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MATHEMATICAL MODELING TO OPTIMIZE CONTROL STRATEGIES IN AN INDUSTRIAL BIOTRICKLING FILTER FOR BIOGAS SWEETENING

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Biological Treatment of Pollutants: Gases and Odors

INTRODUCTION

Burning biogas in a combined heat and power (CHP) plant is a promising option to reduce the emissions and the operational cost of wastewater treatment plants (WWTP). However, the biogas generated in anaerobic digestion facilities in WWTPs contains average concentrations of hydrogen sulfide (H_2S) in the range from 0.1 to 0.5 vol.% which has to be removed to avoid corrosion, unnecessary production of by-products, and SO_2 emissions. In a biotrickling filter (BTF), the H_2S is absorbed and removed in a packed column where biomass is immobilized, being a liquid phase continuously recirculated from the bottom of the reactor.

Advances in mathematical modelling of biofilters have allowed improving the knowledge of the phenomena and interactions involved in the biological desulfurization of biogas (Almenglo et al. 2013). The main limitation for the long term operation of BTF in biogas sweetening is the accumulation of elemental sulphur due to oxygen mass transfer limitations. Apart from reducing the removal efficiency, this accumulation increases pressure drops, thus increasing the operation cost to blow the air through the bed and, consequently forcing frequent maintenance tasks to replace or wash the packing material.

MATHEMATICAL MODEL OF BIOTRICKLING FILTER

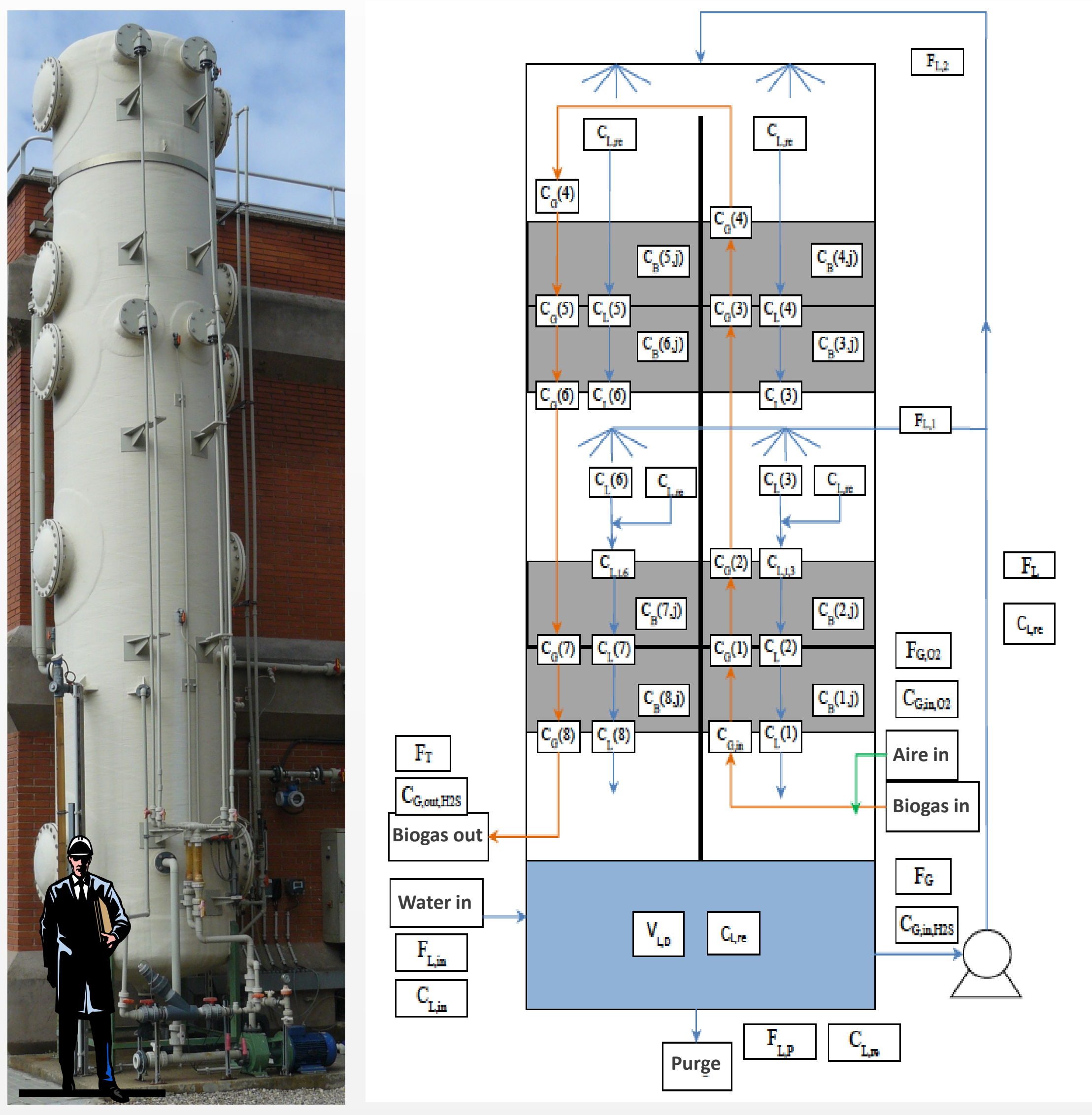
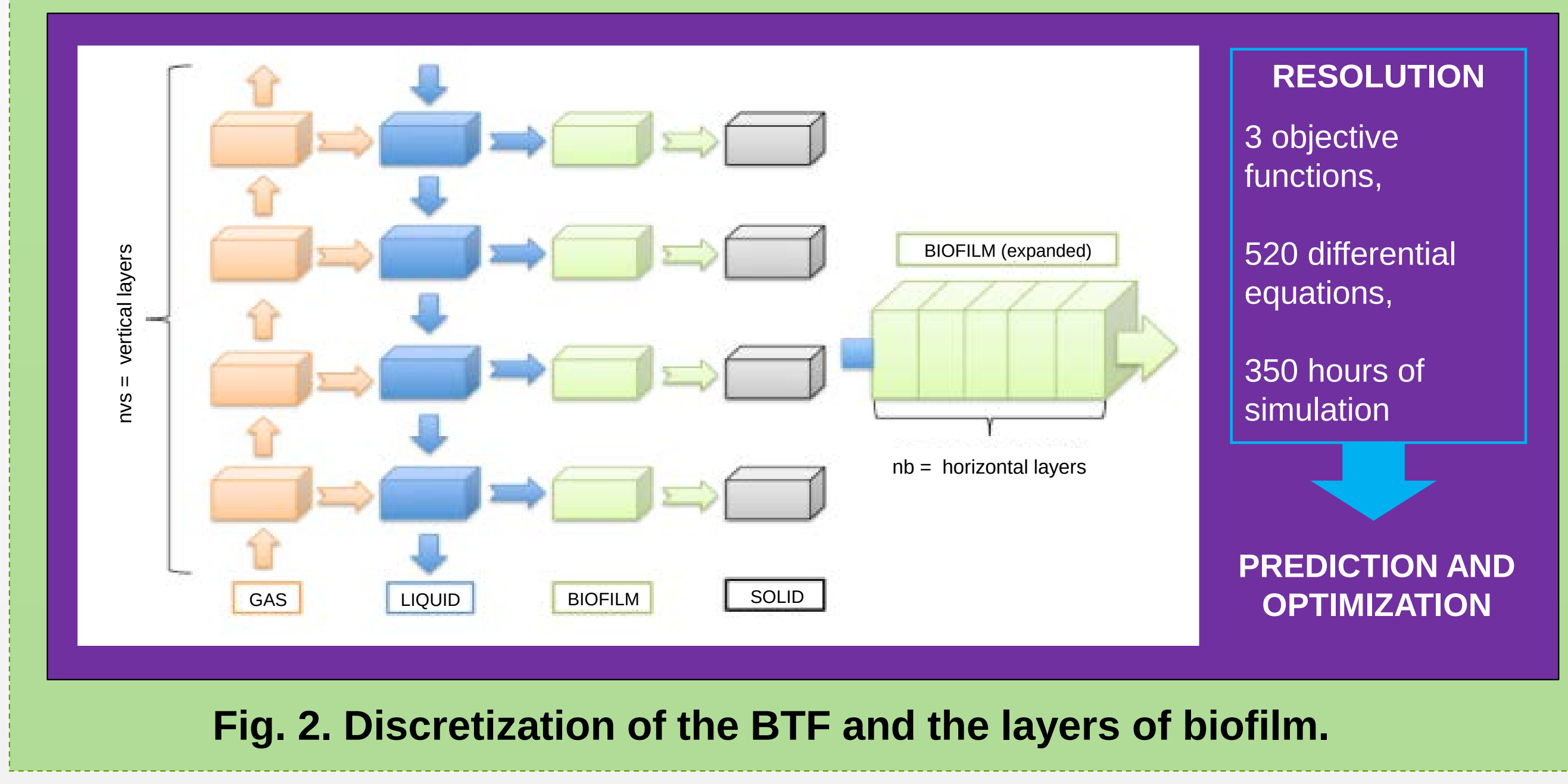


Fig. 1. Details of the industrial BTF.

Rodriguez (2013) developed a **mathematical model that describes the behavior of a BTF for the H_2S removal located in the WWTP of Manresa** (Barcelona). The model was calibrated and validated with experimental data obtained firstly in a lab-scale pilot plant, and then in the industrial BTF facility (figure 1).

Modelization: A set of **differential equations that describes the behavior of the biofilter** depending on the change in the variables over time (t), the height of the reactor (z) and the depth of the layers (x) that compose the BTF.

- The height of **the BTF is divided into nvs layers** (figure 2) for each phase (gas, liquid, biofilm). In these layers is evaluated transfer H_2S and O_2 in the liquid phase, the liquid phase diffusion and reaction in biofilms.
- **The biofilm is divided horizontally into layers nb**, in order to describe the concentrations profile (figure 2).
- **Assumptions for modelling are described in figure 3**.



RESOLUTION

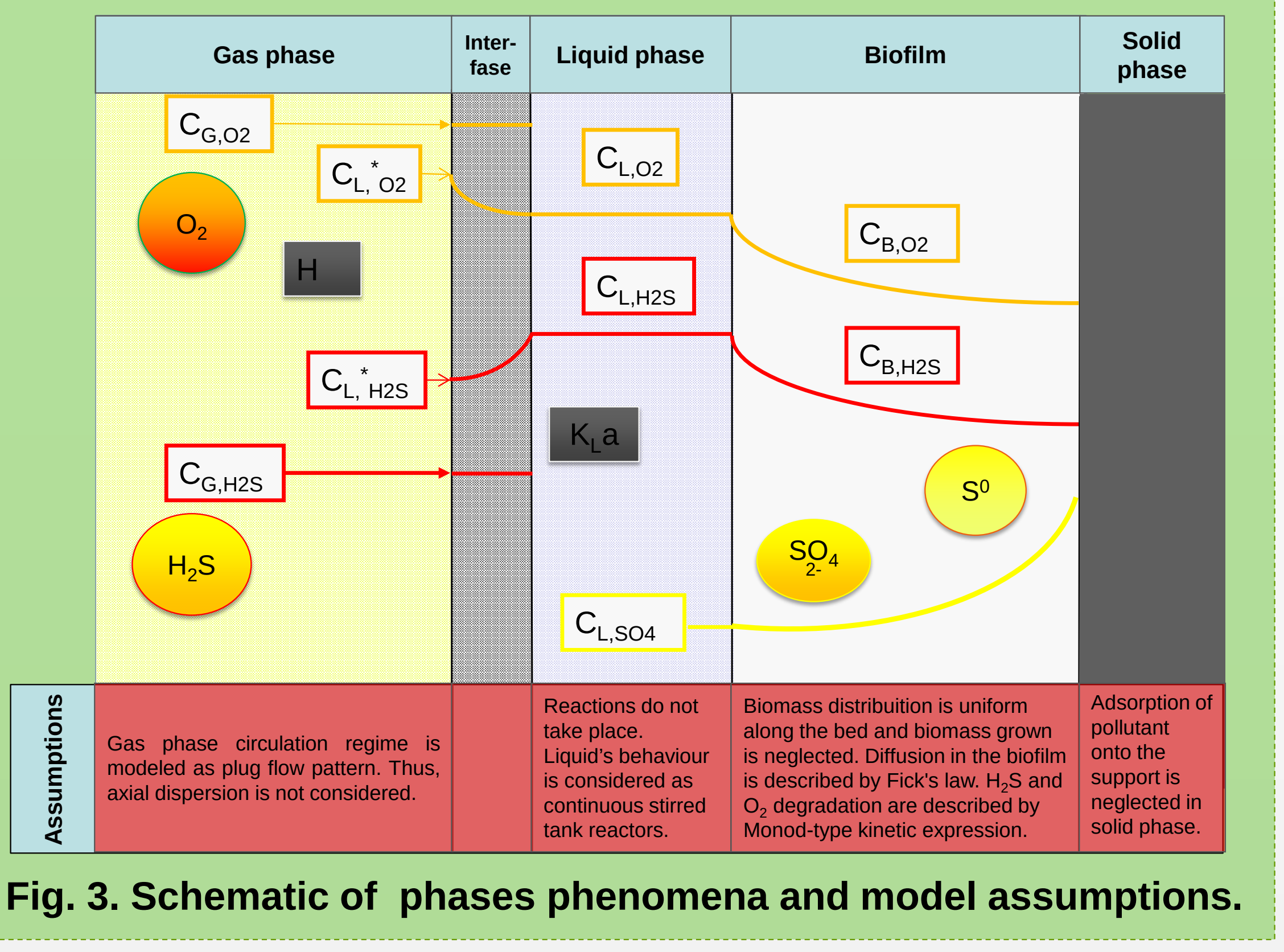
3 objective functions,

520 differential equations,

350 hours of simulation

PREDICTION AND OPTIMIZATION

Fig. 2. Discretization of the BTF and the layers of biofilm.



Gas phase circulation regime is modeled as plug flow pattern. Thus, axial dispersion is not considered.

Reactions do not take place. Liquid's behaviour is considered as continuous stirred tank reactors.

Biomass distribuition is uniform along the bed and biomass grown is neglected. Diffusion in the biofilm is described by Fick's law. H_2S and O_2 degradation are described by Monod-type kinetic expression.

Adsorption of pollutant onto the support is neglected in solid phase.

Fig. 3. Schematic of phases phenomena and model assumptions.

The main **differential equations (for H_2S element) which model the BTF** are shown below. In these equations, *i* indicates the modeled vertical layer of BFP from 1 to nvs, and *j* indicates the modeled biofilm layer horizontally from 1 to nb.

Gas phase

$$\left.\frac{dC_{G,H_2S}}{dt}\right|_{i=2}^{i=nvs} = \frac{F_T}{V_{G\_nvs}}\cdot\left(C_{G,H_2S}(i-1)-C_{G,H_2S}(i)\right)-\frac{K_{L,H_2S}\cdot a}{\varepsilon}\cdot\left(\frac{C_{G,H_2S}(i)}{H_{H_2S}}-C_{L,H_2S}(i)\right)$$

Liquid phase

$$\left.\frac{dC_{L,H_2S}(i)}{dt}\right|_{i=1}^{i=nvs,\ j=1} = \frac{F_L}{V_{L\_nvs}}\cdot\left(C_{L,re,H_2S}-C_{L,H_2S}(i)\right)+\frac{K_{L,H_2S}\cdot a}{\varphi}\cdot\left(\frac{C_{G,H_2S}(i)}{H_{H_2S}}-C_{L,H_2S}(i)\right)-\frac{a\cdot D_{H_2S}}{\varphi\cdot\delta_L}\cdot\left(C_{L,H_2S}(i)-C_{B,H_2S}(i,j)\right)$$

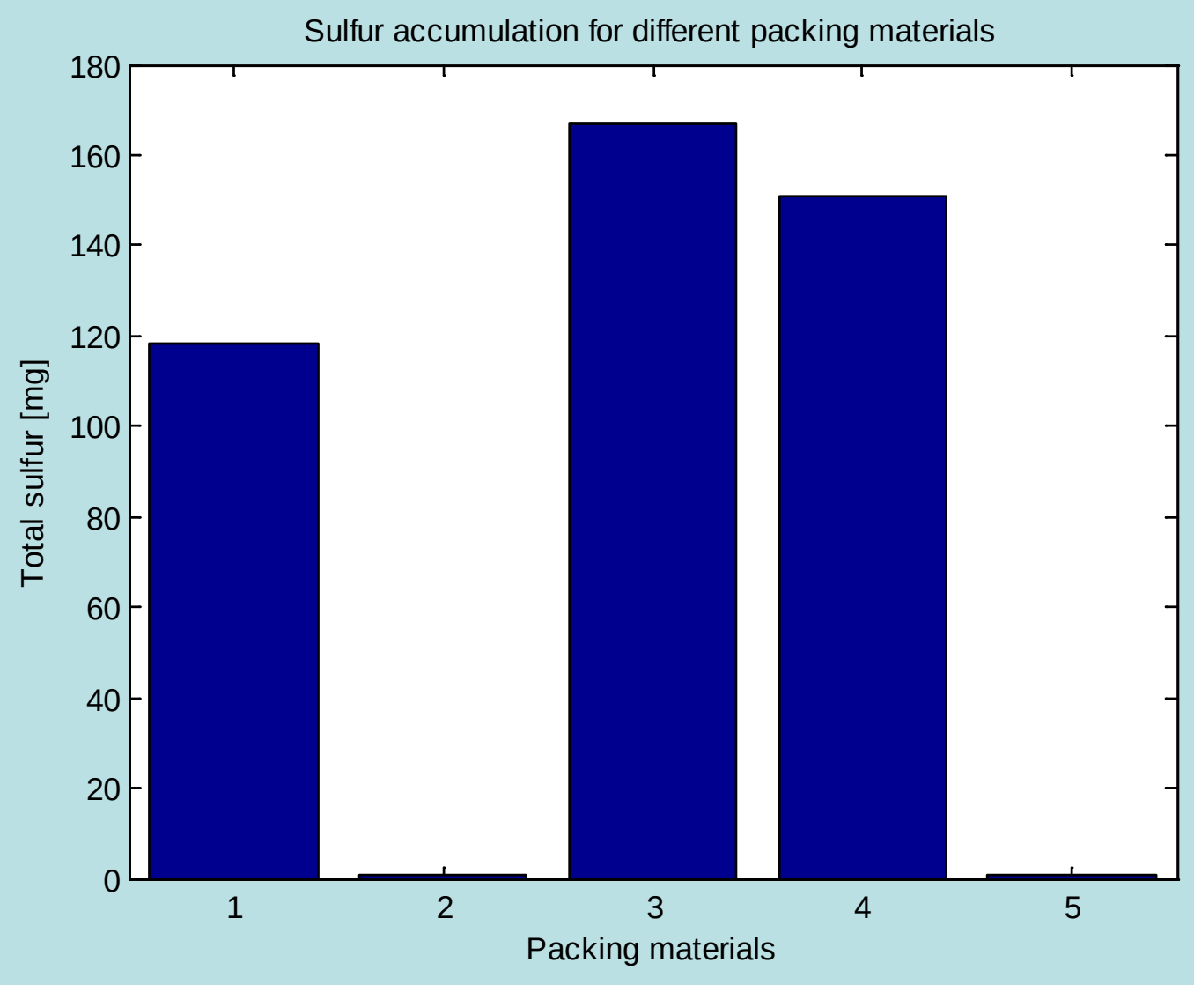
Biofilm

$$\left.\frac{dC_{B,H_2S}(i,j)}{dt}\right|_{i=1,\ j=2}^{i=nvs,\ j=nb-1} = \frac{D_{H_2S}}{\delta_{B-nb}^{\ 2}}\cdot\left(C_{B,H_2S}(i,j-1)-2\cdot C_{B,H_2S}(i,j)+C_{B,H_2S}(i,j+1)\right)-R_{B1}(i,j)$$

RESULTS AND DISCUSSION

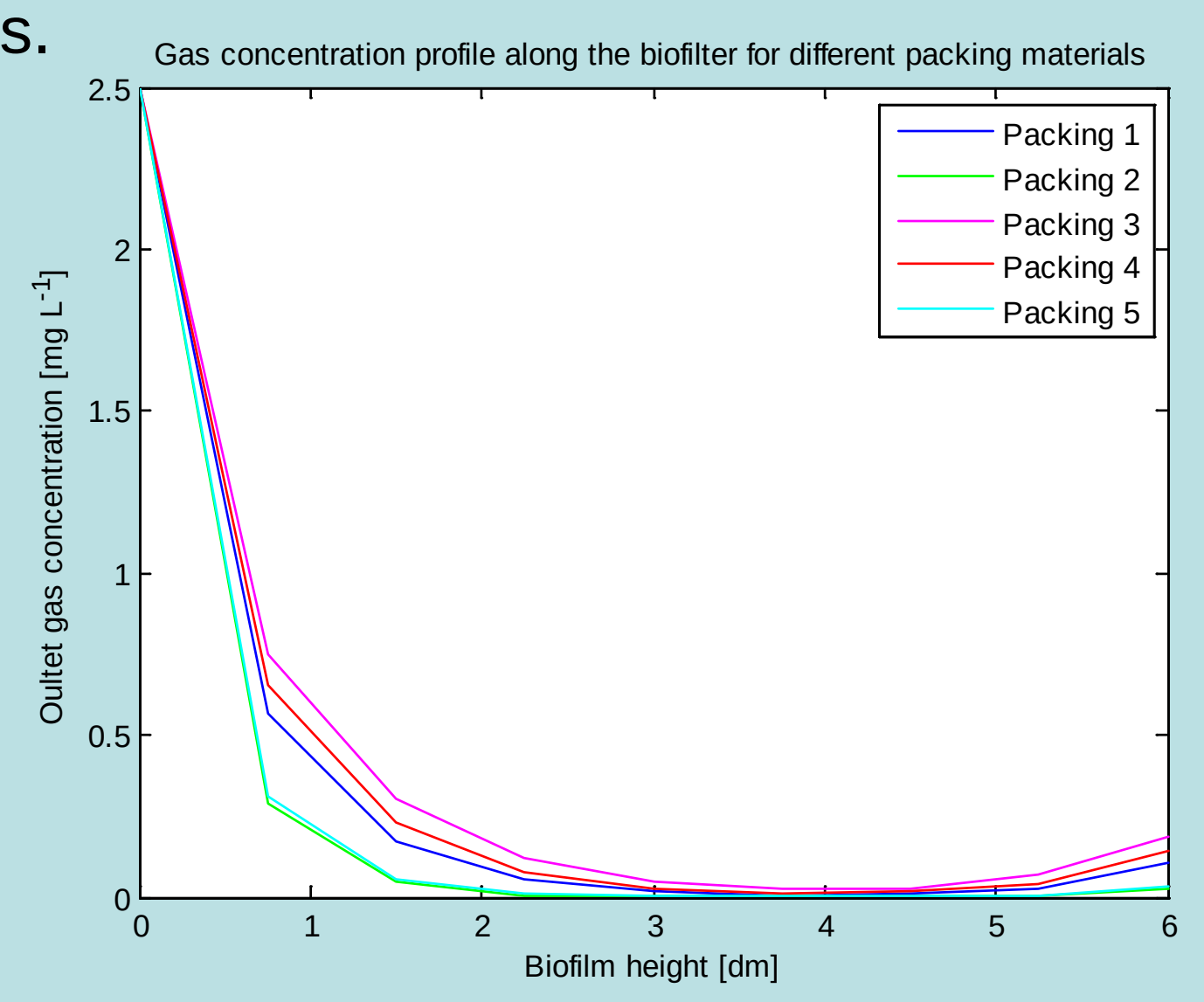
In the present study, the dynamic model developed and validated by Rodriguez (2013) has been used to evaluate different control strategies and optimize the performance of a BTF located in the WWTP. Particularly, the **use of different kind of packing materials (organic and inorganic) has been evaluated to determine in different operation conditions** which removal efficiency (RE) and sulphur accumulation could be expected, i.e time period of operation before the forced shutdown. Additionally, an **optimal distribution of different particle sizes of materials has been proposed** to reduce sulphur rate production, affecting minimally the abatement efficiencies currently obtained.

Next figure shows the **different sulfur accumulation predicted for the operation with 5 common packing materials** used in biofiltration. The area and then the porosity are the most influent characteristics affecting the performance. Therefore, R2 and R5 are the packing materials with lower sulfur accumulation.

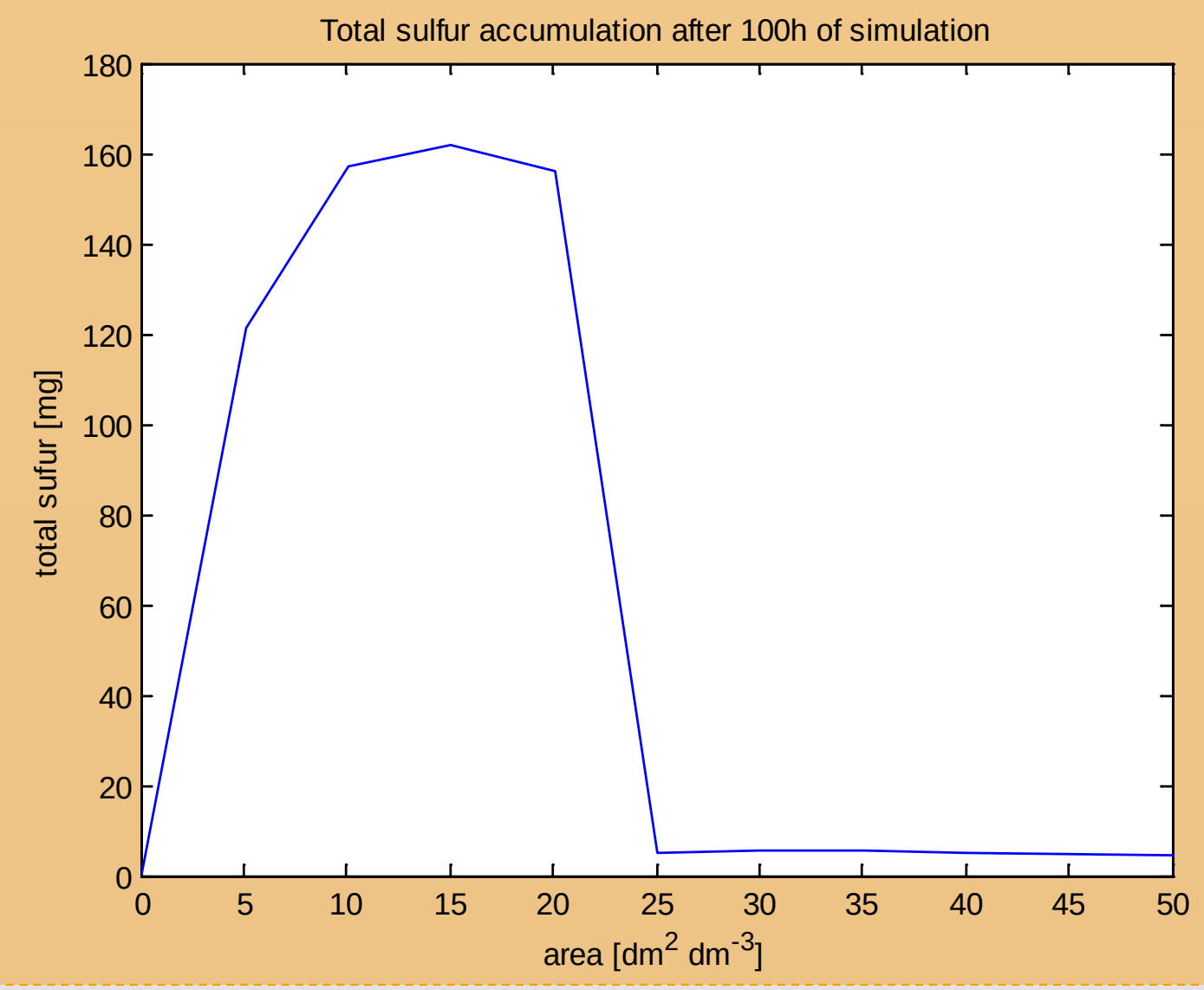


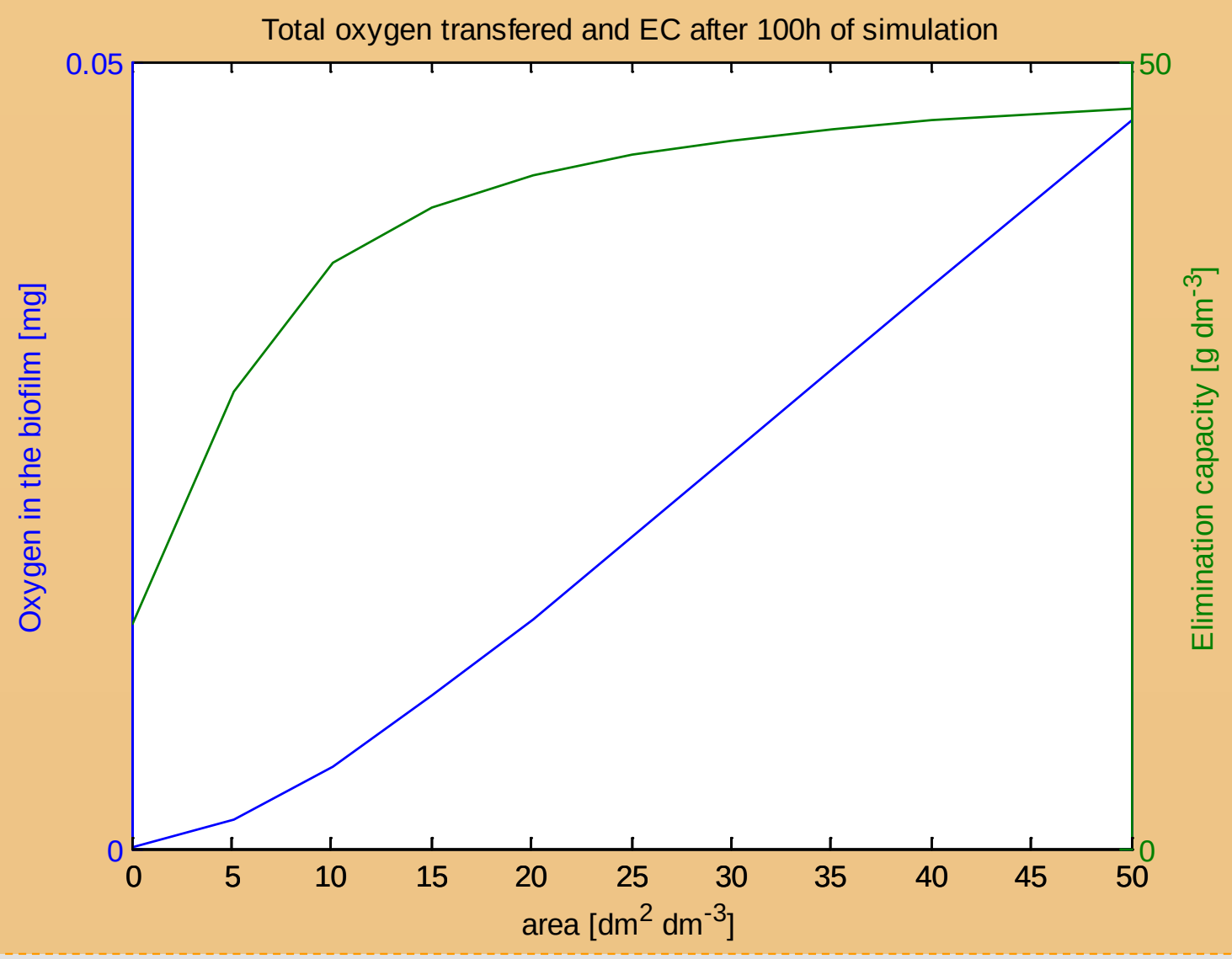
Following figure shows **the concentration profile of H_2S throughout the BTF**. The packing materials with large areas (R2 and R5) are those which remove more H_2S along the biofilter. Since R2 and R5 are the materials with lower sulfur accumulation, this configuration underlines a higher efficiency in the total oxidation to sulfate at higher contact areas.

Name	Type	Area (dm²/dm³)	Poro-sity
R1	PUF	60	0,92
R2	Clay pellets	137,57	0,38
R3	Lave Rock	37,69	0,50
R4	Dixon rings	152,45	0,74
R5	Plastic rings	48	0,92



Next figures show **the variation of the total sulfur accumulation and the oxygen in the biofilm depending on the area jointly with the corresponding elimination capacity (EC)**. We can see that more area (more biofilm), less accumulation of sulfur and, moreover, the oxygen transferred to the biofilm increases linearly with the interfacial area. With these two graphs, we can conclude that at area superior to 25 dm² dm⁻³ the complete oxidation to sulfate is favored.

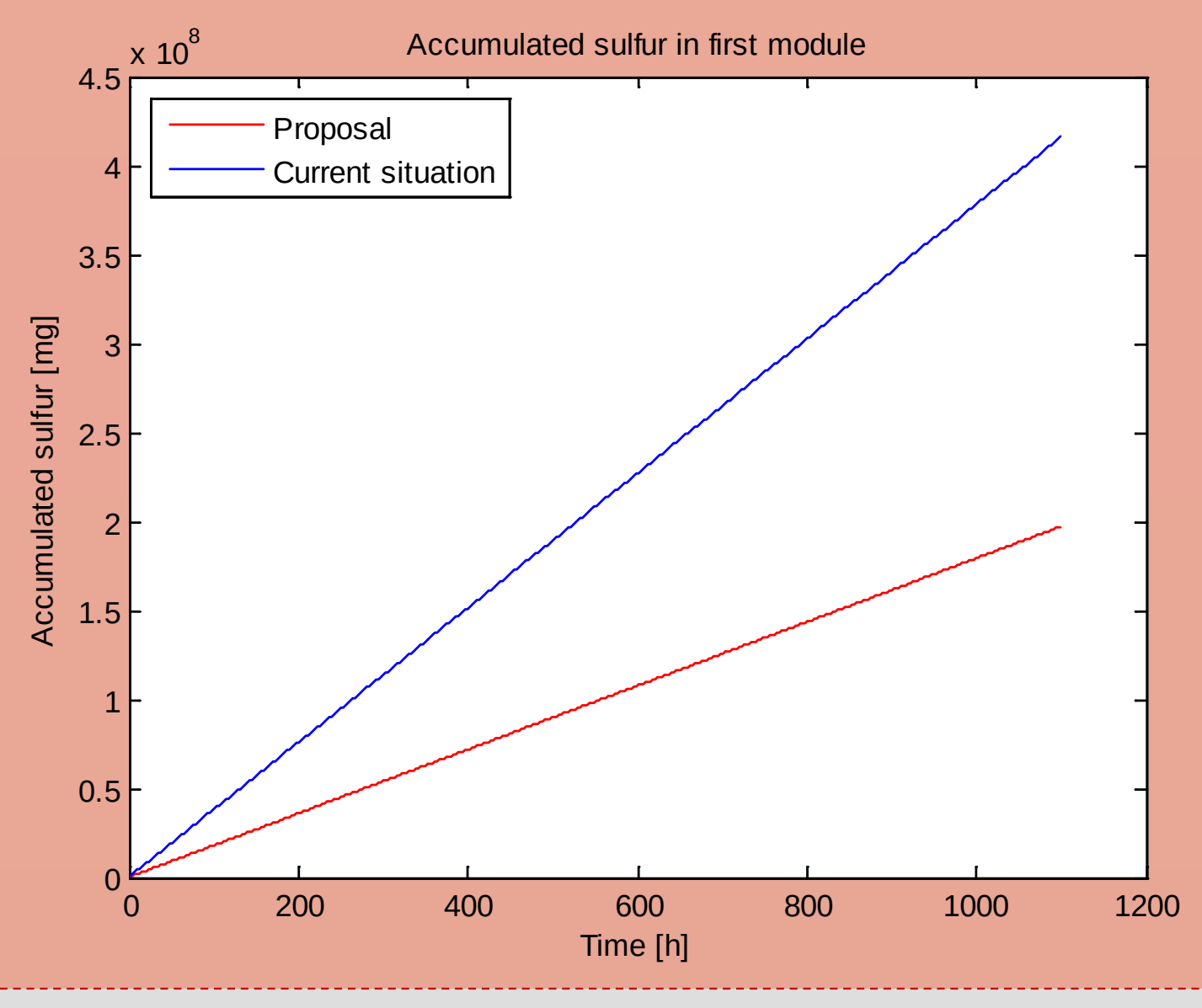


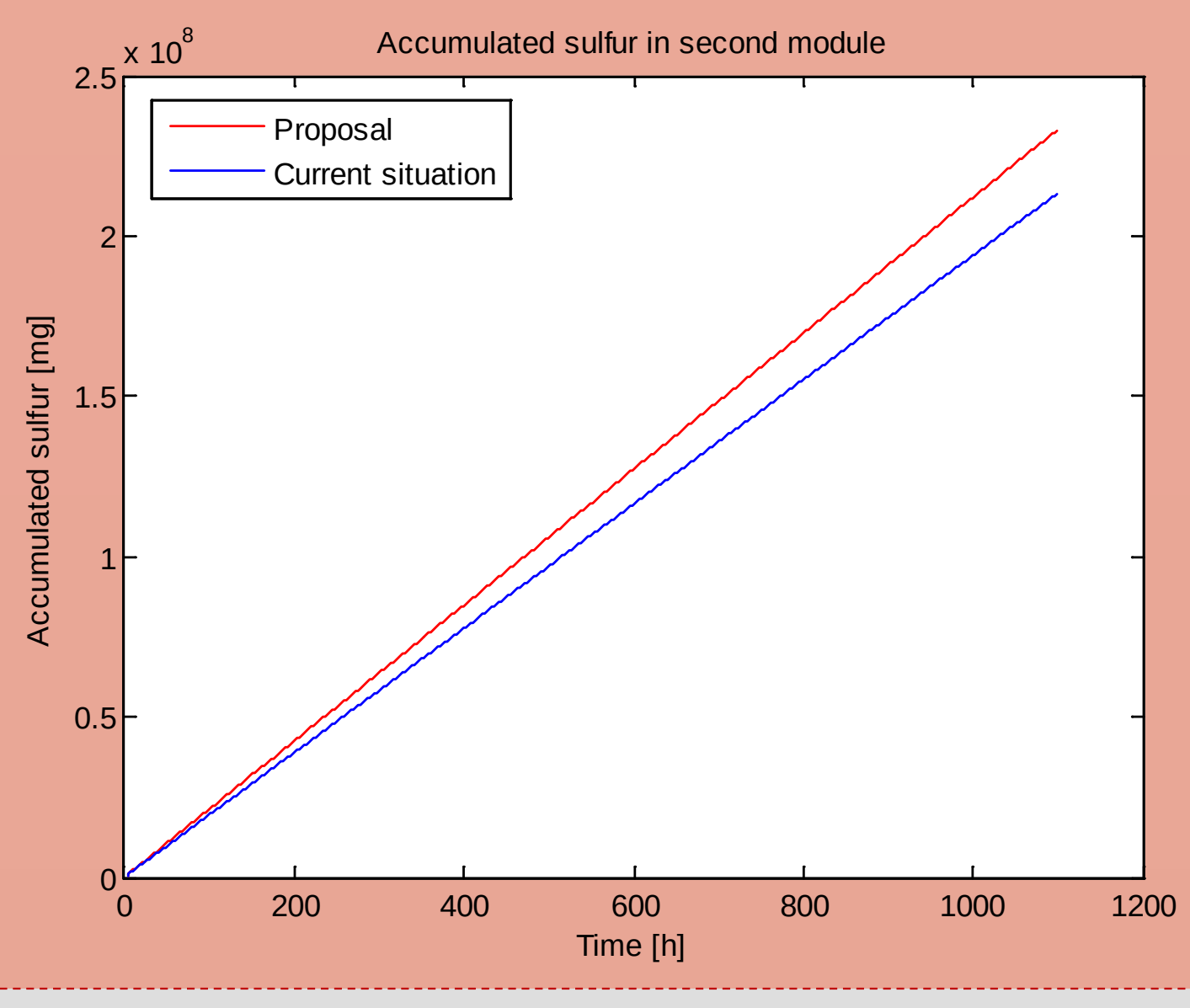


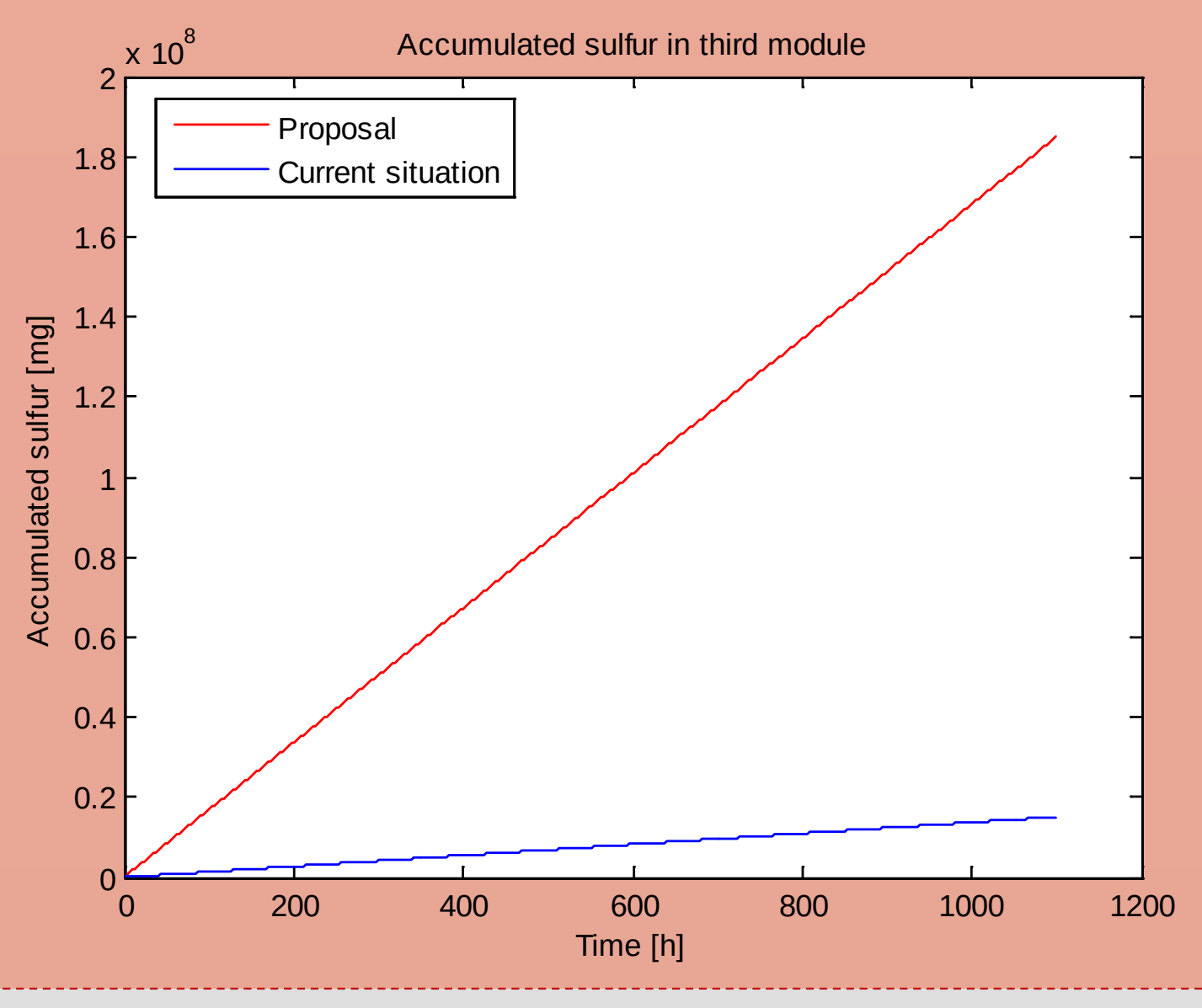
Figures below show the **amount of sulfur accumulated in each module of the BTF** at the current and proposed situation. Reducing progressively the areas of the packing material from the intel to the outlet, the first module reduces its activity and the other modules increases, comparing with the current distribution. With this new configuration, all the modules of the BTF present activity and the accumulation of sulfur remains distributed. Therefore, this change in the distribution of packing materials could reduce maintenance tasks and thus, duplicate the BTF operation lifetime. However, the EC is practically not affected by this change.

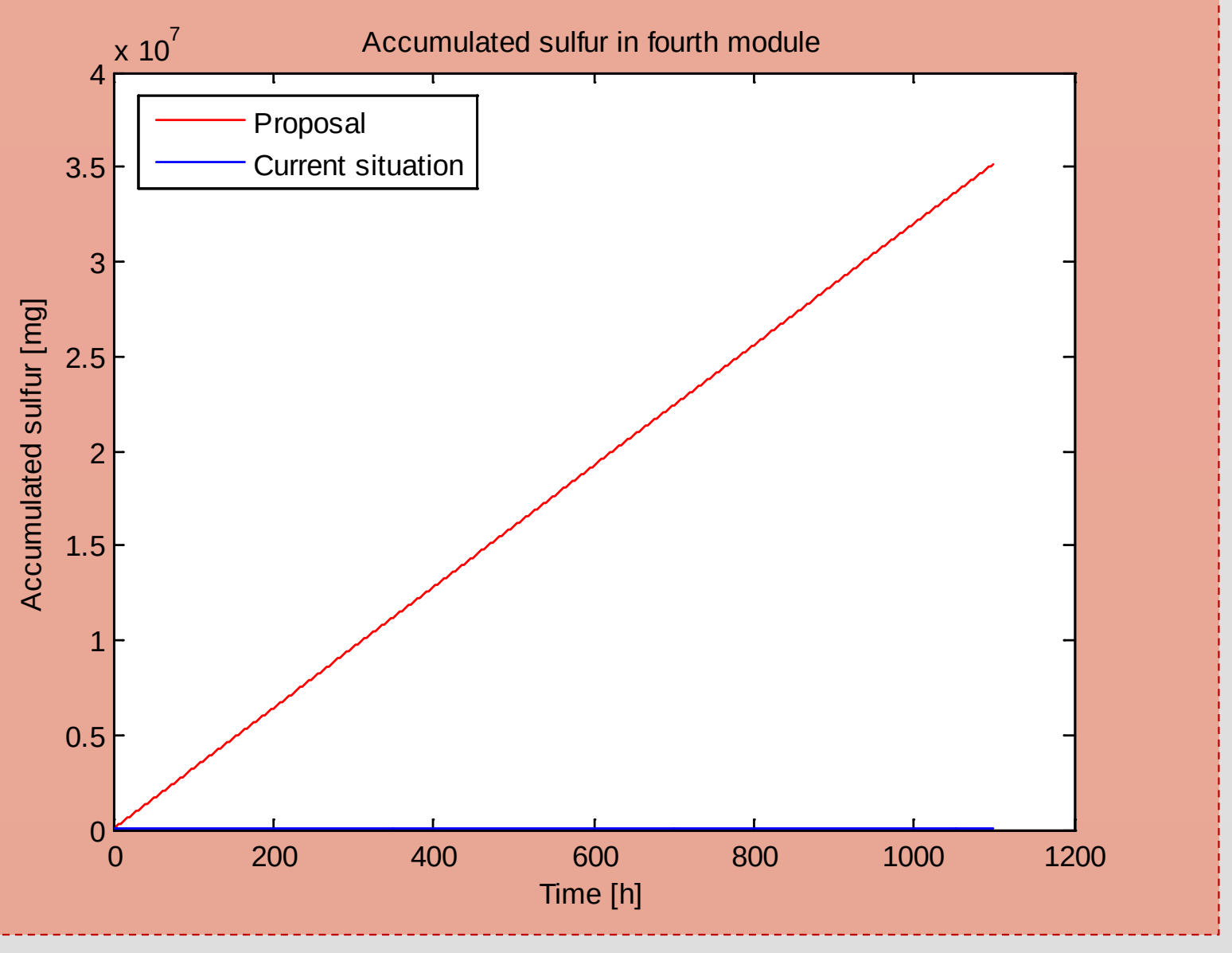
Module	Current distribution	
	Area (dm²/dm³)	Porosity
1	17,5	0,9
2	17,5	0,9
3	17,5	0,9
4	17,5	0,9

Module	Proposed distribution	
	Area (dm²/dm³)	Porosity
1	7,46	0,92
2	10,21	0,95
3	13,07	0,96
4	17,5	0,9









CONCLUSIONS

The proposed technique has proven its suitability to **study different strategies (without using a pilot plant)**, to **evaluate different operation strategies** and, finally, to **optimize processes.**

After evaluating different strategies with the BTF mathematical model, it can be concluded: the area of packing material is an influent factor in H_2S removal and the operating life of the BTF is extended if in each module of the BTF an appropriate contact area is selected.

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Almenglo, F. et al (2013). Modeling and control strategies development for anoxic biotrickling filtration. *Biotechniques for air pollution control and bioenergy,* pp. 123-131.

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