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### ► **To cite this version:**

Sidonie Durieux, Y Bessiere, Etienne Paul. Modeling EPS recovery: from bacterial production to reactor extraction, using SUMO software. WRRMod 2021, Aug 2021, Arosa, Switzerland. ⟨hal-04794923⟩

**HAL Id: hal-04794923**

**<https://hal.science/hal-04794923v1>**

Submitted on 21 Nov 2024

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## Modeling EPS recovery using SUMO software: from bacterial production to reactor extraction

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**Keywords:** Granules, EPS production and recovery, modelling, SUMO

### Introduction

EPS valorization has recently been considered as one of the most promising ways to recover resources from wastewater treatment (van der Hoek et al., 2016). The number of Nereda plants is constantly increasing (“Nereda® Plants,” n.d.), and EPS present various properties such as gelling (Lin et al., 2015; Seviour et al., 2009), and flame-retardant properties (Kim et al., 2020). Netherlands is even already commercializing EPS under the brand “Kaumera”.

The strategy of EPS production should be questioned. Which population should be favored for the production of EPS? The gelling EPS ‘granular’ discovered by Seviour et al. (Seviour et al., 2010) has been shown to be present in the *Competibacter*-enriched granules only, whereas they were absent from the *Accumulibacter*-enriched granules and denitrifying granules (Seviour et al., 2011). It was taken as model EPS in this study. Can the EPS be extracted in the outlet or is it necessary to purge granules? The latter option will lead to a change of SRT. Following, the SRT can influence the dominating populations in the granules (Pronk et al., 2015), the EPS proportion (Rollemberg et al., 2020), and a long SRT can lead to destabilization of the granules (Franca et al., 2018). Thus, in the aim of modelling EPS production, it seems important to be able to model these granular removals, and their effects on the granule composition.

Although the different aspects of granular sludge process have been abundantly studied using modelling (Baeten et al., 2019), the EPS production has been let apart so far. This study aims at modelling the EPS production process of ‘granular’ and in particular we focus on the impact of the anaerobic time on the EPS production, and on the effect of the removal of granules on the quantity of EPS collected.

### Methodological Approach

The SUMO software (Dynamita) was used in order to perform the simulations necessary to answer the different questions of this study. The bioprocess unit used was a granular SBR bioreactor. The diameter of the reactor was 15 cm, the working volume 17 L, the VER 0.5 and the granular bed height was of 20 cm, defining the fixed number of granules. In this unit, granules are considered as spherical objects of 1.5 mm with three layers of same thickness. Initial biomass can grow in this granule up to a maximum TSS concentration defined as the biofilm density multiplied by the dry matter content corresponding to 55000 g TSS/m<sup>3</sup>. Once the limit concentration is reached a TSS detachment process is activated towards the bulk. The diffusion rate of soluble compounds is reduced by a factor of 0.5 in the granules compared to the bulk, as set by default.

This model has been modified to control the concentration of MLSS in the bulk that settles as a proportion of the bulk concentration of particulates (proportion fixed at 90%). It has also been modified to allow the punctual removal of granular sludge, which, to our knowledge, has never been reported in modeling granular sludge SBR. The granule concentration will be decreased to a target concentration at the frequency set by the user, by a very fast removal process that is homogeneous inside all layers of granules.

The biological model used was the SUMO 2C model, including the calculation of EPS concentration as a calculated variable (Hauduc et al., 2019). The biological model was evaluated by comparison with measurements and proved to be satisfying. This EPS calculation has been modified for the EPS to be a fraction of the GAO instead of the whole biomass according to Seviour et al, 2011. In the calculations, the concentration of EPS was averaged for one cycle.

**Table 1:** Reference simulation main parameters

Cycle time (min)			Feeding composition (mg O <sub>2</sub> /L)				Ratios of feeding (mg/mg)	
Feeding	Anaerobic	Total	COD	VFA	S <sub>B,poly</sub>	X <sub>B</sub>	COD/N	COD/P
30 min	1 h	3 h	750	250	437.5	62.5	22	65
Initial composition of the sludge (g COD/m <sup>3</sup> )								
OHO	PAO	GAO	MEOLO	AOB	NOB	AMX	X <sub>U</sub>	X <sub>E</sub>
12.65	15.08	8.19	0.01	0.61	0.38	0.03	40.77	22.27

The simulations were performed on 100 days. Initially there was the same amount of biomass in the bulk and in the granular compartments with the particulate distribution that can be found in **Table 1**. There was no biomass in the feed. A reference simulation with the operating parameters of **Table 1** has been performed. The OLR was 3 kg COD/m<sup>3</sup>/d. Biodegradable particulate (including nitrogen) was introduced to simulate the presence of peptone, the rest of nitrogen was introduced as ammonium. The phosphorus was introduced as phosphates.

**Table 2:** Simulations performed and the varied parameters

Study on the anaerobic time							
Simulation number	1	2	3	4 (ref)	5	6	7
Anaerobic time (min)	0	30	45	60	75	90	120
Study on the discharge							
Simulation number	8	9	10	11	12		
Target concentration (g TSS/m <sup>3</sup> )	49500	44000	41250	38500	33000		

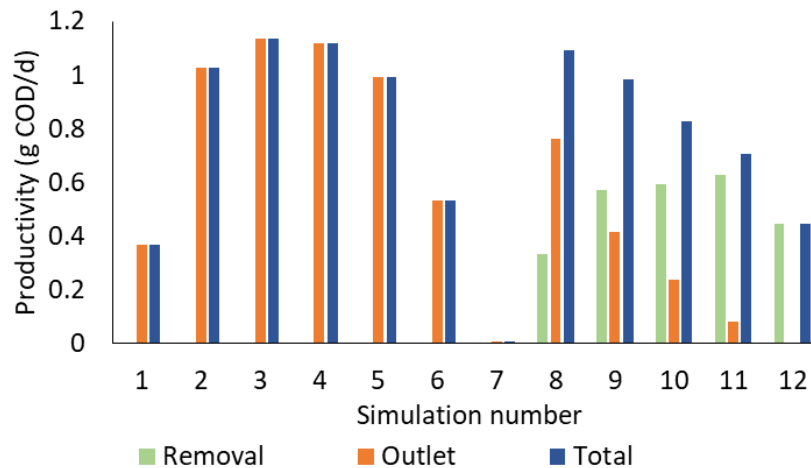
The effects of the anaerobic time on the EPS productivity was observed in seven simulations, and the effects of granule removals performed every second day were observed through five simulations (**Table 2**).

## Results and Discussion

The **Figure 1** represents the daily EPS production at 100 days, in total, and detailed by hydraulic and granular purge for all the simulations. This figure allows to compare the efficiency of each scenario in terms of EPS production.

The reference simulation is simulation 4. The parameters of this simulation were defined according to an experimental reactor, with 60 min anaerobic time. On **Figure 1**, one can see that the EPS productivity of this simulation is of 1.1 g COD/d, with EPS representing 3% of the total VSS in the outlet. All of these EPS are recovered in the hydraulic purge, thus in slow settling biomass, which may affect the recovery of

these EPS. In this simulation, GAO became dominant over PAO around 50 days in the exterior layer. As one could expect, the EPS in the outlet increased with the concentration of GAO increasing inside the reactor due to detachment of the outer layer.



**Figure 1:** Comparison of the productivity in EPS induced by different anaerobic time imposed and different granule removal strategy.

In the same **Figure 1**, the results of the simulations performed with different anaerobic time (simulations 1 to 7) are presented. It was observed that increasing the anaerobic time up to 45 min increased the EPS productivity from 0.37 g COD/d to 1.135 g COD/d. In simulations 1 to 3, the increase in EPS productivity is driven by an increase in GAO concentration, due to higher formation of glycogen. The storage-ability of GAO give them an advantage over the OHO. The longer the anaerobic period, the higher this advantage. For longer anaerobic times, the concentration of GAO at 100 days decreases, due to a higher concentration in PAO, which consume the main COD sources. When the anaerobic time was increased further to 2h, the GAO could not develop, because the glycogen was only very partially consumed during the aerobic period.

One can see on **Figure 1** that in all the studied scenarios with removals, the total EPS productivity was inferior to the reference simulation. The EPS productivity decreases from simulation 8 to 12 from 1.0 g COD/d to 0.45 g COD/d. In the meantime, the VSS productivity remain similar in all simulations, around 20 g VSS/d. In the reference simulation, GAO benefit from a higher SRT than PAO, due to a higher growth in the middle layer. PAO only grow in the exterior layer and get detached. When homogenous granule removals are performed, GAO lose this advantage and their SRT decreases, their growth is slower. PAO grow faster in this case because of advantageous biological parameters, and the EPS concentration and productivity decreases. In simulation 12, the removals are so important that the maximum TSS concentration in the granule is never reached and detachment never triggered, explaining the absence of productivity via the outlet.

## Conclusion

The EPS productivity has been studied through different simulations. First, it has been shown that the optimum anaerobic time is around 45 to 60 min, given the highest EPS productivity. Then, for simulations with granules removals, the EPS productivity

was found lower than the one of the reference simulation, given the homogeneous decrease in SRT inside granules. However, a frequent removal of granule could facilitate EPS recovery as well as granular sludge stability. In addition, the content and quality of the EPS in the outlet is still to be studied.

Challenges remain to fully understand the EPS production process. First, the EPS model should be further improved, to consider the EPS as a state variable. Secondly, the SUMO model should be compared with what is observed in reality by testing of strong hypothesis and calibration with experimental data. It seems that those challenges are of high importance to help moving further and faster towards the valorization of gelling EPS.

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