Aerobic granular sludge: formation and performance with addition of granular activated carbon and biochar

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Highlights:

- The addition of biochar accelerated granulation in 20 days;
- GAC was not an effective granulation core probably because of its high density;
- High COD and ammonia removals (> 90%) were achieved in all the reactors.

Keywords: aerobic granular sludge; biochar; granular activated carbon.

INTRODUCTION

Aerobic granular sludge (AGS), an innovative technology that uses bacterial granules, is capable of simultaneously removing carbon, nitrogen, and phosphorus from wastewater in a single reactor. This approach is recognized as one of the most promising among biological treatment technologies in the 21st century (Rollemberg et al., 2020). Compared to conventional activated sludge, AGS demonstrates greater settleability, biomass retention, and resistance to shocks (Rollemberg et al., 2019). However, the formation of aerobic granular sludge occurs under specific conditions and may require a long start-up period (Nancharaiah & Reddy, 2018).

Among the strategies to accelerate and enhance AGS formation, the addition of carbonaceous materials, such as granular activated carbon (GAC) and biochar, as nucleation agents has proven effective (Li, Li & Yu, 2011; Ming et al., 2020). GAC and biochar have a large specific surface area and good settleability. Their irregular and rough surfaces, together with their characteristic adsorption properties, create a microenvironment conducive to bacterial growth (Li et al., 2011; Zhao & Lang, 2018). Thus, they may accelerate microbial aggregation, shortening granulation time and improving granule stability.

Therefore, this study investigated the impact of adding GAC and sugarcane bagasse biochar as nucleation agents to accelerate granulation time and improve the stability and performance of AGS sequencing batch reactors (SBRs) treating synthetic wastewater.

METHODOLOGY

Three 8-L bench-scale SBRs (R1, R2, and R3) were inoculated with sludge from a UCT system used to treat domestic sewage at an initial concentration of 2 $g \cdot L^{-1}$ of VSS (volatile suspended solids). R1 was the control reactor, whereas R2 and R3 had 2 $g \cdot L^{-1}$ of GAC and biochar (particle size of 0.2-0.6 mm), respectively, added to their inoculum. The reactors were fed with synthetic wastewater containing 1000 mg $COD \cdot L^{-1}$ of propionic acid, 50 mg $N\text{-}NH_4^+ \cdot L^{-1}$ of ammonium chloride, 7 mg $P\text{-}PO_4^{3-} \cdot L^{-1}$ of potassium phosphate, 1 ml·L^{-1} of a micronutrient solution (Rollemberg et al., 2019), and 2.5 g·L^{-1} of sodium bicarbonate to buffer the medium. The reactors were aerated by mini air compressors.

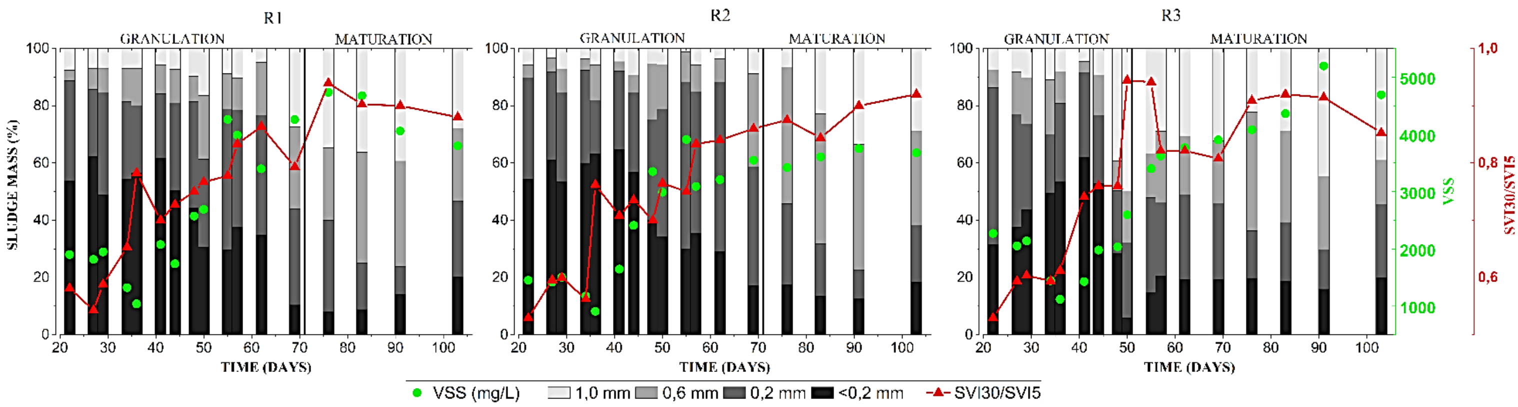
The reactors were operated in 6-h cycles (20 min of filling, 120 min of anaerobic reaction, 199-214 min of aerobic reaction, 5-20 min of settling and 1 min of decanting), with a 50% volumetric exchange ratio, over two phases (granulation and maturation). The granulation phase was divided into four stages, in which the settling time was reduced from 20 to 15, 10, and 5 min as a granulation strategy. Each stage lasted around one or two weeks, and the time removed from settling was added to aerobic reaction. The maturation phase had the same configurations as the stage 4 of the granulation phase.

COD, N-NH_4^+, N-NO_3^-, N-NO_2^-, P-PO_4^{3-}, and VSS were determined according to American Public Health Association (APHA, 2012). The granulation process was evaluated in terms of particle size (0.2, 0.6, and 1.0 mm), settleability (sludge volumetric index at 30 and 5 min ratio, SVI_{30}/SVI_5, and production of extracellular polymeric substances (EPS) (sum of polysaccharides, PS, and proteins, PN) as described elsewhere (Rollemberg et al., 2019). The physical strength analysis (shear test) of the granule was performed according to the methodology described by Nor Anuar et al. (2012), where the granules (> 0.2 mm) were subjected to a shear force caused by a rotation of 200 rpm for 10 min. The fragmented fraction identified was expressed in terms of stability coefficient (S). The coefficient is divided into three categories: very resistant (S < 5%), resistant (5% ≤ S ≤ 20%), and non-resistant (S > 20%).

RESULTS AND CONCLUSIONS

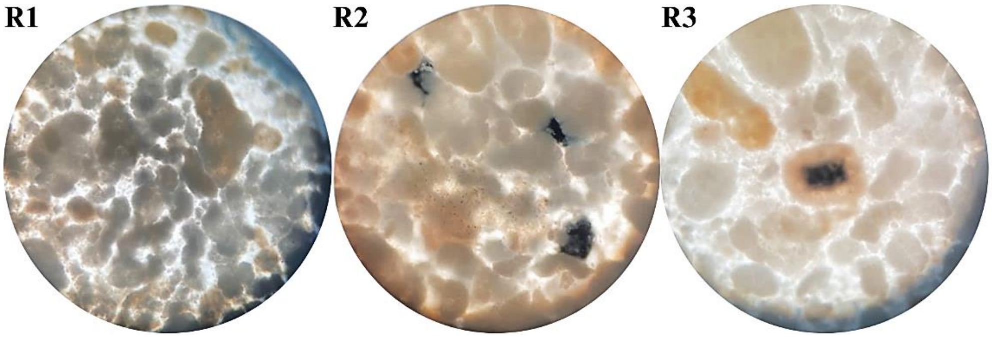
Figure 1 shows the characteristics of the sludge in the granulation and maturation phases. In the first 35 days, the solids were low and variable due to the reduction in the settling time to select biomass with better settleability. After stabilizing at a settling time of 5 min, sludge with good settleability developed, and there was a gradual increase in the VSS concentration. In addition, granulation is achieved when two criteria are met: 80% per cent of granules with size above 0.2 mm and SVI_{30}/SVI_5 ratio above 0.8 (De Kreuk et al., 2007). Thus, R1 and R2 granulated on day 70, whereas R3 granulated on day 50. In the maturation phase, all reactors showed VSS above 3500 mg·L^{-1}.

Figure 1: Particle size, sedimentation capacity and solids concentration.



Granulation in R3 (biochar) took place 20 days earlier than in R1 (control) and R2 (GAC). Although the use of GAC as a nucleation agent is reported in the literature (Li et al., 2011), in this study, it did not adhere to the biomass, probably due to its density, which was too high for the resuspension capacity of the air compressor. On the other hand, the sugarcane bagasse biochar, with lower density, adhered to the sludge and was effective as a nucleation agent, facilitating biomass aggregation. Another important parameter in verifying the stability of the granules is the shear strength, measured by the stability coefficient (S). The S values obtained were 17.25%, 9.92%, and 11.57% for R1, R2, and R3, respectively, indicating that all the granules formed were considered resistant. Both reactors with additives presented higher shear strength values when compared to the control reactor. Figure 2 shows images obtained by optical microscopy with a 40× zoom of the granulated biomass of the reactors, where it is possible to visualize the CAG loose among the granules and, in turn, the biochar incorporated as the nucleus of an aerobic granule.

Figure 2: Morphological characteristics of the granules after 90 days of operation



The carbonaceous materials did not affect the removal performance of the reactors. High COD and ammonia removals (> 90%) were achieved in all the reactors (Table 1). COD removal remained stable throughout the experiment, whereas ammonia removal varied slightly during the granulation phase, reaching stability in the maturation phase. Although nitrification occurred effectively, denitrification was not so efficient, particularly in the maturation phase, when total N removal was below 65% (Table 1). As for total P removal, the efficiencies varied a lot during the experiment, with low average values in both phases (Table 1). As for total EPS, there was no change between the two phases, but, after maturation, the three reactors showed an increase in PS production, reducing the PN/PS ratio (Table 1). PS contributes significantly to the formation of the granular structure, and PN to its stability and hydrophobicity (Feng et al., 2021). Therefore, an increase in PS indicates a tendency towards greater structural strengthening of the mature granule.

Table 1: Reactor operating performance.

Parameter	Granulation			Maturation		
	R1	R2	R3	R1	R2	R3
COD removal (%)	98.3 ± 3.8	98.6 ± 2.3	97.1 ± 4.1	98.9 ± 1.1	97.7 ± 3.3	93.6 ± 3.6
N-NH_4^+ removal (%)	98.8 ± 7.8	98.5 ± 14.4	98.9 ± 12.1	98.8 ± 0.4	98.9 ± 0.3	99.1 ± 0.5
TN removal (%)	74.9 ± 7.1	73.0 ± 11.5	74.0 ± 13.2	63.2 ± 17.8	61.3 ± 19.3	63.5 ± 19.4
TP removal (%)	36.4 ± 14.9	29.2 ± 15.1	35.0 ± 16.5	25.3 ± 8.1	20.4 ± 8.9	20.3 ± 6.6
EPS (g/g VSS)	1.62 ± 0.85	1.54 ± 0.56	1.48 ± 0.63	1.75 ± 0.48	1.84 ± 0.48	1.82 ± 0.62
PN/PS ratio	0.78	0.89	0.73	0.44	0.43	0.45

EPS: extracellular polymeric substances; TN: total nitrogen; TP: total phosphorus; PN: proteins; PS: polysaccharides.

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