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Formation of aerobic granules for the treatment of real and low-strength municipal wastewater using a sequencing batch reactor operated at constant volume

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ABSTRACT

This study aimed at evaluating the formation of aerobic granular sludge (AGS) for the treatment of real and low-strength municipal wastewater using a column sequencing batch reactor (SBR) operated in fill-draw mode (constant volume). The focus was on understanding how the wastewater upflow velocity (V_{WW}) applied during the anaerobic feeding influenced the sludge properties and in turn the substrate conversion. Two different strategies were tested: (1) washing-out the flocs by imposing high wastewater upflow velocities (between 5.9 and 16 m h^{-1}) during the anaerobic feeding (Approach #1) and (2) selective utilization of organic carbon during the anaerobic feeding (1 m h^{-1}) combined with a selective sludge withdrawal (Approach #2). A column SBR of 190 L was operated in constant volume during 1500 days and fed with real and low-strength municipal wastewater. The formation of AGS with SVI_{30} of around 80 mL g_{TSS}^{-1} was observed either at very low (1 m h^{-1}) or at high V_{WW} (16 m h^{-1}). At 16 m h^{-1} the AGS was mainly composed of large and round granules (d > 0.63 mm) with a fluffy surface, while at 1 m h^{-1} the sludge was dominated by small granules (0.25 < d < 0.63 mm). The AGS contained a significant fraction of flocs during the whole operational period. A considerable and continuous washout of biomass occurred at V_{WW} higher than 5.9 m h^{-1} (Approach #1) due to the lower settling velocity of the AGS fed with municipal wastewater. The low sludge retention observed at V_{WW} higher than 5.9 m h^{-1} deteriorated the substrate conversion and in turn the effluent quality. High solid concentrations (and thus solid retention time) were maintained during Approach #2 (V_{WW} of 1 m h^{-1}), which resulted in an excellent effluent quality. The study demonstrated that the formation of AGS is possible during the treatment of real and low-strength municipal wastewater in a SBR operated at constant volume. Low wastewater upflow velocities should be applied during the anaerobic feeding phase in order to ensure enough biomass retention and efficient substrate removal.

1. Introduction

The formation of aerobic granules has been extensively investigated over the last 20 years (Morgenroth et al., 1997). Granular sludge is today foreseen as one of the main advanced technology for wastewater treatment (van Loosdrecht and Brdjanovic, 2014). Despite several full-scale applications of aerobic granular sludge (AGS) systems, the operating conditions required to form granules during the treatment of low-strength municipal wastewater remain unclear. Most studies on aerobic granulation were indeed performed at laboratory-scale using synthetic influents. Those synthetic influents typically contain readily biodegradable substrate such as carbohydrates or volatile fatty acids at large concentrations, ranging from few hundreds to few thousands mg_{COD} L^{-1}. Such high substrate concentrations allow growing aerobic granules within few weeks (Beun et al., 2000; Dangcong et al., 1999; Gao et al., 2011; Zheng et al., 2006). However, the aforesaid influents are not representative of real municipal wastewaters,

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which usually contain much lower organic substrate concentrations (between 250 and 430 $mg_{COD}\ L^{-1}$) with a significant fraction in the particulate (X_S) form, e.g., 50% (Metcalf and Eddy, 2003).

Only few studies reported successful granule formation using complex influents such as municipal wastewaters (Table 1). Different observations can be drawn from these studies:

(i) Very long (more than one year) start-up periods are required to achieve full granulation. Ni et al. (2009) and Giesen et al. (2013), for example, reported periods of 10 and 13 months to achieve 85% and 90% granulation, respectively.

(ii) Aerobic granules developed with real municipal wastewater are rather small, with diameters varying between 200 and 1300 μm (Liu et al., 2010; Ni et al., 2009; Wagner and da Costa, 2013). These values are much smaller than the ones usually reported for aerobic granules cultivated with synthetic influents (diameters higher than 2000 μm).

(iii) Settling properties of aerobic granules fed with municipal wastewater are usually very good. Values for SVI_5 and SVI_{30} below 50 mL g_{TSS}^{-1} were reported (Giesen et al., 2013; Ni et al., 2009) but higher values were also observed (i.e. slightly below 100 mL g_{TSS}^{-1} for Coma et al. (2012)). A similar observation is drawn for the SVI_{30} to SVI_{10} ratio. A ratio close to 1 is representative of full granulation. However, a SVI ratio smaller than 1 are often reported (Coma et al., 2012; Wagner and da Costa, 2013).

(iv) The performances of the AGS systems in terms of substrate conversion were not clearly evaluated. Information about the denitrification or phosphorus removal are often not reported. Also, the existence of simultaneous nitrification-denitrification (as expected due to oxygen diffusion limitation inside the granules) is not clearly established based on the data reported in the literature (Giesen et al., 2013; van der Roest et al., 2011).

Even though the studies listed in Table 1 undoubtedly advanced our understanding about aerobic granule formation during the treatment of municipal wastewaters, they also display some limitations. Some studies were performed with mixed influents, e.g. mixture of municipal and industrial wastewaters (Giesen et al., 2013; Liu et al., 2010) or municipal wastewater with addition of acetate (Coma et al., 2012; Rocktäschel et al., 2015). This can result in influents with high COD concentrations that are not representative of the typical values found for municipal wastewater, e.g.1800 $mg_{COD}\ L^{-1}$ (Liu et al., 2010). To what extent successful granulation can be achieved with real and low-strength municipal wastewater containing a significant fraction of organic substrate in the particulate form (X_S) still remains uncertain. Secondly, the studies listed in Table 1 did not clearly describe the system performances regarding substrate conversion, especially in terms of denitrification and phosphorus removal. In theory, a key advantage of the AGS systems is that simultaneous nitrification-denitrification can be achieved under aerobic conditions in the bulk liquid. Based on the existing literature, it remains unclear if denitrification is observed simultaneously to nitrification or if it occurs during the anaerobic feeding phase. The performances of AGS systems in terms of effluent quality must be assessed in order to evaluate the precise potential of this technology for the treatment of real and low-strength municipal wastewaters. Finally, the operating conditions to achieve granulation seem rather diverse. Sequencing batch

Table 1
Overview of the main characteristics and results of published studies about aerobic granulation using municipal wastewater.

Influent	Substrate concentrations ($mg_{COD}\ L^{-1}$)	Organic load ($kg_{COD}\ m^3\ d^{-1}$)	SBR operation	Time to achieve granulation	Settling properties (SVI, ratio of SVIs)	Fraction of granules	Size of granules (mm)	Effluent quality (mg L^{-1})	Reference
Municipal wastewater (China)	COD tot: 95-200 COD sol: 35-120	0.6–1	Variable volume (15–30 min settling)	10 months (300 days)	SVI_5: 40 mL g^{-1} SVI_{30}: 40 mL g^{-1} Ratio: 1	80%	0.2–0.8	Ammonia: 0.5 Nitrate: 4 Orthophosphate: 0.5 Suspended solids: 15	(Ni et al., 2009)
Municipal (40%) and industrial (60%) wastewater (China)	COD sol: 250-1800		Variable volume	400 days	SVI_{30} < 50 mL g^{-1} Ratio: 1	80-90%	0.35		(Liu et al., 2010)
Municipal wastewater (Nereda® plant, South Africa)	COD tot: 1265		Constant volume. V_{WW} unknown.		SVI_5: 30 mL g^{-1}				(Giesen et al., 2013; van der Roest et al., 2011)
Municipal + industrial wastewater (Nereda® plant in Epe, The Netherlands)			Constant volume. V_{WW} unknown	13 months	SVI_5: 60 mL g^{-1} SVI_{30}: 40 mL g^{-1} Ratio: 0.66	Around 90% under stable operating conditions		Ammonia:0.5 Nitrate: 4 Orthophosphate: 0.5 Suspended solids: 10-20	(Giesen et al., 2013; van der Roest et al., 2011)
Municipal wastewater + acetate (Australia)	[a]COD tot: 326 ± 77 [a]COD sol: 179 ± 46	Variable volume		SVI_{30} < 100 mL g^{-1} [b] Ratio: ≈ 0.9[b]				Nitrite accumulation during aerobic phase	(Coma et al., 2012)
Municipal wastewater (Brazil)[c]	COD sol: 430 ± 140	1–1.40	Variable volume (15 min settling)	140 days	SVI_{30} ≈ 53 mL g^{-1} Ratio ≈ 0.9		0.3–1.3	Ammonia: 3 Suspended solids: 25-125	(Wagner and da Costa, 2013)
Municipal wastewater + acetate (Germany)	COD tot: 287-492	0.5–2.0	Variable volume (15–30 min settling)	125 days		98%	1.1–1.8	Orthophosphate: <3 Suspended solids: 40-100	

[a] Before addition of acetate.
[b] Data of the "100%-flocs" conditions.
[c] Data of Stage I and II (without addition of acetate).