–14th	5			4		
15th–28th	3			3		
29th–32nd	2			2		
33th–101st					4.8	
102nd–128th			SBBC			SBBC