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Design and start-up experiences of 19,000 m^3/d Camp de Tarragona-Vilaseca Water Reclamation Plant

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ABSTRACT

Within the current and future world's water scarcity, the reuse of treated waste water for specific applications offers an appealing alternative to conventional fresh water sources that cannot meet the expectations, mostly in terms of quantity. Spain is no exception to this global situation, with a constantly increasing population, in combination with growing water demand for applications such as production industry, exportation oriented agriculture, tourism development, and booming construction, access to sufficient quantities of fresh water is currently a rising concern. Camp de Tarragona (ACA) Water Reclamation Project is a prime example how water scarcity can be solved regionally by reclaiming water that would otherwise be discharged to the sea. The new reclamation plant treats municipal secondary effluent from Tarragona and Salou/Vilaseca Wastewater Treatment Plants to supply process water for the petrochemical industry of Tarragona. The plant capacity is currently 19,000 m^3/d (Phase I), and further expansions are planned for increases up to 29,000 m^3/d (Phase II) and even to 55,000 m^3/d (Phase III) in the coming years. This additional supply would replace the water currently taken from the Ebro River, thus releasing this volume for drinking water supply to the population. Utilizing such a process, the industrial growth in water scarce regions can be supported and industry sustainability is increased further. A pipeline connects the two different Wastewater Treatment Plants (WWTPs), 10 km apart from each other, and feeds secondary treated effluent to the reverse osmosis (RO) pretreatment process. The pretreatment consists of ballasted flocculation, followed by disc filtration, sand filtration, and multimedia filtration prior feeding it to the two pass RO system. Final permeate treatment is done by UV light and chlorine disinfection, prior releasing water to the distribution system. This paper will review the detailed design of the plant, as a scale-up of pilot plant results, as well as the RO membranes performance data obtained during the start-up of the installation. RO performance is evaluated in detail taking into account the performance differences when different combinations of raw water sources were used. This paper will also explain in detail the preservation of the installation by means of 5-Chloro-2-Methyl-2H-

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Isothiazol-3-one/2-Methyl-2HIsothiazol-3-one (CMIT/MIT), during a medium term stop of the plant.

Keywords: Water; Reuse; Reverse osmosis; Start-up; Industrial

1. Introduction

Seasonal droughts and regional water scarcity has pushed to the search of alternative sources of water in Spain. Water reclamation and reuse soon appeared as solution in the early 90s, with the aim of producing water for irrigation. The 2007–2015 National Plan for water quality, sanitation, and purification is now easing the use of reclaimed water as a source for industrial water production [1].

Camp de Tarragona-Vilaseca Wastewater Reuse Plant is a prime example how wastewater can be used to increase the industry sustainability and support industrial growth in a water scarce region as Catalonia's Baix Camp.

The reuse plant start-up design and start-up performances, as well as its preservation during a medium term stop are discussed.

2. Plant design

Camp de Tarragona Water Reclamation Plant is located nearby Tarragona (Spain). It is operated by a Joint Venture and treats water from Tarragona and Vilaseca Municipal Wastewater Plants, more specifically from their secondary treatments, currently discharged in to the sea.

The purpose of the water reclamation plant is to feed various industries from a neighbor industrial complex, for various uses (mainly cooling tower supply), and substituting the current supply of industrial water, mainly made up of treated surface water (Ebro River).

The capacity of the plant is nowadays 19,000 m^3/d of treated water (Phase I), while further expansions are planned to reach capacities of 29,000 m^3/d (Phase II) and even 55,000 m^3/d (Phase III) in the coming years. These capacities were established during a collaborative agreement study to identify the potential water demand and the quality requirements for industrial use [2].

Prior to the plant design and execution, a demonstration project was performed during a nine months period. The project, performed with Tarragona secondary effluent as a feed, confirmed the effectiveness and the reliability of the selected treatment process. It, among others, confirmed the need of a second pass reverse osmosis (RO) to reach the water quality requirements, and thus comply with both RD 1620/2007 (Cooling towers) and some additional industrial operational specifications [2].

Once the appropriateness of the treatment line was proven for Tarragona secondary effluent, the scaled up water reclamation plant was designed and executed. Construction works began in November 2009 and were completed by July 2011. The plant start-up took place during the autumn of 2011.

Raw water (a mixture of secondary treated waters from two different WWTPs, Tarragona and Vilaseca, 10 km apart from each other) is pumped and mixed into a balancing tank. And additional pumping system feeds then the mixture to the pretreatment process, consisting of ballasted flocculation, followed by disc filtration, gravity dual media filtration, and pressurized sand filtration [3]. The pretreatment is intended to remove high concentration of total suspended solids and preventing organic fouling and biofouling in the RO stage.

In the heart of the process, a double pass RO system will turn effluent water to industrial water quality. Extra fouling resistant RO membranes [4,5], DOW FILMTEC™ BW30XFR-400/34i, were chosen for the first pass, after the successful results obtained by fouling resistant RO elements during the demonstration project, fed with Tarragona secondary effluent and after small-scale pilot trials at Vilaseca secondary effluent, demonstrating DOW FILMTEC™ BW30XFR-400/

Table 1
Design parameters reverse osmosis plants installed

Unit	Design rec. (%)	Staging (# vessels)	Number of trials	Product installed	Total number of modules
RO First pass	75	60 + 40 + 20	2	Dow FILMTEC™ BW30XFR-400/34i	1,440
RO Second pass	95	36 + 14 + 6	2	Dow FILMTEC™ LE-440i	672

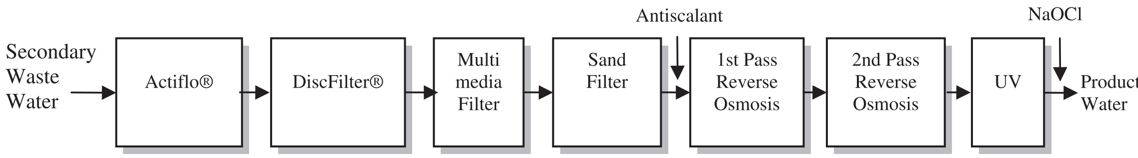

Fig. 1. Process flow diagram of Camp de Tarragona wastewater reuse plant.

34i to be most resistant against fouling [6,7]. Low energy RO membranes, DOW FILMTEC™ LE-440i, were selected for the second pass (See Table 1 for further details). The double pass RO system, currently made up of two identical parallel lines, is designed to reach the requested permeate quality of NH4 < 0.8 ppm and conductivity <2,000 μS/cm (although 10 ppm TDS can be reached) [8].

Final permeate treatment is done by UV light and chlorine disinfection. The permeate is then hold in a permeate buffer tank from where it is pumped into the distribution system [3] (see Fig. 1).

3. Plant start-up

The water reclamation plant start-up took place during the early autumn of 2011. Since the plant can be feed with three different sources/mixtures of raw water (secondary effluent from Tarragona WWTP, secondary effluent from Vilaseca WWTP, and a mixture of both of them), the performance tests were performed under the three regimes.

No flushing or chemical cleanings were performed when the source of raw water was switched.

3.1. Characterization of the reuse sources of water

Although the variability of secondary effluent parameters is high, since it changes seasonally and daily, the characterization campaigns of Vilaseca and Tarragona WWTP secondary effluents lead to averaged values, as shown in Table 2. These values correspond to the typical and maximum compositions feeding the reclamation plant, during the start-up period. Table 3 shows, on the other hand, the RO feed averaged composition after the reclamation plant pretreatment. Again these values correspond only to the start up-period.

The comparison of Tables 2 and 3 suggests that the Tarragona WWTP secondary effluent includes higher concentration of solids, but associated to lower values of turbidity. The amount of organic matter, being of similar order of magnitude to Vilaseca's, seems to be less retained by the water reclamation plant pretreatment.

This suggests that the organic composition in Vilaseca WWTP secondary effluent might be more of a low size, dissolved type, and not so easily retained in the pretreatment and thus, potentially causing fouling on the RO.

Table 2
Averaged and peak compositions of Vilaseca and Tarragona WWTP secondary effluents

Parameter	Unit	Tarragona secondary effluent averaged composition	Tarragona secondary effluent peak values	Vilaseca secondary effluent averaged composition	Vilaseca secondary effluent peak values
pH	–	7.9	8.11	7.7	8.11
Temperature	℃	24.8	27.0	25.8	28.7
Conductivity	μS/cm	2,330.0	2,820.0	2,480.0	2,850.0
Turbidity	NTU	2.53	10.1	5.6	24.5
TSS	mg/L	14.0	–	8.2	63.6
COD	mg O_2/L	37.5	59.0	35.1	47.0
TOC	mg C/L	13.8	16.0	13.7	16.0
BOD_5	mg/L	6.6	8.0	7.2	10.0
NH_4	mg NH_4/L	14.7	32.0	30.6	65.1
Ortho-phosphates	mg P/L	1.7	5.0	2.1	8.6
Total Fe	mg Fe/L	0.2	0.4	0.5	0.6
MFI	L/s^2	26.0–194.5	194.5	3.4–18	18

Table 3
Averaged compositions of RO feed (after pretreatment) when water reclamation plant is fed with Vilaseca and Tarragona WWTP secondary effluents

Parameter	Unit	Tarragona secondary effluent averaged composition—after WRU plant pretreatment	Vilaseca secondary effluent averaged composition—after reuse plant pretreatment
pH	–	7.47	7.36
Temperature	˚C	26.0	25.8
Turbidity	NFU	0.67	0.52
TOC	mg C/L	6.7	3.6
COD	mg O_2/L	–	32.2
Orthophosphates	mg P/L	<0.05	0.14
Total Fe	mg Fe/L	0.04	<0.01
Total Al	mg Al/L	0.10	0.04

Further analyses performed on the first pass RO feed suggest that about 96% of the TOC of the stream has a dissolved character. Among these dissolved organic substances, around 36% can be classified under the group of humic substances (approx. molecular weight ~1,000 g/mol), around 33% of these are building blocks type (approx. molecular weight ~300–500 g/mol and mostly, break down products of humic substances), and around 27% are neutral substances (molecular weight < 350 g/mol, including mono-oligosaccharides, alcohols, aldehydes, ketones, and aminosugars).

3.2. First pass performance

The operating data throughout the plant start-up has been normalized to determine the changes in membranes performance over time. This normalization is done by means of the FTNORM tool [9]. FTNORM is a Microsoft® Excel® spreadsheet-based program which allows normalizing operating data and graphing the selected parameters, such as normalized permeate flow and normalized salt passage.

The normalized permeate flow tendency of the RO membranes in the first pass (Fig. 2) associated to the operation with Tarragona WWTP secondary

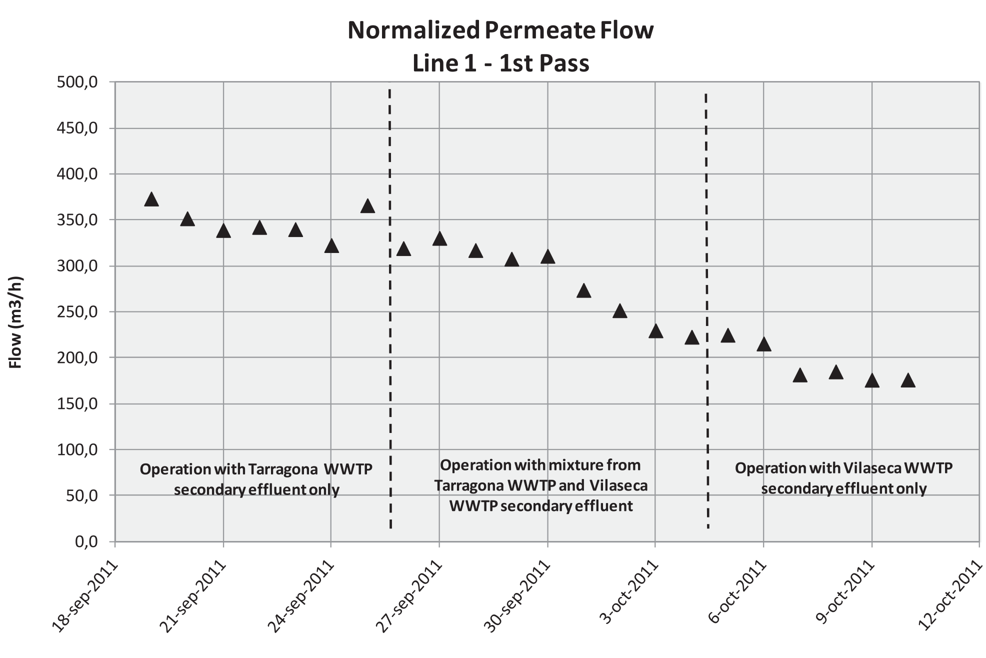

Fig. 2. First pass. Line 1. Normalized permeate flow performance.

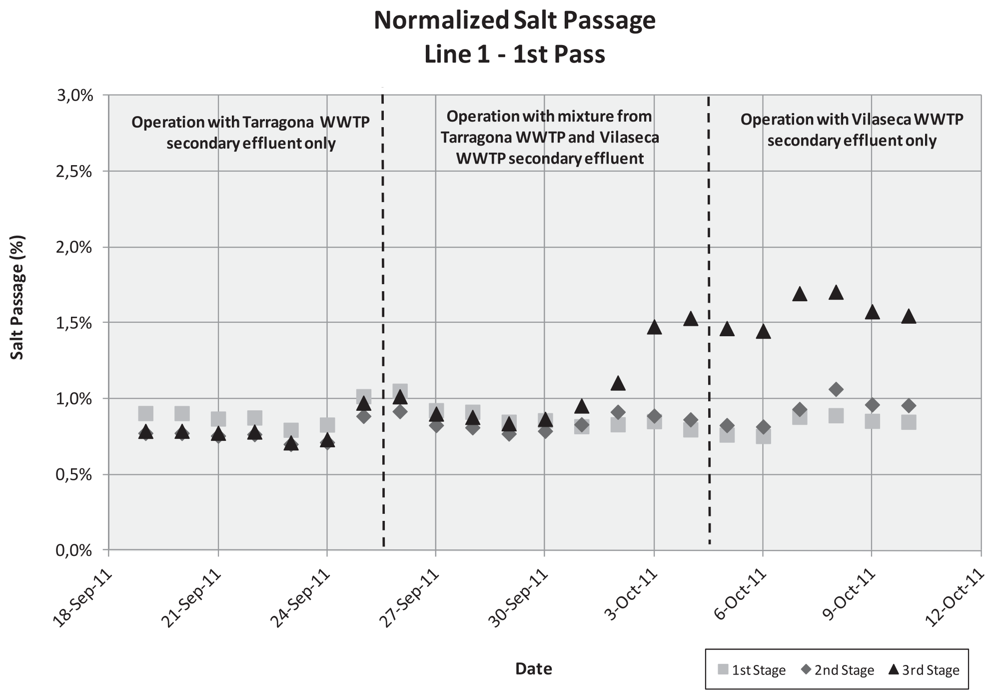

Fig. 3. First pass. Line 1. Normalized salt passage performance.

effluent is consistent with the results obtained during the demonstration project. However, a significant decrease in normalized permeate flow was experienced upon switching to feeding the plant with Vilaseca WWTP secondary effluent. This is observed both when feed water is a mixture with Tarragona WWTP secondary effluent, and by itself, and the impact is strongest when only Vilaseca wastewater is used. The influence of using Vilaseca WWTP secondary effluent can also be seen in the evolution of

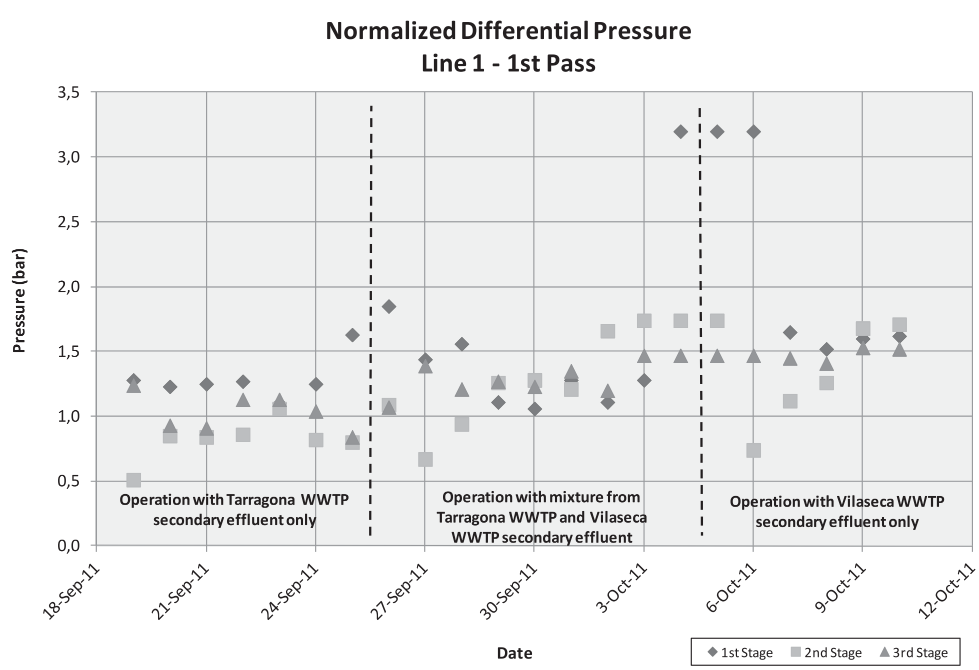

Fig. 4. First pass. Line 1. Normalized differential pressure performance.

normalized salt passage and differential pressure (Figs. 3 and 4, respectively), both showing an increase in tendency. Since the concentrate pressure is not an online measure in the plant, the differential pressure values should be treated carefully.

The decreasing tendency in normalized permeate flow and normalized salt passage when Vilaseca WWTP secondary effluent is introduced in the feed stream would suggests fouling of the RO membranes by the presence of small size organic substances. These substances, usually present in the wastewater effluents, shown high affinity by the membranes. The characterization of Vilaseca WWTP effluent is thus consistent with the tendencies observed on the operation data of first pass.

Overall, the start-up experience with different combinations of raw water sources has demonstrated a significant difference between the two different wastewater sources, albeit those being fairly equal in terms of the analyzed water quality parameters. The experience shows that the most suitable combination for a stable operation is Tarragona and/or a mixture of Tarragona and Vilaseca secondary effluent. The demonstration project with the final pretreatment selection and operational parameters was performed only with the Tarragona WWTP effluent, and it has been demonstrated to correlate well with the actual large-scale plant performance. A separate demonstration with Vilaseca effluent was not performed, but some information could be leveraged from separate small-scale pilot trials, though executed with a different pretreatment [6,7]. These pilot studies have shown Vilaseca effluent to be challenging to treat with membranes and thus, a certain level of fouling was expected and has been taken account in the plant design (dimension of the high pressure pumps). These pilot studies have also demonstrated membrane fouling to be reversible, thus suggesting the need of establishing an efficient cleaning regime for the plant when operated with Vilaseca effluent.

3.3. Second pass performance

Second pass performance shows stable performance, with regard to normalized permeate flow (Fig. 5) and differential pressure (Fig. 6), and is not impacted by the change in the feed water source to the reclamation plant.

This can be considered normal as the first pass RO membranes remove remaining feed water contaminants extremely efficiently. The performance is consistent with the predicted plant performance.

4. Plant stop and preservation

Once the performance tests under the three different regimes of operation (secondary effluent from Tarragona WWTP, secondary effluent from Vilaseca WWTP, and a mixture of both of them) were performed, the plant was chemically cleaned and pre-

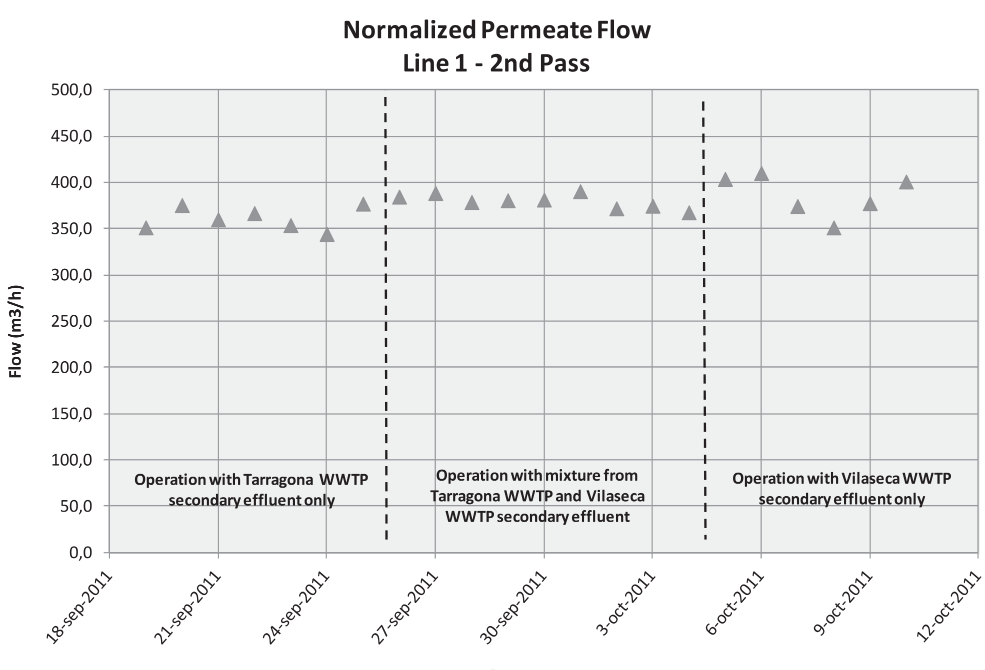

Fig. 5. Second pass. Line 1. Normalized permeate flow performance.

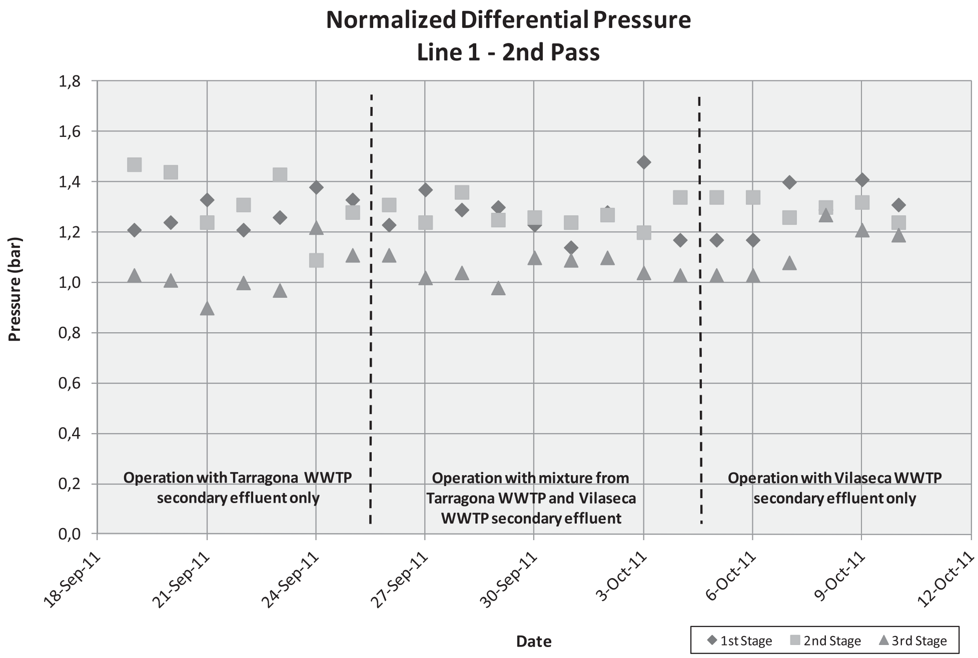

Fig. 6. Second pass. Line 1. Normalized differential pressure performance.

pared for a medium term shut-off with nonoxidative biocide.

The cleaning procedures performed in the plant included an overnight caustic cleaning (pH = 12.5) followed by 2 h acid cleaning (pH = 2) for the first pass and a low pressure caustic once through injection (pH = 12) for the second pass.

On the immediate hours after the cleaning, both first and second passes were soaked into a biocide solution with CMIT/MIT as the main active ingredient. As nonoxidative biocide, CMIT/MIT, is known to be compatible with Thin Film Composite Polyamide membranes. It is known for its antibacterial and antifungal effects being effective against gram-positive and gram-negative bacteria, yeast, and fungi.

Since then, the evolution of the biocide status and effect is followed up by means of monthly controls and sampling.

Samples are analyzed to determine turbidity, conductivity, redox potential, dissolved O_2, and sulfur content.

Microbiological analyses are performed in addition to determine:

- Total cell counting as well as determination of the dead/alive portions.
- Cell viability by means of incubation.

In parallel, the biocide status (and its active ingredient concentration in the system) is quantified:

- With the help of a local portable kit based on a colorimetric reactive to determine the remaining concentration, as an order of magnitude.
- By an high performance liquid chromatography dedicated procedure, applied to stabilized samples.

The follow-up is performed with the aim of detecting possible untimely changes on the biocide effectiveness, and thus being able to perform preventive maintenance on the RO system preservation. Long-term preservation of RO membranes with nonoxidative biocides, especially at the scale of Camp de Tarragona plant is still not very common. The follow-up conducted during preservation will serve as an excellent example for the industry.

5. Conclusions

The current paper has reviewed Camp de Tarragona wastewater reclamation installation, proposed after a successful demonstration project.

After an intensive pretreatment consisting of coagulation–flocculation, lamella clarification, followed by disc filtration, sand filtration, and multimedia filtration, the water is treated by means of a two pass RO system, thus able to meet the quantity and quality of reclaimed water, as necessary for its industrial use.

The start-up experience with different combinations of raw water sources has demonstrated a significant difference between the two different wastewater sources, albeit those being fairly equal in terms of the analyzed water quality parameters. The experience shows that the most suitable combination for a stable operation is Tarragona and/or a mixture of Tarragona and Vilaseca secondary effluent. An efficient cleaning regime needs to be established for the plant upon operation with Vilaseca effluent.

Because of the plant medium term stops, a CMIT/MIT biocide has been used for the preservation of the elements. The preservation follow-up for the first month seems to indicate proper effectiveness.

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