Innovative concept for Ultrafiltration systems: Integration of ultrafiltration cartridges and strainer in a single vessel

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Abstract:

The Integrated UF or i-UF is a new product line that combines two concepts:

- Elimination of the housing and the accessories of UF membrane modules, introducing UF fibers directly into a pressure vessel.
- Integration of UF pre-strainer within the same pressure vessel.

The resulting integrated UF (i-UF) provides the following benefits:

- The i-UF vessel is designed to work outdoors. This dramatically decreases investment costs and lead time, as the need for a UF building is eliminated.
- The plant's footprint decreases, and fewer auxiliary elements are required (i.e. equipment, piping, valves, control elements, etc.).
- High Pressure Tolerance that allows Direct Coupling UF to RO: Reduced CAPEX (RO Pumps, Break Tank & RO Cartridge Filters and Reduced RO Fouling Risk due to close system
- Water consumption is optimized, as the same cleaning water volume is used to clean both the UF membranes and the strainer.
- The pressure drop in the system is lower (no dP due to interconnecting piping and accessories), which improves the energy efficiency of the plant.
- I-UF system is similar to the multimedia filtration system, making it easier to retrofit these conventional systems.

The i-UF combines a 100-300 µm self-cleaning strainer and UF membrane cartridges in the same pressure vessel, generally made of fiberglass-reinforced polyester.

This equipment includes actuated valves and pressure switches that will allow automatic backwashes. Both stages can be backwashed with the same water flow, ´thus saving on water and valves. If necessary, each stage could be backwashed individually.

1 Introduction

In recent years, hollow fiber Ultrafiltration (UF) technology has established itself as a reliable pretreatment alternative for Reverse Osmosis (RO) systems over traditional methods, for reasons such as lower footprint, lower environmental impact or higher efficiency in the removal of particulate, colloidal and suspended matter. On the other hand, more stringent water quality regulatory requirements around the world together with a higher industry experience and references, and the increasing proliferation of new applications and providers, has further driven the Ultrafiltration technology current consolidation.

Thus, in search of more competitive and efficient Ultrafiltration systems, an innovative concept has been developed and tested, where the ultrafiltration modules and the protective strainer are integrated in a single vessel. Advantages of this approach are minimal footprint, higher system recovery, installation outdoors which reduces civil work needs and cost, streamlined retrofitting of existing conventional media filters, and higher pressure tolerance with facilitates direct coupling of UF and RO systems. Besides, the ultrafiltration cartridges feature the last generation of high permeability and high productivity PVDF ultrafiltration fibers, which achieve a significant reduction of energy consumption compared to the previous fiber generation.

In this article, design and operational aspects of this innovative ultrafiltration system will be shared. Secondary waste water and open intake seawater sources were field trialed, achieving comparable performance parameters in terms of membrane permeability, system recovery and chemical consumption as standard ultrafiltration skids. Moreover, novel methods were as well implemented to increase membrane cleaning efficiency.

2 Description of the Technology

The i-UF combines a 100-300 µm self-cleaning strainer and UF membrane cartridges in the same pressure vessel, generally made of fiberglass-reinforced polyester.

This equipment includes actuated valves and pressure switches that will allow automatic backwashes. Both stages can be backwashed with the same water flow, thus saving on water and valves. If necessary, each stage could be backwashed individually.

The i-UF unit is to be used in the water treatment sector, in applications where the ultimate purpose is to eliminate suspended solids (where it acts as the main treatment) or dissolved solids (in which case it acts as pre-treatment).

3 Basic engineering

Starting from the products already on the market, the R&D department of Fluytec embarked on a design phase (basic engineering) to create a product that could bring together the two stages of filtration in a single unit: primary or coarse filtration and the fine, ultrafiltration stage.

The product was created with the following main objectives in mind:

- To reduce the plant floor-space required and do away with the need to erect a building around the UF unit.
- To substantially reduce investment costs in main, auxiliary and control equipment.
- To substantially reduce the amount of filtered water used for washing (maintenance operations) and thus also reduce operating costs (since that water has to be pumped and in many cases chemically treated in the current system).
- To simplify and minimize the operation and maintenance of the whole unit compared to the current system with its two units, and thus reduce operating and maintenance costs.
- To enable ultrafiltration cartridges to be replaced without having to discard the housings.

In pursuit of these goals, Fluytec applied its broad experience in the desalination market and in the design and manufacturing of filtration equipment and took as its reference point the FRP (fiberglass-reinforced polyester) cartridge filters which are currently the star product in its portfolio.

It is well-known that FRP units provide optimal performance with water with different degrees of salinity, cut down on maintenance in these conditions, and optimize filter equipment installation costs. They can also be installed outdoors without detriment to their useful lifetimes. They were therefore considered as the ideal material for meeting part of the goals set.

The next step was to develop conventional knowledge to bring it forward from cartridge filtration to ultrafiltration. Fluytec had already noted that the market was calling for ever-larger filters containing more and more cartridges, and that small PVC cartridges were being relegated to use in specific, low flow-rate projects.

Once the goals were clear it was time to focus efforts on choosing the right type of membrane that would fit as well as possible into the unique operating characteristics of i-UF. In this case the type of membrane selected was the last generation of high permeability PVDF hollow-fibers from DOW™, with an Outside-In filtration pattern and a nominal pore size of 0.03 microns.

Finally, there was a need to work on the idea of bringing together the required primary or coarse filtration and ultrafiltration in a single unit. An important point in the design of this profile was to find a way of cleaning the unit that did not necessitate dismounting the equipment to gain access to it. Accordingly, a metal section was designed that houses a brush that can be moved with a propeller attached to one end of the brush.

This resulted in an i-UF unit that looked like this:

Figure 1: Cross-section of the i-UF with internal mechanisms

4 Pilot unit and piloting

Once the detail engineering was completed a prototype was manufactured for an output of ~10 m3/h of ultra-filtered water. This prototype includes not only the i-UF itself but also the auxiliary elements required for cleaning.

The i-UF500 consists of a filter body manufactured in FRP with a diameter of 500 mm. Inside this body is a 150 µm metal mesh for coarse-filtering the infeed water. The ultrafiltration part is made up of 3 cartridges of 55 m2 each (165 m2 of total filtering surface area).

The front valve and instrument frame houses all the tubing, valves and instruments required for the filtration and cleaning sequences.

The i-UF500 unit and its auxiliary frames have been treating sewage water at the Southeast Wastewater Treatment Plant owned by the Southeast Supramunicipal District, in the municipality of Agüimes on the island of Grand Canary; Spain.

The intention was to check how efficiently it runs and how effective the filtration and cleaning processes are, with a view to using it as a strong alternative to conventional filtration systems in water treatment plants.

Figure 2: Pilot i-UF400 installed in Southeast Supramunicipal District waste water Treatment Plant, in the municipality of Agüimes on the island of Grand Canary; Spain

As highlighted in the conclusions, this piloting was a success, so the equipment has been taken to the Desalination plant of Las Palmas III, in Las Palmas de Gran Canaria, Spain in order to test its efficiency treating sea water. The results of this second piloting will be available by the end of September 2018 .

4.1 Objectives of the pilot in Southeast Wastewater Treatment Plant

The main objectives of the piloting are the following:

• Validate the concept of Integrated Ultrafiltration as a filtration system, verifying the behavior of the unit in relation to permeability parameters, system recovery, efficiency of cleaning cycles and consumption of chemicals compared to Conventional Ultrafiltration.

• Validate the DOW^{TM} Ultrafiltration technology for the treatment of wastewater from the secondary treatment of the Southeast WWTP, after the clarification process and subsequent chlorination, prior to the tertiary treatment.

• Establish the optimal design parameters (i.e. flux, backwash frequencies, frequencies of chemical washes, etc.) for the different qualities of water inlet.

• Demonstrate a stable operation (i.e. permeability, transmembrane pressure, flow rate and filtering quality) for the different operating conditions during the testing phase.

• Monitor the input and output quality parameters of the UF (by the Southeast Supramunicipal District through the operating company of the Acciona Aguas facility).

4.2 Description of the pilot plant 10_i-UF_500 PN5 GRP

The design of the Integrated Ultrafiltration System i-UF consists of a filter body called i-UF, whose key lies in the integration, in a single set, of two stages of filtration than in conventional water treatment plants, up to the date, they are executed individually, as they are a primary filtration (or roughing) and a refining stage by means of ultrafiltration membranes.

Figure 3: General view body 10_i-UF_500 PN5 GRP

This filtration system is composed of a main body; a metal frame, auxiliary equipment and an electrical and control panel:

- Main body: houses the two stages of filtration, includes filtering profile and membrane cartridges.
- Metallic frame: includes valves and instrumentation and connection boxes.
- Auxiliaries: consists of the following equipment:
- Raw water pumping system
- Filtered water tank / BW
- Backwash system (BW)
- Chemical dosing system
- Compressed air system,
- Chemical cleaning system (CIP)
- Electrical and Control Panel

The pilot plant 10_i-UF_500 PN5 GRP, built by Fluytec Filtration Technologies, includes three (3) DOW^{TM} Ultrafiltration cartridges of 55 m2 of membrane surface each, with high permeability fibers of the latest generation, and is able to produce up to 10.8 m3 / h.

4.3 Water Sampling and Analysis Program

As part of the piloting objectives, it is necessary to take water samples periodically and analyze the parameters shown in Table 1 below, which includes sampling points and recommended frequencies for each parameter.

Table 1. Sampling and Analysis Program

Parameter	Unit	Sampling Point	Frecuency	Result [1]
Turbidity	NTU	Inlet Filtrate	Daily	**5.5/13.2** **0.2/0.5**
Suspended Solids (SS)	mg/L	Inlet Filtrate	Twice per week	**6.8/13.0** **0/2**
Chemical Oxigen Demand (COD)	mg/L	Inlet Filtrate	Twice per week	**54.7/72.4** **35.7/48.6**
Biologic Oxigen Demand (BOD)	mg/L	Inlet Filtrate	Twice per week	**19.3/29.0** **11.7/17.0**
Temperature	ºC	Inlet	Daily	**24º/29º**
Microbiology **(Total Coliforms, E.Coli,** **TVC at 22C and 37C, Clostridium,** **Enterococci)**	**u/100mL**	**Inlet** **Filtrate**	**6 months**	

Note 1: Average & Maximum values

4.4 Record of Operational Data

Operational data have been recorded periodically to study, interpret and optimize the operation of the unit. These data refer mainly to dates, flows, pressures of entry and exit to the UF, water temperature; inlet and outlet output turbidity and suspended solids.

This operational data has been entered into the DOW™ Ultrafiltration Normalization Sheet.

4.5 Testing Protocol

Table 2 below shows the proposed Test Protocol for the water exiting the secondary treatment, after passing through the chlorination coil. This inlet water is characterized by turbidity <6 NTU, SS <7 mg / L, BOD <20 mg / L and COD <60 mg / L (average values).

The protocol was divided into different phases, starting from a conservative approach and aiming to gradually optimize the operation as the set points defined in each phase are achieved and consolidated. The parameter in red indicates the modifications to be made with respect to the previous phase.

The operation parameters that were most optimal in terms of recovery of the system were 50 LMH of flux and 30 to 40 minutes of filtration cycle.

Table 2. Testing Protocol for Turbidity < 10 NTU, SS < 10 mg/L and BOD < 20 mg/L (media values)

		VALIDATION PHASE				OPTIMIZATION PHASE		
Parameter	**Basis of Design (Guidelines) -Target-**	**Initial Phase**	**Phase 2**	**Phase 3**	**Phase 4 (Target Conditions)**	**Phase 5**	**Phase 6**	**Phase 7**
Start - Date	-	19-Sep-17	10-Oct-17	3-Nov-17	7-Jan-18	4-Feb-18	16-Feb-18	6-Mar-18
Stop - Date	-	10-Oct-17	3-Nov-17	29-Nov-17	4-Feb-18	16-Feb-18	26-Feb-18	19-Mar-18
No. of Operation Days	-	21	24	26	28	12	10	13
Module information:		IC-55XP	IC-55XP	IC-55XP	IC-55XP	IC-55XP	IC-55XP	IC-55XP
Membrane area (m^2)	3 x 55	165	165	165	165	165	165	165
Operation Parameter:								
Instantaneous Filtration Flux, LMH	60	40	50	55,0	60	60	65	50
Filtration Gross Flow, m3/h	9,9	6,6	8,3	9,1	9,9	9,9	10,7	8,3
Backwash Flux, LMH	100	100	100	100	100	100	100	100
Backwash Flow, m3/h	16,5	16,5	16,5	16,5	16,5	16,5	16,5	16,5
Air Scour Flow (per cartridge), Nm3/h	10	10	10	10	10	10	10	10
Recovery, %	>90	91,98%	94,63%	93,79%	93,18%	93,69%	92,93%	95,65%
TMP Setpoint for CIP, bar (Temp. corrected)	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
Filtration Duration, min.	30	30	30	30	30	40	30	40
Air Scour Duration, sec.	30	30	30	22	22	22	22	22
Drain Duration, sec.	30	30	30	40	40	40	40	40
Backwash Duration, sec.	30	30	30	30	30	30	30	30
Forward Flush Duration, sec.	30	30	30	12	12	12	12	12
CEB1: Oxidant+Alkali								
CEB1, Chemical, Dose (mg/L) and pH target	750 ppm NaClO 650 ppm NaOH, pH 12	750 ppm NaClO 650 ppm NaOH, pH 12 (optimize)	750 ppm NaClO 650 ppm NaOH, pH 12 (optimize)					
CEB1 Flux, LMH	Same as BW	Same as BW	Same as BW					
CEB1, frequency	Every 12 hours	Every 12 hours	Every 12 hours	Disabled	Disabled	Disabled	Disabled	Disabled
CEB1 (Top), Dosing Time, sec.	30	30	30					
CEB1 (Bottom), Dosing Time, sec.	30	30	30					
CEB1, Soak Duration, min.	10	10	10					
CEB1, Backwash Rinse Time, sec.	60	60	60					
CEB2: Acid								
CEB2, Chemical and pH target	pH 2 HCl	pH 2 HCl	pH 2 HCl					
CEB2 Flux, LMH	Same as BW	Same as BW	Same as BW					
CEB2, frequency	Every 36 hours	Every 36 hours	Every 36 hours					
CEB2 (Top), Dosing Time, sec.	30	30	30	Disabled	Disabled	Disabled	Disabled	Disabled
CEB2 (Bottom), Dosing Time, sec.	30	30	30					
CEB2, Soak Duration, min.	10	10	10					
CEB2, Backwash Rinse Time, sec.	60	60	60					
CIP								
Frequency (days)	30	As Required	Done on 3-Nov	Mini-CIP	Mini-CIP	Mini-CIP	Mini-CIP	Mini-CIP

4.6 Analysis of the Operation of the Pilot Plant

The indicated parameters include the specific characteristics of the feed water and system requirements, as well as the design of the system developed to meet said requirements based on known design factors. Any change in the characteristics of the feedwater (quality or quantity) or other aspects of the configuration of the unit have significantly modified the overall functioning of the system.

Table 3 lists power specifications and system requirements.

Table 3.

Parameter	Power
Power	400 V / 3 P / 50 Hz
Amperage	63 A
Total Nominal Power	70 kVA

Tables 4 and 5 summarize the configuration data of the system, flows and consumptions.

Table 4.

Parameters	System Data
Type of membrane cartridges	IC-55-XP (Prototype)
Configuration	Hollow Fibers Out/In
Membrane Area	55 m^2
Number of membrane cartridges	3
Total Membrane area	165 m^2
Nominal diameter of the pore	0,03µm
Maximum operational pressure	6 bar at 20ºC
Typical operational pressure	< 1.5 barg
Cartridge membrane length	2,020 mm

Table 5.

Parameters	System Data
Filtered water flow	Up to 10.80 m^3/h
Backwash flow	16.50 m^3/h
Recovery	Up to 94%
Operational pressure	Inlet – 2,0 barg, Outlet 0,6 barg

4.7. Results:

Figure 2 shows the normalized permeability profile during the pilot period. The permeability, expressed in Liters / hour. m2 membrane.barg (LMH / bar), is one of the most important operating indicators in an ultrafiltration system, since it allows us to study the tendency of membrane fouling and the efficiency of chemical cleaning. The greater the permeability of the membranes, the lower the energy consumption of the process. The permeability decreases as the membranes become dirty, and reaching a minimum value, it is necessary to carry out a chemical cleaning to recover it. The term Normalization refers to the adjustment of the data to a common reference temperature, in this case 25ºC, to eliminate the deceptive effects that changes in the viscosity of water as a function of temperature have on the permeability, and differentiate them from those due exclusively to fouling phenomena, which are what we are interested in studying.

The normalized permeability at the start of the equipment in September 2017 was around 95-100 LMH / bar. A drop in permeability up to about half is observed due to the low efficiency of the Chemically Enhanced Backwash (CEB) washes during the first weeks of operation. The recovery of permeability observed around November 3 is due to a Clean in Place (CIP) cleaning that was carried out that day with ultrafiltered water.

As of November 21, the strategy of chemical cleaning changes; the CEBs are disabled and cleaned with short CIP programs ("Mini-CIP"), based on cleanings with caustic soda (NaOH) at pH 11.5 and sodium hypochlorite (NaOCl) at concentrations around 1000-1500 ppm, combined with cleanings with hydrochloric acid (HCl) at pH 2 every three cycles of alkaline cleaning.

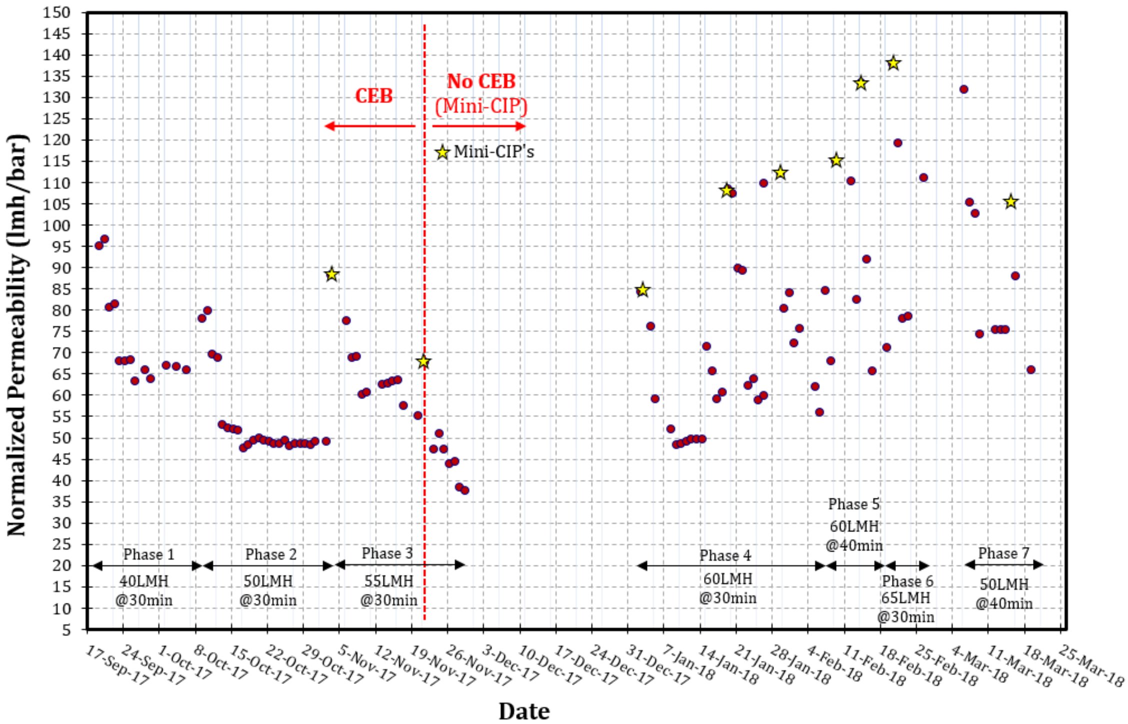

Figure 4. Normalized Permeability

After the stop for the Christmas period, the unit started again with a Mini-CIP on January 2nd, which recovers the permeability around 85 LMH / bar. The next mini-CIP on January 19 raises the permeability to 110 LMH / bar. The successive Mini-CIPs recover the permeability to values up to almost 140 LMH / bar.

It is observed that in general the strategy of applying Mini-CIPs is more effective than the CEBs, achieving better recovery of permeability and a more stable operation.

Figure 3, on the other hand, shows the tendency of the Transmembranal Pressure (TMP), with initial values around 0.40 bar. The graph shows real values of TMP, not normalized (although the file that is attached in Appendix A also includes the standardized TMP graph).

The average value of TMP for the entire pilot period was 0.87 bar, which would correspond to an average energy consumption of around 0.033 kWh / m3 of filtered water. This value refers exclusively to the filtration process through the ultrafiltration fibers, without taking into account the protective filter, the additional pressure losses in the system or the cleaning operations. The total energy consumption of the process is estimated around 0.08-0.10 kWh / m3 of filtered water.

The TMP follows an inverse tendency to the permeability (that is to say, the increase of TMP is reflected in a decrease of the permeability), due to the fouling of the membranes. It must also be borne in mind that an increase in the operating flux also results in an increase in the TMP, hence the jumps observed between the different phases of the pilotage when the operating flux varies. It is also important to point out that the maximum allowed value of TMP to avoid problems of integrity of the ultrafiltration fibers is 2.1 bar, although the maximum value that has been reached during the piloting was 1.5 bar.

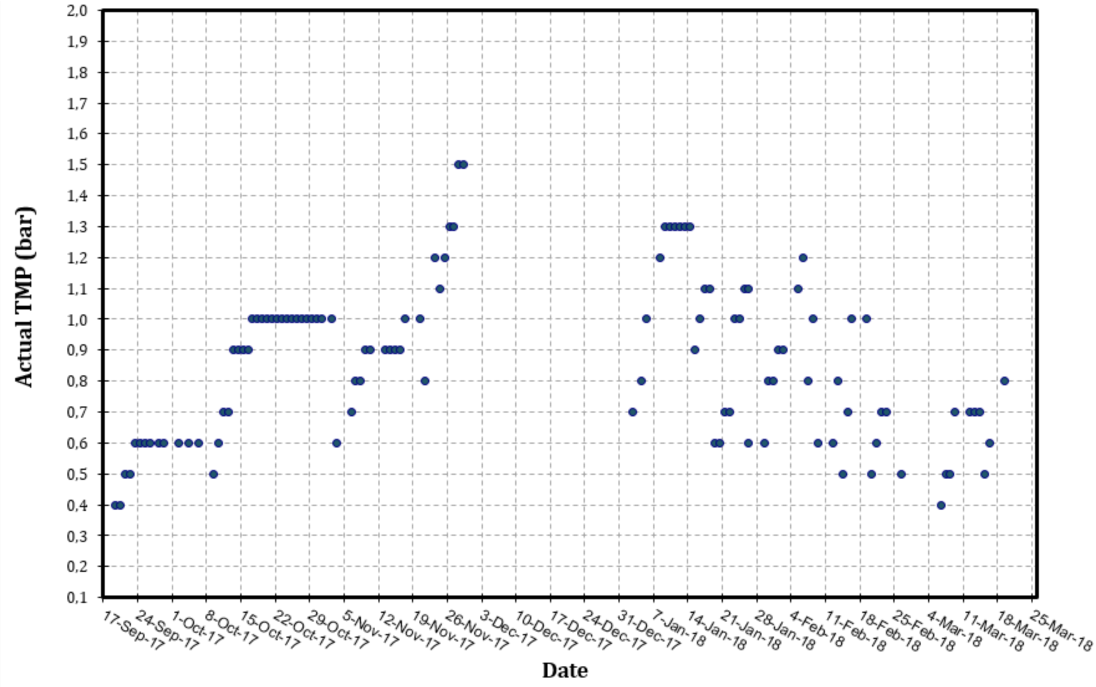

Figure 5. TMP

Finally, Figure 6 shows the values of turbidity and suspended solids (SS) in the inlet and outlet of the unit. It is observed that the filtrate shows average values below 0.2 NTU and absence of SS.

Conclusions of the pilot

The concept of Integrated Ultrafiltration has been verified as a filtration system, demonstrating a stable operation in terms of permeability, recovery of the system (with values up to 95%), transmembrane pressure, efficiency of chemical cleaning and quality of filtered water, being equivalent to those of a standard ultrafiltration and improving the performance of conventional granular filters without the need to use complex and expensive previous coagulation / flocculation processes, and with the added advantage of occupying a smaller space.

The average value of transmembrane pressure (TMP) for the entire pilot period was 0.87 bar, which corresponds to an average energy consumption of around 0.033 kWh / m3 of filtered water. On the other hand, the quality of the filtrate has been consistently maintained below 0.2 NTU of turbidity and absence of solids in suspension, incomparable to the quality that can be obtained with a conventional granular filter and therefore more suitable as feeding to subsequent reverse osmosis processes.

The operation parameters that were most optimal in terms of recovery of the system were 50 LMH of flux and 30 to 40 minutes of filtration cycle.

During the pilotage it has been observed that in general the strategy of applying Mini-CIPs for chemical cleaning is more effective than the CEBs, achieving a better recovery of the permeability and a more stable operation, with the addition of requiring a lower chemical consumption.