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Activated Sludge Process Design & Simulation of a Domestic Wastewater Influenced by Wine Production

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1. Abstract

Urban wastewater can have different characteristics depending on its origin and the industrial component. When focusing on wastewater influenced by wine industry, these characteristics are very significant for the design of a Wastewater Treatment Plant. This wastewater gathers a high quantity of organic matter during the harvest of the grapes season (vintage). In this study are evaluated and solved the main difficulties in the design of an Activated Sludge (AS) process from an urban WWTP in a winery region in Aragón, Spain.

After a research, it has been concluded that the main challenges for the water treatment of urban winery regions like this are the high flowrate and high organic matter load, especially in the shape of readily biodegradable organic matter (mainly organic acids, sugars and alcohols). Another difficulty found has been the lack of nutrients needed for the microorganisms to biologically treat the organic matter in this wastewater.

After the research has been done, the peaks of organic matter have been solved by designing the AS process with the influent parameters from the month of October as a worst-case scenario. Designing the plant to meet parameters in this scenario ensures that the system will overcome the increase of organic load provoked during vintage period. The AS process will also perform properly during the rest of the year.

Secondly, through the influent analysis, the nitrogen scarcity challenge has been analyzed. It has been concluded that the minimum BOD_5 ratio of BOD_5:TKN:TP = 100:5:1 has not been achieved during some parts of the year. Because of this, the minimum nitrogen and phosphorous ratio in the Activated Sludge process has been increased into BOD_5:TKN:TP = 100:7:1.2 to calculate the ammonia and orthophosphates addition that is needed in every month of the year.

Then, a preliminary design of the AS process has been performed according the ASM1 model and using the worst-case scenario influent. This model can give an idea of the dimensions of the system, which is adjusted and checked later through simulation. However, this model requires a COD fractioning, and, in this case, it hugely varies from a standard one because the readily biodegradable COD fraction (like organic acids, sugars and alcohols) takes a high percentage. COD fractioning from Beck and collaborators work (2005 [(1)]) has been used as a reference, since it is also devoted to urban wastewater from a winery region. This fractioning suits better because it lowers the recalcitrant fraction of the COD in the influent and increases the biodegradable one.

After the ASM1 calculation, the design volume of the aerobic reactor has been set at 248.8 m^3 and its Solid Retention Time has been stablished at 5 days. The design inlet flowrate has been 1.5 times higher than the flowrate of the worst-case scenario influent.

In the last part of the report, LynxASM1 software has been used to perform the simulation of the AS system and it takes the ASM1 values obtained in the preliminary design. A worst-case scenario and a yearly simulation have been made to assure that the effluent meets the legislation standards of a WWTP with no nitrogen release limitations.

2. Nomenclature

- AS: Activated Sludge
- WWTP: Wastewater Treatment Plant
- COD: Chemical Oxygen Demand
- S_I: Non-biodegradable soluble COD
- S_S: Readily biodegradable COD
- S_O: Dissolved oxygen
- S_{NO}: Nitrate and nitrite nitrogen
- S_{NH}: Ammoniacal nitrogen
- S_{ND}: Biodegradable soluble organic nitrogen
- X_I: Non-biodegradable particulate COD
- X_S: Slowly biodegradable COD
- X_{BH}: Active heterotrophic biomass
- X_{BA}: Active autotrophic biomass
- X_P: Particulate products arising from biomass decay
- X_{ND}: Particulate biodegradable organic nitrogen
- TSS: Total Suspended Solids
- BOD: Biological Organic Demand
- SRT: Solids Retention Time
- HRT: Hydraulic Retention Time
- $C_{D,BOD5}$: BOD load in the inlet
- Ks: Half-saturation coefficient for heterotrophs
- Kd: Heterotrophic decay rate
- μ_H: Heterotrophic specific growth rate
- $\mu_{H,MÁX}$ Heterotrophic maximum specific growth rate
- θ_X: SRT
- $\theta_{X,MIN}$: Minimum SRT
- $S_{S,OUT}$: Readily biodegradable COD in the outlet of the AS
- Y_H: Heterotrophic yield

- **Q:** AS inlet Flowrate
- **V**: Reactor Volume
- **$X_{BH,R}$:** Heterotrophic biomass in the settler
- **Q_W:** AS Purge flowrate
- **R**: Recirculation flowrate factor
- **Q_{rs}:** AS recirculation flowrate
- **Q_{in}:** AS inlet flowrate
- **$Y_{H,OBS}$:**Observed Heterotrophic yield
- **$X_{BH,W}$:** Heterotrophic Biomass in the recirculation
- **r_{so}:** Oxygen consumption rate
- **V**: Reactor Volume
- **OR**: Oxygen Rate

3. Introduction

The project has started with the analysis and characterization of the wastewater to be treated. Yearly data of a real influent from Aragon Autonomous Region, Spain, has been provided.

The wastewater data comes from a domestic sewage in a small town located in a wine region of the Autonomous Community of Aragón, Spain. Wine production is one of the most robust industries in the world and every year is increasing its production. The global production of wine in 2013 was of 265 MhL which 68% came from Europe [(2)].

Wine production has always been known as a clean process. However, there is a great quantity of waste generated for every liter of wine produced. It has been estimated that for every 100 kg of grapes, 23.5 kg of residues (skins, seeds, lees, etc.) and 141 kg of wastewater are produced (most from cleaning the tanks and bottling facilities) [(3)].

If focusing just in wastewater, 1 to 4 liters of wastewater are generated for every liter of wine produced and it varies depending on the working period of the wine cellar (racking, bottling or vintage) [(4)]. These are the main characteristics of raw winery wastewater:

- Variable pH: Slightly acidic due to the accumulation of fermentation process waste. However, the mixture with the rest of the domestic wastewater sets the pH value in the inlet of the AS process near to 7 almost all year.

- High organic load: The major constituents of these effluents are organic acids (tartaric, lactic and acetic), sugars (glucose and fructose) and alcohols (ethanol and glycerol). Except of polyphenols, a great part of them are biodegradable (5).

- Lack of nutrients: There can be found a low concentration of nitrogen and phosphorus, which may cause an imbalance on the recommended ratios for biological treatment when this effluent is submitted to conventional treatment.

- Seasonal: Wine production involves several steps that take place during all year. Each one of them leads to significant variations in volume, organic load and other parameters of the wastewater.

The main environmental impact of winery wastewater when is not properly treated is eutrophication (due to an excess of easily biodegradable organic content like sugars or alcohols, not to nutrient excess) which can lead the consumption of the dissolved oxygen in rivers or lakes. Other impacts of winery wastewater can be the alteration of physiochemical properties of groundwater, the inhibition effects on plant growth (due to high electrical conductivity), and the hazardous effects produced by small concentration of some phenolic compounds (6,7,8).

However, the wastewater data that is being analyzed doesn't have a high percentage of raw wastewater because, as it was said before, it comes from a small town where it is mixed with urban wastewater. This mixture is done to lower the risk of receiving high organic loads in the WWTP.

The treated water coming out from this WWTP will have to reach European Union legal requirements. These requirements are the ones marked in the "*Council Directive 91/271/EEC concerning urban waste-water treatment*" (9), exactly the ones referring to WWTP's working with a secondary treatment. In Table 1 are shown the main parameters limits for these WWTP's:

Table 1: Legal concentration requirements for wastewater disposal in the EU.

PARAMETER	**CONCENTRATION (mg/L)**	**% MIN. REDUCTION**
BOD_5	25	70-90
COD	125	75
TSS	35	90

4. Goals

The general objective has been to determine the conditions of design and operation of a wastewater treatment based on an activated sludge system and that it guarantees a good quality of the effluent, despite the nutrient scarcity and the organic load and flow peaks caused by the wine industry activity in the area.

To achieve this objective, the following steps have been pursued and achieved:

- Analysis of the annual influent data.

- Determination of worst-case scenario of operation.

- Preliminary calculation of the design according to the ASM1 model and based on the worst-case scenario.

- Simulation of the process according to the results of the ASM1 calculation until reaching the design and operation conditions that allow to obtain an effluent within the legal limitations.

- Verification, with a yearly simulation, that the limitations are also met throughout the year, maintaining the same design and operation conditions.

5. Methodology

The methodology of this report involves all the tools used to pre-design and simulate and Activated Sludge process. The key tools used from design and simulation have been the ASM1 Model and the LynxASM1 simulator, respectively.

Activated Sludge Model No. 1 was created in 1983 by the International Association on Water Quality (IAWQ) and it facilitates the application of practical models or design and operations of biological wastewater treatment systems [10]. It easies the design because it just involves 7 COD components, 7 Nitrogen components and 2 other components:

- S_I: Non-biodegradable soluble COD
- S_S: Readily biodegradable COD
- X_I: Non-biodegradable particulate COD
- X_S: Slowly biodegradable COD
- X_{BH}: Active heterotrophic biomass
- X_{BA}: Active autotrophic biomass

- X_P: Particulate products arising from biomass decay

- S_{NO}: Nitrate and nitrite nitrogen
- S_{NH}: Ammoniacal nitrogen
- S_{ND}: Biodegradable soluble organic nitrogen
- X_{ND}: Particulate biodegradable organic nitrogen
- S_{NI}: Non-biodegradable soluble organic nitrogen
- X_{Ni}: Particulate non-biodegradable organic nitrogen
- X_{NP}: Particulate nitrogen arising from biomass decay

- S_O: Dissolved oxygen
- S_{ALK}: Alkalinity

This total of 16 variables are consumed or produced in a total of 8 dynamic processes in the biological reactors of activated sludge:

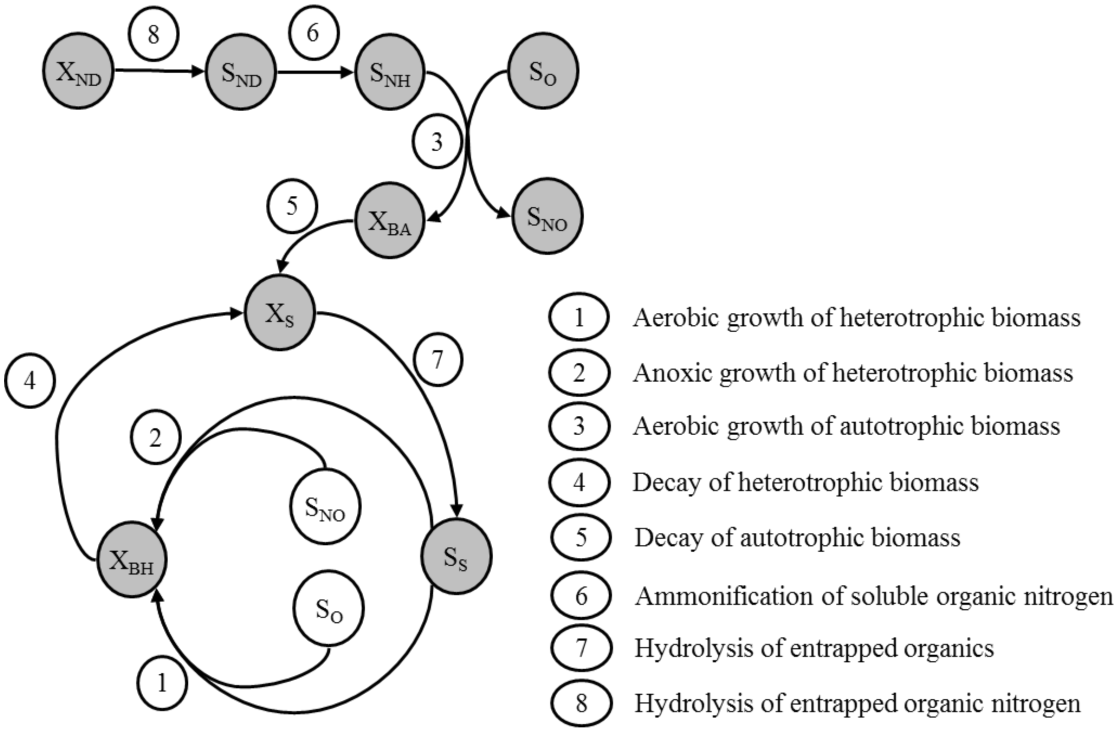


Figure 1: Dynamic processes involved in the ASM1 model

These 8 dynamic processes can be all simulated at the same time in a biological reactor using the LynxASM1 simulator. LynxASM1 is a free of charge simulation software designed by *Aula Bioindicación Gonzalo Cuesta (ABGC) from IIAMA-UPV (Instituto de Ingeniería del Agua y Medio Ambiente de la Universitat Politècnica de València).* This program allows to simulate AS processes in a very practical and easy way because it allows to change the inlet parameters of the previous 16 variables and the kinetic values of the following Table 2.

The kinetic parameters, as growth rate (Kd) or decay rate (μ_H) decrease their value as the temperature lowers because microorganisms are less active. During the design with ASM1 and simulation of this with LynxASM1, kinetics values at 10ºC have been used because the WWTP is located in a cold area and also because it is a worst-case scenario due to the low activity of the microorganisms.

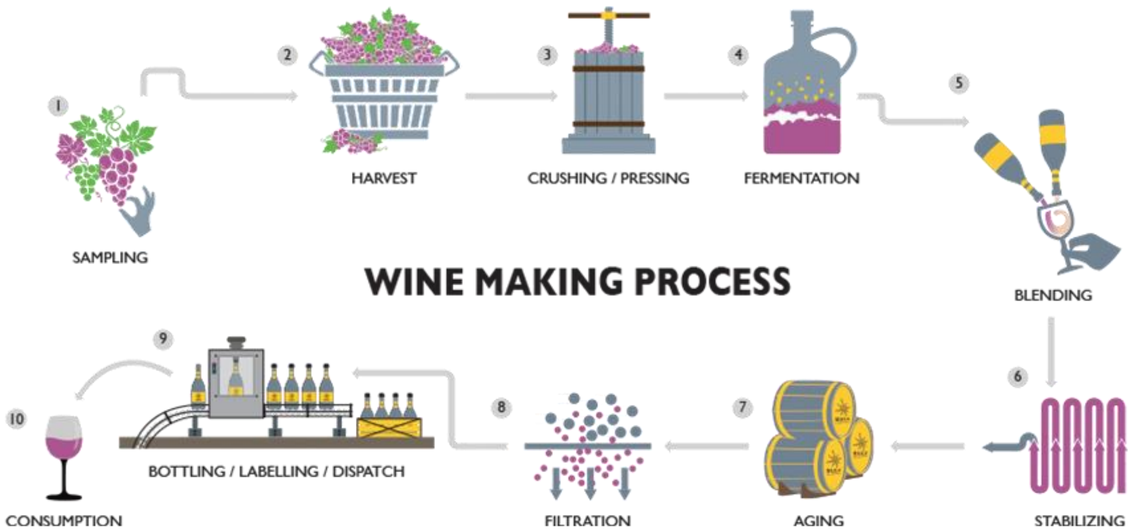
Table 2: Kinetic parameters of the ASM1 Model (10)

IAWQ model parameters	symbol	unit	20 °C	10 °C	literature
Stoichiometric parameters					
Heterotrophic yield	Y_H	g cell COD formed (g COD oxidized)$^{-1}$	0.67	0.67	0.38-0.75
Autotrophic yield	Y_A	g cell COD formed (g N oxidized)$^{-1}$	0.24	0.24	0.07-0.28
Fraction of biomass yielding particulate products	f_P	dimensionless	0.08	0.08	–
Mass N/mass COD in biomass	i_{XB}	g N (g COD)$^{-1}$ in biomass	0.086	0.086	–
Mass N/mass COD in products from biomass	i_{XP}	g N (gCOD)$^{-1}$ in endogenous mass	0.06	0.06	–
Kinetic parameters					
Heterotrophic max. specific growth rate	$\hat{\mu}_H$	day^{-1}	6.0	3.0	0.6-13.2
Heterotrophic decay rate	b_H	day^{-1}	0.62	0.20	0.05-1.6
Half-saturation coefficient (hsc) for heterotrophs	K_S	g COD m^{-3}	20	20	5-225
Oxygen hsc for heterotrophs	$K_{O,H}$	g O_2 m^{-3}	0.20	0.20	0.01-0.20
Nitrate hsc for denitrifying heterotrophs	K_{NO}	g NO_3-N m^{-3}	0.50	0.50	0.1-0.5
Autotrophic max. specific growth rate	$\hat{\mu}_A$	day^{-1}	0.80	0.30	0.2-1.0
Autotrophic decay rate	b_A	day^{-1}	0.20	0.10	0.05-0.2
Oxygen hsc for autotrophs	$K_{O,A}$	g O_2 m^{-3}	0.4	0.4	0.4-2.0
Ammonia hsc for autotrophs	K_{NH}	g NH_3-N m^{-3}	1.0	1.0	–
Correction factor for anoxic growth of heterotrophs	η_g	dimensionless	0.8	0.8	0.6-1.0
Ammonification rate	k_a	m^3 (g COD day)$^{-1}$	0.08	0.04	–
Max. specific hydrolysis rate	k_h	g slowly biodeg. COD (g cell COD day)$^{-1}$	3.0	1.0	–
Hsc for hydrolysis of slowly biodeg. substrate	K_X	g slowly biodeg. COD (g cell COD)$^{-1}$	0.03	0.01	–
Correction factor for anoxic hydrolysis	η_h	dimensionless	0.4	0.4	–

6. Results

6.1.1 Influent Analysis and Worst-Case Scenario Determination

As said before, seasons have a significant importance in wine industry. Its production process can be summarized in the following six steps (As it is seen in Picture 1: Wine making process steps.): grape harvesting (1-2), crushing (3), fermentation (4), aging (7), filtration (8) and (9) bottling [11]. However, it can be simplified into vintage, aging and bottling.



Picture 1: Wine making process steps.

Vintage involves from harvesting to fermentation and it lasts from 2 to 6 weeks (in the North Hemisphere is set between August and October). This period produces the highest organic load and suspended solids concentration, it reduces the pH of the recipient water streams and it involves up to 50% of total water consumption. In the other hand, aging and bottling increase the pH of the recipient water streams due to the addition of NaOH into the tanks cleaning water processes.

Due to the high organic load the most difficult conditions to treat the wastewater are those related to the vintage season. Because of this, the average conditions of the consecutive Octobers from 2014 to 2016 have been selected as the design conditions for the simulation and as the worst-case scenario possible.

Table 3: Vintage wastewater parameters and their average values from 2014 to 2016

YEAR	MONTH	BOD_5	COD	pH	TSS	S_{NH}	S_{NO}	TKN	TP	FLOWRATE
2014	OCTOBER	1580.00	2782.33	6.41	557.46	16.40	1.41	37.25	5.97	122
2015	OCTOBER	1039.17	2534.39	6.35	408.72	12.51	3.30	39.35	7.74	159
2016	OCTOBER	1221.78	2460.88	6.06	356.24	6.33	4.20	20.60	4.43	151

YEAR	MONTH	BOD_5	COD	pH	TSS	S_{NH}	S_{NO}	TKN	TP	FLOWRATE
	AVERAGE	1280.31	2592.53	6.27	440.80	11.75	2.97	32.40	6.04	144
	(UNITS)	mg/L	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	m^3/day

The most important parameters of the worst-case scenario have been the flowrate of 144 m^3/day and the COD concentration of 2592.53 mg/L, which are key for the following pre-design of the AS process.

As it can also be seen with TKN, S_{NH}, COD and TSS values in Table 3, these parameters have been decreasing their concentration every year. This is because the wineries from the region have been increasing their wastewater treatment effectiveness in site in order to prevent fines and lawsuits from the local entities.

In the following Chart 1 are shown the legal required parameters from the 2016 to analyze the difference of organic load depending on the wine season:

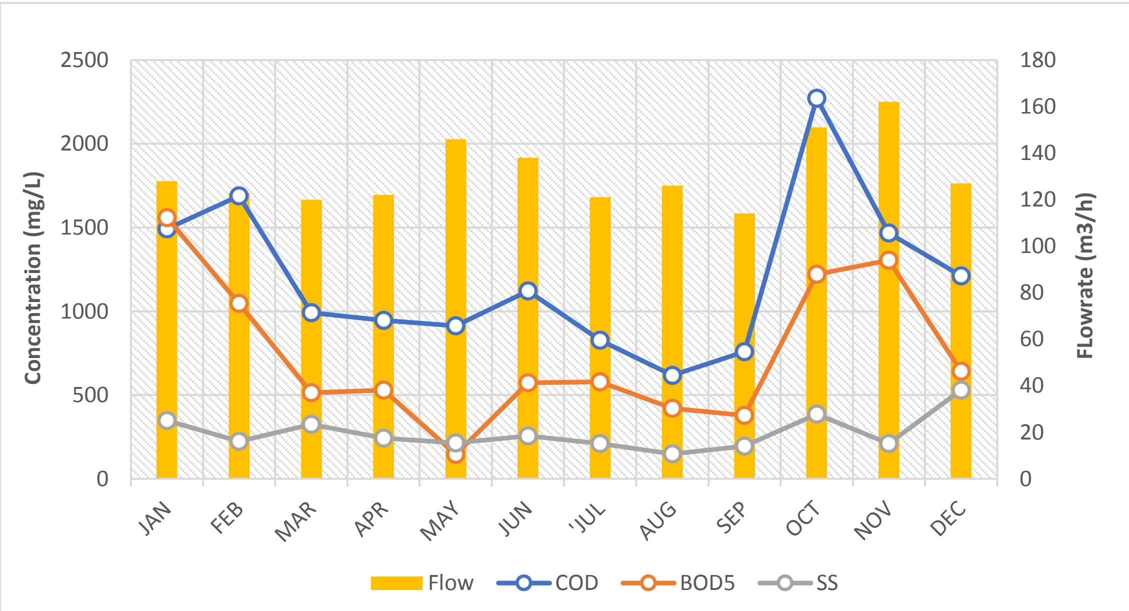


Chart 1: Monthly COD, BOD and SS during the 2016 year.

As it is seen in both Table 3 and Chart 1, the organic load increases significantly in October compared with the non-vintage period (March to September). However, the flow is maintained during these months because the urban wastewater disposal from the town is stable during all year and it's not influenced by the wine harvesting periods.

To sum up, if the AS process is designed with parameters from the worst-case scenario, it will assure that a quality effluent during the rest of the year.

6.1.2 Other Influent Parameters

6.1.2.1 Nutrients Ratio

A balanced nutrient ratio is crucial for microorganisms to grow and function effectively. These main nutrients are Nitrogen and Phosphorous and both are lacking when treating winery wastewater.

Because of that, there is the need to make a small calculation to see if this lack of nutrients is indeed real and to know how much of a nutrient addition would be needed. The maximum nutrient ratio for achieving microorganism's growth is shown in Equation 1.

Equation 1: Maximum Nutrient Ratio for microorganism sgrowth. (12)

$$BOD_5 : TKN : TP = 100 : 5 : 1 \quad \frac{BOD_5}{TKN} = 20 \quad \frac{BOD_5}{TP} = 100$$

Nutrient scarcity is a common problem all year long, as we can see in the small calculation done in Appendix 8.1. BOD/TKN and BOD/TP ratios have been over the maximum in 13 and 20 of the 36 months from 2014 to 2016, respectively, being October the month where both nutrient lacks have been always present.

The worst-case scenario, which is the average of the months of October from 2014 to 2016, has had the following nutrient ratio.

Table 4: Nutrients analysis for worst-case scenario.

	BOD_5 (mg/L)	TKN (mg/L)	TP (mg/L)	BOD_5/TKN	BOD_5/TP
WORST-CASE	1280.31	32.40	6.04	39.52	211.86

As it was displayed before, the maximum ratio for Nitrogen and Phosphorous is 20 and 100, respectively, and in both cases those values are not reached in the worst-case scenario. The solution to this concern is to externally add urea (mainly ammonia) to increase TKN concentration and orthophosphates to increase TP concentration (these results are shown in Simulation Chapter 6.3).

6.1.2.2 COD Fractioning

A bibliographical research has been carried out to detail a suitable fractioning of COD contained in the influent. This fractioning is required to perform ASM1 calculation and also to do the mathematical simulation of the process.

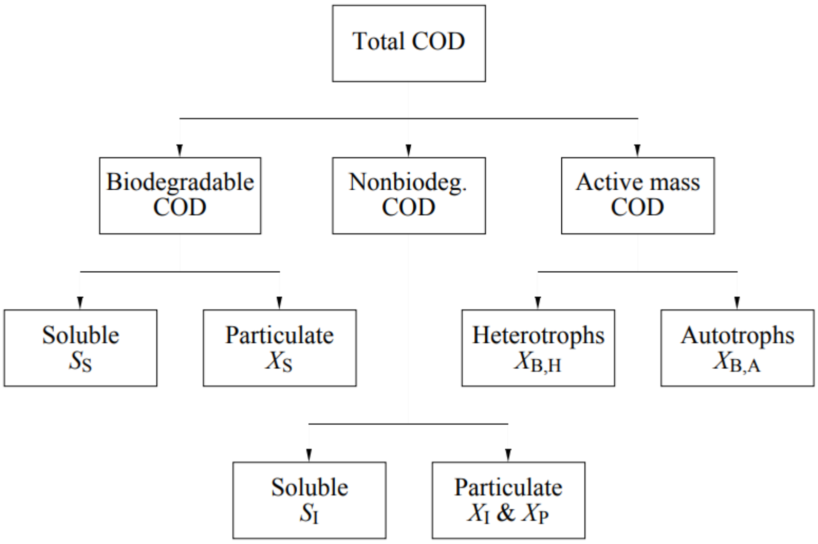


Figure 2: COD Fractioning in the ASM1 model. (10)

In the ASM1 model it is estimated that in the inlet of the AS process there is zero concentration of biomass. Consequently, there are 4 parameters remaining in the COD fractioning:

- S_I: Non-biodegradable soluble COD
- S_S: Readily biodegradable COD
- X_I: Non-biodegradable particulate COD
- X_S: Slowly biodegradable COD

For urban wastewater with the influence of winery industry, the COD fractioning used comes from Beck and collaborators work (2005 [1]) which characterizes a mixed urban effluent from different spots from a winery region in Germany (Haut-Rhin).

Table 5: COD fractioning used in the design and simulation of the WWTP

		BECK ET AL.	
COD	**IWA (ASM1)**	Vintage period	Non-vintage period
Ss	0.46	0.85	0.31
Si	0.04	0.012	0.15
Xs	0.47	0.094	0.5
Xi	0.03	0.05	0.04

As it is seen in Table 5, during vintage period, readily biodegradable COD (Ss) has a higher fraction due to the load of organic acids, sugars and alcohols. This fractioning is applied then for the worst-case scenario simulation and for October and November months in the dynamic simulation. In the other hand, ASM1 default domestic fractions are used in the dynamic simulation of non-vintage periods [10].

As COD fractioning is done, a preliminary calculation of the AS design has been developed by using the ASM1 model of the IWA (International Water Association) before making a simulation.

6.2 AS Design

6.2.1 Introduction in the Design

In its simpler version, the AS wastewater treatment process is based on an aerobic reactor followed by a settler where all the sludge created is separated from the cleared water. AS processes are optimal for the oxidation of high load of carbonaceous of biological matter. In Figure 3 there is a basic overlook of the process

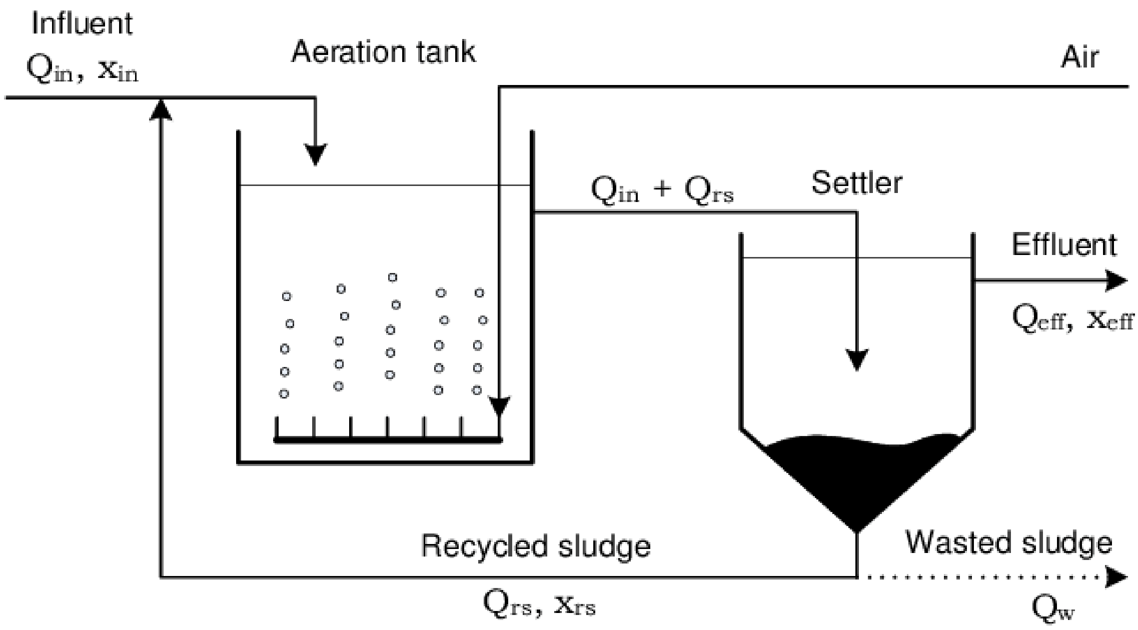


Figure 3: Diagram of an activated sludge system process (13)

All nutrient removal operations have not been studied since the location of the WWTP is not a sensitive area according to *BOE-A-2009-2347, referring to the Inspection report of the Management of the Tax for private use or special use of the local public domain* [14]. No restrictions are imposed in the nitrogen content of the WWTP effluent.

6.2.2 AS Design with ASM1 Model

To obtain the preliminary design values of the AS, ASM1 model seen in Chapter "Methodology" has been used. Additional information regarding the Solids Retention Time (SRT) has been taken from the ATV-DVWK-A 131E standards [15]. After all the calculations (shown in Appendix 8.2), Table 6 summarizes the main parameters obtained, which will be key for the simulation of the AS process. As it was said in in Chapter "Methodology", all kinetic parameters from the ASM1 calculation are at 10ºC [10] and the design flowrate is 1.5 times the worst-case scenario (216 m^3/day).

Table 6: ASM1 parameters obtained

Definition	Value	Units
SRT	5	Days
Minimum SRT	0.36	Days
HRT	27.6	Hours
Reactor Volume	248.8	m^3
F/M ratio	0.599	
Sludge in reactor	3200	mg cel. COD/L
Recirculation ratio (Qr/Q)	0.770	
Purge Ratio (Qw/(Qr+Qw))	0.130	
Sludge production	159.2	Kg SSV/day
Oxygen demand	316.1	Kg O_2/day

6.3 Simulation Process

6.3.1 Worst-Case Scenario Simulation

Once the initial calculations have been carried out, a worst-case scenario simulation with the software LynxASM1 has been executed. However, previously there has been the need to know which value of concentration of ammonia and ortophosphates is needed to reach the maximum BOD_5/TKN and BOD_5/TP ratio of 20 and 100, respectively.

The concentration needed to reach the maximum nutrient ratio of BOD_5/TKN = 20 and BOD_5/TP = 100 in the worst-case scenario is the next:

Table 7: Nutrients concentration required for the maximum the worst-case scenario.

	Real	Needed	Added (Needed-Real)
TKN	32.40	64.02	31.62
TP	6.04	12.80	6.76

By adding this new concentration in form of ammonia, the first simulation of the worst-case scenario has been carried (phosphorous is not considered in the ASM1 model). The following parameters have been added in the influent data:

Table 8: Worst-case scenario influent data with maximum nutrient ratio (Part 1)

	Flowrate	S_S	X_S	X_{BH}	X_{BA}	X_P	S_O	S_{NO}	S_{NH}
Value	216	2206.65	246.7	0	0	0	0	2.97	43.37
Units	*m^3/day*	*mg COD/L*	*mg COD/L*	*mg COD/L*	*mg COD/L*	*mg COD/L*	*mg O_2/L*	*mg NO_3/L*	*mg NH_4/L*

Table 9: Worst-case scenario influent data with maximum nutrient ratio (Part 2)

	S_{ND}	X_{ND}	S_{ALK}	S_I	X_I
Value	9.11	11.54	100	31.11	129.63
Units	*mg N/L*	*mg N/L*	*mmol CO^{3-}/L*	*mg COD/L*	*mg COD/L*

Then, by inserting the reactor volume, the recirculation ratio and the purge ratio into the software, the results of the first simulation have been the following:

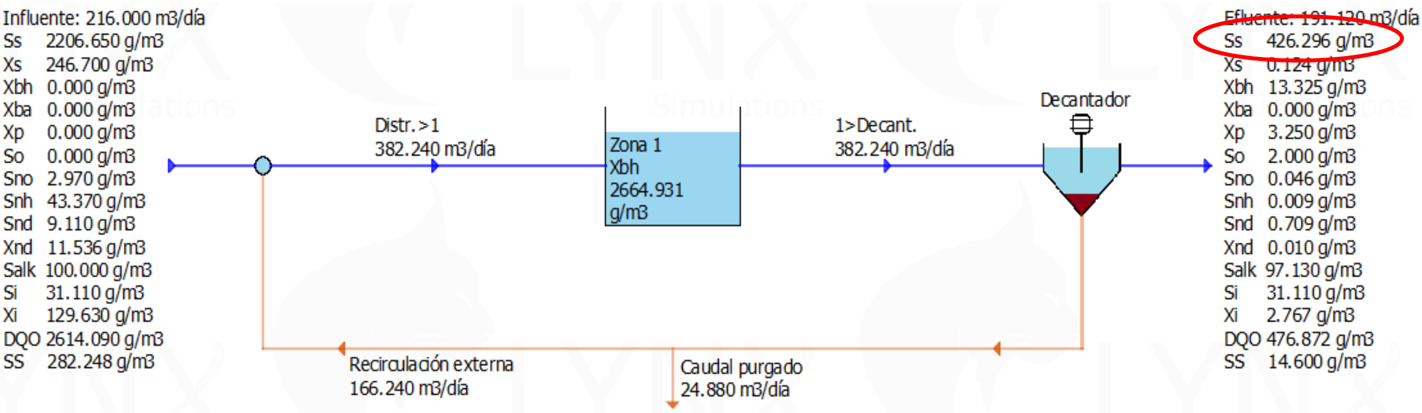


Figure 4: Worst-case simulation with the maximum nutrient ratio of BOD/TKN=20.

As it can be seen in the simulation, there has not been a good organic matter removal since the concentration of readily biodegradable COD in the effluent (Ss), has been too high and it has not reached the compliance of the *"Council Directive 91/271/EEC concerning urban waste-water treatment"* [(9)]. The next step therefore has been to slightly modify the nutrient maximum ratio to ensure that all the microorganisms have the enough nitrogen to grow.

Knowing that the maximum ratio of $BOD_5/TKN = 20$ and $BOD_5/TP = 100$ has not been enough to achieve a good quality effluent, the best option has been to lower the maximum ratio, so the ammonia concentration is higher during the simulation. The nutrient ratio for the AS process has been increased into the one in Equation 2:

Equation 2: Real nutrient ratio for the WWTP design.

$$BOD_5 : TKN : TP = 100 : 7 : 1.2 \qquad \frac{BOD_5}{TKN} = 14.29 \qquad \frac{BOD_5}{TP} = 83.33$$

Then, the new concentration of TKN and TP needed to reach the correct nutrient ratio in the worst-case scenario has increased into the one in Table 10 (in mg/L):

Table 10: Nutrients required for the worst-case scenario.

	Real (mg/L)	Needed (mg/L)	Added (Needed-Real) (mg/L)
TKN	32.40	89.62	57.22
TP	6.04	15.36	9.32

Now, the inlet parameters have the same value as the ones in Table 8 y Table 9 except from the ammonia concentration (S_{NH}), which has increased from 43.37 to 68.97 mg/L due to the change of the nutrient ratio. The results of the simulation with the new nutrient ratio are shown in the following Figure 5 and Table 11.

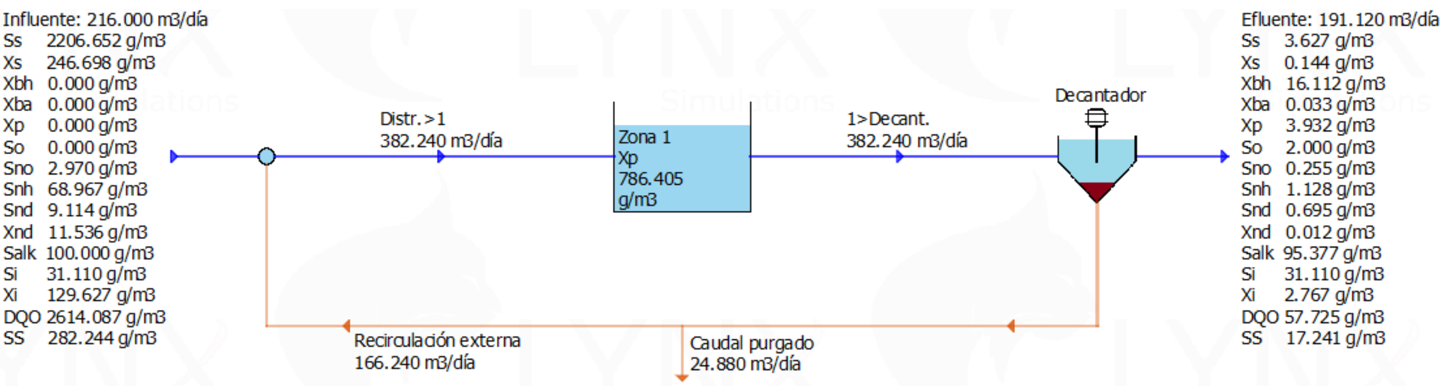


Figure 5: LynxASM1 diagram of the AS process.

Table 11: Results of the simulation of the worst-case scenario.

Parameter	**Inlet**	**Outlet**	**Units**	**% Reduction**
Flowrate	216.00	191.12	m^3/day	-
S_S	2206.65	3.63	mg COD/L	-
X_S	246.70	0.14	mg COD/L	-
X_{BH}	0.00	16.11	mg COD/L	-
X_{BA}	0.00	0.03	mg COD/L	-
X_P	0.00	3.93	mg COD/L	-
S_O	0.00	2.00	mg O_2/L	-
S_{NO}	2.97	0.26	mg NO_3/L	-
S_{NH}	68.97	1.13	mg NH_4/L	-
S_{ND}	9.11	0.70	mg N/L	-
X_{ND}	11.54	0.01	mg N/L	-

Parameter	**Inlet**	**Outlet**	**Units**	**% Reduction**
S_{ALK}	100.00	95.38	mmol CO^{3-}/L	-
S_I	31.11	31.11	mg COD/L	-
X_I	129.63	2.77	mg COD/L	-
COD	2614.09	57.73	mg COD/L	**97.79**
TSS	282.24	17.24	mg / L	**93.89**
BOD_5	1280.31	2.36*	Mg O_2/L	**99.82**

* Outlet BOD Estimation = (X_S + S_S) / 1.6 [16]

As it can be seen in Table 11, the legal requirements of BOD, COD and Suspended Solids from Table 1 have been achieved in both concentration and in the percentage of minimum reduction. The main advantage is that if this design is suitable for the most strictive conditions, it also assures a good quality effluent during the rest of the year.

However, a pseudo-dynamic simulation for all year has been done to ensure a good quality effluent every month of the year, and not just for the worst-case scenario of the month of October.

6.3.2 Pseudo-Dynamic Simulation

The inlet parameters used for this simulation have been the monthly averages from the 2014 to 2016, which are shown in Appendix 8.3. The AS design and operation conditions maintained were those obtained from the worst-case scenario simulation.

Twelve simulations (one for each month) have been performed. The parameters obtained from inside the reactor by the end of January simulation were transferred to the beginning of February simulation, and so on, in order to obtain a pseudo-dynamic simulation. No real dynamic simulation could be performed with this software since it does not provide the possibility to introduce variability in operating parameters such as the purge or the recirculation ratio. By the end of each month, the outlet parameters obtained were considered the averaged effluent values of the corresponding month.

However, to assure that this pseudo-dynamic simulation has a final nutrient ratio of BOD_5/TKN = 14.29 it has been key to know the TKN and TP necessary concentration in every month.

6.3.2.1 Nutrient Stream Calculation (Urea and Orthophosphates)

Urea

With the BOD_5 monthly values of Appendix 8.1, the average of the TKN needed to get $BOD_5/TKN = 14.29$ in every month from 2014 to 2016 has been calculated with Equation 3 and is shown in Table 12.

Equation 3: TKN Needed in every month equation

$$TKN\ Needed\left(\frac{mg}{L}\right) = Avrg\ BOD\left(\frac{mg}{L}\right) / \ 14.29$$

Table 12: Monthly TKN values needed to achieve the sufficient nutrient ratio

MONTH	TKN NEEDED (mg/L) 2014	2015	2016	**AVERAGE**
JANUARY	86.63	80.15	109.20	91.99
FEBRUARY	55.48	63.42	73.31	64.07
MARCH	81.38	34.91	36.05	50.78
APRIL	38.33	65.33	37.08	46.91
MAY	80.15	32.20	10.20	40.85
JUNE	18.38	73.50	40.08	43.98
JULY	30.10	24.50	40.60	31.73
AUGUST	21.93	30.72	29.45	27.37
SEPTEMBER	28.70	16.45	26.50	23.88
OCTOBER	110.60	72.74	85.52	89.62
NOVEMBER	53.03	57.23	91.36	67.20
DECEMBER	24.50	19.25	44.89	29.55

With the TKN needed from the different months, the next step has been to know which of these months do already have this TKN needed in the influent or instead needs to be added externally. The following calculation to know the TKN to add in every month has been done:

Equation 4: TKN to add equation

$$TKN\ to\ add\ \left(\frac{mg}{L}\right) = TKN\ Needed\ \left(\frac{mg}{L}\right) - TKN\ \left(\frac{mg}{L}\right)$$

Table 13: TKN to add for every month in the pseudo-dynamic simulation

MONTH	**Avrg. BOD_5 (mg/L)**	**Avrg. TKN**	**Avrg.TKN Needed (mg/L)**	**TKN to add (mg/L)**
JANUARY	1314.17	42.70	91.99	49.29
FEBRUARY	915.25	50.28	64.07	13.78
MARCH	725.42	31.29	50.78	19.49
APRIL	670.19	54.48	46.91	-7.57*
MAY	583.56	47.42	40.85	-6.57*
JUNE	628.33	41.05	43.98	2.93
JULY	453.33	52.47	31.73	-20.73*

MONTH	Avrg. BOD_5 (mg/L)	Avrg. TKN	Avrg.TKN Needed (mg/L)	TKN to add (mg/L)
AUGUST	390.96	46.08	27.37	-18.72*
SEPTEMBER	341.17	27.73	23.88	-3.85*
OCTOBER	1280.31	32.40	89.62	57.22
NOVEMBER	960.05	31.92	67.20	35.28
DECEMBER	422.11	77.77	29.55	-48.22*

*(*The ratio of BOD_5:TKN:TP = 100:7:1.2 is already achieved so there is no need to add nutrients externally.)*

In 6 of 12 average months there is the necessity to add nitrogen to increase the TKN concentration. This is the reason why the nutrient addition stream of urea (mainly ammonia) has been calculated for every month simulation. The urea flowrate for every month has been achieved by knowing the design flowrate of the AS process (216000 L/day) and by knowing the TKN load this would mean. An example of the calculation is shown below:

Equation 5: Calculation of the monthly TKN load

$$TKN\ load\ \left(\frac{kg}{day}\right) = TKN\ to\ add\ \left(\frac{mg}{L}\right) \cdot \frac{1\ kg}{10^6 mg} \cdot \frac{2{,}16 \cdot 10^5\ L}{1\ day}$$

The final values of the urea load are shown in the last column of Table 13:

Equation 6: Calculation of the monthly urea load (17)

$$Urea\ load\ \left(\frac{kg}{day}\right) = TKN\ load\ \left(\frac{kg}{day}\right) \cdot \frac{1\ kg\ Urea}{0{,}47\ kg\ N}$$

Table 14: Urea load calculation every month

MONTH	TKN Load (kg/day)	Urea load (kg/day)
JANUARY	10.6	23.146
FEBRUARY	2.977	6.473
MARCH	4.209	9.150
APRIL	*	*
MAY	*	*
JUNE	0.634	1.377
JULY	*	*
AUGUST	*	*
SEPTEMBER	*	*
OCTOBER	12.360	26.869
NOVEMBER	7.621	16.567
DECEMBER	*	*

*(*The minimum ratio of BOD_5:TKN:TP = 100:7:1.2 is already achieved so there is no need to add nutrients externally.)*

Going back to the simulations, the urea addition produces the increase of the inlet S_{NH} concentration during the pseudo-dynamic simulation into the next ones (S_{NH} final):

Table 15: Final ammonia (SNH) inlet concentration in every month simulation

MONTH	**Avrg S_{NH} (mg/L)**	**S_{NH} to add (mg/L)**	**S_{NH} final (mg/L)**
JANUARY	25.850	49.290	75.140
FEBRUARY	26.717	13.780	40.497
MARCH	32.300	19.490	51.790
APRIL	33.683	*	33.683
MAY	33.133	*	33.133
JUNE	22.267	2.930	25.197
JULY	29.833	*	29.833
AUGUST	34.683	*	34.683
SEPTEMBER	17.633	*	17.633
OCTOBER	11.745	57.220	68.965
NOVEMBER	19.522	35.280	54.802
DECEMBER	29.667	*	29.667

*(*The ratio of BOD_5:TKN:TP = 100:7:1.2 is already achieved so there is no need to add nutrients externally.)*

Orthophosphates

In the other hand, the same calculations have been used to know the Orthophosphates flowrates:

Equation 7: TP Needed in every month

$$TP\ Needed\left(\frac{mg}{L}\right) = Avrg\ BOD\left(\frac{mg}{L}\right) / \, 83.33$$

Equation 8: TP to add in every month

$$TP\ to\ add\ \left(\frac{mg}{L}\right) = TP\ Needed\ \left(\frac{mg}{L}\right) - TP\ \left(\frac{mg}{L}\right)$$

Equation 9: Calculation of the monthly phosphorous load.

$$TP\ load\ \left(\frac{kg}{day}\right) = TP\ to\ add\ \left(\frac{mg}{L}\right) \cdot \frac{1\ kg}{10^6 mg} \cdot \frac{2{,}16 \cdot 10^5\ L}{1\ day}$$

Equation 10: Ortophosphates monthly load calculation (17)

$$Ortophosphates\ load\left(\frac{kg}{day}\right) = TP\ load\ \left(\frac{kg}{day}\right) \cdot \frac{1\ kg\ Ortophosphates}{0{,}33\ kg\ P}$$

The final values of orthophosphates monthly loads are shown in the last column of Table 16. However, phosphorous is not considered in ASM1 model so there is not a change in the inlet parameters in the simulation like urea.

Table 16: Orthophosphates monthly load for every month.

MONTH	**Avrg. BOD_5 (mg/L)**	**Avg. P needed (mg/L)**	**TP to add (mg/L)**	**TP Load (kg/day)**	**Ortophosphates Load (kg/day)**
JANUARY	1314.17	15.77	9.984	2.157	6.535
FEBRUARY	915.25	10.98	4.952	1.070	3.241
MARCH	725.42	8.71	3.550	0.767	2.324
APRIL	670.19	8.04	*	*	*
MAY	583.56	7.00	0.046	0.010	0.030
JUNE	628.33	7.54	1.279	0.276	0.837
JULY	453.33	5.44	*	*	*
AUGUST	390.96	4.69	*	*	*
SEPTEMBER	341.17	4.09	*	*	*
OCTOBER	1280.31	15.36	9.321	2.013	6.101
NOVEMBER	960.05	11.52	6.369	1.376	4.169
DECEMBER	422.11	5.07	*	*	*

*(*The ratio of BOD5:TKN:TP = 100:7:1.2 is already achieved so there is no need to add nutrients externally.)*

6.3.2.2 Pseudo-Dynamic Simulation Final Results

By changing the inlet S_{NH} in every month (as represented in Table 15) and running all the twelve simulations, in the following Chart 2 are displayed the monthly outlet concentrations achieved from the legal required parameters (COD and TSS). All the rest of the parameters obtained in the outlet are shown in Appendix 8.3.

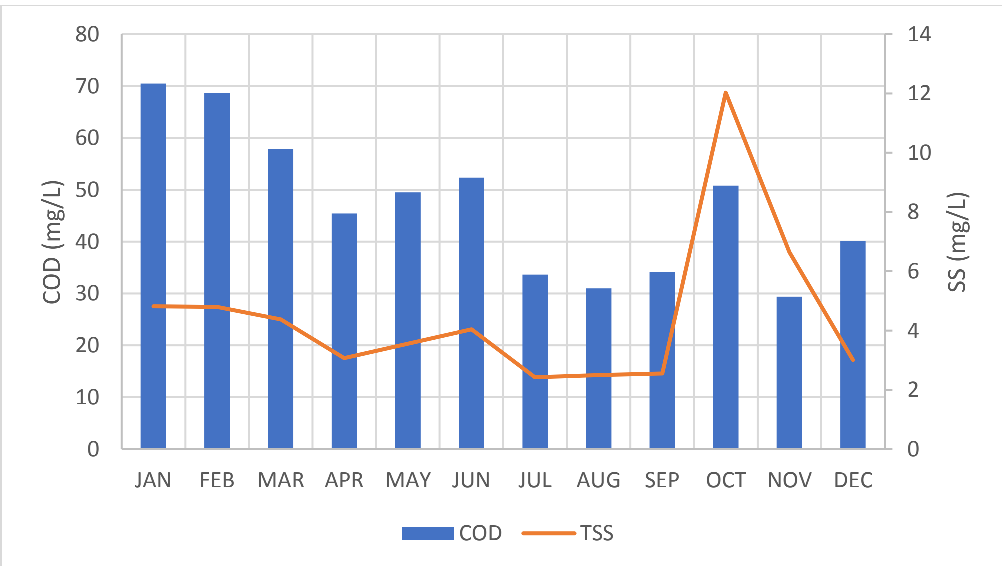


Chart 2: Outlet COD and TSS in the outlet of the dynamic simulation of the WWTP.

As it can be seen in Chart 2, the concentration of COD and TSS have never reached the maximum legal required values of 125 mg/L and 35 mg/L. each. Since the ASM1 model and simulation do not work with BOD_5, it is not possible to know whether the legal limit of 25 mg/L has been exceeded in the tested period. However, as it is seen in the outlet concentration values in Appendix 8.3, the biodegradable fractions of the COD (Xs and Ss) have almost been eliminated. The remaining COD in the outlet stream comes from the non-biodegradable soluble fraction (Si) which is not involved with the concentration of BOD_5 and cannot be removed from the wastewater by biological processes. This fraction cannot be extracted by settling and purging either because it is dissolved.

The main weakness from the dynamic simulation has been the excess of nitrates in the outlet stream of treated water related to the external dosing of nutrients, as it is seen in the following Table 17.

Table 17: Nitrates concentration in the outlet stream of the WWTP

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
S_{NO} (mg/L)	21.079	0.712	17.877	5.258	1.008	0.195	12.794	14.07	0.052	0.102	6.539	20.735

As it is seen in Table 17, the S_{NO} concentration exceeds 15 mg/L in January, March and December and exceeds 10 mg/L also in July and August. These two values of 10 mg/L and 15 mg/L of nitrates are key because these are the legal concentration limit of Nitrogen (which include TKN, nitrites and nitrates) by the *"Council Directive 91/271/EEC concerning urban waste-water treatment"*(9). 15 mg/L of nitrogen is the limit from WWTP treating water from 10,000 to 100,000 inhabitants and 10 mg/L of nitrogen is the one from WWTP for more than 100,000 inhabitants in sensitive regions.

According to what is explained in *BOE-A-2009-2347, referring to the Inspection report of the Management of the Tax for private use or special use of the local public domain* (14), the current WWTP is located in an area where no regulations on nitrogen concentration are applied. However, this nitrate excess could be prevented by implementing an automated control that regulates the amount of nutrients to add by detecting the COD that is entering the AS process at every moment.

7. Conclusions

Urban wastewater influenced by wine industry has chemical characteristics that widely vary depending on the harvest period that is occurring. Vintage period (set between August and October in the North Hemisphere and between February and April in the South Hemisphere) always produces the most difficult water to treat due to the important increase in the wastewater organic load. Because of this, the worst-case scenario of water treatment in this urban WWTP designed is in October, when there is an average inlet flowrate of 144 m3/day and COD concentration of 2592.53 mg/L.

The organic load from the wine industry that is added to the urban wastewater is mainly easily biodegradable (in form of sugars, organic acids and alcohols). Consequently, the COD fractioning during vintage periods significantly differs in comparison with a standard urban wastewater. Readily and slowly biodegradable COD fractions (S_s and X_s) widely increase due to this load.

During high organic load months, a scarcity of biologically required nitrogen and phosphorous appears in the water to be treated. This should be solved by external addition of nutrients, which could be calculated with the starting minimum ratio of BOD_5:TKN:TP=100:5:1.

The ASM1 model has allowed to obtain a pre-design of the AS system that could treat 216 m^3/day of worst-case scenario wastewater effectively, by implementing an aerobic reactor of 248,8 m^3 in the system.

With the results of the ASM1 pre-design and with the starting nutrient ratio, the worst-case scenario simulation of the system has been carried out but the minimum legal requirements for the outlet water have not been fulfilled. As a solution, the nutrient ratio has been raised into BOD_5:TKN:TP=100:7:1.2 which successfully achieved the legal requirements by incrementing the TKN concentration.

The monthly flowrates of urea and orthophosphates have been obtained with the new optimal nutrient ratio. With this data it has been possible to perform a pseudo-dynamic simulation of an entire year in the AS process. It has effectively treated the water under the maximum legal concentrations of BOD_5, COD and TSS for all twelve months.

8. Appendix

8.1 Nutrient Ratio

The following tables have been used to analyze in Chapter 6.1.2.1 the nutrients from the influent data given.

Table 18: 2016 Nutrient Analysis

MONTH	BOD_5	TKN	TP	BOD_5/TKN	BOD_5/TP
JANUARY	1560	43.0	5.85	36.28	266.67
FEBRUARY	1047	40.4	5.58	25.92	187.68
MARCH	515	48.6	5.83	10.60	88.34
APRIL	530	31.4	4.70	16.90	112.71
MAY	146	34.3	3.44	4.25	42.34
JUNE	573	36.3	5.54	15.77	103.34
JULY	580	52.3	9.57	11.09	60.61
AUGUST	421	47.2	9.07	8.91	46.39
SEPTEMBER	379	24.9	5.27	15.20	71.82
OCTOBER	1222	20.6	4.43	59.31	276.11
NOVEMBER	1305	29.1	6.37	44.93	204.89
DICEMBER	641	138.0	23.40	4.65	27.41
			MAXIMUM RATIO	**20**	**100**

Table 19: 2015 Nutrient Analysis

MONTH	BOD_5	TKN	TP	BOD_5/TKN	BOD_5/TP
JANUARY	1145	46.0	5.14	24.92	222.76
FEBRUARY	906	50.3	9.45	18.01	95.87
MARCH	499	1.9	4.32	258.42	115.45
APRIL	933	63.2	7.39	14.77	126.30
MAY	460	60.2	9.07	7.65	50.72
JUNE	1050	46.6	7.06	22.53	148.73
JULY	350	43.4	2.89	8.06	121.11
AUGUST	439	55.4	7.47	7.93	58.74
SEPTEMBER	235	33.6	6.47	6.99	36.32
OCTOBER	1039	39.4	7.74	26.41	134.26
NOVEMBER	818	44.8	4.22	18.27	193.95
DECEMBER	275	37.5	4.26	7.33	64.55
			MAXIMUM RATIO	**20**	**100**

Table 20: 2014 Nutrient Analysis

MONTH	BOD_5	TKN	TP	BOD_5/TKN	BOD_5TP
JANUARY	1238	39.2	6.37	31.61	194.27
FEBRUARY	793	60.2	3.07	13.18	258.56
MARCH	1163	43.4	5.32	26.82	218.72
APRIL	548	68.9	16.50	7.95	33.18

MONTH	**BOD_5**	**TKN**	**TP**	**BOD_5/TKN**	**BOD_5TP**
MAY	1145	47.8	8.36	23.95	136.96
JUNE	263	40.3	6.19	6.52	42.44
JULY	430	61.7	10.30	6.97	41.75
AUGUST	313	35.7	8.09	8.78	38.75
SEPTEMBER	410	24.7	6.69	16.60	61.29
OCTOBER	1580	37.3	5.97	42.42	264.88
NOVEMBER	758	22.0	4.87	34.49	155.54
DECEMBER	350	57.8	5.65	6.06	61.95
			MAXIMUM RATIO	**20**	**100**

8.2 AS Process Design Calculations

The following pre-design parameters of the AS systems have been obtained with the ASM1 Model equations and with the influent values of the worst-case scenario from *Table 3: Vintage wastewater parameters and their average values from 2014 to 2016*

8.2.1 SRT Calculation

Solid Retention Time estimation has been done by picking the recommended one in the ATV-DVWK-A 131E standards. Previously, a calculation of the BOD load has been made to decide whether to use 5 or 4 days of SRT (as the Table 21 shows).

Equation 11: BOD load calculation with the ATV Standards

$$C_{d,\,BOD5}\left(\frac{kg}{day}\right) = Daily\ BOD\ load = 1280.31\frac{mg\ BOD5}{L}\cdot 216{,}000\frac{L}{day}\cdot\frac{1\ kg}{10^6\ mg} = 276.55\frac{kg}{d}$$

As it is seen in Table 21 the final SRT for the design of the AS without nitrification is 5 days. However, the minimum SRT has been calculated before to ensure that these 5 days of final SRT can be reached. Minimum SRT is obtained with the following equation from the ASM1 model:

Table 21: Recommended SRT for an AS process by the ATV-DVWK-A 131E standards.

Size of the plant $B_{d,BOD,I}$	Up to 1,200 kg/d		Over 6,000 kg/d	
Dimensioning temperature	10° C	12° C	10° C	12° C
Without nitrification	5		4	
With nitrification	10	8.2	8	6.6
With nitrogen removal V_D/V_{AT} = 0.2 0.3 0.4 0.5	 12.5 14.3 16.7 20.0	 10.3 11.7 13.7 16.4	 10.0 11.4 13.1 16.0	 8.3 9.4 11.0 13.2
Sludge stabilisation incl. nitrogen removal	25		Not recommended	

Equation 12: Calculation of the minimum SRT (ASM1 Model)

$$\mu_{H,max}\cdot\left(\frac{Ss}{Ss+Ks}\right) = \frac{1}{\theta_{x,min}} + Kd$$

- Ks (Half-saturation coefficient for heterotrophs at 10ºC) = 20 mg COD/L
- Kd (Heterotrophic decay rate at 10ºC) = 0.2 day^{-1}
- $\mu_{H,máx}$ (Heterotrophic max. specific growth rate at 10ºC) = 3 day^{-1}
- Ss (Readily biodegradable COD in the inlet) = 2203.65 mg/L =2203.65 mg COD/L
- $\theta_{x,min}$ = Minimum SRT (days)

$$\theta_{x,min} = \frac{1}{\mu_{H,max} \cdot \left(\frac{Ss}{Ss + Ks}\right) - Kd} = \frac{1}{3d^{-1} \cdot \left(\frac{2203.65 \frac{mg\ COD}{L}}{2203.65 \frac{mg\ COD}{L} + 20 \frac{mg\ COD}{L}}\right) - 0{,}2\ d^{-1}} = 0{,}36\ days$$

The minimum SRT of 0,36 days confirms the design SRT of 5 days.

8.2.2 COD in the Effluent

A calculation of the theorical concentration of outlet COD has been performed to ensure that the chosen SRT is the correct to treat the water to a concentration lower than the legal limit (legal limit viewed in *Table 1: Legal concentration requirements for wastewater disposal in the EU.)*. The equation used from the ASM1 model has been the following one:

Equation 13: Readily biodegradable COD (Ss) in the outlet calculation.

$$S_{S,OUT} = \frac{Ks\,(1 + Kd \cdot \theta_x)}{\mu_{H,max} \cdot \theta_x - (1 - Kd \cdot \theta_x)}$$

- Ks (Half-saturation coefficient for heterotrophs at 10ºC) = 20 mg COD/L
- Kd (Heterotrophic decay rate at 10ºC) = 0.2 day^{-1}
- $\mu_{H,max}$ (Heterotrophic maximum specific growth rate at 10ºC) = 3 day^{-1}
- $S_{S,OUT}$ (Readily biodegradable COD in the outlet) = mg COD/L
- θ_x (SRT) = 5 days

$$S_{S,OUT} = \frac{20 \frac{mg\ COD}{L} (1 + 0{,}2\ d^{-1} \cdot 5\ d)}{3\ d^{-1} \cdot 5\ d - (1 - 0{,}2\ d^{-1} \cdot 5\ d)} = 3.077 \frac{g\ COD}{L} = \left(\frac{mg\ COD}{L}\right)$$

If the obtained concentration of readily biodegradable COD ($S_{S,OUT}$) sums with the concentration of soluble non-biodegradable COD (Si) in the inlet* we have a concentration of COD in the outlet of 31.11 mg COD/L. This concentration of COD in the outlet is lower in than the legal limit viewed in Table 1 of 125 mg COD/L, which means that the SRT used will be enough to treat the water.

*The concentration of soluble non-biodegradable COD (Si) is the same in the inlet and in the outlet because it can't be oxidized by the biomass and cannot be settled and then removed in form of sludge.

8.2.3 HRT and Volume of the Reactor

With the ASM1 model, it is possible to know the Hidraulic Retention Time (HRT) of the reactor only if a value of heterotrophic biomass (X_{BH}) is estimated. Because of this, a concentration of heterotrophic biomass of 3200 mg COD/L has been estimated in the aerobic reactor for the worst-case scenario. In addition, a concentration of heterotrophic biomass of 6400 mg COD/L has also been estimated in the settler ($X_{BH,R}$).

The HRT of the reactor is calculated with the following equation

Equation 14: Calculation of the HRT with the ASM1 Model.

$$HRT_{reactor} = Y_H \cdot \frac{\theta_x}{X_{BH}} \cdot \left(\frac{S_s}{(1+\theta_x \cdot k_d)} - \frac{Ks}{\theta_x \cdot \mu_{H,máx} - (1+\theta_x \cdot k_d)} \right)$$

- Ks (Half-saturation coefficient for heterotrophs at 10ºC) = 20 mg COD/L
- Kd (Heterotrophic decay rate at 10ºC) = 0.2 day^{-1}
- $\mu_{H,max}$ (Heterotrophic maximum specific growth rate at 10ºC) = 3 day^{-1}
- θ_x (SRT) = 5 days
- Y_H (Heterotrophic yield) = 0.67 mg cell COD formed (mg COD oxidized)$^{-1}$
- S_s (Readily biodegradable COD in the inlet) = 2203.65 mg/L =2203.65 mg COD/L
- $HRT_{reactor}$ (Hidraulic Retention Time of the reactor) = days
- X_{BH} (Heterotrophic Biomass in the aerobic reactor) = 3200 mg COD/L

$$HRT_{reactor} = 1{,}15\ days = 27{,}64\ hours$$

The volume of the reactor can be obtained by multiplying the HRT with the design flowrate of the WWTP:

$$V = Q \cdot HRT_{reactor} = 216{,}000 \frac{L}{day} \cdot 1{,}15\ days = 248803\ L = 248.8\ m^3$$

- Q (WWTP Flowrate) = 216 m^3/d = 2166,000 L/day
- V (Reactor Volume) = m^3

8.2.4 Food/Microorganisms Ratio

The food to microorganism (F/M) ratio is one of the most important design parameters of activated sludge systems because a good balance between substrate consumption and biomass generation prevents the microorganisms to die or to suffer bulking or foaming in the biomass. The equation to get the value of F/M ratio is the following one:

Equation 15: Food/Microorganisms ratio equation using the readily biodegradable COD

$$\frac{F}{M} = \frac{Q \cdot (S_S - S_{S,OUT})}{V \cdot X_{BH}}$$

- X_{BH} (Heterotrophic Biomass in the aerobic reactor) = 3200 mg COD/L
- $S_{S,OUT}$ (Readily biodegradable COD in the outlet) = 3.077 mg COD/L
- S_s (Readily biodegradable COD in the inlet) = 2203.65 mg/L =2203.65 mg COD/L
- V (Reactor Volume) = 248,8 m^3 = 248,800 L
- Q (AS inlet Flowrate) = 216 m^3/d = 2166,000 L/day

$$\frac{F}{M} = 0.598$$

The efficiency of an activated sludge process can be defined by its F/M ratio, and for conventional activate sludge systems cannot be over 1,4 in high organic wastewaters to prevent the growth of filamentous bacteria, which will not settle easily due to its long tails. (18)

8.2.5 Recirculation and Purge ratio

The recirculation and purge ratio have been calculated with the following Equation 16 from the biomass mass balance in the activated sludge system. The flowrate of settled water that is going to be purged from the recirculation has been obtained with the following equation:

Equation 16: Purge flowrate equation with the ASM1 mass balance.

$$Q_w = \frac{X_{BH} \cdot V}{X_{BH,W} \cdot \theta_x}$$

- X_{BH} (Heterotrophic Biomass in the aerobic reactor) = 3200 mg COD/L
- $X_{BH,W}$ (Heterotrophic Biomass in the recirculation) = 6400 mg COD/L

As it was said in Appendix 8.2.3, the initial estimation of the concentration of heterotrophic biomass in the secondary settler is the double of the concentration in the aerobic reactor. Obviously, the concentration of heterotrophic biomass from the recirculation stream will be the same, as it comes out from the settler.

- V (Reactor Volume) = 248,8 m^3 = 248,800 L
- θ_x (SRT) = 5 days
- Q_w (AS purge Flowrate) = L/day

$$Q_w = 24880.26 \frac{L}{day} = 24.88 \frac{m^3}{day}$$

This 24.88 m^3/day is the flowrate of water which is high concentrated in biomass and that would flow out of the AS process.

The recirculation flowrate is obtained by multiplying the inlet flowrate with the following recirculation factor.

- X_{BH} (Heterotrophic Biomass in the aerobic reactor) = 3200 mg COD/L

Equation 17: Recirculation factor equation with the ASM1 biomass mass balance

$$R = \frac{(\theta_x - HRT_{reactor}) \cdot X_{BH}}{(X_{BH,R} - X_{BH}) \cdot \theta_x}$$

- $X_{BH,R}$ (Heterotrophic Biomass in the settler) = 6400 mg COD/L
- θ_x (SRT) = 5 days
- $HRT_{reactor}$ (Hidraulic Retention Time of the reactor) = 1.15 days
- R (Recirculation Factor)

$$R = 0.7696$$

$$Q_{rs} = Q \cdot R = 216 \frac{m^3}{day} \cdot 0.7696 = 166.239 \frac{m^3}{day}$$

- Q_{rs} (WWTP recirculation Flowrate) = m^3/day
- Q (AS inlet Flowrate) = m^3/day

The final flowrate of settled water that returns to the influent is 166.239 m^3/day.

8.2.6 Sludge Production

Sludge production (P_x) is obtained by applying the kinetic reactions shown in the ASM1 Model. There is going to be more or less production depending on the observed heterotrophic yield. The observed heterotrophic yield is obtained with the following equation of kinetic parameters.

Equation 18: Observed heterotrophic yield equation with the ASM1 Model

$$Y_{H,OBS} = \frac{Y_H}{(1 + k_d \cdot \theta_x)}$$

- Kd (Heterotrophic decay rate at 10ºC) = 0.2 day^{-1}
- θ_x (SRT) = 5 days
- Y_H (Heterotrophic yield) = 0.67 mg cellular COD formed $(\text{mg COD oxidized})^{-1}$
- $Y_{H,OBS}$ (Observed Heterotrophic yield) = mg cellular COD formed $(\text{mg COD oxidized})^{-1}$

$$Y_{H,OBS} = \frac{Y_H}{(1 + k_d \cdot \theta_x)} = 0.335 \frac{g\ cell\ COD\ formed}{g\ COD\ oxidized}$$

The observed heterotrophic yield is going to be lower than the theoretical one (set in 0,67 mg cellular COD/mg COD oxidized) due to the low weather temperature in the WWTP and due to the short SRT of 5 days.

The total sludge production per hour and liter is the following:

Equation 19: Sludge production equation with the ASM1 Model

$$p_x = \frac{P_x}{Q} = Y_{H,OBS} \cdot (S_S - S_{S,OUT})$$

- $S_{S,OUT}$ (Readily biodegradable COD in the outlet) = 3,077 mg COD/L
- S_s (Readily biodegradable COD in the inlet) = 2203.65 mg/L = 2203.65 g COD/m^3
- Q (WWTP inlet Flowrate) = 216 m^3/d = 2166,000 L/day

$$p_x = \frac{P_x}{Q} = Y_{H,OBS} \cdot (S_S - S_{S,OUT}) = 0.335 \cdot \left(2203.65 \frac{mg\ COD}{L} - 3{,}077 \frac{mg\ COD}{L}\right) = 737{,}19\ \frac{mg\ COD}{L}$$

$$P_x = p_x \cdot Q = 737{,}19\ \frac{mg\ COD}{L} \cdot 216000 \frac{L}{day} \cdot \frac{1\ kg}{1 \cdot 10^6\ mg} = 159.23 \frac{kg\ COD}{day}$$

This value of sludge production is not used during the simulation of the AS. However, this is a very important factor if a rigorous design of the settler is done. It is also a key factor to design a posttreatment of the purged sludge like thickening or dewatering.

8.2.7 Oxygen Demand

The oxygen demand has been calculated by applying the oxygen mass balance in the ASM1 model. Its value is not also used in the simulation, but it is needed if the final design of the aerobic reactor in case it would be required.

Equation 20: Oxygen consumption rate with the ASM1 oxygen mass balance.

$$r_{SO} = \frac{dS_O}{dt} = \left(\frac{1-Y_H}{Y_H}\right)\mu_{max,H} \cdot \frac{S_S}{K_S + S_S} \cdot X_{BH} + k_d \cdot X_{BH}$$

- Ks (Half-saturation coefficient (hsc) for heterotrophs at 10ºC) = 20 mg COD/L
- Kd (Heterotrophic decay rate at 10ºC) = 0.2 day^{-1}
- $\mu_{max,H}$ (Heterotrophic max. specific growth rate at 10ºC) = 3 day^{-1}
- Y_H (Heterotrophic yield) = 0.67 mg cell COD formed (mg COD oxidized)$^{-1}$
- S_s (Readily biodegradable COD in the inlet) = 2203.65 mg/L =2203.65 mg COD/L
- $r_{SO} = \frac{dS_O}{dt}$ (Oxygen consumption rate) = mg O2/L·day

Equation 21: Oxygen required rate in the aerobic reactor.

$$r_{SO} = \frac{dS_O}{dt} = 1270.45 \frac{mg\ O_2}{L \cdot day}$$

When the oxygen consumption rate is obtained, it needs to be multiplied with the volume to know the oxygen rate the reactor needs to carry on the aerobic functions well.

$$OR = r_{so} \cdot V$$

- V (Reactor Volume) = 248,8 m^3 = 248,800 L
- OR (Oxygen Rate) = mg/day

$$OR = r_{so} \cdot V = 1270.45 \frac{mg\ O_2}{L \cdot day} \cdot 248{,}000\ L \cdot \frac{1\ kg}{1 \cdot 10^6\ mg} = 316{,}09\ kg\ \frac{kg\ O_2}{day}$$

8.3 Dynamic Simulation

These are the parameters and concentration values of the mixture of inlet water and nutrients. These concentrations and flowrates are the average of the given values from 2014 to 2016.

Table 22: Inlet stream concentrations and parameters from the dynamic simulation of the WWTP

	INLET FLOWRATE (m^3/day)	S_i (mg/L)	S_s (mg/L)	S_o (mg/L)	S_{NO} (mg/L)	S_{NH} (mg/L)	S_{ND} (mg/L)	X_I (mg/L)	X_S (mg/L)	X_{BH} (mg/L)	X_{BA} (mg/L)	X_P (mg/L)	X_{ND} (mg/L)	RECIRCULATION FLOWRATE (m^3/day)
JAN	97.000	60.751	698.638	0.000	2.915	75.140	5.278	45.563	713.826	0.000	0.000	0.000	3.942	99.534
FEB	101.333	58.816	676.384	0.000	2.820	40.497	7.381	44.112	691.088	0.000	0.000	0.000	5.514	102.869
MAR	113.000	48.730	560.391	0.000	9.012	51.790	6.144	36.547	572.574	0.000	0.000	0.000	4.590	111.848
APR	99.000	38.007	437.076	0.000	1.257	33.683	6.515	28.505	446.577	0.000	0.000	0.000	4.866	101.073
MAY	107.667	41.316	475.133	0.000	0.927	33.133	4.474	30.987	485.462	0.000	0.000	0.000	3.342	107.743
JUN	119.333	43.379	498.859	0.000	1.348	25.197	5.883	32.534	509.704	0.000	0.000	0.000	4.395	116.722
JUL	111.000	27.102	311.676	0.000	1.160	29.833	7.089	20.327	318.451	0.000	0.000	0.000	5.295	110.309
AUG	131.333	24.269	279.096	0.000	0.930	34.683	3.571	18.202	285.163	0.000	0.000	0.000	2.667	125.958
SEP	120.500	27.037	310.922	0.000	0.570	15.700	2.850	20.278	317.681	0.000	0.000	0.000	2.129	117.620
OCT	144.000	31.110	2203.653	0.000	2.970	68.965	6.469	129.627	243.698	0.000	0.000	0.000	4.832	135.707
NOV	143.333	17.144	1214.377	0.000	5.685	54.802	5.302	71.434	134.296	0.000	0.000	0.000	3.961	135.193
DEC	114.000	32.802	377.228	0.000	1.853	29.667	15.065	24.602	385.428	0.000	0.000	0.000	11.254	112.618

These are the concentration values obtained inside the biological reactor after the simulation of every entire month indicated. Every monthly value obtained is used as the initial configuration for the following month. By doing this, a more realistic dynamic simulation is assured.

Table 23: Reactor parameters at the end of every monthly simulation.

	S_i (mg/L)	S_s (mg/L)	S_o (mg/L)	S_{NO} (mg/L)	S_{NH} (mg/L)	S_{ND} (mg/L)	X_I (mg/L)	X_S (mg/L)	X_{BH} (mg/L)	X_{BA} (mg/L)	X_P (mg/L)	X_{ND} (mg/L)
JAN	60.751	3.313	2.000	21.079	0.942	0.676	103.714	12.103	894.014	11.834	263.167	0.715
FEB	58.816	3.436	2.000	0.712	0.950	0.697	103.661	12.442	897.808	3.449	260.463	0.744
MAR	48.730	3.339	2.000	17.877	0.980	0.698	93.292	11.210	821.101	8.877	232.461	0.669
APR	38.007	3.335	2.000	5.258	0.945	0.722	66.536	7.730	568.205	5.104	169.436	0.471
MAY	41.346	3.422	2.000	1.008	0.965	0.686	76.605	9.214	665.343	3.432	192.046	0.546
JUN	43.379	3.564	2.000	0.195	0.976	0.703	86.654	10.896	765.627	1.294	213.825	0.650
JUL	27.102	3.339	2.000	12.794	0.975	0.774	51.923	6.136	448.826	7.009	131.335	0.385
AUG	24.269	3.363	2.000	14.070	1.102	0.708	52.711	6.451	467.703	8.284	130.611	0.386
SEP	27.037	3.690	2.000	0.052	0.755	0.682	54.953	9.706	480.117	0.205	136.328	0.408
OCT	31.110	3.628	2.000	0.102	1.034	0.663	695.274	19.855	2210.821	1.758	579.956	1.616
NOV	17.144	3.387	2.000	6.539	1.037	0.680	217.548	10.508	1213.699	8.634	321.915	0.865
DEC	32.802	3.339	2.000	20.735	0.982	0.891	63.720	7.622	557.273	10.334	160.120	0.512

These are the outlet stream concentrations of the AS process.

Table 24: Outlet stream concentration values of the WWTP.

	OUTLET FLOWRATE (m^3/day)	S_I (mg/L)	S_S (mg/L)	S_O (mg/L)	S_{NO} (mg/L)	S_{NH} (mg/L)	S_{ND} (mg/L)	X_I (mg/L)	X_S (mg/L)	X_{BH} (mg/L)	X_{BA} (mg/L)	X_P (mg/L)	X_{ND} (mg/L)	COD	TSS
JAN	72.120	60.751	3.313	2.000	21.079	0.942	0.676	0.519	0.061	4.470	0.059	1.316	0.004	70.488	4.818
FEB	76.453	58.816	3.436	2.000	0.712	0.950	0.697	0.518	0.062	4.489	0.017	1.302	0.004	68.641	4.792
MAR	88.120	48.730	3.339	2.000	17.877	0.980	0.698	0.466	0.056	4.106	0.044	1.162	0.003	57.903	4.376
APR	74.120	38.007	3.335	2.000	5.258	0.945	0.722	0.333	0.039	2.841	0.026	0.847	0.002	45.427	3.064
MAY	82.790	41.346	3.422	2.000	1.008	0.965	0.686	0.383	0.046	3.327	0.017	0.960	0.003	49.501	3.550
JUN	94.453	43.379	3.564	2.000	0.195	0.976	0.703	0.433	0.054	3.828	0.006	1.069	0.003	52.334	4.044
JUL	86.120	27.102	3.339	2.000	12.794	0.975	0.774	0.260	0.031	2.244	0.035	0.657	0.002	33.667	2.420
AUG	106.453	24.269	3.363	2.000	14.070	1.102	0.708	0.264	0.032	2.339	0.041	0.653	0.002	30.961	2.497
SEP	95.620	27.037	3.690	2.000	0.052	0.755	0.682	0.275	0.035	2.401	0.001	0.682	0.002	34.119	2.544
OCT	119.120	31.110	3.628	2.000	0.102	1.034	0.663	1.976	0.099	11.054	0.009	2.900	0.008	50.776	12.029
NOV	118.453	17.144	3.387	2.000	6.539	1.037	0.680	1.088	0.053	6.068	0.043	1.610	0.004	29.392	6.646
DEC	89.120	32.802	3.339	2.000	20.735	0.982	0.891	0.319	0.038	2.786	0.052	0.801	0.003	40.136	2.997

9. References

1. C. Beck, G. Prades, A. Sadowski, Activated sludge wastewater treatment plants optimization to face pollution overloads during grape harvest periods, Water Sci. Technol. 51 (1) (2005) 81–88.

2. OIV—International Organisation of Vine and Wine Situation Report for The World Vitivinicultural Sector in 2013. (www.oiv.int)

3. G.A. Brito, J.M. Peixoto, J.M. Oliveira, C. Oliveira, R. Nogueira, A. Rodrigues, Brewery and winery wastewater treatment: Some focal points of design and operation—In Utilization of by-products and treatment of waste food industry, in: V. Oreopoulou, W. Russ (Eds.), Chapter 7, Springer, London, 2007, pp. 1–22

4. D. Bolzonella, F. Fatone, P. Pavan, F. Cecchi, Application of a membrane bioreactor for winery wastewater treatment, Water Sci. Technol. 62 (2010) 2754–2759.

5. Chapman, J., Baker, P., Wills, S., 2001. Winery Wastewater Handbook: Production, Impacts and Management. Winetitles, Adelaide, Australia.

6. X. Melamane, R. Tandlich, J. Burgess, Anaerobic digestion of fungally pre-treated wine distillery wastewater, Afr. J. Biotechnol. 6 (17) (2007) 1990–1993.

7. S. Mohana, B.K. Acharya, D. Madamwar, Distillery spent wash: treatment technologies and potential applications, J. Hazard. Mater. 163 (1) (2009) 12–25.

8. P.J. Strong, J.E. Burgess, Treatment methods for wine-related and distillery wastewaters: a review, Biorem. J. 12 (2) (2008) 70–87.

9. Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment. OJ L 135, 30.5.1991, p. 40–52

10. IWA taskgroup on mathematical modelling for design and operation of biological wastewater treatment (2000). Activated sludge models ASM1, ASM2, ASM2d and ASM3, Scientific and Technical Report 9.

11. Traversac, J.B., Rousset, S., Perrier-Cornet, P., 2011. Farm resources, transaction cost and forward integration in agriculture: evidence from French wine producers. Food Pol. 36, 839e847.

12. The relationship between BOD:N ratio and wastewater treatability in a nitrogen-fixing wastewater treatment system. Slade AH, Thorn GJ, Dennis MA. Water Sci Technol. 2011;63(4):627-32. doi: 10.2166/wst.2011.215.

13. Chai, Q & Bakke, Rune & Lie, Bernt. (2006). Object-oriented modeling and optimal control of a biological wastewater treatment process. 2006. 218-223.

14. Resolución de 28 de octubre de 2008, aprobada por la Comisión Mixta para las Relaciones con el Tribunal de Cuentas, en relación al Informe de fiscalización de la Gestión de la Tasa por utilización privada o aprovechamiento especial de dominio público local. Publicado en: «BOE» núm. 36, de 11 de febrero de 2009, páginas 14531 a 14616 (86 págs.)

15. ATV-DVWK Standard A 131E. Dimensioning of Single-Stage Activated Sludge Plants. – 2000

16. Applications of Activated Sludge Models edited by Damir Brdjanovic, S. C. F. Meijer, C. M. Lopez-Vazquez, C. M. Hooijmans, Mark C. M. van Loosdrecht

17. IV Jornada de Transferencia de Tecnología sobre Microbiología del Fango Activo. Determinación de la fracción de Nutrientes por Respirometría en procesos de depuración biológica aerobia. Emilio Serrano - SURCIS, S.L.

18. Impact of food-to-microorganisms ratio on the stability of aerobic granular sludge treating high-strength organic wastewater - Rania Ahmed Hamza, Zhiya Sheng, Oliver Terna Iorhemen, Mohamed Sherif Zaghloul, Joo Hwa Tay - Department of Civil Engineering, University of Calgary, 2500 University Drive NW, Calgary, AB, T2N 1N4, Canada