DESIGN OF A PILOT PLANT FOR THE RECLAMATION OF INDUSTRIAL WASTEWATER WITH MINIMUM LIQUID DISCHARGE

Final Degree Project

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VIST I PLAU DEL TUTOR ACADÈMIC

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GLOSSARY OF ABBREVIATIONS AND SYMBOLS

Symbols

Symbol	Defined parameter	Symbol	Defined parameter
$Ø_{in}$	Inner diameter	N_T	Total Nitrogen
$Ø_{out}$	Outer diameter	P	Pressure
C	Conductivity	P_T	Total Phosphorous
$N_{inorganic}$	Inorganic Nitrogen	T	Temperature
$N_{Kjeldahl}$	Kjeldahl Nitrogen		

Abbreviations

Abbreviation	Meaning	Abbreviation	Meaning
AEQT	*Associació Empresarial Química de Tarragona*	**CEPCI**	Chemical Engineering Plant Cost Index
AISI	American Iron and Steel Institute	**CF**	Cartridge filter
AITASA	*Aguas Industriales de Tarragona S.A.*	**CFU**	Colony-Forming Unit
Amb.	Ambient	**CIP**	Clean in Place
ANSI	American National Standards Institute	**CP**	Concentration Polarization
AO	Analogic Output	**CTA**	Cellulose Triacetate
AOX	Adsorbable Organic Halides	**DAF**	Dissolved Air Flotation
API	American Petroleum Institute	**DDB**	Double Declining Balance
APQ	*Almacenamiento de Productos Químicos*	**DEMC**	*Departament d'Empresa i Treball*
ASME	American Society of Mechanical Engineers	**DO**	Digital Output
Atm.	Atmospheric	**DOC**	Dissolved Organic Carbon
BREF	Best Available Techniques Reference Documents	**ED**	Electrodialysis
CA	Cellulose Acetate	**EDR**	Electrodialysis Reversal
CAPEX	Capital Expenditures	**EU**	European Union
CEB	Chemically Enhanced Backwash	**FFR**	Feed Flow Reversal

Abbreviation	Meaning	Abbreviation	Meaning
FO	Forward Osmosis	**PVA**	Polyvinyl alcohol
MBR	Membrane Bioreactor	**PVC**	Polyvinyl chloride
MC	Membrane Contactor	**PVDF**	Polyvinylidene fluoride
MCr	Membrane Crystallization	**PVP**	Polyvinylpyrrolidone
MD	Membrane Distillation	**R&D**	Research & Development
MF	Microfiltration	**RD**	*Real Decreto*
MIE	*Ministerio de Industria y Energía*	**RO**	Reverse osmosis
NF	Nanofiltration	**RSF**	Rapid Sand Filtration
NFF	Normal Forward Feed	**SCH**	Schedule
NPS	Nominal Pipe Size	**SDI**	Silt Density Index
NTU	Number of Turbidity Units	**SL**	Straight-Line
nZLD	Near Zero Liquid Discharge	**SOYD**	Sum Of the Years Digits
OD	Osmosis Distillation	**SSF**	Slow Sand Filtration
OPEX	Operational Expenditures	**SSM**	Suspended Solid Matter
P&ID	Piping and Instrumentation Diagram	**TDS**	Total Dissolved Solids
PA	Polyamide	**TFC**	Thin Film Composite
PAN	Polyacrylonitrile	**TIC**	Total Inorganic Carbon
PC	Polycarbonate	**TOC**	Total Organic Carbon
PCD	Process Control Diagram	**UF**	Ultrafiltration
PE	Polyethylene	**ULTIMATE**	indUstry water-utiLiTy symbIosis for a sMarter wATer sociEty
PEEK	Polyether Ether Ketone	**UNE**	*Una Norma Española*
PES	Polyether sulphone	**UTM**	Universal Transverse Mercator
PESK	Polyethersulfoneketone	**WAVE**	Water Application Value Engine
PFA	Perfluoroalkoxy	**WSIS**	Water Smart Industrial Symbiosis
PP	Polypropylene	**WRP**	Water reclamation plant
PPS	Polyphenylene sulfide	**WWTP**	Wastewater Treatment Plant
PS	Polystyrene	**ZLD**	Zero Liquid Discharge
PSF	Polysulfone	**ZLDD**	Zero Liquid Discharge Desalination

1. INTRODUCTION

The present final degree project consists of the design and development of a pilot plant for the reclamation of industrial wastewater with a minimum liquid discharge system (also known as near zero liquid discharge system, nZLD) for the petrochemical complex in Tarragona. It is part of ULTIMATE, a 4-year Horizon2020 project under the EU *Water in the Context of the Circular Economy* programme (grant agreement 869318).

ULTIMATE's main aim is to create economic value and increase sustainability by valorising resources within the water cycle. Thus, several pilots are to be constructed in different locations all over Europe in order to stimulate symbiosis and partnership between business from four of the most important sectors in Europe: agro-food processing, beverages, petrochemical and biotech (ref. 1).

Figure 1.1. ULTIMATE's logo. Source: (ref. 1).

In the particular case of Tarragona, the symbiosis to be strengthened is the already existing one between AEQT and AITASA based on reclaimed water use in the complex. AITASA currently supplies urban reclaimed water to the complex for cooling and heating purposes with its WRP, and is also constructing a centralized WWTP for industrial wastewater polishing to meet the future BREF requirements of the sector (ref. 2).

This WWTP is expected to be operative in February 2022, and it will consist of a dissolved air flotation (DAF) followed by a biologic aerobic treatment using membranes (MBR) and a final polishing with activated carbon filtration. As this sector is experiencing economic growth, an increase on water demand is expected for the following years, so new resources need to be implemented to ensure the sustainability of the production.

ULTIMATE's purpose is to demonstrate a new reclamation system based on nZLD technologies to produce water for cooling and heating purposes from the future WWTP. To do so, a pilot plant will be designed and constructed by combining different innovative technologies to prove the feasibility of water reclamation and reuse from this source. Its operation will last for two years, and during this time, minimum or near zero liquid discharge will be generated.

In order to elaborate a preliminary design of the pilot, a state of the art on the current status of nZLD technologies has been conducted, and it has enabled the later selection of the technologies to be implemented. Once selected, these technologies have been designed and characterized by combining experimental data obtained in Eurecat's laboratories, theoretical calculations and simulations with specialized software. With this information, the various diagrams that represent their operation have been elaborated.

The present document also contains a description of the systems' operation under different modes, as well as the guidelines to guarantee their proper maintenance.

Finally, a financial study to estimate the associated CAPEX and OPEX has been prepared. This has been done by contacting different suppliers to evaluate their proposed alternatives (on instruments, installation complements…) and hence work with real values, thus making an accurate budget.

During the elaboration of this project, several meetings with AITASA have been conducted with a view on knowing their opinion about the P&IDs and clarifying some issues regarding the quality of the water to be treated. One of these meetings consisted of a visit to their installations in *Polígon Entrevies*, where they showed and explained to the Eurecat team their current water treatment system as well as the area where their new WWTP is being constructed.

2. PRELIMINARY STAGE

In this chapter the general characteristics of the project are defined, as well as the considered approach, and its planning.

2.1. Description of the project

The project consists of the design of a pilot plant to demonstrate the feasibility of water reclamation from the wastewater produced in Tarragona's petrochemical park. The pilot plant will be operative for two years, and will treat aggregated wastewater with high concentration of salts and ammonia.

This treatment will consist of an advanced RO module coupled with a membrane distillation system, thus enabling the extraction of the water contained in the RO brines and guaranteeing high water recovery. A final polishing step of adsorption on zeolites will be added to remove the remaining ammonia.

Originally, the WWTP that precedes this system was supposed to be under construction for the first month of the operation of the pilot, as the pilot should be operative in January 2022 and the WWTP will not be operative until February 2022. Hence, a pre-treatment formed by a cartridge filter and an UF module was included to prevent RO filters from suffering any kind of damage during that time. However, AITASA informed at the beginning of the month of May that the WWTP would be operational, and after discussing what to do with the pre-treatment, it was agreed to maintain it as they want to test the pilot performance with both the inlet and the outlet of the WWTP.

2.2. Scope of the project

The scope of this project comprises the design of a nZLD scheme for water reclamation consisting of an advanced RO module and its final stage of membrane distillation. The pilot also considers its pre-treatment (which comprises a cartridge filter and an UF module), and an ammonium recovery system by adsorption on zeolites to polish the produced water.

These designs have been elaborated by considering water quality requirements (which can be found in *3.1.3. Specifications of the produced water*) and the various specific characteristics which are inherent to the nature of each technology.

The addition of any other treatment stage to polish water quality from the outlet of any of the selected technologies is considered outside the scope of this project.

2.3. Historical background

2.3.1. What is ULTIMATE?

ULTIMATE is a 4-year Horizon2020 project under the EU Water in the *Context of the Circular Economy* programme (grant agreement 869318). The project's main aim is to catalyse WSIS in which water or wastewater plays a key role both as a reusable resource but also as a vector for energy and materials to be extracted, treated, stored and reused within a dynamic socio-economic and business-oriented industrial ecosystem. This is being implemented with an evidence-based approach anchored on 9 large-scale demonstrations all over Europe, which are indicated in the picture below:

Figure 2.1. ULTIMATE's pilot sites. Source: (ref. 1).

All cases are supported so that their replicability would be ensured, which is conducted by using smart tools to optimize and control, assessing costs and benefits, minimizing risks and helping stakeholders identify their emerging business opportunities.

By mobilizing this strong partnership between water companies and water service providers, industries and research centres, it is expected to stimulate the ongoing research on water issues and ensure real impact (ref. 1).

2.3.2. Tarragona’s site

2.3.2.1. Current status

Tarragona’s site is characterized by counting on an already existing industrial cluster conformed by more than 30 companies and an industrially owned water-energy-telecom multiutility.

During the 80s, these companies were dependent on water transfers from the Ebro River to meet their consumption needs, but as their increasing demand outpaced the system’s capacity, a reclamation plant started operating in 2012 to feed industrial uses. This plant reclaims municipal WWTP effluent by using RO as its main process, producing water that is primarily used in cooling towers and boilers.

However, new water sources are needed to fulfil the future water demand of the complex. Taking into consideration the future BREF requirements for wastewater discharge of the sector (ref. 2), an industrial WWTP will be commissioned in 2022 to polish the aggregated wastewater from the petrochemical park. This new WWTP could be used as a new water resource to increase water availability in the complex (ref. 3) (ref. 4).

Therefore, ULTIMATE will demonstrate the feasibility of water reclamation from this new industrial WWTP using a tertiary treatment based on nZLD systems. And will do it both at bench and pilot scale, providing insights on the feasibility of increasing water availability in the complex as well as demonstrating the possibilities to obtain fit-for-purpose water for later uses.

The construction of a full-scale tertiary treatment based on the pilot’s results is envisaged for the future to increase the current water reclamation capacity of the complex (ref. 1).

The main reason why the study of the performance of this pilot is so interesting, is its potential to satisfy the water needs of the petrochemical complex in the near future, as the already existing infrastructure for water regeneration may not be enough to supply enough water for both industrial and urban purposes in the near future. Moreover, the economic growth of the petrochemical complex is tightly entwined with water availability. Because of this, it is interesting for AEQT companies to have at their disposal this WWTP as well as this tertiary treatment in order to increase their water provision.

2.3.2.2. Operation of the reclamation plant of AITASA's installations

AITASA's installations were visited the 7th of May 2021, and the operation of their reclamation plant was explained to the Eurecat team.

A brief explanation of the operation of each treatment stage is indicated below:

1. Water reception

Water from the various plants of the complex is fed to a raft by gravity, and is pumped into the pre-treatment units:

Figure 2.2. Raft with two pipelines to pre-treatment.

2. Decantation

Coagulant PAX-14 is added, and water is agitated at a very high speed. Then, silica sand is added to accelerate the decantation process, and hence, reduce the decantation space. After the addition of flocculants, water goes to a maturation raft, and then to the decanter.

The obtained sludge is recirculated into a hydrocyclone to recover about 85% of silica sand.

Figure 2.3. Decanter (right) and decanter outlet (left).

3. Hydrotech & open filters

Water goes through Hydrotech filters to retain solids that have not been eliminated in the previous stage, and then, by gravity, water is fed into other open filters. There, some hypochlorite is added so that it reacts with ammonium and forms monochloramine, which is a disinfectant agent that reduces biofouling in the later membrane stages.

Figure 2.4. Hydrotech filter.

Figure 2.5. Open filters with water and monochloramine.

4. <u>Closed filters</u>

In these sand filters, an organic product is added to make particles bigger and therefore retain them.

Figure 2.6. Closed sand filters.

5. <u>Cartridge filters & reverse osmosis</u>

Cartridge filters are the last stage of the pre-treatment. Their smaller pore size enables them to act as safety filters to prevent sand or other solids from entering the reverse osmosis modules. They are changed twice a week.

There are two RO racks with three stages each. These membranes reduce even more the salts content and eliminate microbiologic activity.

Preventive maintenance is conducted every 6 months, and in this process membranes are chemically cleaned either under acidic (pH = 1.5) or basic (pH = 10.5) conditions at temperatures that range between 30ºC and 35ºC. Acidic cleaning dissolves TOC, and the basic one dissolves TOC and eliminates biofouling.

Additionally, the plant operation is stopped every day for an hour to make permeate at 35ºC with NaOH flow in parallel to reduce osmotic pressure. In turn, this flashing reduces serious cleaning times and extends the service life of the membranes.

Figure 2.7. Cartridge filters (front) and reverse osmosis racks (back).

2.3.2.3. Operation of the future WWTP of AITASA's installations

AITASA's future WWTP comprises five different stages: homogenization, physicochemical treatment, ozonation, biologic treatment and filtration with activated carbon.

1. <u>Homogenization</u>

A homogenization system is required to supply water with a stable composition to the system.

2. <u>Physicochemical treatment</u>

This stage comprises coagulation, flocculation and decantation to eliminate suspended solids and heavy metals.

3. <u>Ozonation</u>

With a partial chemical oxidation by ozone, DOC can be reduced so that colour and the presence of chemical compounds can be reduced. Additionally, as the DOC from water has a high percentage of refractory and slow biodegradation compounds, this process increases their biodegradability and also improves filterability.

4. <u>Biologic treatment</u>

A membrane bioreactor (MBR) has been selected to eliminate nutrients (nitrogen and phosphorous) and DOC with a setup that combines anoxic, facultative and oxic zones.

5. <u>Filtration with activated carbon</u>

Filtration with activated carbon is the last stage of this WWTP, and its main aim is to adsorb the remaining metals, sulphurs and other compounds that have not been eliminated during the previous stages.

2.4. <u>Bibliographic review / Process alternatives</u>

For each of the studied steps of the treatment scheme, different alternatives have been considered. The selected options and their commercial models are listed below. The detailed study of alternatives can be found in annex *A.1. STUDY OF ALTERNATIVES*, and the information about each commercial piece of equipment in *4.2.3. Equipment design.*

- Pre-treatment technologies:
  - Cartridge filter: Diproclean, 100 μm.
  - Ultrafiltration: Biosnar, 100 kDa ceramic membrane.

- Minimum liquid discharge technologies:
  - RO module: DuPont, XLE-2540.
  - Membrane distillation system: Solar Spring MD Lab.
- Ammonium recovery / treatment: adsorption on zeolites.

2.5. Initial planification of the project

A Gantt diagram has been done to show in a visual way the initial planification of the project:

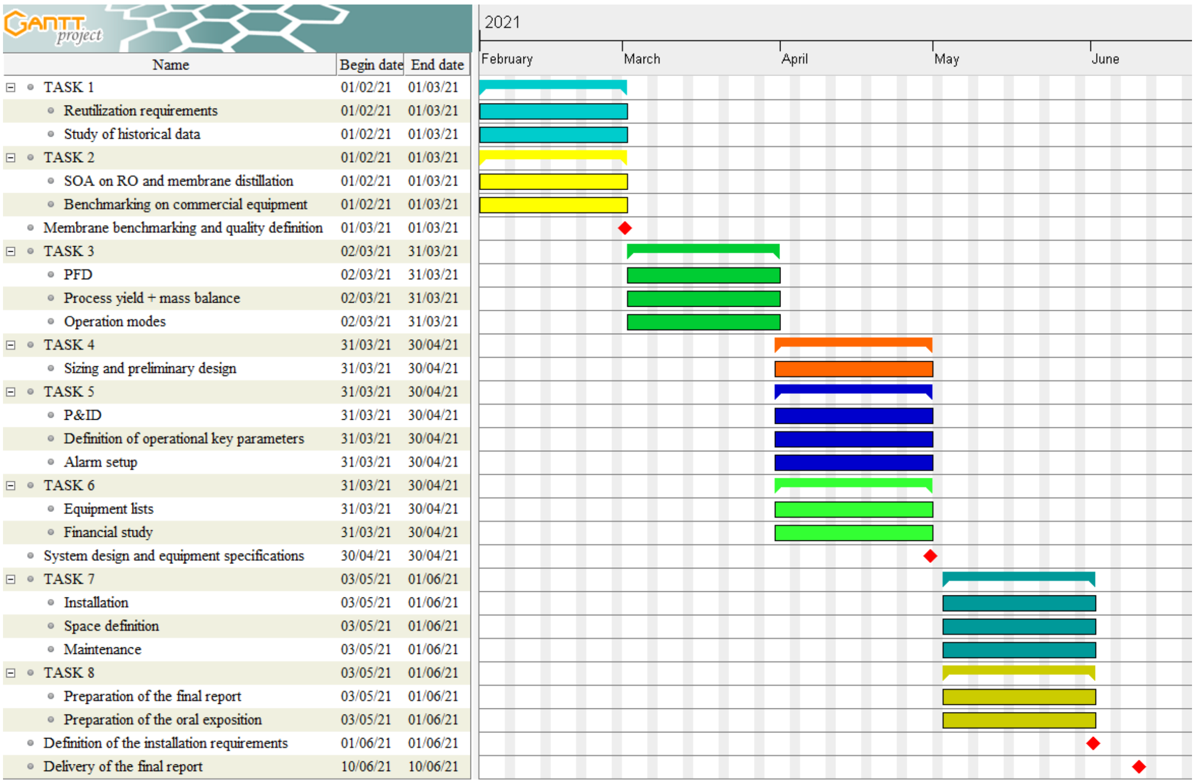


Figure 2.8. Gantt diagram with the planification of the project

Despite having the project planned as indicated in the picture above, there have been various modifications on the timing derived from various factors. For example, a preliminary version of the P&IDs of the system had to be delivered to the European commission in mid-March, and then several modifications had to be conducted for other meetings with AITASA. Hence, the project has progressed at a different rhythm.

3. BASIS FOR THE DEVELOPMENT OF THE PROJECT

3.1. Design basis

This chapter describes the characteristics and properties of the water streams as well as the design principles on which this project is based.

3.1.1. Specifications of the feedwater

The characterization of the feedwater to be treated has been done with data provided by AITASA, which is based on several analysis that were conducted from March to December 2020. All of these samples were extracted from the output of the industrial system prior to the future WWTP.

The average values and their standard deviation can be observed in the table below. However, a general view of the results for each parameter can be found in annex *A.2. FEEDWATER CHARACTERIZATION*.

Table 3.1. Feedwater composition characterization.

Parameter	Concentration units	Average value	Standard deviation	Limit
TOC	mg/L	53.0	38.6	33
DOC	mg/L	195.3	63.2	100
SSM	mg/L	53.8	58.4	25
N_T	mg/L	21.0	6.8	25
$N_{inorganic}$	mg/L	14.3	7.0	20
$N-NH_4$	mg/L	13.8	7.2	-
$N-NO_3$	mg/L	3.0	2.7	-
$N-NO_2$	mg/L	1.2	3.0	-
$N_{Kjeldahl}$	mg/L	20.4	7.1	-
P_T	mg/L	3.4	1.7	3
AOX	mg/L	1.8	2.1	1
Cr	µg/L	25.7	7.9	25
Cu	µg/L	51.4	60.7	50
Ni	µg/L	28.9	10.5	50
Zn	µg/L	286.7	122.7	300
Cd	µg/L	<20	0	8
Hg	µg/L	0.2	0.2	1
Pb	µg/L	<20	0	30
Benzene	µg/L	25.3	45.5	50
Hydrocarbons	mg/L	<5	0	3

3.1.2. Capacity, operational flexibility and service factor

As the project's nature is purely demonstrative (that is, proving whether it is feasible or not to treat water from the petrochemical park with a nZLD system), the capacity of the selected technologies varies depending on their commercial availability and current development.

As RO is a widely studied and implemented technology, a wide range of products is available in the market. The selected RO capacity is 12 m^3/day. And so is the capacity of the cartridge filter and the UF used as a pre-treatment for this stage. However, as it has been explained in *2.1. Description of the project*, the pre-treatment may not necessarily be used all the time, but it is included as a conservative approach.

On the other hand, MD and adsorption on zeolites capacities are lower, mainly as MD is a quite recent technology that is currently being extensively studied. MD selected capacity is 1.8 m^3/day, whereas the one for the adsorption on zeolites is 1 m^3/day. These capacities were selected as relevant for technology demonstration within the framework of the project.

3.1.3. Specifications of the produced water

The water obtained from this treatment system has to meet both RD 1620/2007 (ref. 5) standards as well as AITASA's quality standards. Moreover, as water may be used in boilers, it must also meet the quality guidelines defined by UNE-EN 12952-12:2004 "Water tube boilers and auxiliary installations – Part 12: Requirements for boiler feedwater and boiler water quality" (ref. 6).

The table below summarizes the combination of parameters of the three abovementioned guidelines that are to be considered. The specific conditions of each of these three requirements can be found in *A.3. PRODUCED WATER SPECIFICATIONS*.

It must be highlighted that membrane technologies do not guarantee the total elimination of bacteria, as this can only be achieved through chlorine addition. Although membrane's permeates do not contain any bacteria, there is a potential regrowth risk in tanks. As this chlorination step is critical, especially if water is to be used in cooling towers, a final chlorination stage is required, but it is considered out of the scope as this is a R&D project.

Table 3.2. Summary of the specifications that treated water must meet.

Parameter	Units	Limit value	Regulation
Acid conductivity at 25ºC	µS / cm		UNE
Without phosphate dosing		< 30	
With phosphate dosing		< 40	
Ammonium	mg / L	0.8	AITASA
Chlorides	mg / L	350	AITASA
DOC	mg / L	20	AITASA
Direct conductivity at 25ºC	µS / cm	< 30	UNE
E. coli	CFU / 100 mL	Absence	RD
Intestinal nematodes	eggs / 10 L	1	RD
Legionella	eggs / 10 L	Absence	RD
Ortophosphates	mg / L	5	AITASA

Parameter	Units	Limit value	Regulation
pH at 25ºC	-	9.3 – 9.7	UNE
Phosphates	mg / L	< 3	UNE
Silica concentration	mg / L	See figures A.3.1 & A.3.2.	UNE
Sulphate	mg / L	200	AITASA
Total suspended solids	mg / L	5	RD
Turbidity	NTU	1	RD

3.1.4. Design rules to apply

3.1.4.1. Tanks

The present system is requires 6 tanks in order to operate the units independently. One has an electric resistance that acts as a heater, and another one has a coil that acts as a chiller. Despite having some process sections operating at very high pressures, all tanks are atmospheric as the system setup enables them to work under atmospheric conditions.

However, all of them have been designed by following a combination of the guidelines of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 (ref. 7) and the API 650, Welded Tanks for Oil Storage (ref. 8) with a view on making them resistant in case there were operational changes, as the ASME Code is for the design of pressurized vessels and the API 650 one for the design of atmospheric tanks. The obtained values from these calculations have been used as a guide when selecting commercial tanks, although most of the calculated parameters were not available because of the nature of commercial atmospheric water tanks.

3.1.4.2. Pipes

ANSI standards have been followed in all pipelines design. In all cases Schedule 40 has been selected.

3.1.4.3. Dynamic equipment: pumps

The selection of the pumps required in this project has been founded on the smart-sizing tools from Grundfos (ref. 9) and Cat Pumps (ref. 10) websites. The calculations that have been conducted to obtain the values with which the selections have been made, can be found in *A.4. PUMP DESIGN.*

3.1.5. Other design criteria

When designing the equipment that conforms the present installation, not only are the design rules indicated in the previous section to be applied, but also other criteria concerning the singularities of the project’s nature, which are listed below:

- The pilot must operate for 2 years.
- The plant operation must be fully automated and each unit must be independent from the other ones.
- Liquid discharge must be minimum.
- The whole pilot except from the feedwater tank must fit into a 40 ft container (whose internal measures are: 12 m x 2.35 m x 2.39 m) in order to facilitate its transportation.

- The container will have a heat pump that will keep temperature conditions stable. Therefore, the only temperature protection measures are to be implemented in the feedwater tank and the pipes that connect it to the rest of the pilot.
- The pilot must be flexible enough in water quality terms to treat the inlet or the outlet of the WWTP under construction.
- As the obtained brines are very corrosive, materials are to be selected taking into account this aspect to prevent corrosion.
- The obtained water to be reused must meet RD 1620/2007, UNE-EN 12952-12:2004 and AITASA's standards. Chlorination should be considered in distribution.
- The financial cost of the project should be in line with the defined budget of 160,000 €.

3.2. Basic data for the engineering development

3.2.1. Site characterization

The pilot will be installed in an area from the petrochemical park known as *Polígon Entrevies*, in AITASA's installations. It will be located in front of the WWTP that is currently under construction:

Figure 3.1. Construction of the WWTP.

3.2.1.1. Location

The pilot location was selected during Eurecat's visit to AITASA's installations the 7th of May of 2021. The location was selected by considering the proximity to the feed and outlet lines of the future WWTP, and also the need for having an electrical enclosure nearby:

Figure 3.2. Future location of the pilot plant.

The approximate coordinates of the pilot are:

Table 3.3. Approximate coordinates of the pilot in Longitude - Latitude and UTM format.

Geographic coordinates		Projection UTM 31N (ETRS89)	
Longitude	**Latitude**	**X (m)**	**Y (m)**
1º 11' 38.5" E	41º 05' 53.3" N	348,235.47	4,551,097.66

3.2.1.2. Climatology

The meteorological conditions of the area are the ones that correspond to the meteorological station of Tarragona - Complex Educatiu (Tarragonès), which have been extracted from DEMC's webpage, in the "Meteorological Data" section (ref. 11), and they can be found in the following table:

Table 3.4. Meteorological data from the site. Source: (ref. 11).

Meteorological parameter	Considered value	
Ambient temperature (ºC):	17,4	
Average land temperature (ºC):	17,4	
Relative humidity (%):	76	
Wind speed (m/s) prevailing stability:	4,05 D	1,46 F
Predominant direction of the wind in predominant stability:	O	N

3.2.1.3. Elevation and land characterization

The area does not have any relevant orographic incidents, the base of the *Cap de Salou* television repeater, at 71 m above sea level, is the highest elevation within the territorial area under study. The nearest water sources are the Boella stream and the Francolí river.

3.2.2. Available energy and utilities

The site has an electrical enclosure and is close to the water feed and outlet of the WWTP.

Figure 3.3. Electrical enclosure (back), WWTP feed (left pipe) and WWTP outlet (right pipe).

Instrumentation air will be obtained from a small compressor that will be installed by the 40 ft container.

3.2.3. Energy prices

The cost of industrial electricity in Spain has been bibliographically determined, and it is 42.08 €/MWh (ref. 12).

4. BASIC ENGINEERING DEVELOPMENT

4.1. Elaboration of diagrams

4.1.1. Block diagram

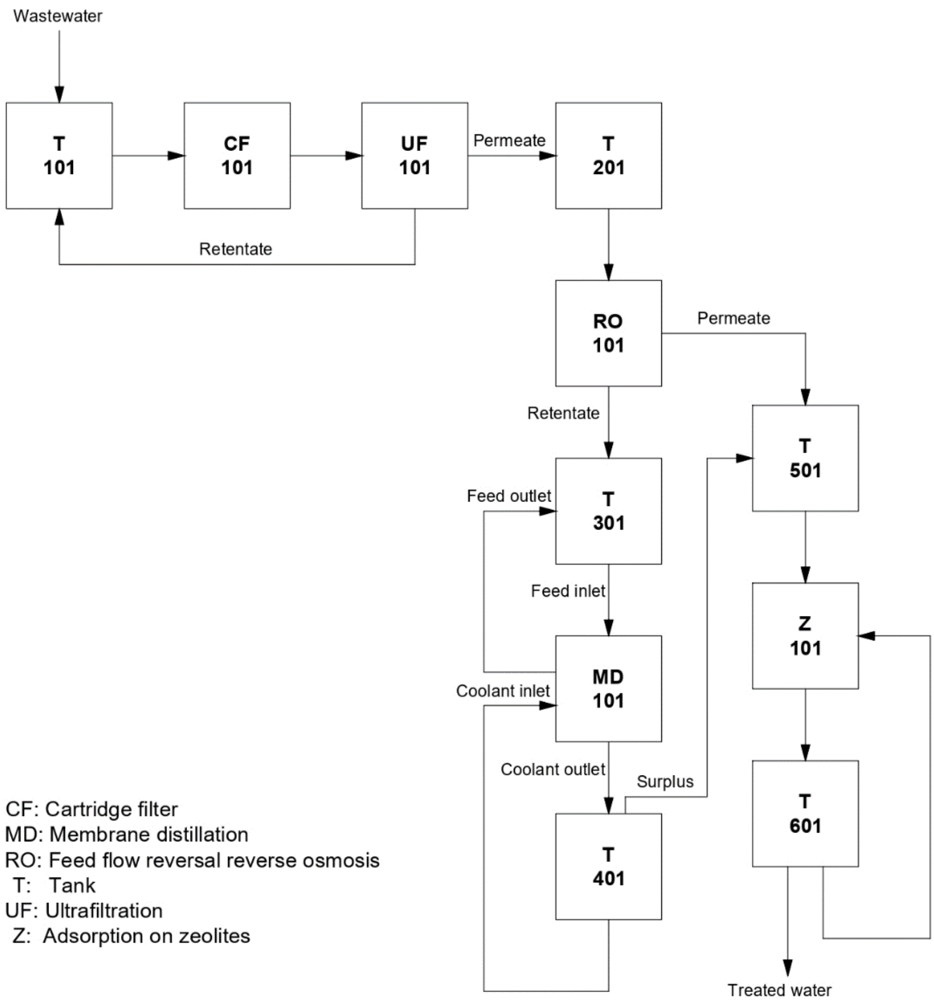


Figure 4.1. Block diagram

4.1.2. Simulation diagram

The modelling software WAVE (Water Application Value Engine) by DuPont has been used to model the RO module as laboratory experiments have not been conducted yet. This way, approximate values of the various studied parameters can be obtained.

The report generated at the end of the simulation can be found in the following pages:

WATER APPLICATION VALUE ENGINE

WATER SOLUTIONS

WAVE Program Version: 1.81.814

Calculation Engine Version: 01.11.19.00

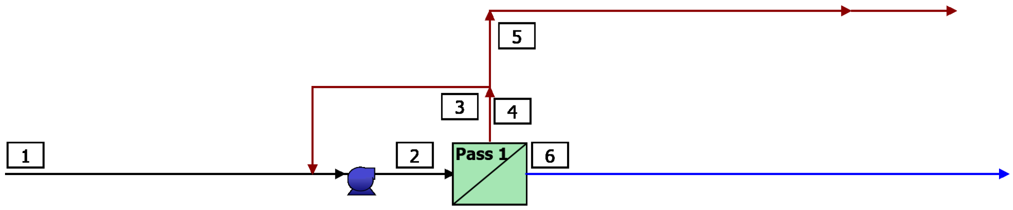
Database Version: 23

Project Name:	ULTIMATE v2
Case Name:	Case 1
Customer:	
Prepared by:	Wave Tango
Company:	DuPont
Country:	
Date Created:	May 22, 2021
Project Notes:	
Case #:	1 of: 1
Case Notes:	Case 1

Keywords:

RO Detailed Report

RO System Flow Diagram



#	Description	Flow (m³/d)	TDS (mg/L)	Pressure (bar)
1	Raw Feed to RO System	10.8	6,107	0.0
2	Net Feed to Pass 1	17.7	9,847	12.4
3	Concentrate Recycle from Pass 1 to Pass 1	6.90	15,689	9.3
4	Total Concentrate from Pass 1	10.6	15,689	9.3
5	Net Concentrate from RO System	3.72	15,689	9.3
6	Net Product from RO System	7.08	1,081	0.0

RO System Overview

Total # of Trains	1	Online =	1	Standby =	0	RO Recovery	65.6 %
System Flow Rate	(m³/d)	Net Feed =	10.8	Net Product =	7.08		

Pass		Pass 1
Stream Name		Stream 1
Water Type		Waste Water (With conventional pretreatment, SDI < 5)
Number of Elements		12
Total Active Area	(m²)	31.2
Feed Flow per Pass	(m³/d)	17.7
Feed TDS[a]	(mg/L)	9,847
Feed Pressure	(bar)	12.4
Flow Factor Per Stage		0.85, 0.85
Permeate Flow per Pass	(m³/d)	7.08
Pass Average flux	(LMH)	9.5
Permeate TDS[a]	(mg/L)	1,081
Pass Recovery		40.0 %
Average NDP	(bar)	1.8
Specific Energy	(kWh/m³)	1.08
Temperature	(°C)	25.0
pH		7.0
Chemical Dose		-
RO System Recovery		65.6 %
Net RO System Recovery		65.6%

Footnotes:

[a]Total Dissolved Solids includes ions, SiO_2 and $B(OH)_3$. It does not include NH_3 and CO_2

RO Flow Table (Stage Level) - Pass 1

Stage	Elements	#PV	#Els per PV	Feed				Concentrate			Permeate			
				Feed Flow (m^3/d)	Recirc Flow (m^3/d)	Feed Press (bar)	Boost Press (bar)	Conc Flow (m^3/d)	Conc Press (bar)	Press Drop (bar)	Perm Flow (m^3/d)	Avg Flux (LMH)	Perm Press (bar)	Perm TDS (mg/L)
1	XLE-2540	1	6	17.7	6.90	12.1	0.0	12.2	10.6	1.5	5.47	14.6	0.0	676.6
2	XLE-2540	1	6	12.2	0.0	10.4	0.0	10.6	9.3	1.1	1.61	4.3	0.0	2,454

RO Solute Concentrations - Pass 1

Concentrations (mg/L as ion)								
		Adjusted Feed		Concentrate		Permeate		
	Raw Feed	Initial	After Recycle	Stage1	Stage2	Stage1	Stage2	Total
NH_4^+	13.02	13.02	20.80	29.37	32.95	1.63	5.76	2.57
K^+	36.06	36.06	57.59	81.36	91.23	4.45	16.19	7.12
Na^+	2,046	2,046	3,280	4,639	5,209	242.0	874.2	385.7
Mg^{+2}	53.09	53.09	88.57	126.7	144.0	3.30	12.49	5.39
Ca^{+2}	193.3	193.3	322.6	461.6	524.7	11.88	45.33	19.48
Sr^{+2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ba^{+2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_3^{-2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HCO_3^-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NO_3^-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F^-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cl^-	3,549	3,549	5,709	8,082	9,084	403.9	1,464	644.8
Br^{-1}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO_4^{-2}	217.6	217.6	367.9	528.2	602.6	9.47	36.59	15.63
PO_4^{-3}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TDS[a]	6,107	6,107	9,847	13,948	15,689	676.6	2,454	1,081
Est. Cond. µS/cm	10,995	10,995	17,043	23,392	26,013	1,373	4,710	2,155
pH	7.0	7.0	6.8	6.7	6.6	7.8	7.3	7.7

Footnotes:

[a]Total Dissolved Solids includes ions, SiO_2 and $B(OH)_3$. It does not include NH_3 and CO_2

RO Design Warnings

None

Special Comments

None

RO Flow Table (Element Level) - Pass 1

Stage	Element	Element Name	Recovery (%)	Feed Flow (m^3/d)	Feed Press (bar)	Feed TDS (mg/L)	Conc Flow (m^3/d)	Perm Flow (m^3/d)	Perm Flux (LMH)	Perm TDS (mg/L)
1	1	XLE-2540	8.3	17.7	12.1	9,847	16.2	1.47	23.5	373.9
1	2	XLE-2540	7.3	16.2	11.7	10,703	15.0	1.19	19.0	491.5
1	3	XLE-2540	6.3	15.0	11.5	11,509	14.1	0.95	15.3	644.2
1	4	XLE-2540	5.4	14.1	11.2	12,243	13.3	0.76	12.2	837.1
1	5	XLE-2540	4.6	13.3	11.0	12,893	12.7	0.61	9.8	1,072
1	6	XLE-2540	3.9	12.7	10.8	13,459	12.2	0.49	7.9	1,346
2	1	XLE-2540	3.1	12.2	10.4	13,948	11.9	0.38	6.0	1,755
2	2	XLE-2540	2.7	11.9	10.2	14,337	11.5	0.32	5.1	2,083
2	3	XLE-2540	2.4	11.5	10.0	14,675	11.3	0.27	4.4	2,419
2	4	XLE-2540	2.1	11.3	9.8	14,973	11.0	0.24	3.8	2,757
2	5	XLE-2540	1.9	11.0	9.6	15,238	10.8	0.21	3.4	3,093
2	6	XLE-2540	1.8	10.8	9.5	15,475	10.6	0.19	3.0	3,423

Footnotes:

[a]Total Dissolved Solids includes ions, SiO_2 and $B(OH)_3$. It does not include NH_3 and CO_2

RO Solubility Warnings

None

RO Chemical Adjustments

	Pass 1 Feed	RO 1st Pass Conc
pH	7.0	6.6
Langelier Saturation Index	0.00	0.00
Stiff & Davis Stability Index	0.00	0.00
TDS[a] (mg/l)	6,107	15,689
Ionic Strength (molal)	0.11	0.30
HCO_3^- (mg/L)	0.00	0.00
CO_2 (mg/l)	0.00	0.00
CO_3^{-2} (mg/L)	0.00	0.00
$CaSO_4$ (% saturation)	3.5	12.6
$BaSO_4$ (% saturation)	0.00	0.00
$SrSO_4$ (% saturation)	0.00	0.00
CaF_2 (% saturation)	0.00	0.00
SiO_2 (% saturation)	0.00	0.00
$Mg(OH)_2$ (% saturation)	0.00	0.00

Footnotes:

[a]Total Dissolved Solids includes ions, SiO_2 and $B(OH)_3$. It does not include NH_3 and CO_2

RO Utility and Chemical Costs

Service Water

	Flow Rate (m^3/d)	Unit Cost ($/$m^3$)	Hourly Cost ($/h)	Daily Cost ($/d)
Non-Product Feed Water				
Pass 1	3.7	0.1400	0.02	0.52
Total Non-product Feed Water Cost	3.7		0.02	0.52
Waste Water Disposal				
Pass 1	3.7	0.6900	0.11	2.57
Total Waste Water Disposal	3.7		0.11	2.57
Total Service Water Cost				3.09

Electricity

Peak Power	(kW)	0.3
Energy	(kWh/d)	7.6
Electricity Unit Cost	($/kWh)	0.0900
Electricity Cost	($/d)	0.7
Specific Energy	(kWh/m^3)	1.08

Pump	**Flow Rate (m^3/d)**	**Power (kW)**	**Energy (kWh/d)**	**Cost ($/d)**
Pass 1				
Feed	17.70	0.32	7.61	0.69
Pass 1 Total		0.32	7.61	0.69
System Total		0.32	7.61	0.69

Chemical

Chemical	**Unit Cost ($/kg)**	**Dose (mg/L)**	**Volume (L/d)**	**Cost ($/d)**
Total Chemical Cost				0.0

Utility and Chemical Cost	($/d)	3.8
Specific Water Cost	($/$m^3$)	0.535

4.1.3. Process Flow Diagram (PFD) and Process Control diagram (PCD)

- Key: page 27.
- General PFD: page 28.
- Pre-treatment PFD: page 29.
- FFR RO & MD PFD: page 30.
- Adsorption on zeolites PFD: page 31.
- Pre-treatment & FFR RO PCD: page 32.
- MD & Adsorption on zeolites PCD: page 33.

Mass balances have been done using experimental data from several essays and analysis that have been conducted in Eurecat's laboratories with water samples from AITASA, except from the case of RO, as its performance has been simulated with WAVE.

The chemicals which are dosed to guarantee the proper maintenance of the membrane systems have not been considered due to their low flow and concentration (as it is the case of the chemicals which are dosed inline to the RO), or because they are used for maintenance purposes, which just occur with certain periodicity (as it is the case of the CIPs and CEBs). Mains water has not been considered either, as it is only used for cleaning purposes except from the case of the one that flows through the coil, as it is used to cool down water in T401. As the quality of mains water is unknown, its concentration values have not been indicated.

It must also be mentioned that the MD system experiences accumulation of concentrated brines, so that this makes all concentrations (both, hot and cold outlets) vary over time. The present PFD shows the concentration values after two cycles (that is, two days of operation) to give an approximate picture of how would concentrations be.

As it has not been possible to determine how pH varies during MD, the pH cells of this and later operation modules are left blank.

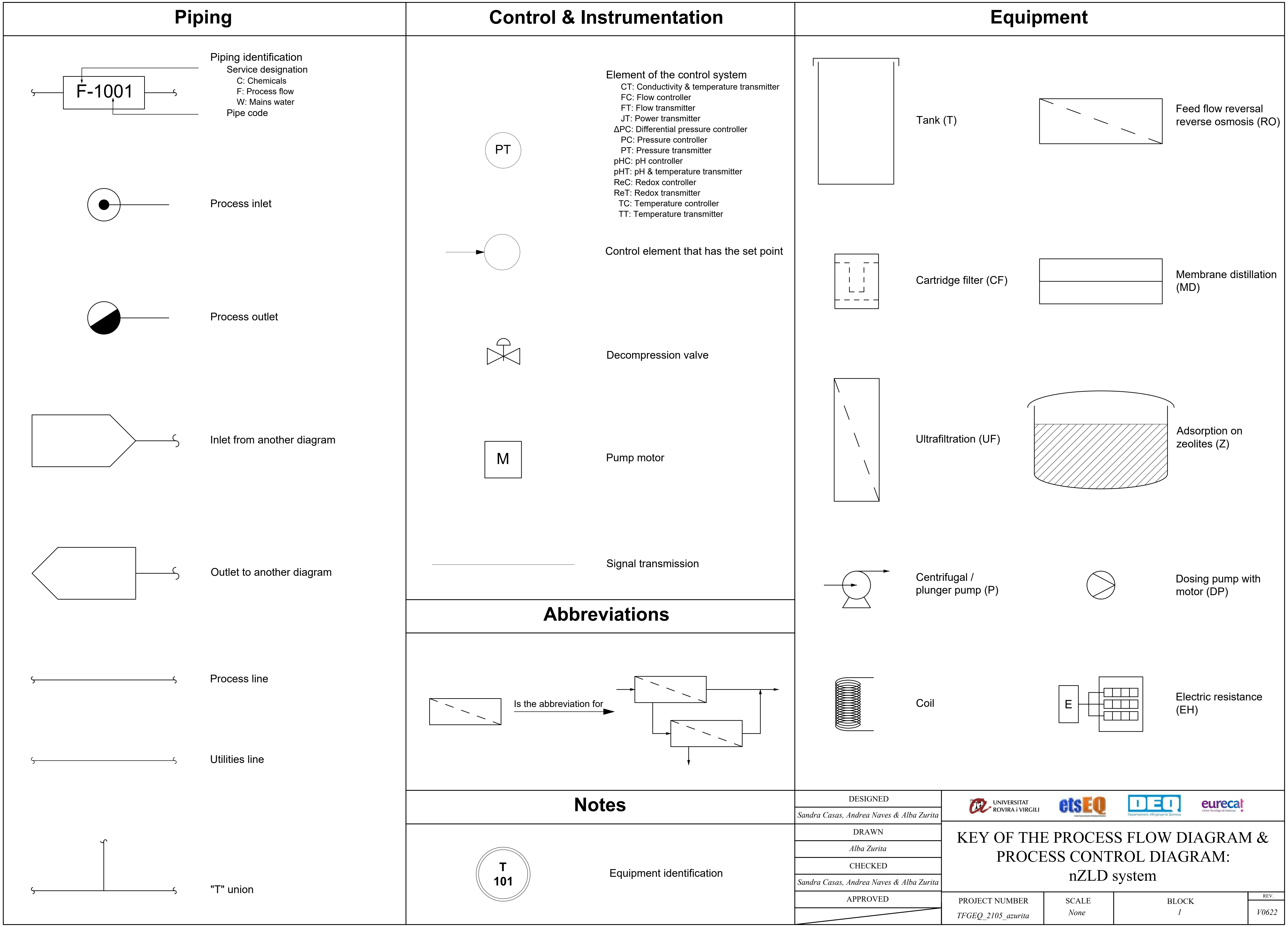
Regarding the PCDs, no regulation systems are installed in the chemicals' lines as the flows are so low that there are no instruments that can work under those conditions. The regulation of their dosage is conducted by the dosing pump setup.

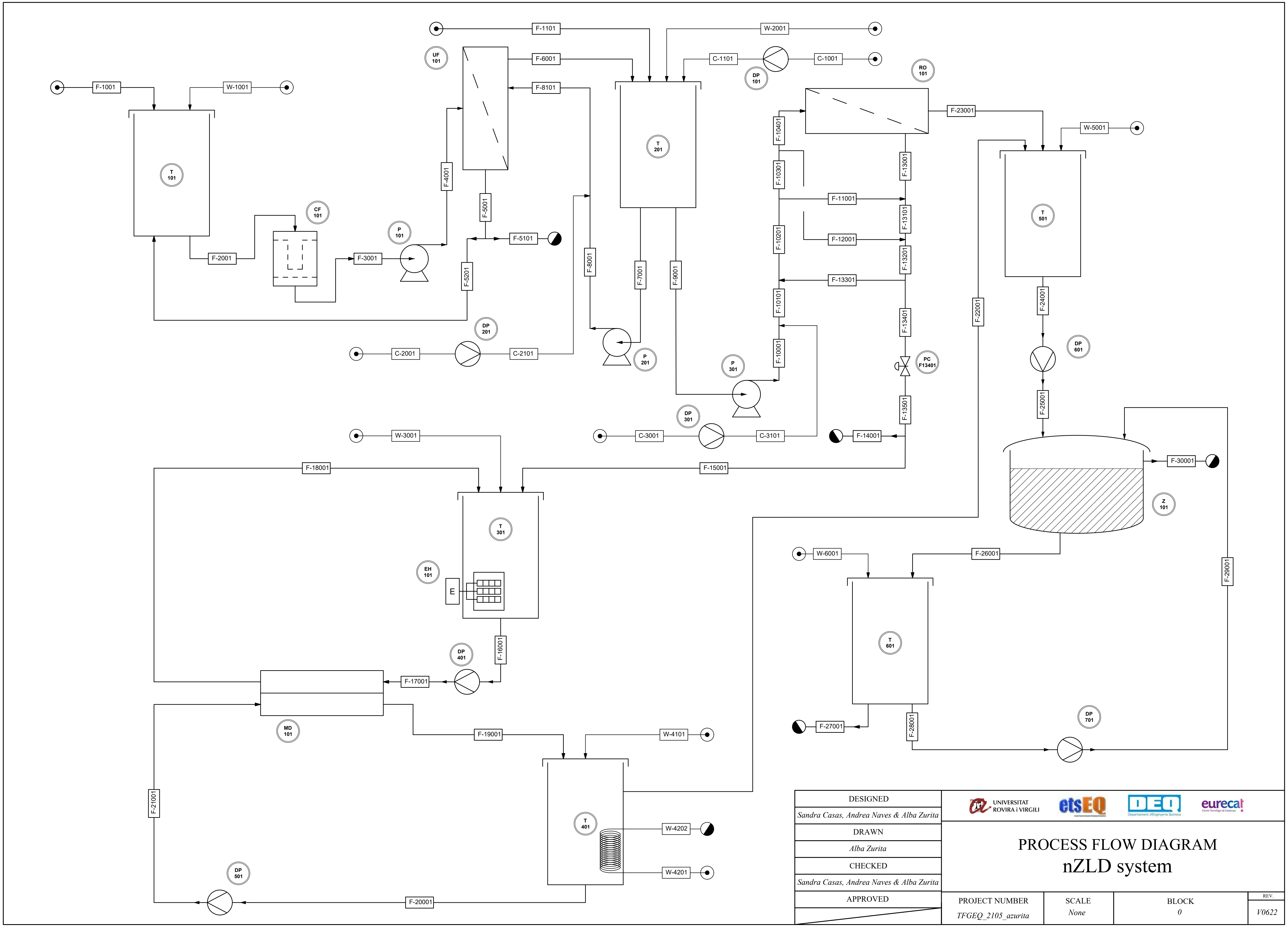
4.1.4. Piping and Instrumentation Diagram (P&ID)

- Key: page 34.
- Pre-treatment: page 35.
- FFR RO & MD: page 36.
- Adsorption on zeolites: page 37.

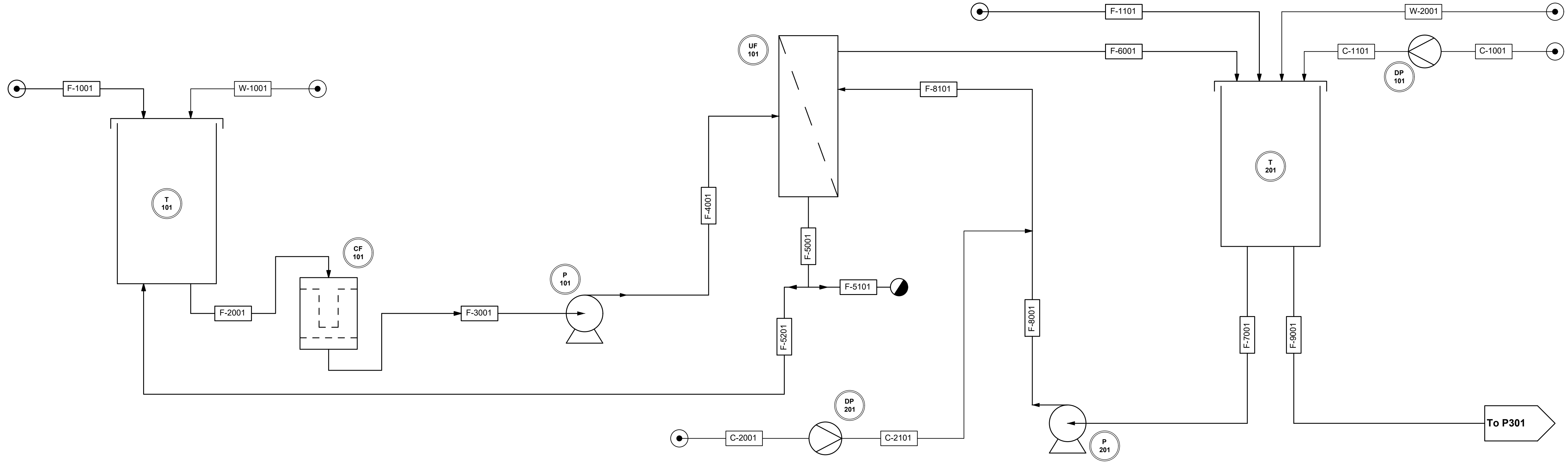
4.1.5. Plot plan

The plot plan representing the location of the pilot in the infrastructures of AITASA has been elaborated by extracting a base plan from Vissir3, a tool from the Institut Cartogràfic i Geològic de Catalunya (ref. 13). This plot plan can be found in page 38.


Piping
Control & Instrumentation
Equipment
Piping identification
Service designation
C: Chemicals
F: Process flow
W: Mains water
Pipe code
F-1001
Process inlet
Process outlet
Inlet from another diagram
Outlet to another diagram
Process line
Utilities line
"T" union
Element of the control system
CT: Conductivity & temperature transmitter
FC: Flow controller
FT: Flow transmitter
JT: Power transmitter
ΔPC: Differential pressure controller
PC: Pressure controller
PT: Pressure transmitter
pHC: pH controller
pHT: pH & temperature transmitter
ReC: Redox controller
ReT: Redox transmitter
TC: Temperature controller
TT: Temperature transmitter
PT
Control element that has the set point
Decompression valve
M
Pump motor
Signal transmission
Abbreviations
Is the abbreviation for
Notes
T
101
Equipment identification
Tank (T)
Feed flow reversal reverse osmosis (RO)
Cartridge filter (CF)
Membrane distillation (MD)
Ultrafiltration (UF)
Adsorption on zeolites (Z)
Centrifugal / plunger pump (P)
Dosing pump with motor (DP)
Coil
E
Electric resistance (EH)
DESIGNED
Sandra Casas, Andrea Naves & Alba Zurita
DRAWN
Alba Zurita
CHECKED
Sandra Casas, Andrea Naves & Alba Zurita
APPROVED
UNIVERSITAT ROVIRA i VIRGILI
etsEQ
DEQ
eurecat
KEY OF THE PROCESS FLOW DIAGRAM & PROCESS CONTROL DIAGRAM: nZLD system
PROJECT NUMBER
TFGEQ_2105_azurita
SCALE
None
BLOCK
1
REV.
V0622



DESIGNED				
Sandra Casas, Andrea Naves & Alba Zurita	UNIVERSITAT ROVIRA i VIRGILI	etsEQ	DEQ	eurecat
DRAWN	PROCESS FLOW DIAGRAM			
Alba Zurita	nZLD system			
CHECKED				
Sandra Casas, Andrea Naves & Alba Zurita				
APPROVED	PROJECT NUMBER	SCALE	BLOCK	REV.
	TFGEQ_2105_azurita	*None*	*0*	*V0622*

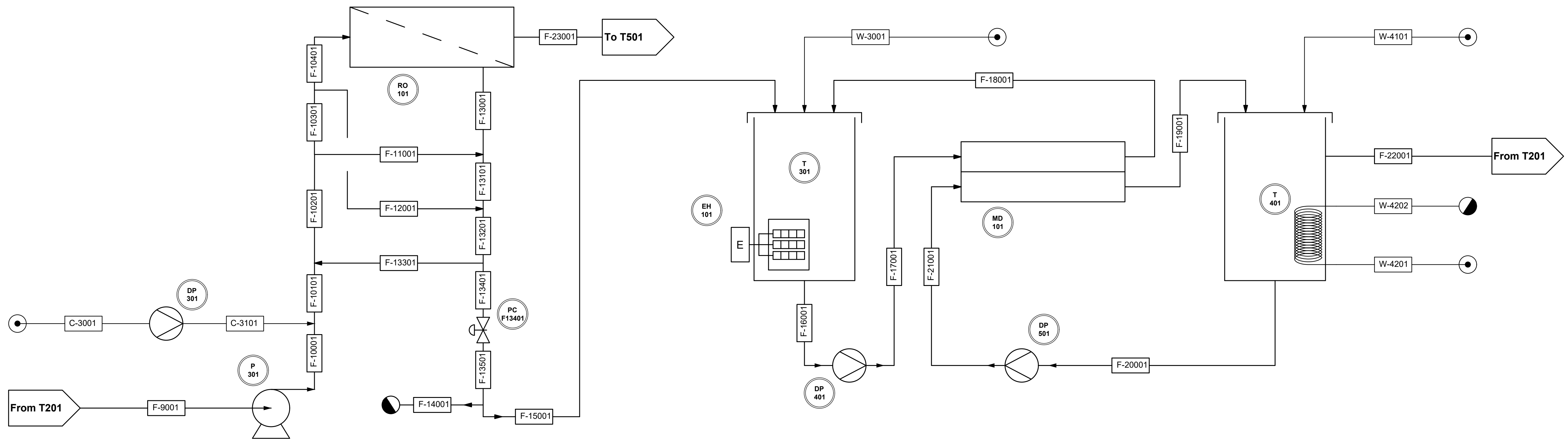


Line	Units	F1001	F1101	F2001	F3001	F4001	F5001	F5101	F5201	F6001	F7001	F8001	F8101	F9001	W1001	W2001	C1001	C2001
NH_4^+	mg/L	13.02	-	13.02	13.02	13.02	13.02	-	13.02	13.02	-	-	-	13.02	-	-	-	-
K^+	mg/L	36.06	-	36.06	36.06	36.06	36.06	-	36.06	36.06	-	-	-	36.06	-	-	-	-
Na^+	mg/L	2,046	-	2,046	2,046	2,046	2,046	-	2,046	2,046	-	-	-	2,046	-	-	-	-
Mg^{2+}	mg/L	53.09	-	53.09	53.09	53.09	53.09	-	53.09	53.09	-	-	-	53.09	-	-	-	-
Ca^{2+}	mg/L	193.3	-	193.3	193.3	193.3	193.3	-	193.3	193.3	-	-	-	193.3	-	-	-	-
Cl^-	mg/L	3,549	-	3,549	3,549	3,549	3,549	-	3,549	3,549	-	-	-	3,549	-	-	-	-
SO_4^{2-}	mg/L	217.6	-	217.6	217.6	217.6	217.6	-	217.6	217.6	-	-	-	217.6	-	-	-	-
TDS	mg/L	6,107	-	6,107	5,496	5,496	10,239	-	10,239	4,969	-	-	-	4,969	-	-	-	-
Conductivity	µS/cm	11,000	-	11,000	11,000	11,000	11,000	-	11,000	11,000	-	-	-	11,000	-	-	-	-
pH	-	7.0	-	7.0	7.0	7.0	7.0	-	7.0	7.0	-	-	-	7.0	-	-	-	-
Flow	m^3/day	12	-	12	12	12	1.2	-	1.2	10.8	-	-	-	10.8	-	-	-	-
Pressure	bar_g	0	-	-0.4	-0.5	1	0.8	-	0.8	0	-	-	-	-0.5	-	-	-	-
Temperature	ºC	Amb.	-	Amb.	Amb.	Amb.	Amb.	-	Amb.	Amb.	-	-	-	Amb.	-	-	-	-

DESIGNED
Sandra Casas, Andrea Naves & Alba Zurita
DRAWN
Alba Zurita
CHECKED
Sandra Casas, Andrea Naves & Alba Zurita
APPROVED

PROCESS FLOW DIAGRAM
nZLD system: Pre-treatment

PROJECT NUMBER	SCALE	BLOCK	REV.
TFGEQ_2105_azurita	*None*	*1*	*V0609*



Line	Units	F9001	F10001	F10101	F10(2-4)01	F11001	F12001	F13(0-2)01	F13301	F13401	F13501	F14001	F15001	F16001	F17001	F18001	F19001	F20001
NH_4^+	mg/L	13.02	13.02	13.02	20.80	-	-	32.95	32.95	32.95	32.95	-	32.95	29.96	29.96	264.23	0.5	0.35
K^+	mg/L	36.06	36.06	36.06	57.59	-	-	91.23	91.23	91.23	91.23	-	91.23	83.78	83.78	754.04	0	0
Na^+	mg/L	2,046	2,046	2,046	3,280	-	-	5,209	5,209	5,209	5,209	-	5,209	4,781	4,781	42,989	3.99	2.76
Mg^{2+}	mg/L	53.09	53.09	53.09	88.57	-	-	144.0	144.0	144.0	144.0	-	144.0	132.24	132.24	1,190	0	0
Ca^{2+}	mg/L	193.3	193.3	193.3	322.6	-	-	524.7	524.7	524.7	524.7	-	524.7	480.66	480.66	4,304	2.00	1.39
Cl^-	mg/L	3,549	3,549	3,549	5,790	-	-	9,084	9,084	9,084	9,084	-	9,084	8,338	8,338	74,969	6.96	4.81
SO_4^{2-}	mg/L	217.6	217.6	217.6	367.9	-	-	602.6	602.6	602.6	602.6	-	602.6	552.85	552.85	4,965	0.92	0.64
TDS	mg/L	4,969	4,969	4,969	8,000	-	-	11,349	11,349	11,349	11,349	-	11,349	10,423	10,423	93,807	0	0
Conductivity	µS/cm	11,000	11,000	11,000	17,043	-	-	26,013	26,013	26,013	26,013	-	26,013	23,881	23,881	214,782	13.75	9.50
pH	-	7.0	7.0	7.0	6.8	-	-	6.6	6.6	6.6	6.6	-	6.6					
Flow	m^3/day	10.8	10.8	10.8	17.7	-	-	10.62	6.90	3.72	3.72	-	3.72	1.80	1.80	0.20	3.40	1.80
Pressure	bar_g	-0.5	12.4	12.4	12.4	-	-	9.3	9.3	9.3	0	-	0	-0.25	1	0.9	0.9	-0.5
Temperature	ºC	Amb.	Amb.	Amb.	Amb.	-	-	Amb.	Amb.	Amb.	Amb.	-	Amb.	75	75	65	30	Amb.

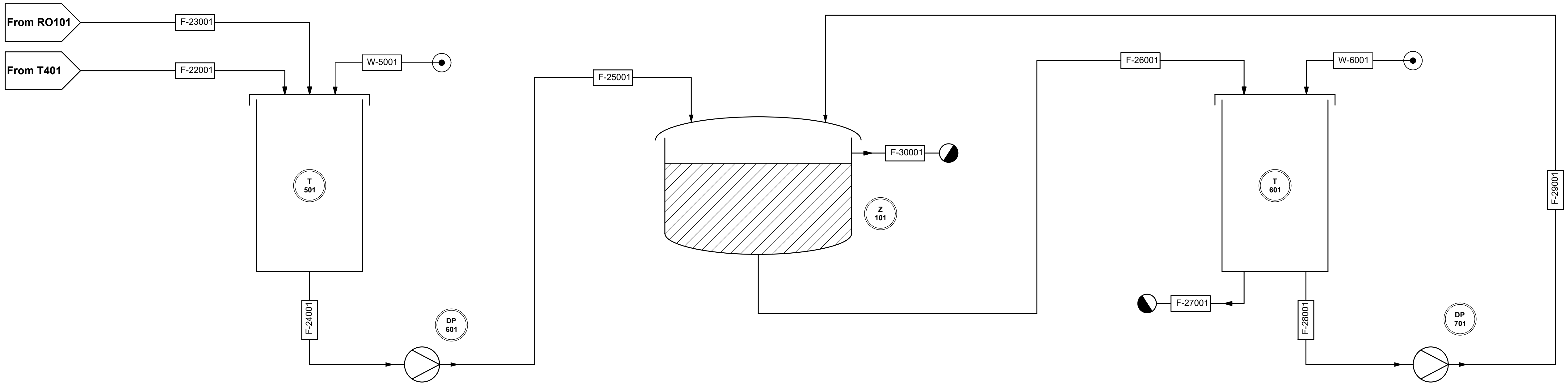
Line	Units	F21001	F22001	F23001	C3001	C3101	W3001	W4101	W4201	W4202
NH_4^+	mg/L	0.35	0.35	2.57	-	-	-	-	-	-
K^+	mg/L	0	0	7.12	-	-	-	-	-	-
Na^+	mg/L	2.76	2.76	385.7	-	-	-	-	-	-
Mg^{2+}	mg/L	0	0	5.39	-	-	-	-	-	-
Ca^{2+}	mg/L	1.39	1.39	19.48	-	-	-	-	-	-
Cl^-	mg/L	4.81	4.81	644.8	-	-	-	-	-	-
SO_4^{2-}	mg/L	0.64	0.64	15.63	-	-	-	-	-	-
TDS	mg/L	0	0	879.6	-	-	-	-	-	-
Conductivity	µS/cm	9.50	9.50	2,155	-	-	-	-	-	-
pH	-			7.7	-	-	-	-	-	-
Flow	m^3/day	1.80	0.95	7.08	-	-	-	-	4.90	4.90
Pressure	bar_g	1	0	0	-	-	-	-	0	0
Temperature	ºC	Amb.	Amb.	Amb.	-	-	-	-	Amb.	25

DESIGNED	*Sandra Casas, Andrea Naves & Alba Zurita*
DRAWN	*Alba Zurita*
CHECKED	*Sandra Casas, Andrea Naves & Alba Zurita*
APPROVED	

UNIVERSITAT ROVIRA i VIRGILI

PROCESS FLOW DIAGRAM
nZLD system: FFR RO & MD

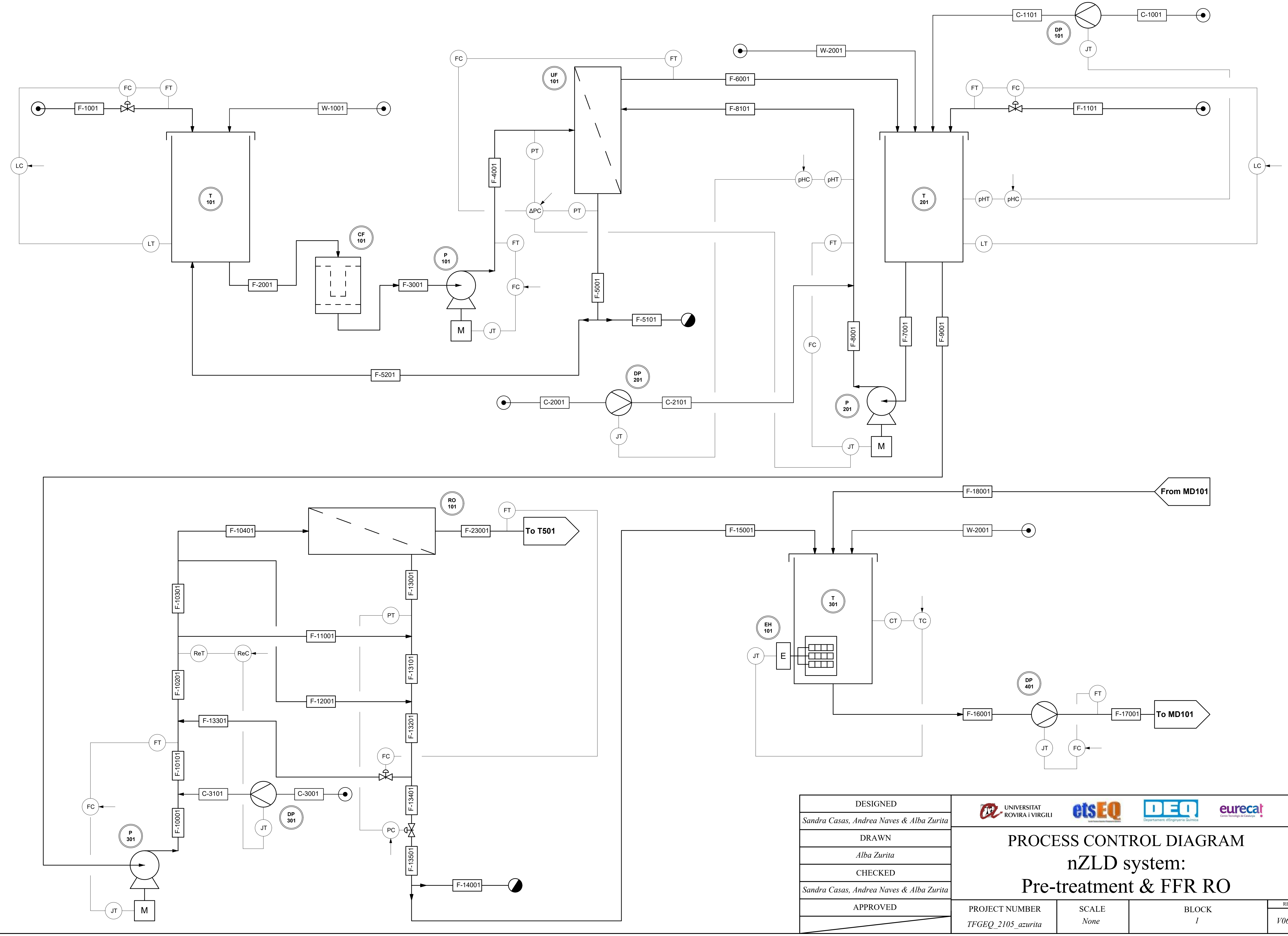
PROJECT NUMBER	SCALE	BLOCK	REV.
TFGEQ_2105_azurita	*None*	2	*V0622*



Line	Units	F22001	F23001	F24001	F25001	F26001	F27001	F28001	F29001	F30001	W5001	W6001
NH_4^+	mg/L	0.35	2.57	2.31	2.31	0	0	-	-	-	-	-
K^+	mg/L	0	7.12	6.28	6.28	6.28	6.28	-	-	-	-	-
Na^+	mg/L	2.76	385.7	340.4	340.4	340.4	340.4	-	-	-	-	-
Mg^{2+}	mg/L	0	5.39	4.75	4.75	4.75	4.75	-	-	-	-	-
Ca^{2+}	mg/L	1.39	19.48	17.34	17.34	17.34	17.34	-	-	-	-	-
Cl^-	mg/L	4.81	644.8	569.09	569.09	569.09	569.09	-	-	-	-	-
SO_4^{2-}	mg/L	0.64	15.63	13.86	13.86	13.86	13.86	-	-	-	-	-
TDS	mg/L	0	879.6	775.54	775.54	775.54	775.54	-	-	-	-	-
Conductivity	µS/cm	9.50	2,155	1,901	1,901	1,901	1,901	-	-	-	-	-
pH	-		7.7					-	-	-	-	-
Flow	m^3/day	0.95	7.08	1	1	1	1	-	-	-	-	-
Pressure	bar_g	0	0	-0.5	1	0	0	-	-	-	-	-
Temperature	ºC	Amb.	Amb.	Amb.	Amb.	Amb.	Amb.	-	-	-	-	-

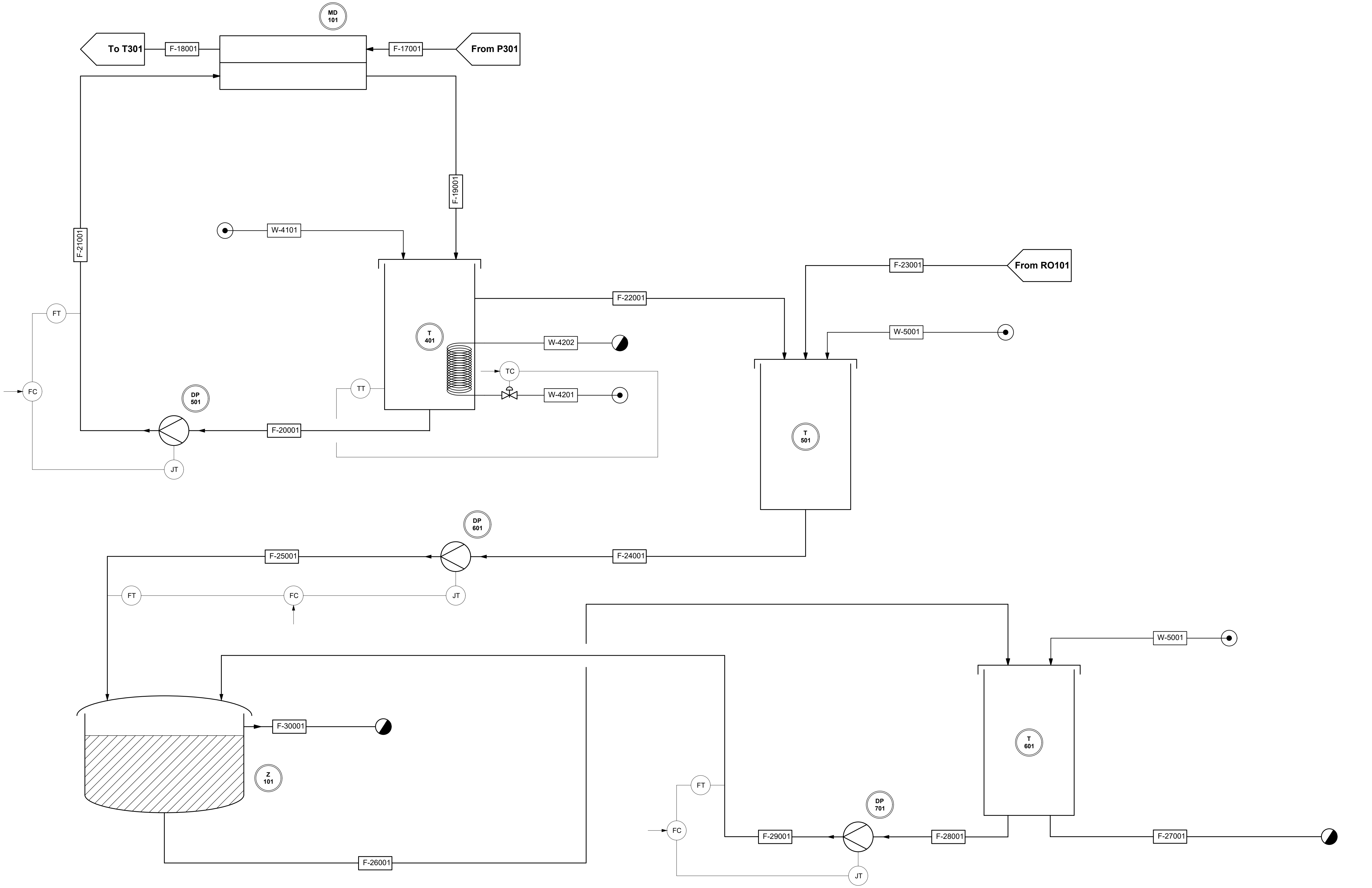
DESIGNED	
Sandra Casas, Andrea Naves & Alba Zurita	
DRAWN	PROCESS FLOW DIAGRAM
Alba Zurita	nZLD system: Adsorption on Zeolites
CHECKED	
Sandra Casas, Andrea Naves & Alba Zurita	
APPROVED	

PROJECT NUMBER	SCALE	BLOCK	REV.
TFGEQ_2105_azurita	*None*	3	*V0622*



DESIGNED	PROCESS CONTROL DIAGRAM
Sandra Casas, Andrea Naves & Alba Zurita	nZLD system:
DRAWN	Pre-treatment & FFR RO
Alba Zurita	
CHECKED	
Sandra Casas, Andrea Naves & Alba Zurita	
APPROVED	

PROJECT NUMBER	SCALE	BLOCK	REV.
TFGEQ_2105_azurita	*None*	*1*	*V0605*

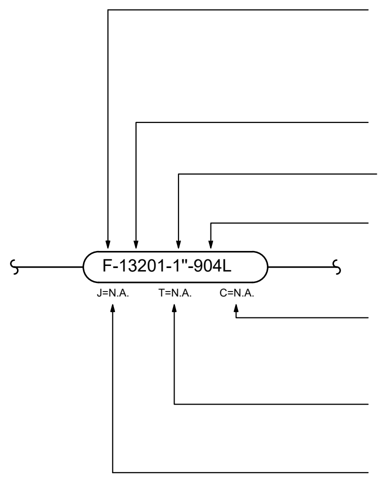


DESIGNED	UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ · eurecat
Sandra Casas, Andrea Naves & Alba Zurita	
DRAWN	PROCESS CONTROL DIAGRAM nZLD system: MD & Adsorption on zeolites
Alba Zurita	
CHECKED	
Sandra Casas, Andrea Naves & Alba Zurita	
APPROVED	

PROJECT NUMBER	SCALE	BLOCK	REV.
TFGEQ_2105_azurita	*None*	2	*V0622*

KEY OF THE PIPING & INSTRUMENTATION DIAGRAM: nZLD system

Piping identification



Service designation
- C Chemicals
- F Process flow
- W Mains water

Line identification

Nominal pipe size

Pipe material
- 904L Stainless steel 904L (UNS N08904)
- PVC Polyvinyl chloride

Heat-sinking (N.A. / Type & Thickness)
- CF Ceramic fibre
- N.A. Not applicable

Tracing (N.A. / Type)
- N.A. Not applicable

Jacket (N.A. / Type)
- N.A. Not applicable

Piping

- Process inlet
- Process outlet
- Process drain
- Process line
- Utilities line
- "T" union (threaded)
- "T" union (welded)
- Flange
- Screw plug
- Ring spacer

Notes

- T 101 — Equipment identification
- T1A 1" — Nozzle identification
- A — Footnote

Control & Instrumentation

Pneumatic signal

Electric signal

Flanged instrument (CT F10401)
- Type of instrument
  - CT: Conductivity & temperature transmitter
  - FT: Flow transmitter
  - PT: Pressure transmitter
  - pHT: pH & temperature transmitter
  - ReT: Redox transmitter
- Instrument identification

Threaded instrument (LT T1003)
- Type of instrument
  - CT: Conductivity & temperature transmitter
  - FT: Flow transmitter
  - LT: Level transmitter
  - PT: Pressure transmitter
  - pHT: pH & temperature transmitter
  - TT: Temperature transmitter
- Instrument identification

Instrument with electric union (JT MP1002)
- Type of instrument
  - JT: Power transmitter
- Instrument identification

Pneumatic actuator (TC W4201)
- Type of actuator
  - FC: Flow controller
  - PC: Pressure controller
  - TC: Temperature controller
  - IH: Electric signal emissor
- Actuator identification

Electric actuator (JY MP2003)
- Type of actuator
  - JY: Power regulator
  - JS: Power switch (on / off)
- Actuator identification

Flanged field display (FI F13302)
- Type of display
  - FI: Flow indicator
- Indicator identification

Order (AI T3002)
- Type of signal
  - DI: Digital input
  - DO: Digital output
  - AI: Analogic input
  - AO: Analogic output
- Order identification

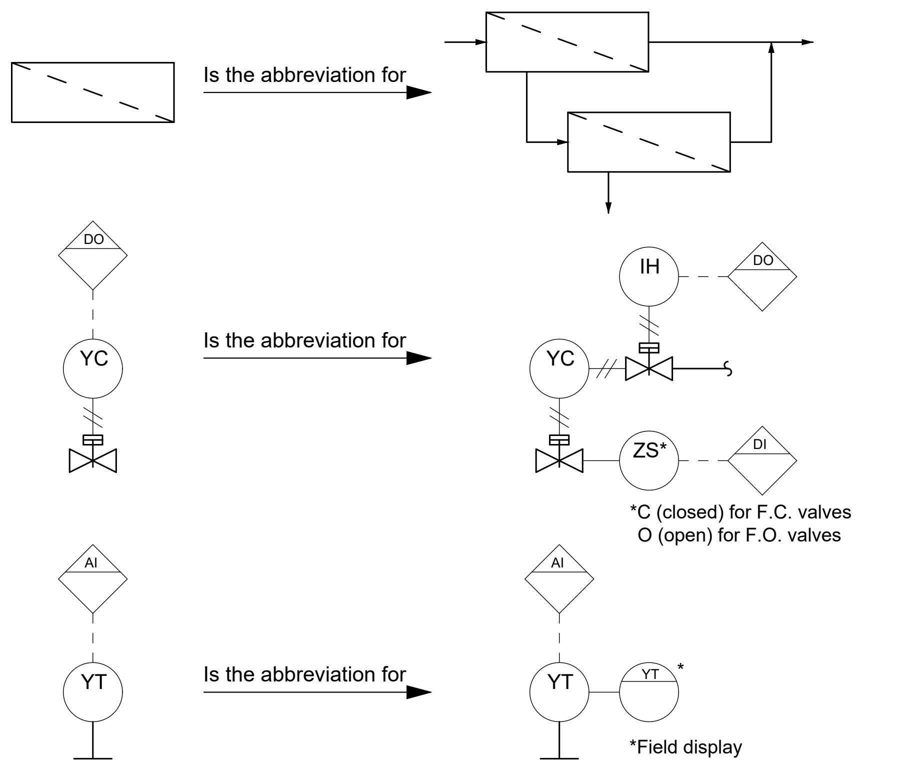
Valves

- Manual valve (MV)
- Control valve
- Automatic valve
- Check valve (KV)
- S — Sampling point
- F.C. — Valve note
  - F.C.: Failure close
  - F.O.: Failure open
  - Lock open: Blocked open
- MVF12002 — Valve identification
  - Valve code
  - Service designation
  - Type of valve
    - KV: Check valve
    - MV: Manual valve

Equipment

- Tank (T)
- Cartridge filter (CF)
- Ultrafiltration (UF)
- Coil
- E — Electric resistance (EH)
- Feed flow reversal reverse osmosis (RO)
- Membrane distillation (MD)
- Adsorption on zeolites (Z)
- Centrifugal / plunger pump (P) with motor (MP) & variator of the pump motor (VPM)
- Dosing pump with motor (DP)

Abbreviations



DESIGNED	Sandra Casas, Andrea Naves & Alba Zurita		
DRAWN	Alba Zurita		
CHECKED	Sandra Casas, Andrea Naves & Alba Zurita		
APPROVED			
PROJECT NUMBER: TFGEQ_2105_azurita	SCALE: None	BLOCK: 1	REV.: V0622

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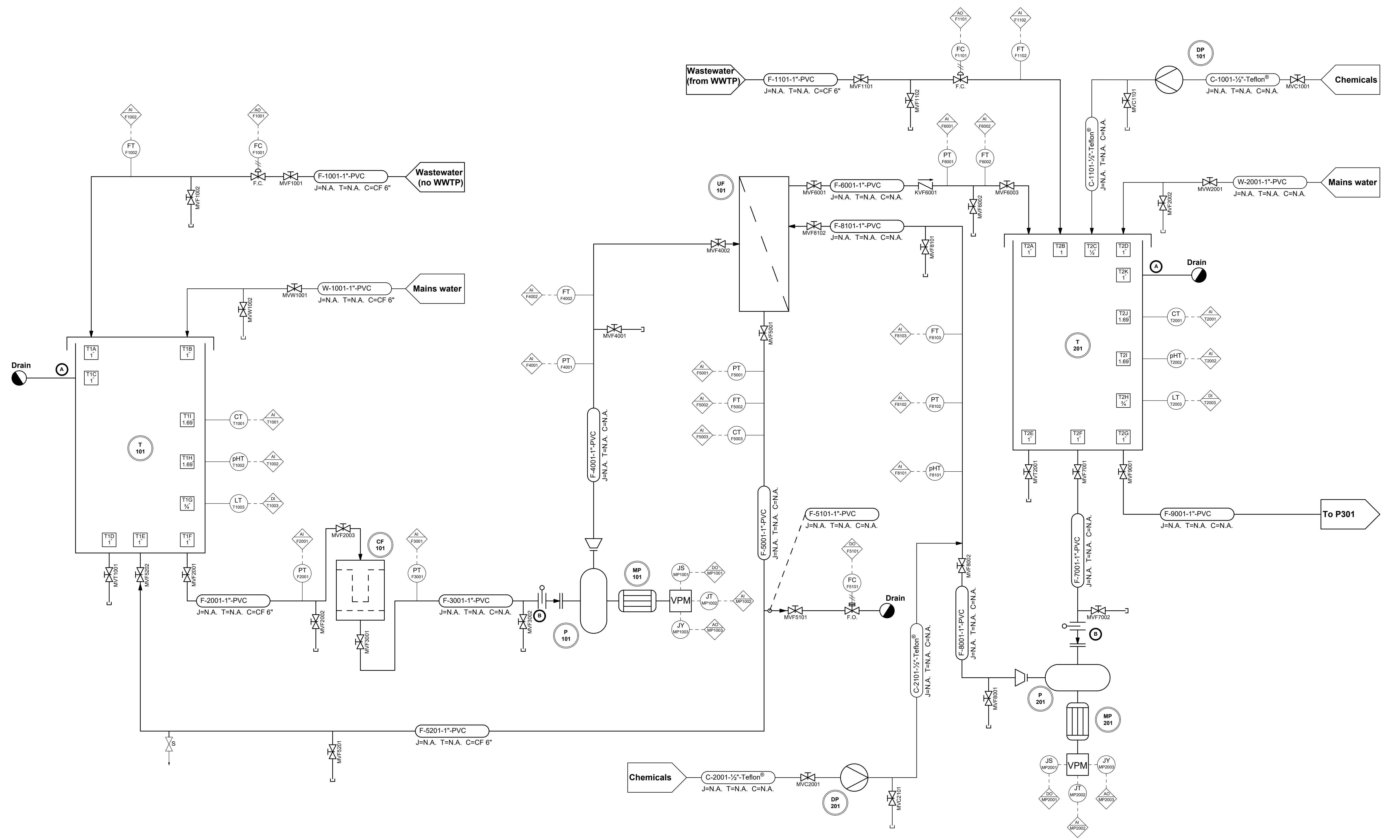
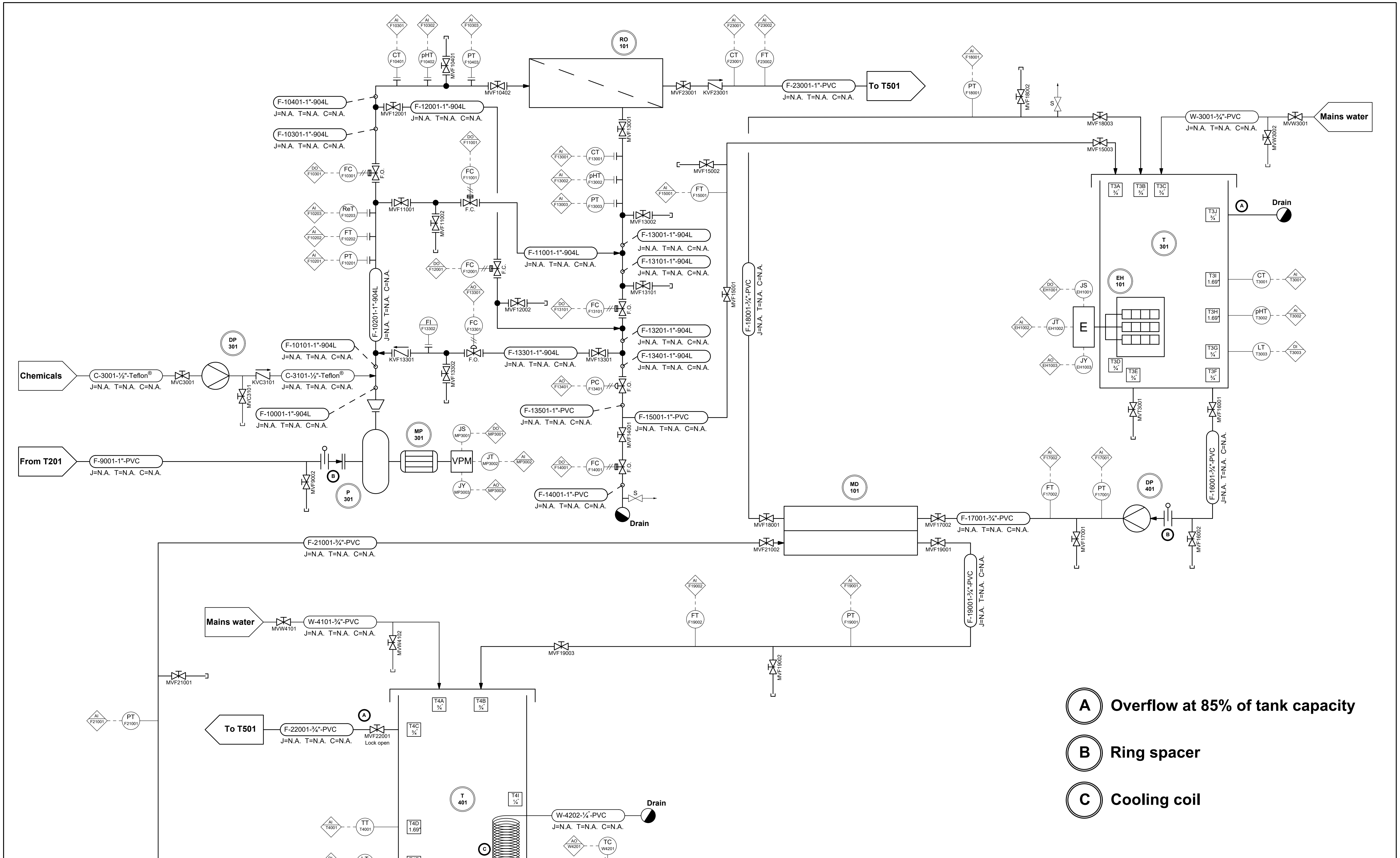


(A) Overflow at 85% of tank capacity

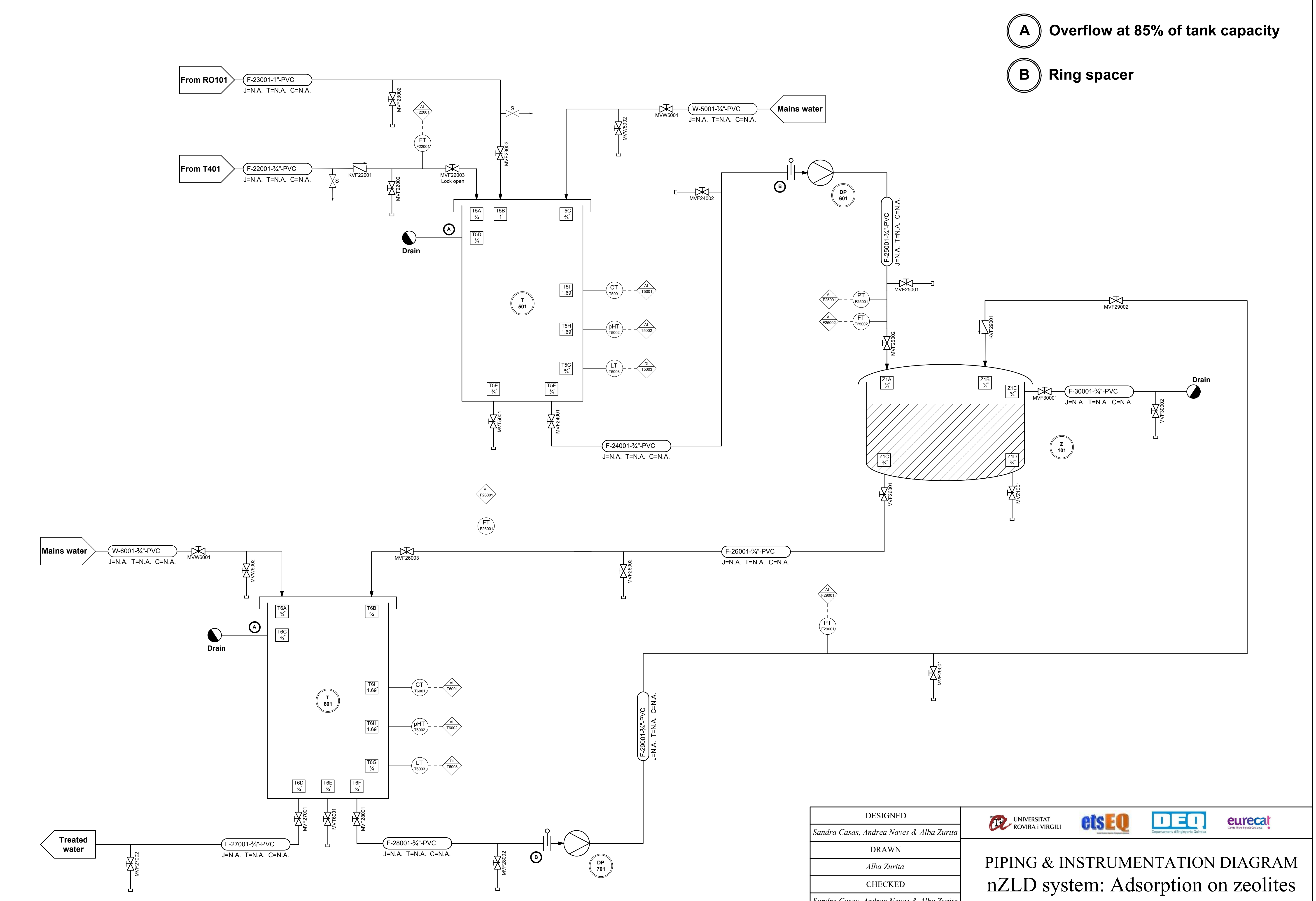
(B) Ring spacer

DESIGNED	PIPING & INSTRUMENTATION DIAGRAM nZLD system: Pre-treatment
Sandra Casas, Andrea Naves & Alba Zurita	
DRAWN	
Alba Zurita	
CHECKED	
Sandra Casas, Andrea Naves & Alba Zurita	
APPROVED	

PROJECT NUMBER	SCALE	BLOCK	REV.
TFGEQ_2105_azurita	*None*	*1*	*V0623*



DESIGNED	UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ Departament d'Enginyeria Química · eurecat			
Sandra Casas, Andrea Naves & Alba Zurita				
DRAWN	PIPING & INSTRUMENTATION DIAGRAM nZLD system: FFR RO & MD			
Alba Zurita				
CHECKED				
Sandra Casas, Andrea Naves & Alba Zurita				
APPROVED	PROJECT NUMBER *TFGEQ_2105_azurita*	SCALE *None*	BLOCK 2	REV. *V0623*



DESIGNED	Sandra Casas, Andrea Naves & Alba Zurita
DRAWN	Alba Zurita
CHECKED	Sandra Casas, Andrea Naves & Alba Zurita
APPROVED	

PIPING & INSTRUMENTATION DIAGRAM
nZLD system: Adsorption on zeolites

PROJECT NUMBER	SCALE	BLOCK	REV.
TFGEQ_2105_azurita	None	3	V0623

DESIGNED	UNIVERSITAT ROVIRA i VIRGILI		
Sandra Casas, Andrea Naves & Alba Zurita			
DRAWN			
Alba Zurita	Plot plan		
CHECKED			
Sandra Casas, Andrea Naves & Alba Zurita			
APPROVED	PROJECT NUMBER	SCALE	BLOCK	REV.
	TFGEQ_2105_azurita	None	1	V0602

4.2. Basic design

4.2.1. Piping design

Despite working with a very small capacity and requiring very small pipes, all process pipes have been selected wit nominal pipe sizes (NPS) that range between ¾ and 1 inch. Otherwise, it would not be possible to install instruments in them to monitor the process under the project requirements.

As some pipes are located outside the 40 ft container, they require a layer of insulation to prevent water from freezing during cold days. The calculations that have been conducted to determine the thickness of this layer can be found in *A.5. PIPING INSULATION*.

Table 4.1. List of pipelines.

Pipe	Linked sections	Nature of the fluid (state)	P (bar_g)	T (ºC)	Schedule / NPS (in)	$Ø_{out}$ / $Ø_{in}$ (in)	Material	Heat-sinking (thickness) / tracing	Possible isolation areas
C-1001	Stored chemicals & DP101	NaClO (liquid)	-0.5	Amb.	SCH 40 ½”	1.050 0.824	Teflon®	-	Manual valve MVC1001 at the inlet of the line.
C-1101	DP101 & T201	NaClO (liquid)	1	Amb.	SCH 40 ½”	1.050 0.824	Teflon®	-	-
C-2001	Stored chemicals & DP201	NaClO or H_2SO_4 (liquid)	-0.5	Amb.	SCH 40 ½”	1.050 0.824	Teflon®	-	Manual valve MVC2001 at the inlet of the line.
C-2101	DP201 & Union with F-8001	NaClO or H_2SO_4 (liquid)	1	Amb.	SCH 40 ½”	1.050 0.824	Teflon®	-	-
C-3001	Stored chemicals & DP301	Antiscalants (liquid)	-0.5	Amb.	SCH 40 ½”	1.050 0.824	Teflon®	-	Manual valve MVC3001 at the inlet of the line.
C-3101	DP301 & Union with F-10001	Antiscalants (liquid)	1	Amb.	SCH 40 ½”	1.050 0.824	Teflon®	-	-
F-1001	WWTP feed & T101	Water (liquid)	Atm.	Amb.	SCH 40 1”	1.315 1.049	PVC	6 mm / -	Manual valve MVF1001 at the inlet of the line.
F-1101	WWTP outlet & T201	Water (liquid)	Atm.	Amb.	SCH 40 1”	1.315 1.049	PVC	6 mm / -	Manual valve MVF1101 at the inlet of the line.
F-2001	T101 & CF101	Water (liquid)	Atm.	Amb.	SCH 40 1”	1.315 1.049	PVC	6 mm / -	Manual valve MVF2001 at the tank outlet and manual valveMVF2003 at the inlet of the cartridge filter.
F-3001	CF101 & P101	Water (liquid)	-0.5	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVF3001at the outlet of the cartridge filter.
F-4001	P101 & UF101	Water (liquid)	1	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVF4002 at the inlet of the UF module.
F-5001	UF101 & Bifurcation	Water (liquid)	0.8	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVF5001 at the UF outlet.
F-5101	Bifurcation & Drain	Water (liquid)	0.8	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVF5101.
F-5201	Bifurcation & T101	Water (liquid)	0.8	Amb.	SCH 40 1”	1.315 1.049	PVC	6 mm / -	Manual valve MVF5001 at the UF outlet and MVF5202 at T101 recirculation.

Pipe	Linked sections	Nature of the fluid (state)	P (bar_g)	T (ºC)	Schedule / NPS (in)	$Ø_{out}$ / $Ø_{in}$ (in)	Material	Heat-sinking (thickness) / tracing	Possible isolation areas
F-6001	UF101 & T201	Water (liquid)	Atm.	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVF6001 at the UF permeate and manual valve MVF6003 at T201 feed.
F-7001	T201 & P201	Water (liquid)	-0.5	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVF7001 at T201 outlet.
F-8001	P201 & Union with C-2101	Water (liquid)	2	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVF8002 before the union with C-2101
F-8101	Union with C-2101 & UF101	Water or water & antiscalants (liquid)	2	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVF8102 at the UF inlet.
F-9001	T201 & P301	Water (liquid)	-0.5	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVF9001 at T201 outlet.
F-10001	P301 & union with C-3101	Water (liquid)	12.4	Amb.	SCH 40 1”	1.315 1.049	Stainless steel 904L (UNS N08904)	-	-
F-10101	Union of F-10001 with C-3101 & F-13301	Water (liquid)	12.4	Amb.	SCH 40 1”	1.315 1.049	Stainless steel 904L (UNS N08904)	-	-
F-10201	Union of F-10101 with F-13301 & Branch to F-11001	Water or water & antiscalants (liquid)	12.4	Amb.	SCH 40 1”	1.315 1.049	Stainless steel 904L (UNS N08904)	-	Manual valve MVF11001 at the beginning of F-11001.
F-10301	Branch to F-11001 & Branch to F-12001	Water or water & antiscalants (liquid)	12.4	Amb.	SCH 40 1”	1.315 1.049	Stainless steel 904L (UNS N08904)	-	Manual valve MVF11001 at the beginning of F-11001 and manual valve MVF12001 at the beginning of F-12001.
F-10401	Branch to F-12001 & RO101	Water or water & antiscalants (liquid)	12.4	Amb.	SCH 40 1”	1.315 1.049	Stainless steel 904L (UNS N08904)	-	Manual valve MV10402 at RO101 inlet.
F-11001	Branch to F-11001 & Union with F-13001	Water or water & antiscalants (liquid)	12.4	Amb.	SCH 40 1”	1.315 1.049	Stainless steel 904L (UNS N08904)	-	Manual valve MVF11001 at the beginning of the line.
F-12001	Branch to F-12001 & Union with F-13101	Water or water & antiscalants (liquid)	12	Amb.	SCH 40 1”	1.315 1.049	Stainless steel 904L (UNS N08904)	-	Manual valve MVF12001 at the beginning of the line.
F-13001	RO101 & Union with F-11001	Water or water & antiscalants (liquid)	9.3	Amb.	SCH 40 1”	1.315 1.049	Stainless steel 904L (UNS N08904)	-	Manual valve MVF13001 at RO101 outlet & automatic valves AVF11001 & AVF13101.
F-13101	Union with F-11001 & Union with F-12001	Water or water & antiscalants (liquid)	9.3	Amb.	SCH 40 1”	1.315 1.049	Stainless steel 904L (UNS N08904)	-	Automatic valve AV13101.
F-13201	Union with F-12001 & branch to F-13301	Water or water & antiscalants (liquid)	9.3	Amb.	SCH 40 1”	1.315 1.049	Stainless steel 904L (UNS N08904)	-	Automatic valves AVF12001 & AV13101.

Pipe	Linked sections	Nature of the fluid (state)	P (bar_g)	T (ºC)	Schedule / NPS (in)	$Ø_{out}$ / $Ø_{in}$ (in)	Material	Heat-sinking (thickness) / tracing	Possible isolation areas
F-13301	F-13201 & F-10101	Water or water & antiscalants (liquid)	9.3	Amb.	SCH 40 1”	1.315 1.049	Stainless steel 904L (UNS N08904)	-	Manual valve MV13301 at the beginning of the line and check valve KV13301 at the end.
F-13401	Branch to F-13301 & decompression valve F-13401 inlet	Water or water & antiscalants (liquid)	9.3	Amb.	SCH 40 1”	1.315 1.049	Stainless steel 904L (UNS N08904)	-	Automatic valve AV13101.
F-13501	Decompression valve outlet & Bifurcation.	Water or water & antiscalants (liquid)	Atm.	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valves at each of the two branches of the bifurcation: MVF14001 and MVF15001.
F-14001	Bifurcation & Drain	Water or water & antiscalants (liquid)	Atm.	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVF14001 at the beginning of the line.
F-15001	Bifurcation & T301	Water (liquid)	Atm.	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVF15001 at the beginning of the line and manual valve MVF15003 at T301 inlet.
F-16001	T301 & P401	Concentrated brines (liquid)	-0.25	75	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF16001 at T301 outlet.
F-17001	P401 & MD101	Concentrated brines (liquid)	1	75	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF17002 at MD101 inlet.
F-18001	MD101 & T301	Concentrated brines (liquid)	0.9	65	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF18001 at MD101 outlet and manual valve MVF18003 at T301 inlet.
F-19001	MD101 & T401	Water (liquid)	0.9	30	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF19001 at MD101 outlet and manual valve MVF19003 at T401 inlet.
F-20001	T401 & P501	Water (liquid)	-0.5	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF20001 at T401 outlet.
F-21001	P501 & MD101	Water (liquid)	1	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF21002 at MD101 inlet.
F-22001	T401 & T501	Water (liquid)	-0.5	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF22001 at T401 surplus and manual valve MVF22003 at T501 inlet.
F-23001	RO101 & T501	Water (liquid)	Atm.	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVF23001 at RO outlet and manual valve MVF23003 at T501 inlet.
F-24001	T501 & P601	Water (liquid)	-0.5	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF24001 at T501 outlet.
F-25001	P601 & Z101	Water (liquid)	1	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF25001 at Z101 inlet.

Pipe	Linked sections	Nature of the fluid (state)	P (bar_g)	T (ºC)	Schedule / NPS (in)	$Ø_{out}$ / $Ø_{in}$ (in)	Material	Heat-sinking (thickness) / tracing	Possible isolation areas
F-26001	Z101 & T601	Water (liquid)	Atm.	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF26001 at Z101 outlet and manual valve MVF26003 at T601 inlet.
F-27001	T601 & Equipment that uses regenerated water	Water (liquid)	Atm.	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF27001 at T601 outlet.
F-28001	T601 & P701	Water (liquid)	-0.5	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF28001 at T601 outlet.
F-29001	P701 & Z101	Water (liquid)	1	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF29002 at Z101 inlet.
F-30001	Z101 & Drain	Water (liquid)	0	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVF30001at Z101 outlet.
W-1001	Water mains & T101	Water (liquid)	Atm.	Amb.	SCH 40 1”	1.315 1.049	PVC	6 mm / -	Manual valve MVW1001 at the inlet of the line.
W-2001	Water mains & T201	Water (liquid)	Atm.	Amb.	SCH 40 1”	1.315 1.049	PVC	-	Manual valve MVW2001 at the inlet of the line.
W-3001	Water mains & T301	Water (liquid)	Atm.	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVW3001 at the inlet of the line.
W-4101	Water mains & T401	Water (liquid)	Atm.	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVW4001 at the inlet of the line.
W-4201	Water mains & Cooling coil inlet	Water (liquid)	Atm.	Amb.	SCH 40 ¼”	0.540 0.344	PVC	-	Manual valve MVW4201 at the inlet of the line.
W-4202	Cooling coil outlet & Drain	Water (liquid)	Atm.	25	SCH 40 ¼”	0.540 0.344	PVC	-	-
W-5001	Water mains & T501	Water (liquid)	Atm.	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVW5001 at the inlet of the line.
W-6001	Water mains & T601	Water (liquid)	Atm.	Amb.	SCH 40 ¾”	1.050 0.824	PVC	-	Manual valve MVW6001 at the inlet of the line.

4.2.2. Control and instrumentation design

In order to design the control strategies, it is essential to have clear understanding of the equipment (both auxiliar and main) that makes up the system as well as of all those variables to be controlled or regulated in them.

The equipment that conforms the system and their most relevant parameters are the ones indicated in the table below:

Taula 4.2. List of equipment and pipelines in the process order and their relevant parameters.

Equipment or line	Relevant parameters							
	C	**Flow**	**Level**	**pH**	**Power**	**P**	**Redox**	**T**
Cartridge filter						X		
UF	X	X		X		X		X
FFR RO	X	X		X		X	X	X
MD	X	X		X		X		X
Electric resistance (heater)	X		X	X				X
Coil (chiller)	X		X	X				X
Adsorption on zeolites	X	X				X		X
Tanks T101, T201, T301, T501, T601	X		X	X				X
Tank T401			X					X
Centrifugal / plunger pumps		X			X	X		
Dosing pumps		X						
Wastewater lines (feeds)		X						
Mains water lines		X						
Chemicals lines		X		X				

As this project is a demonstrative R&D project, monitoring requirements are increased in respect to a commercial or industrial system. With a view on simplifying the explanation of the control strategies, two tables have been designed in order to visually interpret the system's operation depending on several conditions. The first table indicates the various operational scenarios, whereas the second one includes the different scenarios that could require the activation of the alarms.

The first table indicates the way control and automatic valves will act by following the code below:

- Green cells O : indicate that the valve remains open.
- Red cells C : indicate that the valve remains closed.
- Blue cells O/C : indicate that the valve will open or close depending on the system's needs.

Table 4.3. Operation conditions.

	Start & stop			Conventional operation		Maintenance & cleaning																				
	1st start-up	Shutdown	Emptying of the system	Conventional operation (NFF)	Conventional operation with RO in FFR	Maintenance	Cleaning of T101 during NFF	Cleaning of T101 during FFR	Cleaning of T201 during NFF	Cleaning of T201 during FFR	Cleaning of T301 during NFF	Cleaning of T301 during FFR	Cleaning of T401 during NFF	Cleaning of T401 during FFR	Cleaning of T501 during NFF	Cleaning of T501 during FFR	Cleaning of T601 during NFF	Cleaning of T601 during FFR	UF backwash during NFF operation	UF backwash during FFR operation	Chemical cleaning of RO during NFF operation	Chemical cleaning of RO during FFR operation	Chemical cleaning of MD during NFF operation	Chemical cleaning of MD during FFR operation	Zeolites regeneration during NFF	Zeolites regeneration during FFR
CVF1001 (MBR inlet)	O/C	C	C	O/C	O/C	C	C	C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C
CVF1101 (MBR outlet)	O/C	C	C	O/C	O/C	C	O/C	O/C	C	C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C
AVF5101 (UF drain)	C	C	O	C	C	C	C	C	O	O	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
AVF10201 (RO feed)	O	C	C	O	C	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C
AVF11001 (FFR)	C	C	C	C	O	C	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O
AVF12001 (FFR)	C	C	C	C	O	C	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O
AVF13101 (RO retentate)	O/C	C	O	O	C	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C
CVF13401 (Retentate decompression)	O/C	C	O	O/C	O/C	C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C
CVF13301 (RO recycle)	O/C	C	C	O/C	O/C	C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C
AVF14001 (RO drain)	C	C	O	C	C	C	C	C	C	C	O	O	C	C	C	C	C	C	C	C	C	C	C	C	C	C
CVW4201 (Mains water W4201)	O/C	C	C	O/C	O/C	C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C	O/C

Table 4.4. Alarm setup for each relevant parameter of each piece of equipment

Parameter & units	Equipment	Setpoint	Alarm			
			Warning (low)	Operation stop (low)	Warning (high)	Operation stop (high)
Conductivity (mS/cm)	T301	- (1)	- (1)	- (1)	265	385 (2)
Feed flow (L/h)	UF101	500	400	300	600	700
	RO101	450	300	250	600	650
	Z101	42	30	25	50	60
Feed pressure (bar_g)	UF101	1	- (3)	- (3)	8.5	10
	RO101	12.1	- (3)	- (3)	20	41
Level (capacity %)	TX01	- (4)	15 (5)	10 (6)	- (7)	- (7)
Pressure drop (bar_g)	CF101	- (8)	- (8)	- (8)	1	- (9)
	RO101	- (8)	- (8)	- (8)	0.8	0.9
Redox (mV)	RO101	350	-	-	400 (10)	-
Temperature (ºC)	T301	75	65	60	80	85
	T401	25	- (11)	- (11)	30	35

(1): There is no conductivity setpoint, and low conductivity is not critical.

(2): Conductivity associated to brines with a concentration of 250 g/L of NaCl. This value has been obtained from the correlation between total dissolved solids (TDS) and conductivity at ambient temperature (k_T) for the case of NaCl (ref. 14):

$$TDS = 0.65 \cdot k_T \quad (4.1.)$$

(3): There are no low pressure limitations defined by the supplier.

(4): There is no level setpoint. The tank operation is appropriate as long as the level is not low.

(5): Tank operation at 15% of its capacity for 2 minutes.

(6): Tank operation at 10% of its capacity for 1 minute.

(7): There is no high level alarm as the tank has a drain that carries overflows.

(8): There is no pressure drop setpoint and there are no low pressure drop alarms, as operation can go without pressure drop.

(9): Operation does not have to be stopped because of a very high pressure drop. It is assumed that when the warning alarm goes off an operator will change the cartridge filter.

(10): 400 mV means that there is free chlorine in the medium, and it has been experimentally observed that RO membranes cannot tolerate it.

(11): Operation at lower temperatures is not critical.

Table 4.5. List of valves

Valve name	P&ID	Description	Type	Signal	Connection type	Line / equipment	Schedule	NPS (in)	Material
AVF5101	1	Automatic valve	Ball	DO	Threaded	F-5101	SCH 40	1	316L
AVF10201	2	Automatic valve	Ball	DO	Flanged	F-10201	SCH 40	1	904L
AVF11001	2	Automatic valve	Ball	DO	Flanged	F-11001	SCH 40	1	904L
AVF12001	2	Automatic valve	Ball	DO	Flanged	F-12001	SCH 40	1	904L
AVF13101	2	Automatic valve	Ball	DO	Flanged	F-13101	SCH 40	1	904L
AVF14001	2	Automatic valve	Ball	DO	Threaded	F-14001	SCH 40	1	316L
CVF1001	1	Control valve	Plug	AO	Threaded	F-1001	SCH 40	1	316L
CVF1101	1	Control valve	Plug	AO	Threaded	F-1101	SCH 40	1	316L
CVF13301	2	Control valve	Seat	AO	Threaded	F-13301	SCH 40	1	316L
CVF13401	2	Control valve	Needle	AO	Flanged to F-13401 & threaded to F-13501	F-13401	SCH 40	1	904L
CVW4201	2	Control valve	Seat	AO	Threaded	F-42001	SCH 40	¼	316L
KVC3101	2	Check valve	Swing	-	Threaded	C-3101	SCH 40	½	316L
KVF6001	1	Check valve	Swing	-	Threaded	F-6001	SCH 40	1	316L
KVF13301	2	Check valve	Swing	-	Flanged	F-13301	SCH 40	1	904L
KVF22001	2	Check valve	Swing	-	Threaded	F-22001	SCH 40	¾	316L
KVF23001	2	Check valve	Swing	-	Threaded	F-23001	SCH 40	1	316L
KVF29001	3	Check valve	Swing	-	Threaded	F-29001	SCH 40	¾	316L
MVC1001	1	Manual valve	Gate	-	Threaded	C-1001	SCH 40	½	316L

Valve name	P&ID	Description	Type	Signal	Connection type	Line / equipment	Schedule	NPS (in)	Material
MVC1101	1	Manual valve	Gate	-	Threaded	C-1101	SCH 40	½	316L
MVC2001	1	Manual valve	Gate	-	Threaded	C-2001	SCH 40	½	316L
MVC2101	1	Manual valve	Gate	-	Threaded	C-2101	SCH 40	½	316L
MVC3001	1	Manual valve	Gate	-	Threaded	C-3001	SCH 40	½	316L
MVC3101	1	Manual valve	Gate	-	Threaded	C-3101	SCH 40	½	316L
MVF1001	1	Manual valve	Gate	-	Threaded	F-1001	SCH 40	1	316L
MVF1002	1	Manual valve	Gate	-	Threaded	F-1001	SCH 40	1	316L
MVF1101	1	Manual valve	Gate	-	Threaded	F-1101	SCH 40	1	316L
MVF1102	1	Manual valve	Gate	-	Threaded	F-1101	SCH 40	1	316L
MVF2001	1	Manual valve	Gate	-	Threaded	F-2001	SCH 40	1	316L
MVF2002	1	Manual valve	Gate	-	Threaded	F-2001	SCH 40	1	316L
MVF2003	1	Manual valve	Gate	-	Threaded	F-2001	SCH 40	1	316L
MVF3001	1	Manual valve	Gate	-	Threaded	F-3001	SCH 40	1	316L
MVF3002	1	Manual valve	Gate	-	Threaded	F-3001	SCH 40	1	316L
MVF4001	1	Manual valve	Gate	-	Threaded	F-4001	SCH 40	1	316L
MVF4002	1	Manual valve	Gate	-	Threaded	F-4001	SCH 40	1	316L
MVF5001	1	Manual valve	Gate	-	Threaded	F-5001	SCH 40	1	316L
MVF5101	1	Manual valve	Gate	-	Threaded	F-5101	SCH 40	1	316L
MVF5201	1	Manual valve	Gate	-	Threaded	F-5201	SCH 40	1	316L
MVF5202	1	Manual valve	Gate	-	Threaded	F-5201	SCH 40	1	316L

Valve name	P&ID	Description	Type	Signal	Connection type	Line / equipment	Schedule	NPS (in)	Material
MVF6001	1	Manual valve	Gate	-	Threaded	F-6001	SCH 40	1	316L
MVF6002	1	Manual valve	Gate	-	Threaded	F-6001	SCH 40	1	316L
MVF6003	1	Manual valve	Gate	-	Threaded	F-6001	SCH 40	1	316L
MVF7001	1	Manual valve	Gate	-	Threaded	F-7001	SCH 40	1	316L
MVF7002	1	Manual valve	Gate	-	Threaded	F-7001	SCH 40	1	316L
MVF8001	1	Manual valve	Gate	-	Threaded	F-8001	SCH 40	1	316L
MVF8002	1	Manual valve	Gate	-	Threaded	F-8001	SCH 40	1	316L
MVF8101	1	Manual valve	Gate	-	Threaded	F-8101	SCH 40	1	316L
MVF8102	1	Manual valve	Gate	-	Threaded	F-8101	SCH 40	1	316L
MVF9001	1	Manual valve	Gate	-	Threaded	F-9001	SCH 40	1	316L
MVF9002	2	Manual valve	Gate	-	Threaded	F-9001	SCH 40	1	316L
MVF10401	2	Manual valve	Gate	-	Flanged	F-10401	SCH 40	1	904L
MVF10402	2	Manual valve	Gate	-	Flanged	F-10401	SCH 40	1	904L
MVF11001	2	Manual valve	Gate	-	Flanged	F-11001	SCH 40	1	904L
MVF11002	2	Manual valve	Gate	-	Flanged	F-11001	SCH 40	1	904L
MVF12001	2	Manual valve	Gate	-	Flanged	F-12001	SCH 40	1	904L
MVF12002	2	Manual valve	Gate	-	Flanged	F-12001	SCH 40	1	904L
MVF13001	2	Manual valve	Gate	-	Flanged	F-13001	SCH 40	1	904L
MVF13002	2	Manual valve	Gate	-	Flanged	F-13001	SCH 40	1	904L
MVF13101	2	Manual valve	Gate	-	Flanged	F-13101	SCH 40	1	904L

Valve name	P&ID	Description	Type	Signal	Connection type	Line / equipment	Schedule	NPS (in)	Material
MVF13301	2	Manual valve	Gate	-	Flanged	F-13301	SCH 40	1	904L
MVF13302	2	Manual valve	Gate	-	Flanged	F-13301	SCH 40	1	904L
MVF14001	2	Manual valve	Gate	-	Threaded	F-14001	SCH 40	1	316L
MVF15001	2	Manual valve	Gate	-	Threaded	F-15001	SCH 40	1	316L
MVF15002	2	Manual valve	Gate	-	Threaded	F-15001	SCH 40	1	316L
MVF15003	2	Manual valve	Gate	-	Threaded	F-15001	SCH 40	1	316L
MVF16001	2	Manual valve	Diaphragm	-	Threaded	F-16001	SCH 40	¾	316L & plastic
MVF16002	2	Manual valve	Diaphragm	-	Threaded	F-16001	SCH 40	¾	316L & plastic
MVF17001	2	Manual valve	Diaphragm	-	Threaded	F-17001	SCH 40	¾	316L & plastic
MVF17002	2	Manual valve	Diaphragm	-	Threaded	F-17001	SCH 40	¾	316L & plastic
MVF18001	2	Manual valve	Diaphragm	-	Threaded	F-18001	SCH 40	¾	316L & plastic
MVF18002	2	Manual valve	Diaphragm	-	Threaded	F-18001	SCH 40	¾	316L & plastic
MVF18003	2	Manual valve	Diaphragm	-	Threaded	F-18001	SCH 40	¾	316L & plastic
MVF19001	2	Manual valve	Gate	-	Threaded	F-19001	SCH 40	¾	316L
MVF19002	2	Manual valve	Gate	-	Threaded	F-19001	SCH 40	¾	316L

Valve name	P&ID	Description	Type	Signal	Connection type	Line / equipment	Schedule	NPS (in)	Material
MVF19003	2	Manual valve	Gate	-	Threaded	F-19001	SCH 40	¾	316L
MVF20001	2	Manual valve	Gate	-	Threaded	F-20001	SCH 40	¾	316L
MVF20002	2	Manual valve	Gate	-	Threaded	F-20001	SCH 40	¾	316L
MVF21001	2	Manual valve	Gate	-	Threaded	F-21001	SCH 40	¾	316L
MVF21002	2	Manual valve	Gate	-	Threaded	F-21001	SCH 40	¾	316L
MVF22001	2	Manual valve	Gate	-	Threaded	F-22001	SCH 40	¾	316L
MVF22002	3	Manual valve	Gate	-	Threaded	F-22001	SCH 40	¾	316L
MVF22003	3	Manual valve	Gate	-	Threaded	F-22001	SCH 40	¾	316L
MVF23001	2	Manual valve	Gate	-	Threaded	F-23001	SCH 40	1	316L
MVF23002	3	Manual valve	Gate	-	Threaded	F-23001	SCH 40	1	316L
MVF23003	3	Manual valve	Gate	-	Threaded	F-23001	SCH 40	1	316L
MVF24001	3	Manual valve	Gate	-	Threaded	F-24001	SCH 40	¾	316L
MVF24002	3	Manual valve	Gate	-	Threaded	F-24001	SCH 40	¾	316L
MVF25001	3	Manual valve	Gate	-	Threaded	F-25001	SCH 40	¾	316L
MVF25002	3	Manual valve	Gate	-	Threaded	F-25001	SCH 40	¾	316L
MVF26001	3	Manual valve	Gate	-	Threaded	F-26001	SCH 40	¾	316L
MVF26002	3	Manual valve	Gate	-	Threaded	F-26001	SCH 40	¾	316L
MVF26003	3	Manual valve	Gate	-	Threaded	F-26001	SCH 40	¾	316L
MVF27001	3	Manual valve	Gate	-	Threaded	F-27001	SCH 40	¾	316L
MVF27002	3	Manual valve	Gate	-	Threaded	F-27001	SCH 40	¾	316L

Valve name	P&ID	Description	Type	Signal	Connection type	Line / equipment	Schedule	NPS (in)	Material
MVF28001	3	Manual valve	Gate	-	Threaded	F-28001	SCH 40	¾	316L
MVF28002	3	Manual valve	Gate	-	Threaded	F-28001	SCH 40	¾	316L
MVF29001	3	Manual valve	Gate	-	Threaded	F-29001	SCH 40	¾	316L
MVF29002	3	Manual valve	Gate	-	Threaded	F-29001	SCH 40	¾	316L
MVF30001	3	Manual valve	Gate	-	Threaded	F-30001	SCH 40	¾	316L
MVF30002	3	Manual valve	Gate	-	Threaded	F-30001	SCH 40	¾	316L
MVT1001	1	Manual valve	Gate	-	Threaded	T101	SCH 40	1	316L
MVT2001	1	Manual valve	Gate	-	Threaded	T201	SCH 40	1	316L
MVT3001	2	Manual valve	Diaphragm	-	Threaded	T301	SCH 40	¾	316L & plastic
MVT4001	2	Manual valve	Gate	-	Threaded	T401	SCH 40	¾	316L
MVT5001	3	Manual valve	Gate	-	Threaded	T501	SCH 40	¾	316L
MVT6001	3	Manual valve	Gate	-	Threaded	T601	SCH 40	¾	316L
MVW1001	1	Manual valve	Ball	-	Threaded	W-1001	SCH 40	1	316L
MVW1002	1	Manual valve	Ball	-	Threaded	W-1001	SCH 40	1	316L
MVW2001	1	Manual valve	Ball	-	Threaded	W-2001	SCH 40	1	316L
MVW2002	1	Manual valve	Ball	-	Threaded	W-2001	SCH 40	1	316L
MVW3001	2	Manual valve	Ball	-	Threaded	W-3001	SCH 40	¾	316L
MVW3002	2	Manual valve	Ball	-	Threaded	W-3001	SCH 40	¾	316L
MVW4101	2	Manual valve	Ball	-	Threaded	W-4101	SCH 40	¾	316L
MVW4102	2	Manual valve	Ball	-	Threaded	W-4101	SCH 40	¾	316L

Valve name	P&ID	Description	Type	Signal	Connection type	Line / equipment	Schedule	NPS (in)	Material
MVW4201	2	Manual valve	Ball	-	Threaded	W-4201	SCH 40	¾	316L
MVW4202	2	Manual valve	Ball	-	Threaded	W-4201	SCH 40	¼	316L
MVW5001	3	Manual valve	Ball	-	Threaded	W-5001	SCH 40	¾	316L
MVW5002	3	Manual valve	Ball	-	Threaded	W-5001	SCH 40	¾	316L
MVW6001	3	Manual valve	Ball	-	Threaded	W-6001	SCH 40	¾	316L
MVW6002	3	Manual valve	Ball	-	Threaded	W-6001	SCH 40	¾	316L

Table 4.6. List of instruments.

Instrument name	P&ID	Measured / indicated parameter	Measure range	Calibration range	Working T (ºC)	Max. working P (bar_g)	Min. immersion (mm)	Materials	Ø / L (mm)	Connection type	Fastening thread	Connector	Location	Manufacturer & Model	Installation
CT T1001	1	Conductivity	10 µs/cm - 80 mS/cm	6 mS/cm - 16 mS/cm	0 - 80	5 (25ºC)	10	**Temperature sensor:** Pt1000. **Body:** titanium. **Electrodes:** titanium.	12.1 110	Threaded	PG 13.5	MP-5	T101	CRISON CRI5388.99	-
CT T2001	1	Conductivity	10 µs/cm - 80 mS/cm	6 mS/cm - 16 mS/cm	0 - 80	5 (25ºC)	10	**Temperature sensor:** Pt1000. **Body:** titanium. **Electrodes:** titanium.	12.1 110	Threaded	PG 13.5	MP-5	T201	CRISON CRI5388.99	-
CT T3001	2	Conductivity	200 µs/cm - 2 S/cm	21mS - 1 S/cm	(-10) - 200	13.8 (200ºC)	- (Inductive)	**Body:** PEEK.	39.6 127	Threaded	¾” NPT	-	T301	HACH 3727E2T.99	-
CT T5001	3	Conductivity	10 µs/cm - 80 mS/cm	1.4 mS - 2.6 mS	0 - 80	5 (25ºC)	10	**Temperature sensor:** Pt1000. **Body:** titanium. **Electrodes:** titanium.	12.1 110	Threaded	PG 13.5	MP-5	T501	CRISON CRI5388.99	-
CT T6001	3	Conductivity	10 µs/cm - 80 mS/cm	1.4 mS - 2.6 mS	0 - 80	5 (25ºC)	10	**Temperature sensor:** Pt1000. **Body:** titanium. **Electrodes:** titanium.	12.1 110	Threaded	PG 13.5	MP-5	T601	CRISON CRI5388.99	-
CT F5003	1	Conductivity	0.1 µs/cm - 10 mS/cm	6 mS/cm - 16 mS/cm	0 - 100	10 (25ºC)	10	**Temperature sensor:** Pt1000. **Body:** titanium. **Electrodes:** platinum.	12.7 50	Threaded	½” NPT	MP-5	F-5001	CRISON CRI5392.99	-
CT F10401	2	Conductivity	0.1 µs/cm - 10 mS/cm	12 mS/cm - 22 mS/cm	0 - 100	10 (25ºC)	10	**Temperature sensor:** Pt1000. **Body:** titanium. **Electrodes:** platinum.	12.7 50	Flanged	½” NPT	MP-5	F-10401	CRISON CRI5392.99	(1)
CT F13001	2	Conductivity	0.1 µs/cm - 10 mS/cm	16 mS/cm - 36 mS/cm	0 - 100	10 (25ºC)	10	**Temperature sensor:** Pt1000. **Body:** titanium. **Electrodes:** platinum.	12.7 50	Flanged	½” NPT	MP-5	F-13001	CRISON CRI5392.99	(1)
CT F23001	2	Conductivity	0.1 µs/cm - 10 mS/cm	0.9 mS/cm - 3 mS/cm	0 - 100	10 (25ºC)	10	**Temperature sensor:** Pt1000. **Body:** titanium. **Electrodes:** platinum.	12.7 50	Threaded	½” NPT	MP-5	F-23001	CRISON CRI5392.99	-
FI F13302	2	Flow	40 L/h - 400 L/h	40 L/h - 400 L/h	0 - 55	15	-	**Tube:** styrene methyl methacrylate copolymer. **Union bushes:** PVC-U. **O-ring seal:** EPDM. **Indicator:** PE. **Float:** AISI 316. **Float stops:** PVDF.	25 260	Flanged	Flange diameter: 105 mm	-	F-13301	CEPEX UP.92.FLG.M 05.92.225A	-
FT F1002	1	Flow	Electromagnetic induction	400 L/h - 600 L/h	(-20) - 150	40	- (Inductive)	**Coating:** PFA. **Electrodes:** Hastelloy C. **Transmitter:** polyamide.	10 -	Threaded	½” NPT	DN10	F-1001	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1RA10-1LA1	(2)
FT F1102	1	Flow	Electromagnetic induction	400 L/h - 600 L/h	(-20) - 150	40	- (Inductive)	**Coating:** PFA. **Electrodes:** Hastelloy C. **Transmitter:** polyamide.	10 -	Threaded	½” NPT	DN10	F-1101	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1RA10-1LA1	(2)
FT F4002	1	Flow	Electromagnetic induction	400 L/h - 600 L/h	(-20) - 150	40	- (Inductive)	**Coating:** PFA. **Electrodes:** Hastelloy C. **Transmitter:** polyamide.	10 -	Threaded	½” NPT	DN10	F-4001	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1RA10-1LA1	(2)
FT F5002	1	Flow	Electromagnetic induction	6 L/h - 10 L/h	(-20) - 150	40	- (Inductive)	**Coating:** PFA. **Electrodes:** Hastelloy C. **Transmitter:** polyamide.	10 -	Threaded	½” NPT	DN10	F-5001	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1RA10-1LA1	(2)

Instrument name	P&ID	Measured / indicated parameter	Measure range	Calibration range	Working T (ºC)	Max. working P (bar_g)	Min. immersion (mm)	Materials	Ø / L (mm)	Connection type	Fastening thread	Connector	Location	Manufacturer & Model	Installation
FT F6002	1	Flow	Electromagnetic induction	400 L/h - 600 L/h	(-20) - 150	40	- (Inductive)	**Coating:** PFA. **Electrodes:** Hastelloy C. **Transmitter:** polyamide.	10 -	Threaded	½" NPT	DN10	F-6001	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1RA10-1LA1	(2)
FT F8103	1	Flow	Electromagnetic induction	400 L/h - 600 L/h	(-20) - 150	40	- (Inductive)	**Coating:** PFA. **Electrodes:** Hastelloy C. **Transmitter:** polyamide.	10 -	Threaded	½" NPT	DN10	F-8101	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1RA10-1LA1	(2)
FT F10202	2	Flow	Electromagnetic induction	400 L/h - 600 L/h	(-20) - 150	40	- (Inductive)	**Coating:** PFA. **Electrodes:** Hastelloy C. **Transmitter:** polyamide.	10 -	Threaded	½" NPT	DN10	F-10201	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1RA10-1LA1	(2)
FT F15001	2	Flow	Electromagnetic induction	650 L/h - 850 L/h	(-20) - 150	40	- (Inductive)	**Coating:** ceramic. **Electrodes:** platinum. **Transmitter:** polyamide	3 -	Threaded	½" NPT	DN3	F-15001	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1HA20-2LA1	(2)
FT F17002	2	Flow	Electromagnetic induction	50 L/h - 100 L/h	(-20) - 150	40	- (Inductive)	**Coating:** ceramic. **Electrodes:** platinum. **Transmitter:** polyamide	3 -	Threaded	½" NPT	DN3	F-17001	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1HA20-2LA1	(3)
FT F19002	2	Flow	Electromagnetic induction	100 L/h - 200 L/h	(-20) - 150	40	- (Inductive)	**Coating:** ceramic. **Electrodes:** platinum. **Transmitter:** polyamide	3 -	Threaded	½" NPT	DN3	F-19002	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1HA20-2LA1	(2)
FT F22001	3	Flow	Electromagnetic induction	20 L/h - 60 L/h	(-20) - 150	40	- (Inductive)	**Coating:** ceramic. **Electrodes:** platinum. **Transmitter:** polyamide	3 -	Threaded	½" NPT	DN3	F-22001	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1HA20-2LA1	(2)
FT F23002	2	Flow	Electromagnetic induction	250 L/h - 300 L/h	(-20) - 150	40	- (Inductive)	**Coating:** ceramic. **Electrodes:** platinum. **Transmitter:** polyamide	3 -	Threaded	½" NPT	DN3	F-23001	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1HA20-2LA1	(2)
FT 25002	3	Flow	Electromagnetic induction	20 L/h - 60 L/h	(-20) - 150	40	- (Inductive)	**Coating:** ceramic. **Electrodes:** platinum. **Transmitter:** polyamide	3 -	Threaded	½" NPT	DN3	F-25001	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1HA20-2LA1	(2)
FT 26001	3	Flow	Electromagnetic induction	20 L/h - 60 L/h	(-20) - 150	40	- (Inductive)	**Coating:** ceramic. **Electrodes:** platinum. **Transmitter:** polyamide	3 -	Threaded	½" NPT	DN3	F-26001	SIEMENS FM MAG1 100 + MAG5000 7ME6110-1HA20-2LA1	(2)
LT T1003	1	Level	Capacitive based on frequency variations	-	(-10) - 100	10	-	**Body:** thermoplastic polyester. **Cover:** transparent thermoplastic polycarbonate (PC). **Sensor:** PPS.	¾" 100	Threaded	¾" NPT	-	T101	SIEMENS SITRANS CLS100 RF switch 7ML5610	-
LT T2003	1	Level	Capacitive based on frequency variations	-	(-10) - 100	10	-	**Body:** thermoplastic polyester. **Cover:** transparent thermoplastic polycarbonate (PC). **Sensor:** PPS.	¾" 100	Threaded	¾" NPT	-	T201	SIEMENS Pointek CLS100 RF switch	-
LT T3003	2	Level	Capacitive based on frequency variations	-	(-10) - 100	10	-	**Body:** thermoplastic polyester. **Cover:** transparent thermoplastic polycarbonate (PC). **Sensor:** PPS.	¾" 100	Threaded	¾" NPT	-	T301	SIEMENS SITRANS CLS100 RF switch	-

Instrument name	P&ID	Measured / indicated parameter	Measure range	Calibration range	Working T (ºC)	Max. working P (bar_g)	Min. immersion (mm)	Materials	Ø / L (mm)	Connection type	Fastening thread	Connector	Location	Manufacturer & Model	Installation
LT T4002	2	Level	Capacitive based on frequency variations	-	(-10) - 100	10	-	**Body:** thermoplastic polyester. **Cover:** transparent thermoplastic polycarbonate (PC). **Sensor:** PPS.	¾" 100	Threaded	¾" NPT	-	T401	SIEMENS SITRANS CLS100 RF switch	-
LT T5003	3	Level	Capacitive based on frequency variations	-	(-10) - 100	10	-	**Body:** thermoplastic polyester. **Cover:** transparent thermoplastic polycarbonate (PC). **Sensor:** PPS.	¾" 100	Threaded	¾" NPT	-	T501	SIEMENS SITRANS CLS100 RF switch	-
LT T6003	3	Level	Capacitive based on frequency variations	-	(-10) - 100	10	-	**Body:** thermoplastic polyester. **Cover:** transparent thermoplastic polycarbonate (PC). **Sensor:** PPS.	¾" 100	Threaded	¾" NPT	-	T601	SIEMENS SITRANS CLS100 RF switch	-
PT F2001	1	Pressure	0 bar_g - 1 bar_g	0 bar_g - 1 bar_g	(-15) - 125	2.5 bar_g	-	**Measuring cell:** Al_2O_3 96%. **Process connection:** AISI 316L. **Annular ring:** FPM. **Casing:** AISI 316L.	-	Threaded	G½"	M12	F-2001	SIEMENS SITRANS P200 7MF1565	-
PT F3001	1	Pressure	0 bar_g - 1 bar_g	0 bar_g - 1 bar_g	(-15) - 125	2.5 bar_g	-	**Measuring cell:** Al_2O_3 96%. **Process connection:** AISI 316L. **Annular ring:** FPM. **Casing:** AISI 316L.	-	Threaded	G½"	M12	F-3001	SIEMENS SITRANS P200 7MF1565	-
PT F4001	1	Pressure	0 bar_g - 1 bar_g	0 bar_g - 1 bar_g	(-15) - 125	2.5 bar_g	-	**Measuring cell:** Al_2O_3 96%. **Process connection:** AISI 316L. **Annular ring:** FPM. **Casing:** AISI 316L.	-	Threaded	G½"	M12	F-4001	SIEMENS SITRANS P200 7MF1565	-
PT F5001	1	Pressure	0 bar_g - 1 bar_g	0 bar_g - 1 bar_g	(-15) - 125	2.5 bar_g	-	**Measuring cell:** Al_2O_3 96%. **Process connection:** AISI 316L. **Annular ring:** FPM. **Casing:** AISI 316L.	-	Threaded	G½"	M12	F-5001	SIEMENS SITRANS P200 7MF1565	-
PT F6001	1	Pressure	0 bar_g - 1 bar_g	0 bar_g - 1 bar_g	(-15) - 125	2.5 bar_g	-	**Measuring cell:** Al_2O_3 96%. **Process connection:** AISI 316L. **Annular ring:** FPM. **Casing:** AISI 316L.	-	Threaded	G½"	M12	F-6001	SIEMENS SITRANS P200 7MF1565	-
PT F8102	1	Pressure	0 bar_g - 2 bar_g	0 bar_g - 2 bar_g	(-15) – 125	4 bar_g	-	**Measuring cell:** AISI 316L. **Process connection:** AISI 316L. **Casing:** AISI 316L.	-	Threaded	G½"	M12	F-8101	SIEMENS SITRANS P220 7MF1567	-
PT F10201	2	Pressure	0 bar_g - 20 bar_g	0 bar_g - 15 bar_g	(-15) – 125	62.5 bar_g	-	**Elements in contact with the fluid:** AISI 316L. **Elements not in contact with the fluid:** AISI 316L.	-	Flanged	G½"	M12	F-10201	SIEMENS SITRANS P200 7MF1567	-

Instrument name	P&ID	Measured / indicated parameter	Measure range	Calibration range	Working T (ºC)	Max. working P (bar_g)	Min. immersion (mm)	Materials	Ø / L (mm)	Connection type	Fastening thread	Connector	Location	Manufacturer & Model	Installation
PT F10403	2	Pressure	0 bar_g - 20 bar_g	0 bar_g - 15 bar_g	(-15) - 125	62.5 bar_g	-	**Elements in contact with the fluid:** AISI 316L. **Elements not in contact with the fluid:** AISI 316L.	-	Flanged	G½"	M12	F-10401	SIEMENS SITRANS P200 7MF1567	-
PT F13003	2	Pressure	0 bar_g - 20 bar_g	0 bar_g - 15 bar_g	(-15) - 125	62.5 bar_g	-	**Elements in contact with the fluid:** AISI 316L. **Elements not in contact with the fluid:** AISI 316L.	-	Flanged	G½"	M12	F-13001	SIEMENS SITRANS P200 7MF1567	-
PT F17001	2	Pressure	0 bar_g - 1 bar_g	0 bar_g - 1 bar_g	(-40) - 100	2.5 bar_g	-	**Filling of the measure cell:** silicon oil. **Body of the sensor:** AISI 316L. **Membrane material:** AISI 316L.	-	Threaded	14 NPT	M12	F-17001	SIEMENS SITRANS P320 7MF0300	(4)
PT F18001	2	Pressure	0 bar_g - 1 bar_g	0 bar_g - 1 bar_g	(-40) - 100	2.5 bar_g	-	**Filling of the measure cell:** silicon oil. **Body of the sensor:** AISI 316L. **Membrane material:** AISI 316L.	-	Threaded	14 NPT	M12	F-18001	SIEMENS SITRANS P320 7MF0300	(4)
PT F19001	2	Pressure	0 bar_g - 1 bar_g	0 bar_g - 1 bar_g	(-15) - 125	2.5 bar_g	-	**Elements in contact with the fluid:** ceramic, stainless steel and sealing material. **Elements not in contact with the fluid:** stainless steel.	-	Threaded	G½"	M12	F-19001	SIEMENS SITRANS P200 7MF1565	-
PT F21001	2	Pressure	0 bar_g - 1 bar_g	0 bar_g - 1 bar_g	(-15) - 125	2.5 bar_g	-	**Elements in contact with the fluid:** ceramic, stainless steel and sealing material. **Elements not in contact with the fluid:** stainless steel.	-	Threaded	G½"	M12	F-21001	SIEMENS SITRANS P200 7MF1565	-
PT F25001	3	Pressure	0 bar_g – 1 bar_g	0 bar_g - 1 bar_g	(-15) - 125	2.5 bar_g	-	**Measuring cell:** AISI 316L. **Process connection:** AISI 316L. **Casing:** AISI 316L.	-	Threaded	G½"	M12	F-25001	SIEMENS SITRANS P200 7MF1565	-
PT F29001	3	Pressure	0 bar_g – 1 bar_g	0 bar_g - 1 bar_g	(-15) - 125	2.5 bar_g	-	**Measuring cell:** AISI 316L. **Process connection:** AISI 316L. **Casing:** AISI 316L.	-	Threaded	G½"	M12	F-29001	SIEMENS SITRANS P200 7MF1565	-
pHT T1002	1	pH	0 - 14	5 - 9	0 - 80	6	17	**Ref. element:** encapsulated Ag/AgCl crystals. **Diaphragm:** 3 ceramic. **Electrolyte:** gel. **Body:** glass.	12 120	Threaded	PG 13.5	S8	T101	CRISON CRI5303.99	-
pHT T2002	1	pH	0 - 14	5 - 9	0 - 80	6	17	**Ref. element:** encapsulated Ag/AgCl crystals. **Diaphragm:** 3 ceramic. **Electrolyte:** gel. **Body:** glass.	12 120	Threaded	PG 13.5	S8	T201	CRISON CRI5303.99	-

Instrument name	P&ID	Measured / indicated parameter	Measure range	Calibration range	Working T (ºC)	Max. working P (bar_g)	Min. immersion (mm)	Materials	Ø / L (mm)	Connection type	Fastening thread	Connector	Location	Manufacturer & Model	Installation
pHT T3002	2	pH	0 - 14	5 - 9	0 - 80	6	17	**Ref. element:** encapsulated Ag/AgCl crystals. **Diaphragm:** 3 ceramic. **Electrolyte:** gel. **Body:** glass.	12 120	Threaded	PG 13.5	S8	T301	CRISON CRI5303.99	-
pHT T5002	3	pH	0 - 14	5 - 9	0 - 80	6	17	**Ref. element:** encapsulated Ag/AgCl crystals. **Diaphragm:** 3 ceramic. **Electrolyte:** gel. **Body:** glass.	12 120	Threaded	PG 13.5	S8	T501	CRISON CRI5303.99	-
pHT T6002	3	pH	0 - 14	5 - 9	0 - 80	6	17	**Ref. element:** encapsulated Ag/AgCl crystals. **Diaphragm:** 3 ceramic. **Electrolyte:** gel. **Body:** glass.	12 120	Threaded	PG 13.5	S8	T601	CRISON CRI5303.99	-
pHT F8101	1	pH	0 - 14	5 - 9	0 - 80	6	17	**Ref. element:** encapsulated Ag/AgCl crystals. **Diaphragm:** 3 ceramic. **Electrolyte:** gel. **Body:** glass.	12 120	Threaded	PG 13.5	S8	F-8101	CRISON CRI5303.99	-
pHT F10402	2	pH	0 - 14	5 - 9	0 - 80	6	17	**Ref. element:** encapsulated Ag/AgCl crystals. **Diaphragm:** 3 ceramic. **Electrolyte:** gel. **Body:** glass.	12 120	Flanged	PG 13.5	S8	F-10401	CRISON CRI5303.99	(1)
pHT F13002	2	pH	0 - 14	5 - 9	0 - 80	6	17	**Ref. element:** encapsulated Ag/AgCl crystals. **Diaphragm:** 3 ceramic. **Electrolyte:** gel. **Body:** glass.	12 120	Flanged	PG 13.5	S8	F-13001	CRISON CRI5303.99	(1)
ReT F10203	2	Redox	±2,000 mV	±2,000 mV	0 - 80	6	17	**Ref. element:** encapsulated Ag/AgCl crystals. **Diaphragm:** 3 ceramic. **Electrolyte:** gel. **Body:** glass.	12 120	Flanged	PG 13.5	S8	F-10201	CRISON CRI5362.99	(1)
TT T4001	2	Temperature	(-20ºC) - 150ºC	50 - 90	(-20ºC) - 150ºC	6	17	**Temperature sensor:** Pt1000. **Body:** AISI 316L.	12 120	Threaded	½" NPT	MP-5	T401	CRISON CRI5526.99	-

(1): As the line operation pressure is higher than the maximum pressure in which the transmitter can operate, it needs to be installed in a by-pass (depressurized) so that it can measure the desired parameter without experiencing pressure damage.

(2): The installation of an AISI 316L conical thread is required. Reference: FDK: 083G0080.

(3): The installation of an earthing ring is required. Reference: A5E01018395.

(4): The installation of a separator seal is required. Reference: 7MF0810-0BD00-0BD0-Z C11+C12+D66.

- : Unavailable information

4.2.3. Equipment design

4.2.3.1. Cartridge filter

To avoid damage derived from the high concentration of solids that the feed contains in the centrifugal pump P101, a Diproclean's disposable cartridge filter with a pore size of 100 μm is selected to eliminate most gross solids.

The reason why a disposable model has been selected is because of the versatility it offers, as it can be easily replaced and in case it does not satisfy the system's needs, it can be substituted by a different model.

The database of this element can be found in page 62.

4.2.3.2. UF module

During the experimental analysis that have been conducted in Eurecat to determine the most suitable operation conditions for the UF module, a ceramic membrane by Biosnar with 100 kDa pores has operated at 1 bar_g and 60 $L\cdot m^{-2}\cdot h^{-1}\cdot bar^{-1}$.

Figure 4.2. UF experimental setup. Source: Eurecat.

Knowing this, the treated daily volume can be calculated:

$$Daily\ treated\ volume: 60\,\frac{L}{m^2\cdot h\cdot bar}\cdot 1\ bar\cdot\frac{24\ h}{1\ day}\cdot\frac{1\ m^3}{1{,}000\ L}=1.44\ \frac{m}{day} \quad (4.2.)$$

As the flow inlet is 12 m^3/day and the percentage of recovery is 90% (value extracted from experimental data), the permeate flow is:

$$Daily\ permeate\ flow: 12\,\frac{m^3}{day}\cdot 0.9=10.8\,\frac{m^3}{day} \quad (4.3.)$$

With the two previous values, the required membrane area can be calculated:

$$Membrane\ area: \frac{10.8\,\frac{m^3}{day}}{1.44\,\frac{m}{day}}=7.5\ m^2 \quad (4.4.)$$

And finally, knowing the commercial membrane area, the number of required modules can be calculated:

$$Number\ of\ modules: \frac{7.5\ m^2}{37\ channels\cdot\frac{0.36\ m^2}{channel}}=0.56 \quad (4.5.)$$

This means that just one module is enough.

The datasheet of the selected UF module can be found in page 63.

4.2.3.3. FFR RO

The configuration of the FFR RO module has been designed thanks to WAVE (see *4.1.2. Simulation diagram*), and it has been determined that the system requires 1 pass and two stages, with 6 DuPont XLE-2540 membranes each (12 membranes in total).

The datasheet for the selected RO membranes can be found in page 64.

4.2.3.4. MD system

Because of the small flow that this technology has to treat (1.8 m^3/day), the smallest commercially available MD module has been selected.

Knowing that its membrane area is 0.0375 m^2 , and considering that it has been experimentally operated at 1 bar_g and 30 $L\cdot m^{-2}\cdot h^{-1}\cdot bar^{-1}$, the litres per hour that produces as well as its yield can be calculated:

$$1.8\,\frac{m^3}{day}\cdot\frac{1\,day}{24\,h}\cdot\frac{1{,}000\,L}{1\,m^3}\cdot\frac{m^2\cdot h\cdot bar}{30\,L}\cdot\frac{1}{0.0375\,m^2}=66.66\,L/h \quad (4.6.)$$

$$\eta=\frac{Production}{Feed}\cdot 100=\frac{66.66\,L/h}{1.8\frac{m^3}{day}\cdot\frac{1\,day}{24\,h}\cdot\frac{1{,}000\,L}{1\,m^3}}\cdot 100=88.88\% \quad (4.7.)$$

From previous MD experiments with a ΔT = 45ºC between the hot and the cold feed, it is known that the rejection factor for the following ions is the one indicated below:

Table 4.7. Rejection factor for some of the studied ions.

Ion:	**Na^+**	**K^+**	**Mg^{2+}**	**Ca^{2+}**	**Cl^-**	**SO_4^{2-}**
Rejection factor:	0.999	1.000	1.000	0.995	0.999	0.998

As NH_4^+ and conductivity on the permeate were not studied or measured in the outlet of the conducted experiments, their values have been determined by using bibliographic values. It has been seen that 98% of NH_4^+ is rejected (ref. 15) and that conductivity is reduced a 99.91 % (ref. 16). It has not been possible to determine how pH variates in the outlets of the system as no suitable data has been found about it.

It must also be noted that MD operates in a way by which the concentration in both T301 and T401 varies over time due to the constant recirculation of hot and cold streams, hence, the previous rejection values may vary over time.

The datasheet with the various properties of the selected MD system can be found in page 65.

4.2.3.5. Electric resistance

An electric resistance is located in T301 to heat the concentrated brines it contains, as they are the hot feed of the MD module.

This resistance must be able to keep brines at a temperature of 75ºC to guarantee a proper separation in the MD module, and it must also be able to heat the whole content of the tank in a couple of hours.

Knowing that the effective volume of T301 is 102 L, the required heat to heat the tank is:

$$Q=m\cdot C_{P,water}\cdot\Delta T=102kg\cdot\frac{1{,}000g}{1kg}\cdot 4.1813\,\frac{J}{g\cdot K}\cdot\frac{1kJ}{1{,}000J}\cdot(75℃-20℃)=23{,}457.09\,kJ \quad (4.8.)$$

As the tank is to be heated in two hours, the required power is 3.26 kWh.

Due to the extremely corrosive environment in T301, a conventional resistance cannot be installed, as the metal would be quickly degraded because of the high concentration of salts. Therefore, an anti-corrosion electric resistance has been selected.

This electric resistance supplied by Backer Facsa is covered in Teflon, so that it cannot suffer corrosion damage. This supplier was contacted to know their range of anti-corrosion resistances as well as their prices, and the power of the selected resistance is slightly superior to the required one. This electric power is 4 kW, as it the model that was closer to the system's needs.

The datasheet for the electric resistance can be found in page 66.

4.2.3.6. Coil

A coil is installed in T401 to cool down the MD outlet, as the water that goes through the MD membrane is heated by the brines, and hence return to the tank at a higher temperature.

The present coil has been designed so that it can be able to cool down the whole tank in 1 hour. Knowing from previous experiments conducted in Eurecat's laboratories that water fed into the MD experiences a ΔT of 10ºC (and hence leaves the module at 30ºC) and that it is necessary to feed water into the MD at ambient temperature (20ºC), and that the effective volume of T401 is 102L, the heat that is to be dissipated in 1 hour is:

$$Q = m \cdot C_P \cdot \Delta T = 102kg \cdot \frac{1{,}000g}{1kg} \cdot 4.1813 \frac{J}{g \cdot K} \cdot \frac{1kJ}{1{,}000J} \cdot (20℃ - 30℃) = -4{,}264.926\, kJ \qquad (4.9.)$$

The required water flow to cool down the whole volume of the tank can be determined knowing from previous experiments that cooling water experiences a ΔT of 5ºC:

$$\dot{m}_{cooling\ water} = \frac{Q}{C_p \cdot \Delta T} = \frac{4{,}264.926\, kJ}{4.1813\frac{J}{g \cdot K} \cdot \frac{1kJ}{1{,}000J} \cdot \frac{1{,}000\, g}{1\, kg}(25℃ - 20℃)} = 204\, kg/h \qquad (4.10.)$$

Assuming that water flows through the coil at a rate of 1 m/s, its internal diameter can be obtained:

$$\dot{m} = v \cdot A \rightarrow A = \frac{\dot{m}}{v} = \pi \frac{d^2}{4} \rightarrow d = \sqrt{\frac{4\dot{m}}{\pi v}} = \sqrt{\frac{4 \cdot 200\frac{kg}{h} \cdot \frac{1L}{1kg} \cdot \frac{1m^3}{1{,}000L} \cdot \frac{1h}{3{,}600s}}{\pi \cdot 1\frac{m}{s}}} \cdot \frac{1{,}000mm}{1m} = 8.41\, mm \qquad (4.11.)$$

Which is approximately a NPS of ¼".

4.2.3.7. Adsorption on zeolites

The design of the adsorption on zeolites needs to take into consideration that zeolites will be cleaned every week to guarantee their proper performance.

In order to determine the volume of the system, it has been determined that the system must be able to treat the ammonium concentration of the RO permeate, 2.57 mg NH_4^+/L, without considering the dilution effect derived from the mixing with T401 overflow.

Knowing that their average adsorption capacity is 9.3 mg $NH_4^+ \cdot g_{media}^{-1}$ (ref. 17), and that the density of the zeolites which are currently being tested in the laboratory is 350 g/L, the required zeolites volume can be calculated:

$$7\, days \cdot 1\frac{m^3}{day} \cdot \frac{1{,}000L}{1m^3} \cdot \frac{2.57\, mgNH_4^+}{1L} \cdot \frac{g\, zeolite}{9.3\, mgNH_4^+} \cdot \frac{L\, zeolite}{350\, g\, zeolite} = 5.53\, L\, zeolite \qquad (4.12.)$$

Therefore, to keep all zeolites, a 6 L recipient has been selected.

4.2.3.8. Tanks

As this pilot is purely demonstrative and due to space restrictions derived from keeping the whole installation in a 40 ft container, all tanks have been sized to keep the volume of an hour of operation of the technology to which they supply water. The only tank that does not follow this criterion is T101, which stores enough volume to operate for two hours, as it is the feed tank and is outside the container.

Despite not being pressurized tanks, they have been designed following a combination of the API 650 (ref. 8) standard and the ASME Code (ref. 7) guidelines. The calculation expressions and the obtained results can be found in *A.6. TANK DESIGN*.

However, when selecting commercial tanks it has been seen that all the determined conditions where difficult to meet due to the nature of water commercial tanks, as various calculated parameters were not indicated by the suppliers.

Therefore, the obtained results have been used to select similar commercial tanks, and the datasheets of each of them can be found in pages 67-72.

4.2.3.9. Pumps

All pumps have been dimensioned by following a set of equations that enable the calculation their height and power, which can be found in *A.4. PUMP DESIGN*.

Once these theoretical values have been obtained, the smart sizing tools of Grundfos (ref. 9) have been used to size and select all pumps except from P301 (because of its high pressure and low flow), for which the ones from Cat Pumps have been used (ref. 10).

The reason why there are so many dosing pumps instead of centrifugal ones, is the low flows at which the pilot operates in the MD and zeolites sections. It was not possible to find any centrifugal pump that could operate under those conditions.

P301 is not a centrifugal pump either. Because of the high pressure and the low flow at which the RO system operates, a plunger pump has been selected. Plunger pumps are not recommended for membrane systems because their pulses could damage the membrane; however, the commercial selected pump is designed so that pulses are smoother and hence membranes do not suffer any damage.

In case this project was to be scaled up to operate with higher water volumes, centrifugal pumps could be used instead in those sections.

In pages 73-82, there can be found the datasheets for each of the selected pumps. The last three datasheets correspond to the dosing pumps that add chemicals for the UF or RO modules as all process pumps appear in order first, which explains why the apparition order of the dosing pumps is not correlative.

UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ · eurecat	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	30/05/2021
		PREPARED	30/05/2021
	Cartridge filter CF101	REVISED	30/05/2021
		APPROVED	-

SUPPLIER & MODEL		DIPROCLEAN PR-SWS10100			
SERVICE		Cartridge filter	**ITEM**		CF101
TYPE		Disposable	**NUMBER OF UNITS**		1
FLUID					
PRODUCT		Water	TEMPERATURE		20 ºC
SOLID		N.A. % weight	VAPOUR PRESSURE		0.023 bar
DENSITY		1,000 kg/m^3	VISCOSITY		0.001 Pa·s
OPERATION CONDITIONS					
MAXIMUM OPERATION CONDITIONS	TEMPERATURE	50 ºC	RESISTANCE TO	CHEMICALS	Good
	PRESSURE	5 bar_g		BACTERIA	Immune
	FLOW	6,000 L/h			
MATERIALS, CONSTRUCTION & DIMENSIONS					
MATERIAL		Heat-sealed polypropylene microfibers	DIAMETER	OUTSIDE	61 mm
				INTERNAL	28 mm
PORE SIZE		100 µm	LENGTH		254 mm

IMAGES

COMMENTS

N.A.: not applicable

UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ Departament d'Enginyeria Química · eurecat Centre Tecnològic de Catalunya	SPECIFICATIONS	PROJECT:	TFGEQ_2105 _azurita
		SHEET NUM.:	1/1
		DATE	23/05/2021
		PREPARED	23/05/2021
	Ultrafiltration membrane UF101	REVISED	23/05/2021
		APPROVED	-

SUPPLIER	Biosnar		
SERVICE	UF module	**ITEM**	UF101
TYPE	Ceramic	**NUMBER OF UNITS**	1

FLUID

PRODUCT	Water		TEMPERATURE	20	ºC
SOLID	N.A.	% weight	VAPOUR PRESSURE	0.023	bar
DENSITY	1,000	kg/m^3	VISCOSITY	0.001	Pa·s

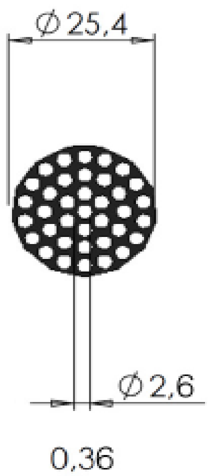
OPERATION CONDITIONS

pH	OPERATION	2 - 13		PRESSURE	OPERATION	1	bar_g
	CIP	1 - 14			BACKWASH	2	bar_g
TEMPERATURE	OPERATION	20	ºC		MAXIMUM	10	bar_g
	MAXIMUM	95	ºC	MAX. FLOW PURE WATER AT 25ºC		250 ± 25	$L/m^2 \cdot h \cdot bar$

MATERIALS, CONSTRUCTION & DIMENSIONS

MATERIAL	SUPPORT	TiO_2		PORE PASS	100	kD
	MEMBRANE	TiO_2			25	nm
SETUP		Multitubular		NUMBER OF CHANNELS	37	
LENGTH		1,178	mm	UNIT FILTERING SURFACE AREA	0.36	m^2
DIAMETER	OUTER	25	mm			
	INNER	2.6	mm			

IMAGES



COMMENTS

N.A.: not applicable

UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ Departament d'Enginyeria Química · eurecat Centre Tecnològic de Catalunya	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	23/05/2021
		PREPARED	23/05/2021
	Reverse Osmosis membranes RO101	REVISED	23/05/2021
		APPROVED	-

SUPPLIER & MODEL	DuPont XLE-2540		
SERVICE	RO modules	**ITEM**	RO101
TYPE	Polymeric	**NUMBER OF UNITS**	12

FLUID

PRODUCT	Water		TEMPERATURE	20	ºC
SOLID	N.A.	% weight	VAPOUR PRESSURE	0.023	bar
DENSITY	1,000	kg/m^3	VISCOSITY	0.001	Pa·s

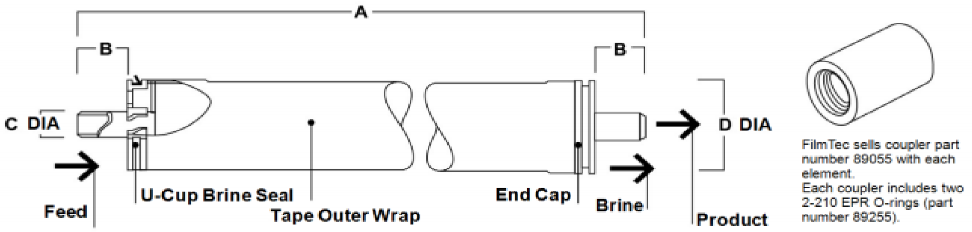
OPERATION CONDITIONS

TYPICAL PROPERTIES	APPLIED PRESSURE	6.9	bar_g	PRESSURE	OPERATION	12.1	bar_g
					MAXIMUM	41	bar_g
	PERMEATE FLOW RATE	3.2	m^3/day		MAX. DROP	0.9	bar_g
				FREE CHLORINE TOLERANCE		< 0.1	ppm
	STABILIZED SALT REJECTION	99	%	TEMPERATURE	OPERATION	20	ºC
					MAXIMUM	45	ºC
pH	CONTINUOUS OPERATION	2 - 11		FEED FLOW RATE	OPERATION	0.74	m^3/h
					MAXIMUM	1.40	m^3/h
	SHORT-TERM CLEANING	1 - 13		MAXIMUM FEED SILT DENSITY INDEX		SDI 5	

MATERIALS, CONSTRUCTION & DIMENSIONS

MEMBRANE TYPE	Polyamide Thin-Film Composite	DIMENSIONS					
		A	1,016	mm	C	19.0	mm
		B	30.2	mm	D	61.0	mm

IMAGES



COMMENTS

Keep all elements moist at all times after initial wetting.

To prevent biological growth during prolonged system shutdowns, it is recommended that membrane elements be immersed in a preservative solution.

Permeate obtained from the first hour of operation should be discarded.

During start-up, a gradual change from a standstill to operating state is recommended as follows:
- Feed pressure should be increased gradually over a 30-60 second time frame.
- Cross-flow velocity at set operating point should be achieved gradually over 15-20 seconds.

N.A.: not applicable

SolarSpring membrane solutions

Membrane Distillation Lab Unit

Technical Data SolarSpring MD Lab

The MD Lab is a fully automated, 24-hour operation lab unit for investigations in various MD configurations. All set points can be set on the handheld tablet which is connected via WIFI to the server. The Connectors, vessels, sensors and piping is constructed to be highly flexible which allows experimental constructions of nearly every different type of MD. Data acquisition of all process-relevant sensor values are automatically written in a .csv file.
The SolarSpring Test Cell allows to build variable module configurations, channel thicknesses, membranes and spacer geometries leading to thorough studies on heat and mass transfer, scaling / fouling potential as well as membrane aging tests and up-scaling calculations.
The high precision MD Lab combined with the multi variable TestCell allows to validate your simulation model for any MD configuration.

Temperature range / precision Evaporator	(IN or OUT controlled) Condenser (IN or OUT controlled)	30°C – 85°C / ±0,2K* 5°C – 75°C / ±0,2K*
Temperature range	Evaporator (IN or OUT controlled) Condenser (IN or OUT controlled)	
Condenser flow rate	50 – 300 l/h	
Operating modes	DCMD, AGMD, V-AGMD, PGMD, VMD	
Test Cell: Effective membrane surface	S1: 250mm x 150mm (375 cm²) S2: 100mm x 60mm (60 cm²) S3: 670mm x 310mm (2077 cm²)	
Test Cell: Auxiliary parts	Sealings: silicone or FKM Channel plates: PP Front plate: PMMA or PP Housing: stainless steel 316Ti	
Feed tank	20l to 600l	
Temperature measuring	Pt100 class A	
Flow measuring	Magnetic inductive	
Conductivity measuring	Evaporator: inductive Condenser: inductive Product: conductive	0 – 500 mS/cm 0 – 50 mS/cm 0 – 2000 µS/cm
Pressure measuring	Air gap / Vacuum gap Condenser channel Evaporator channel	0-1600 mbar absolute 0-1600 mbar relative 0-1600 mbar relative
Weight measuring / accuracy	0 – 30kg / 1g or 0-15kg / 0,5g	
Pumps	Membrane TPE, Housing PP	
Vacuum pump	Membrane TPE, Housing PP	Max flow: 32 l/min Max vacuum: 50 mbar abs
Heat exchanger (Plate and Frame)	Stainless steel 1.4401 plates with copper or nickel brazing or Gasketed with Titanium plates	
Operation / settings /display	Handheld tablet	
Rack / Housing	ITEM PA / Pan PP	
Dimensions of MD Lab**	1,4m L x 0,88m W x 1,6m H	
Heating	Electric (3 – 12 kW)	
Cooling	Vapour-compression refrigeration cycle (2,5 kW)	
Add-Ons	pH, turbidity, TDS Sensors	

*** - At steady state**
**** - Additional space is required if the tank size exceeds 20l**
All control variables and / or measurement parameters in the MD Lab can be tailored according to specific requirements
The MD Lab is well equipped with safety shutdown to protect from pump dry run, module over pressure and system overheating

grafic: www.formfee.de current status: 02/2019

UNIVERSITAT ROVIRA i VIRGILI / etsEQ / DEQ / eurecat	SPECIFICATIONS	PROJECT:	TFGEQ_2105_ azurita
		SHEET NUM.:	1/1
		DATE	05/06/2021
		PREPARED	05/06/2021
	Electric resistance EH101	REVISED	05/06/2021
		APPROVED	-

SUPPLIER & MODEL		Backer Facsa. Polaris for corrosive fluids				
SERVICE		Heating of T301		**ITEM**	EH101	
TYPE		Immersive		**NUMBER OF UNITS**	1	
FLUID						
PRODUCT		Water		TEMPERATURE	75	ºC
SOLID		N.A.	% weight	VAPOUR PRESSURE	0.47	bar
DENSITY		- (1)	kg/m^3	VISCOSITY	- (1)	Pa·s
OPERATION CONDITIONS						
POWER		4,000	W	MAXIMUM HEATING TEMPERATURE	100	ºC
TENSION		240	V	LOCATION	Immersed in T301	
MATERIALS, CONSTRUCTION & DIMENSIONS						
DIMENSIONS	WIDTH	50	mm	MATERIAL	Teflon	
	LENGTH	445	mm	LENGTH OF THE CORROSION RESISTANT CABLE	1.5	m
	HEIGHT	292	mm			

GRAPHS & IMAGES

COMMENTS

Approvals: UL (USA), CE (Europe), BS EN ISO 60519 / 60335 (UK)

(1) As brines are recirculated, their concentration increases over time.

-: Unavailable information.

N.A.: Not applicable

UNIVERSITAT ROVIRA i VIRGILI / etsEQ / DEQ / eurecat	SPECIFICATIONS		PROJECT:	TFGEQ_2105_azurita	
			SHEET NUM.:	1/1	
			DATE	25/05/2021	
			PREPARED	25/05/2021	
	Tank T101		REVISED	25/05/2021	
			APPROVED	-	

SUPPLIER & MODEL		Leroy Merlin. Drinking water tank 2000L EDD			
SERVICE		Feed tank	**ITEM**		T101
TYPE		Vertical & plastic	**NUMBER OF UNITS**		1
FLUID					
PRODUCT		Water	DENSITY		1,000 kg/m^3
TEMPERATURE		20 ºC	FLOW	INLET	0.55 m^3/h
PRESSURE		0 bar_g		OUTLET	0.5 m^3/h
MATERIALS, CONSTRUCTION & DIMENSIONS					
SHAPE	BODY	Prism	DIMENSIONS	HEIGHT	1.85 m
	HEAD	Flat		WIDTH	0.79 m
	BOTTOM	Flat		LENGTH	1.85 m
INSTALLATION		Vertical	THICKNESS	BODY	- mm
VOLUME	NOMINAL	2,000 L		HEAD	- mm
	EFFECTIVE	1,700 L		BOTTOM	- mm
MATERIALS	BODY	High density poliethylene (HDPE)	INSULATION		None
	HEAD	High density poliethylene (HDPE)	PAINTING		None
WEIGHT		76 kg	COLOUR		Blue
DESIGN CONDITIONS & TESTING					
DESIGN CODES		-	TEST PRESSURE	HYDRAULIC	- bar_g
		-		PNEUMATIC	- bar_g
DESIGN CONDITIONS	TEMPERATURE	130 (1) ºC	MAXIMUM ALLOWABLE STRESS		-
	PRESSURE	2 (2) bar_g			

NOZZLES

NAME	SIZE (")	SERVICE	COMMENTS
T1A	1	Wastewater feed not treated by the MBR (F-1001)	
T1B	1	Mains water feed (W-1001)	
T1C	1	Overflow at 85% of tank capacity	
T1D	1	Tank drain	
T1E	1	UF retenate recycle (F-5201)	
T1F	1	CF feed (F-2001)	
T1G	3/4	Level transmitter	
T1H	1.69	pH transmitter	
T1I	1.69	Conductivity transmitter	

IMAGE

COMMENTS

(1) Value estimated from the thermal properties of HDPE.

(2) Value estimated from the volume the tank can keep.

-: Unavailable information.

UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ · eurecat	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	25/05/2021
		PREPARED	25/05/2021
	Tank T201	REVISED	25/05/2021
		APPROVED	-

SUPPLIER & MODEL	Amazon. Poliethylene tank for drinking water (600L)		
SERVICE	RO feed	**ITEM**	T201
TYPE	Vertical & plastic	**NUMBER OF UNITS**	1

FLUID

PRODUCT	Water		DENSITY		1,000 kg/m^3
TEMPERATURE	20 ºC		FLOW	INLET	0,45 (1) m^3/h
PRESSURE	0 bar_g			OUTLET	0.45 (2) m^3/h

MATERIALS, CONSTRUCTION & DIMENSIONS

SHAPE	BODY	Prism	DIMENSIONS	HEIGHT	1.35 m
	HEAD	Flat		WIDTH	0.74 m
	BOTTOM	Flat		LENGTH	0.74 m
INSTALLATION		Vertical	THICKNESS	BODY	- mm
VOLUME	NOMINAL	600 L		HEAD	- mm
	EFFECTIVE	510 L		BOTTOM	- mm
MATERIALS	BODY	Poliethylene	INSULATION		None
	HEAD	Poliethylene	PAINTING		None
WEIGHT		- kg	COLOUR		Blue

DESIGN CONDITIONS & TESTING

DESIGN CODES		-	TEST PRESSURE	HYDRAULIC	- bar_g
		-		PNEUMATIC	- bar_g
DESIGN CONDITIONS	TEMPERATURE	115 (3) ºC	MAXIMUM ALLOWABLE STRESS		-
	PRESSURE	2 (4) bar_g			

NOZZLES

NAME	SIZE (")	SERVICE	COMMENTS
T2A	1	UF permeate inlet (F-6001)	
T2B	1	Wastewater feed treated by the MBR (F-1101)	
T2C	1/2	Chemical feed for UF CIP (C-1001)	
T2D	1	Mains water feed (W-2001)	
T2E	1	Tank drain	
T2F	1	UF backwash (F-7001)	
T2G	1	RO feed (F-9001)	
T2H	3/4	Level transmitter	
T2I	1.69	pH transmitter	
T2J	1.69	Conductivity transmitter	
T2K	1	Overflow at 85% of tank capacity	

IMAGE

COMMENTS

(1) Flow considering the UF permeate only. There will be times where some chemicals will be added for cleaning purposes.

(2) Flow considering the RO feed only. There will be periodical backflushes to clean the membrane.

(3) Value estimated from the thermal properties of poliethylene.

(4) Value estimated from the volume the tank can keep.

-: Unavailable information.

UNIVERSITAT ROVIRA i VIRGILI – etsEQ – DEQ Departament d'Enginyeria Química – eurecat Centre Tecnològic de Catalunya	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	25/05/2021
		PREPARED	25/05/2021
	Tank T301	REVISED	25/05/2021
		APPROVED	-

SUPPLIER & MODEL	Amazon. HELGUEFER PLASTICS - 120 L tank leaf spring lock		
SERVICE	MD hot stream	**ITEM**	T301
TYPE	Vertical & plastic	**NUMBER OF UNITS**	1

FLUID

PRODUCT	Concentrated brines	DENSITY		- [1] kg/m^3
TEMPERATURE	75 ºC	FLOW	INLET	0.16 m^3/h
PRESSURE	0 bar_g		OUTLET	0.075 m^3/h

MATERIALS, CONSTRUCTION & DIMENSIONS

SHAPE	BODY	Cylindre	DIMENSIONS	HEIGHT	0.792 m
	HEAD	Flat		DIAMETER	0.485 m
	BOTTOM	Flat		TOP DIAMETER	0.382 m
INSTALLATION		Vertical	THICKNESS	BODY	- mm
VOLUME	NOMINAL	120 L		HEAD	- mm
	EFFECTIVE	102 L		BOTTOM	- mm
MATERIALS	BODY	High density poliethylene (HDPE)	INSULATION		None
	HEAD	Polypropilene (PP)	PAINTING		None
WEIGHT		- kg	COLOUR		Blue

DESIGN CONDITIONS & TESTING

DESIGN CODES		-	TEST PRESSURE	HYDRAULIC	- bar_g
		-		PNEUMATIC	- bar_g
DESIGN CONDITIONS	TEMPERATURE	98 [2] ºC	MAXIMUM ALLOWABLE STRESS		-
	PRESSURE	2 [3] bar_g			

NOZZLES

NAME	SIZE (")	SERVICE	COMMENTS
T3A	3/4	RO retenate (F-15001)	
T3B	3/4	MD recycle (F-18001)	
T3C	3/4	Mains water feed (W-3001)	
T3D	3/4	Electric heater connection	
T3E	3/4	Tank drain	
T3F	3/4	MD feed (F-16001)	
T3G	3/4	Level transmitter	
T3H	1.69	pH transmitter	
T3I	1.69	Conductivity transmitter	
T3J	3/4	Overflow at 85% of tank capacity	

IMAGE

COMMENTS

(1) As brines are recirculated, their concentration increases over time.

(2) Value estimated from the thermal properties of polipropylene.

(3) Value estimated from the volume the tank can keep.

-: Unavailable information.

	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	25/05/2021
		PREPARED	25/05/2021
	Tank T401	REVISED	25/05/2021
		APPROVED	-

SUPPLIER & MODEL	Amazon. HELGUEFER PLASTICS - 120 L tank leaf spring lock		
SERVICE	MD cool stream	**ITEM**	T401
TYPE	Vertical & plastic	**NUMBER OF UNITS**	1

FLUID

PRODUCT	Water	DENSITY		1,000 kg/m^3
TEMPERATURE	20 ºC	FLOW	INLET	0.14 m^3/h
PRESSURE	0 bar_g		OUTLET	0.11 m^3/h

MATERIALS, CONSTRUCTION & DIMENSIONS

SHAPE	BODY	Cylindre	DIMENSIONS	HEIGHT	0.792 m
	HEAD	Flat		DIAMETER	0.485 m
	BOTTOM	Flat		TOP DIAMETER	0.382 m
INSTALLATION		Vertical	THICKNESS	BODY	- mm
VOLUME	NOMINAL	120 L		HEAD	- mm
	EFFECTIVE	102 L		BOTTOM	- mm
MATERIALS	BODY	High density poliethylene (HDPE)	INSULATION		None
	HEAD	Polypropilene (PP)	PAINTING		None
WEIGHT		- kg	COLOUR		Blue

DESIGN CONDITIONS & TESTING

DESIGN CODES		-	TEST PRESSURE	HYDRAULIC	- bar_g
		-		PNEUMATIC	- bar_g
DESIGN CONDITIONS	TEMPERATURE	98 (1) ºC	MAXIMUM ALLOWABLE STRESS		-
	PRESSURE	2 (2) bar_g			

NOZZLES

NAME	SIZE (")	SERVICE	COMMENTS
T3A	3/4	Mains water feed (W-4001)	
T3B	3/4	MD cool outlet (F-19001)	
T3C	3/4	Overflow at 85% of tank capacity (F-22001)	
T3D	1.69	Temperature transmitter	
T3E	3/4	Level transmitter	
T3F	3/4	MD cool feed (F-20001)	
T3G	3/4	Tank drain	
T3H	1/4	Coil inlet (W-4201)	
T3I	1/4	Coil outlet (W-4202)	

IMAGE

COMMENTS

(1) Value estimated from the thermal properties of polipropylene.

(2) Value estimated from the volume the tank can keep.

-: Unavailable information.

UNIVERSITAT ROVIRA i VIRGILI / etsEQ / DEQ / eurecat	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	25/05/2021
		PREPARED	25/05/2021
	Tank T501	REVISED	25/05/2021
		APPROVED	-

SUPPLIER & MODEL	Amazon. HELGUEFER PLASTICS - 60 L tank leaf spring lock		
SERVICE	Zeolites feed tank	**ITEM**	T501
TYPE	Vertical & plastic	**NUMBER OF UNITS**	1

FLUID

PRODUCT	Water	DENSITY		1,000 kg/m^3
TEMPERATURE	20 ºC	FLOW	INLET	0.33 m^3/h
PRESSURE	0 bar_g		OUTLET	0.04 m^3/h

MATERIALS, CONSTRUCTION & DIMENSIONS

SHAPE	BODY	Cylinder	DIMENSIONS	HEIGHT	0.62 m
	HEAD	Flat		DIAMETER	0.36 m
	BOTTOM	Flat		TOP DIAMETER	0.30 m
INSTALLATION		Vertical	THICKNESS	BODY	- mm
VOLUME	NOMINAL	60 L		HEAD	- mm
	EFFECTIVE	51 L		BOTTOM	- mm
MATERIALS	BODY	High density poliethylene (HDPE)	INSULATION		None
	HEAD	Polypropilene (PP)	PAINTING		None
WEIGHT		- kg	COLOUR		Blue

DESIGN CONDITIONS & TESTING

DESIGN CODES		-	TEST PRESSURE	HYDRAULIC	- bar_g
		-		PNEUMATIC	- bar_g
DESIGN CONDITIONS	TEMPERATURE	98 (1) ºC	MAXIMUM ALLOWABLE STRESS		-
	PRESSURE	2 (2) bar_g			

NOZZLES

NAME	SIZE (")	SERVICE	COMMENTS
T5A	3/4	T401 overflow (F-22001)	
T5B	3/4	RO permeate (F-23001)	
T5C	3/4	Mains water feed (W-5001)	
T5D	3/4	Overflow at 85% of tank capacity	
T5E	3/4	Tank drain	
T5F	3/4	Zeolites feed (F-24001)	
T5G	3/4	Level transmitter	
T5H	1.69	pH transmitter	
T5I	1.69	Conductivity transmitter	

IMAGE

COMMENTS

(1) Value estimated from the thermal properties of polipropylene.

(2) Value estimated from the volume the tank can keep.

-: Unavailable information.

UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ Departament d'Enginyeria Química · eurecat Centre Tecnològic de Catalunya	SPECIFICATIONS	PROJECT:	TFGEQ_2105_a zurita
		SHEET NUM.:	1/1
		DATE	25/05/2021
		PREPARED	25/05/2021
	Tank T601	REVISED	25/05/2021
		APPROVED	-

SUPPLIER & MODEL	Amazon. HELGUEFER PLASTICS - 60 L tank leaf spring lock		
SERVICE	Treated water tank	**ITEM**	T601
TYPE	Vertical & plastic	**NUMBER OF UNITS**	1

FLUID

PRODUCT	Water		DENSITY		1,000 kg/m^3
TEMPERATURE	20	ºC	FLOW	INLET	0.04 m^3/h
PRESSURE	0	bar_g		OUTLET	0.04 (1) m^3/h

MATERIALS, CONSTRUCTION & DIMENSIONS

SHAPE	BODY	Cylinder		DIMENSIONS	HEIGHT	0.620 m
	HEAD	Flat			DIAMETER	0.36 m
	BOTTOM	Flat			TOP DIAMETER	0.30 m
INSTALLATION		Vertical		THICKNESS	BODY	- mm
VOLUME	NOMINAL	60	L		HEAD	- mm
	EFFECTIVE	51	L		BOTTOM	- mm
MATERIALS	BODY	High density poliethylene (HDPE)		INSULATION		None
	HEAD	Polypropilene (PP)		PAINTING		None
WEIGHT		-	kg	COLOUR		Blue

DESIGN CONDITIONS & TESTING

DESIGN CODES		-		TEST PRESSURE	HYDRAULIC	- bar_g
		-			PNEUMATIC	- bar_g
DESIGN CONDITIONS	TEMPERATURE	115 (2)	ºC	MAXIMUM ALLOWABLE STRESS		-
	PRESSURE	2 (3)	bar_g			

NOZZLES

NAME	SIZE (")	SERVICE	COMMENTS
T5A	3/4	Mains water feed (W-6001)	
T5B	3/4	Zeolites outlet (F-26001)	
T5C	3/4	Overflow at 85% of tank capacity	
T5D	3/4	Treated water outlet (F-27001)	
T5E	3/4	Tank drain	
T5F	3/4	Zeolites cleaning (F-28001)	
T5G	3/4	Level transmitter	
T5H	1.69	pH transmitter	
T5I	1.69	Conductivity transmitter	

IMAGE

COMMENTS

(1) Flow considering the produced water only. However, there will be a weekly cleaning of the zeolites, so this value may vary.

(2) Value estimated from the thermal properties of polipropylene.

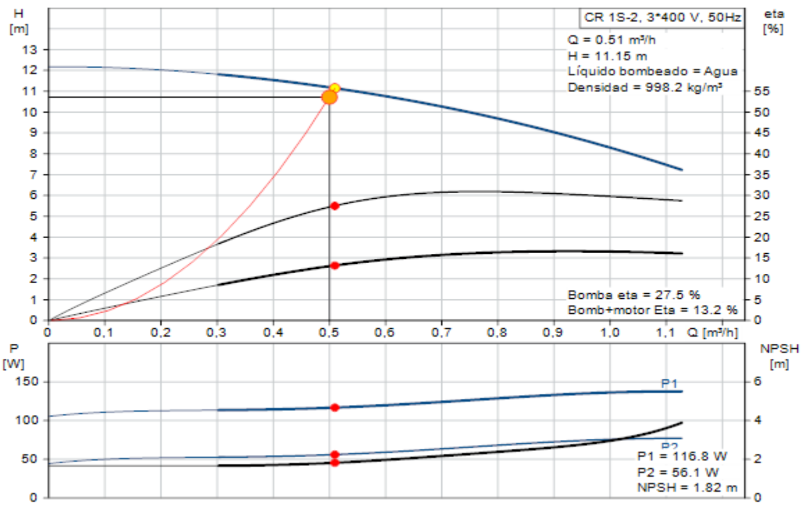
(3) Value estimated from the volume the tank can keep.

-: Unavailable information.

UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ · eurecat	SPECIFICATIONS	PROJECT:	TFGEQ_2105_ azurita
		SHEET NUM.:	1/1
		DATE	18/05/2021
		PREPARED	18/05/2021
		REVISED	18/05/2021
	Centrifugal pump P101	APPROVED	-

SUPPLIER & MODEL		Grundfos CR 1S-2 A-A-A-E-HQQE			
SERVICE		UF feed	**ITEM**		P101
TYPE		Centrifugal	**NUMBER OF UNITS**		1
FLUID					
PRODUCT		Water	TEMPERATURE		20 ºC
SOLID		N.A. % weight	VAPOUR PRESSURE		0.023 bar
DENSITY		1,000 kg/m^3	VISCOSITY		0.001 Pa·s
OPERATION CONDITIONS					
CAPACITY	NORMAL	0.50 m^3/h	DIFFERENTIAL HEIGHT	NOMINAL	11.5 m
	DESIGN	0.51 m^3/h		MAXIMUM	12.3 m
IMPULSION PRESSURE	NOMINAL	1.00 bar_g	NPSH	AVAILABLE	4.99 m
	MAXIMUM	16.00 bar_g		REQUIRED	1.82 m
ASPIRATION PRESSURE	NOMINAL	-0.50 bar_g	AMBIENT TEMPERATURE	OPERATION	20 ºC
	MINIMUM	-0.71 bar_g		MAXIMUM	60 ºC
MATERIALS, CONSTRUCTION & DIMENSIONS					
PUMP ORIENTATION		Vertical	SEALING		Single
MATERIALS	BASE	Cast iron ASTM A48-25B	CONNECTION	TYPE	Oval / Rp
	IMPELLER	Stainless steel AISI 304		NOM. PRES.	16 bar
	BUSHING	SIC		INLET SIZE	1 inch
MOTOR FLANGE SIZE		FT85		OUTLET SIZE	1 inch
WEIGHT	NET	18.3 kg			
	GROSS	20.9 kg			
MOTOR & ELECTRIC DATA					
MOTOR CLASS		71A	EFFICIENCY	CLASS	IE3 73.8%
POWER	NOMINAL	0.37 kW		MOTOR FULLY LOADED	73.8 %
	OPERATION POINT	0.056 kW		MOTOR 3/4 LOADED	79.0 %
INTENSITY	NOMINAL	1.74 / 1.00 A		MOTOR 1/2 LOADED	75.0 %
	START	490 - 530 %			
SPEED	NOMINAL	2,850 - 2,880 rpm			
	DEFAULT	2,873 rpm	ENCLOSURE CLASS (IEC 34-5)		55 Dust / Jetting
MAINS FREQUENCY		50 Hz	TYPE OF INSULATION (IEC 85)		F
NUMBER OF POLES		2			

GRAPHS & IMAGES



COMMENTS

Approvals in the nameplate: CE, EAC, ACS

Curve tolerance: ISO9906:2012 3B

N.A.: not applicable

UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ Departament d'Enginyeria Química · eurecat Centre Tecnològic de Catalunya	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	22/05/2021
		PREPARED	22/05/2021
	Centrifugal pump P201	REVISED	22/05/2021
		APPROVED	-

SUPPLIER & MODEL	Grundfos CR 1S-5 A-A-A-E-HQQE		
SERVICE	UF backwash	**ITEM**	P201
TYPE	Centrifugal	**NUMBER OF UNITS**	1

FLUID

PRODUCT	Water		TEMPERATURE	20	ºC
SOLID	N.A.	% weight	VAPOUR PRESSURE	0.023	bar
DENSITY	1,000	kg/m^3	VISCOSITY	0.001	Pa·s

OPERATION CONDITIONS

CAPACITY	NORMAL	0.50	m^3/h	DIFFERENTIAL HEIGHT	NOMINAL	27.78	m
	DESIGN	0.521	m^3/h		MAXIMUM	30.30	m
IMPULSION PRESSURE	NOMINAL	2.00	bar_g	NPSH	AVAILABLE	4.99	m
	MAXIMUM	16.00	bar_g		REQUIRED	1.82	m
ASPIRATION PRESSURE	NOMINAL	-0.50	bar_g	AMBIENT TEMPERATURE	OPERATION	20	ºC
	MINIMUM	-	bar_g		MAXIMUM	60	ºC

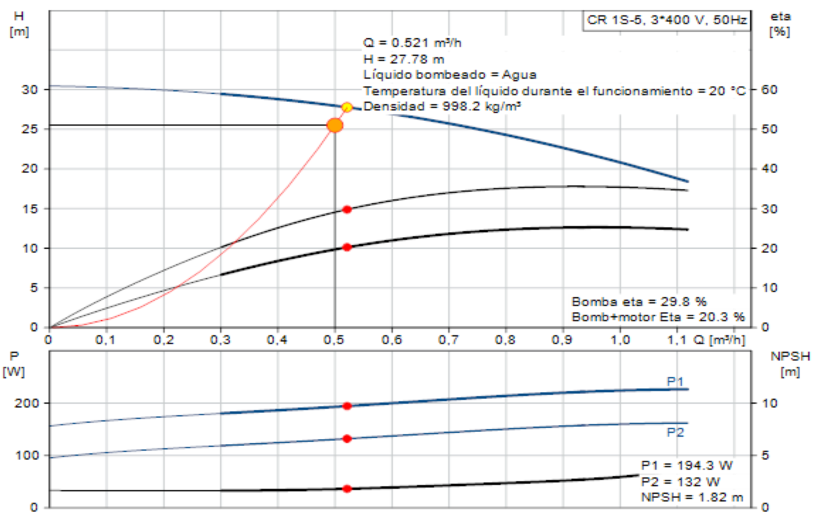
MATERIALS, CONSTRUCTION & DIMENSIONS

PUMP ORIENTATION		Vertical	SEALING		Single	
MATERIALS	BASE	Cast iron ASTM A48-25B	CONNECTION	TYPE	Oval / Rp	
	IMPELLER	Stainless steel AISI 304		NOM. PRES.	16	bar
	BUSHING	SIC		INLET SIZE	1	inch
MOTOR FLANGE SIZE		FT85		OUTLET SIZE	1	inch
WEIGHT	NET	19.3 kg				
	GROSS	21.9 kg				

MOTOR & ELECTRIC DATA

MOTOR CLASS		71A		EFFICIENCY	CLASS	IE3 73.8%	
POWER	NOMINAL	0.37	kW		MOTOR FULLY LOADED	73.8	%
	OPERATION POINT	0.132	kW		MOTOR 3/4 LOADED	79.0	%
INTENSITY	NOMINAL	1.74 / 1.00	A		MOTOR 1/2 LOADED	75.0	%
	START	490 - 530	%				
SPEED	NOMINAL	2,850 - 2,880	rpm				
	DEFAULT	2,873	rpm	ENCLOSURE CLASS (IEC 34-5)		55 Dust / Jetting	
MAINS FREQUENCY		50	Hz	TYPE OF INSULATION (IEC 85)		F	
NUMBER OF POLES		2					

GRAPHS & IMAGES



COMMENTS

Approvals in the nameplate: CE, EAC, ACS

Curve tolerance: ISO9906:2012 3B

-: Unavailable information

N.A.: not applicable

UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ · eurecat	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	07/06/2021
		PREPARED	07/06/2021
	Plunger pump P301 & motor	REVISED	07/06/2021
		APPROVED	-

SUPPLIER & MODEL	Cat Pumps 3CP1141 & Motorseg SS-90L-B14		
SERVICE	FFR RO feed	**ITEM**	P301
TYPE	Plunger	**NUMBER OF UNITS**	1

FLUID

PRODUCT	Water	TEMPERATURE	20 ºC
SOLID	- % weight	VAPOUR PRESSURE	0.023 bar
DENSITY	1,000 kg/m^3	VISCOSITY	0.001 Pa·s

OPERATION CONDITIONS

CAPACITY	NORMAL	0.74 m^3/h	MAXIMUM INLET CONDITIONS	PRESSURE	4.9 bar_g
	DESIGN	0.82 m^3/h		TEMPERATURE	71 ºC
IMPULSION PRESSURE	NOMINAL	12.40 bar_g	STROKE		11 mm
	RANGE	7 - 55 bar_g			

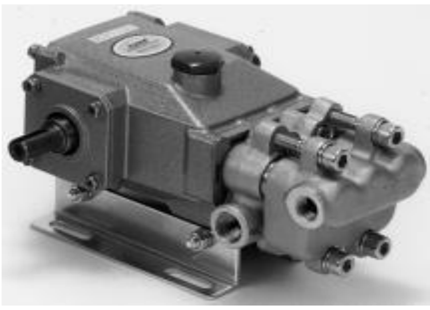
MATERIALS, CONSTRUCTION & DIMENSIONS

MATERIALS	PLUNGERS	Ceramic, graphite impregnated	PORTS	INLET	1/2" NPT
	VALVES	Heat treated stainless steel AISI 316L		OUTLET	3/8" NPT
	MANIFOLD	Stainless steel AISI 316L	DIMENSIONS	WIDTH	245 mm
	CRANKSHAFT	Chrome-moly		LENGTH	223 mm
	CRANKCASE	Die cast aluminium		HEIGHT	136 mm
SHAFT DIAMETER		16.5 mm	PULLEY OUTER DIAMETER		Direct drive
BORE		18 mm	WEIGHT		6.7 kg
CRANKCASE CAPACITY		0.3 L			

MOTOR & ELECTRIC DATA

MOTOR TYPE	Squirrel-case asynchronous motor	EFFICIENCY	CLASS	IE1 / IE2
POWER	1.5 kW		YIELD	79 %
SPEED	1,500 rpm	CONTINUOUS SERVICE		S1
TENSION	230 / 400 V	CRANKCASE	CAPACITY	90 L
MAINS FREQUENCY	50 / 60 Hz		MATERIAL	Aluminium
INTENSITY	6.31 / 3.65 A	DIAMETERS	SHAFT	24 mm
NUMBER OF POLES	2		FLANGE	140 mm
SUBJECTION	B14 Flange	WEIGHT		13.2 kg
PROTECTION	IP55	COLOUR		Blue

GRAPHS & IMAGES



COMMENTS

Triplex plunger design gives smoother fluid flow.

Motor approval: CE

-: Unavailable information

	SPECIFICATIONS	PROJECT:	TFGEQ_2105_ azurita
		SHEET NUM.:	1/1
		DATE	07/06/2021
		PREPARED	07/06/2021
		REVISED	07/06/2021
	Dosing pump DP401	APPROVED	-

SUPPLIER & MODEL	Grundfos DMH 100-10 B-PV/T/C-X-E1U3U3XEMAG		
SERVICE	MD hot feed	**ITEM**	DP401
TYPE	Dosing	**NUMBER OF UNITS**	1

FLUID

PRODUCT	Concentrated brines		TEMPERATURE	75	ºC
SOLID	N.A.	% weight	VAPOUR PRESSURE	0.4736	bar
DENSITY	- [(1)]	kg/m^3	VISCOSITY	- [(1)]	Pa·s

OPERATION CONDITIONS

CAPACITY	NORMAL	0.075	m^3/h	MAXIMUM OPERATING PRESSURE	10	bar_g
	MAXIMUM	0.1	m^3/h	MAXIMUM PERMISSIBLE INLET PRESSURE	5	barg
MAXIMUM VISCOSITY		10	mPa·s			
DIFFERENTIAL HEIGHT	NOMINAL	7.65	m			
	MAXIMUM	101	m			

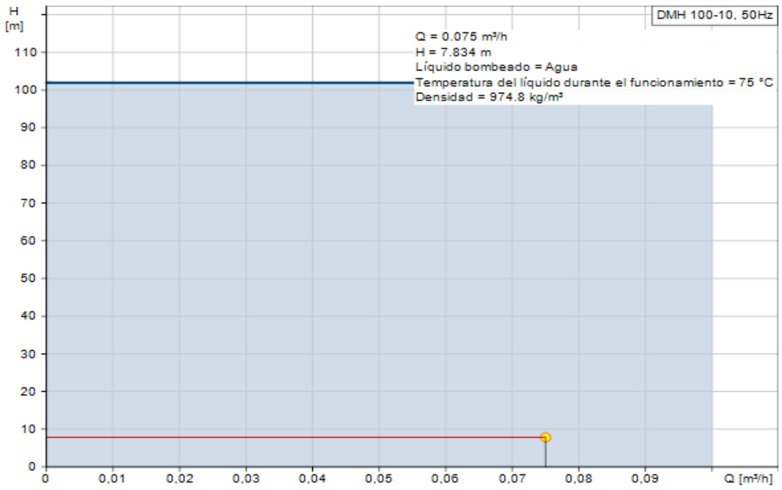
MATERIALS, CONSTRUCTION & DIMENSIONS

MATERIALS	PUMP HOUSING	Aluminium	NO RETURN VALVE TYPE	INLET	Standard	
	DOSING HEAD	PVDF		OUTLET	Standard	
	VALVE BALL	PVDF	WEIGHT	NET	15	kg
	VALVE SEAT	PTFE		GROSS	26.3	kg
	VALVE GASKET	PTFE				

MOTOR & ELECTRIC DATA

POWER INPUT P1	0.2	kW	INLET CONNECTION	TYPE	Connection pack
MAINS FREQUENCY	50	Hz		SIZE	19/27, 20/25
RATED VOLTAGE	3 x 230/240 V		OUTLET CONNECTION	TYPE	Connection pack
ENCLOSURE CLASS (IEC 34-5)	IP65			SIZE	19/27, 20/25

GRAPHS & IMAGES



COMMENTS

[(1)] As brines are recirculated, their concentration increases over time.

Approvals in the nameplate: CE, EAC, CNROHSEX.

-: Unavailable information.

N.A.: Not applicable.

UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ Departament d'Enginyeria Química · eurecat Centre Tecnològic de Catalunya	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	22/05/2021
		PREPARED	22/05/2021
	Dosing pump DP501	REVISED	22/05/2021
		APPROVED	-

SUPPLIER & MODEL	Grundfos DDE 120-7 B-PVC/E/C-F-31U3U3FG		
SERVICE	MD cool feed	**ITEM**	DP501
TYPE	Dosing	**NUMBER OF UNITS**	1

FLUID

PRODUCT	Water		TEMPERATURE	20	ºC
SOLID	N.A.	% weight	VAPOUR PRESSURE	0.023	bar
DENSITY	1,000	kg/m^3	VISCOSITY	0.001	Pa·s

OPERATION CONDITIONS

CAPACITY	NORMAL	0.075	m^3/h	DIFFERENTIAL HEIGHT	NOMINAL	10.70	m
	MAXIMUM	0.12	m^3/h		MAXIMUM	71.50	m
	MINIMUM	150	mL/h	MAXIMUM OPERATING PRESSURE		7.0	bar_g
TURN-DOWN RATIO		1 : 800		ACCURACY OF REPEATABILITY		5.0	%
MAXIMUM SUCTION LIFT	OPERATION	3.0	m	AMBIENT TEMPERATURE	OPERATION	20	ºC
	PRIMING	1.5	m		RANGE	0-45	ºC
MAXIMUM VISCOSITY	100 %	100	mPa·s				
	SLOW MODE 50%	-	mPa·s				
	SLOW MODE 25%	-	mPa·s				

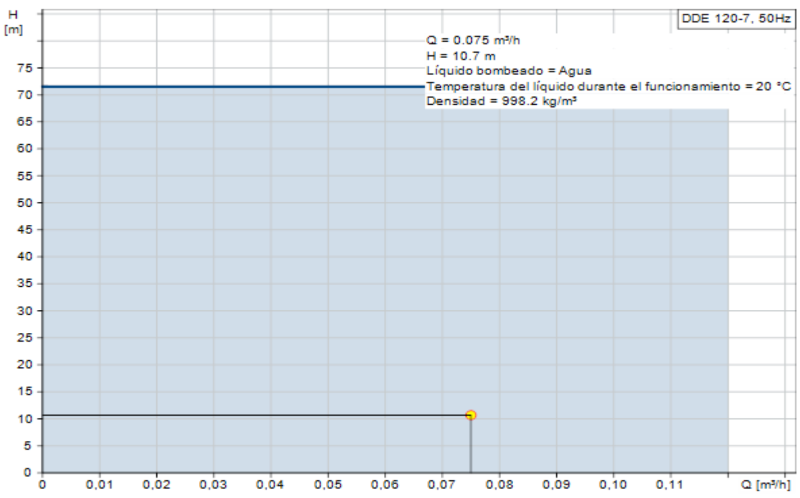
MATERIALS, CONSTRUCTION & DIMENSIONS

MATERIALS	DOSING HEAD	PVC		CONNECTION	PUMP INLET	Conn. pack U3 (hose ID 19 mm)
	VALVE BALL	Ceramic			PUMP OUTLET	Conn. pack U3 (hose ID 19 mm)
	GASKET	EPDM				
WEIGHT	NET	6	kg	VALVE TYPE		Standard
	GROSS	7	kg	COLOUR		Red

MOTOR & ELECTRIC DATA

MAXIMUM POWER INPUT	62	W	LENGTH OF CABLE	1.5	m
MAINS FREQUENCY	50 / 60	Hz	TYPE OF CABLE PLUG	EU	
RATED VOLTAGE	1 x 100 - 240 V		INRUSH CURRENT	70 A at 240 V 35 A / 100 V for 2 ms	
ENCLOSURE CLASS (IEC 34-5)	IP65 / NEMA 4X				

GRAPHS & IMAGES



COMMENTS

Approvals in the nameplate: CE, CSA-US, NSF61, EAC, RCM.

-: Unavailable information.

N.A.: Not applicable.

UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ Departament d'Enginyeria Química · eurecat Centre Tecnològic de Catalunya	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	22/05/2021
		PREPARED	22/05/2021
	Dosing pump DP601	REVISED	22/05/2021
		APPROVED	-

SUPPLIER & MODEL	Grundfos DDE 120-7 B-PVC/E/C-F-31U3U3FG		
SERVICE	Zeolites feed	**ITEM**	DP601
TYPE	Dosing	**NUMBER OF UNITS**	1

FLUID

PRODUCT	Water		TEMPERATURE	20	ºC
SOLID	N.A.	% weight	VAPOUR PRESSURE	0.023	bar
DENSITY	1,000	kg/m^3	VISCOSITY	0.001	Pa·s

OPERATION CONDITIONS

CAPACITY	NORMAL	0.042	m^3/h	DIFFERENTIAL HEIGHT	NOMINAL	10.69	m
	MAXIMUM	0.12	m^3/h		MAXIMUM	71.50	m
	MINIMUM	150	mL/h	MAXIMUM OPERATING PRESSURE		7.0	bar_g
TURN-DOWN RATIO		1 : 800		ACCURACY OF REPEATABILITY		5.0	%
MAXIMUM SUCTION LIFT	OPERATION	3.0	m	AMBIENT TEMPERATURE	OPERATION	20	ºC
	PRIMING	1.5	m		RANGE	0-45	ºC
MAXIMUM VISCOSITY	100 %	100	mPa·s				
	SLOW MODE 50%	-	mPa·s				
	SLOW MODE 25%	-	mPa·s				

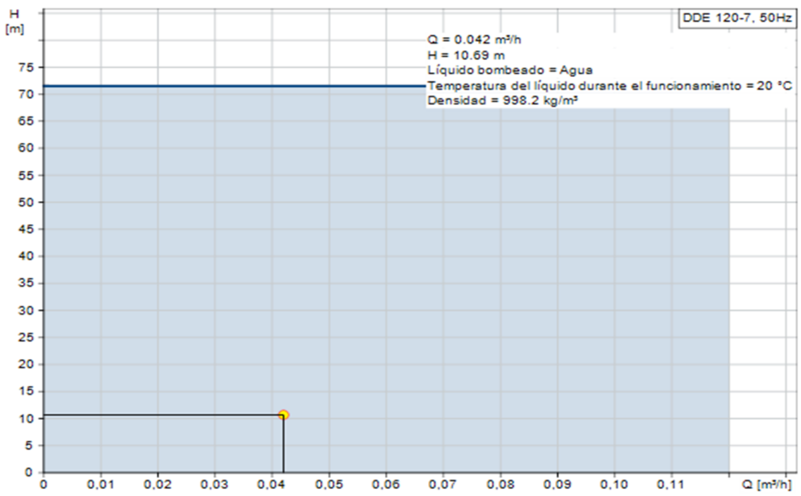
MATERIALS, CONSTRUCTION & DIMENSIONS

MATERIALS	DOSING HEAD	PVC		CONNECTION	PUMP INLET	Conn. pack U3 (hose ID 19 mm)
	VALVE BALL	Ceramic			PUMP OUTLET	Conn. pack U3 (hose ID 19 mm)
	GASKET	EPDM				
WEIGHT	NET	6	kg	VALVE TYPE		Standard
	GROSS	7	kg	COLOUR		Red

MOTOR & ELECTRIC DATA

MAXIMUM POWER INPUT	62	W	LENGTH OF CABLE	1.5	m
MAINS FREQUENCY	50 / 60	Hz	TYPE OF CABLE PLUG	EU	
RATED VOLTAGE	1 x 100 - 240 V		INRUSH CURRENT	70 A at 240 V	
ENCLOSURE CLASS (IEC 34-5)	IP65 / NEMA 4X			35 A / 100 V for 2 ms	

GRAPHS & IMAGES



COMMENTS

Approvals in the nameplate: CE, CSA-US, NSF61, EAC, RCM.

-: Unavailable information.

N.A.: Not applicable.

UNIVERSITAT ROVIRA i VIRGILI · etsEQ · DEQ Departament d'Enginyeria Química · eurecat Centre Tecnològic de Catalunya	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	22/05/2021
		PREPARED	22/05/2021
	Dosing pump DP701	REVISED	22/05/2021
		APPROVED	-

SUPPLIER & MODEL	Grundfos DDE 120-7 B-PVC/E/C-F-31U3U3FG		
SERVICE	Zeolites cleaning	**ITEM**	DP701
TYPE	Dosing	**NUMBER OF UNITS**	1

FLUID

PRODUCT	Water		TEMPERATURE	20	ºC
SOLID	N.A.	% weight	VAPOUR PRESSURE	0.023	bar
DENSITY	1,000	kg/m^3	VISCOSITY	0.001	Pa·s

OPERATION CONDITIONS

CAPACITY	NORMAL	0.042	m^3/h	DIFFERENTIAL HEIGHT	NOMINAL	16.29	m
	MAXIMUM	0.12	m^3/h		MAXIMUM	71.50	m
	MINIMUM	150	mL/h	MAXIMUM OPERATING PRESSURE		7.0	bar_g
TURN-DOWN RATIO		1 : 800		ACCURACY OF REPEATABILITY		5.0	%
MAXIMUM SUCTION LIFT	OPERATION	3.0	m	AMBIENT TEMPERATURE	OPERATION	20	ºC
	PRIMING	1.5	m		RANGE	0-45	ºC
MAXIMUM VISCOSITY	100 %	100	mPa·s				
	SLOW MODE 50%	-	mPa·s				
	SLOW MODE 25%	-	mPa·s				

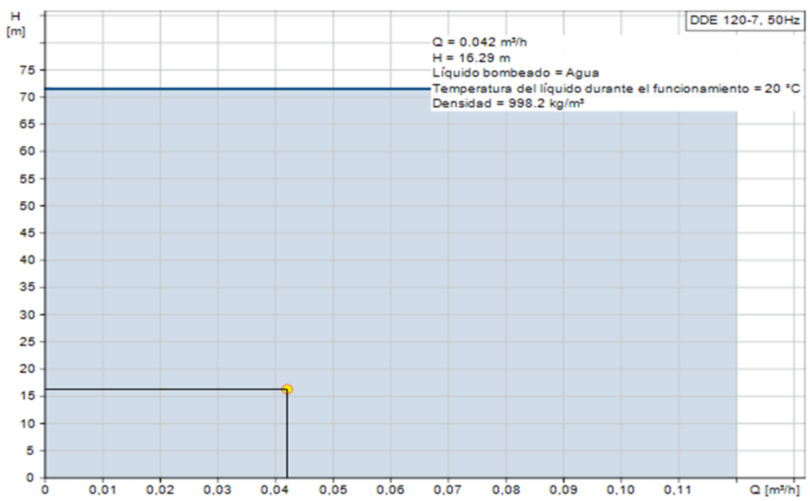
MATERIALS, CONSTRUCTION & DIMENSIONS

MATERIALS	DOSING HEAD	PVC		CONNECTION	PUMP INLET	Conn. pack U3 (hose ID 19 mm)
	VALVE BALL	Ceramic			PUMP OUTLET	Conn. pack U3 (hose ID 19 mm)
	GASKET	EPDM				
WEIGHT	NET	6	kg	VALVE TYPE		Standard
	GROSS	7	kg	COLOUR		Red

MOTOR & ELECTRIC DATA

MAXIMUM POWER INPUT	62	W	LENGTH OF CABLE	1.5	m
MAINS FREQUENCY	50 / 60	Hz	TYPE OF CABLE PLUG	EU	
RATED VOLTAGE	1 x 100 - 240 V		INRUSH CURRENT	70 A at 240 V 35 A / 100 V for 2 ms	
ENCLOSURE CLASS (IEC 34-5)	IP65 / NEMA 4X				

GRAPHS & IMAGES



COMMENTS

Approvals in the nameplate: CE, CSA-US, NSF61, EAC, RCM.

-: Unavailable information.

N.A.: Not applicable.

SPECIFICATIONS		PROJECT:	TFGEQ_2105_a zurita
		SHEET NUM.:	1/1
		DATE	22/05/2021
		PREPARED	22/05/2021
Dosing pump DP101		REVISED	22/05/2021
		APPROVED	-

SUPPLIER & MODEL	Grundfos DDA 7.5-16		
SERVICE	UF CIP	**ITEM**	DP101
TYPE	Dosing	**NUMBER OF UNITS**	1

FLUID

PRODUCT	NaClO 15%		TEMPERATURE	20	ºC
SOLID	N.A.	% weight	VAPOUR PRESSURE	-	bar
DENSITY	1,110	kg/m^3	VISCOSITY	-	Pa·s

OPERATION CONDITIONS

CAPACITY	NORMAL	3.06	L/h	DIFFERENTIAL HEIGHT	NOMINAL	14.77	m
	MAXIMUM	7.5	L/h		MAXIMUM	125.0	m
	MAX. SLOW MODE 50%	3.75	L/h	MAXIMUM OPERATING PRESSURE		16.0	bar_g
	MAX. SLOW MODE 25%	1.88		ACCURACY OF REPEATABILITY		1.0	%
	MINIMUM	2.5	mL/h	AMBIENT TEMPERATURE	OPERATION	20	ºC
TURN-DOWN RATIO		1 : 3,000			RANGE	0-45	ºC
MAXIMUM VISCOSITY	100 %	50	mPa·s	MAXIMUM SUCTION LIFT	OPERATION	6.0	m
	SLOW MODE 50%	1,800	mPa·s		PRIMING	2.0	m
	SLOW MODE 25%	2,500	mPa·s				

MATERIALS, CONSTRUCTION & DIMENSIONS

MATERIALS	DOSING HEAD	PP		CONNECTION	PUMP INLET	4/6, 6/9, 6/12, 9/12 mm
	VALVE BALL	Ceramic			PUMP OUTLET	4/6, 6/9, 6/12, 9/12 mm
	GASKET	EPDM		VALVE TYPE		Standard
WEIGHT	NET	2	kg	COLOUR		Red
	GROSS	3	kg			

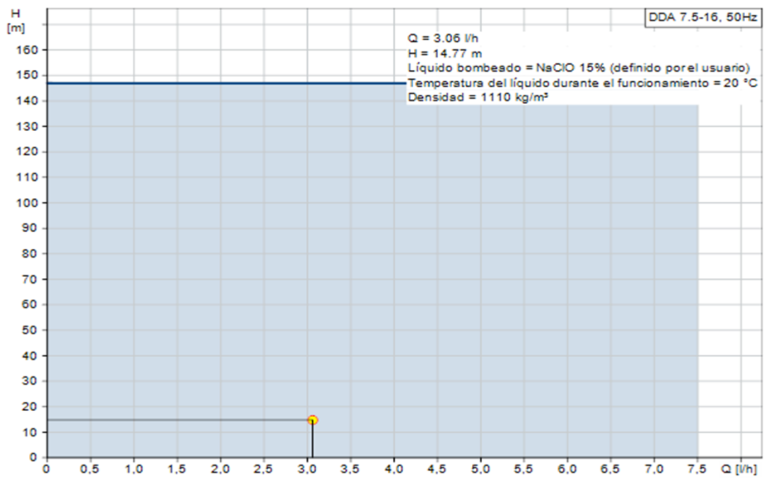
MOTOR & ELECTRIC DATA

MAXIMUM POWER INPUT	24	W	LENGTH OF CABLE	1.5	m
MAINS FREQUENCY	50 / 60	Hz	TYPE OF CABLE PLUG	EU	
RATED VOLTAGE	1 x 100 - 240 V		INRUSH CURRENT	25 A at 240 V for 2 ms	
ENCLOSURE CLASS (IEC 34-5)	IP65 / NEMA 4X				

CONTROLS

CONTROL VARIANT	AR	PULSE CONTROL	Yes
CONTROL PANNEL	FRONT-MOUNTED	EXT. STOP INPUT	Yes
LEVEL CONTROL	YES	BUS COMMUNICATION	Yes
ANALOG INPUT	0 / 4-20 MA	OUTPUT RELAYS	2
ANALOG OUTPUT	0 / 4-20 MA		

GRAPHS & IMAGES



COMMENTS

Approvals in the nameplate: CE, CSA-US, EAC, RCM.

-: Unavailable information.

N.A.: Not applicable.

UNIVERSITAT ROVIRA i VIRGILI / etsEQ / DEQ / eurecat	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	22/05/2021
	Dosing pump DP201	PREPARED	22/05/2021
		REVISED	22/05/2021
		APPROVED	-

SUPPLIER & MODEL	Grundfos DDA 7.5-16		
SERVICE	UF CEB	**ITEM**	DP201
TYPE	Dosing	**NUMBER OF UNITS**	1

FLUID

PRODUCT	NaClO 15% // H_2SO_4 50%		TEMPERATURE	20	ºC
SOLID	N.A.	% weight	VAPOUR PRESSURE	-	bar
DENSITY	1,110 // 1,390	kg/m^3	VISCOSITY	-	Pa·s

OPERATION CONDITIONS

CAPACITY	NORMAL	225.22 // 89.92	mL/h	DIFFERENTIAL HEIGHT	NOMINAL	14.78 // 12.0	m
	MAXIMUM	7.5	L/h		MAXIMUM	125.0	m
	MAX. SLOW MODE 50%	3.75	L/h	MAXIMUM OPERATING PRESSURE		16.0	bar_g
	MAX. SLOW MODE 25%	1.88		ACCURACY OF REPEATABILITY		1.0	%
	MINIMUM	2.5	mL/h	AMBIENT TEMPERATURE	OPERATION	20	ºC
TURN-DOWN RATIO		1 : 3,000			RANGE	0-45	ºC
MAXIMUM VISCOSITY	100 %	50	mPa·s	MAXIMUM SUCTION LIFT	OPERATION	6.0	m
	SLOW MODE 50%	1,800	mPa·s		PRIMING	2.0	m
	SLOW MODE 25%	2,500	mPa·s				

MATERIALS, CONSTRUCTION & DIMENSIONS

MATERIALS	DOSING HEAD	PP		CONNECTION	PUMP INLET	4/6, 6/9, 6/12, 9/12 mm
	VALVE BALL	Ceramic			PUMP OUTLET	4/6, 6/9, 6/12, 9/12 mm
	GASKET	EPDM		VALVE TYPE		Standard
WEIGHT	NET	2	kg	COLOUR		Red
	GROSS	3	kg			

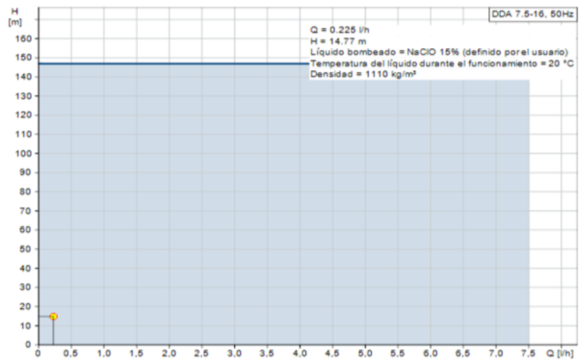
MOTOR & ELECTRIC DATA

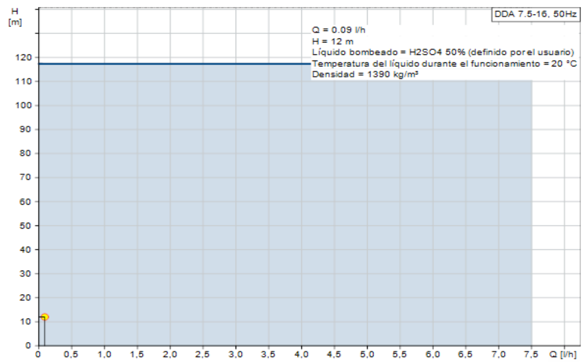
MAXIMUM POWER INPUT	24	W	LENGTH OF CABLE	1.5	m
MAINS FREQUENCY	50 / 60	Hz	TYPE OF CABLE PLUG	EU	
RATED VOLTAGE	1 x 100 - 240 V		INRUSH CURRENT	25 A at 240 V for 2 ms	
ENCLOSURE CLASS (IEC 34-5)	IP65 / NEMA 4X				

CONTROLS

CONTROL VARIANT	AR	PULSE CONTROL	Yes
CONTROL PANNEL	FRONT-MOUNTED	EXT. STOP INPUT	Yes
LEVEL CONTROL	YES	BUS COMMUNICATION	Yes
ANALOG INPUT	0 / 4-20 MA	OUTPUT RELAYS	2
ANALOG OUTPUT	0 / 4-20 MA		

GRAPHS & IMAGES





COMMENTS

Approvals in the nameplate: CE, CSA-US, EAC, RCM.

-: Unavailable information.

N.A.: Not applicable.

	SPECIFICATIONS	PROJECT:	TFGEQ_2105_azurita
		SHEET NUM.:	1/1
		DATE	22/05/2021
		PREPARED	22/05/2021
	Dosing pump DP301	REVISED	22/05/2021
		APPROVED	-

SUPPLIER & MODEL	Grundfos DDA 7.5-16		
SERVICE	RO dosing	**ITEM**	DP301
TYPE	Dosing	**NUMBER OF UNITS**	1

FLUID

PRODUCT	$NaHSO_3$ 39%		TEMPERATURE	20	ºC
SOLID	N.A.	% weight	VAPOUR PRESSURE	-	bar
DENSITY	1,320	kg/m^3	VISCOSITY	-	Pa·s

OPERATION CONDITIONS

CAPACITY	NORMAL	8.75	mL/h	DIFFERENTIAL HEIGHT	NOMINAL	12.58	m
	MAXIMUM	7.5	L/h		MAXIMUM	125.0	m
	MAX. SLOW MODE 50%	3.75	L/h	MAXIMUM OPERATING PRESSURE		16.0	bar_g
	MAX. SLOW MODE 25%	1.88		ACCURACY OF REPEATABILITY		1.0	%
	MINIMUM	2.5	mL/h	AMBIENT TEMPERATURE	OPERATION	20	ºC
TURN-DOWN RATIO		1 : 3,000			RANGE	0-45	ºC
MAXIMUM VISCOSITY	100 %	50	mPa·s	MAXIMUM SUCTION LIFT	OPERATION	6.0	m
	SLOW MODE 50%	1,800	mPa·s		PRIMING	2.0	m
	SLOW MODE 25%	2,500	mPa·s				

MATERIALS, CONSTRUCTION & DIMENSIONS

MATERIALS	DOSING HEAD	PP		CONNECTION	PUMP INLET	4/6, 6/9, 6/12, 9/12 mm
	VALVE BALL	Ceramic			PUMP OUTLET	4/6, 6/9, 6/12, 9/12 mm
	GASKET	EPDM		VALVE TYPE		Standard
WEIGHT	NET	2	kg	COLOUR		Red
	GROSS	3	kg			

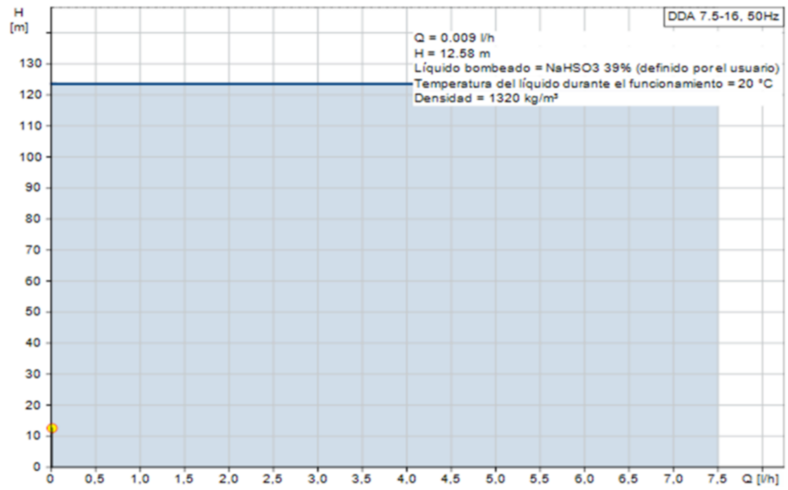
MOTOR & ELECTRIC DATA

MAXIMUM POWER INPUT	24	W	LENGTH OF CABLE	1.5	m
MAINS FREQUENCY	50 / 60	Hz	TYPE OF CABLE PLUG	EU	
RATED VOLTAGE	1 x 100 - 240 V		INRUSH CURRENT	25 A at 240 V for 2 ms	
ENCLOSURE CLASS (IEC 34-5)	IP65 / NEMA 4X				

CONTROLS

CONTROL VARIANT	AR	PULSE CONTROL	Yes
CONTROL PANNEL	FRONT-MOUNTED	EXT. STOP INPUT	Yes
LEVEL CONTROL	YES	BUS COMMUNICATION	Yes
ANALOG INPUT	0 / 4-20 MA	OUTPUT RELAYS	2
ANALOG OUTPUT	0 / 4-20 MA		

GRAPHS & IMAGES



COMMENTS

Approvals in the nameplate: CE, CSA-US, EAC, RCM.

-: Unavailable information.

N.A.: Not applicable.

5. PERSONAL SAFETY AND MAINTENANCE OF THE INSTALLATION

General maintenance shall be carried out in accordance with the instructions in article 49 of the MIE APQ-1 (ref. 18), section 4, from which it should be noted:

- Personal protective equipment shall comply with the provisions of Law 31/1995 (ref. 19).
- The operating procedures will be available in written format, and personnel will receive training on the properties of the products and the purpose and correct use of personal protective equipment and installations.
- The periodic revisions of the equipment will be recorded.

To establish an adequate maintenance system, it is necessary to determine to what extent the equipment is critical by using a risk matrix. With this information, the actions to be followed in order to guarantee its proper maintenance can be defined. The various types of maintenance are the ones indicated below:

- Preventive: takes action to ensure that the service is maintained within certain levels of service.
- Predictive: seeks to know the status and wear of the equipment, and defines actions based on this.
- Reactive: actions are taken after the failure of the equipment.

In Risk Based Maintenance, the criticality level of each piece of equipment of the pilot can be determined by the following expression:

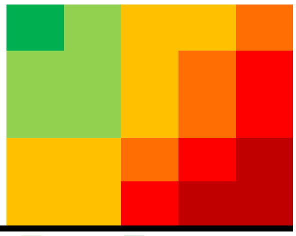
$$Criticality = Probability \cdot Consequences \quad (5.1.)$$

The following matrix contains the definitions of frequency, probability and consequences:

Table 5.1. Risk matrix

Key				
Frequency (events / year)			**Consequences**	
1	Improbable	$f \leq 10^{-6}$	**1**	Negligible
2	Rare	$10^{-5} \geq f \geq 10^{-6}$	**2**	Minor
3	Unlikely	$10^{-4} \geq f \geq 10^{-5}$	**3**	Moderate
4	Possible	$10^{-3} \geq f \geq 10^{-4}$	**4**	Major
5	Very likely	$f \geq 10^{-3}$	**5**	Catastrophic

Probability 1 2 3 4 5 — **Consequences** 1 2 3 4 5



Type of risk: Unacceptable, High, Medium-High, Moderate, Low, Negligible

The categories of the consequences are governed on the basis of their impact on staff, population, the environment and the installation production. The impact associated to each of these areas for each category of consequences is shown in the table below:

Table 5.2. Definition of the categories of consequences.

Cat.	Damage to staff	Effect on population	Environmental impact	Production loss
5	Death or permanent total incapacity, serious injuries or illnesses in one or more members of the company.	Death or permanent total incapacity, serious injuries or illnesses in one or more members of the population.	Irreversible damage that violates environmental regulations and laws.	Production of 5 days.
4	Partial or permanent disability, severe injuries or illnesses in one or more members of the company.	Partial or permanent disability, severe injuries or illnesses in at least one member of the population.	Reversible damage which violates environmental regulations and laws.	Production of 1 day.
3	Severe injuries or illnesses in various members. Necessity of work suspension.	Hospitalisation of at least 3 people.	Reversible environmental damage that does not violate laws and regulations, and where restoration can be accumulated.	25% of the daily production.
2	Medical treatment or first aid requirement.	Medical treatment or first aid requirement.	Minimum environmental damage without violating laws and regulations.	10% of the daily production.
1	Unaffected.	Unaffected.	No damages and violation of laws	Unaffected.

Finally, the following table shows the highest frequency for the possible events that can occur in each of the system's equipment, together with their consequence and criticality values, as well as the type of maintenance required and the actions to be carried out.

Table 5.3. Criticality associated with each equipment and recommended maintenance actions.

Equipment	Criticality index				Maintenance philosophy	Maintenance plan
	Freq. (1)	Prob.	Conseq.	Criticality		
TX01	10^{-4}	**3**	**2**	**6**	Preventive / Predictive	- Daily visual revision. - Annual external and internal inspection of T101, T201, T401, T501, T601. - Internal and external inspection every three months to control abrasion in T301.
CF101	10^{-4}	**3**	**2**	**6**	Preventive / Reactive	- Daily visual revision. - Weekly substitution to prevent pore obstruction.
UF101	10^{-4}	**3**	**3**	**9**	Preventive / Reactive	- Daily visual revision. - Backwashes programmed every 2 hours with a duration of 3 minutes. - Weekly CEB, with a duration of 15 minutes. - Trimestral CIP, with a duration of 4 hours. - Installation of a methacrylate panel to prevent any harm derived from the explosion of the module.
RO101	10^{-4}	**3**	**3**	**9**	Preventive / Reactive	- Daily visual revision. - Constant dosage of a mixture of antiscalants and bisulphite. - Chemical cleaning every six months for maintenance. - Installation of a methacrylate panel to prevent any harm derived from the explosion of the module.
MD101	10^{-4}	**3**	**2**	**6**	Preventive / Reactive	- Daily visual revision. - Manual chemical cleaning every six months.
Z101	10^{-4}	**3**	**2**	**6**	Preventive / Reactive	- Daily visual revision. - Weekly regeneration.

Equipment	Criticality index				Maintenance philosophy	Maintenance plan
	Freq. [(1)]	Prob.	Conseq.	Criticality		
P101 **P201**	$5·10^{-5}$	**3**	**3**	**9**	🟨 Preventive / Reactive	- Daily visual revision. - Weekly maintenance and monthly lubrication control.
P301 **DPX01**	$4.4·10^{-3}$	**5**	**2**	**10**	🟥 Preventive / Reactive	- Daily visual revision. - Technical revision every three months.
Pipelines with nominal Ø<75mm	$5·10^{-6}$	**2**	**3**	**6**	🟩 Preventive / Predictive	- Daily visual revision. - Daily visual inspection of F-17001 & F-18001 to avoid abrasion damage.
Instruments	-	**2**	**2**	**4**	🟩 Predictive	- Daily visual revision. - Calibration every three months.

(1): All frequency values have been extracted from the manual BEVI Risk Assessment (ref. 20). The categories for each piece of equipment are the following ones:

T10X & Z101: Scenarios for single containment atmospheric storage tanks. G3: Continuous release from a hole with effective diameter of 10 mm.

CF101, UF101, RO101 & MD101: Scenarios for reactor vessels and process vessels. G3: Continuous release from a hole with an effective diameter of 10 mm.

P101 & P201: Scenarios for centrifugal pumps and centrifugal compressors. G2: Leak (10% diameter).

P301 & DPX01: Scenarios for reciprocating pumps and reciprocating compressors. G2: Leak (10% diameter).

Pipelines: Scenarios for pipelines aboveground. G2: Leak with an effective diameter of 10% of the nominal diameter, up to maximum of 50 mm.

6. MANUALS

6.1. Operation manual

This section includes the explanation and the various aspects to consider during the pilot operation. The position in which both automatic and control valves are for each case, can be found in *Table 4.3. Operation conditions*.

6.1.1. Start-up

During the start-up of the process, the following aspects need to be considered:

- All drains must be closed (except from the overflow ones)
- All water mains lines must be closed.

For the specific case of the RO membranes, DuPont has guidelines on how to do the start-up of their modules (although this can also be applied to the UF membrane to prevent it from suffering any damage derived from the exposure to a sudden high pressure). The various steps indicated in that document (ref. 21) are indicated below:

1. Before initiating the start-up sequence, thoroughly rinse the pre-treatment section to flush out debris and other contaminants without letting the feed enter the elements.
2. Check all valves to ensure that settings are correct. The feed pressure control and concentrate control valves should be fully open.
3. Use low-pressure water at a low flowrate to flush the air out of the elements and pressure vessels. Flush at a gauge pressure of 0.2-0.4 MPa. All permeate and concentrated flows should be directed to an appropriate waste collection drain during flushing.
4. During the flushing operation, check all pipe connections and valves for leaks. Tighten connections where necessary.
5. After the system has been flushed for a minimum of 30 minutes, close the feed pressure control valve.
6. Ensure that the concentrate control valve is open.
7. Slowly crack open the feed pressure control valve (feed pressure should be less than 0.4 MPa).
8. Start the high-pressure pump.
9. Slowly open the feed pressure control valve, increasing the feed pressure and feed flowrate to the membrane elements until the design concentrate flow is reached. The feed pressure increase to the elements should be less than 0.07 MPa per second to achieve a soft start. Continue to send all permeate and concentrate flows to an appropriate waste collection drain.
10. Slowly close the concentrate control valve until the ratio of permeate flow to concentrate flow approaches, but does not exceed, the design ratio (recovery). Continue to check the system pressure to ensure that it does not exceed the upper design limit.
11. Repeat steps “9” and “10” until the design permeate and concentrate flows are obtained.
12. Calculate the system recovery and compare it to the system’s design value.

13. Check the addition of pre-treatment chemicals. Measure feedwater pH.
14. Check the Langelier Saturation Index (LSI) or the Stiff & Davis Stability Index (S&DSI) of the concentrate by measuring pH, conductivity, calcium hardness, and alkalinity levels and then making the necessary calculations.
15. Allow the system to run for one hour. Permeate obtained from this first hour of operation should be discarded.
16. Take the first reading of all operating parameters.
17. Check the permeate conductivity from each pressure vessel to verify that all vessels conform to performance expectations.
18. After 24-48 hours of operation, review all recorded plant operating data such as feed pressure, differential pressure, temperature flows, recovery and conductivity readings. At the same time draw samples of feedwater, concentrate and permeate for analysis of constituents.
19. Compare system performance to design values.
20. Confirm proper operation of mechanical and instrumental safety devices.
21. Switch the permeate flow from drain to the normal service position.
22. Lock the system into automatic operation.
23. Use the initial system performance information obtained in steps “16” through “18” as a reference for evaluating future system performance. Measure system performance regularly during the first week of operation to check for proper performance during this critical initial stage.

6.1.2. Steady state operation

6.1.2.1. Pre-treatment

During steady state operation, wastewater is to be fed into T101 at a rate of 12 m^3/day, and it flows into the cartridge filter, where gross solids are removed. Then, water is pumped into the UF module, where 10.8 m^3/day permeate and go to T201, whereas the remaining 0.2 m^3/day are retained and then recirculated into T101.

In case the pilot operated with the outlet of the WWTP, this stage would not exist, as water would be directly fed into T201.

6.1.2.2. FFR RO

The UF permeate is fed into T201, and is then pumped into the FFR RO module. This module can operate in two different ways, as it is able to change the flow direction once solids are about to precipitate on the membrane, thus preventing scaling.

During Normal Forward Feed operation (NFF), water flows straight through the pipes F-10X01 until they get into the membrane. Once in the membrane, the permeate leaves the module through pipe F-23001 to get into T-501 (the zeolites’ feed tank), whereas the retentate leaves through F-13X01 lines. It must be underlined that before decompressing the retentate, a part of it is recirculated into the FFR RO module, and that the rest is decompressed to be fed into T301.

If the FFR RO module operates in Feed Flow Reversal (FFR) mode, water flows through lines F-10001, F-10101 and F-10201, and then flows through F-11001, goes up into the membrane module without crossing it, and then flows through F-10301 until it gets into F-12001. Then, a part of this retentate is recirculated whilst the rest is decompressed to go to T301.

6.1.2.3. MD

Once in T301, the RO retentate is heated thanks to an electric resistance with a view on keeping it at 75ºC, which is temperature that enables a good temperature difference to do the separation in the MD module.

Brines are pumped at a rate of 1.8 m^3/day into the MD module, where this hot feed contacts a water stream on the other side of the membrane (without mixing), so that this temperature difference makes water from the brines permeate the membrane and hence leave the module through F-19001. Once outside the MD module, brines are recirculated into T301, and cycle after cycle, their water is extracted.

Water that crosses the MD membrane is then cooled in T401, and is recirculated back into the MD module to guarantee the thermal contrast that enables the extraction of water from the brines. This tank also has an overflow at 85% of its capacity, so that this water can then be fed into T501, together with the RO permeate.

6.1.2.4. Adsorption on zeolites

Both the RO permeate and T401 overflow are fed into T501, which is the feed tank for the module of adsorption on zeolites.

This module is fed with water from T401 at a rate of 1m^3/day, and ammonium is eliminated from water. Finally, treated water is fed into T601, from which water can be sent to its desired applications.

6.1.3. Plant stop

During the plant stop, it must be guaranteed that the FFR RO module remains filled with water (with sodium bisulphite in case the stop is prolonged for more than 48 h) to avoid membrane damage, as the membranes are polymeric. The UF module does not need that because ceramic membranes are not that delicate.

6.2. Maintenance manual

In this section, some maintenance requirements that are mentioned in the previous section, *5. PERSONAL SAFETY AND MAINTENANCE OF THE INSTALLATION* are described in order to show how to operate under those conditions.

6.2.1. UF maintenance

UF maintenance comprises three different operations: backwashes, CEBs, and CIPs.

6.2.1.1. Backwashes

Backwashes consist in making UF permeate cross the membrane on the opposite direction to reduce fouling. These backwashes last for 3 minutes and are programmed every 2 hours (ref. 22).

They do not imply the stop of the plant operation. During backwashes, the same flow that permeates the membrane will be fed at a pressure of 2 bar_g thanks to P201, and after these 3 minutes, the UF operation will go back to normal.

6.2.1.2. Chemically Enhanced Backwashes (CEBs)

CEBs are the same as backwashes, but in them some chemicals are added (sulfuric acid or NaClO) through DP201 to enhance fouling reduction (ref. 22).

This treatment lasts for 15 minutes, of which the chemical dosing lasts for 30 seconds only. This operation is programmed so that it takes place once a week for 15 minutes.

6.2.1.3. Cleanings In Place (CIPs)

CIPs are a more sophisticated UF cleaning, which implies the dosing of NaClO until a concentration up to 4,000 mg/L is reached, so that the membrane can be chemically cleaned. They are trimestral and last for 4 hours (ref. 22).

6.2.2. Maintenance of the adsorption on zeolites

Zeolites are weekly cleaned to guarantee their good performance. During this cleaning, water from T601 is pumped into the system, as it is almost pure, and then, once the zeolites system is filled, water is drained through the drainage at the top.

6.2.3. Maintenance of other pieces of equipment

The pilot has been designed so that all units can independently operate. That is, that they can operate even though the previous or later units are not operating. Hence, the pilot operation will not be altered during maintenance as long as the feed tank of each unit is filled.

7. FINANCIAL STUDY

7.1. Capital expenditures (CAPEX)

To determine the initial investment, the cost for each of the required pieces of equipment is summarized in the table below. The present data has been obtained by contacting suppliers or by consulting previous projects in which similar pieces of equipment have been used. The detailed cost for some items can be found in *A.7. FINANCIAL STUDY CALCULATIONS*.

Land costs and its adequation, and the construction of auxiliary buildings are not considered as the project consists in constructing a pilot plant in an already existing infrastructure. The 40 ft container and the air compressor for instruments are not considered either.

Table 7.1. Equipment cost

Equipment	Price (€)
UF module	350.90
FFR RO system	2,208.00
MD module	35,000.00
Electric resistance	865.42
Adsorption on zeolites	34.16
Tanks	1,116.95
Pumps	22,346.00
Pipes	384.01
Insulation	58.53
Instruments	47,473.96
Valves	23,139.55

Therefore, the total required cost is 132,977.48 €, which is below the budgeted 160,000 €.

7.2. Operational expenditures (OPEX)

Operational expenditures (OPEX) consider the many other needs the system has in order to operate: from utilities to reparations and laboratory analysis, among many other.

The table below summarizes the various expenses associated to the operation of the pilot, and the calculations that have been conducted to obtain these values can be found in *A.7 FINANCIAL STUDY CALCULATIONS*.

Table 7.2. Operation costs

Item	Cost (€ / year)
Operator	31,344.07
Cartridge filters	275.60
Chemicals	124.18
Mains water	896.48
Electricity	2,247.85
Laboratory analysis	11,829.12
Maintenance and reparations	3,324.44
Insurance	664.89

Item	Cost (€ / year)
Depreciation	1st year: 16,622.19 2nd year: 15,514.04

The total OPEX without considering depreciation are 50,706.62 €/year. In case depreciation is considered, the OPEX for the two years of operation of the pilot are 133,549.46 €.

7.3. Profit

As the daily volume of water that has gone through all treatment stages is 1 m^3, the annual produced volume is 365 m^3.

As in Tarragona's province the cost of 1 m^3 of industrial water for a company that is supplied with 20 m^3/month is 1.715€ (without value added taxes) (ref. 23) and considering that the value added taxes for water supply are of a 10% (ref. 24), the annual income is 688.573 €.

This profit value is so low as the pilot is purely demonstrative, and therefore the total volume of treated water is very low. This project is not focused on the profitability of the treated water, it is focused on testing whether it is feasible or not to meet some quality standards to obtain as much water as possible from concentrated brines.

Hence, it the profitability of the infrastructure is not relevant at this scale.

8. CONCLUSIONS

After the completion of this final project, the following conclusions are reached:

The total design of the nZLD system formed by a FFR RO system and a MD module as well as its pre-treatment (formed by a cartridge filter and an UF module) and its final polishing with adsorption on zeolites has been satisfactorily conducted. The selection of these technologies has been done by analysing the current trends on nZLD systems and trying to balance effectivity and innovation. Once selected, their operation as well as their maintenance requirements have been detailed.

The main challenges faced during the design process have been both equipment and materials selection due to the operation conditions and scale. The low flows and high pressures at which some process sections operate has led to the selection of dosing pumps instead of centrifugal ones, which has significantly increased the cost of pumps. Moreover, the extremely aggressive nature of the osmosis retentate as well as the one of the concentrated brines of the MD module have made it difficult to find materials that could resist those conditions.

In terms of quality, the resulting water quality meets the requirements defined by RD 1620/2007 (ref. 5). However, a final chlorination step before water distribution is required to guarantee the total absence of bacteria. Despite this, water does not meet UNE-EN 12952-12:2004 standards (ref. 6) because of its high conductivity, so this water would need further treatment steps to reduce it (i.e. ionic exchange resins) in case it is to be used in boilers or other purposes indicated in this standard.

Further optimization of the process needs to be conducted through lab-scale experimentation to better understand the equipment performance. This is due to the fact that not all technologies have been tested yet, and experimental results may differ from those obtained in the simulations and approximations presented in this document.

In what costs concerns, the CAPEX and OPEX of the pilot are 132,977.48 €, and 133,549.46 €, respectively.

The reason why CAPEX is so high despite being a pilot plant is mainly derived from the costs of the MD module as well as the ones of valves and instrumentation.

The high cost of the MD module is derived from the disruptive nature of this technology, as it is recent and very efficient; hence, the commercially available technologies are expensive. On the other hand, the high cost on instrumentation and valves is due to the nature of the project, as it is an R&D project and hence it is crucial to monitor as many parameters as possible to have detailed information about the system. Then, all this information would be used to evaluate the feasibility of scaling up the system.

Despite this, the CAPEX is about 30,000 € below the projected costs for the pilot, so the alternatives presented in this document can be an attractive option for the pilot construction.

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ANNEXES

A.1. STUDY OF ALTERNATIVES

A.1.1. Pre-treatment technologies

As it has been indicated in *2.1. Description of the project*, this pre-treatment was originally designed to prevent RO filters from experiencing any malfunctioning derived from the variability of the wastewater feed. However, as the WWTP treatment will be operational once the pilot will be constructed, the role of this pre-treatment is to enable AITASA to study the effect of its presence or absence when working with the WWTP feed or outlet.

In this section, some possible pre-treatment technologies are characterized, and then, a selection is made by considering the features these technologies have.

A.1.1.1. Characterization

A.1.1.1.1. Cartridge filters

Cartridge filters are filtration modules that are available in various lengths and diameters as well as construction materials (woven, non-woven and membranes). As the flow is outside-to-inside, they require a strong core to handle the increased pressure differential during operation, and some manufacturers even provide outer cages to increase the stability and capacity of the modules.

In what the installation refers, the cartridges are installed in pressure vessels with guide rods that facilitate the installation, and they can be either vertical or horizontal. The sealing between the cartridge and the vessel can be single o-rings, double o-rings, tie rods or other.

Properties like materials, textures, pore sizes and physical sizes can be selected depending on the needs, as there is a wide offer in the market (ref. 25).

An important characteristic to consider when selecting a cartridge filter is the type of cleaning to apply once the filter is fully loaded. In this regard, there are four categories of filters:

- Throwaway or disposable: they cannot be cleaned, therefore, they need to be replaced.
- Cleanable-in-place: they can be readily cleaned and reused several times, even if eventually they may need to be replaced.
- Service-cleanable: they must be removed from the filter and subjected to specialized cleaning, either on site or by returning to the manufacturer or to a service company.
- Reclaimable: they must be returned to the manufacturer, who strips them down and rebuilds them after replacing the filter medium.

The differences between them derive from the filter medium and the filtration mechanism in which the system is based, as they define the cleaning difficulty and therefore the filter category to be selected.

As these cartridges are used to remove solids or liquids from flows, they will eventually get too dirty to continue operating. Therefore, it is recommended to install two filters instead of one with a view on guaranteeing flow continuity. This way, the fluid can be switched from the dirty unit to the clean one with almost no impact (ref. 26).

A.1.1.1.2. Dissolved Air Flotation (DAF)

Dissolved air flotation (DAF) consists in transferring flocs to the surface of water through the attachment of air bubbles to the floc. Then, the flocs accumulate on the surface, forming the “float”, which is skimmed off as sludge, and the clarified water is removed from the bottom and is called subnatant or “floated” water (ref. 27). The clarified effluent quality depends on operational parameters like recycling rate, air tank pressure, hydraulic retention time and particle floating rate, whereas the slurry concentration depends on the skimmer speed and its overboard above the water surface (ref. 28).

Bubbles are produced when the dissolution of air in water occurs under very high pressure (3-9 bar), and these bubbles' diameter typically ranges between 10 and 100 μm, with a mean value of 40 μm (ref. 27) (ref. 29) (ref. 30). The production of fine bubbles is based on the higher solubility of air in water as pressure increases.

In what the set up refers, flotation tanks must be fully enclosed in buildings to prevent problems with the float derived from rain, snow, wind and freezing, and in some cases the flocculation tanks that precede flotation ones are enclosed too (ref. 27).

A.1.1.1.3. Microfiltration (MF)

Microfiltration is a pressure-driven separation process whose main aim is to concentrate, purify or separate macromolecules, colloids and suspended particles from solution by following a sieving mechanism, thus, solutes that are smaller than the membrane pores are not retained. To do so, this membrane-based technology employs membranes whose pores' nominal size oscillates between 0.05 and 10 μm and relatively low transmembrane pressures, which typically range between 1 - 3 bar (ref. 31) (ref. 32) (ref. 33).

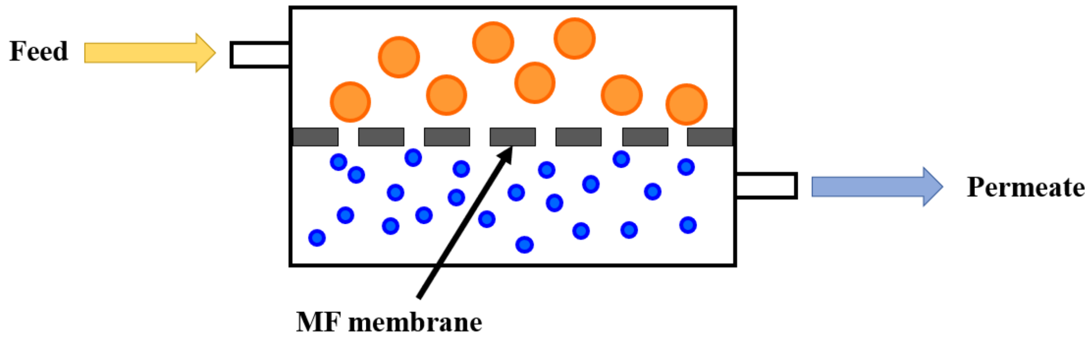

Figure A.1.1. MF operation scheme.

MF is a technique that can be typically found as a pre-treatment filter prior to UF, NF and RO processes, and whose operating pressure and cost are the lowest and the flux the highest compared to membrane filtrations of other higher regimes (ref. 33) (ref. 34). Membrane's skin layer can be either symmetric or asymmetric, which means that it can be 10-150 μm or 1 μm thick, respectively, but materials are what truly define this membrane's performance.

Polymeric membranes are typically made of Teflon®, PVDF, PP, PS, cellulose, PE, polycarbonate, polyester, polyether imide and nylon 6. Whereas ceramic membranes are typically made of γ-alumina (γ-Al_2O_3) and α-alumina. The main differences between them are the cost and the thermal and chemical stability: as ceramic membranes are more stable and resist chemical attack better, their cost is higher (ref. 31).

The main drawbacks this technology has are its low purification range and fouling, which sometimes make it be replaced by UF membranes when a high degree of separation is required and the cost can be afforded, as UF membranes experience less fouling and therefore guarantee a more stable separation (ref. 33) (ref. 34). In any case, fouling problems can be reduced by operating the membrane in cross-flow mode instead of dead-end mode (ref. 31). This aspect is widely detailed in the UF section, as it is more relevant for this technology.

A.1.1.1.4. Sand filtration

Sand filtration is a physical filtration process that can be operated in two different ways: slow sand filtration (SSF) and rapid sand filtration (RSF).

In SSF, raw water goes through a sand medium, and as this water passes through the sand, solids, microorganisms and heavy metals are removed. A bacterial community gradually forms a layer called *schmutzdecke*, whose function is to prey upon bacteria from the raw water. Despite being an easy-to-operate technology, it has several drawbacks, as its need of large areas per unit volume of treated water (which makes it unsuitable for operating large volumes), its low flow rate, the need of a maturation period before its use and the need of some time to regrow the *schmutzdecke* after cleaning the filters. Additionally, factors like salinity and suspended solids are to be considered, as salinity has an inverse relationship with organic content removal and excessive suspended solids can clog the filters.

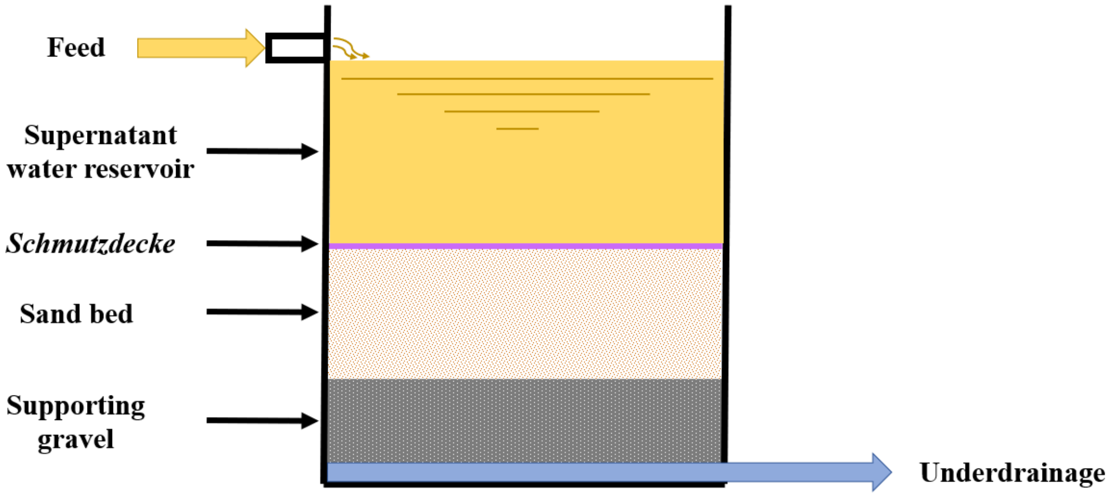

Figure A.1.2. SSF operation scheme.

On the other hand, RSF requires less space than SSF, but it does not have such a significant biological layer or *schmutzdecke*. Hence, pathogenic substances are removed in pre and post treatment stages and therefore, fouling is also prevented. In general terms, more than one RSF system is installed with a view on having one or more “offline” for backwashing purposes. However, the sand quality deteriorates over the years because of the adsorption of organics and inorganics on the surface of sand granules.

In this technology, inorganics are removed by heterogeneous oxidation on the surfaces of granular material, by biological oxidation by microbes attached to the granular matter or by homogeneous oxidation in the supernatant and water phase in the filter.

The main competitive features that both sand filtration techniques have are their low price and their easy operation compared to MF or UF processes (ref. 35).

A.1.1.1.5. Ultrafiltration (UF)

This membrane-based technology employs membranes whose pores’ molecular weight cut-off is around 10-20 kDa, which enables the conductance of an efficient separation of both low and high molecular weight solutes under low pressures (2-5 bar) that is founded on a sieving process (ref. 31) (ref. 36).

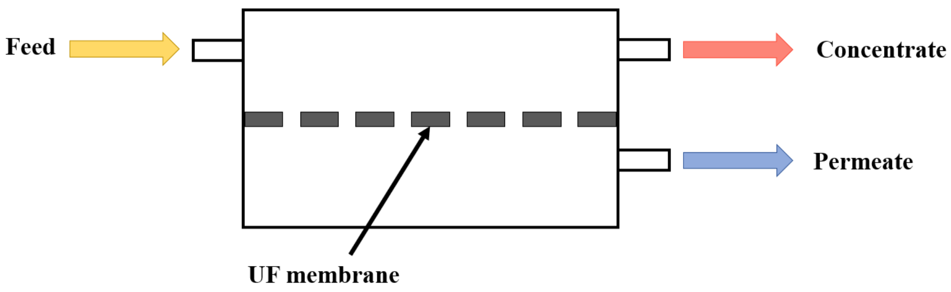

Figure A.1.3. UF operation scheme.

UF membranes are more commonly found as RO desalination pre-treatment than MF, as UF membranes are able to remove suspended organics, silt pathogens and viruses, whereas MF ones are unable to remove viruses.

The use of combined UF-RO when compared with a conventional pre-treatment and a RO module has been financially studied by some authors, and it has been observed that the specific investment cost is almost the same in both cases. However, despite having lower operational expenses in the UF-RO system, UF membranes replacement is significantly expensive, which makes it difficult to determine which system is more beneficial in economic terms (ref. 37).

In UF modules, the feed can be applied in different ways, thus determining the type of performed filtration, which can be dead-end filtration or cross-flow filtration.

In dead-end filtration, a feed is perpendicularly applied to a membrane, without any flow going along it. However, rejected solutes tend to accumulate near the membrane surface, which leads to a progressive decrease on fluxes due to the resistance of the accumulated compounds, thus, stirring is typically applied to reduce polarization by obtaining a high Reynolds number.

In general terms, dead-end filtration design is simple, but its operation is not, mainly as polarization is to be considered as well as the fact that flux is described as a time-dependent function. With a view on compensating flux reduction with time, it can be operated at constant flux and increasing pressure, or alternatively at constant pressure and decreasing flux (ref. 38).

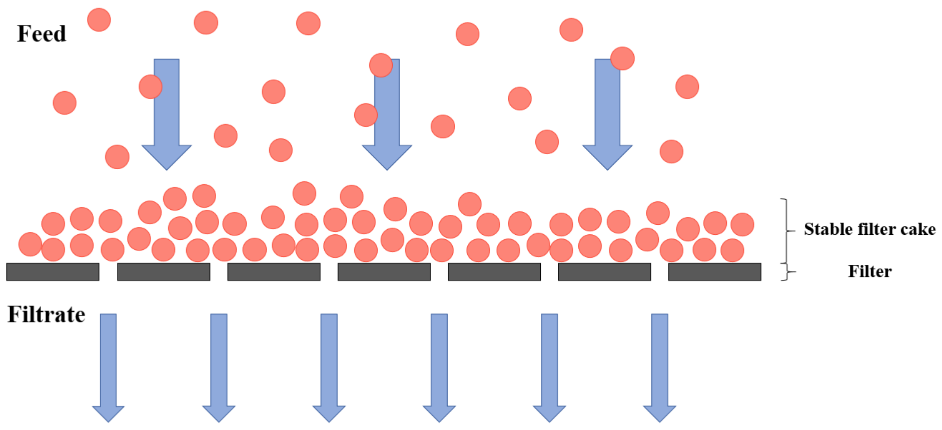

Figure A.1.4. Dead-end filtration scheme.

It is to be considered that normally in this type of filtration the filter ends up being a consumable component that is to be disposed with the filtered solids, so it needs to be periodically replaced (ref. 39).

On the other hand, cross-flow filtration intends to improve flux's stability and rejection through a flow of the feed along the membrane, thus applying shear forces on the membrane surface (ref. 38). The flow is tangentially fed across the membrane, so that the turbulence created across the membrane surface guarantees optimal flux performance and prolongs the filter functionality, as the solids' build-up is minimal and the flow resistance is low.

In contrast with dead-end filtration, it is to highlight that the membrane is not a consumable component, as it lasts longer (ref. 39).

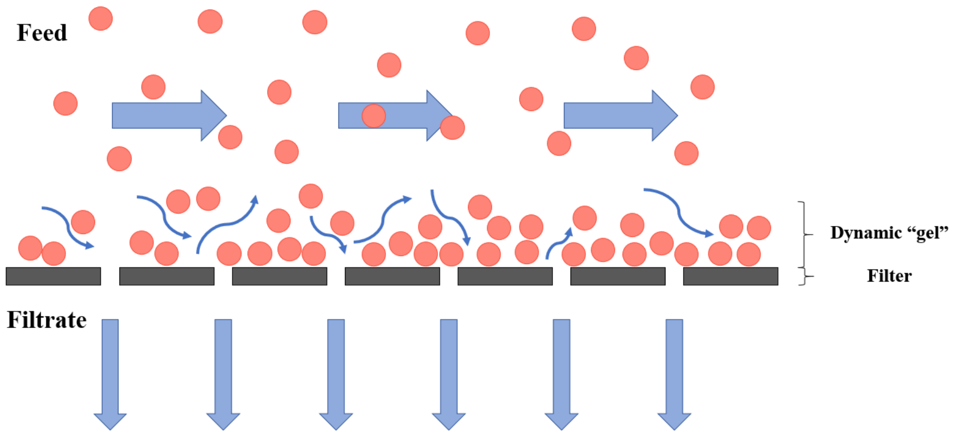

Figure A.1.5. Cross-flow filtration scheme.

Despite its many advantages, this process requires more energy, even though its performance balances this financial inconvenient· (ref. 38), and it is to note that cross-flow systems are a very attractive alternative to guarantee a proper oil-water separation.

Apart from flow circulation, materials also determine the UF performance, and they are selected depending on the processes requirements as well as thermal stability and fouling tendency. In general terms, the selected membranes for UF have an asymmetric (anisotropic) structure, which means that they consist of a very dense skin that typically ranges between 0.1 - 1.0 µm.

If UF membranes are made with polymers, they are typically made of polyether sulphone (PES), polyacrylonitrile (PAN), polyvinylpyrrolidone (PVP) and polyvinylidene fluoride (PVDF). However, there are also cellulosic membranes, but they are less stable than the previously mentioned ones.

On the other hand, if UF membranes are made with ceramic materials, the most commonly used are γ-alumina (γ-Al_2O_3) and α-alumina (ref. 31). Because of their greater rigidity, ceramic membranes can accommodate greater fluxes and be periodically backwashed without experiencing damages on their skin layer, and they are also more resistant to cleaning chemicals and can last up to 10 years (which is longer than polymeric membranes). Despite their benefits, it is to take into account that they are much more expensive and brittle (ref. 32).

A.1.1.2. Selection

The selected technologies to be used in the pre-treatment stage are cartridge filters (CF) and ultrafiltration (UF).

The versatile nature of CF makes them a great technology to be implemented, as it will enable the elimination of the gross pollutants that may be found in water and an easy adaptation to feedwater quality, as modules can be easily changed and disposed.

The fact of having a CF enables the use of UF instead of MF, as the filters will not experience as much fouling as they would if the CF was not there. Moreover, as it has previously been indicated, UF has greater elimination capacity than MF, and by following a cross-flow scheme, fouling can be significantly reduced and therefore the membrane's durability can be significantly increased.

Sand filtration (SSF, and RSF) are not appropriate choices for the present pilot because of the big required areas, as the pilot size is limited to the dimensions of a 40 ft container.

A.1.2. Near zero liquid discharge (nZLD) technologies

The described technologies from this section are the ones that can be commonly found in already existing nZLD, ZLD and ZLDD systems. As in the previous section, the characteristics of these technologies as well as their main advantages and drawbacks are described, and after considering them, a final selection is made.

A.1.2.1. Characterization

A.1.2.1.1. Electrodialysis (ED)

ED is a low-pressure process based on an electro-separation membrane that combines selective ion-exchange membranes with an outside electric field to produce cations and anions diffusion in opposite directions, thus enabling the desalination and concentration of two streams (ref. 31) (ref. 40).

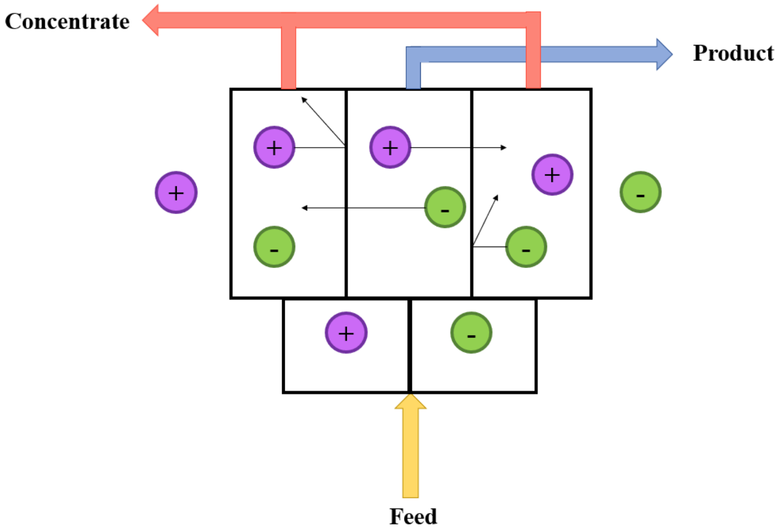

Figure A.1.6. Electrodialysis operation scheme.

The main advantages of ED systems are their high water recovery and selectivity, as well as their economic feasibility due to their ability to treat feeds with high salt concentration (ref. 40).

Additionally, the use of ED as a treatment for RO-concentrated brine has been reported by some authors, and has shown high rejection, high concentration ratio and high water recovery (ref. 41) (ref. 42). Despite this, fouling and scaling increase stack resistance and power requirements, therefore, it is to highlight that to solve this issue this technology can adopt a configuration known as electrodialysis reversal (EDR), which enables the self-cleaning of the membrane by periodically reversing the polarity (every 15-20 min) to reduce fouling (ref. 31) (ref. 43).

However, in waters whose TDS concentration is high, ED can't compete with RO because of the high energy consumption required to treat these waters.

In what materials refers, the abovementioned ion-exchange membranes are a bit special, as they are made of hydrophobic polymers like PE and PS, but in this case they are presented as highly swollen gels with polymers with a fixed ionic charge. The main features these membranes have are their high permselectivity and their low resistance to electricity (ref. 31).

A.1.2.1.2. Forward Osmosis (FO)

Forward osmosis (FO) is a membrane-based separation process that occurs in a natural and spontaneous way, as the osmotic pressure difference between a concentrated (draw) and a low-concentration (feed) solution leads to a water flow across a semipermeable membrane from the feed solution to the draw one (ref. 32) (ref. 44) (ref. 45).

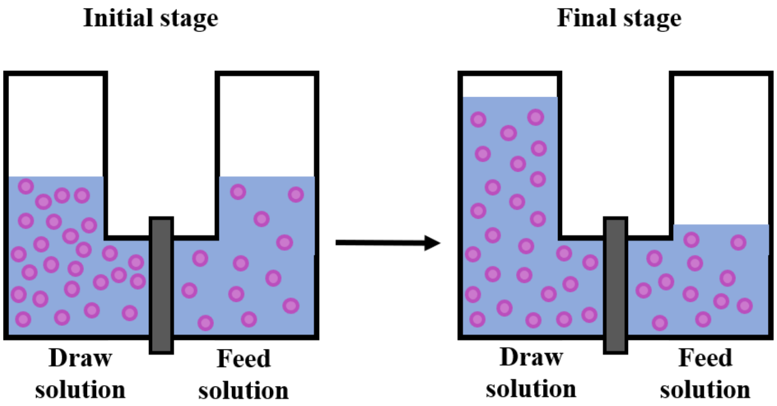

Figure A.1.7. Representation of the osmosis concept.

FO membranes are asymmetric membranes with a very thin and selective active layer, a porous support layer that brings mechanical stability to the active one. They are their water and solute permeability as well as the structural parameter of their support layer what determines the transport, as well as the concentration difference between both sides of the active layer (as it defines the osmotic pressure difference and therefore the water flux through the membrane) (ref. 44).

What makes FO an attractive process is that, unlike RO, it is not limited by osmotic pressure, which enables it to treat high salinity waters, and makes it also less prone to experience feed-side fouling (ref. 32) (ref. 46). Although these features may make FO look like an attractive option, it has a huge energy consumption, superior to RO's (ref. 32), and scaling mechanisms in FO are more complex than the ones in RO. Moreover, FO is only economically feasible if it is applied in the treatment of high salinity feeds (ref. 45).

However, FO can be an attractive pre-treatment for RO, as its low propension to experience fouling on the feed-side can enhance RO performance (ref. 32).

A.1.2.1.3. Membrane Distillation (MD)

MD is a thermally driven process that isolates two different temperature solutions with macro hydrophobic pores.

The feed (high-temperature side) experiences vapor evaporation, and then this vapor passes through the pores and condensates on the other side of the membrane. This is due to the difference in vapor partial pressure driven by the temperature difference: the bigger the temperature difference, the more vapour flux, and as MD membranes are hydrophobic, the separation can be achieved because only vapor molecules can pass through them. This way, permeates can reach high purity, thus obtaining a rejection rate that can be over 99%; and as the membrane pores are larger than the ones of RO, fouling is prevented and thereby is the need of requiring a feed-water pre-treatment too (ref. 32) (ref. 46).

Additionally, MD temperature operation ranges (60-80ºC) are lower than in most thermal processes, which can facilitate the use of waste heat to run the separation, and as the membranes have high contact area per unit of equipment volume, they are very compact installations. They can be coupled with RO to achieve ZLD.

A type of MD is OD (Osmosis Distillation), for which the condenser side is a concentrated salt solution which has lower vapor pressure than the feed side. In general terms, their operation is isothermal even though they may require some extra energy to regenerate the draw solution.

And MCr (Membrane Crystallization) is another type of MD that is able to produce crystals by removing solvents from a saturated solution. These systems provide well-controlled nucleation and growth kinetics as well as faster crystallization rates and shorter induction times, and have low operation temperatures and energy requirements, which are features that make them an attractive method for both water recovery and crystal production (especially for high-value by-products) (ref. 46).

A.1.2.1.4. Nanofiltration (NF)

Nanofiltration (NF) is a pressure-driven filtration membrane process that enables the separation of solutes by applying pressures between 5 and 15 bar and by using membranes with a nominal pore size of less than 2 nm (ref. 31). Due to the membranes' pores and the transmembrane pressure difference, two different types of flux transport occur: convective and diffusive, and the separation efficiency is governed by a sieving effect or by the solution and diffusion of the solute molecules (ref. 47).

The main features this technology has are its high rejection of multivalent ions (>99%), its low to moderate rejection to monovalent ions (around 70%) and its high rejection of organic compounds whose molecular weight is above the molecular weight of the membrane (>90%) (ref. 44) (ref. 47) (ref. 48). Another very unique feature of NF is the fact that its separation capability is very close to RO's, but without requiring such high transmembrane pressures, which makes it an attractive alternative to RO in desalination as it implies a reduction on energy consumption (ref. 49). In general terms, it can be affirmed that NF is a process that lies between UF and RO in terms of rejection of molecular or ionic species (ref. 44) (ref. 49).

However, the main issues to tackle in NF are, among others, fouling, chemical resistance and limited lifetime of membranes, and insufficient rejection of pollutants (ref. 50). Despite this, several studies have proved that fouling levels in NF modules are lower than in RO, therefore, this fact combined with previously mentioned low energy consumption can be great reasons to replace existing RO facilities for NF (ref. 49).

As in MF and UF, NF membranes can be either polymeric or ceramic. Polymeric materials for NF include cellulose, PSF, PES, PA, PVA, PVDF, chitosan or chitin, and PESK; and they provide high temperature resistance as well as low fouling and low cost (ref. 48). On the other hand, ceramic materials present higher resistance to severe fouling conditions; however, unlike polymeric NF membranes, they show high variability in the rejection of charged compounds, mainly derived from polarisation, as ceramic membranes have a strong negative charge (ref. 51).

A.1.2.1.5. Reverse Osmosis (RO)

Reverse Osmosis (RO) is a pressure-driven filtration membrane process that enables the separation of solutes by applying pressures between 15 and 75 bar and by using membranes with a nominal pore size of less than 0.5 nm. The employed semipermeable membranes selectively allow the passage of water, but reject almost all the ions and salts, which is based on a solution-diffusion mechanism. This way, a concentrated salt on the feed side of the membrane and a virtually ion-free water product on the other side are obtained (ref. 31) (ref. 34).

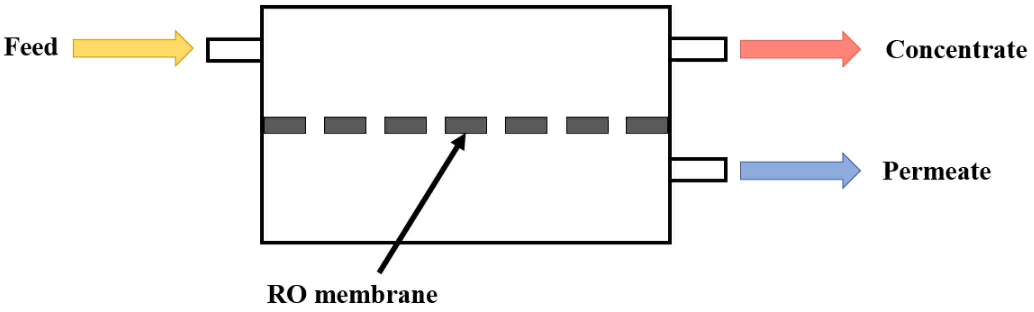

Figure A.1.8. RO operation scheme.

In RO, unlike FO, the separation is performed by applying a pressure that is higher than the osmotic one to force water to flow from the concentrated to the diluted solution (ref. 32):

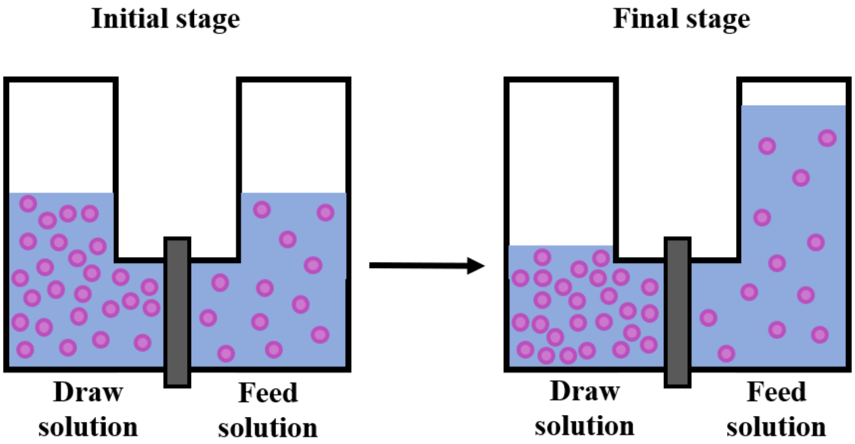

Figure A.1.9. Representation of the reverse osmosis concept.

However, the membrane's properties are typically tailored to the type of application in order to meet rejection requirements. The main rejection properties to be considered are the following ones:

- Multivalent ions (Ca^{2+}, Mg^{2+}) have a higher rejection than the monovalent ones (Na^{+}).
- Undissociated or poorly dissociated substances have lower rejections.
- Acids and bases are rejected to a lower extent than their salts.
- Rejection of weak acids and bases has a strong dependence on pH: when ionised, the rejection is high, whereas when nonionised the rejection is low.
- Co-ions affect the rejection of a particular ion (Na^{+} has higher rejection as Na_2SO_4 than as NaCl).
- Trace quantities of univalent ions generally have poor rejection.

The structure of those membranes is semiporous, asymmetric and thin-film composites. In case of being made from polymeric materials, the most frequent ones are CA, PA, TFC and CTA (ref. 31).

Despite RO being a widely used technology in ZLD systems due to its energy savings when compared to other desalination methods (ref. 46), the performance of RO in desalination processes is limited by membrane mineral scaling derived from the precipitation of sparingly soluble salts (typically gypsum, calcite and barite), which in turn can cause a flux reduction as well as it can potentially damage the membrane. Thereby, these issues limit the recovery and increase the water production cost, even when using antiscalants. Moreover, the use of antiscalants may increase the potential propensity of biofouling on the membrane.

To prevent scaling while reducing or eliminating the use of antiscalants, Feed Flow Reversal (FFR) is the ideal operation mode for RO.

In FFR, as feed flows in the normal forward flow (NFF) mode, the operation is as in conventional RO: water enters the membrane from its "normal" feed side, and salt concentrations axially increase along the feed channel and to a larger degree at the membrane surface because of concentration polarization (CP). Once the scaling level reaches a specific threshold, FFR is initiated, whereby the raw feed is redirected to enter through the previously designated outflow end, while the previous "entrance" end becomes the "exit" end of the module.

The exposure to the undersaturated raw feed that the entrance "end" (scaled in the NFF period) experiences, leads to the dissolution of the mineral salts on the membrane surface due to the reversal of the driving force.

The main advantage of this operation mode is that, in contrast to other methods, the permeate production is not interrupted. However, the onset of mineral scaling may vary over FFR cycles as the nucleation of mineral crystallization is a stochastic process and also because feedwater quality may temporally vary with respect to its mineral scaling propensity due to its composition and temperature. Therefore, the implementation of FFR requires real-time mineral scale monitoring to enable the system to self-adapt with a view on providing the most suitable cycles in terms of frequency and duration (ref. 52).

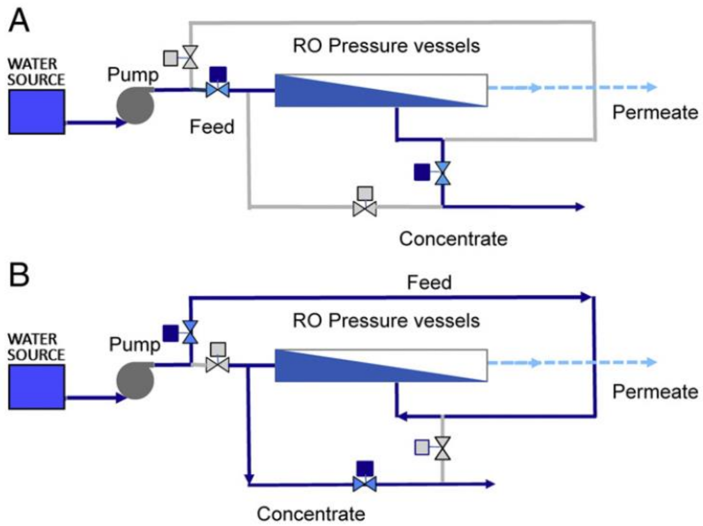

Figure A.1.10. Representation of the operation modes, where A is NFF and B FFR. Source: (ref. 52).

A.1.2.2. Selection

Membrane distillation (MD) is a very innovative technology through which very high separation rates can be achieved, and because of this and its innovative nature, it is a technology to be implemented on the pilot.

As it requires a pre-treatment due to its pore size, a reverse osmosis (RO) module will be installed before the MD feed to guarantee its proper conditions. The reason why RO will be installed instead of nanofiltration (NF) is mainly due to the operational versatility and the better membrane maintenance and protection that can be achieved by implementing feed flow reversal (FFR) operation.

Forward osmosis (FO) and electrodialysis (ED) have both been discarded for the current application as they are very energy-intensive processes.

A.1.3. Ammonium recovery / treatment

A.1.3.1. Characterization

A.1.3.1.1. Adsorption on zeolites

Zeolites are crystalline microporous solids formed by TO_4 tetrahedra (with T being Si, Al, Ge, B… and staying in the tetrahedral position) whose structures contain channels of diameters between 0.3-1.5 nm. These silicate-based materials can be commonly found in volcanic areas, and there are about 45 natural types, although they can also be synthetically produced.

Zeolites not only do they have exceptional physicochemical properties and high functionality, but also great adsorption capacity. Thus, many industrial separation processes include adsorption on zeolites.

Historically, the general trend has been selecting natural zeolites for these purposes. However, the presence of impurities and the lack of uniformity leaded to requiring their processing to avoid limiting their adsorption capacity, which in turn ended up leading to the use of synthetic zeolites.

This tendency to opt for synthetic zeolites widened the number of commercially available structures, and also stimulated the development of tailored adsorption properties by controlling the framework (Si / Al ratio) as well as the extra-framework (use of cations) and other post-synthesis modifications (ref. 53).

It is to note that there are some types of zeolites that are specifically competent when it comes to treating ammonium in water due to their high selectivity for this cation, as clinoptilolite (HEU) or mordenite (MOR) can be (ref. 54).

A.1.3.1.2. Membrane contactors (MC)

A membrane contactor (MC) is a device containing either a ceramic or a polymeric porous membrane whose main aim is to stimulate the contact between two phases (gas-gas, gas-liquid, liquid-liquid) to achieve mass transfer without dispersion of one phase within another. This membrane works only as a physical barrier that increases the surface for mass transfer exchange, therefore, it does not confer any selectivity to the separation (ref. 32) (ref. 55).

This nondispersive contact of phases and the larger interfacial area prevents the typical problems that many conventional technologies experience due to the interdependence of both phases, as the formation of emulsions, foaming, unloading and flooding can be. Additionally, they have more operational flexibility, linear scale-up, compactness and less energy consumption compared to conventional systems. Moreover, they offer 30 and 500 times more area than gas absorbers and liquid-liquid extraction columns, respectively.

The driving force varies depending on the system, and it can be achieved by using selective solvents, vacuum, sweep gas, osmotic solutions, and many others (ref. 55).

In what the structure refers, MC modules contain thousands of microporous hollow fibres knitted into a fabric that is wound around a distribution tube with a central baffle, which reduce the pressure drop and guarantee a proper water distribution (ref. 32).

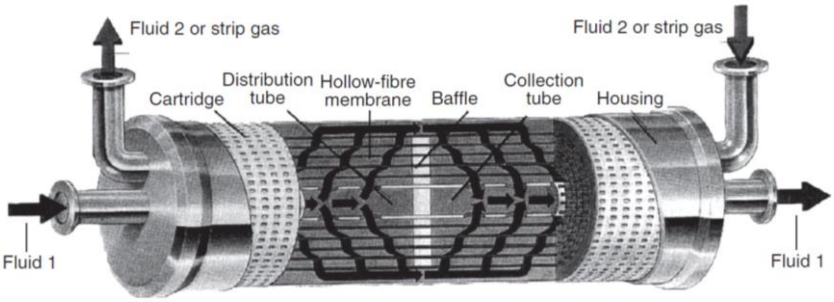

Figure A.1.11. Liqui-cell® MC module. Source: (ref. 32).

Despite its many benefits, this technology is limited by some shortcomings that need to be considered: additional transport resistance, limited lifetime, fouling, and operating pressures conditioned by breakthrough pressure (ref. 56).

A.1.3.1.3. Stripping

Ammonium can be recovered through a stripping-adsorption process based on the volatilization of ammonia at high temperature or pH. If the equilibrium is shifted towards the gaseous phase and then the solution is stripped, the stripped ammonia can be adsorbed by acid solutions.

An interesting option could be using sulphuric acid to form ammonium sulphate, as it is a widely used fertilizer and could make the process economically attractive. Alternatively, it can be harvested in the liquid ammonia as an ammonia-rich solution (ref. 57).

A.1.3.2. Selection

The fact that the pilot is purely demonstrative and that the ammonium concentration is not high enough to consider the implementation of a system through which ammonia could be revalorized, make membrane contactors and stripping unsuitable alternatives for the pilot. Hence, the selected technology to be implemented is adsorption on zeolites. The main advantage that zeolites present is the great number of types that can be commercially found, which enables to select the most suitable type depending on the process' needs.

A.2. FEEDWATER CHARACTERIZATION

In this annex there can be found some graphs that have been constructed in order to characterize how the water to be treated will be. In those graphs, the limit values (if any) have been represented by a scattered red line, whilst values have been plotted by dots, the tendency line in a straight blue line, and the range in which values are in a greyish area.

It is to note that with a view on plotting the obtained data in a clear and representative way, several outliers from various parameters have not been included in the present representations.

Data from Cr, Cd, Ni, Pb and Hydrocarbons have not been plotted as their values remained constant or almost constant in all measures. Cr values were mostly equal to 20 µg/L or lower, Cd was mainly below 20 µg/L, and the same happened with Ni and Pb, and Hydrocarbons were below 5 µg/L in all sampling dates.

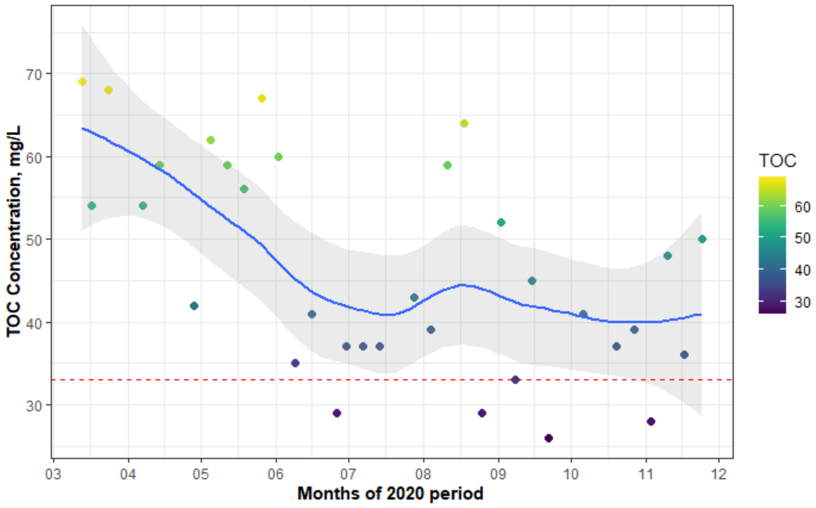

Figure A.2.1. TOC concentration from March to December 2020

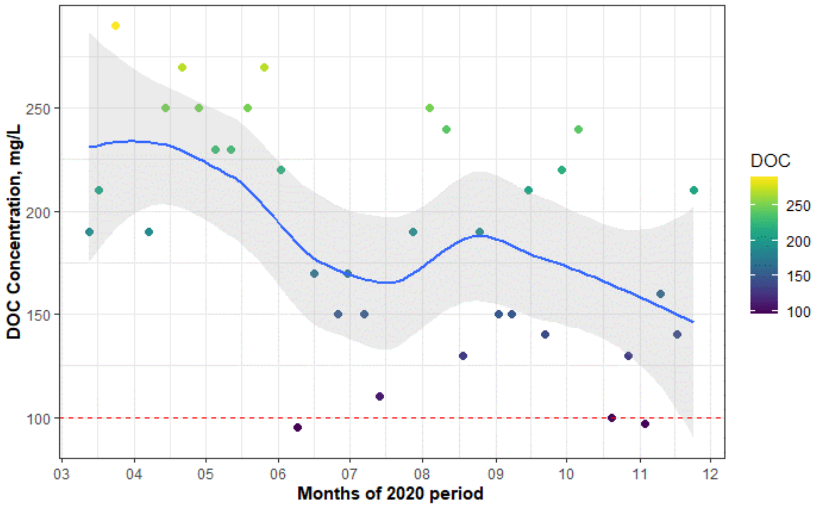

Figure A.2.2. DOC concentration from March to December 2020

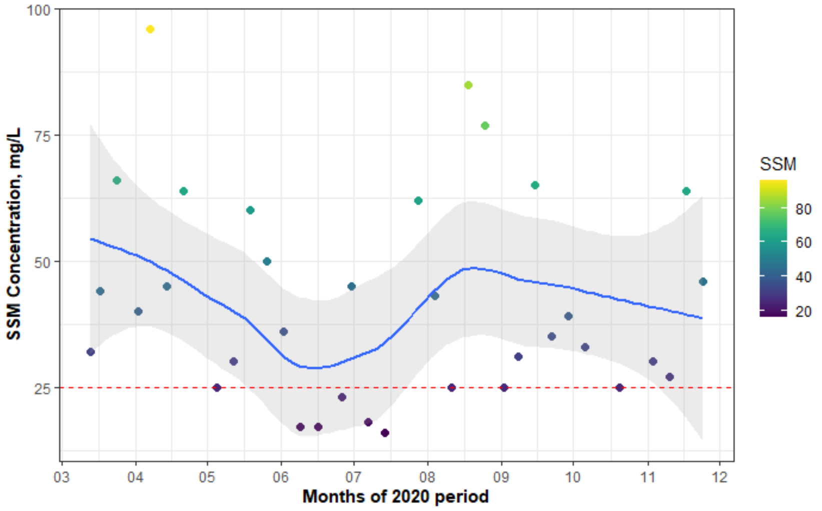

Figure A.2.3. SSM concentration from March to December 2020

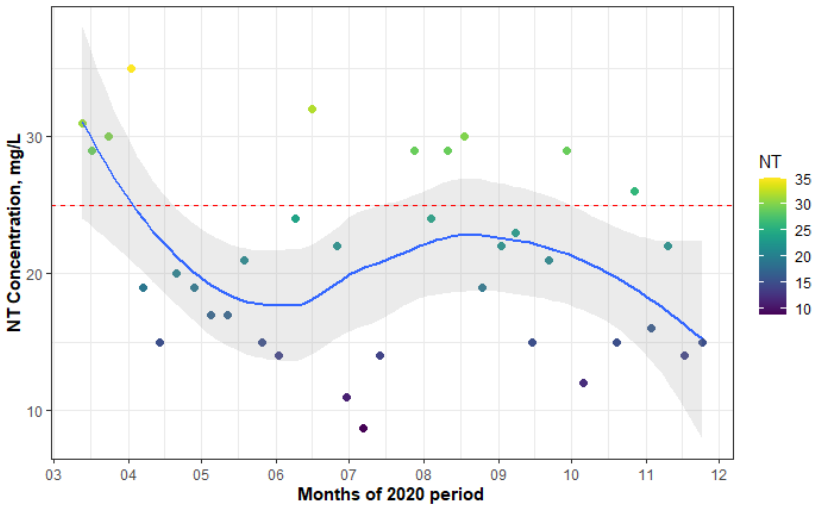

Figure A.2.4. N_T concentration from March to December 2020

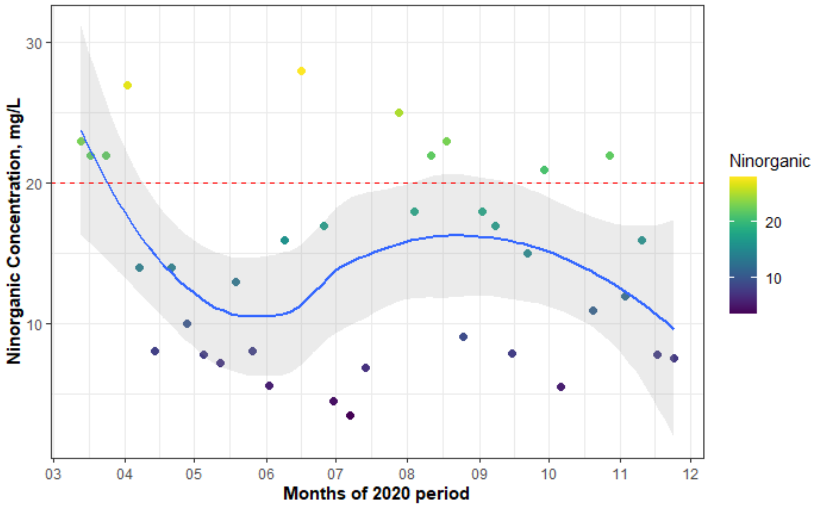

Figure A.2.5. $N_{inorganic}$ concentration from March to December 2020

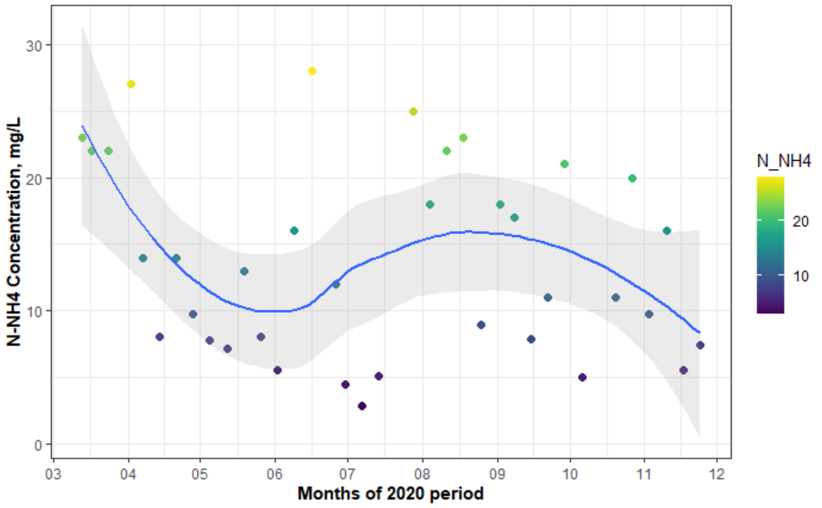

Figure A.2.6. N-NH_4 concentration from March to December 2020

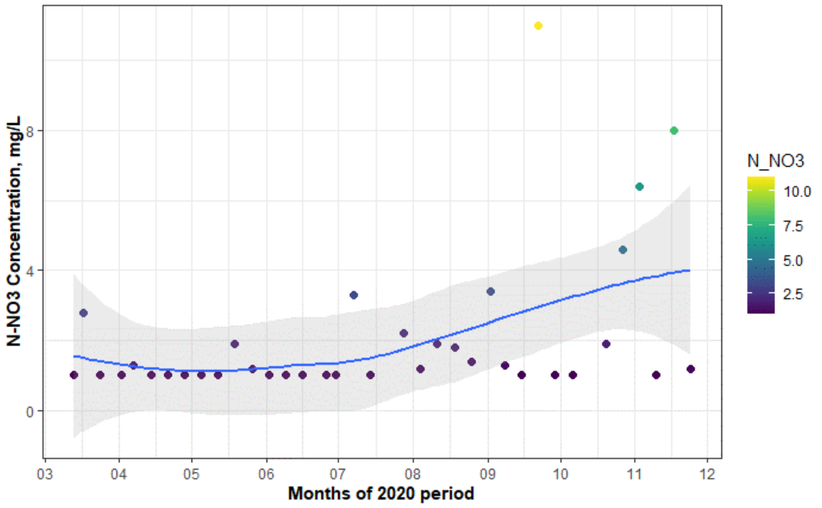

Figure A.2.7. N-NO_3 concentration from March to December 2020

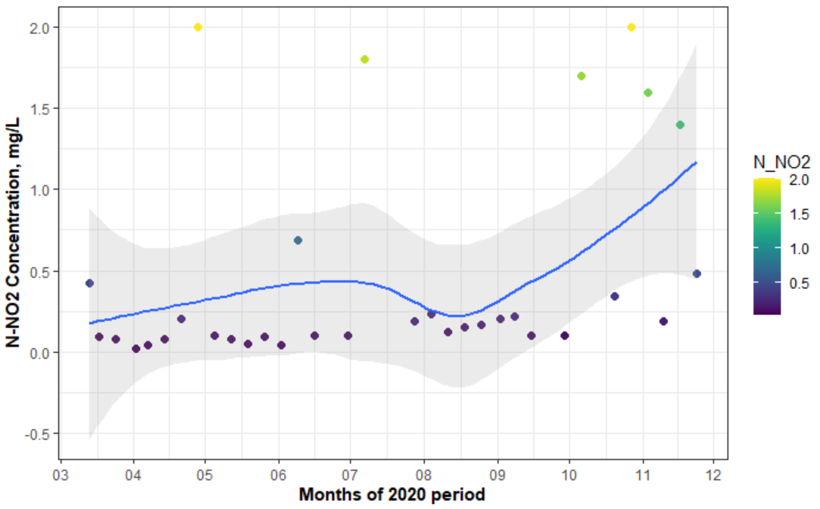

Figure A.2.8. N-NO_2 concentration from March to December 2020

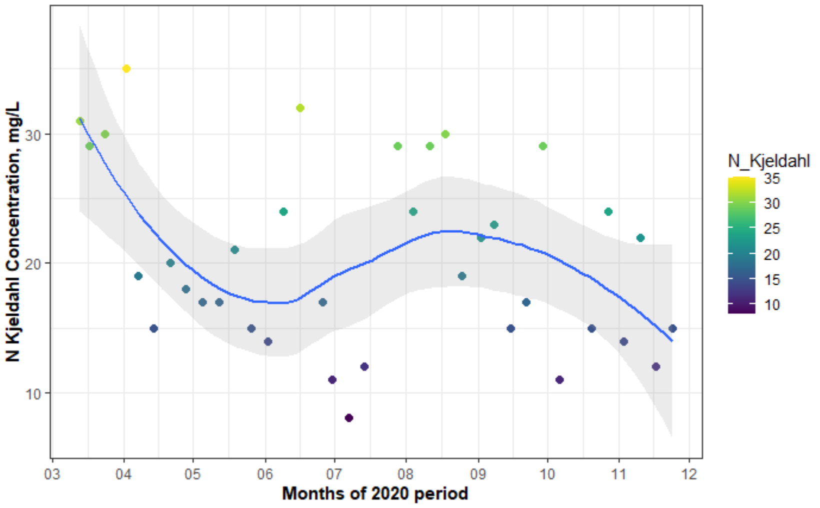

Figure A.2.9. $N_{Kjeldahl}$ concentration from March to December 2020

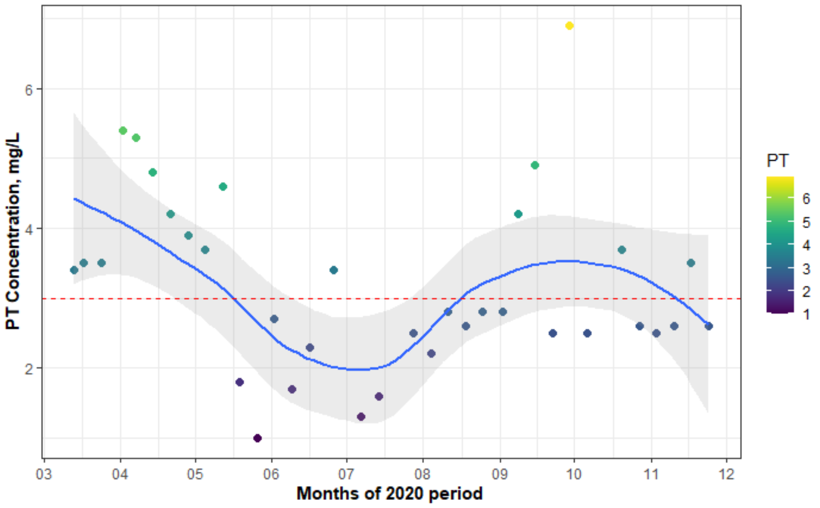

Figure A.2.10. P_T concentration from March to December 2020

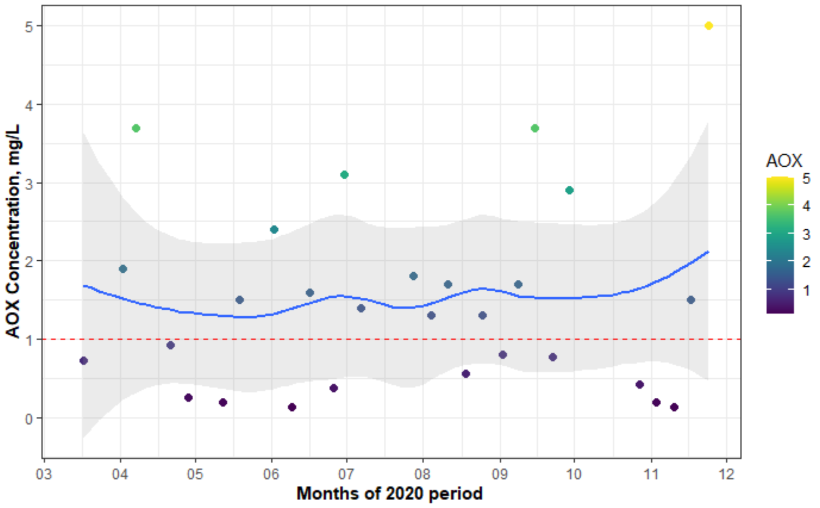

Figure A.2.11. AOX concentration from March to December 2020

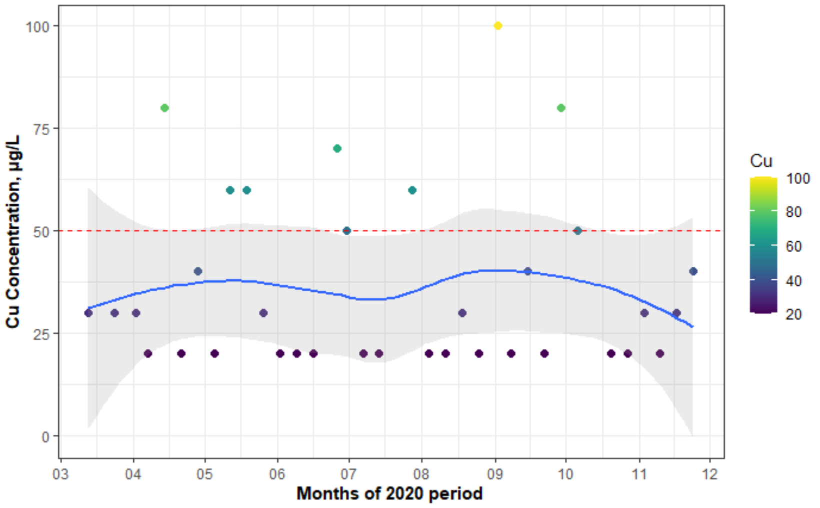

Figure A.2.12. Cu concentration from March to December 2020

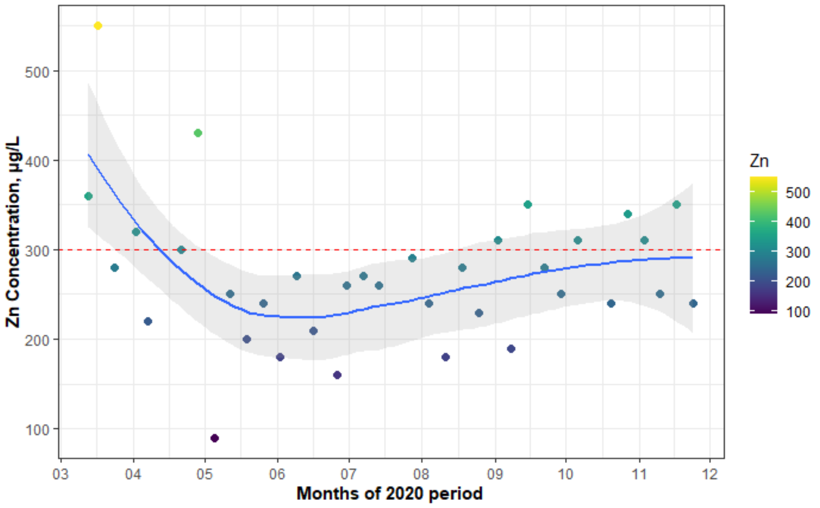

Figure A.2.13. Zn concentration from March to December 2020

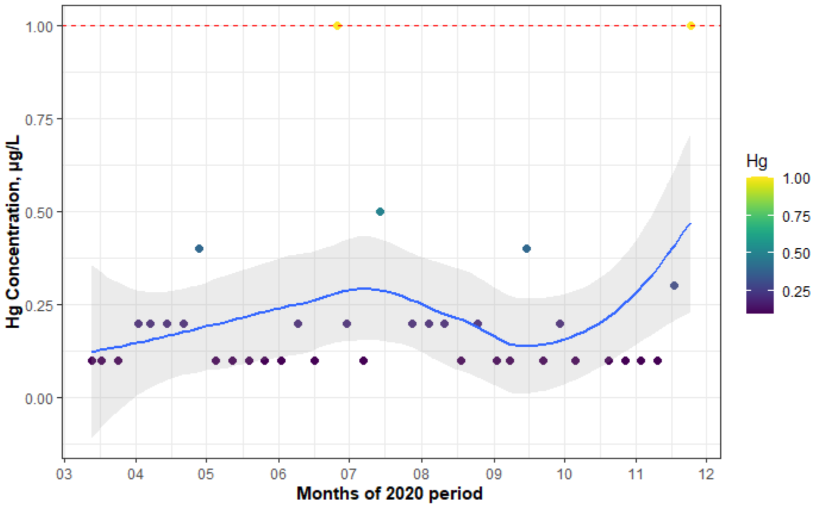

Figure A.2.14. Hg concentration from March to December 2020

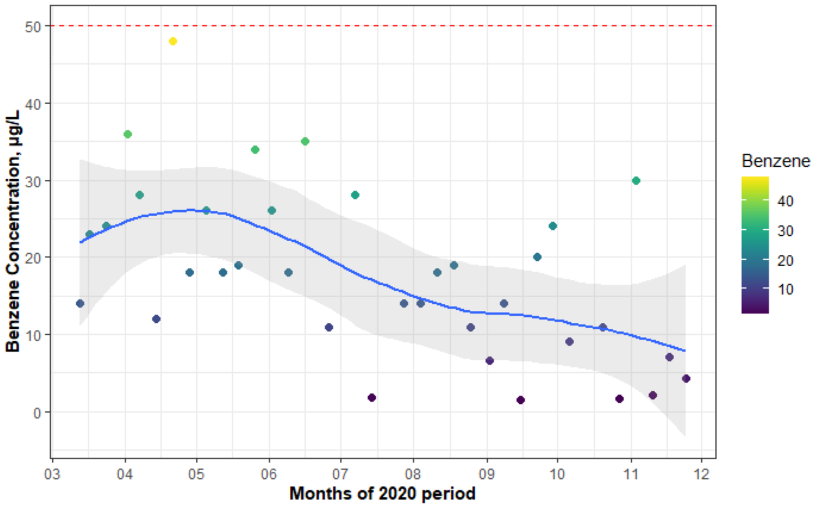

Figure A.2.15. Benzene concentration from March to December 2020

A.3. PRODUCED WATER SPECIFICATIONS

In this section, the quality standards defined by the three regulations that water produced by the pilot must meet are indicated.

A.3.1. RD 1620/2007

The standards defined by RD 1620/2007 regarding water reuse for industrial purposes are the following ones:

Table A.3.1. Maximum permissible values for industrial wastewater reclamation defined by RD 1620/2007. Source: (ref. 5).

Expected water use	Intestinal nematodes (eggs / 10 L)	*E. coli* (CFU / 100 mL)	Suspended solids (mg / L)	Turbidity (NTU)	Other criteria
Cooling towers and evaporative condensers	1	Absence	5	1	*Legionella*: Absence

A.3.2. UNE-EN 12952-12:2004

As this treated water may also be used in boilers, it is necessary to follow the quality guidelines defined by UNE-EN 12952-12:2004 “Water tube boilers and auxiliary installations – Part 12: Requirements for boiler feedwater and boiler water quality” (ref. 6). As there are different requirements depending on water conductivity and service pressure, as a conservative approach, the most restrictive one has been selected:

Table A.3.2. Standards for steam boilers that use demineralized feedwater with acid conductivity ≤ 0.2 μS/cm. Alkalinization of boiler water with solid alkalinising agents. Source: (ref. 6).

Parameter	Units	Limit
Service pressure	bar	> 100
Appearance	-	Clear, without stable foam
Direct conductivity at 25ºC	μS/cm	< 30
Acid conductivity at 25ºC	μS/cm	
With phosphate dosing		< 30
Without phosphate dosing		< 40
pH at 25ºC	-	9.3 – 9.7
Alkalinity	mmol/L	-
Silica concentration (SiO_2)	mg/L	See figures A.3.1. & A.3.2.
Phosphate (PO_4)	mg/L	< 3
Organic substances	mg/L	Concentration must be as low as possible

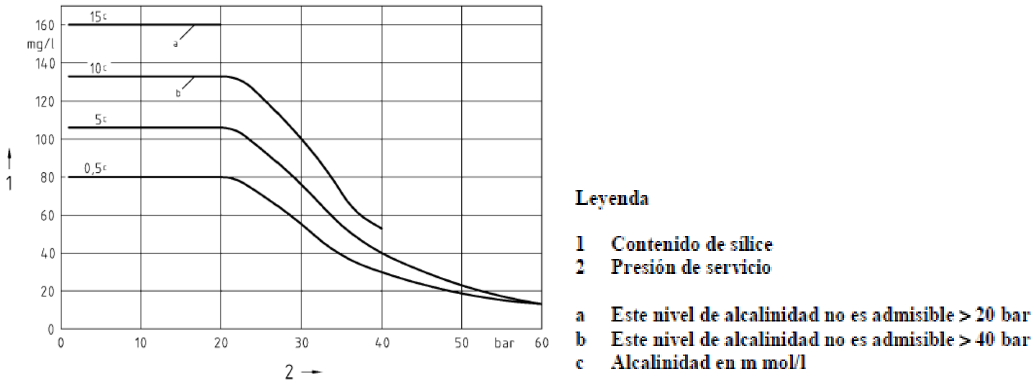

Figure A.3.1. Maximum admissible silica content of boiler water for pressures from 0 to 60 bar. Source: (ref. 6).

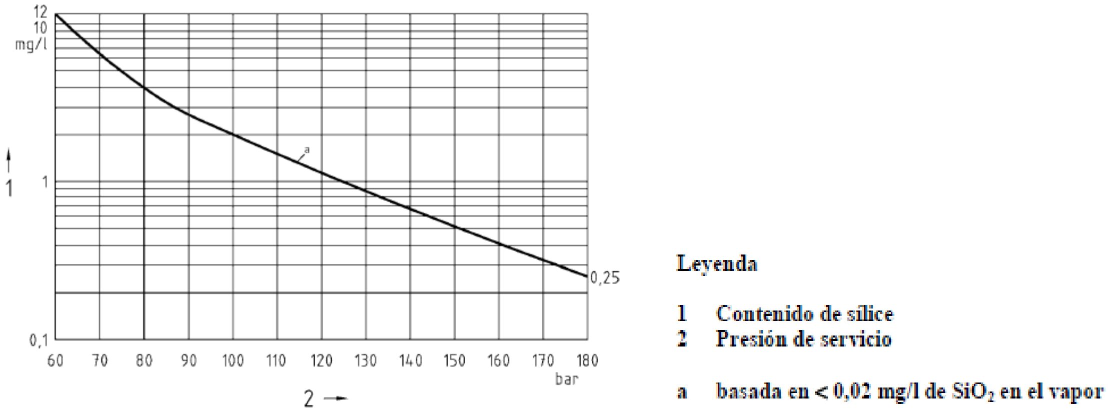

Figure A.3.2. Maximum admissible silica content of boiler water for pressures from 60 to 180 bar. Source: (ref. 6).

A.3.3. AITASA's quality standards

AITASA's standards are based on their defined limits for the regenerated water they currently supply to the chemical complex, and they are specially focused on ammonium, because as it has been previously mentioned, water from the petrochemical complex has high ammonium loads.

Table A.3.3. AITASA's standards on regenerated water.

Parameter	Units	Limit
Ammonium	mg/L	0.8
Conductivity	µS/cm	2,000
Turbidity	NTU	1
Orthophosphates	mg/L	5
DOC	mg/L	20
TSS	mg/L	5
Chlorides	mg/L	350
Sulphates	mg/L	200

A.4. PUMP DESIGN

In this annex there can be found the various design criteria involved in the pump selection, from the calculations to determine the pump properties to the pump selection from commercial catalogues.

A.4.1. Calculations

The different step by step calculations that have been conducted to determine each pump's height as well as its power and available NPSH are indicated below:

A.4.1.1. Pipe diameters

The diameters of the lines before and after the pump can be calculated by following the expression below:

$$A = \frac{Q}{v} \rightarrow \pi \frac{D^2}{4} = \frac{Q}{v} \rightarrow D = \sqrt{\frac{4 \cdot Q}{v \cdot \pi}} \qquad \text{(A.4.1.)}$$

Where Q is the flow in m^3/s, v the velocity in m/s, A the area in m^2 and D the diameter in m.

As the only known parameter is flow, the velocity value can be estimated by taking into consideration that liquids' velocity typically ranges between 0,5 and 3,5 m/s.

With flow and this supposed velocity value, a theoretical diameter can be calculated and can be later compared to the internal diameter of commercial standards:

Table A.4.1. Standard dimensions for schedule 40 PVC and CPVC. Source: (ref. 58).

Nominal pipe size (in)	$Ø_{out}$ (mm)	Minimum wall thickness (mm)	$Ø_{in}$ (mm)	Nominal pipe size (in)	$Ø_{out}$ (mm)	Minimum wall thickness (mm)	$Ø_{in}$ (mm)
½	21.3	2.77	15.8	**4**	114	6.02	102
¾	26.7	2.87	20.9	**5**	141	6.55	128
1	33.4	3.38	26.6	**6**	168	7.11	154
1 ¼	42.2	3.56	35.1	**8**	219	8.18	203
1 ½	48.3	3.68	40.9	**10**	273	9.27	255
2	60.3	3.91	52.5	**12**	324	10.3	303
2 ½	73	5.16	62.7	**14**	356	11.1	333
3	88.9	5.49	77.9	**16**	406	12.7	381

Once the commercial dimensions are selected, the velocity value can be calculated with the previous equations in order to determine the real velocity of the fluid that flows through the pipe.

However, as the pilot operates with very low flows, the required nominal diameters were of about ½" or even lower, and in these sizes it is not possible to install instruments. Because of this, all nominal diameters of the sections that work with flows of about 12 m^3/day are of 1", whereas the others are of ¾".

A.4.1.2. Friction loss

Friction loss is the loss of pressure or "head" that takes place in pipes because of the effect of the fluid's viscosity near the surface of the pipe or other elements that can be found along it.

There are two types of friction losses: major (h_f) and minor (h_{min}). Major loss is the energy loss derived from the friction between the moving fluid and the pipe, whereas minor loss is the additional energy loss in the pipe that is caused by the complements it has installed.

First of all, it is necessary to calculate the Reynolds number (Re) of both aspiration and impulsion lines. It can be calculated with the following expression:

$$Re = \frac{\rho \cdot v \cdot D}{\mu} \quad \text{(A.4.2.)}$$

Where ρ is the fluid density in kg/m^3, v the real velocity of the fluid in m/s, D the commercial diameter of the pipe in m, and μ the dynamic viscosity of the fluid in Pa·s.

As the system's fluid is water, density has been approximated to the one of pure water (1,000 kg/m^3) and the same has been done with dynamic viscosity (0.001 Pa·s).

Once the Reynolds number is known, the correction factor for friction losses (f) can be calculated with the following expression:

$$f = \frac{0.25}{\left[\log\left[\frac{\varepsilon/D}{3.7} + \frac{5.74}{Re^{0.9}}\right]\right]^2} \quad \text{(A.4.3.)}$$

Where ε is the pipe rugosity in m, D the commercial diameter in m, and Re the Reynolds number.

PVC pipes have a rugosity value of $1.5 \cdot 10^{-6}$ m, and the ones made of steel have a rugosity of $6 \cdot 10^{-5}$ m (ref. 59).

Once this correction factor is known, major and minor losses can be calculated for both aspiration and impulsion lines.

Major losses (in m) can be calculated as:

$$h_f = \frac{L}{D} \cdot \frac{v^2}{2g} \cdot f \quad \text{(A.4.4.)}$$

Where L is the pipe's length in m, D the commercial diameter in m, v the real velocity value in m/s, g the force of gravity (9.81 m/s^2) and f the correction factor.

Whereas minor losses (in m) can be calculated as:

$$h_{min} = k \cdot \frac{v^2}{2g} \quad \text{(A.4.5.)}$$

Where k is a factor that depends on the accessory, v is the real velocity value in m/s and g the force of gravity (9.81 m/s^2).

k can be calculated with the following expression:

$$k = f \cdot \frac{Le}{D} \quad \text{(A.4.6.)}$$

Where f is the correction factor and Le/D the equivalent length in pipe diameter. The Le/D values depend on the complement, and they can be found in the table below:

Table A.4.2. Equivalent lengths in pipe diameter (Le/D). Source: (ref. 60).

Complement	Le/D value	Complement	Le/D value
Globe valve (fully open)	340	**Standard 90º elbow**	30
Angle valve (fully open)	150	**90º long radius elbow**	20
Ball valve (fully open) **¾ open** **½ open** **¼ open**	8 35 160 900	**90º threaded elbow**	50
Swivel check valve	100	**Standard 45º elbow**	16
Ball check valve	150	**45º threaded elbow**	26
Throttle check valve fully open (2 to 8 inch) **10 to 14 inch** **16 to 24 inch**	45 35 25	**Standard T with direct flow** **Standard T with flow to branch**	20 60
Foot valve with stem disc	420	**Valve closed on return**	50
Foot valve with hinged disc	75	**Instruments**	25

A.4.1.3. Pump height

Once friction loss is known, the pump height can be calculated thanks to the energy balance of Bernoulli's equation between the aspiration (asp) and impulsion (imp) lines:

$$h_{pump} = \left(\frac{P_{imp}}{g \cdot \rho_{imp}} - \frac{P_{asp}}{g \cdot \rho_{asp}}\right) + \left(\frac{v_{imp}^2 - v_{asp}^2}{2 \cdot g}\right) + \left(z_{imp} - z_{asp}\right) + h_f \qquad (A.4.7.)$$

Where P is the absolute pressure in Pa, ρ the fluid's density in kg/m^3, g the force of gravity (9.81 m/s^2), v the real velocity value in m/s, z the height in m, and h_f friction loss in m.

A.4.1.4. Pump power

Knowing the pump's height, its required power can be calculated with the expression below:

$$P = h_{pump} \cdot \rho \cdot g \cdot Q \qquad (A.4.8.)$$

Where h_{pump} is the pump's height in m, ρ the fluid's density in kg/m^3, g the force of gravity (9.81 m/s^2) and Q the flow value (m^3/s).

A.4.1.5. Available NPSH

Finally, the available NPSH (net positive suction head) can be calculated with the conditions of the aspiration line:

$$NPSH_A = \frac{P_{asp}}{\rho \cdot g} + \frac{v_{asp}^2}{2 \cdot g} - \frac{P_{vap}}{\rho \cdot g} \qquad (A.4.9.)$$

Where P_{asp} is the absolute pressure in Pa, ρ the fluid's density in kg/m^3, g the force of gravity (9.81 m/s^2), v_{asp} the fluid's velocity in m/s and P_{vap} the vapour pressure of the fluid in Pa.

Vapour pressure can be calculated with Antoine's equation (as pressure is obtained in mmHg, its conversion to Pa is included in the expression):

$$P_{vap} = \left(10^{A-\frac{B}{T+C}}\right) mmHg \cdot \frac{101325\,Pa}{760\,mmHg} \quad \text{(A.4.10.)}$$

Where T is the fluid's temperature in Celsius grades (ºC), and A, B and C Antoine's constant for a certain substance under certain conditions.

As the system's fluid is water, Antoine's constants are:

Table A.4.3. Antoine's constants for water. Source: (ref. 61).

Fluid	A	B	C
Water (0 ºC - 60 ºC)	8.10765	1,750.286	235.000
Water (60 ºC - 150 ºC)	7.96681	1,668.210	228.000

$NPSH_A$ importance lies on the fact that it shows how close is the fluid to cause cavitation in the pump, as cavitation occurs when the pressure in some point of the circuit is lower than the vapor pressure of the liquid, and this phenomenon can damage the pump.

Once this value is known, it needs to be compared with the required NPSH ($NPSH_R$) of the selected pump, as it is the limit value to prevent the pump from cavitating. Cavitation occurs when $NPSH_A < NPSH_R$.

A.4.2. Results

The table below summarizes the height, power and available NPSH values for each pump (except the ones for the dosing pumps that dose chemicals):

Table A.4.4. Calculated height, power and available NPSH for each of the process pumps.

Pump	Height (m)	Power (W)	$NPSH_A$
UF feed (P101)	15.31	20.86	4.99
UF backwash (P201)	25.51	34.76	4.99
RO feed (P301)	209.00	256.30	4.99
MD hot feed (DP401)	7.65	1.56	2.95
MD cool feed (DP501)	10.70	2.19	4.99
Zeolites feed (DP601)	10.70	1.21	4.99
Zeolites cleaning (DP701)	16.79	1.85	4.99

These results have been used to select each process pump by consulting the smart sizing tools by Grundfos (ref. 9) and Cat Pumps (ref. 10).

Because of the low flows at which some process sections operate, it has not been possible to select centrifugal pumps, and dosing pumps have been selected instead. In the case of the RO feed pump, a plunger pump from Cat Pumps has been selected, as no centrifugal pump that could supply the desired pressure and flow to the system was found.

The sizing of dosing pumps has been conducted by considering the required flow (which is extremely low) and using Grundfos' smart sizing tools to find a suitable model.

A.5. PIPING INSULATION

As the inlets and outlets of T101(wastewater feed tank) are located outdoors, they are exposed to cold temperatures during the winter that may lead to the freezing of the fluid, thus obstructing the pipes. Therefore, the insulating material to be used and its thickness have been determined.

A.5.1. Material selection

As the fluid from these lines is at room temperature and pipes are made of PVC, it is not necessary to avoid insulating materials that may be prone to absorb moisture, water or both.

The various existing insulating materials are the ones indicated below:

Table A.5.1. Properties of several insulating materials.

Insulating material	Properties
Calcium silicate	- Rigid elements reinforced with fibres. - Can be used from 35ºC to 815ºC. - Non-combustible. Absorbs moisture. - Good resistance to bending and compression.
Fiberglass	- Can be found in the form of flexible or rigid elements. - Can be used from -40ºC to 232ºC. - Binders can produce acidic or basic pH. - Non-combustible. Absorbs water.
Mineral wool	- Fibres with high temperature resistant binders. - Can be used up to 1,035ºC. - Non-combustible. Absorbs water.
Cellular glass	- Can be found in the form of blocks or boards. - Can be used between 273ºC and 200ºC. - Non-combustible and non-absorbent. Resistant to chemical attack. - Good structural strength and low resistance to impact
Perlite	- Can be found in the form of blocks and preformed elements. - Used at intermediate and high temperatures. - Cellular structure. Not very absorbent. - Corrosion resistant and non-combustible.
Elastomeric foam	- Foamed resins combined with elastomers. - Flexible. - Can be used below 105ºC. - Resistant to water and humidity. May be flammable.
Plastic foam	- Foamed plastics that form rigid cellular structures. - Can be found as panels or preformed elements. - Used at low temperatures. - Flammable, and must contain flame retardant elements.
Refractory fibre	- Mineral or ceramic fibres compacted with inorganic binders. - Very high temperature resistance (up to 1,750ºC). - Non-combustible. - Can be found as rigid elements or blankets.

Because of the process conditions, the fluid's nature and the abovementioned properties, all materials can be used, as there are no conditions under which their use would be inappropriate. However, because of their wide commercial availability, ceramic fibres or fiberglass are recommended. In the present case, ceramic fibres have been selected.

A.5.2. Thickness calculation

The required thickness for each of the pipes located outside the container (F-1001, F-2001, F-5201 and W-1001) is calculated by following an iterative process. As all pipes are made of the same material (PVC) and have the same nominal diameter (1"), the results obtained in the calculations are the same for all of them.

The several steps that have been followed are indicated below:

A.5.2.1. External transport coefficient (h_a) calculation

This coefficient describes the heat transfer from the outer wall to the environment. It is calculated with the following expression:

$$h_a = A + 0.005 \cdot (T_f - T_a) \qquad \text{(A.5.1.)}$$

Where A is a coefficient for horizontal pipes that varies depending on the material used. As these pipes are made of PVC, its value is 8.5. T_f is the fluid temperature and T_a ambient temperature. As this insulation's aim is to prevent the fluid from freezing, T_a value is -10ºC, as it is the worst situation that can be experienced in terms of low temperature, and the selected T_f value is 5ºC because it is a low temperature in which the fluid will not yet be frozen.

For all cases, h_a value is 10.05 $W \cdot m^{-2} \cdot K^{-1}$.

A.5.2.2. Theoretical thickness calculation

Once the transport coefficient is known, an iterative method is followed to obtain the required theoretical thickness by using the equation below:

$$T_s = \frac{(T_f - T_a)}{r_2 \cdot h_a \cdot \left(\frac{ln\left(\frac{r_1}{r_i}\right)}{k_1} + \frac{ln\left(\frac{r_2}{r_1}\right)}{k_2} + \frac{1}{r_2 \cdot h_a} \right)} + T_a \qquad \text{(A.5.2.)}$$

Where T_s is the temperature on the surface of the insulating material, T_f the fluid temperature, T_a ambient temperature, k_1 the heat transfer coefficient of the pipe (in this case, PVC, 0.16 $W \cdot m^{-1} \cdot K^{-1}$ (ref. 62)), k_2 the heat transfer coefficient of the insulating material (in the case of ceramic fibres, 0.101 (ref. 63)) r_i the internal radius of the pipe (13.3 mm), r_1 the external radius of the pipe (16.7 mm), and r2 the radius of r1 plus the thickness of insulating material (t):

$$t = r_2 - r_1 \qquad \text{(A.5.3.)}$$

The process by which t can be calculated is by defining an ideal T_s value and then iterating r_2 until this value is reached.

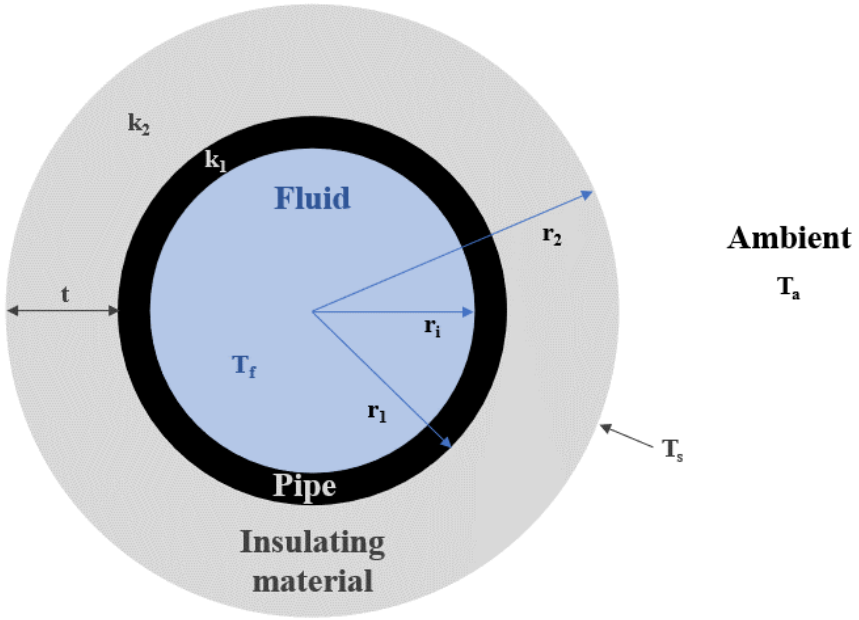

Figure A.5.1. Pipe section with all parameters indicated

T_s has been assumed to be 0ºC, and the iterations led to an r_2 value of 0.019 m and hence a required thickness of 2.18 mm.

A.5.2.3. Real thickness and T_s recalculation

When theoretical thickness is known, this value must be compared to the commercially available ones, and in case there is no exact match, it must be approximated to the immediately superior one, otherwise thickness would be insufficient to protect the pipe.

After selecting a commercial thickness, r_2 and T_s can be recalculated with the equations from the previous subsection to obtain their real values.

As there is no exact match for 2.18 mm, the selected thickness has been 6 mm (ref. 63), and the new r_2 and T_s values are 22.7 mm and -2.57ºC, respectively.

A.6. TANK DESIGN

In this annex the various design criteria involved in the tanks sizing as well as the selection of their materials can be found.

A.6.1. Volume

As the pilot is purely demonstrative and is located inside a 40 ft container, all tanks have been sized to keep the volume of an hour of operation of the technology to which they supply water. The only tank that does not follow this criterion is T101, which stores enough volume to operate for two hours, as it is the feed tank and is located outside the container.

Knowing that the cartridge filter and the UF and RO modules treat 12 m^3/day, that the MD treats 1.8 m^3/day and that the zeolites treat 1 m^3/day, the tank volumes are:

- T101: 1 m^3
- T201: 0.5 m^3
- T301 and T401: 75 L
- T501 and T601: 42 L

A.6.2. Materials

As all these tanks contain wastewater or brines at ambient temperature, the selected material for their construction has been polypropylene due to its corrosion and abrasion resistance (ref. 64). It must be considered that T301 operates at 75ºC and that polypropylene resists temperatures up to 98ºC. However, the tank will count on an alarm system that will warn operators and stop the operation in case the temperature rose to values above 75ºC.

A.6.3. Dimensions

It is to note that all the tanks that conform the system are atmospheric despite storing (in some cases) water from membrane modules that operate at very high pressures. This is because depressurization valves have been installed in some lines in order to prevent some tanks from suffering any kind of damage derived from the reception of high pressure water

Despite being atmospheric and made of a plastic material, their sizing has been done by following the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 (ref. 7) and the API 650 standard (ref. 8) guidelines in order to build strong tanks and hence, select the most similar commercial tanks.

The various steps followed are described below:

First of all, the following operational parameters and properties need to be defined:

Table A.6.1. Parameters required in the tanks sizing calculations

Parameter	Symbol	Units	Value
Maximum allowable stress of the tank material (PP) at room temperature:	S	MPa	130 (ref. 65)
Welding efficiency factor	E	-	1
Density of the tank material (PP)	ρ_m	kg/m^3	920 (ref. 66)
Fluid density	ρ_w	kg/m^3	1,000

Parameter	Symbol	Units	Value
Volume to be stored	V	m^3	**T101:** 1 **T201:** 0.5 **T301 & T401:** 0.075 **T501 & T601:** 0.042
Tank operation temperature	T	ºC	**T101:** 30 **T201, T401, T501, T601:** 20 **T301:** 75
Tank pressure	P_w	bar_g	0
Gravity	g	m/s^2	9.81

Note 1: due to the variable nature of the water to be treated, density has been assumed to be the one of pure water in all cases.

Note 2: the welding efficiency factor has been selected as 1 as polypropylene tanks are not welded.

Note 3: unlike the other non-heated tanks, the operation temperature of T101 is 30ºC. This is because this tank will be outdoors, and during the summertime it may be exposed to temperatures of 40ºC. Thus, the value of 30ºC has been selected as a conservative way of ensuring the thermal resistance of the tank.

Once they are defined, the sizing calculations can start.

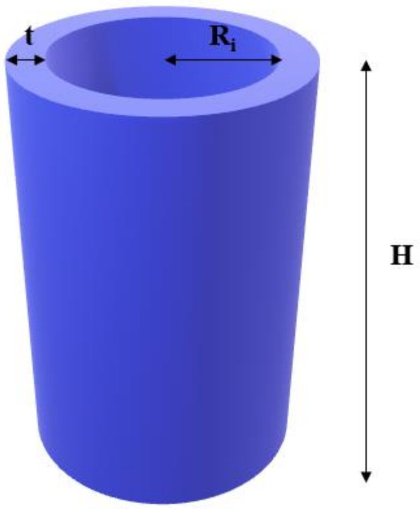

Figure A.6.1. Schematic representation of the dimensions of the cylindric body of the tank.

First of all, the tank volume is overdimensioned a 15% in order to prevent any damage derived from level overflow:

$$V_{ov} = V \cdot 1.15 \quad \text{(A.6.1.)}$$

Once this volume is known, a value for the internal radius (R_i) must be assigned so that the tank height can be calculated:

$$H = \frac{V_{ov}}{\pi \cdot R_i^2} \quad \text{(A.6.2.)}$$

If tanks had non-flat heads and bottoms, according to the ASME Code it would be necessary to calculate the design pressure of each tank section (head, body and bottom) and then calculate the required thickness for each one. However, as the used tanks are flat, the only pressure to be considered is the one withstood by the cylindrical body.

Knowing this, design pressure can be calculated by considering the tank pressure (P_w, which in the present case is 0 bar_g in all cases as all tanks are atmospheric), the pressure of the liquid column (P_c) and adding a 10% of the tank pressure or 1 bar. As tanks work under atmospheric conditions, the additional pressure will be 1 bar_g. In order to make the calculations homogeneous, Pa are used instead of bar, as it can be seen in the expression below, where the necessary conversions are indicated:

$$P_d = P_w + P_c + 1\ bar_g \rightarrow P_d = P_w + \rho_w \cdot g \cdot H + 1\ bar_g \cdot \frac{10^5\ Pa}{1\ bar} \quad \text{(A.6.3.)}$$

Once design pressure is known, the maximum allowable working pressure (MAWP) can be determined, as it is the lowest pressure from the head, body and bottom pressures. As in this case the head and the bottom are flat, the only pressure to be considered is the body one, which is the same as the design pressure. Therefore:

$$MAWP = P_d \quad \text{(A.6.4.)}$$

Design temperature can be easily calculated by just adding 20 ºC to the tank's temperature:

$$T_d = T + 20\ ℃ \quad \text{(A.6.5.)}$$

Then, the tank thickness (t) in mm can be determined by following the defined thickness values depending on the radius defined in API 650, however, as a conservative design criterion, 1 mm of additional thickness is added to the body, the head and the bottom. Moreover, as the bottom is the part under more stress of the whole tank, one more extra millimetre is added.

Knowing that the diameter of all tanks is less than 15.2 m, according to API 650 the minimum required thickness for the body is 4.76 mm, but with the extra millimetre the total thickness of all bodies is 5.76 mm. As the minimum head thickness has no dependence on the diameter, its value for all cases is 4.76 mm too, and therefore the heads' thickness is 5.76 mm, and the bottoms' thickness is 6.76 mm.

As all tops and bottoms of the tanks are flat, they can be modelled on a solid cylinder, whose radius is the internal radius of the tank (R_i) plus its wall thickness (t_{body}), and whose height is their thickness (t_{head} or t_{bottom}):

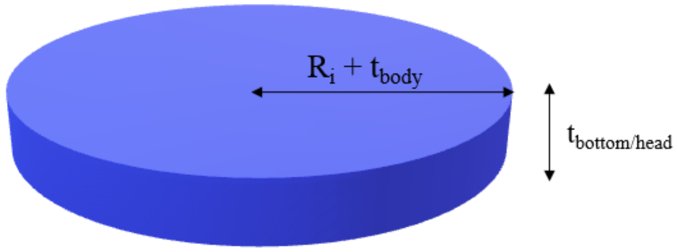

Figure A.6.2. Schematic representation of the top and bottom of the tank.

Then, the mass of the tank (M_t) can be calculated by calculating the body mass and the mass of the bottom and the top. The body mass is the one of an empty cylinder, whereas the one of the bottom and the top are the ones of a solid cylinder:

$$M_t = M_{empty\ cylinder} + M_{solid\ cylinder\ (bottom)} + M_{solid\ cylinder\ (head)} \quad \text{(A.6.6.)}$$

$$M_{empty\ cylinder} = \pi \cdot ((R_i + t)^2 - R_i^2) \cdot H \cdot \rho_m \quad \text{(A.6.7.)}$$

$$M_{solid\ cylinder} = \pi \cdot (R_i + t)^2 \cdot t \cdot \rho_m \quad \text{(A.6.8.)}$$

Finally, the hydraulic test pressure can be calculated as follows:

$$P_t = 1.3 \cdot MAWP \cdot \frac{S\ at\ test\ temperature}{S\ at\ operation\ temperature} \quad (A.6.9.)$$

The obtained results for each of the abovementioned parameters for each tank can be found in the table below:

Table A.6.2. Calculated parameters.

Parameter	Units	T101	T201	T301	T401	T501 & T601
Internal radius (R_i)	m	0.5	0.4	0.2	0.2	0.15
Internal diameter (D_i)	m	1	0.8	0.4	0.4	0.3
Height (H)	m	1.46	1.14	0.69	0.69	0.68
Volume of the overdimensioned tank (V_{ov})	m^3	1.15	0.575	0.086	0.086	0.048
Design pressure (P_d) & MAWP	MPa_g	0.114	0.111	0.107	0.107	0.107
Design temperature (T_d)	ºC	50	40	95	40	40
Thickness (t) **Body / Head:** **Bottom:**	mm	5.76 6.76	5.76 6.76	5.76 6.76	5.76 6.76	5.76 6.76
Total mass of the tank (M_t)	kg	33.7	21.30	6.17	6.17	4.36
Hydraulic test pressure (P_t)	MPa_g	0.149	0.145	0.139	0.139	0.139

A.6.4. Selection of commercial tanks

For the selection of commercial water tanks, the parameters indicated in the previous chart have been considered in order to find a tank whose characteristics are similar to the calculated values. However, as water tanks are widely spread products and do not contain any hazardous substances, the specifications that have been commercially found do not indicate design pressure and temperature, thicknesses and test pressures.

Hence, the datasheets that have been prepared to indicate the characteristics of the selected tanks do not have all the information they should. The only values that have been approximated have been design pressure (which has been estimated by considering the process conditions) and temperature (which has been estimated with the thermal properties of the tank material).

A.7. FINANCIAL STUDY CALCULATIONS

A.7.1. CAPEX

In this section, the prices of the various pieces of equipment and their complements is detailed.

A.7.1.1. FFR RO

As 12 FilmTec™ XLE-2540 membranes are required, Univar Solutions, the official DuPont suppliers in Spain, has been contacted to ask for a quotation.

As the price per unit is 184.00€, the total cost on RO membranes is 2,208.00 €.

A.7.1.2. Adsorption on zeolites

The cost associated to the module of adsorption on zeolites comprises two elements: the zeolites and the recipient that contains them.

The zeolites that have been tested in Eurecat are from ZeoCat, and their gross cost is 1 €/kg if a 20 kg sack is bought (that is the minimum quantity that can be bought). Hence, the total cost associated to zeolites is 20€.

The recipient that contains them has a total volume of 6 L(as the volume of the zeolites is 5.53 L) and its associated cost is 14.16 € (ref. 67).

Therefore, the total cost associated to module of adsorption on zeolites is 34.16 €.

A.7.1.3. Tanks

The selected tanks and their prices and suppliers are listed in the table below. Prices have been obtained as they are indicated on the website.

Table A.7.1. Cost of tanks

Tank	Supplier	Cost (€)
T101	Leroy Merlin	659.00
T201	Amazon	299.95
T301 & T401	Amazon	54.00
T501 & T601	Amazon	25.00

Hence, the total cost of tanks is 1,116.95 €.

A.7.1.4. Pumps

The selected pumps and their prices and suppliers are listed in the table below. Prices for Grundfos pumps have been obtained from their website, whereas the one for P301 has been approximated from a quotation for a similar pump that was bought in Eurecat some years ago.

Table A.7.2. Cost of pumps

Pump	Supplier	Cost (€ / unit)
P101	Grundfos	1,053.00
P201	Grundfos	1,173.00
P301	Cat Pumps	950.00

Pump	Supplier	Cost (€ / unit)
DP401	Grundfos	3,933.00
DP101, DP201, DP301	Grundfos	1,534.00
DP501, DP601, DP701	Grundfos	3,545.00

The total cost of pumps is 22,346.00 €. However, due to the high number of required dosing pumps, it is very likely that if a quotation was asked, the price would be lower as some discounts would be applied.

A.7.1.5. Pipes

The price for the various types of pipes that can be found in the system has been consulted to Arcamo Controls. As lengths are not definitively defined, an approximate quotation of the price per meter has been offered, which results in the costs indicated in the table below:

Table A.7.3. Approximate cost of pipes.

Type of pipe	Price per meter (€/m)	Approximate length (m)	Cost (€)
PVC, ¼”	1.05	3	3.15
PVC, ¾”	1.10	20	22
PVC, 1”	1.37	30	41.1
Stainless steel 904L, 1”	34.68	7	242.76
Teflon, ½”	25	3	75

Hence, the approximate cost of pipes is 384.01 €.

A.7.1.6. Insulation

As the length of the pipes is something that it is still not defined, the exact cost of insulation cannot be determined. However, it can be estimated that just one roll (7,320 mm x 610 mm) will be enough, and its cost is 58.53 € (ref. 63).

A.7.1.7. Instruments

In order to select the most suitable instruments for each measure, two suppliers have been contacted: Hach, and Siemens.

Hach has offered a quotation on conductivity, pH and redox sensors as well as their transmitters and installation complements, which can be found in the table below:

Table A.7.4. Cost of redox, conductivity and pH instruments and their complements (gross).

Product	Price per unit (€)	Units	Cost (€)
CRI4400.99.1113 Multimeter 44, 3 channels (pH & Redox).	1,863.00	3	5,589.00
CRI4400.99.2223 Multimeter 44, 3 channels (Conductivity).	1,863.00	2	3,726.00
CRI4400.99.1203 Multimeter 44, 2 channels (pH & Redox).	1,528.00	1	1,528.00

Product	Price per unit (€)	Units	Cost (€)
CRI4420.99 Conductivity base + temperature for Multimeter 44.	332.00	1	332.00
CRI5303.99 pH electrode.	210.00	8	1,680.00
CRI5362.99 Platinum redox transmitter.	220.00	1	220.00
CRI5388.99 Conductivity sensor for tanks.	402.00	4	1,608.00
CRI5390.99 Conductivity sensor for pipes.	420.00	4	1,680.00
3727E2T.99 Inductive conductivity sensor.	1,050.00	1	1,050.00
CRI6101.99 Immersion probe.	164.00	9	1,476.00
CRI7601.99 Insertion probe.	158.00	4	632.00
CRI5526.99 Temperature transmitter.	134.00	1	134.00
CRI1010.99 Coaxial cable connector AS9.	91.50	9	823.50
CRI9046.99 Multiple cable, connector MP-5.	108.00	9	972.00

As they apply a 23% of discount in the gross price, and value added taxes are a 21%, the total cost of these instruments and their complements is 19.985.43 €.

On the other hand, Siemens has offered a quotation on flow, pressure and level transmitters, and the price of these elements as well as the ones of their complements can be found in the table below:

Table A.7.5. Cost of level, flow and pressure transmitters and their complements

Product	Price per unit (€)	Units	Cost (€)
SITRANS CLS100 7ML5610-0AD20 Capacitive level transmitter. Insertion of 100. Connection ¾” NPT.	185.13	6	1,110.78
SITRANS P220 7MF1567-9AA00-1AA1 H1Y Relative pressure transmitter. Range 0-2 bar. Connection G½”.	127.75	1	127.75
SITRANS P200 7MF1565-3BA00-1AA1 Relative pressure transmitter. Range 0-1 bar. Connection G½”.	127.75	9	1,149.75

Product	Price per unit (€)	Units	Cost (€)
SITRANS P200 7MF1567-9AA00-1AA1 H1Y Relative pressure transmitter. Range 0-20 bar. Connection G½".	127.75	3	383.25
SITRANS P320 7MF0300-1JU01-5AF2-Z B13+E00+Y01 Relative pressure transmitter. Range 1 bar with DN 25 316L membrane with PTFE.	562.28	2	1,124.56
7MF0810-0BD00-0BD0-Z C11+C12+D66 Separator seal, flange type, for absolute and relative pressure transmitters (pressure series).	405.00	2	810.00
SITRANS FM MAG1 100 + MAG5000 7ME6110-1RA10-1LA1 Sandwich electromagnetic flow sensor DN10 PFA and transmitter MAG5000 230 VaC 4-20 mA.	1,464.77	7	10,253.39
SITRANS FM MAG1 100 + MAG5000 7ME6110-1HA20-2LA1 Sandwich electromagnetic flow sensor DN3 ceramic and transmitter MAG5000 230 VaC 4-20 mA.	1,496.75	7	10,477.25
FDK: 083G0080 Accessories for MAG DN2-10, tube conical thread, SS316.	128.47	13	1,670.11
A5E01018395 ½ inch G, ISO 7-1 PVDF thread, grounding ring Hastelloy C22	241.79	1	241.79

Therefore, the total cost of these instruments and their complements is 27,348.63 €.

Finally, a flow indicator has been searched to indicate the flow that circulates through the RO recirculation:

Table A.7.6. Cost of the flow indicator. Source: (ref. 68).

Product	Price per unit (€)	Units	Cost (€)
UP.92.FLG.M 05.92.225A – Flowmeter Methyl methacrylate. With flanges	139.90	1	139.90

Therefore, the total cost associated to all instruments and their complements, from Hach, Siemens and the flow indicator, is 47,473.96 €.

A.7.1.8. Valves

Both the selection and price estimation of valves has been conducted thanks to the recommendations of Arcamo Controls' sales representatives. The pricing of the various components has been estimated with the prices indicated in (ref. 69). As they are expressed in dollars and are from the year 1990, they have been converted into 2021 prices with the following equation:

$$Price_{2021} = Price_{1990} \cdot \frac{CEPCI_{2021}}{CEPCI_{1990}} = Price_{1990} \cdot \frac{614.13}{361.30} \quad \text{(A.7.1.)}$$

CEPCI values for the years 1990 and 2017 were available by Arcamo Controls' sales representatives, and the 2021 value was obtained by estimating that CEPCI has increased a 10% since 2017. It must also be noted that prices in the used reference are in dollars, so prices need to be converted into euros knowing that 1 $ is 0.82 € (ref. 70).

The reason why valves' cost has been estimated like this is because valves are almost fit-for-purpose components. Therefore, it is necessary to have a developed detailed engineering design, and hence, to get a general view of their cost, the use of these tables has been recommended.

However, these tables do not contemplate two factors which are relevant for the present project: the use of materials with a resistance superior to the one of AISI 316L, and the cost of actuators.

For the cost of those valves which are made of stainless steel 904L, it has been estimated that their cost is three times the one for an AISI 316L valve. And in what actuators concerns, their cost has been determined from the sales representatives' experience. The cost of a complete actuator (solenoid valve, limit switch, positioner…) is 900 € for 1" valves, 800 € for ¾" valves and 600 € for ¼" valves.

The resulting cost for each type of valve can be found in the table below.

Table A.7.7. Approximate cost of valves

Type of valve	NPS (in)	Material	Cost / unit (1990, $)	Cost / unit (2021, €)	Number of units	Actuator	Total cost (€)
Automatic, ball	1	316L	11.00	15.33	2	2	1,830.66
Automatic, ball	1	904L	33.00	46.00	4	4	3,783.98
Control, needle	1	904L	49.50	68.99	1	1	968.99
Control, plug	1	316L	115.00	160.29	2	2	2,120.58
Control, seat	1	904L	49.50	68.99	1	1	968.99
Control, seat	¼	316L	12.00	16.73	1	1	616.73
Check, swing	1	904L	33.00	46.00	1	-	46.00
Check, swing	1	316L	11.00	15.33	2	-	30.66
Check, swing	¾	316L	9.50	13.24	2	-	26.48
Check, swing	½	316L	8.00	11.15	1	-	11.15

Type of valve	NPS (in)	Material	Cost / unit (1990, $)	Cost / unit (2021, €)	Number of units	Actuator	Total cost (€)
Manual, ball	1	316L	11.00	15.33	4	-	61.33
Manual, ball	¾	316L	11.00	15.33	10	-	153.32
Manual, diaphragm	¾	316L	1,000.00	1,393.82	8	-	11,150.55
Manual, gate	1	904L	30.00	41.81	11	-	459.96
Manual, gate	1	316L	10.00	13.94	35	-	487.84
Manual, gate	¾	316L	9.00	12.54	28	-	351.24
Manual, gate	½	316L	8.50	11.85	6	-	71.08

Therefore, the total cost of valves is 23,139.55 €.

A.7.2. OPEX

A.7.2.1. Cost of labour

As this is a pilot plant, no constant supervision is required, which means it is enough to have an operator periodically going to the pilot to check whether everything is fine.

However, as a conservative measure, it has been considered that the pilot plant has an operator exclusively devoted to it.

To determine the expenses associated to the salary of a worker, it must be considered that the worker must receive a gross salary and that his/her Social Security contributions must be paid.

Assuming a gross annual salary of 24,110.82 €, his/her Social Security contribution is 7,233.25 €, and hence, the total annual expense is 31,344.07 €.

A.7.2.2. Cost of cartridge filters

Despite cartridge filters being pieces of equipment, they are fungible elements, that is, that they are weekly replaced. Thus, they are considered in the OPEX instead of the CAPEX.

100 µm cartridge filters from Diproclean have a price of 5.30 €/unit (ref. 71). As there are 52 weeks in one year, the total annual cost of cartridge filters is 275.60 €.

A.7.2.3. Cost of chemicals

Depending on the membrane system, the chemicals to add differ.

In the case of reverse osmosis, a constant supply of a mixture of antiscalant and bisulphite is required, whereas in the UF backwash and in T201 a periodical dosage of acids/bases is needed.

A.7.2.3.1. Dosage of antiscalants and bisulphite in during RO operation

In the case of reverse osmosis, it has been observed during previous pilot studies in Eurecat that the most appropriate dosage of the mixture of antiscalant and bisulphite is of 0.010 kg/m^3.

Knowing that the mixture's density is 1.32 g/cm^3 and that the volume to be treated is 10.8 m^3/day, the total volume of the mixture can be obtained:

$$10.8\frac{m^3\ H_2O}{day}\cdot\frac{0.010\ kg\ mixture}{1\ m^3\ H_2O}\cdot\frac{1{,}000\ g\ mixture}{1\ kg\ mixture}\cdot\frac{1cm^3 mixture}{1.32\ g\ mixture}=81.82\ \frac{cm^3\ mixture}{day} \tag{A.7.1.}$$

However, it must be considered that the product is sold in a concentration of 39%. Hence, the real daily volume is 209.79 cm^3.

Knowing that the cost of 60 L of sodium bisulphite is 60.50 € (ref. 72), the cost of chemicals for the reverse osmosis module can be estimated:

$$209.79\frac{cm^3\ mixture}{day}\cdot\frac{1\ L}{1{,}000\ cm^3}\cdot\frac{60.50\ €}{60\ L}\cdot\frac{365\ days}{1year}=77.21\frac{€}{year} \tag{A.7.2.}$$

A.7.2.3.2. NaClO for the Cleaning in Place (CIP)

CIP takes place every 3 months, and consists in adding NaClO to the UF permeate tank until reaching a concentration up to 4,000 mg/L to later chemically clean the membrane (ref. 22).

Since the effective volume of T201 is 510 L, and the density of NaClO is 1.11 g/cm^3, the annually required NaClO can be calculated:

$$510L\cdot\frac{4{,}000\ mg\ NaClO}{1L\cdot CIP}\cdot\frac{1g}{1{,}000\ mg}\cdot\frac{1\ cm^3\ NaClO}{1.11\ g\ NaClO}\cdot\frac{4\ CIP}{1year}=7{,}351.35\ \frac{cm^3\ NaClO}{year} \tag{A.7.3.}$$

As the concentration in which the product is sold is 15%, the real volume that is to be added is 49,009 cm^3.

As the cost of 25L of NaClO is 22 € (ref. 73), the annual CIP cost can be estimated:

$$49{,}009\ cm^3 NaClO\cdot\frac{1L}{1{,}000cm^3}\cdot\frac{22€}{25\ L\ NaClO}=43.13\ € \tag{A.7.4.}$$

A.7.2.3.3. NaClO and H_2SO_4 for the Chemically Enhanced Backwash (CEB)

CEB is a weekly cleaning in which some chemicals (acids or bases) are dosed in line during the backwash. For basic cleaning, NaClO, which acts as a biocide, is typically dosed to obtain concentrations of 150 mg/L while for acid cleaning H_2SO_4 is dosed to obtain concentrations of about 250 mg/L (ref. 22).

Assuming that half of the CEB will be acid and the other half basic, there will be 26 CEBs for each type. It must also be noted that CEBs last for about 15 minutes, and it is just for 30 seconds that the chemicals are dosed.

As NaClO properties are known from the previous section and the backwash flow is 12 m^3/day:

$$12\frac{m^3\ H_2O}{day}\cdot\frac{1\ day}{24\ h}\cdot\frac{1\ h}{60\ min}\cdot\frac{15\ min}{1\ CEB}\cdot\frac{1{,}000L}{1m^3}\cdot\frac{150\ mg\ NaClO}{1L\ H_2O}\cdot\frac{1g}{1000mg}\cdot\frac{1\ cm^3\ NaClO}{1.11\ g\ NaClO}=16.89\ \frac{cm^3 NaClO}{CEB} \tag{A.7.5.}$$

Because of its concentration of 15%, the real required volume is 112.61 cm^3 per CEB. Then, the cost can be calculated:

$$112.61\ \frac{cm^3 NaClO}{CEB} \cdot \frac{1L}{1{,}000cm^3} \cdot \frac{22€}{25\ L\ NaClO} \cdot \frac{26\ CEB}{year} = 2.58\frac{€}{year} \quad \text{(A.7.6.)}$$

And the same calculation is done for H_2SO_4:

$$12\frac{m^3\ H_2O}{day} \cdot \frac{1\ day}{24\ h} \cdot \frac{1\ h}{60\ min} \cdot \frac{15\ min}{1\ CEB} \cdot \frac{1{,}000L}{1m^3} \cdot \frac{250\ mg\ H_2SO_4}{1L\ H_2O} \cdot \frac{1g}{1000mg} \cdot \frac{1\ cm^3\ H_2SO_4}{1.39\ g\ H_2SO_4} = 22.48\frac{cm^3 H_2SO_4}{CEB} \quad \text{(A.7.7.)}$$

However, it must be considered that the product is sold in a concentration of 50%. Hence, the real daily volume is 44.96 cm^3.

As the cost of 25 L is 27.00€ (ref. 74), the annual cost for acid CEBs can be estimated:

$$44.96\ \frac{cm^3 H_2SO_4}{CEB} \cdot \frac{1L}{1{,}000cm^3} \cdot \frac{27€}{25\ L\ H_2SO_4} \cdot \frac{26\ CEB}{year} = 1.26\frac{€}{year} \quad \text{(A.7.8.)}$$

A.7.2.3.4. Total cost of chemicals

The total cost of chemicals is the sum of the annual costs of each item. The total cost of chemicals is 124.18 €/year.

A.7.2.4. Cost of mains water

Mains water is used for two different purposes in the pilot plant: cleaning, and cooling.

Tanks will be preventively cleaned every six months, which means they will be totally filled (overflow drains closed) twice a year.

Knowing that T101 volume is 2,000L, that of T201 600L, that of T301 and T401 120 L and that of T501 and T601 60 L, the total required water volume for each maintenance is 2,960 L.

As on average the cost for the production of 1 m^3 of water is of about 0.5 €, and assuming that AITASA uses its own produced water, the total cost for cleaning all tanks twice a year is:

$$2{,}960\frac{L\ mains\ water}{maintenance} \cdot 2\frac{maintenance}{year} \cdot \frac{1\ m^3}{1{,}000\ L} \cdot \frac{0.5€}{m^3\ mains\ water} = 2.96\frac{€}{year} \quad \text{(A.7.9.)}$$

And as the total volume of water devoted to the cooling of T401 is 204 L/h, the cooling cost is:

$$204\frac{L\ mains\ water}{h} \cdot \frac{24h}{1\ day} \cdot \frac{365\ days}{1\ year} \cdot \frac{1\ m^3}{1{,}000\ L} \cdot \frac{0.5€}{m^3\ mains\ water} = 893.52\frac{€}{year} \quad \text{(A.7.10.)}$$

The annual cost of mains water is 896.48 €.

A.7.2.5. Cost of electricity

Knowing that the cost of industrial electricity in Spain is 42.08 €/MWh (ref. 12), the electricity cost associated to each piece of equipment that requires it can be calculated. It is assumed that both pumps and the electric resistance operate 24 hours a day during the whole year, although this is not exactly true as their power will be adjusted depending on the process needs and there may be some stops for maintenance purposes.

The electricity cost associated to DP101 and DP201 has not been calculated as their operation is punctual and hence not representative.

Consumption for P101 and P201 has been obtained from Grundfos' smart sizing, while for P301 and dosing pumps their maximum power input has been selected as a conservative criterion.

Table A.7.8. Annual cost of electricity for each piece of equipment that requires it.

Name	Consumption (kW)	Annual consumption (kW)	Annual cost (€)
P101	0.056	490.56	20.64
P201	0.132	1,156.32	48.66
P301	1.500	13,140.00	552.93
DP401	0.200	1,752.00	73.72
DP501	0.062	543.12	22.85
DP601	0.062	543.12	22.85
DP701	0.062	543.12	22.85
DP301	0.024	210.24	8.85
EH101	4.000	35,040.00	1,474.48

Hence, the annual electricity consumption is 2,247.85€.

A.7.2.6. Cost of laboratory analysis

Due to the experimental nature of the project, there are several analysis that need to be periodically conducted in the pilot plant.

The table below indicates these analysis as well as the pilot sections that require them and their periodicity and cost. The costs associated to each analysis type are the prizes for which Eurecat offers its laboratory services.

Table A.7.9. Laboratory expenses

Analysis	Cost per analysis (€)	Section(s) to analyse	Periodicity		Total annual cost (€)
			15 days	Monthly	
Conductivity	10.5	Treated water	X		252.00
DOC	46.25	UF permeate RO permeate RO retentate Treated water	 X	X X X	2,775.00
E. coli	17.27	Treated water	X		414,48
Legionella	32.22	Treated water	X		773,28
NH_4^+	26.63	RO permeate Treated water	 X	X	958.68
$N_{Kjeldahl}$	46.32	UF permeate RO retentate		X X	1,111.68
Oils & Grease	52.50	Wastewater feed UF permeate		X X	1,260.00
pH	8.50	Wastewater feed UF permeate		X X	204.00
SDI	56.25	UF permeate		X	675.00

Analysis	**Cost per analysis (€)**	**Section(s) to analyse**	**Periodicity**		**Total annual cost (€)**
			15 days	**Monthly**	
SSM	19.25	Wastewater feed		X	1,155.00
		UF permeate		X	
		RO retentate		X	
		Treated water	X		
TIC	45.00	UF permeate		X	1,080.00
		RO retentate		X	
Turbidity	16.25	Wastewater feed		X	1,170.00
		UF permeate		X	
		RO permeate		X	
		RO retentate		X	
		Treated water	X		

Therefore, the total annual cost of laboratory analysis is 11,829.12 €.

The reason why it is so high is because of the nature of the project. As it is a research project, there is a great number of variables that need to be assessed on a regular basis, because the main aim of the project is to obtain as much information as possible.

A.7.2.7. Cost of service and maintenance

It has been bibliographically determined that the expenses associated to service and maintenance activities account for 2.5% of the initial investment (CAPEX) of the pilot (ref. 75).

Hence, the annual cost of service and maintenance is 3,324.44 €.

A.7.2.8. Cost of insurance

It has been bibliographically determined that insurance costs account for 0.5% of the initial investment (CAPEX) of the pilot (ref. 75).

Hence, the annual insurance cost is 664.89 €.

A.7.2.9. Depreciation

Depreciation is the value or worth decrease that the physical plant experiences during time. To determine its value, three different calculation methods have been compared: Straight-Line depreciation method (SL), Sum of the Years Digits depreciation method (SOYD), and Double Declining Balance depreciation method (DDB):

$$d_k^{SL} = \frac{[FCI_L - S]}{n} \quad \text{(A.7.11.)}$$

$$d_k^{soyd} = \frac{[n+1-k]\cdot[FCI_L - S]}{\frac{n}{2}\cdot[n+1]} \quad \text{(A.7.12.)}$$

$$d_k^{DDB} = \frac{2}{n}\cdot\left[FCI_L - \sum_{j=0}^{j=k-1} d_j\right] \quad \text{(A.7.13.)}$$

Where FCI_L is the fixed capital investment, which is the fixed capital investment used to build the plant minus the cost of land, and represents the depreciable capital investment (in this case, CAPEX). S is the salvage value, which is the FCI_L value evaluated at the end of the plant life; it usually represents a small fraction of the initial capital investment, but it is often assumed as

0. n is the number of years that are evaluated, k the year of study, and d_j the sum of the previous d_k^{DDB} values (ref. 76).

Considering that the pilot will operate for two years, but that once this period ends its various components will be reused for other purposes, the selected n value is 15 (ref. 77). S is assumed to be 0, and FCI_L is 132,977.48 €, which is the value obtained in section *7.1. Capital expenditures (CAPEX)*.

Annual depreciation has been calculated with each of the previous expressions, and then the total depreciation of the period has obtained by adding up the annual values for each method.

The obtained values for each method are indicated in the table below:

Table A.7.10. Total depreciation (€) in 15 years for each depreciation method.

Year	Straight-Line (SL)	Sum of the Years Digits (SOYD)	Double Declining Balance (DDB)
0	**-**	**-**	**-**
1	8,865.17	16,622.19	53,190.99
2	8,865.17	15,514.04	31,914.60
3	8,865.17	14,405.89	19,148.76
4	8,865.17	13,297.75	11,489.25
5	8,865.17	12,189.60	6,893.55
6	8,865.17	11,081.46	4,136.13
7	8,865.17	9,973.31	2,481.68
8	8,865.17	8,865.17	1,489.01
9	8,865.17	7,757.02	893.40
10	8,865.17	6,648.87	536.04
11	8,865.17	5,540.73	321.63
12	8,865.17	4,432.58	192.98
13	8,865.17	3,324.44	115.79
14	8,865.17	2,216.29	69.47
15	8,865.17	1,108.15	41.68
TOTAL	132,977.48	132,977.48	132,914.96

The selected depreciation method is SOYD, as it is the one that best represents the effect of time on the equipment value. Thus, the first two values of the series are the ones to be considered in the OPEX calculations: 16,622.19 € for the first year and 15,514.04 € for the second one.