Evaluation of Aerobic Granular Sludge SBR Performances

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Abstract
Aerobic granular sludge has several advantages over conventional activated sludge flocs such as fast settling ability, high biomass retention and ability to withstand high organic loading including potential toxic substrates, leading towards a compact reactor system – aerobic granular sludge sequential batch reactor (AGSBR).
Aerobic granules have been successfully cultivated, previously, in SBR systems from flocculated activated sludge fed with synthetic medium with acetate as the sole carbon source or with real municipal wastewater.
The main objective of this study was to investigate the possibility of an aerobic granular system to simultaneously remove the organic loading, nitrogen and phosphorus content. The experiments were performed in a SBR reactor with a hydraulic reaction time of 12 hours at loadings rates of up to 3.0 kg m^{-3} day^{-1} COD and 0,2 kg $m^{-3}day^{-1}$ of N-NH_4^+. Compact granules with good settling ability were maintained during the experimental period and high COD removal but ordinary global nitrogen and phosphorus removal efficiencies were registered.
Aerobic granules possess high activity, compact structure and good settling ability, and have the potential to simultaneously treat wastewater with high organic and ammonium loading in sequential system at relatively low hydraulic retention times.

Keywords
SBR, wastewater treatment, aerobic granular sludge

INTRODUCTION

After the phenomenon of aerobic granules has been first reported by Mishima and Nakamura (1991) in a continuous aerobic upflow sludge blanket reactor, at the end of the 1990s, based on the researches on biofilm structure and on the role of storage polymers (extracellular polymeric substances - EPS) on biofilm formation, van Loosdrecht (1997) understood the possibility of growing aerobic granules without carrier material on readily biodegradable substrates in Sequencing Batch Reactor (SBR). Since then, formation of microbial granules from activated sludge flocs, under aerobic conditions is an active area of investigation for developing new generation of wastewater treatment plants. Compact structured, biologically efficient aerobic sludge granules with wide diverse microbial species and excellent settling capabilities have been developed in sequencing batch reactors on various substrates including glucose, acetate, phenol, starch, ethanol, molasses, sucrose and other synthetic wastewater components (Bumbac et al., 2009, Liu and Tay, 2004; Tay et al., 2002; Tay et al., 2004; Zheng et al., 2005, Adav et al., 2007a,b,c) as well as on real wastewater streams (de Bruin et al., 2004; Schwarzenbeck et al., 2005;Wang et al., 2007).
Compared to the loose, fluffy, and irregular conventional activated sludge flocs, the aerobic granular sludge is known to:

- have denser and stronger microbial structure;
- have regular, smooth round shape, and a clear outer surface;
- be visible as separate entities in the mixed liquor during both the mixing and the settling phases;
- have a high biomass retention – up to 10-25g/l compared to 3-5 g/l in conventional activated sludge systems
- have excellent settleability - granules settle with a velocity of 10 to 40 m/h (while activated sludge settles with only 1 m/h);

- be capable to withstanding high flow rates;
- be able to withstand high organic loading rates;
- be less vulnerable than the suspended sludge to the toxicity of organic chemicals and heavy metals in wastewater.

The granular structure has many advantages, as stated above. Due to diffusion gradients of substrate, nutrients and oxygen, the conditions needed for various processes, usually accommodated in various tanks, are now concentrated inside the granular sludge and thus only one tank without large recycle flows is needed to achieve similar performances concerning organic load, nitrogen and phosphorus removal. Theoretically, fast growing, heterotrophic microorganisms responsible for COD removal are located in the outer layer of the granule while slow growing, autotrophic microorganisms could be found in deeper zones of the granule with lower oxygen availability (van Loosdrecht et al., 1995); (fig.1.).

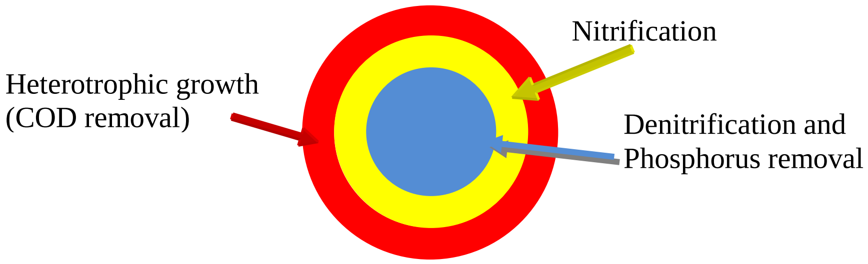


Fig.1. Schematic representation of different process conditions possible within the sludge granule

MATERIALS AND METHOD

Experimental setup and operating conditions

The experimental setup consisted of a Plexiglas pilot-scale column-type sequencing batch reactor with a working volume of 10 L, which had an internal diameter of 12 cm and a total height of 120 cm (fig.2). The reactor was equipped at the bottom end with a air sparging membrane that assured the homogenous distribution of air within the column. The cyclic operation of the SBR system was assured by pumps and electrovalves controlled by a PLC (programmable logic controller) using the following time sequence: 10 minutes influent feeding (VERDER peristaltic pump); 11,5 hours of aerobic reaction (4 L/min airflow velocity), 10 minutes of settling, 10 minutes of effluent withdrawal summing a total hydraulic retention time of 12 hours. The experiment was conducted at room temperature, respectively 25^0C ± 3^0C. The relative high airflow velocity was used in order to assure sufficient hydrodynamic shear forces needed for granule formation.

Settling time is an important hydraulic selection pressure operational parameter on the microbial community in the bioreactor. Thus, the short settling time preferentially selects for the growth of fast settling bacteria while the sludge with poor settleability is being washed out.

The reactor was fed with a synthetic wastewater with sodium acetate as the sole carbon source, containing (mg/l): sodium acetate (3000), NH_4Cl (300), $K_2HPO_4{\cdot}3H_2O$ (80), $CaCl_2$ (30), $MgSO_4{\cdot}7H_2O$ (30), $FeSO_4{\cdot}7H_2O$ (20), trace element solution, 2ml L^{-1}. The composition of the trace solution was prepared according to Sponza et al. (2001). The reactor was inoculated with 4L of activated sludge (MLSS = 3.1 g L^{-1}) from the aerobic tank of a municipal treatment plant.

When predominant granular sludge was obtained, the concentrations of N-NH_4^+ was doubled in order to evaluate the stability of the SBR system and the possibility for simultaneous nutrient removal.

Analytical methods

COD, MLSS total nitrogen and total phosphorus were measured, using the respective standard methods: SR ISO 6060-96, STAS 6953-81, SR ISO 10048-01 and SR EN ISO 6878-05. Nitrate, nitrite and ammonium were measured by ion chromatography (IC-DIONEX)

Sludge volume index (SVI) was measured in a 1000 mL graduated cylinder with sludge sample taken from the mixed liquor at the end of the cycle (before settling). SVI_5, SVI_{10} and SVI_{30} were respectively measured after 5, 10 and 30 min. Observations on aerobic granules morphology were carried out using an optic microscope (trinocular microscope OPTECH connected with a Canon digital camera) and a stereomicroscope (MOTIC with built-in camera).

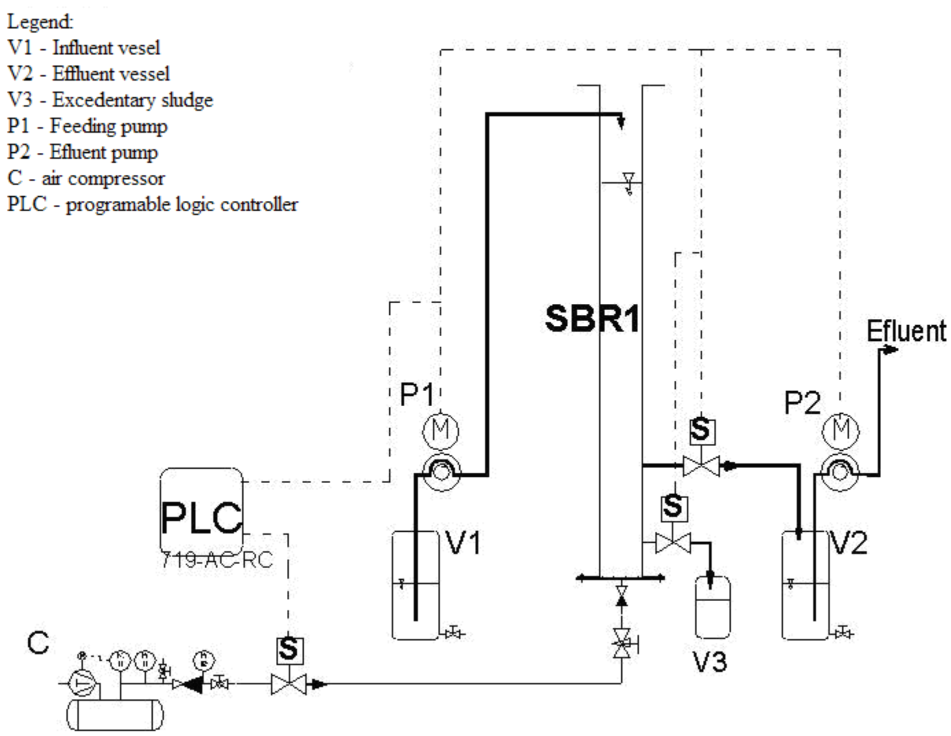


Fig. 2. Schematic representation of the aerobic granular sludge SBR

RESULTS AND DISCUSSIONS

Granule formation and characteristics

The sludge used in both systems as inoculum was the typical flocculent activated sludge with a fluffy, irregular and loose morphology (Fig.3.a.). The settling properties of this sludge were: SVI of 120 mL/g MLSS, and a settling velocity of 1,4 m/h. During the first five experimental days considerable washout of the suspended biomass was observed because of the operational strategy of the SBR, in which short settling time (10 minutes) was applied. Thus, all flocs or aggregates of biomass with settling velocity slower than 8,4 m/h were removed from the system.

The relative high airflow velocity assured sufficient hydrodynamic shear forces for aerobic granules to be formed. Microscopic examination, in time, of the sludge showed that the morphology of the granular biomass was completely different from the flocculent sludge used as inoculum. Aerobic granules were observed after 20 days while predominant granular sludge, round shaped with a compact aspect and a very clear outline was obtained within 60 days of operation of the acetate fed SBR. Figure 3 presents the evolution in time of aerobic granules formation process starting from the initial inoculum (conventional activated sludge from Pitesti WWTP) to bacterial agglomerations (fig.3b), predominant granular sludge (fig 3.c, d) and granular sludge (fig.3.e,f)

The size of the granules varied between 1 and 3 mm in diameter by the end of the experiment (Fig.4.). The biomass concentration reached 8,7 g/l after 60 days. The ratio between SVI_5/SVI_{30} decreased gradually from almost 2 to 1,07 at the end of experiment indicating a fast settling aerobic granular sludge.

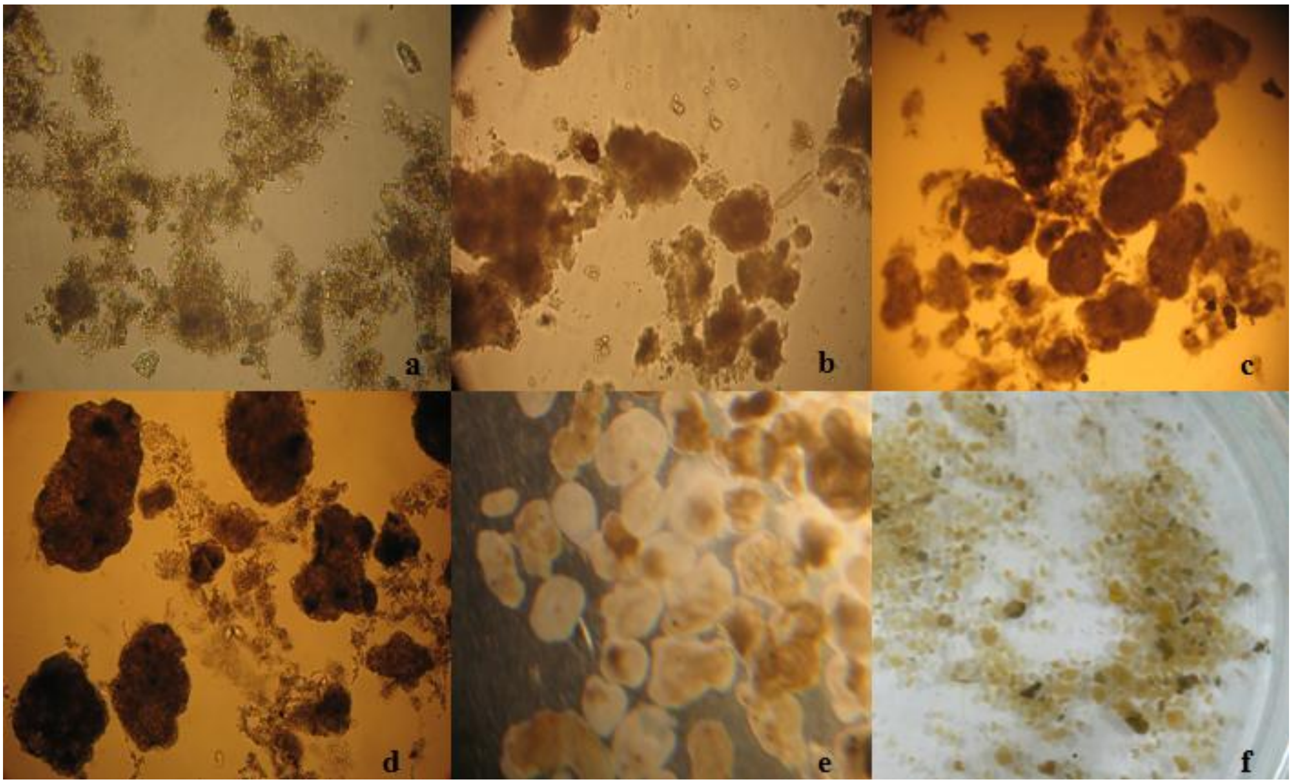


Fig. 3. Microscopic aspect of aerobic granules evolution from (a) seed sludge (microscopic image 20x), in time: (b)-after 20 days sludge agglomerations (microscopic image 20x); (c) after 40 days aerobic granules (microscopic image 10x); after 60 days predominant granular sludge: (d) microscopic image 4x; (e) stereomicroscopic image (4x); (f) digital camera photo

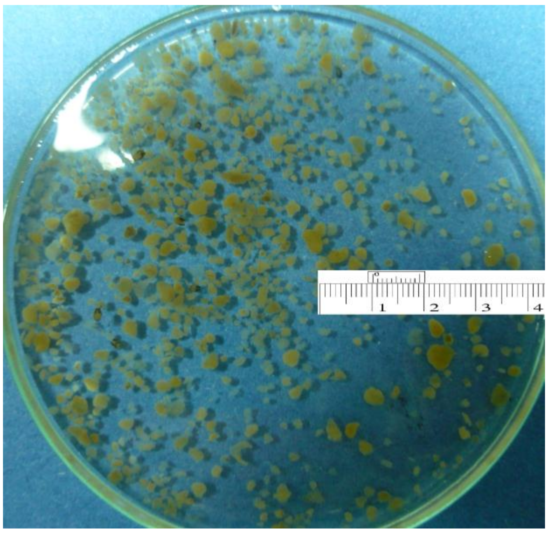


Fig. 4. Aerobic granules on a Petri dish – macroscopic image, (digital photo camera Lumix Panasonic)

Evaluation of nutrients removal efficiencies

The reactor was operated for 120 days of which the first 60 days were dedicated for stable aerobic granules formation in the reactor while the second 60 days were dedicated for the assessment of simultaneous nutrient removal efficiency. During the first period, the reactor was fed with a synthetic influent with 3g/L of acetate (as sole carbon source), 100 ± 5 mg/L N-NH_4^+, and 10,8 ± 0,5 mg/L P_{tot}. Due to continuous air supply, the reactor fast recovered after an initial partial washout of the sludge used as inoculums, thus, within less than a week of operation the COD removal efficiencies were above 90 percent and stable while the ammonium concentrations decreased significantly reaching after approximately 14 days 90 % (Fig.5. and 6.). Still, because the aerobic granules were under formation, poor global nitrogen and phosphorus removal efficiencies were recorded in the first 40 days (approximately 50%). Most of the influent ammonium was oxidized to nitrate and no significant amounts of nitrite were recorded. The following 20 days the removal efficiencies increased significantly, to global nitrogen and phosphorus removal efficiencies of 82 % and respectively 84%. The COD removal efficiency maintained at about 95% which was expected considering the biodegradability of the substrate. After day 60, the influent N-NH_4^+ and total P concentrations were doubled. The loading shock did not affect the COD removal efficiency but affected the nitrogen and phosphorus removal efficiencies. After another 20 days the removal efficiencies for nitrogen and phosphorus stabilized at about 65% and respectively 62 %.

Fig.5. Evolution of nutrients in AGSBR effluent

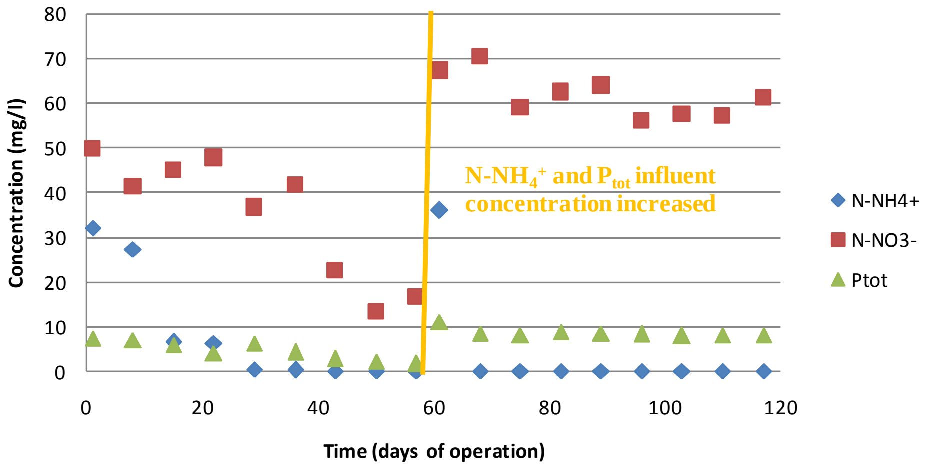
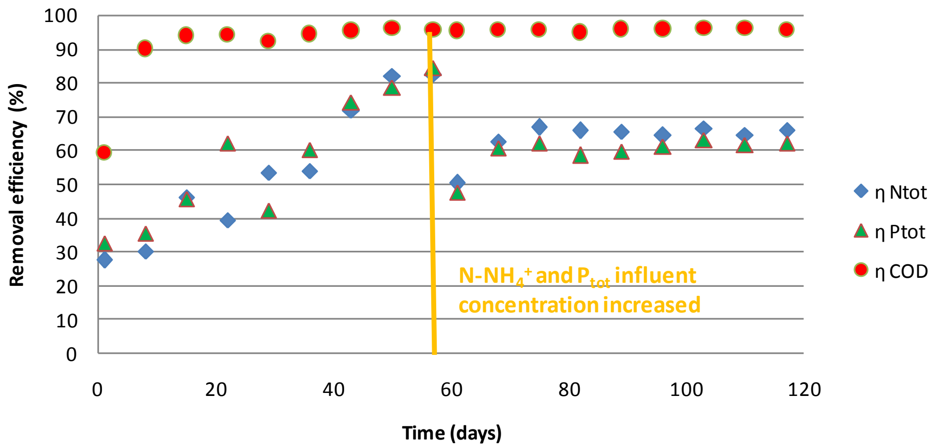


Fig.6. Global nutrient removal efficiencies



The size of the granule is closely related to the size of the anoxic zone: the lower the oxygen concentration or the bigger the granule, the larger the anoxic zone and thus, the larger the nitrogen and phosphorus removal capacity (Li et al., 2008). In our study, the aeration intensity was maintained constant during the entire reaction period, in order to maintain the hydrodynamic shear forces within the reactor and implicitly the compact structure of the granules. Still, the denitrification and phosphorus removal efficiencies are dependent on the oxygen concentration which can be correlated with the granule size and diffusion processes within the granules.

CONCLUSION

The processes of aerobic COD removal, nitrification, denitrification and phosphorus removal can occur simultaneously in an aerobic granular sludge reactor fed with acetate. However, in case of higher concentrations of influent nitrogen and phosphorus different aeration or feeding strategies should be considered.

The performance of a biological system for wastewater treatment depends significantly on the active biomass concentration, the overall biodegradation rates, the reactor configuration, and the feeding rates of the pollutants and oxygen. The efficiency of nutrient removal processes can be improved by using aerobic granular sludge in ways that allow high conversion rates and efficient biomass separation to minimize the reactor volume.

Further studies will be focused on improving the removal efficiencies of nutrients in aerobic granular SBR systems adopting different feeding and aeration strategies.

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