

Technologies for Pollution Control

Biological Processes

KEYWORDS: Biological Treatment / Aerobic Granular Sludge / Sequencing Batch Reactor / Wastewater Treatment

Aerobic granular sludge (AGS) technology operated as a sequential batch reactor (SBR) was successfully applied to the treatment of low-strength wastewater (municipal effluent) and the co-treatment of high-strength wastewater (leachate) with low-strength wastewater (municipal effluent).

Introduction

For over a century, conventional activated sludge (CAS) processes have been at the forefront of wastewater treatment, renowned for their cost-effectiveness and low environmental impact. However, certain drawbacks persist, mainly: (i) the demand for high implantation areas due to the use of multiple treatment units for nitrification, denitrification, and sedimentation of biological sludge, (ii) the elevated cost associated with piping and pumps for effluent/sludge recirculation, and (iii) heightened sensitivity to abrupt variations in pollutant concentrations. Additionally, addressing refractory organic matter, high ammonia content, heavy metals, and other inhibitory substances in high-strength effluents, such as landfill leachates, poses a significant challenge for biological processes. In response to these limitations, several innovative biological treatment solutions have emerged as alternatives to CAS, such as membrane bioreactor (MBR), moving bed biofilm reactor (MBBR), integrated fixed-film activated sludge (IFAS), and aerobic granular sludge (AGS). Within this project's scope, AGS was selected as the preferred alternative.

AGS is a relatively recent technology capable of carrying out almost all biological reactions (nitrification, denitrification, etc.) in a single system. Granules' layered structure, with an aerobic outer layer and anaerobic/anoxic core, enables the presence of diverse microbial populations without the need for support, allowing simultaneous removal of different pollutants in a single unit. Besides, its strong and compact arrangement provides higher tolerance to toxic pollutants and the ability to withstand large load fluctuations, as well as good settling properties and better water-sludge separation. Since AGS is still a recent technology, further studies are essential to explore its application to both low-strength and high-strength wastewater remediation. Accordingly, this project focuses on applying AGS to (i) the treatment of municipal wastewater and (ii) the co-treatment of landfill leachate with municipal wastewater.

Current Development

In the framework of this research project, an autonomous AGS prototype operating as a sequential batch reactor (SBR) was designed and assembled, as illustrated in Fig 1. The operational sequence featured five different stages: (i) filling (anaerobic, to select beneficial microorganisms for the granules); (ii) reaction (anaerobic, aerobic, anoxic); (iii) settling (<30-min, to washout the undesired fast-growing and floc-forming organisms); (vi) decanting; and (v) idling. The AGS-SBR system comprises the following key components: (i) two identical granular sludge reactors (GSR), each one having three discard points at distinct heights (for distinct volume exchange ratios); (ii) two feeding tanks; (iii) temperature, pH and dissolved oxygen (DO) controllers, for continuous monitoring; (iv) acid and base dosing pumps, for pH adjustment; (v) a thermostatic bath, to control the temperature of the GSRs; (vi) an air compressor connected

to a flow meter, to control the air flow entering the bottom of the GSRs through 8 porous stones; (vii) peristaltic pumps, to feed the effluent to the GSRs; and (viii) a programmable logic controller (PLC) connected to a computer. The PLC was used to control the cycle length and duration of each phase and to automate valves, pumps, stirrers, and controllers. Mechanical stirrers can also be used, if necessary, to promote the contact of the leachate with the biomass during the feeding step and, in the GSRs during the reaction step, to promote a homogeneous distribution of the leachate inside the reactor.

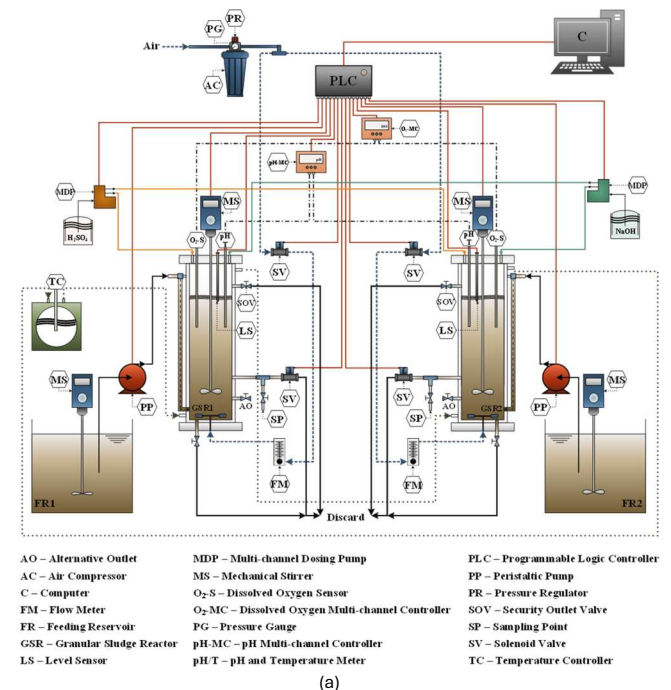


Fig 1. Schematic representation (a) and photographs (b) of the AGS-SBR system for wastewater treatment during idle (left) and reaction (right) phases.

As a first approach, the AGS-SBR technology was applied to the treatment of simulated municipal wastewater in close collaboration with the Federal University of Santa Catarina, Brazil. This study investigated the effects of the carbon-to-nitrogen (C/N) ratio on AGS using two identical biological reactors (C/N = 5 and C/N = 10). After 84 days of operation,

the reactors' organic substrate was switched from a simple synthetic carbon source (acetate and propionate) to a more complex carbon source (50% volatile fatty acids and 50% fermentable substrate). The C/N = 10 resulted in smaller, uniform granules ($200 < \text{Diameter}(D)(\mu\text{m}) < 500$) with improved settling characteristics (sludge volumetric index - SVI₅ < 30 mL gTSS L⁻¹), as displayed in Fig 2. The nitrogen compounds in the influent influenced the protein/polysaccharide ratio (PN/PS), with higher PS content observed under C/N = 5 and lower PS content under C/N = 10. Both C/N ratios achieved high carbon removal rates (~90%), but ammonia oxidation was lower under C/N = 5 (up to 45%) due to alkalinity deficiency. Insufficient alkalinity and higher nitrogen compounds in the influent negatively affected phosphorus removal by reducing the activity of phosphorus-accumulating organisms and promoting the growth of glycogen-accumulating organisms. The complexity of the organic substrate hindered microbial activities through intermediate products from glucose and amino acid metabolic pathways. EPS-producing denitrifying organisms (*Thauera* and *Xanthomonas*) were favored in C/N = 5, while at C/N = 10, organisms associated with granular biomass stability (*Zoogloea* and *Flavobacterium*) were selected. The addition of glucose in the effluent led to a significant increase in fermentative organisms (*Aeromonadaceae*). This study emphasizes the crucial role of the C/N ratio and organic substrate complexity in achieving optimal performance in AGS systems.

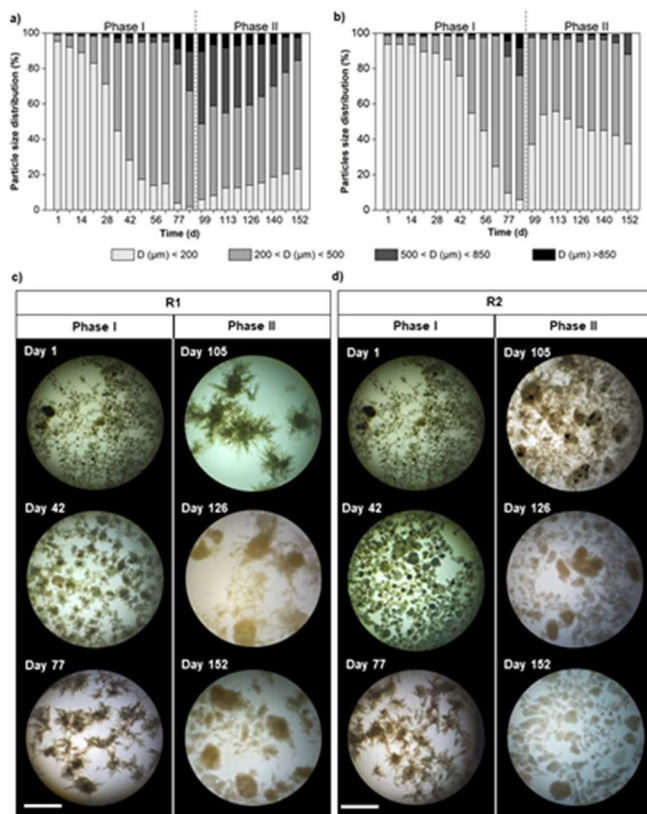


Fig 2. Particle size distribution and microscopic images during the experimental period in reactor 1-R1 (a and c) and reactor 2-R2 (b and d) during the two operational phases. Bar = 1 mm.

In a second approach, the AGS-SBR technology was employed for the co-treatment of a real landfill leachate,

which was collected downstream a leachate treatment plant after a coagulation process, with synthetic municipal wastewater, through a collaborative effort with the Federal University of Ceará, Brazil. This work was focused on the evaluation of the engineering and microbiological aspects of leachate co-treatment with sewage in step-feeding (R1) and conventional (R2) AGS systems. Initially, synthetic sewage with a gradual increase in the organic load for granule formation was used (Periods I and II). Subsequently, co-treatment with leachate pre-treated by coagulation-flocculation was carried out with 5% (Period III) and 10% (Period IV) concentrations. Finally, methanol supplementation was conducted as an attempt to improve nutrient removal performance (Period V). Based on the results obtained, the co-treatment in granular reactors was feasible. The best conditions were obtained in R1 during Period V with methanol supplementation. Step-feeding produced a more compact and resistant aerobic granular biomass, resulting in better operational stability. Moreover, this strategy favored denitrification, especially during methanol supplementation, minimizing one of the main problems reported regarding leachate co-treatment in AGS systems. As a result, higher total nitrogen (TN) removals were obtained. At the end of the last period, in R1, chemical oxygen demand (COD), TN, and dissolved organic carbon (DOC) removals were 93%, and phosphorus removal was 54%, reaching values higher or similar to other AGS investigations with sewage, leachate, or co-treatment. Thus, the strategies investigated unprecedentedly contribute to consolidating the domestic sewage co-treatment with leachate in AGS systems and providing a good perspective for other industrial wastewaters.

Future Perspectives

The AGS research will advance through a series of studies aimed at a comprehensive evaluation of different granulation methods for the co-treatment of coagulated leachate with synthetic wastewater: (i) conventional reactor vs. modified reactor with a Monera[®] biomedica; (ii) conventional feeding vs. feeding with saline pulses; (iii) conventional reactor vs. modified reactor operating under fill-draw mode. In addition, the research will explore the use of real leachate pre-treated by ozonation at different ozone doses, combined or not with real municipal wastewater.

Related Sustainable Development Goals



Outputs

PhD Theses

- [1] Jéssica Antunes Xavier, Granulação e estabilidade de lodo granular aeróbio desenvolvido em reator em bateladas sequenciais operado em diferentes condições operacionais, UFSC, FEUP, 2021
- [2] Vicente Elício Porfiro Sales Gonçalves da Silva, Aerobic granular sludge system optimization strategies for landfill leachate treatment and co treatment with domestic sewage, UFC, FEUP, 2023

Selected Publications

- [1] P.J. Reis et al., J. Hazard. Mater. 358, 310 (2018)
- [2] J.A. Xavier et al., J. Water Process. Eng. 40, 101917 (2021)
- [3] V.E. Silva et al., Environ. Sci. Pollut. Res. 29, 45150 (2022)
- [4] V.E. Silva et al., Chem. Eng. J. 470, 144178 (2023)
- [5] J.A. Xavier et al., J. Environ. Chem. Eng. 11, 110457 (2023)

Team

Vítor Vilar Principal Researcher; Tânia Silva Junior Researcher; Jéssica Xavier, PhD Student; Vicente Silva, PhD Student; Sara Santos, PhD Student

Funding

FCT/CAPES Transnational Project, DRI/CAPES 5431, 2019-2020

LSRE-LCM Base Funding, UIDB/50020/2020, 2020-2023

LSRE-LCM Programmatic Funding, UIDP/50020/2020, 2020-2023

LA LSRE-LCM Funding, UID/EQU/50020/2019, 2019

LA LSRE-LCM Funding, POCI-01-0145-FEDER-006984,2013-2018

FCT Grants: CEECIND/01317/2017, CEECIND/01386/2017

FCT Scholarships: 2020.04970. BD

Other Scholarships: CNPq: 140878/2017-3, CAPES:

88887.624997/2021-00