Technical Final Report

LIFE SEACAN

Reducing the pressure of fish canneries on the marine environment with novel effluent treatment and ecosystem monitoring

Authors: Celia Castro, Tamara Casero, Anuska Mosquera, Paula Carrera, Jesús Troncoso, Marina Gómez

Project Manager: Celia Castro
Area Manager: Alberto Sánchez

Affiliations: CETGAL, CETBCN, USC, UVIGO

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LIFE SEACAN

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Data Beneficiary

Name Beneficiary:	Fundación Centro Gallego de Investigaciones del Agua
Contact person:	Dr. Celia M. Castro Barros
Postal address:	Edificio Emprendia, Campus Vida, s/n 15782, Santiago de Compostela, Spain
Telephone:	+34 981525323
E-mail:	cmcastro@cetaqua.com
Project Website:	www.life-secan.eu

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List of abbreviations

AEC	Annual Equivalent Costs
AGS	Aerobic Granular Sludge
CAS	Conventional Activated Sludge
CBA	Cost Benefit Assessment
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
HSmix wastewater	High Strength mixed wastewater
LCA	Life Cycle Assessment
LSmix wastewater	Low Strength mixed wastewater
MBBR	Moving Bed Biofilm Reactor
NPV	Net Present Values
SALR	Surface Area Loading Rate
SARR	Surface Area Removal Rate
sCOD	Soluble Chemical Oxygen Demand
SRT	Solid Retention Time
tCOD	Total Chemical Oxygen Demand
TN	Total Nitrogen

2. Summary

Galicia (NW Iberian Peninsula) has one of the marine ecosystems with the highest levels of biodiversity of the world due to its unique conditions. Galician coastal areas are mostly an alternate series of *rías*, submerged valleys where the sea penetrates tens of kilometres inland. Southern *rías* (*Rías Baixas*) are rich in marine life, promoting fishing and aquaculture activities which account for 3% of Galician Gross Internal Product. In this sense, Galicia accounts for the highest production of transformed fish products in Europe and in some cases in the world (mussels canning), highly depending on such activities. Many industries in the *Rías Baixas* are dedicated to transform raw fish and seafood collected from the sea into products with higher organoleptic quality, longer shelf life and, ultimately, higher value-added products. However, their production process is characterized by high water consumption and the subsequent emission of large quantities of wastewater which demands adequate treatment.

LIFE SEACAN demonstrated the potential of two innovative biofilm-based technologies (aerobic granular sludge (AGS) and moving bed biofilm reactor (MBBR)) to **decrease the impact of industrial activity on marine ecosystems.** Biofilm-based systems have been successfully applied in several industrial sectors, but the application to fish canning effluents at a representative scale had not been reported until this project. The selection of the biofilm-based technologies for the treatment of fish canning wastewater was made based on their potential benefits in comparison to conventional treatments: reduction of energy consumption, improvement of the effluent quality, and lower footprint.

LIFE SEACAN prototypes were implemented in a representative fish cannery industry located in Galicia, where almost 80% of Spanish fish canning industries are gathered. The potential effects of industrial activity over marine environment were quantified and evaluated at two different locations in *Rías Baix*as (Ría de Muros and Ría de Arousa) with fish canning activity.

LIFE SEACAN demonstrated the flexibility, robustness and feasibility of biofilm-based technologies for the treatment of complex industrial wastewater. The main technical results showed high removal efficiencies for these technologies (80-90% for organic matter; 90% and 70% for nitrogen for low and high strength wastewater, respectively) and important advantages compared to conventional treatments: lower footprint (up to 70% lower), lower CAPEX (20-50% less depending on the load of the wastewater) and lower environmental impact.

Biofilm-based systems (AGS and MBBR) are promising technologies for the effective and efficient treatment of industrial effluents, with significant environmental and economic advantages. Thus, these technologies can contribute to meet more restrictive discharge limits imposed by future legislation in the industrial sector.

3. Introduction

Conventional wastewater technologies based on activated sludge systems are able to remove both organic matter and nitrogen. The convention activated sludge (CAS) process with denitrification technology is a popular system able to withstand moderate organic loads. Generally, a higher oxygen availability is required

in fish processing wastewater compared to other food processing wastewater. Aerobic technologies have the capacity of removing nutrients such as nitrogen, responsible for the environmental phenomena eutrophication. However, the limitation coming from the load organic loads which can be applied together with the low tolerance to the salinity makes the technology of activated sludge unsuitable.

The interest in saline effluent treatment processes, both for salt and organic matter removal, has been increasing rapidly over the last 20 years. Saline effluents are usually treated through physic-chemical means, as conventional biological treatment is known to be strongly inhibited by salt (mainly NaCl). However, physic-chemical techniques are energy and chemical-consuming and their start-up and running costs are high. Nowadays, alternative systems for the removal of organic matter are studied, most of them involving anaerobic or aerobic biological treatment based on biofilm technologies.

Biofilms are complex and coherent structure of cells spontaneously formed as large and dense granules or growing attached to a surface, which can be static or mobile. The implementation of biofilm-based systems increases the retention of biomass within the bioreactor, resulting in an improved volumetric conversion and easier separation from treated water. Organic matter and oxygen diffusion along the biofilm structure promote different environmental conditions and concentration profiles, allowing a more diverse bacteria consortium able to accomplish with different treatment pathways, i.e. nitrification and denitrification. The existence of a growth rate gradient stratifies the biofilm, promoting the inner development of slower-growing organisms well-protected from external shear forces and less likely to be lost due to detachment and/or wash-out. Therefore, there are different types of biofilm systems depending on several design aspects and process variables.

Case Study 1: Aerobic Granular Sludge (AGS) reactor

Industrial references using aerobic granules can be found in several countries, but none of these are focused on removing the pollutants present in the effluents generated in fish processing industries. Previous lab-scale studies about the stability of an aerobic granular reactor fed with wastewater from the seafood industry showed stable performance treating organic loading rates up to 4.4 kg COD/m^3·d with removal efficiencies of 90% in terms of nitrogen and organic matter with lower biomass production (reduction of 54% in comparison to conventional systems). Based on those previous experiences, a demo-scale AGS reactor was designed and built as SBR to promote the development of aerobic granules and to carry out a complete optimisation of the process variables.

Case Study 2: Moving Bed Biofilm Reactor (MBBR)

The use of biomass grown on carrier materials have been widely used for anaerobic treatment of different highly loaded wastewaters. However, the number of references using hybrid aerobic MBBR to treat industrial wastewater is scarce, and negligible in the case of fish canning industries. In case study 2, an aerobic process was developed in a packed bed reactor where biofilm grew attached to carriers, integrating an additional stage where suspended and fixed biomass coexisted. This innovative configuration provides high flexibility treating variable organic loads and excellent performance in terms of nutrient removal.

LIFE SEACAN is suitable for those industries whose activity relies on the sustainability and good status of marine environment but, however, are exerting significant pressure in the sea derived from its industrial activity.

As the main outcome, LIFE SEACAN provided a complete assessment of two innovative wastewater treatment technologies based on the use of aerobic biofilm reactors treating effluents generated in fish canneries. Different criteria and performance indicators were employed considering every possible aspect related to sustainability, including:

- Biodiversity analyses in the benthic ecosystem.
- Attenuation of disturbances related to effluent quality that influence patterns of benthic assemblages nearby to discharge points
- Energy consumption of the treatment processes
- Quality of treated effluent as a function of several indicators such as organic and nutrient content, pathogen load, pH, conductivity, etc.
- Knowledge on technical aspects of the two biofilm processes for their design and performance optimization
- Economic motivations and identification of possible constraints, based on a complete Cost-Benefit analysis
- Transferability of LIFE SEACAN to other industrial sectors and geographies
- Environmental performance in terms of Life-Cycle Assessment

LIFE SEACAN contributes to the achievement of EU policy with regard to Water Framework Directive and the challenges in the water sector through i) policy making, ii) technical solutions, iii) management solutions, iv) social responsibility. According to the legislation for the Food, Beverage and Milk industry, included in the new BREFs for this sector, LIFE SEACAN can contribute to achieve the new limits (stricter than the current ones) and to meet the new normative.

4. Technical results of the project

ACTION A1. Preliminary activities: characterisation of industrial effluents, selection of the prototype location and selection of the carrier material for biofilm development	
Objectives. • To validate baseline conditions of the existing technologies and selected effluent to be treated in terms of quality and quantity • To identify the optimal location where the prototype will be installed in order to perform the tasks described in the implementation actions • To select the most appropriate support material for the development of a biofilm	*Status:* Completed

A1.1. Data compilation of effluent characteristics and treatment systems

A bibliographic compilation was performed as well as a sample collection over fish canning industries in Galicia in order to determine the main characteristics of effluents generated. In total, 7 facilities were visited. Due to the secrecy of this industry in Galicia, it was impossible to achieve the goal of 10 visits and to provide the name of the visited industries. However, the facilities visited included most of the different types of fish canning wastewater, for which the data obtained was representative. Summarizing, the fish canning wastewater has high and variable COD concentrations (1000-20.000 mg/L) and extreme saline concentration (1 to 18 mS/cm). Accordingly, it was elucidated that conventional wastewater treatments are not suitable for these streams and alternative wastewater treatments, such as biofilm-based technologies (AGS and MBBR) are presented as promising innovative biological systems. This sub-action was finished in December 2015 and Deliverable D1 collects all the data performed regarding this task.

A1.2. Site selection

The plant finally selected had the following characteristics:

- Existing WW treatment: DAF
- Flow treated: 1,200 m^3/d
- WW composition: variable (the factory processes several raw materials)
- Other comments: Need for a change in the WWTP; wide experience in collaboration with other research projects

A1.3. Selection of the carrier material for the development of the attached biofilm

Three different carriers were tested at laboratory scale in order to choose the best option in terms of biomass attachment for the operation of the MBBR prototype. The tested carriers were Levapor, Mutag Biochip and Aqwise. Each carrier was tested for a month in a continuous reactor with a useful volume of 7 L and fed with fish canning wastewater. The specific conditions of the tests and detailed results were presented in the Mid-term report.

The summary of the results from the tests with the three carriers is shown in **Table 1**. Levapor was the carrier with a higher capacity to attach biomass, but no nitrifying activity was obtained during the operation of the reactor. The reason for this behaviour is the high specific area of this material, which created zones in the inside the carrier where the biomass was occluded and without access to the substrate.

Table 1 Summary of the operational results with the carriers Levapor, Biochip and Aqwise

		LEVAPOR	MUTAG BIOCHIP	AQWISE
	Time of operation (days)	31	36	47
	Filling ratio	12%	15%	30%
SOLID PHASE	$VSS/V_{carrier}$ (g/L)	6.48	6.03	4.1
	VSS/specific area (g/m^2)	**0.77**	**2.01**	**6.3**
	$VSS_{carrier}/V_{reactor}$ (g/L)	1.6	0.15	1.2
	$VSS_{effluent}/V_{reactor}$ (g/L)	0.72	1.12	0.48
	$VSS_{suspended}/VSS_{attached}$	**0.45**	**7.5**	**0.4**
LIQUID PHASE	COD removal (%)	85-90	85-90	85-90
	Nitrification	**NO**	**YES**	**YES**

Biochip presented nitrifying activity, but the attached biomass was low, representing a small percentage of the solid content in the reactor, therefore **Aqwise was selected as the best carrier to perform the experiments in the prototype**. Moreover, Biochip presented operational problems of flotation during the first days of operation, whereas Aqwise carriers did not give any operational problem.

ACTION B1. Prototype design and installation	
Objectives. • To design the prototype based on the requirements and needs of the selected site • To develop engineering, construction and installation of the prototype in the selected site • To automatize the prototype operation	*Status:* Completed

B1.1. Prototype design and construction

Prototype design was carried out with the leading of CETGAL and with the collaboration of CETBCN and USC. Two prototypes were designed and constructed: Aerobic Granular Sludge (AGS) and Moving Bed Biofilm Reactor (MBBR).

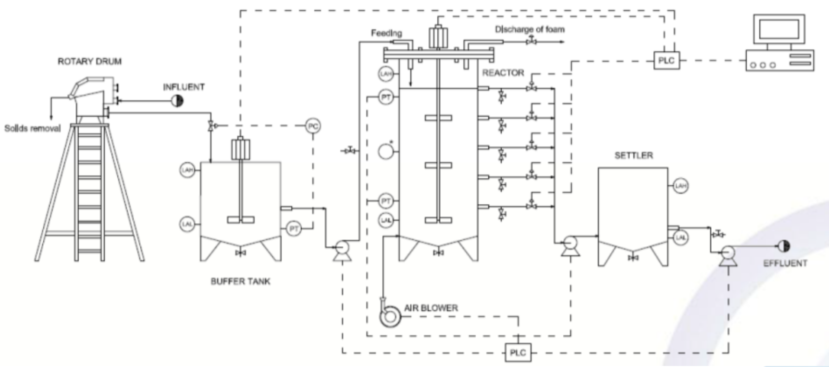

Figura 1 Configuration of the aerobic granular sludge prototype

B1.2. Definition of the prototype control system for automation

For each prototype, a control system was defined for the automation and optimisation of the prototypes. The details were presented in the Mid-term report.

The automation system for the AGS prototype was made taking into account a sequencing batch operation, for which the cycles were defined. The system was flexible to perform changes along in the operation due to the variability of the influent wastewater and to be able to assess different operational conditions.

The MBBR control and automation system was designed considering a continuous operation. The prototype has the flexibility to be operated as a MBBR or as an IFAS systems (if phosphorous removal is needed). Also, depending on the organic loading rate, the system could be operated with different number of tanks. A specific dissolved oxygen control system was established.

Both prototypes had remote control, enabling the control and modification of parameters from any location. Also, some parameters were online recorded (dissolved oxygen, pH, temperature, conductivity, flow rates).

B1.3. Prototype installation and performance verification

Both AGS and MBBR prototypes were at the fish cannery in November 2017. The AGS prototype was transported from Asturias (Spain), where it was constructed and the MBBR prototype was transported by ship from Israel by Aqwise.

This sub-action took more time than expected because it was necessary to carry out several works at the site: to fit the prototypes to the available space at the fish cannery, adapt and connect all the equipment including hydraulic and electrical installation, carry out hydraulic and automation tests (by USC, CETGAL and CETBCN).

ACTION B2. Prototype operation and integration of results	
Objectives. • To acquire experience about the two units (AGU and ABU) performance and their feasibility for the treatment of effluents from a fish cannery with the quality required for direct discharge to the sea	*Status:* Completed

AGS prototype

The development the AGS technology was performed first at lab-scale and then at pilot-scale. Following, a description of both operational periods is provided, focussing in the pilot-scale operation description.

AGS laboratory-scale operation

Due to the delay of the installation of the prototypes, an initial laboratory experiment was performed in a reactor of 1.7 L with wastewater from a fish cannery. The experiments had a duration of 226 days (October 2016-May 2017). The results and experience gained with this laboratory experimentation was useful to facilitate the start-up of the aerobic granular prototype. The detailed results of the laboratory experiments were presented in the Mid-term report.

The reactor use for the experiments was a Sequencing Batch Reactor (SBR), operated in two stages: i) operational cycle of 3 hours (days 0-92) and ii) cycle of 4 hours (days 93-226). Each cycle included a short feeding phase, an aerobic phase where the biological reactions take place, a settling stage and the withdrawal of the effluent. This operational approach was used later in the AGS prototype.

The average concentration of all the wastewater used in the laboratory reactor is shown in **Table 2**.

Table 2 Average influent wastewater composition for the AGS laboratory test

Parameter	pH	sCOD	TSS	VSS	NH_4^+-N	NaCl
Units	-	g/L	g/L	g/L	mgN/L	g/L
Value	6.82±0.71	1.20±0.41	0.20±0.04	0.14±0.03	90.25±21.30	9.03±3.55

Figure 1 shows the variability of the Organic Loading Rate (OLR) and Nitrogen Loading Rate (NLR) applied during the operation of the laboratory reactor.

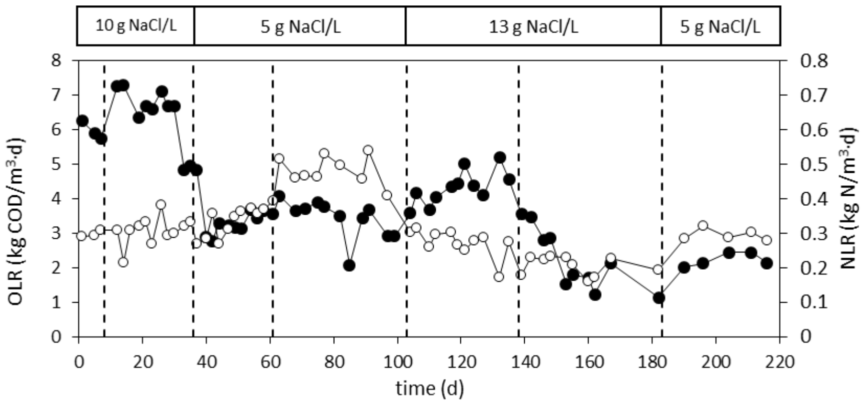

Figure 1 Organic Loading Rate (OLR, ●) and Nitrogen Loading Rate (NLR, ○) applied during the operation of the reactor. Each vertical line represents a change of the batch of wastewater

During the first 3-4 days of operation, the major washout of the biomass took place. Then the concentration started to increase up to 5.23 g TSS/L at day 13. The first granules appeared on day 22, with a particle diameter of 1.51 mm (**Figure 2**.a).

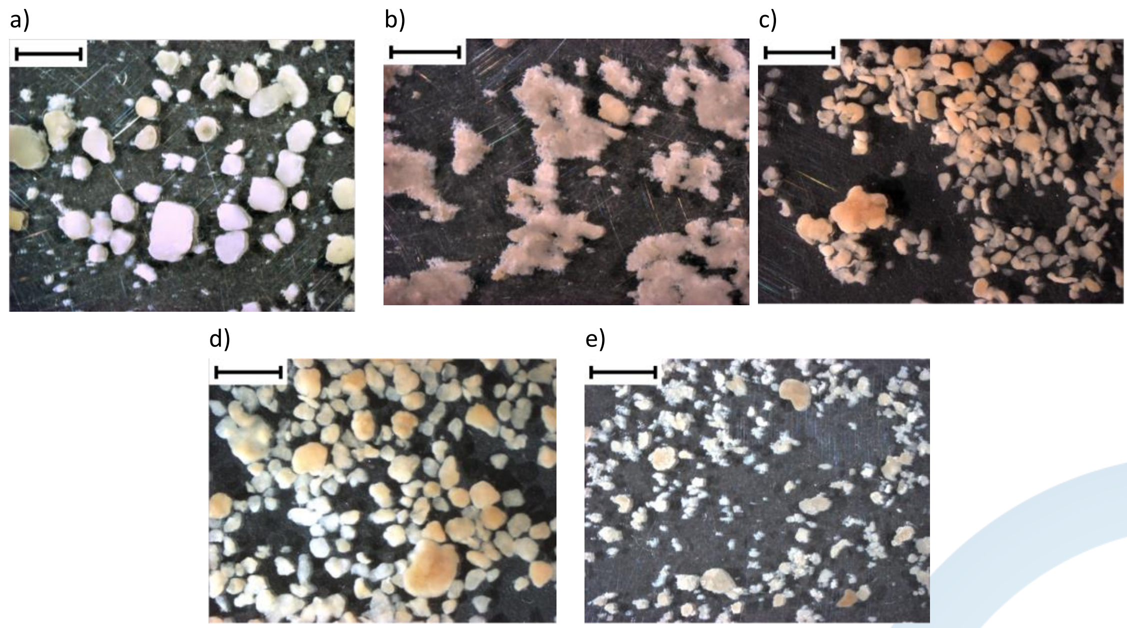

Figure 2 Images of the granules on day 22 (a), 43 (b), 147 (c), 197 (d) and 222 (e). The size bar corresponds with 2 mm

Once the settling time was reduced to 1 minute (day 22), the solid concentration increased up to 8.36 g TSS/L due to the accumulation of the biomass inside the reactor and the improvement of its settling properties,

which were in line with the diminishment of the SVI_5 to 56 mL/g TSS. It took 90 days to achieve a fully developed granular system. Until day 90 the biomass was characterized by a coexistence of flocs and granules with good settling properties.

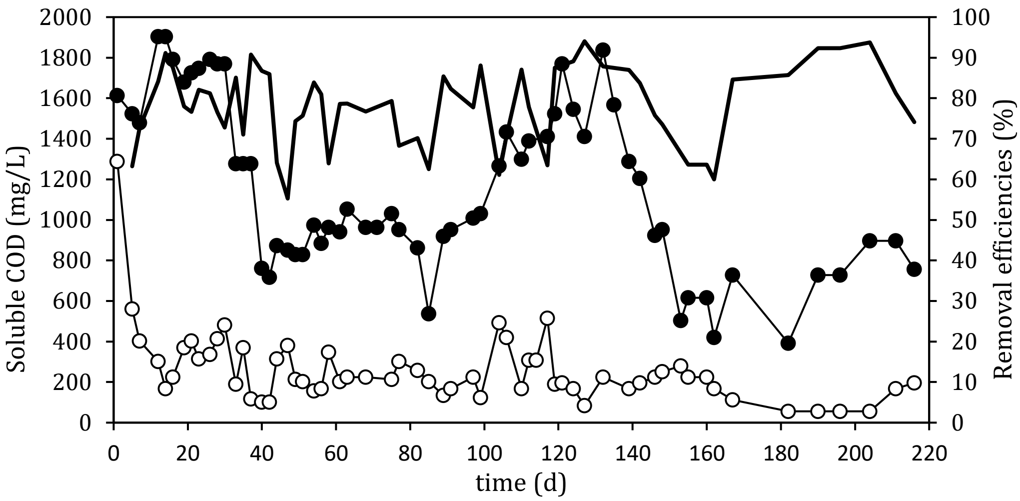

Figure 3 Profile of the soluble COD concentration in the influent (●), effluent (○) and COD removal percentages (–)

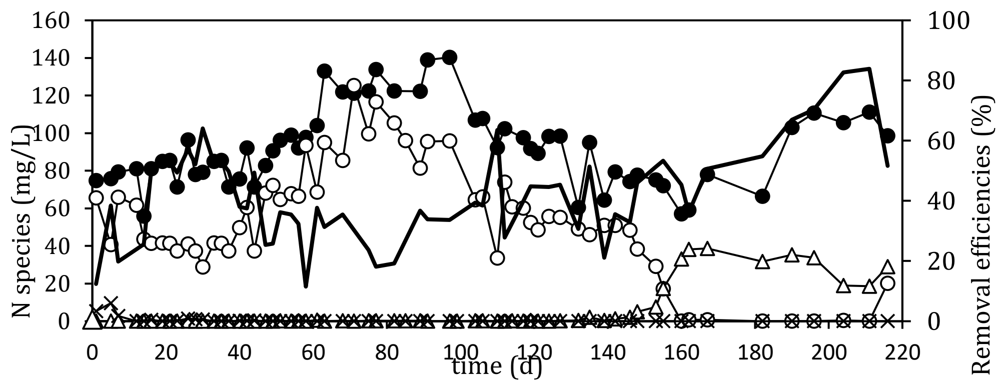

Figure 4 Profile of NH_4^+-N of the influent (●), NH_4^+-N (○), NO_2^--N (Δ), NO_3^--N in the effluent (x) and nitrogen removal (–)

The COD removal efficiencies were stable despite the changes in salinity and OLR, with values of 70-80% (**Figure 3**). The removal of nitrogen was low during the first period of the operation (**Figure 4**).Until day 150, the nitrogen removal was performed due to biomass assimilation, with efficiencies of 30-40%. After day 150, the sludge retention time was increased more than 10 days and the aerobic ammonium oxidizing bacteria started their activity, which can be shown in **Figure 4** with the accumulation of nitrite. In the end, the total nitrogen removal was of 80%. The average diameter of the granules was 1.35 mm on day 197 and the density was 206.32 mL $TSS/L_{granule}$.

In conclusion, after 90 days a full granular system was obtained with variable composition of the influent and at high NaCl concentrations. The salt content of the wastewater had an important impact on the size and density of the granules. High removal efficiencies in terms of soluble COD were achieved (80%) during the whole experiment and the nitrogen removal was improved up to 80% from day 150 onwards due to the oxidation of ammonia to nitrite and the denitritation processes taking place.

AGS prototype operation

The operation of the AGS prototype was divided in three stages. It was firstly operated from **March to May 2018** (Stage I), treating low-strength mixed (LSmix) wastewater with a useful volume of 2 m^3. After a stop due to a failure of the PLC, the prototype was operated from **October 2018 to March 2019**, treating LSmix wastewater with a useful volume of 3 m^3. Afterwards, it was operated from **May to October 2019**, fed with high-strength mixed (HSmix) wastewater. The different operational conditions of each stage are shown in **Table 3.**

The LSmix wastewater corresponds with the actual wastewater of the fish canning factory, which is the result from mixing low-strength wastewater (washing steps) and high-strength wastewater (fish cooking) with a proportion of approximately 96% of low-strength wastewater and 4% of high-strength wastewater. The HSmix wastewater used as feeding in Stage III was the result of mixing LSmix wastewater and high-strength wastewater, to avoid OLRs higher than 6 kg sCOD/m^3·d. The mixture corresponding to the maximum OLR applied during the operation of the prototype corresponded to a 50 – 50 % of LSmix and high-strength wastewater.

Table 3 Operational conditions of the AGS prototype in Stage I, II and III

OPERATIONAL CONDITION	STAGE I	STAGE II	STAGE III
Operation time (days)	63	163	178
Useful volume of the reactor (m³)	2	3	3
Feeding of the reactor	Low-strength mixed (LSmix) wastewater	Low-strength mixed (LSmix) wastewater	High-strength mixed (HSmix) wastewater
Cycle length (h)	3	3	6
Volume exchange ratio (VER, %)	37	50	40
Air flow (m³/h)	40	75	79
Superficial Gas Velocity (SGV, cm/s)	0.7	1.3	1.3
Organic Loading Rate (OLR, kg sCOD/m³·d)	2.0 ± 0.6	1.5 ± 1.3	3.9 ± 2.1

Each operational cycle included a short feeding, followed by an aerobic period, a short settling, the discharge of the effluent and an idle phase (**Table 4**).

Table 4 AGS reactor operational cycle distribution

■					Feeding
	■				Aerobic phase
		■			Settling
			■		Withdrawal
				■	Idle phase
9	131 – 156 - 336	30 - 5	9	1	Time (min)

In order to promote the selection of granular biomass, the settling time was gradually reduced during the operation of the prototype. In Stage I, it was initially 15 min, and was reduced to 5 min on day 17. In Stage II,

it started in 30 min and was reduced to 20 min (day 7), 15 min (day 27), 10 min (day 44), 7 min (day 90) and 5 min (day 118).

In Stage I (treating LSmix wastewater), during the working days of the factory, the length of the operational cycle was fixed to 3 h, and it was increased to 6 h during the weekends and holiday periods. In the case of Stage II, since the volume exchanged in each cycle was higher than in Stage I, the length of the cycles was increased to 6 h and the VER was reduced from 50% to 33% to adjust to the availability of the produced wastewater. In the case of Stage III, the cycle length was extended from 6 to 8 h for the same reason.

Stage I

In Stage I, the settling properties of the biomass were considerably improved at the end of the operation (the SVI_5 and SVI_{30} were reduced from 194 and 86 ml/g TSS on day 0 to 39 ml/g TSS (SVI_5 equal to SVI_{30}) on day 63). In addition, high COD and total nitrogen removal efficiencies of 70 – 80 % and 80 – 90 %, respectively, were achieved. The details about the operation during Stage I were provided in the Progress Report II.

Stage II

The reactor was inoculated with 0.3 m^3 of sludge (10% of the AGS reactor useful volume), from the thickener of a wastewater treatment plant, adapted to high saline concentrations. The inoculum contained 22.5 g TSS/L and 18.8 g VSS/L, and was characterised by an SVI_5 of 174 mL/g TSS and SVI_{30} of 171 mL/g TSS.

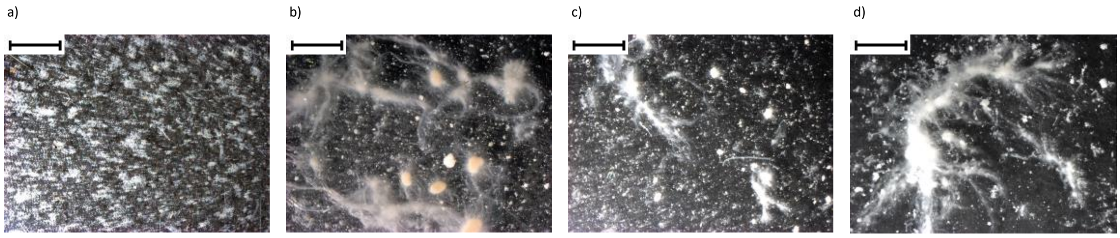

Figure 5 Images of the biomass samples collected on days 0 (a), 30 (b), 120 (c) and 153 (d) of Stage II. The size bar corresponds to 2 mm

The biomass concentration achieved stable values between 1.2 – 1.7 g VSS/L after one month of operation, and the first granules were observed on day 30 (**Figure 5**.b). The biomass considerably improved its settling properties (SVI_5 of 30 – 40 mL/g TSS) and was formed by a mixture of granules and flocs. However, the stability was lost on day 58 due to an episode of almost complete washout of the biomass, due to the presence of detergents in the wastewater (**Figure 6**).

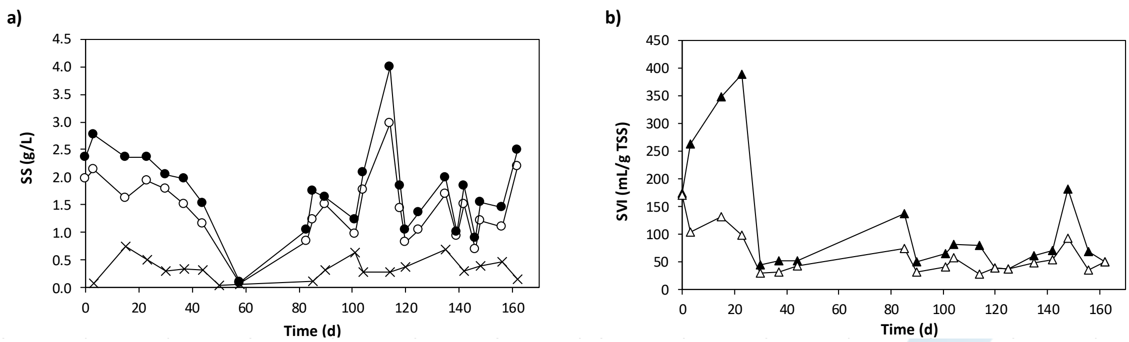

Figure 6 (a) Evolution of the TSS (●) and VSS (○) concentrations in the AGS reactor and TSS concentrations of the effluent (x). (b) Evolution of the biomass SVI_5 (▲) and SVI_{30} (△) in the AGS reactor. These results correspond to Stage II

From day 59 until day 83, the factory stopped its activity, so there was no available low-strength wastewater to feed the reactor. To avoid a complete stop of the prototype, it was manually fed with diluted high-strength wastewater, and longer cycles were stablished (1 – 3 days).

When the factory restarted its activity (day 83), the biomass rapidly recovered the same properties as it had before the washout, and after only a week (day 90) granules were observed again. The biomass concentration was of 1.7 g VSS/L and the SVI_5 was reduced again to 30 mL/g TSS on day 114. However, on day 130 the growth of filamentous bacteria was observed, due to the low concentrations of both COD and nitrogen in the wastewater. This led to a worsening of the settling properties, increasing the SVI_5 from 37 mL/g TSS (equal to SVI_{30}) on day 125 to 180 mL/g TSS on day 148 (SVI_{30} of 93 mL/g TSS). The poor settleability of the big flocs of filamentous bacteria (**Figure 5**.d) caused the continuous washout of biomass in the effluent of the reactor. Despite the short feeding phase and the low retention of the biomass in the reactor, the growth of filamentous bacteria continued until the end of operation.

Regarding the removal efficiencies, the soluble COD concentration of the effluent achieved stable values, like those from Stage I, of 100 - 150 mg/L. The removal efficiencies oscillated between 60 - 80%, depending on the concentration of the influent (**Figure 7**.b). The feast/famine regime was established, being of 40 min at the beginning of the Stage II, and 10-15 min on the last operational days. The total COD removal, like in Stage I, was irregular at the beginning of the Stage, due to the washout of biomass associated to the granulation process, but it was increased and maintained from day 44 onwards, in a range of 70 – 80% (**Figure 7**.a). However, at the end of the operation, due to the presence of filamentous bacteria, the removal efficiencies decreased to 40-70%.

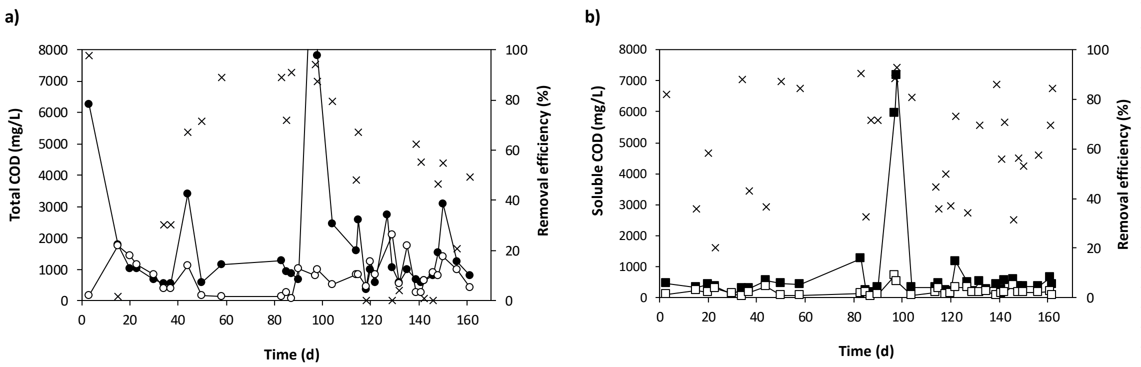

Figure 7 (a) Profile of the total COD concentration in the influent (●), effluent (○) and removal efficiency (x) of the AGS reactor. (b) Profile of the soluble COD concentration in the influent (■), effluent (□) and removal efficiency (x) of the AGS reactor. These results correspond to Stage II

The nitrogen removal pathway, like in Stage I, was its uptake for biomass growth, and neither nitrite nor nitrate were detected in the effluent of the reactor (**Figure 8**).

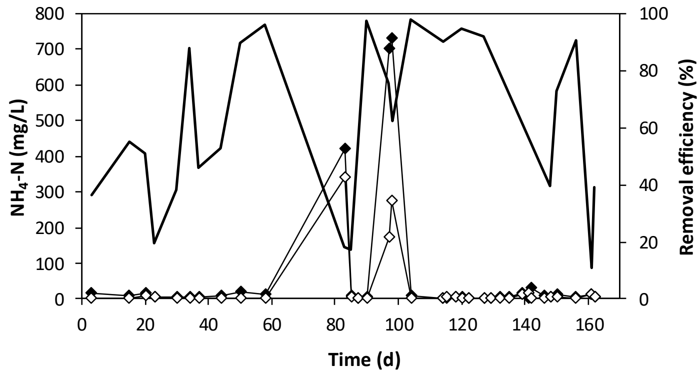

Figure 8 Profile of NH_4^+-N concentration in the influent (◆), effluent (◇) and removal efficiency (-) in the AGS reactor. These results correspond to Stage II.

Stage III

The reactor was inoculated with 0.6 m^3 of sludge (20% of the AGS reactor useful volume), from the thickener of a wastewater treatment plant, adapted to high saline concentrations (Figure 13.a). The biomass concentration in the reactor after the inoculation was 3.36 g TSS/L and 2.73 g VSS/L, and was characterised by an SVI_5 of 300 mL/g TSS and SVI_{30} of 178 mL/g TSS.

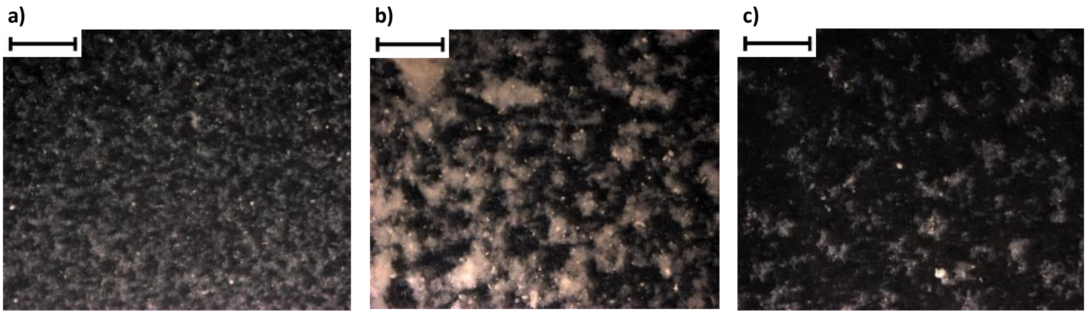

Figure 9 Images of the biomass samples collected on days 0 (a), 33 (b) and 64 (c) of Stage III. The size bar corresponds to 2 mm

The solids concentration in the reactor reached higher values (2 - 3 g VSS/L) compared to Stages I and II, associated to a higher COD concentration in the feeding (**Figure 10**.a). When the OLR was increased to 6 kg sCOD/(m^3·d), between days 49-64, the highest values of solids concentrations, up to 4.5 g VSS/L were observed. After that, there was a diminishment of the OLR during days 65-95, and a decrease and stabilization of the solids concentration to 2 - 3 g VSS/L. In addition, a progressive decrease of the solids of the effluent was observed. The settleability of the biomass remained stable until day 95, with values of SVI_5 of 54 – 70 mL/g TSS (**Figure 10**.b). The good settleability of the biomass and the progressive decrease of the solids in the effluent indicated a good evolution of the biomass.

From day 95 until day 120 the prototype was stopped, due to a stop of the plant. After that, the biomass concentrations fluctuated between 2 – 3.5 g VSS/L, associated to changes in the operational conditions. The settleability of the biomass fluctuated between 30 – 178 mL/g TSS.

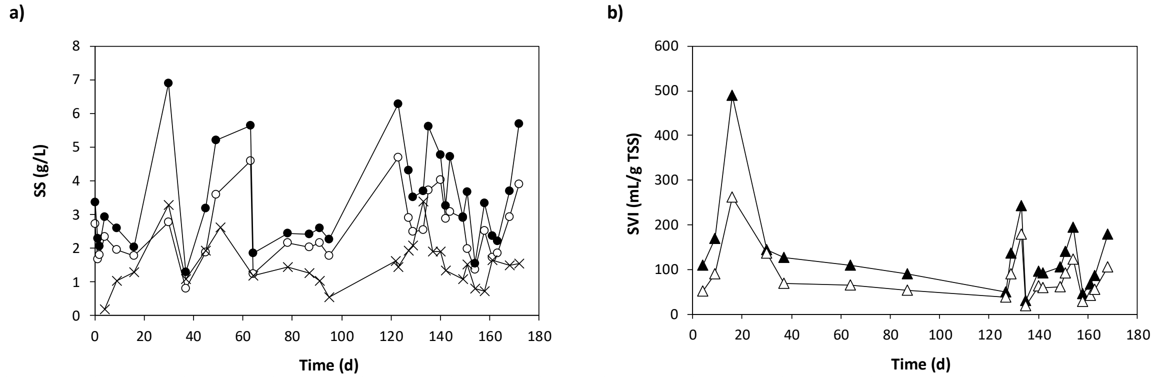

Figure 10 (a) Evolution of the TSS (●) and VSS (○) concentrations in the AGS reactor and TSS concentrations of the effluent (x). (b) Evolution of the biomass SVI_5 (▲) and SVI_{30} (△) in the AGS reactor. These results correspond to Stage III

At the beginning, the biomass was in form of big flocs, with a few aggregates, which could be biological agreggates or solids or greases that entered in the reactor with the feeding (**Figure 9**.b). Afterwards, the size of the flocs decreased, associated to the granulation process (**Figure 9**.c). Although an evolution of the biomass occured, well-defined granules were not observed, since more time was needed to complete the granulation process. Nevertheless, the overgrowth of filamentous bacteria was not observed, due to the higher loading rates applied to the reactor.

The soluble COD removal efficiencies were high since the beginning of the operation (80 - 90%), and more stable than in the previous stages (**Figure 11**.a). A feast/famine regime was also stablished, with feast times of 1 – 2 h. The removal efficiencies corresponding to total COD were of 40 – 70%, and fluctuated associated to the biomass washout due to the selection of aggregates with good settleability (**Figure 11**.b).

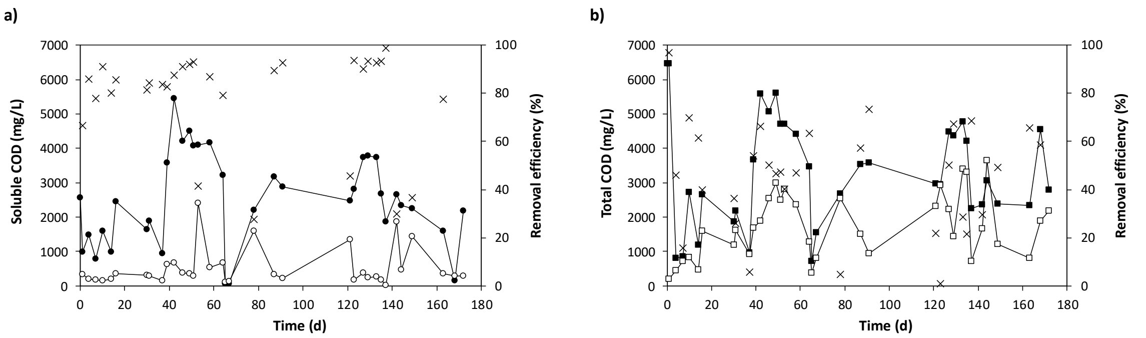

Figure 11 (a) Profile of the total COD concentration in the influent (●), effluent (○) and removal efficiency (x) of the AGS reactor. (b) Profile of the soluble COD concentration in the influent (■), effluent (□) and removal efficiency (x) of the AGS reactor. These results correspond to Stage III

Regarding nitrogen removal, like in the previous stages, it was only due to biomass growth. Nitrifying activity was not observed (neither nitrite nor nitrite were detected in the effluent), because the sludge retention time (SRT) of the reactor was not high enough to promote its growth. The SRT in the reactor oscillated between 2 - 3 days, whereas to observe nitrifying activity values higher than 5-7 days are required. Since the influent concentrations of ammonia were high (200 – 300 mg NH_4^+-N/L), the removal efficiencies were of 30 – 40% (**Figure 12**). Although they were lower than the previous stages, the nitrogen removal capacity of the biomass was considerably higher (0.02 kg N/(m^3·d) and 0.14 kg N/(m^3·d) in Stages II and III, respectively).

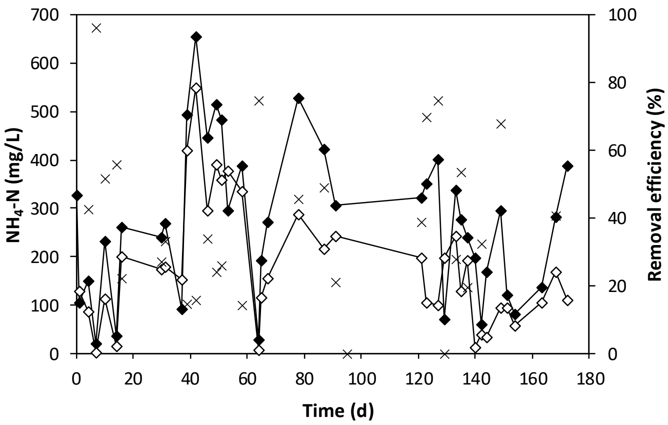

Figure 12 Profile of NH_4^+-N concentration in the influent (◆), effluent (◇) and removal efficiency (x) in the AGS reactor. These results correspond to Stage II

MBBR prototype

The Moving Bed Biofilm Reactor (MBBR) pilot was inoculated with biological activated sludge on 16/02/2018 (day 16 in the results section) and a low influent flow rate of 0.25 m^3/h was fed to the reactor, in order to enhance biofilm formation and to adapt biomass to the industrial wastewater.

The pilot plant was in operation until the stop of the plant for maintenance (07/07/2018). The fish cannery where the prototype was installed stops its production two times per year for maintenance and cleaning activities (July and December). The prototype was re-started on 07/08/2018. In December (17/12/2018), the factory was stopped again (Christmas break) and started-up again in January 2019 (14/01/2019) until April 2019 (10/04/2019). In total, the MBBR was 408 days in operation, with an influent flow rate of 0.36 m^3/h on steady state.

The wastewater used in the prototype was the low-strength mixed (LSmix) wastewater used as well during Stages I and II of the AGS prototype. This wastewater has a high content in grease and fats. According to design specifications from the provider, the MBBR pilot unit should not be fed with concentrations of oil and grease higher than 50 mg/L. Therefore, the grease content in the influent of the MBBR was reduced with the installation of a fat trap, but the average grease content still was 230 mg/l, which makes this a challenge for the project, in order to prove the capacity of the MBBR to cope with high grease concentration of industrial wastewater.

Initially, the MBBR unit was operated with 3 tanks under aerobic conditions and the secondary clarifier. The aeration was controlled with a dissolved oxygen setpoint in tank 1 of 2 mg/L. Samples were taken 2-3 times per week in all tanks, influent, effluent and purge of the secondary clarifier. Total COD in the influent was very variable (1000-3000 mg/L) due to the type of raw material that was processed in the fish cannery plant for each moment.

¡Error! No se encuentra el origen de la referencia. shows the stages during the operation of the MBBR prototype. The operational period was divided in start-up (February – April 2018) and three stages:

- Stage I: focussed on the load increase in the system (May - June 2018)
- Stage II: operation of the system in stationary state after the load increase, including balances of C and N, as well as the study of the aeration system (August - December 2018)
- Stage III: optimization of the elimination performance in the system and effluent quality (January – April 2019)

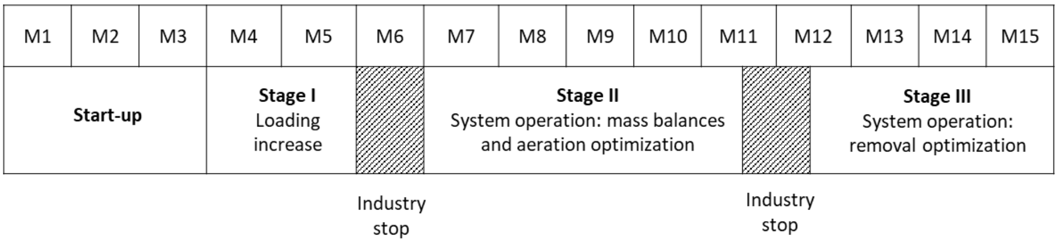

Figure 13 Stages during the MBBR operation

Three months were necessary for the adaptation of the biomass, which was took as the start-up of the MBBR prototype. Before proceeding to the inoculation and acclimation steps, initial inspections about the equipment and carriers were carried out. It is important that carriers mix well, in case of bad mixing, antifoam was dosed. This inspection was made with clean water. Once all results are positives, inoculation and acclimation steps can be carried out.

The pilot was inoculated with biological sludge from a municipal wastewater treatment plant. An amount of 1 m^3 of sludge for every 200 m^3 of reactor volume, a very low ratio. A minimal flow rate around 0.25 m^3/h (the 50% of the plant design flow) was fed to the reactor during a month, to enhance biofilm formation and to adapt biomass to the industrial water.

One of the main goals achieved was the noticeable adhesion of the biofilm to the carriers, which makes possible the removal of the organic matter in the wastewater by the MBBR unit. **Figure 14** shows the evolution of tank 1 in time of the biofilm on the surface of the carriers. Tank 2 had less biofilm formation than tank 1. However, tank 3 presented a poor biofilm formation.

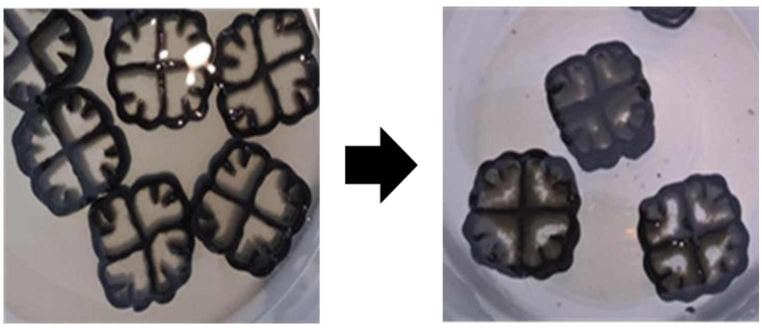

Figure 14 Biofilm on the surface of the carriers of MBBR unit

The results on the performance of soluble COD removal are presented in **Figure 15**. On week 5 of operation, it began to be observed a difference in sCOD concentration between influent and effluent. The soluble average COD removal was about 70%, comparable to the one obtained in the AGS unit, and with an average sCOD in the effluent of 370 mg/l. The tCOD removal reached the 70-80%.

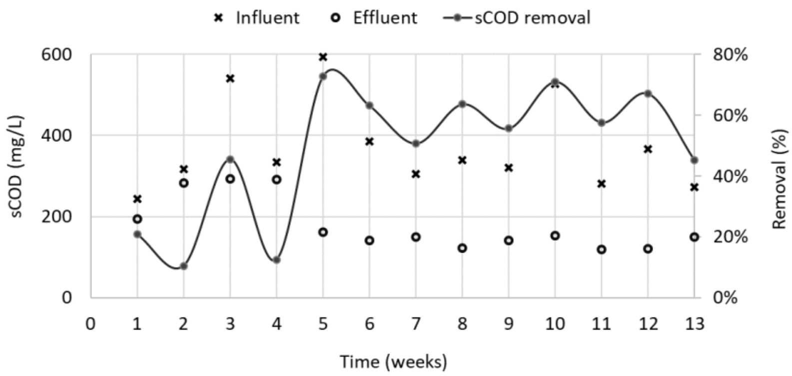

Figure 15 Profile of the soluble COD concentration in the influent, effluent and COD removal efficiency of the MBBR

For the MBBR, carrier surface area is commonly used for expressing performance and loadings, presented as surface area removal rate (SARR) and surface area loading rate (SALR). During the start-up, the flow applied was constant (0.25 m^3/h) but, due to the variability of water the organic loading rate undergo changes, SALR was incremented. When organic load (SALR) increases, also increases the removal rate (SARR), as shown in **Figure 16**.

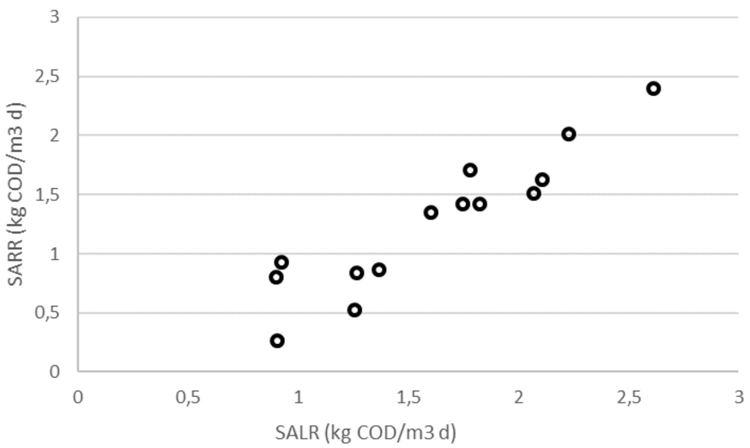

Figure 16 Correlation between the loading rate and removal rate of the MBBR, expressed as SALR and SARR respectively, during the start-up

The nitrogen removal was progressively increased as the organic matter removal increased. This means that the microorganisms present in the biofilm were responsible for the nitrogen consumption. Consequently, the higher biofilm growth, the higher the biological nitrogen requirements and the nitrogen removal. From day 35, an average removal of 50% of soluble nitrogen was observed (**Figure 17**), related to the growth of biomass on the carriers.

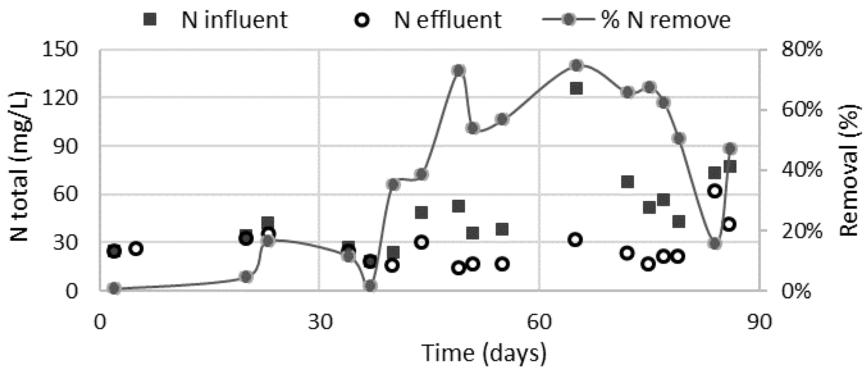

Figure 17 Nitrogen concentration in the influent and effluent and removal efficiency of the pilot plant during the start-up

Three months were necessary for the complete acclimation of biomass to the industrial canning wastewater and obtaining the steady state. During this start up time, a robust formation of biofilm was achieved in tanks 1 and 2. The poor biofilm formation in the last of the tanks (tank 3) was due to little amount of organic matter, which was not enough for the maintenance of the biofilm. The organic matter of the wastewater only allows the maintenance of the biofilm in tank 1 and 2. High removal efficiencies of COD and nitrogen were observed. The system adapted well to the variability of the influent composition with high removal efficiencies even at high influent loads.

For two months, May and June 2018, the increase of the load applied to the system was carried out (Stage I). After the manufacturer visit in June 2018 and from the results obtained in the tanks, it was decided to operate the plant with only two tanks under aerobic conditions (tank 1 and tank 2) and to supress tank 3, which was not necessary for the organic matter removal. Oxygen set point of 2 mg/l was kept in tank 1 for the aeration control and the performance of the MBBR was not altered. In addition, the flow rate in the system was increased from 0.25 m^3/h to 0.36 m^3/h, which resulted in the rise of the organic loading rate in the pilot plant.

These two changes made in the system entail a load increase from an average of 3.8 g $BOD_5/m^2/d$ (expressed in m^2 of carrier surface) to 7.1 g $BOD_5/m^2/d$. With this increase in load, the system reacted with a high percentage of elimination of organic matter with an average of 78% elimination in tCOD.

Since the middle of August from December 2018, a stationary operation was performed. In addition to monitoring the system elimination, mass balances of organic matter and nitrogen, and an oxygen transfer test were carried out. Stationary state was considered during these months of operation due to the fact that the flow of influent was kept constant (0.36 m^3/h). Besides, the thickness of the biofilm remained practically constant during these months. The load variations were exclusively due to the great variability of the water in the canneries.

During the stationary state removals of 80% in BOD_5 and 82% in sCOD were achieved. In terms of tCOD the removal was lower, only 70% was achieved. This lower elimination in tCOD was due to the bad sludge settleability found in the settler. The suspended sludge and solids tend to accumulate. This problem resulted in a breach of the discharge limit of the TSS in the effluent. There were days in which the solids content of the effluent was greater than the influent, also, the limits were not met most days (**Figure 18**).

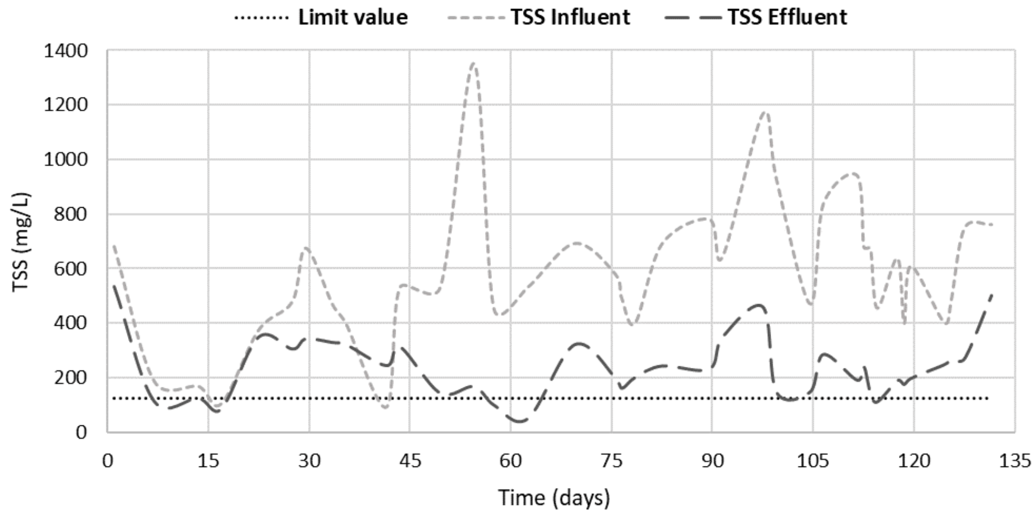

Figure 18 Evolution of TSS during Stage II

In terms of nitrogen, no external nitrogen source was added. During the operation were measured total nitrogen, ammonia and nitrate. An average of the evolution of nitrogen in different tanks is shown in **Figure 19**.

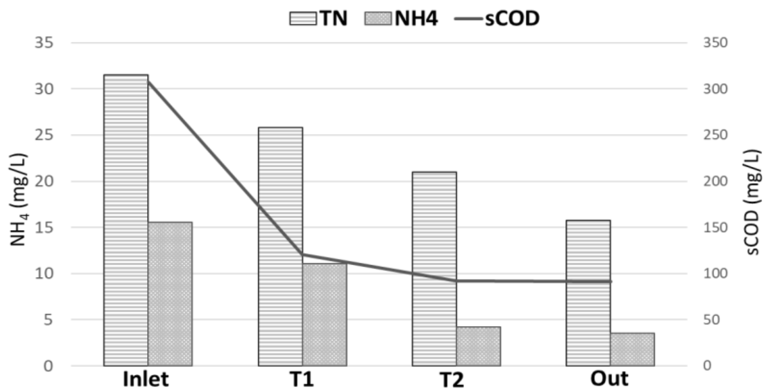

Figure 19 Evolution of sCOD elimination versus TN and NH_4 elimination

Major sCOD removal was observed in tank 1, where the concentration was reduced from 307 mg/L to 121 mg/L. In this tank, for each 100 mg of sCOD removed, 2.4 mg of NH_4 were consumed. This removal is due to the biomass assimilation by the heterotrophic bacteria. There were some days in witch ammonium levels decreased to 0.7 mg/L. It was observed that this value was limiting. In case of NH_4 removal, in tank 2 was observed the major reduction from 11 mg/L to 4 mg/L. In this case, for each 100 mg sCOD removed, 23.8 mg/l of NH_4 were consumed.

The large difference in ammonium consumption between tank 1 and tank 2 could be due to the presence of nitrifying bacteria (autotroph bacteria) in tank 2. The nitrate analysis confirmed the presence of some nitrification. An average, of 2.9 mg/L of NO_3 were measured at the outlet of tank 2.

The design parameter of grease in the pilot plant was 50 mg/L. This value has been exceeded during the operation, reaching values of grease in the influent up to 350 mg/L (**Figure 20**). Despite the high grease values presented in the influent, the elimination of grease carried out by the system has been high. Grease removal

was observed in values higher than 90%. For a good performance of the systems it was set the limit of oil and grease in 200 mg/L (higher than the recommendation of the supplier, 50 mg/L).

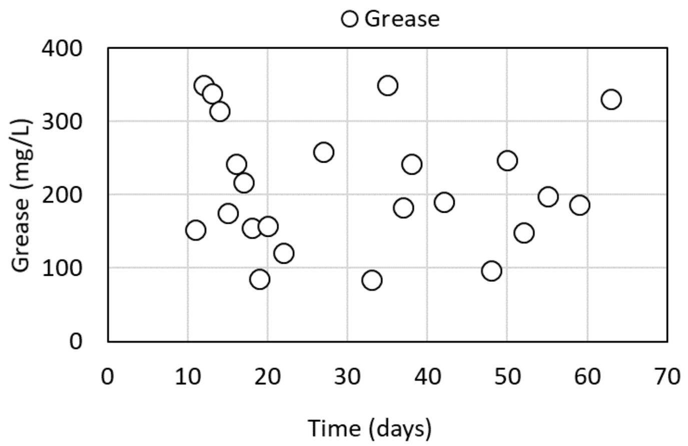

Figure 20 Grease concentration in the influent of the MBBR

Due to the high concentration of chlorides, there was a high salinity and consequently a high conductivity. Chloride values varied from 580 mg/L to more than 12.000 mg/L, higher values than a conventional urban wastewater.

To check how the high conductivity of water affects the elimination of organic matter, a chloride graph was made against the elimination of BOD_5 (**Figure 21**). A decrease in BOD_5 removal over 6 g Cl^-/L was observed. At 8 g Cl^-/L, BOD_5 removal decreased to 40-60%. Still, more research is needed in this field to have more data and conclusive results at high Cl^- concentrations (> 8 g Cl^-/l).

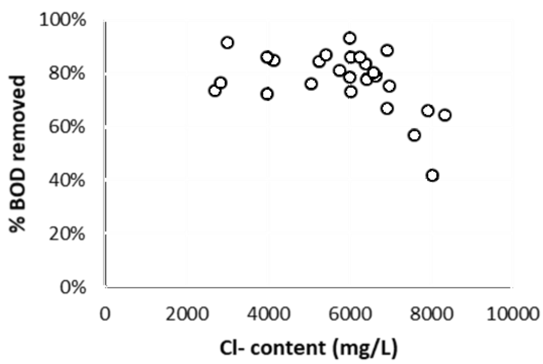

Figure 21 BOD_5 removed against chlorides content in wastewater

Conductivity values varied between 12 and 33 mS/cm. A decreasing tendency of BOD_5 elimination was observed with conductivities higher than 25 mS/cm. This indicates that the high concentration of chlorides, with influences the conductivity, inhibits the elimination activity of the organic matter of the system, i.e. the bacterial activity.

During the operation pH values were maintained in an optimum range for biological processes and according to the operation designs, between 6 and 8. An addition of acid or base was not required for the maintenance of this parameter in the optimal range.

In general, the removal efficiencies are lower than it was expected initially. During stage II, it was verified that the effluent did not meet the discharge limits in terms of solids and tCOD. The influence of the decanter could be related to this fact. The decanter was designed for the treatment of a different wastewater (the one from the first site selected, see description action A1). Therefore, the decanter was not well designed for the actual wastewater to be treated. The optimization of the decanter performance to obtain a high-quality effluent with minimal solids and tCOD was carried out during Stage III (January – April 2019).

This optimization started with the performance of Jart-tests in order to find the correct polymer (cationic polymer) dose. Despite establishing the appropriate polymer dose, the problem was not solved. Other possible causes of the problem of the settler were:

- The water was arrived at the settler which too high dissolved oxygen (DO). This high DO could cause the flotation of sludge.
- The purge frequency of the decanter may not be enough. An accumulation of solids and sludge at the bottom of the settler could cause a rise to the surface over time.

After the improvement of these potential causes of sludge accumulation on the decanter surface, an improvement was observed but not sufficient.

The solution adopted, during stage III, was the operation of the decanter as a flotation system, improving the separation of solids. This improvement in solids separation led to a greater elimination of solids and therefore, tCOD. In order to operate the decanter as a flotation system, the samples were taken in the middle of the unit. Therefore, the accumulation of sludge and grease usually found on the surface of the decanter did not interfere in the effluent quality. This layer of sludge and grease was removed manually during the operation of stage III. The sludge of the bottom of the decanter was removed with the purge of the unit as usual. A more clarified effluent was obtained with low presence of solids.

Clearly, the effluent quality in terms of solids (**Figure 22**) and tCOD (**Figure 23**) remarkably improved in Stage III compared to Stage II. The values stayed under the discharge limit of the plant (125 mg TSS/L and 350 mg tCOD/L), MBBR system meeting the discharge limits. In conclusion, for the current plant, it would be more appropriate to use a flotation system to separate the sludge and solids instead of a decanter.

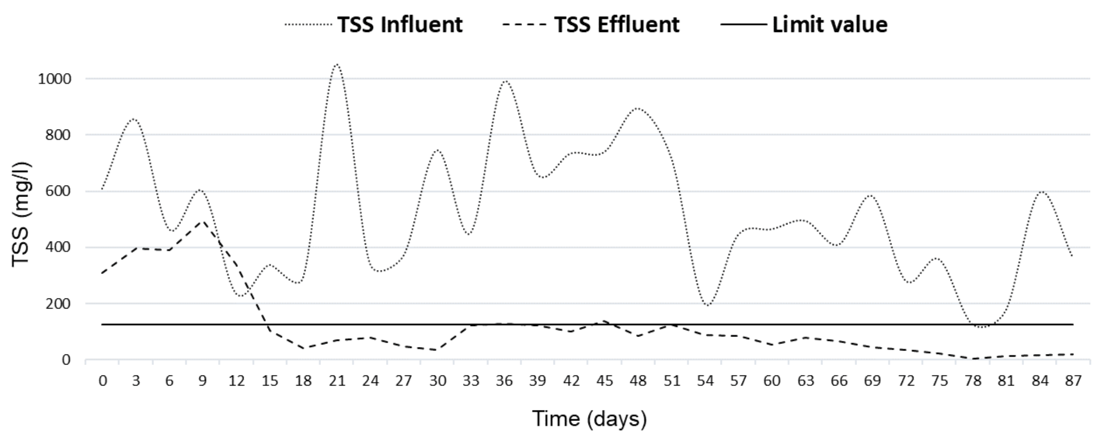

Figure 22 Evolution of solids during stage III

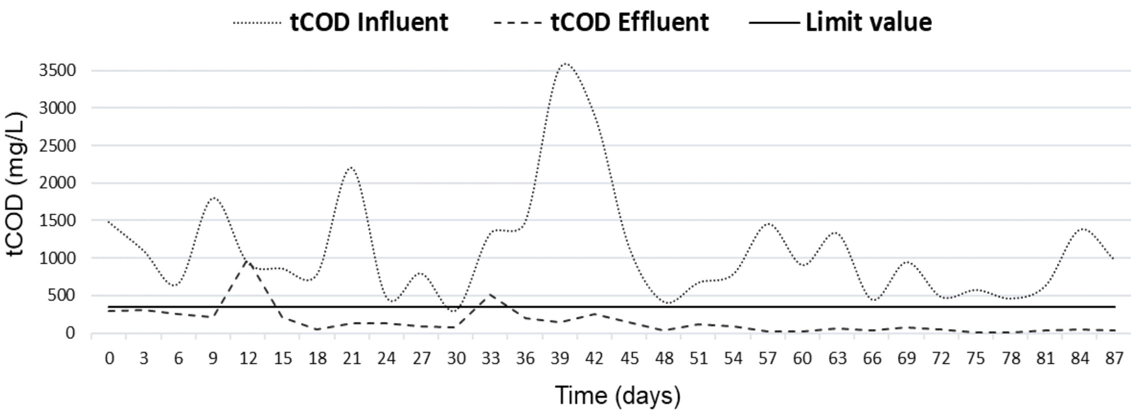

Figure 23 Evolution of tCOD during stage III

Summing up, the MBBR system was demonstrated to be a suitable technology for the treatment of fish canning wastewater with removal efficiencies up to 80%, meeting the current discharge limits. Besides, the MBBR technology presents attractive advantages compared to conventional aerobic treatment systems (e.g. CAS). It is a compact technology which requires less space for its implementation, it can face with high grease concentrations and salinity, and produces significant less sludge.

Comparison between AGS and MBBR technologies from operation results

After operating the two biofilm-based technologies, from a technical point of view, the application of one or other technology will depend on the type of wastewater.

Both technologies gave good removal efficiencies. It is well known that high salinity and high influent variability affects negatively the biological systems. However, the biomass grown in the form of granules or compact aggregates (AGS) or biofilm on the surface of a carrier (MBBR), is not so badly affected. Likely, the biofilm structure gives protection and decreases the negative effects. Therefore, the AGS and MBBR technologies are more recommended than conventional biological systems (flocculent biomass) for the treatment of complex industrial wastewater, as is the case of fish canning wastewater.

MBBR resulted a good system for the treatment of relatively low strength wastewater, since high oil and fats are not allowed in the system and the system did not remove high organic loading rates.

AGS was good for low and high strength wastewater. For the case of low strength wastewater, it is important to not low a limit of COD and nitrogen in order to avoid the grow of filamentous bacteria.

A complete comparison between the AGS and MBBR units was done in action B5, which includes the environmental and cost analysis of both technologies and also compare them to conventional systems (CAS and physic-chemical treatment).

ACTION B.3. Process control and optimization for robustness and replicability.	
Objectives. • To identify parameters which define the accurate and optimised operation of the reactor.	*Status:* Completed

• To define the range of the identified parameters that ensures the optimal performance of the prototype in terms of COD and nutrients removal, as well as the maintenance of the biofilm structures. • To implement a hydrodynamic model for the biofilm-based prototype reactors to provide a tool for the successful scale-up and replicability of the technology	

AGS laboratory-scale reactor operation

The first action for the optimization of the process was related to the definition of a cycle distribution to enhance formation of the granules. For this purpose, a strategy of gradually reducing the settling time was applied. In this way the granulation process was promoted by means of selecting only the biomass with good settling properties and removing from the reactor the biomass which did not settle fast enough. Between days 0 and 15 of operation the settling time was fixed at 7 minutes, then it was reduced to 4 minutes (day 15) and finally to 1 minute on day 22. With this reduction the minimum settling velocity imposed to the granules increased from 1.38 m/h (7 min of settling) to 2.42 m/h (4 min) and 9.66 m/h (1 min). With this strategy aerobic granular sludge was formed after 90 days of operation.

The second evaluated action was applied to improve the organic matter and nitrogen removal percentages. In this case, the cycle length was increased from 3 to 4 hours on day 93 of operation. The increase of length allowed the obtaining of a longer aerobic phase and promoting the retention of the biomass inside the reactor. With this change the loading rates were decreased too, which allowed the reduction of the feast phase length and the complete oxidation of ammonia to nitrite during the aerobic phase. The results from this cycle change are shown in the cycle measurements performed in the reactor presented in the action B.2. An improvement of the nitrogen removal from 40% to almost 80% was observed with this change in cycle length.

AGS and MBBR prototype operation

Adaptation to the routines of the factory

The first step in the process control and optimization of both prototypes was the establishment of the operational conditions adapted to the routines of the factory. Therefore, the discontinuous operation of the factory was considered to define the operational conditions of both prototypes. Every weekend and holidays the factory stopped its production, which meant that wastewater was not generated. Consequently, the volume of available low-strength wastewater was limited to the storage capacity of the dissolved air floatation (DAF) of the factory, where the wastewater was taken from to feed the prototypes. It has a useful volume of 14 m^3, which was divided equally to feed both prototypes, AGS (Aerobic Granular Sludge) and MBBR (Moving Bed Biofilm Reactor).

When the factory stops occurred and the AGS prototype was fed with low-strength wastewater, two different strategies were applied to assure that the prototype was fed, depending on the number of days that the factory was closed:

- Strategy 1 (stop shorter than 3 days): the length of the operational cycle was increased from 3 to 6 h and the VER was maintained.
- Strategy 2 (stop longer than 3 days): the length of the operational cycle was increased from 3 to 6 h and the volume exchange ratio (VER) was decreased from 50 to 33 %.

For the MBBR prototype, two strategies were applied during the stops of the factory:

- Strategy 1 (stop shorter than 3 days): the inlet flow rate was reduced from 360 to 100 L/h.

- Strategy 2 (stop longer than 3 days): the inlet flow rate was reduced from 360 to 100 L/h and the aeration flow to give a dissolved oxygen concentration from 3 to 0,5 ppm.

When the reactor was fed with high-strength wastewater, the capacity of the storage tank of the factory was enough to feed the reactor during the weekends without operational changes. However, to avoid the collection of greases from the upper layer of the tank, the length of the cycle was increased from 6 to 8 h.

During the long stops of two weeks (summer and winter), all the units of the factory were completely emptied and cleaned. To avoid a complete stop of the AGS reactor, 2 – 3 containers of 1 m^3 were filled with high-strength wastewater before the stop. Then, during the stop of the plant, the volume of one container was added to the reactor and it remained aerated during 5 - 6 days. After that, the effluent was discharged (after a settling period) and the volume of another container was added again to the reactor.

Operational conditions of the start-up

Regarding the operational conditions of the start-up of the AGS, two parameters were considered: the applied organic loading rate and the settling time. The initial applied loading rate was of 2 kg/(m^3·d) as soluble COD, and it was gradually increased as the reactor was able to remove all the fed organic matter. To control the OLR, the percentage (in volume) of high-strength wastewater of the total volume of feeding was gradually increased.

The settling time was reduced during the first operational days, in order to provoke the washout of all the biomass with bad settleability. It was gradually reduced to give time to the biomass to adapt to the new conditions and avoid an excessive washout.

Definition of the key parameters for the optimal operation of the prototypes

The identified key parameters included the operational conditions of the prototype, as well as the characteristics of the incoming wastewater. The most important identified parameters of the AGS prototype were:

1. Applied organic loading rate: this parameter should be in a range of 2 – 6 kg/(m^3·d) as soluble COD. Lower values (low-strength wastewater) lead to the overgrowth of filamentous bacteria, whereas higher values lead to the development of poor-settling aggregates. During the start-up, the applied loading rate should be gradually increased, until achieving the maximum value of 6 kg/(m^3·d).
2. Height to diameter ratio: the higher the height to diameter ratio (H/D ratio), the better is the formation of biological aggregates. H/D ratios of at least 2.5 should be used to favour the formation of granules.
3. Volume exchange ratio: a higher VER allows the discharge of a higher volume of effluent, and consequently a higher volume of fed wastewater (which implies higher applied loading rates). The VER should be always higher than 30%, with optimal values between 40-50%.
4. Length and number of cycles per day: depending on the characteristics of the incoming wastewater, the length and number of cycles per day must be adapted to maintain the applied loading rate in the range previously specified and assure the complete removal of the target pollutants. For the treatment of low-strength wastewater, cycles of 3 h are enough to treat the wastewater, whereas for high-strength wastewater cycles of at least 6 h are needed.
5. Settling time: the settling time must be selected to apply settling velocities of the biomass of at least 10 m/h when the system operates with stable AGS. Depending on the VER and the height that the biomass needs to settle to remain in the reactor, the settling time needs to be specified.
6. Air flow: the air flow provided to the system determines the hydrodynamic stress applied to the biomass. To assure the formation of stable granules, the air flow must assure superficial gas velocities

in the reactor ($Q_{air}/S_{reactor}$) of at least 1.2 cm/s. When treating high OLRs (high-strength wastewater) the value should be even higher, near 2 cm/s.

In addition, it is also important to assure a correct pretreatment of the wastewater, to avoid the presence of compounds that might cause operational problems in the reactor. In particular, it is necessary the separation of greases, to avoid foaming and loss of biomass in the reactor. Besides, the separation of solids is also important, to reduce the inorganic content of the biomass and avoid high inert concentrations inside the reactor.

The identified key parameters of the MBBR prototype were:

1. Applied organic loading rate: this parameter should be, as in the AGS prototype for low strength wastewater, in a range of 2 – 3 kg/(m3·d) of soluble COD.
2. Useful volume: since the system contains carriers and liquid, the useful volume is a key parameter, which will be defined by the fraction of the solid and liquid phase. This factor will depend on the specific surface of the carriers (on which the biomass can grow and form the biofilm). For this specific case, the Aqwise carriers should not occupied more than the 46% of the volume of the system. The operation was carried out with 41% of carriers.
3. Dissolved oxygen concentration: the concentration of oxygen in the system is important to develop the aerobic bacteria and to remove the organic matter and nitrogen. The oxygen concentration was set by controlling it in the first tank of the MBBR system with a setpoint of 2 mg/L.
4. Hydraulic retention time: this factor is the key to ensure the removal of the pollutants in the wastewater. It is directly related to the total volume of the system and the inlet flow rate (HRT = V/Q).
5. Greases concentration of the incoming wastewater: during the operation of the MBBR, the concentration of the grease and fats in the wastewater was found as an important parameter. For the present case study, the concentration must be lower than 200 mg/L to not affect negatively in the normal operation. Higher concentrations lead to the clogging of the carriers and the loss of the attached biomass.

In addition, an operation manual for the AGS was made, which includes the equipment list, detailed information about manual and automatic mode for all the equipment and security levels of all the tanks. It was found very useful when the plant was stopped after a flood or an electrical problem.

Hydrodynamic model of the AGS prototype

The computational fluid dynamics assessment began with the evaluation of several air diffuser configuration in order to select, during the reactor design step, the optimal configuration returning the best mixing conditions (**Figure 24**)

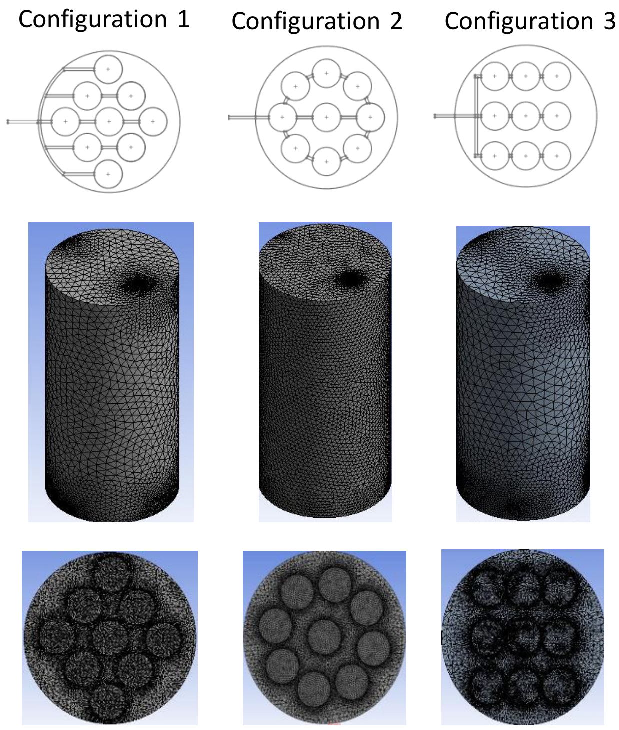

Figure 24 Layout of diffusers configuration and applied mesh for each configuration

The obtained results from the simulation of the three configurations indicated that those which were more concentrical (configurations 1 and 2) offered a slightly more homogeneous distribution of the gas phase in general through the liquid. Configuration 1 did not provide an appropriate flow for the gas circulation in the bottom part of the diffusers and for these reasons, configuration 2 was chosen to be implemented in the in the CFD model and to be used in the prototype construction.

The results obtained from the simulation, considering only mass transfer, indicated that the dissolved oxygen concentration reached concentrations close to saturation only after 20 seconds after the beginning of the aeration phase (**Figure 25**). In these conditions the mixture inside the reactor media is expected to be enough to favour the mass transfer of the dissolved substrates and favour the biological reactions. Furthermore, these results also confirm the appropriate selection of the operational conditions and aeration devices.

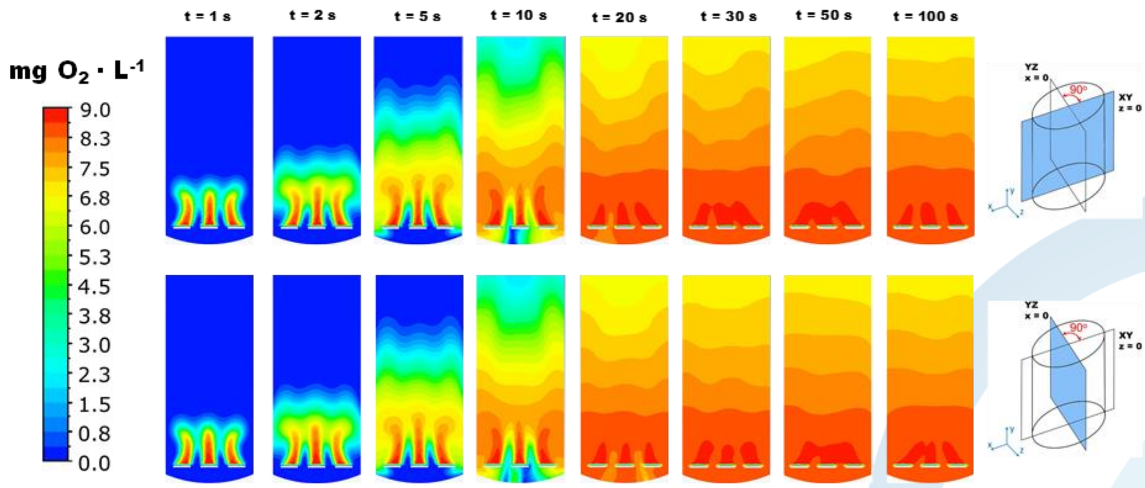

Figure 25 Evolution of the profiles of dissolved oxygen distribution in the planes XY and YZ

To build the hydrodynamic model, biphasic simulations liquid/gas were done, by using the Euler method, the most common used in the case of bubble columns and airlift reactors. The selected turbulence model was the standard k-epsilon. The selected biological model to be combined to the hydrodynamic model was the Activated Sludge Model no. 1 (ASM1). This was not contemplated in the proposal but including the biology in the model would give more useful information from the system and for its optimization and after scaling-up.

The obtained profiles of the biological model simulation for the low-strength wastewater scenario are shown in **Figure 26**.

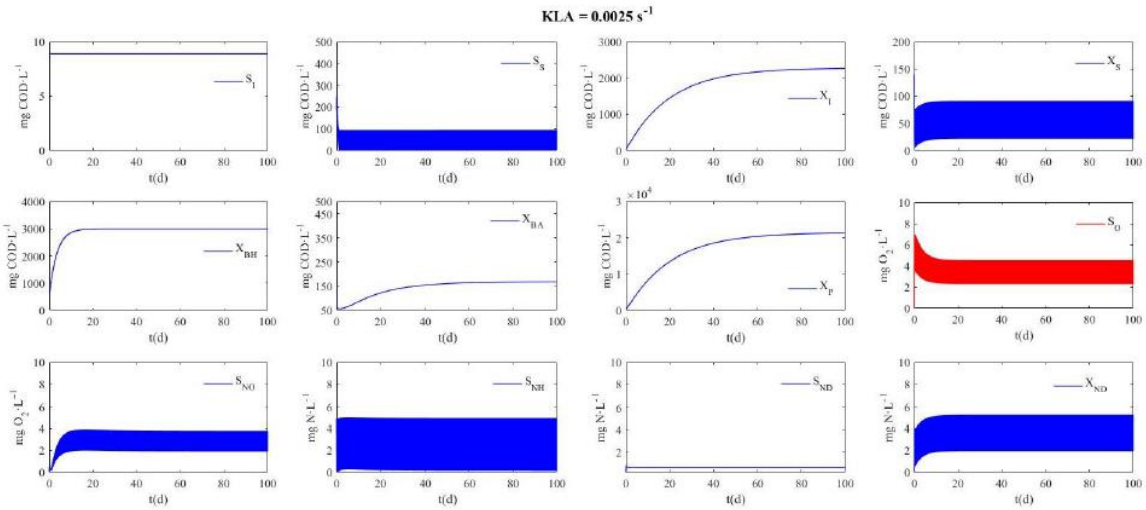

Figure 26 Results of the simulations with the low-strength wastewater scenario

From the results of **Figure 26**, the steady-state values of each variable were calculated, and the value of K_La was adjusted. The optimised value of K_La was 0.0021 s^{-1}, similar to the one obtained from the experimental data.

The results of the hydrodynamic model showed a homogeneous mixture of the solids inside the reactor (**Figure 27**). The average solids concentration is of 1.57 g/L, with a wide distribution and a maximum value of 2.32 g/L in the conic part of the reactor. In addition, the time necessary to achieve a homogeneous mixture of solids inside the reactor at the beginning of the aeration stage was determined. After 7 seconds, the mixture is homogeneous.

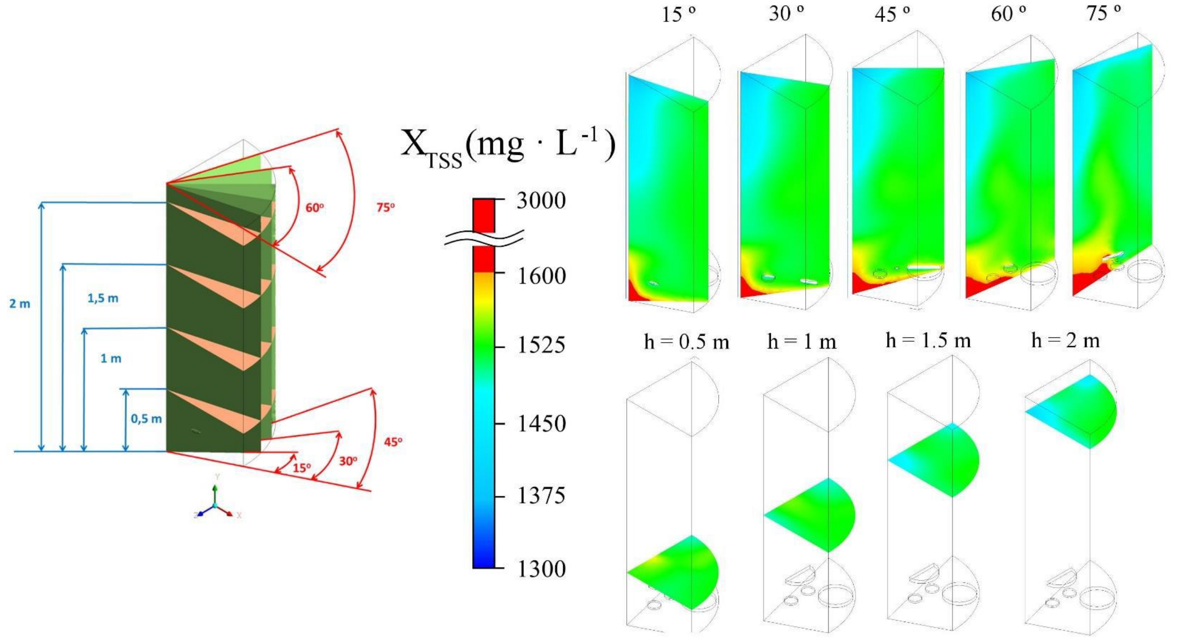

Figure 27 Solids concentration profile inside the reactor at different longitudinal and transverse planes

Regarding the high-strength wastewater scenario, the same procedure was followed. The Sludge Retention Time (SRT) of the reactor was evaluated with the model. To do that, the model was run with different SRT and K_La values. The value of the SRT was adjusted considering the solids inside the reactor at steady-state.

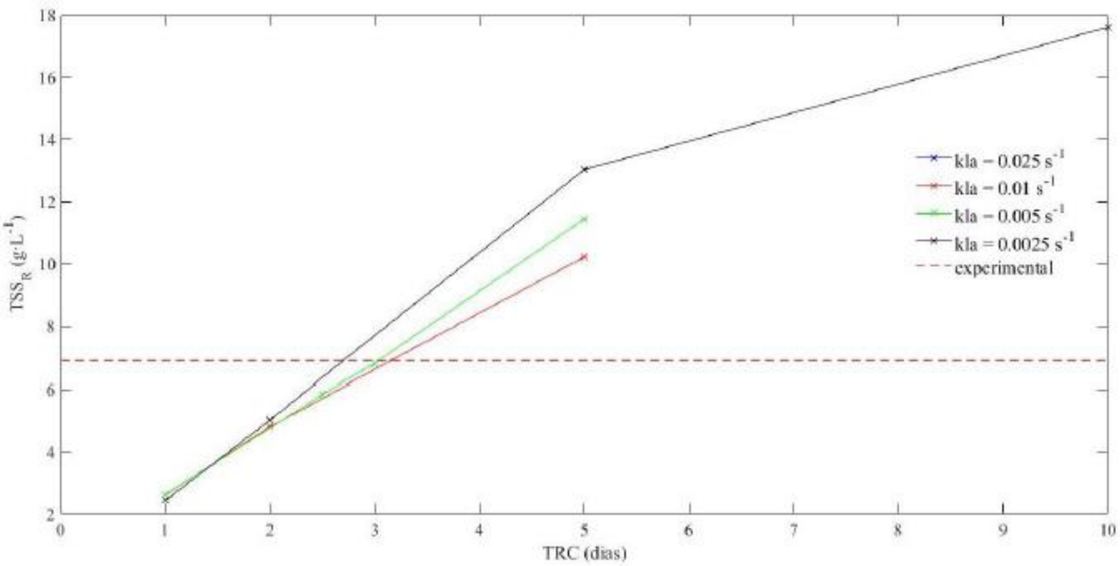

Figure 28 Evolution of the solids content and SRT inside the reactor at different K_La values

The same K_La as estimated in the previous scenario (low-strength wastewater) corresponded to a SRT of 2 – 3 days. However, the oxygen profiles of the model did not fit the experimental data, since the oxygen supply (OTR) was lower than the oxygen demand of the biological system (OUR). Consequently, the value of K_La needed to be increased. Therefore, a simulation with a SRT of 2.5 days (calculated from the experimental data) and a K_La of 0.005 s^{-1} was done to fit the oxygen profile of the model with the experimental data. With this value, the biological model was run, and the results of the simulation are shown in **Figure 29**.

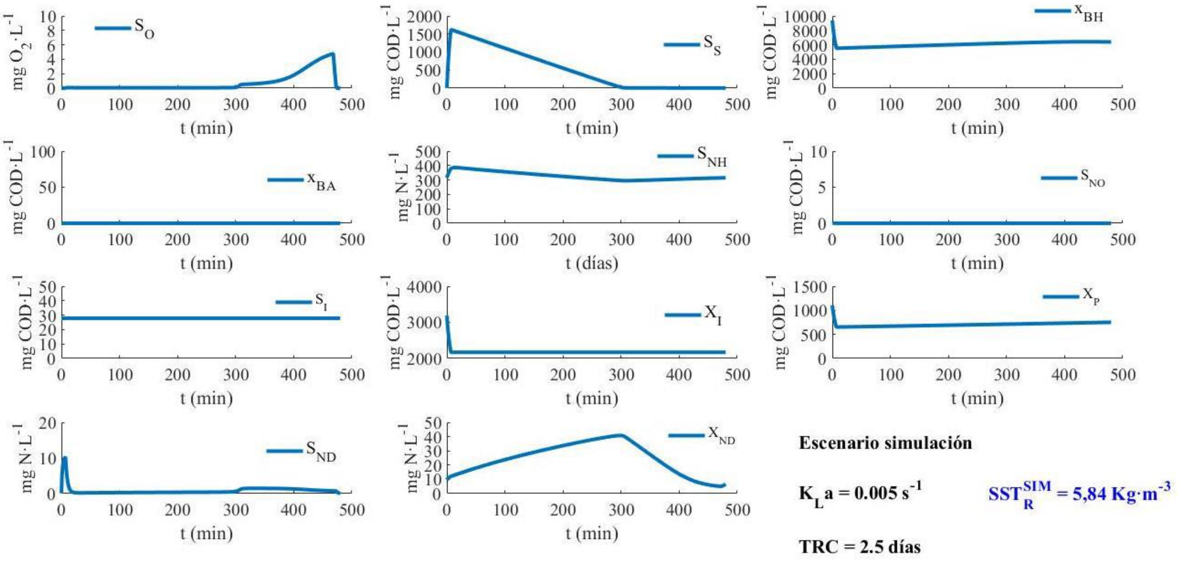

Figure 29 Cycle profiles obtained with ASM1 in steady-state conditions

ACTION B4. Benthic ecosystem analysis to assess the effectiveness of the biofilm-based wastewater treatments

Status: Completed

Objectives:

- To provide the information about the environmental problems caused by the effluents discharged by the fish canneries when submitted to different treatment processes.
- To identify the key factors, concerning the wastewater, that disturb the normal functioning of benthic ecosystems.
- To contribute to the monitoring and integration of the defined factors in the environmental policies.
- To provide an information and diffusion tool at all levels, experts and scientists, and also for decision making in politics.
- To link the results from the prototype operation with the results attained by the benthic ecosystem analysis.

Action B4 was started before its foreseen start date and is currently finished. The actual end date of this action is in accordance with the 8-month extension granted for the project.

As it was explained in the progress report II, due to the change of the location of the fish cannery where the prototypes were finally installed, some samples were taken at **Location 1 - Esteiro (Ría de Muros e Noia),** and other samples were taken at the **Location 2 - O Grove (Ría de Arousa),** where the prototypes were finally installed. This new location was effective in May 2017, and in November 2017 the installation was completed, then starting to work in the beginning of 2018. Four samplings were completed in the new location (Location 2-O Grove) on June 2017, September 2017, December 2017 and March 2018. With the extension of the project confirmed, and because only the last sampling (March 2018) was made with the prototype fully operational, an extra sampling was conducted on March 2019, in order to have more accurate information about the effect of the prototype on the benthic ecosystem.

The activities undertaken on this action were as follows:

1. 9 **samplings** have been successfully completed along project execution time (4 samplings at Location 1 - Esteiro and 5 samplings at Location 2 - O Grove). This includes 1080 faunal samples, 216 sediment samples, 216 water samples and 144 sediment traps. This activity has been carried out by staff from University of Vigo. Some of the instrumental utilized in the sampling campaigns is shown in **Figure 30**.
2. Sorting and identification of the **benthic macrofaunal samples** has been completed for all the 1080 samples collected. This task was carried out by an external laboratory chosen by competitive tender (University of Porto).
3. Analysis of **sediment samples**:
   - The preparation, extraction and processing of the sediment samples for the quantification of inorganic nutrients, total ADN and C content, have been completed for the 960 samples, corresponding to the 9 samplings carried out in the 2 locations. These analyses were carried out by an external laboratory selected by competitive tender (SAI- University of Coruña).
   - The sediment characterization (mean grain size and sorting calculations), together with REDOX measurements, have been completed for the 216 samples collected at both localities by staff from the University of Vigo.
4. **Deposition rate of organic matter**: proteins fluxes were calculated for the 144 sediments traps located on the two locations studied. Samples collection, proteins extraction and calculations activities had been carried out by staff from University of Vigo.
5. Analysis of **water samples**: The physic-chemical parameters (temperature, salinity, pH, oxygen and saturation) were measured for all the 216 water samples collected at the 2 sampling locations. This activity has been carried out by staff from University of Vigo.

With the data collected and in order to provide the information about the environmental problems caused by the effluents discharged by the fish cannery industries, a **complete analysis of the benthic macrofauna community distribution** was achieved and the **structure of benthic communities** was determined from taxonomic point of view. Peaks of abundance of macrofauna (ind. m^{-2}) were observed at times where species richness decreases, which corresponds to moments of dominance of some species tolerant to slight enrichments of organic matter (e.g. *Mediomastus fragilis*). The highest diversity values were recorded at less impacted stations, as in the case of the control station B in the locality 1 - Esteiro.

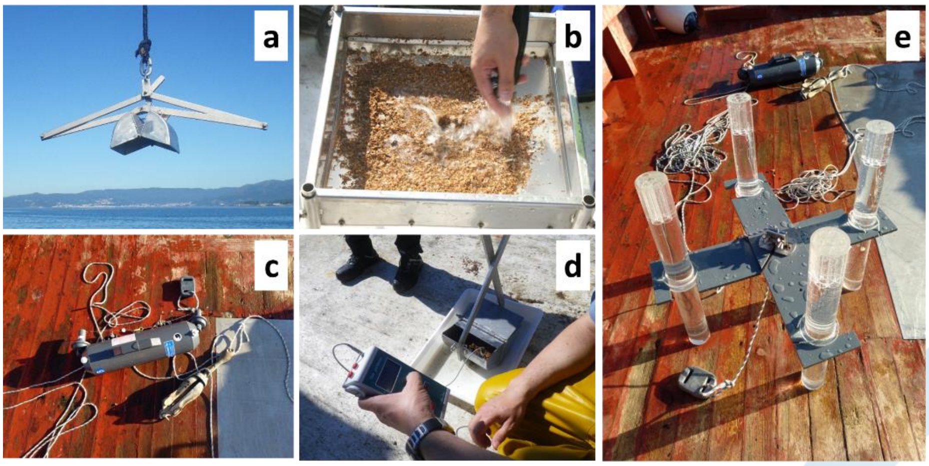

Figure 30 Instrumental used in the samplings: (a) Van-Veen grab; (b) 1.0-mm sieve; (c) Niskin bottle; (d) Eh-meter; (e) Sediment trap

A high spatial variability was detected in the **sediment characteristics**, showing significant differences in the mean grain size, % of fine sand and REDOX potential between stations in the Location 1 - Esteiro. Thus, the sampling station Control A was removed from the analysis of the macrofaunal assemblages because of its

major differences with the three remaining stations regarding sediment type. The main characteristic of the sediment collected at Location 2 - O Grove, was the presence of maërl beds, vegetable formation composed of slow-growing and free-living coralinaceous algae, whose three-dimensional structure serves as a substrate and refuge for a large number of animal and plant species (high diversity ecosystems), and are located in areas of moderate to strong current velocity. All of the maërl collected at the impacted stations (A and B) were living with healthy, uniformly pigmented appearance; while, the maërl around the control was mixed with coarse or very fine sand (see **Figure 31**).

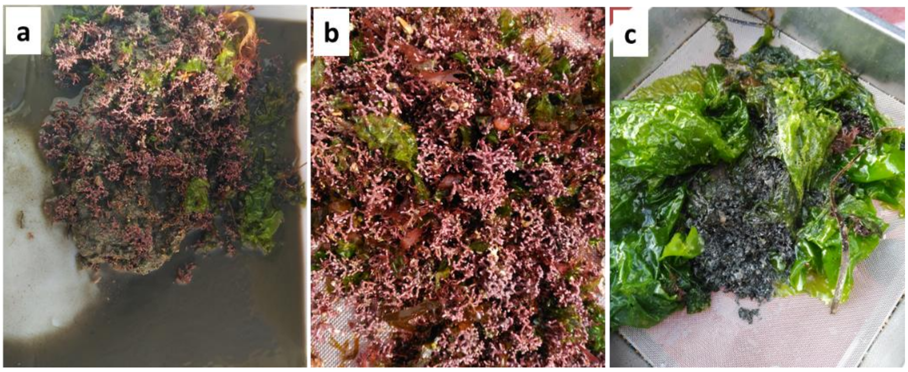

Figure 31 Photos of sediment samples from Location 2- O Grove collected at June 2016 (a) maërl mixed with coarse sand from Control A; (b) maërl from Impacted stations; (c) maërl mixed with very fine sand from Control B

The proteins fluxes from the surface to the bottom seabed were quantified and a clear seasonal pattern of the organic matter sedimentation was detected. Both, **organic matter flux and the physic-chemical parameters of the water column** (e.g. temperature, salinity) have shown no significant effect from the effluent of the canning industry.

The **relationship between community structure and abiotic variables** were determined by BIOENV analysis, which have shown that parameters as redox potential and sediment size (D50) are the main environmental variables affecting benthic community structure. Both abiotic variables (REDOX and D50) are related to organic matter enrichment.

The ecological quality status (EcoQS) of the benthic ecosystem in areas near of the wastewater discharge was determined. With that aim, diversity and biotic indexes were calculated and the result obtained integrated in the conclusions of the report. At the control Location 1- Esteiro, ecological status (according to both AMBI and M-AMBI) was significantly better when compared to both potentially impacted stations (see **Figure 32** and **Figure 33**) while at Location 2 – O Grove no effect of the effluent was observed and a healthy ecological status of the ecosystem was detected throughout the study period. In general, we have identified a moderate organic enrichment situation at Location 1 - Esteiro, but no at location 2 – O Grove, where no significant evidences of any effect associated to the effluent was probed. We hypothesize that the coastal local currents together with the discharged point location on an area with strong hydrodynamism could be modulating the impact of wastewater effluent on the area affected by the activity of the canning industry.

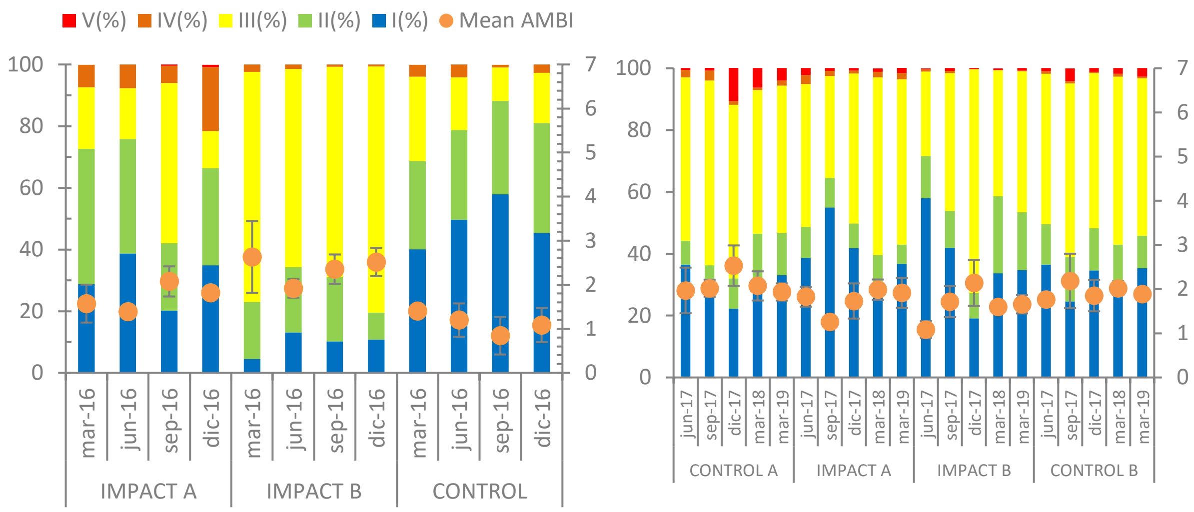

Figure 32 mean contribution of the 5 ecological groups of the benthic macrofauna recorded and mean value (n=6) of the AMBI index calculated at (a) Location 1 – Esteiro, and (b) Location 2 – O Grove

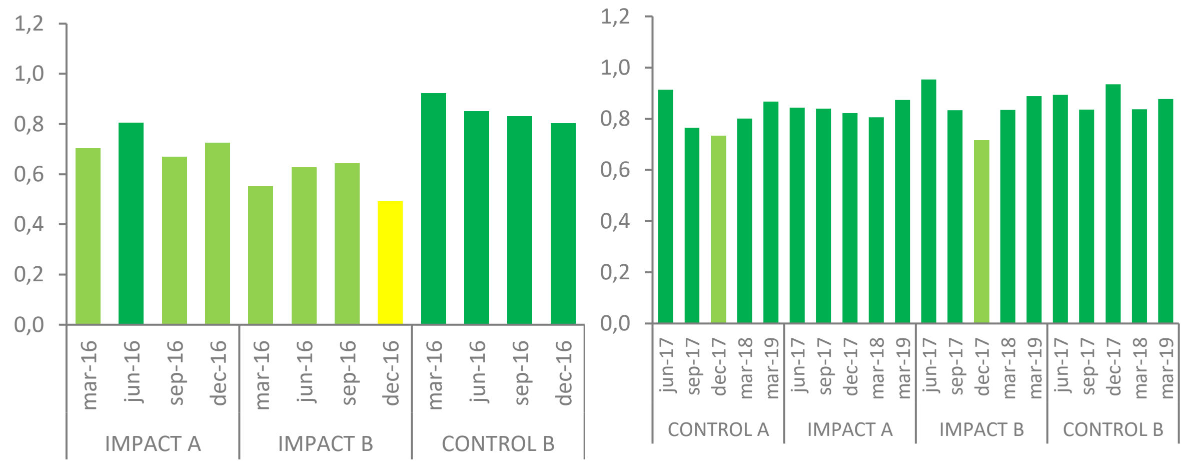

Figure 33 M-AMBI index and ecological status of the benthic ecosystem at (a) Location 1 – Esteiro, and (b) Location 2 – O Grove. The threshold values for the M-AMBI conditions are as follows: high quality > 0.77; good = 0.53–0.77; moderate = 0.38–0.53; poor = 0.20–0.38; and bad < 0.20

One of the main goals achieved with this activity was to obtain an extensive database of environmental and biotic variables on areas affected by discharge of wastewater from the caning industry. Both, the sampling design and the data collection aimed at compiling as much data as possible at a temporal and spatial scale, what has been partially achieved. To need to remark that the change in the place where the prototype was finally installed impacted negatively in linking the results from the prototype functioning with the biological results attained in the benthic ecosystem. The lack of temporal variability data at location 2 made us impossible to detect significant evidences of the positive effect of the new technologies on the benthic ecosystem.

In conclusion, the effect of the effluent discharged of the fish canneries on the sediment characteristics and the benthic community structure was detected. Thus, it was estimated than any improvement on the

technology of the wastewater treatment, as AGS and MBBR technologies, will have a positive effect on the benthic ecosystem status.

ACTION B5. Technical, environmental and economic assessment of the considered technologies	
Objectives. • To evaluate the scale-up of the technology in order to proceed with the technical comparison, a Life Cycle, Assessment and a Cost Benefit Analysis. • To compare the efficiency achieved by the Aerobic Granular Unit (AGU) and Aerobic Biofilm Unit (ABU) treatment units with that obtained in the conventional treatment systems, and between both biofilm configurations. • To perform a Life Cycle Assessment (LCA) to evaluate the two biofilm treatment processes, AGU and ABU, and to compare them with the conventional treatment, in order to validate the expected better performance, in terms of environmental burdens, of these novel technologies. • To conduct a Cost-Benefit Analysis (CBA) to evaluate the two biofilm treatment processes, AGU and ABU, and the conventional treatment from an economic perspective.	*Status:* Completed

In Action B5, the biofilm-based technologies proven in the LIFE SECAN project (AGS and MBBR technologies) were evaluated from a technical point of viewed and scale-up. They were compared to the current most common treatment technologies applied for the treatment of fish canning wastewater (CAS and physic-chemical treatments, the las one implemented at the site where the prototypes were installed). In addition, an environmental assessment was carried out by applying the Life Cycle Assessment (LCA) methodology and an economic assessment through the Cost Benefit Assessment (CBA) technique. The description of the methodology and results are detailed in Deliverable 8 (Annex 2.4).

Definition of scenario analysis

Fish-canning industries mainly generate two types of effluents, low strength (LS) and high strength (HS) wastewaters. Having said that and in order to fulfill all the possible combinations the following scenarios have been considered for the environmental assessment:

- Scenario 0a - baseline: Treatment of the Low Strength mixed (LSmix) wastewater in the actual physiochemical treatment plant;

- Scenario 0b – baseline: Treatment of the High Strength mixed (HSmix) wastewater in a conventional activated sludge (CAS) system, based on external data;

- Scenario 1a: Treatment of the LSmix by the AGS prototype;

- Scenario 1b: Treatment of the HSmix by the AGS prototype;

- Scenario 2: Treatment of the LSmix by the MBBR prototype

Environmental assessment

The LCA methodology aims at quantifying the environmental impacts associated to a product or process, along their whole lifespan and closely looking at each stage of the process. LCA methodology enables evaluating

trade-offs between different environmental areas of concern. In other words, through the LCA results it is possible to discern whether modifying the process to reduce an environmental impact might worsen another environmental vector.

LCAs has been widely used for assessing and comparing wastewater treatment plants (WWTPs) from the environmental point of view. Albeit LCA studies have often been applied to urban wastewater, increasingly more authors are focusing on assessing innovative treatment technologies. Similarly, LCA is increasingly more applied to assess the impact of wastewater treatment from industrial activities, thus enabling to compare the different treatment solutions based on the specific effluent characteristics and needs of the companies.

LCA studies should be applied uniformly to all processes, including the following four stages:

- Goal and Scope definition: The first stage consists in clearly defining the objective of the study, thus identifying the products or processes to be analyzed. The system must be delimitated, in order to clearly state what flows are included or excluded from the study.
- Life Cycle Inventory (LCI): All inputs, both materials and energy, and outputs, including products, byproducts, wastes and emissions to air, water and soil, have to be identified and quantified for each process stage.
- Life cycle impact assessment (LCIA): The inventory gathered is now associated with specific environmental impact categories, which reflect the environmental impacts of the substances included in the LCI.
- Results interpretation: Following the results of LCI and LCIA phases, conclusions must be made taking into consideration the possible issues, underlining the limitations and addressing recommendations.

A complete environmental analysis was conducted in order to study the performance of the two biofilm-based treatment technologies proposed in the project by means of the LCA methodology. Five impact categories from the ReCiPe Midpoint (H) LCIA Methodology were selected for the study (**Table 5**).

Table 5 Environmental impact categories evaluated

Impact Category	Unit	LCIA Methodology
Global Warming Potential (GWP)	kg CO_2 eq	IPCC method (IPCC 2013)
Marine Eutrophication Potential (MEP)	kg N eq	ReCiPe Midpoint (H)
Freshwater eutrophication Potential (FEP)	kg P eq	ReCiPe Midpoint (H)
Human Toxicity Potential (HTP)	kg 1,4-DB eq	ReCiPe Midpoint (H)
Terrestrial Ecotoxicity Potential (TTP)	kg 1,4-DB eq	ReCiPe Midpoint (H)

This selection was carried out based on the experience of previous studies dealing with the environmental analysis of wastewater treatment systems found in literature. One impact category related with energy use global warming potential (GWP), two categories related with eutrophication marine (MEP) and freshwater (FEP) eutrophication potential and two final categories associated with toxicity; human (HTP) and terrestrial ecotoxicity (TTP) composed the final selection.

The LCI including all inputs and outputs in the defined systems for the scenarios considered was carried out.

The results from the Life Cycles Impact Assessment are shown in **Figure 34** (LSmix scenarios) and **Figure 35** (HSmix scenarios). In both figures, values are presented in reference to the baseline scenario, i.e. the actual DAF-based treatment for the LSmix and the hypothetical CAS-based treatment for the HSmix.

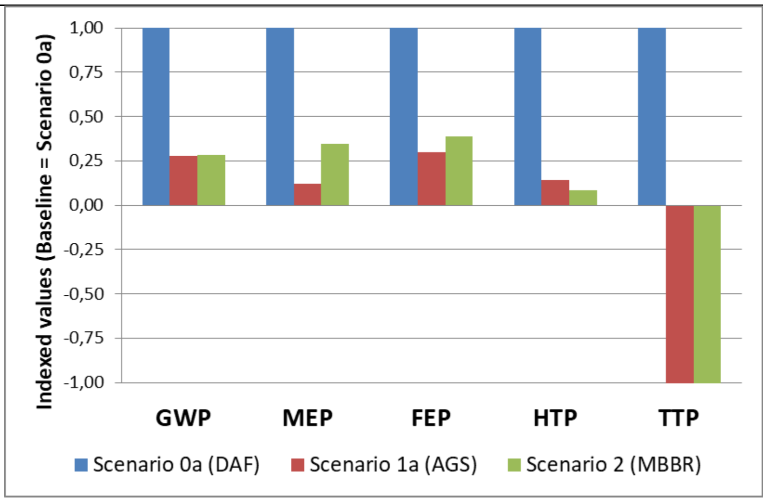

Figure 34 Comparative environmental performance of scenarios for LS mix.

Acronyms: GWP = Global Warming Potential, MEP = Marine Eutrophication Potential, FEP = Freshwater eutrophication Potential, HTP = Human Toxicity Potential, TTP = Terrestrial Ecotoxicity Potential (TTP)

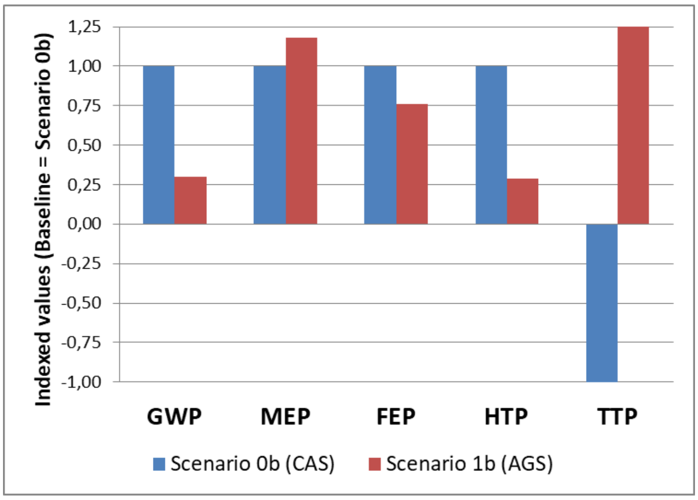

Figure 35 Comparative environmental performance of scenarios for HS mix.

Acronyms: GWP = Global Warming Potential, MEP = Marine Eutrophication Potential, FEP = Freshwater eutrophication Potential, HTP = Human Toxicity Potential, TTP = Terrestrial Ecotoxicity Potential (TTP)

Considering the level of accuracy that can be allocated to the results obtained from the present LCA, based on pilot scale systems, the conclusions that can be derived have to be considered as preliminary. In any case and having said that, it can be confirmed the improved performance of the two technologies tested and validated within the LIFE SEACAN project for all the impact categories under study (**Figure 34**), with the unique exception of a slightly higher impacts for the AGS prototype working with high loaded influent for the MEP and TTP, probably due to underestimations in the CAS system scenario with which is compared to (**Figure 35**).

Economic assessment

The Cost-Benefit Analysis (CBA) is a method frequently used that measures and compares socio-economic and environmental impacts of different alternatives for a project. All impacts are expressed in monetary terms,

through different valuation techniques, in order to be able to compare and rank all alternatives considering all the impacts. The main steps in the CBA are summarized herein:

- Identification of scenarios based on the technical analysis and scope of the project.
- Financial costs assessment of each wastewater treatment alternative.
- Initial investments and operational costs are evaluated for the total life cycle of the assets. The different options are adjusted and weighted in order to be comparable to the benchmark, in this case the actual industrial plant.
- Identification, quantification and evaluation of potential socio-economic benefits and costs resulting from the changes in environmental attributes that each scenario is expected to deliver.
- Integration of both previous results in the CBA.

In the last stage, the discount rate, used to bring to present values future ones is selected according to European recommendations, 4% for a 20-years assessment period. A sensibility analysis was performed to understand the fluctuations in the values under different rates.

Results of net benefits (benefits-costs) and total costs were presented as net present values (NPV), which allows to have a full picture of the financial and economic values for the life cycle of the assessment. In addition, results were annualized in order to display a smaller timescale picture, using the annual-equivalent cost formula.

The **financial assessment** results are presented as total and annual equivalent costs (AEC), as well as the price per cubic meter (**Table 6**).

Table 6 CAPEX estimates for LSmix (in orange) and HSmix (in green)

Scenario	CAPEX (€)	AEC (€/year)	€/m^3
Sc 0.A- DAF (Ph-Ch)	N/A	N/A	-
Sc 1.A- AGS LS	810,191	59,615	0.16
Sc2 - MBBR	771,064	56,736	0.15
Sc 0.B - CAS	1,855,514	136,532	0.36
Sc 1.B - AGS HS	810,191	59,615	0.16

The most advantageous technology for the LS mix in terms of CAPEX is the MBBR, closely followed by the AGS (5% difference). In the case of HS mix, AGS technology presents a clear advantage against the CAS, being a 56% below. The CAPEX for current scenario is not displayed as the study's focus is about the renewal of the present technology.

The recurrent costs (OPEX) are presented in **Table 7**, and their distribution is displayed in **Figure 36** (OPEX distribution for LSmix scenarios) and **Figure 37** (OPEX distribution for HSmix scenarios).

Table 7 OPEX estimates for LSmix (in orange) and HSmix (in green)

Scenario	Annual OPEX (€)	€/m3
Sc 0.A- DAF (Ph-Ch)	**279,263**	0.73
Sc 1.A- AGS LS	**82,041**	0.21
Sc2 - MBBR	**78,740**	0.21
Sc 0.B - CAS	**220,133**	0.57
Sc 1.B - AGS HS	**252,671**	0.66

In the LS mix context, the transformation of current WWTP technology (Sc 0A) to either AGS or MBBR would bring potential savings of 71% and 72% respectively. The major savings would come from the reductions in chemicals consumption. The personnel cost has been kept constant across all scenarios.

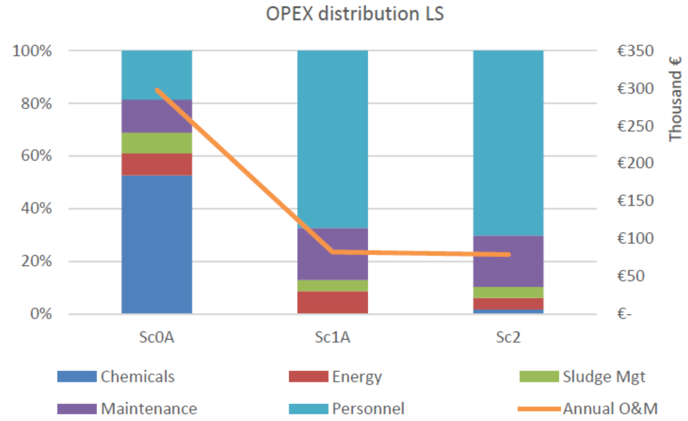

Figure 36 OPEX distribution for LSmix scenarios

The HS mix contexts presents more similar OPEX between scenarios, being the AGS costs a 15% higher than CAS, mostly due to the antifoam consumption. However, the major source of expense in the CAS is the energy bill, which is more vulnerable to fluctuations due to price changes.

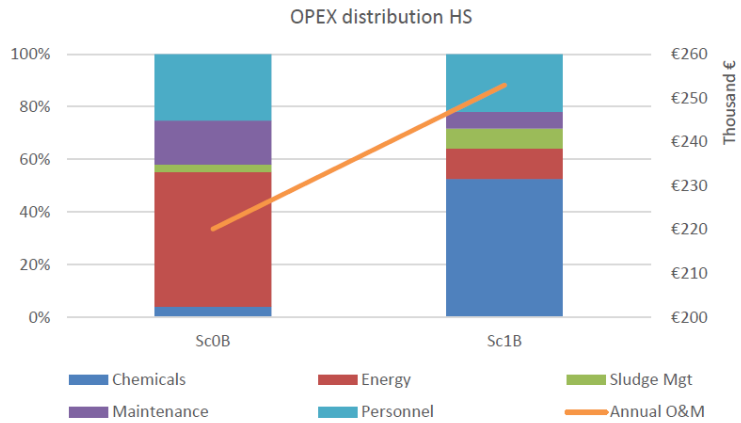

Figure 37 OPEX distribution for HSmix scenarios

The results of the **economic analysis** entail the comparative assessment of the welfare changes for society in general using environmental attributes, such as the monetized pollutant discharges from effluents, energy emissions, saved emissions from chemical agricultural fertilizer (replaced by biological sludge).

Table 8 displays the estimated environmental benefits per scenario, composed by the monetized values of saved air emissions from energy consumption and biological sludge use as fertilizer, and pollutants (N, P, COD) discharged to water bodies through the effluent.

Table 8 Estimated annual environmental benefits per scenario

	Energy emissions savings (€/year)	Water pollution savings, (€/year)	Biological sludge benefits (€/year)	Monetized emissions savings (€/year)
Sc0A -DAF	-			**-**
Sc1A - AGS	2,756	166,480	600	**169,836**
Sc2 – MBBR	3,319	87,790	3,235	**94,344**
Sc0B - CAS	-	-	235	**235**
Sc1B - AGS	13,084	30,264	1,773	**45,121**

Final results are presented as Annual-equivalent present values – annualized net present value of the 20 study period in unitary values in **Table 9**.

Table 9 Unit values of annual-equivalent results (€/m3)

		Net Benefit (€/m3)	Annual Equivalent Cost (€/m3)	Annual-Eq. CAPEX (€/m3)	OPEX (€/m3)	Environmental Benefit (€/m3)
LS mix	Sc0A	- 0.73	- 0.73	-	0.73	-
	Sc1A	0.08	- 0.36	0.16	0.21	0.44
	Sc2	- 0.10	- 0.35	0.15	0.21	0.25
		Net Benefit (€/m3)	Annual Equivalent Cost (€/m3)	Annual-Eq. CAPEX (€/m3)	OPEX (€/m3)	Environmental Benefit (€/m3)
HS	Sc0B	- 0.92	0.92	0.36	0.57	0.00
	Sc1B	- 0.69	0.81	0.16	0.66	0.12

The results displayed present positive net benefits only for the AGS scenario under the LS mix (Sc1a), where 98% of the benefits arise from the avoided water pollution. For the MBBR technology (Sc2), the environmental benefits do not exceed the expected costs, although costs are reduced 51% compared to the current scenario (Sc0a). When comparing HS mix results, net benefits of the AGS scenario, although negative, are a 25% higher than the CAS technology. This comes partially from lower costs (-12%) and substantially higher environmental benefits originated from water and air emissions reductions.

To understand the relevance of the results it is important to keep in mind that the wastewater treatment process of the food & beverage industry is a non-avoidable cost, and thus, the aim is to increase their efficiency and savings of the process. and not to generate a financial profit from it. Therefore, the benefits presented are in terms of welfare economics considered with a positive impact to society.

Conclusions

In conclusion, the two biofilm-based selected technologies for the evaluation within the LIFE SEACAN project have proven a significant reduction in all the impact categories under evaluation, reversing even from an impact to an environmental benefit in TTP due to the valorisation of the biological sludge produced by land application. Focusing on the comparison of the two novel technologies, the AGS-based scenario arises as the best option, reporting better results than MBBR-based scenario for the LSmix influent and reporting promising results for the HSmix influent.

Regarding the economic analysis, the AGS technology presents financial and welfare benefits in comparison to the DAF WWTP for the LS mix influent. MBBR presents 5% lower costs than AGS, subject to effluent discharge legislation, and welfare benefits are significantly lower. In addition, there are potential benefits in local economy from upcycling the biological sludge to agricultural fertilizer in the 2 biofilm-based technologies by both reducing disposed waste and avoiding production and usage of mineral fertilizer and potential space savings for the industry in the HSmix context.

ACTION C2: Geographical and sectorial replicability and transferability		
Objectives. • Identification of other potential geographical areas and ecosystems for the implementation of the demonstrated technology and transferability assessment. • Assessment and validation of the innovative treatment technologies proposed in the LIFE SEACAN project for the treatment of effluents generated in different industrial sectors.		*Status:* Completed
Official start date: 07/2018	Actual start date: 07/2018	
Official end date: 10/2019	Actual end date: 10/2019	

The objectives of this action were to identify potential geographical areas and ecosystems for the implementation of the demonstrated technologies (AGS and MBBR) and transferability assessment; and to assess these technologies for the potential treatment of other types of wastewater generated in different industrial sectors.

C.2.1. Assessment of the replicability to other European areas and elaboration of a Management Plan

It is interesting to find other European areas which are suffering from the same problem as the Galician coast related to the pressure on the marine ecosystem because of the fish canning industry. The main producers of canned fish by order are Spain, France, Italy, Portugal and Germany. The main product is tuna (58%), followed by sardines, mackerel and mussels.

Having a great many European countries with high rates of production, it means that it is possible to find several sensitive water bodies which may be under industrial pressure. One of these zones is the Atlantic Coast, in which fishing has major problems, including the use and dumping of diesel by the fleet and antifouling painting. Other highly affected waterbody is the Mediterranean Sea due to it is receiving water from the tree largest producers of canned fish in Europe. Eventually, notorious problems have been reported in the Baltic Sea given that nearly the entire waterbody is affected by eutrophication as it is shown in the PLC (Pollution Load Compilation) which alarm large amounts of organic load and nutrients released.

Given that the countries in which the canning industry has more presence bathe the Mediterranean Sea, it is presented as one of the most polluted bodies of water in the world. In some areas where the canning industry is important, it causes practically 50% of the water pollution. In some basins in the Mediterranean, the canning industry contributes around 12,000 tons of biochemical oxygen demand (BOD) every day, out of a total of 22,500 tons of wastewater.

Eutrophication is a major problem in the Baltic Sea. Since the beginning of the 20th century, the Baltic Sea has changed from an oligotrophic clear-water sea into a highly eutrophic marine environment. This phenomenon is to a large extent driven by anthropogenic inputs of the nutrients nitrogen and phosphorus, resulting in nutrient over-enrichment and/or changes in nutrient ratios causing elevated levels of macrovegetation, increased turbidity, oxygen depletion in bottom waters, changes in species composition and increase or nuisance blooms of microscopic algae. According to a recent HELCOM assessment of eutrophication status during 2007-2011, nearly the entire Baltic Sea is affected by eutrophication. In this way, it is convenient that countries bathed by the Baltic Sea such as Poland and Germany focus their efforts on the adoption of new technologies to combat the ecological deterioration of their bodies of water.

Taking into consideration that there are several countries with very high production of canned fish, the effects of this type of industrial sector is significant in Europe, but it does not mean that in other parts of the world there are

no effects of producing canned fish. So, it is also possible to find countries which register considerable production in the world such as Thailand, Cambodia, Vietnam, the Caribbean countries or South America. With the aim of collecting the countries in specific zones, it could be defined three areas where sensitive water bodies are found. These are the Gulf of Thailand, the Caribbean Sea and South America Coast, places in which the LIFE SEACAN technology could have room. The Gulf of Thailand includes three large producers of canned food such as Thailand, Cambodia and Vietnam, in which they are suffering from eutrophication with problems as red tide phenomena. In the abovementioned countries, it was registered a rapid decrease in coral reefs and fisheries resources due to mismanagement. The Caribbean Sea bathes the Gulf of Mexico, which is the most polluted area, above all Trinidad and Tobago. In these areas, canning industry releases water high in BOD5, COD and TSS. As for South America coast, Brazil, Uruguay and Chile are the most affected areas of the territory.

An oral presentation of LIFE SEACAN was accepted and presented at the international conference World Water Congress and Exhibition (15-21 September 2018) (action D1). The presentation of the project and the dissemination of the results was useful to establish contacts and make networking with international Univesities/Companies working on biofilm-based technologies and industrial sectors with high saline effluents. The feedback and intereset for the technologies presented was high. It was detected also the interest of the technology in the coast of Brazil (meeting with a professor from there), in which the effluents from meat processing industry cause serios problems in the water bodies. From this interaction it was clear that the LIFE SEACAN technologies have market opportunities in Europe and in the World.

C.2.2. Assessment of the transferability to other industrial sectors

The treatment of industrial effluents is difficult because their features are specific, and the wastewater varied from one sector to other.

Food & Beverage sector is of high importance in the global market. The wastewater characteristics of the F&B wastewater are: biodegradable wastewater, sometimes high nitrogen concentration, high COD concentration, stationary operation, presence of inhibitory compounds (e.g. salinity). Therefore, the treatment of this wastewater with conventional technologies is very difficult. From the results obtained in the LIFE SEACAN project (action B2), it is clear that the biofilm-based technologies, especially the AGS technology, are suitable for the treatment of the F&B effluents, being, in general, the main market for the LIFE SEACAN technologies.

Within the EU, the following specific sectors were identified and described in detail in the Deliverable D11 (Annex 2.9), as potential sectors to be treated with AGS technology, due to the market importance, environmental impact and technical feasibility:

<u>Dairy industry</u>

All 28 Member States produce milk. The main producers of cow milk which are Germany, France, the United Kingdom, the Netherlands, Poland, Italy and Ireland, accounting together for three quarters of total EU production. The remaining 21 Member States produce just a quarter of EU production. Given that Germany is the first producer of cow's milk in Europe, it is suffering from important problems of eutrophication due to the uncontrolled discharges.

Regarding this sector, Cetaqua Galicia has demonstrated the applicability of AGS technology for the treatment of dairy industry wastewater in a reactor of 30 L, which results were very positive and promising, showing the feasibility of the technology for this sector.

<u>Wine production industry</u>

The most important producer is Italy, followed by France and Spain. Despite being Italy the first in terms of production, the Spanish wine industry generates six times more wastewater than France or Italy, mainly due to the low cost of the disposal fee.

This sector is characterized by the stationary production. This could be an advantage for the AGS technology respect to conventional treatment system. The changes and recovery of the AGS system is very rapid, which could make it appropriate for this type of sector.

Poultry meat industry

According to Eurostat, the European Union produced 15.2 million tonnes of poultry meat in 2018, a new high. This represents a cumulative rise of about one quarter or 3.2 million tonnes since 2010.

Since Poland has an important weight in production, the pressure on the environment in this country is remarkable. Apart from the waste related to the breeding of poultry, its passage through the slaughterhouse is also very important, so the impacts of this type of industry are very varied.

The most significant environmental issue resulting from slaughterhouse operations is the discharge of wastewater into the environment. Like many other food-processing activities, the necessity for hygiene and quality control in meat processing results in high water usage and consequently high levels of wastewater generation. Typical water usage in poultry slaughterhouses ranges between 6 and 30 m^3 per tonne of product. Large quantities of water are consumed in poultry slaughterhouses for evisceration, cleaning and washing operations.

Given the problems raised above, the discoveries derived from LIFE SEACAN can be vital to combat the environmental pressure derived from poultry farming in countries like Poland or United Kingdom.

Livestock industry

The Netherlands remained the Member State with the highest livestock density, reaching 3.8 LSU/ha in 2016. Malta and Belgium also reported high livestock densities, with 2.9 and 2.8 LSU/ha respectively. The same three countries recorded the highest densities of grazing livestock in 2016, with 2.7 grazing LSU/ha fodder area in the Netherlands, 2.5 LSU/ha in Malta and 2.4 LSU/ha in Belgium. Therefore, the biggest pollution problems caused by livestock are in the countries named above, although the most serious polluting events are registered in the Netherlands and Belgium.

In Cetaqua Galicia there is also testimony about the application of AGS technology to the livestock industry. The liquid fraction of pig manure was treated in a 30 L reactor, having achieved good granulation (very stable and well-defined granules) as well as an establishment of granulation.

Agricultural sector

In accordance with the data which appears in Eurostat, the higher percentage of millions of hectares cultivated from total surface area is found in France, followed by the Netherlands and Belgium. And as it is well-known, apart from human settlements and industries, agriculture is the major source of water pollution. This sector, which accounts for 70% of water abstractions worldwide, discharge large quantities of agrochemicals, organic matter, drug residues, sediments and saline drainage into water bodies. The fight against the serious effects of some of the aforementioned pollutants must be the motivation for the transferability of the technology used in the LIFE SEACAN to the agriculture sector.

To **sum up**, there are a few places in Europe where there have been registered problems related to the pollution of the seas. Thus, the replicability of the technology developed in the LIFE SEACAN project could be applied in zones such as Mediterranean countries as well as those bathed by the Baltic Sea in order to reduce the pressure over the waterbodies. Considering that the main competitor (Nereda®) is in the urban sector, the market niche is wide in the industrial sector.

In addition, there were identified several industrial sectors which could be appropriate to assume the technology. Food & Beverage sector turned to be the one more suitable for receiving the research derived from LIFE SEACAN due to its wastewater characteristics (biodegradable, COD and N content, high conductivity) as well as the new

legislation (BREFs) which must be met. Specifically, the dairy industry and the livestock are sectors which demonstrations at CETAQUA for the AGS technology have been carried out already with promising results.

ACTION C3: Socio-economic impact assessment	
Objectives. • To assess all the weaknesses ("costs") and strengths ("benefits") of the technology proposed in the Life Seacan, considering all the derived socio-economic effects in comparison with other conventional treatments (i.e. the solution being used at the pilot cannery) • To quantify the socio-economic impact of the project actions on the local economy and population	*Status*: Completed

The socio-economic impact assessment was carried out through the Cost Benefit Analysis. As described in action B5, CBA is a method used to measure and compare socio-economic and environmental impacts of different alternatives for a project. With the aim to appraise the investment decision alternatives related to the implementation of industrial WWTP technologies in the fish processing and canning industry, it is important to address the evaluation of welfare and environmental changes attributable to these alternatives. CBA identifies and compares the costs and benefits brought by the proposed project, including social and environmental costs and benefits. Therefore, all impacts identified within the project are expressed in monetary terms, which is useful to compare and rank alternatives.

In the LIFE SEACAN context, the environmental indicators monetized are emissions to water bodies, emissions from energy consumption, and valorization of the biological sludge for agricultural fertilizer use, which avoids manufacturing new fertilizer. In addition, operation and maintenance costs (OPEX) include energy and chemical consumption, as well as sludge management as relevant actual costs related to environmental and social welfare. The initial investments (CAPEX) for the alternative scenarios have been scaled up from the pilots, and the one for the HS baseline scenario was scaled down from a WWTP with a similar technology in order to match the flow of the case study. Both cost lines are annualized through the study period set at 20 years, to make a comparative of the full picture of costs. Benefits, understood as avoided damages, and costs are added up to obtain the net benefit of each scenario.

The detailed results from the CBA study are presented in Deliverable 18 (Annex 2.6). The global results of the CBA for the LSmix scenarios are shown in **Figure 38**, displaying positive net benefit for the AGS (Sc1a), where 98% of the benefits arise from the avoided water pollution. For the MBBR technology (Sc2), the environmental benefits did not exceed the expected costs, although reducing the costs 51% compared to the current scenario (Sc0a).

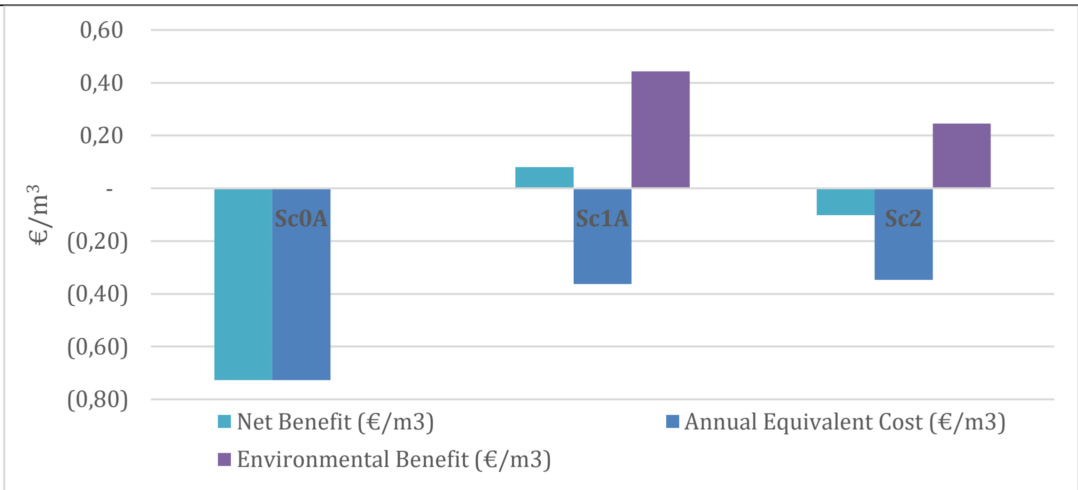

Figure 38 Estimated CBA results for scenarios in LS mix (€/m^3)

In the LS mix context, total costs savings calculated for AGS and MBBR prototypes ranged between 49-51% compared to the current DAF technology, including the additional investment required to renovate the plant. If only operating costs are considered, savings reach up to 72%. Environmental benefits are estimated at 0.44 €/m3 for AGS and 0.25 €/m3 for MBBR, mostly (98%) originated from avoided water pollution discharges.

In the case of HS mix, initial investment costs of AGS are up to 56% lower than CAS technology, partially balanced out by 15% higher OPEX, with a total costs savings of 12%. Benefits estimated for the CAS technology are nearly negligible, while the AGS HS scenario presents 0.12 €/m^3. Lastly, it is relevant for interested industries the benefits related to reduction of space requirements for the AGS technology in this HS mix context. The technology space requirements have been analyzed in order to understand the potential impact to the industries' land management. In the case of HS mix, the AGS technology reduces 81% the space usage compared to the CAS

To conclude, AGS technology presents financial and welfare benefits in comparison to the DAF WWTP for a low strength wastewater mix. MBBR presents 5% lower costs than AGS, subject to effluent discharge legislation, and welfare benefits are significantly lower. In addition, there are potential benefits in local economy from upcycling the biological sludge to agricultural fertilizer by both reducing disposed waste and avoiding production and usage of mineral fertilizer.

5. Benefits of the project

Environmental benefits	
Direct / quantitative environmental benefits	*Energy consumption reduction*. The biofilm-based systems are expected to have an energy savings about 20-30% when compared to conventional activated sludge processes. In this project, the traditional wastewater treatment system DAF (dissolved air flotation) was compared to the AGS and MBBR since this is the actual system being used in the fish canning site where the pilots were installed. After the evaluations, the DAF system resulted to have an energy consumption of 0.758 kWh/m^3. In comparison, MBBR and AGS had less energy consumption, 0.355 kWh/m^3 and 0.251 kWh/m^3, respectively. This implies an energy reduction for the biofilm-based technologies demonstrated in the LIFE SEACAN higher than 50%. *Reduction of environmental pollutants*. Effluents coming from fishery manufactured processes contains elevated values of organic matter and nitrogen, which are conventionally removed with wastewater treatment systems designed for less loaded streams. Advantageously, aerobic granular sludge systems as well as biofilm reactors can withstand with high concentration of both organic matter and nitrogen achieving outstanding removal efficiencies. This would increase the quality of the effluents discharged into the sea avoiding problems such as eutrophication. In the LIFE SEACAN, it was calculated that the marine eutrophication potential is reduced by 85% and a 65% for AGS and MBBR, respectively, in comparison with the actual wastewater treatment (DAF) of the fish canning plant. For the case of Freshwater Eutrophication potential, the AGS technology offered a reduction of 70% meanwhile the MBBR achieved a 60%. *Improvement of effluents quality*. The effluent quality has been improved in terms of nitrogen and COD removal. High efficiency removals have been achieved. AGS protype had a reduction of the 70-80% in terms of total COD and up to 90% nitrogen, fed with low-strength wastewater. In case of AGS fed with high-strength wastewater, COD removals were equal or higher for COD, but nitrogen removal was lower, 30-40% due to the high nitrogen concentration of this type of wastewater. For the MBBR, COD removal efficiency was higher than 70% and total nitrogen removal of 70%, for low strength wastewater. *Reduction of carbon footprint*. The biofilm-based technologies demonstrated in the LIFE SEACAN would lead to a significant reduction of the carbon footprint if compared to conventional systems. Taking into account the scenario of low strength wastewater, the carbon footprint reduction is 74% lower for AGS and 72% for MBBR. AGS technology has a carbon footprint reduction of 73% in comparison with a CAS (Conventional Aerobic Sludge) if considering high-strength wastewater.
Relevance for environmentally significant issues or policy areas	Galician Rías, where 85% of the canneries in Spain are located (discharging 8,600,000 m^3 of wastewater every year), are areas of invaluable environmental relevance. They include a National Park and several areas included in Natura 2000 Network. Water Framework Directive (2000/60/CE) and Marine Strategy Framework Directive (2008/56/CE) highlight the importance of the environmental protection of European waters. Efficient treatment of industrial effluents was optimised: i) To protect, conserve and enhance the Union's natural capital according to the 7th EU Environment Action Programme

	ii) To safeguard the Union's citizens from environment-related pressures and risks to health and wellbeing according to the 7th EU Environment Action Programme iii) to fulfil Industrial Emissions Directive (2000/75/EU) and Marine Strategy Framework Directive (2008/56/EC). The results of the project allowed to determine the environmental relevance of the project in terms of its impact both on benthic faunal assemblages and on physical-chemical features of the sediment and the seawater in the vicinities of the discharge points of wastewater from canning industries. Moreover, the results and technologies are of high importance for the industrial sector. The food, beverage and milk industries are soon releasing a new legislation for the emissions, which is described in the draft of the BREFs published in 2019. In this new legislation it is clear the need of applying new biological systems to meet the new discharge limits.
Long-term benefits and sustainability	
Long-term / qualitative environmental benefits	Improvement of the quality of the marine environment where the effluents are discharged. Protection of marine biodiversity and improvement of productivity. The outcomes of the project are helpful to raise the awareness about the importance of reducing the impact of industrial activities on marine environment, both among industry and among general public. In the project it was studied the application of the biofilm-based technologies to other sectors and areas. If the technology is implemented, the positive environmental impact would be higher than the specific application in the coast of Galicia (Spain).
Long-term / qualitative economic benefits	Cost reduction for water management in CAPEX and OPEX. CAPEX cost in traditional wastewater treatment (CAS) is 0,36 €/m^3, however, AGS and MBBR costs are 0,16€/m^3 and 0,15€/m^3 respectively. The costs associated with OPEX are also lower in biofilm systems compared to traditional systems. DAF system have a cost of 0,73€/m^3 and CAS system of 0,57€/m^3. AGS OPEX cost is 0,21€/m^3 for low-strength, the same cost for MBBR system, and 0,66€/m^3 for high-strength. This savings in CAPEX and OPEX would allow the modernization of the fish-canning industrial sector with the respective benefit in the production costs. A higher awareness about the importance of reducing the impact of industrial activities on marine environment and improving their sustainability can boost the development of new wastewater treatment technologies, both for canneries and for other industrial activities In addition to the conventional CAPEX and OPEX, the environmental benefits (energy savings, water pollution savings and sludge management savings) of each of the technologies proposed were monetized to be included in the economic evaluation. With respect of the studied scenario this environmental savings would suppose 169836 €/year in the case of AGS and 94344€/year in the case of the MBBR. The improvement of the coastal areas will enhance the tourism and sea activities.
Long-term / qualitative social benefits	*Boosting of tourism sector*. The conservation of coastal areas encouraged by LIFE SEACAN project will positively affect the tourism sector related to the marine ambient. Increasing

	the quality of effluents discharged on sea maintaining or improving the environmental status of marine ecosystems. *Increase in the number of potential employment positions* for qualified experts in biofilm-based wastewater treatment systems. Also, the industrial activity would be improved and jobs could be generated in this sector. *Preservation of the human health by producing better quality effluents.* *Improving the environmental quality of Galician Rías* have a remarkable positive impact for economic activities such as fishing, aquaculture and tourism, which have a major socioeconomic relevance in the area. *Increase of fish processing industry sustainability and competitiveness*. The fish processing industry employed almost 150000 people in Europe and accounted for more than 6000 million of Gross Value Added. Particularly, in Galicia fish cannery industry reports 16.000 direct jobs and 12.000 indirect jobs. LIFE SEACAN pursue the preservation of marine ecosystem which have a deep impact in the maintenance and boosting of fishery sector in coastal areas.

Replicability, demonstration, transferability, cooperation

The developed technology AGS is expected to have the potential to be applied in the fish caning sector and other industries from the agro-food sector. Cetaqua had other projects related to this technology but applied to other sectors. Specifically, Cetaqua has demonstrated the AGS technology for the dairy and livestock sector in reactors of 30 l.

The transfer of the technology and its industrialization (AGS) is being carried out. Cetaqua is promoting these activities with the support of Suez Group, which has experts in technology transfer. Besides, Cetaqua has a specific department for communication and transfer.
Near specific actions are:

- Meeting with the managers of the fish canning industry where the pilots were installed to evaluate the implementation of the technology.
- Assessment of implementation in other sectors, firstly in Spain. This is being done by analysing the market opportunities and creating a sectorial decision map.

Moreover, cetaqua has a close collaborative relation with the stakeholder Anfaco-Cecopesca, representing a body of fish cannery industry. A recent project dealing with the recovery of valuable products from wastes and wastewater of fish cannery industry is being carried out between Cetaqua and Anfaco-Cecopesca, besides others. This project came from the LIFE SEACAN collaboration, from which new research and development lines are explored. LIFE SEACAN is dealing with the treatment of wastewater; in a forward step, wastewater treatment will be coupled to valuable products recovery in order to achieve the circular economy concept.

Furthermore, the scientific methods used in this action may be used in the future for similar studies of environmental impact assessment.

Best Practice lessons

From the results of the monitoring campaigns on the benthic ecosystem, it was concluded that innovative technologies need to be applied to improve the wastewater treatment in the industrial sector. In this sense, the application of biofilm-based technologies is a good practice to treat complex industrial wastewater.
Innovation and demonstration value
Aerobic granular sludge reactors have not been tested before for the treatment of fish canning effluents at pilot scale. For this reason, the level of innovation at demonstration scale of this technology is considered high. Moreover, there are not reference regarding the application of MBBR technology for the treatment of fish caning wastewater, being the demonstration of this project the first one. EU funding has made possible the inclusion of this thorough environmental impact assessment action in the project, thus allowing us to determine the environmental relevance, at different levels, of the implementation of new wastewater treatment technologies in industries that discharge their effluents in coastal areas. It is rather infrequent that the environmental performance of prototypes for industrial activities can be assessed with this level of detail. From the environmental and economic assessment, it was shown the high improvement that would be achieved if biofilm-based technologies are applied.