ANALYSIS AND FEASIBILITY OF CHEMICAL PRODUCTS REDUCTION IN THE CLEAN IN PLACE OF ULTRAFILTRATION AS A PRE-TREATMENT TECHNOLOGY FOR REVERSE OSMOSIS DESALINATION

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ABSTRACT:

The reverse osmosis seawater desalination plants open-intake requires different strategies of pre-treatment to reduce the biofouling and scaling. The UltraFiltration (UF) technology is a recent application to this process. In this work, some alternatives to chemical products reducing in chemically enhanced backwash (CEB) and clean in place (CIP) of a UF rack have been studied. Mainly the sodium hypochlorite consumption, due to its biofouling precursor effect over reverse osmosis membranes. For this purpose, the optimal filtration time has been studied, to get the highest water production prior to the CIP, as well as some modifications in the conventional CIP's, modifying the duration of the stages of the same. The results were compared with the current mode of daily operation of the CEB.

The results show that a reduction of up to 60% in the amount of sodium hypochlorite per cubic meter of water produced employed in UF CEB's, mini CIP's and CIP's can be achieved. However, the consumption of the rest of chemical dosing increased notably, and therefore the operating cost of UF also increased. In addition, there was an increase of desalted water consumption to the chemical products removed, up to almost 95,84 %, in comparison with the currently operational mode of CEB. On the other hand, operating the UF plant in the manner proposed requires a automatization of the process and expert staff to programme the control. Therefore, based on the results obtained, the alternatives proposed could reduce the chemical products in use, but it is not conclusive in terms of exploitation operational costs.

Key Words: Ultrafiltration, Reverse osmosis, Open-intake, Clean in place, Chemically Enhanced Backwash, chemical products reduction, biofouling, pre-treatment.

FINANCING

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1. INTRODUCTION

RO technology is limited by three factors associated with the use of membranes: (i) the ability to ensure maximum permeate flux and solute rejection through the membranes, (ii) the frequency of chemical cleaning and (iii) the lifetime of membrane elements. In fact, membrane fouling is recorded as a frequent obstacle in most EDAMs. When feed water is drawn from an open intake fouling is recognized as the main problem in the application of membrane technologies, [1]. An open intake can have a fouling index (SDI) around values of 3 to 5 in the EDAM feedwater. This can cause fouling problems on the membranes. Therefore, it is a matter of designing a good pretreatment for the RO, which is vital to extend the life of the membranes.

UF technology provides us with good filtration quality in systems with open intakes, even with bottom sea, notably reducing the amount of suspended and colloidal solids in the water, as well as the elimination of pathogens, bacteria and viruses, etc. However, this technology also has a number of disadvantages, such as an increase in the operating cost of the plant, as it requires daily chemical maintenance cleaning (CEB-1 and CEB-2) and intensive chemical cleaning (CIP). There is also dependence on a tank required for backwashing in CEB-1 and CEB-2. On the other hand, it is difficult to identify the affected fibers (due to the intrusion of spores on their surface), and exhaustive control of residual chlorine is required to avoid oxidation of RO membranes.

However, UF technology has had a great development and momentum in the last 15 to 20 years, especially in the case of difficult to treat waters such as surface water, wastewater and seawater. Some of the plants worldwide that use this technology are the Jamnagar plant in India, with a production capacity of 1,726,147 m^3 /d and the TUAS III plant in Singapore, with a production of 238,480 m^3 /d [2-5]. In addition, the Maspalomas 1 plant, with a production capacity of 35,000 m^3 /d, is a national reference. This plant was commissioned in 2012, after previous studies and pilot tests carried out with UF technology. The application of this technology was a consequence of the development of the tourism sector in the southern area of the island of Gran Canaria.Due to this, it was necessary to expand the RO plant and modify the seawater intake by an open intake. The use of UF, as a pretreatment to reverse osmosis, was an important challenge, as it was the first desalination plant in the Canary Islands with this technology. This UF process replaced conventional filtration technology [6-9].

The main characteristics and operating modes of the ultrafiltration technology implemented in the desalination plant known as Maspalomas 1 are shown in the following diagram (Figure 1):

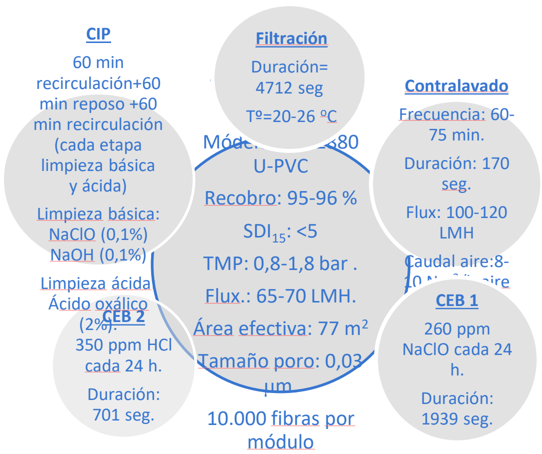

Figure 1: Characteristics and modes of operation of the UF EDAM Maspalomas 1 UF technology.

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However, shortly after the start-up of the Maspalomas 1 plant expansion with the open seawater intake, the first fouling problems appeared in the cartridge filters and the operating parameters of the plant were modified. This caused an increase in the pressure differential in the reverse osmosis, as well as an increase in the replacement rate of the cartridge filters. The diagnosis revealed that the osmosis membranes were suffering from organic and biological fouling known as biofouling, whose development benefits from the effect of sodium hypochlorite (used in UF's BECs) on bacteria. The generation of this film on the surface has a wide variety of functions that make it difficult to eliminate once the point of its formation is reached. Some of these functions are: to serve as an aggregate for the attachment of microorganisms, to act as a storage for nutrients, or to provide stability to the structure and allow communication between microorganisms. In addition, it functions as a protective barrier, as it confers resistance and tolerance to various compounds such as disinfectants and antibiotics [4, 5. 10-15].

The purpose of the work described in this article is to analyze the feasibility of reducing the use of sodium hypochlorite in the BECs required by UF technology as pretreatment in the reverse osmosis of the Maspalomas 1 WWTP.

2. MATERIALS

A pilot plant owned by ELMASA was used to carry out this study, consisting of the following equipment:

- A compressed air system.
- A feed water storage tank with a capacity of 500 liters.
- A feed/backwash pump.
- A UF membrane module with the following characteristics [3]:
    - Manufacturer: Dow
    - Model: SFX-2880 U-PVC
    - Material: H-PVDF
    - Nominal pore diameter: 0.70 mm
    - Filtration area: 77 m^2
    - pH range: 2-11
    - Max. transmembrane pressure: 2.1 bar
    - Working flow rate: 72.5 l/m^2 h
- An ultrafiltered water storage tank with a capacity of 500 liters.
- A chemical cleaning system consisting of the following equipment:
    - A cleaning solution preparation tank with a capacity of 100 liters.
    - A cleaning pump.
    - A lot of instrumentation to know the most characteristic parameters of the process.
    - A distribution and control panel.

The plant is also equipped with a control system consisting of a programmable micro-automaton and a supervision system through a 6" touch screen, which allows configuring flow rates, filtering and backwashing times, transmembrane pressure setpoint, etc.

Regarding the quality of the raw water that feeds the UF pilot plant.

Parameter	Units
Turbidity	0.6 U. N.F
Electrical conductivity	54,200 mS/cm
pH	8,1
Temperature	22.9 ºC
Total organic carbon	< 1 mg/l
Colony count at 22ºC	0 CFU/ml

Table 1Physicochemical characteristics of raw water.

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The ultrafiltration pilot plant, shown in Figure 2, is operated with a feed flow rate of 5.4 m^3 /h and with the physicochemical characteristics shown in Table 1. The feed water is in a raw water tank with a capacity of 500 liters. Every 4712 seconds, a backwash is performed by a centrifugal pump that drives a flow rate of 9.34 m^3 /h of ultrafiltered water that allows us to drag all the colloidal and suspended particles that have previously been shaken off the surface of the UF membrane thanks to a backwash with air 10 Nm^3 /h. The backwashing is performed both through the upper drain port and the lower port and once completed, the membrane enters again in filtration mode, where the water is previously passed through basket strainers with a particle size of 100 microns. Additionally, the ultrafiltered water is passed through a 1 micron particle size cartridge filter to simulate the operating conditions of the industrial plant and whose physical pretreatment is for safety prior to reverse osmosis, to ensure the retention of suspended and colloidal particles (larger than 1 micron in size) in the event that any UF membrane is damaged. On the other hand, once the time setpoint in filtration mode has been reached, a mini CIP or CIP must be carried out with the established operating conditions, as far as the duration of basic and acid cleaning is concerned. For this, a 100 liter tank is required, where the solution is poured, a pump that drives a flow rate of 2 m^3 /h and an isolated hydraulic circuit to pass the solution through the membrane, through the lower port and part of it is discharged through the upper permeate port and the other part through the drainage pipe. All the chemical product, used in the chemical cleaning, is poured into a neutralization tank and once the mini CIP's or CIP's are finished, the membrane is put back into filtration mode.

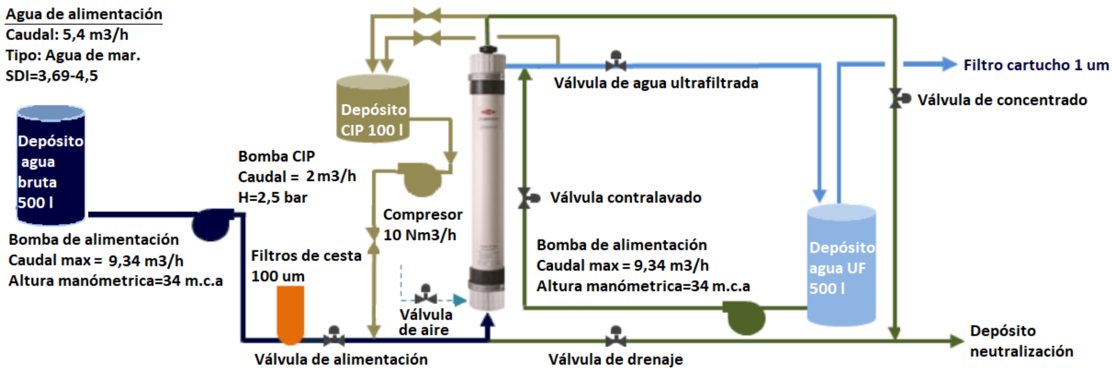

Figure 2: Process diagram of the UF pilot plant.

3. TESTS PERFORMED

The tests performed were as follows:

Evaluation of UF membrane fouling			
No. Assay	**Membrane filtration cycle time (seconds)**	**Type of chemical cleaning**	**Duration of chemical cleaning (minutes)**
1	4.600	CEB1 AND CEB2 (every 24 h)	44 (ceb1+ceb2)
	4.600	-	-
	3.600	-	-
	2.400	-	-
5	4.600	Mini CIP (every 72 h)	30+30 (acidic+basic stage)
	4.600	Mini CIP (every 72 h)	60+60 (acidic+basic stage)
	4.600	Mini CIP (every 72 h)	90+90 (acidic+basic stage)

Table 2Tests performed

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Between each test a CIP is performed to try to start from the values of permeability and TMP of origin, and thus be able to evaluate the membrane fouling curve in the different operating conditions. In order to analyze the evolution of membrane fouling during mini CIP in several operating cycles, the annual production, the recovery, the membrane utilization coefficient and the consumption of chemical products per cubic meter produced with its associated cost have been estimated. In addition, the volume of osmosis water used in the mini CIP's and CIP's of each of the tests carried out, and the percentage reduction of sodium hypochlorite in the chemical cleaning in general, have also been estimated.

4. METHODOLOGY

The methodology applied during the trials (from 06/06 to 13/11) consists of the following stages:

1. **Membrane tuning:** At the beginning of each test, the UF membrane must be tuned by means of a CIP to recover the permeability and transmembrane pressure (TMP) values. Additionally, prior to the development of the tests, an integrity test was performed on the membrane to verify its condition in terms of technical characteristics.
2. **Process control:** In order to correctly monitor the tests and the state of the membrane, the main operating parameters are recorded in the corresponding operating report. These parameters are:
   - UF membrane feed flow rate, in m^3 /h.
   - UF supply temperature, in ºC.
   - Membrane feed pressure, in bar.
   - Transmembrane pressure, in bar.
   - Accumulated volume of water filtered by the membrane, in m^3 .
   - Accumulated volume of water used in backwashing, in m^3 .
   - Accumulated volume of water used in drainage, in m^3 .
   - Recoveries, in %.
   - Measurement of SDI_{15} in UF membrane feed and product.
   - Turbidity in feed and UF membrane product, NTU.
   - Incidents and new developments.
3. **Data analysis:** During the development of the tests, the evolution of the operating parameters is analyzed, such as:
   - Effective filtration time in each operation and recovery cycle.
   - Amount of chemical used per cubic meter produced, during the membrane operation cycle and the associated economic cost.
   - Percentage reduction in chemical consumption, during the membrane operation cycle with respect to CEB_1 and CEB_2 .
   - Utilization factor, in %.
   - Amount of osmosis water used during the displacement of chemical cleaning.
   - Comparison between the proposed modified chemical cleaning (mini CIP) versus maintenance chemical cleaning (CEB).
   - Evolution of the fouling index (SDI) and turbidity.
   - Labor time spent in carrying out chemical cleaning of the membrane in each operating cycle.
4. **Modification of operating conditions:** At the end of each of the tests, based on the results obtained, the operating conditions are modified in order to reduce as much as possible the consumption of chemical products during the UF process, mainly sodium hypochlorite.

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5. RESULTS

5.1 EVALUATION OF THE MEMBRANE FOULING ACCORDING TO THE FILTRATION TIME

Figure 3 shows the membrane fouling curve, operating with different filtration times such as 4,600 seconds (test No. 2), 3,600 seconds (test No. 3) and 2,400 seconds (test No. 4), in order to study the evolution of the membrane permeability without performing daily CEBs. The results revealed that the permeability presented a similar trend and durability in the three cases, where the membrane was practically 7 days in continuous operation, without performing CEB's, before reaching the set point established to perform the mini CIP (tmp=1.7 bar, 41 lmh/bar). It can also be observed that the trend lines do not start from the same initial point of permeability (110 lhm), due to the fact that, after performing the corresponding CIP to start a new test, it is not possible to recover the original values of permeability or transmembrane pressure.

The baseline data in each trial were as follows:

- Test 2: TMP of 0.69 bar at a flow rate of 5.64 m³/h,
- Test 3: TMP was 0.74 bar at a flow rate of 5.62 m³/h,
- Test 4: TMP was 0.82 bar at a flow rate of 5.62 m³/h.

This fact is probably due to the accumulation of fouling on the membrane as a consequence of not performing daily maintenance cleaning. Therefore, in this part of the study, the aim is to analyze the tendency of membrane fouling over time and to determine the filtration time with which the highest volume of water produced is obtained.

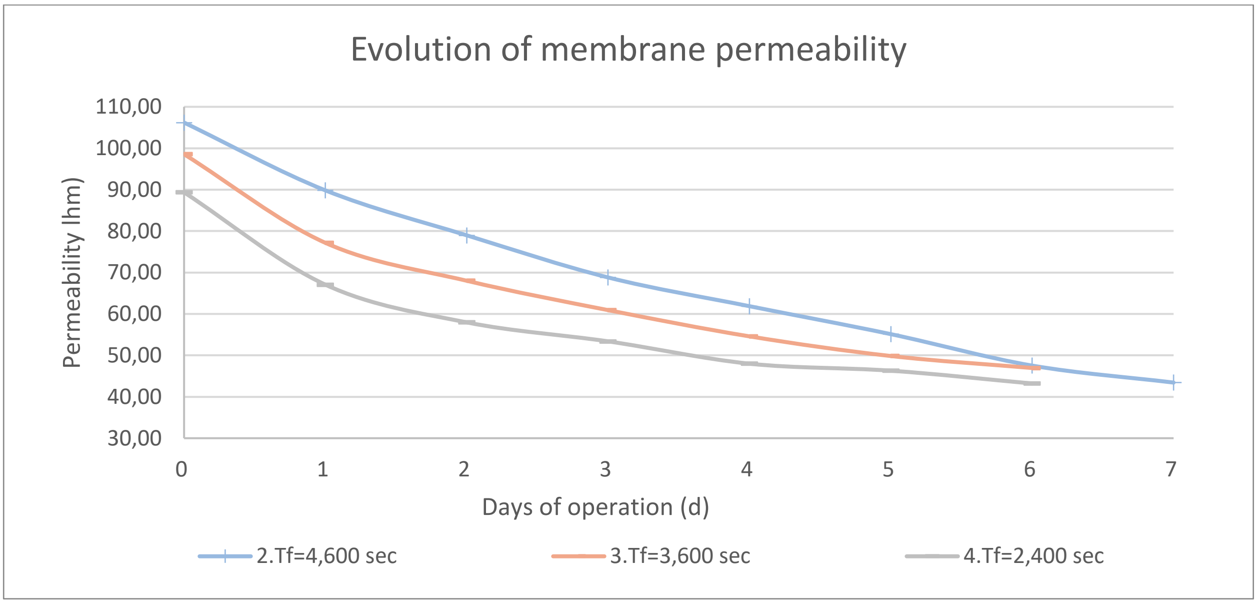

*Figure **3**: Evolution of membrane permeability operating at different filtration times (4,600, 3,600 and 2,400 seconds).*

On the other hand, we analyzed the filtration time that would allow us to have an operating cycle with the highest possible volume of water produced, as well as the highest recovery and operating hours. Thus, based on the results obtained (Table 3), by reducing the filtration time to 2,400 seconds, the volume of ultrafiltrated water produced per day was also reduced, and consequently the recovery. However, operating with a filtration time of 4,600 seconds resulted in a higher volume of ultrafiltrated water and a higher recovery for the same number of hours of operation in the filtration mode. Therefore, it was determined that the filtration time of 4,600 seconds was the optimum.

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ESSAY	Filtration time	Volume of ultrafiltrated water produced	Recovery	Time in filtration mode
	(Seconds)	(m³)	(%)	(hours)
	4.600	784,75	98,70	163,80
	3.600	651,53	97,60	139,80
	2.400	689,82	97,00	160,23

Table 3Results obtained for the volume of ultrafiltrated water produced, recovery and membrane operating hours for the different filtration times.

5.2 EVALUATION OF MEMBRANE FOULING WITH MODIFIED CHEMICAL CLEANINGS FOR ONE CYCLE OF OPERATION

In this second part of the study, an alternative to the CEB's, which are performed on a daily basis, was sought. The alternative studied consisted of carrying out mini CIP's every 72 hours and with a duration time of the basic and acid cleaning stages that was shorter than the time used to carry out a normal CIP. For this purpose, three cases have been analyzed in which the basic and acid cleaning stages of the mini CIP last 30 minutes (test No. 5), 60 minutes (test No. 6), and 90 minutes (test No. 7), respectively, as can be seen in Figure 4.

The results revealed that the membrane operation cycle with daily BEC's has a longer durability than in the case of mini CIP's, since it was operating continuously for 60 days, before reaching the CIP setpoint. On the other hand, several peaks in the permeability curve are observed in the cases in which mini CIP's were performed, this is due to the fact that after these, the fouling is eliminated to a greater extent than with the CEB's, although this will depend mainly on the time spent in the soaking and recirculation stages of basic and acid cleaning, since the longer the chemical product is left in contact with the membrane, the more effective the intensive chemical cleaning will be, and the greater the extent to which the original permeability and transmembrane pressure can be recovered. As for test No. 5, a transmembrane pressure of 1.7 bar was reached after 5 days of continuous operation, so that the membrane operating cycle under these conditions was significantly reduced.

In the case of tests 6 and 7, the membrane was in operation for 26 and 41 days, respectively, to complete an operating cycle. Therefore, consequently, an increase in the plant's operating hours for one operating cycle was obtained, as well as in the volume of water produced with respect to test No. 5. However, said increase in production did not exceed the volume of water produced with the trial, in which the CEB's are performed.

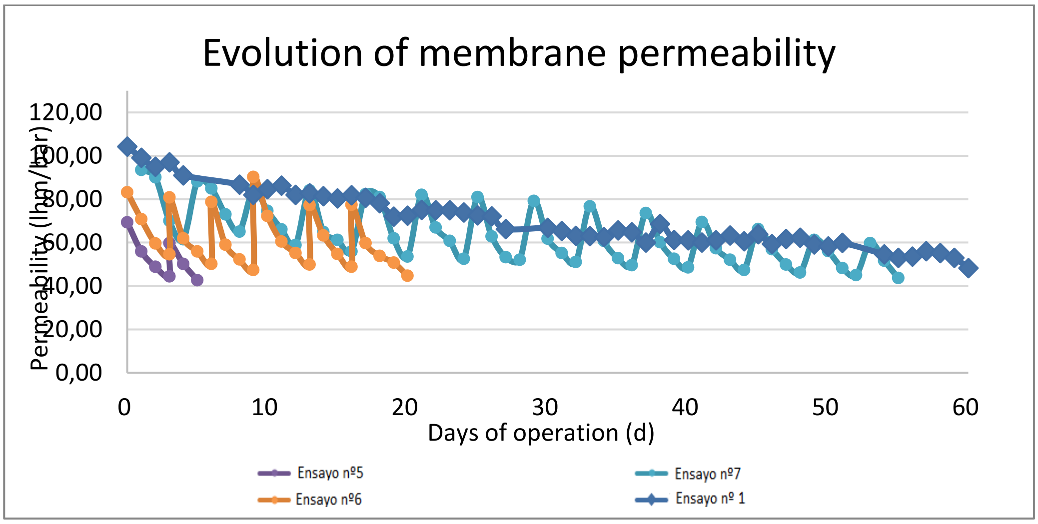

Figure 4: Evolution of membrane permeability at the completion of an operating cycle in the different test cases.

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Table 4 shows that the maintenance cleanings (CEB's) allow us to obtain a higher production, due to the fact that the membrane has a greater number of operating hours for an operating cycle. However, as far as recovery is concerned, a lower value was obtained with respect to the rest of the tests. This is due to the fact that only ultrafiltered water is used in the backwashes during the CEB's, while in the case of the mini CIP's, ultrafiltered water is used in the backwashes and osmotized water is used during the displacement of the chemical products, 17.13 m^3 in each mini CIP or CIP. In this regard, trial No. 7 was the trial that used the largest amount of osmotized water in the mini CIP's, 222.69 m^3 .

ESSAY (nº)	Volume of ultrafiltrated water produced	Recovery	Operating hours in filtration mode	Number of mini CIP's performed	Volume of osmosis water used in mini CIP or CIP
	(m^3)	(%)	(hours)	NO.	(m^3)
1	7.187,04	97,60	1.271,40	0	17,13
5	528,45	98,10	124,00	1	17,13
	2.644,75	98,20	483,32		119,91
	4.491,04	98,40	831,67		222,69

Table 4Summary table of the results obtained in the 4 tests, for an operation cycle with CEB's every 24 hours and mini CIP's every 72 hours.

With respect to the quality of the feed and ultrafiltered water analyzed by measuring the 15-minute SDI and turbidity (Figure 5), it was observed that both remained stable during the time used to carry out this study, regardless of the different tests performed. The purpose of analyzing the evolution of this parameter is to verify the integrity of the membrane during the different cases of study, since if fiber breakage occurs in the membrane used, it would be detected by measuring the SDI.

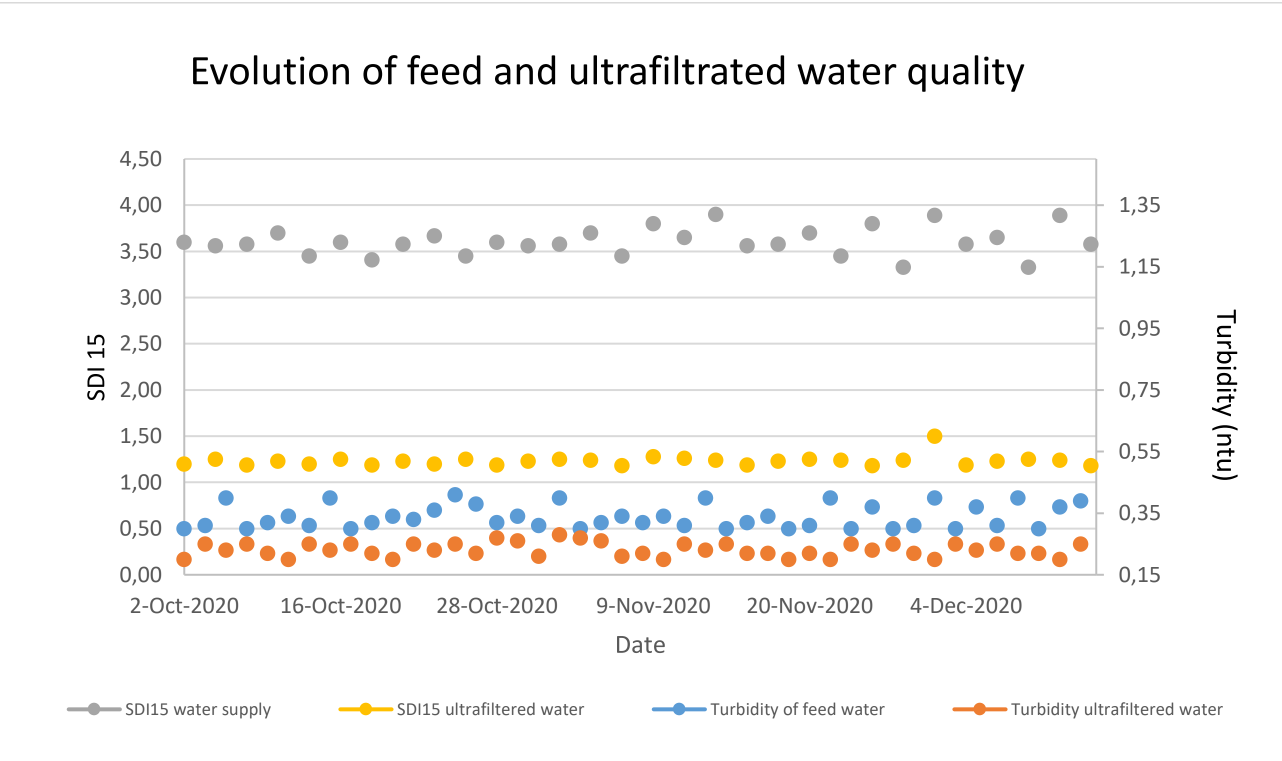

Figure 5: Evolution of feed and ultrafiltered water quality .

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5.3 EVALUATION OF MEMBRANE FOULING WITH MODIFIED CHEMICAL CLEANINGS FOR VARIOUS CYCLES OF OPERATION

- **Trial No. 1: CEB's with daily frequency**

The results indicate that the largest volume of water produced by the UF membrane is obtained by performing daily CEBs. However, with this mode of operation a lower recovery was obtained than in the rest of the tests, due to the fact that ultrafiltered water is used during the displacement of the chemicals used in the CEBs. Additionally, the lowest utilization coefficient was also obtained.

With respect to the consumption of chemical products, the highest consumption of sodium hypochlorite per cubic meter produced was obtained (5.7 ppm), while the consumption of chemical products as a whole was the lowest (7 ppm), with the result that the operating costs of the UF technology in this case is lower than in the other case studies.

As for the amount of osmosis water consumed in the displacement of the CIP's during a year of operation with these conditions, this would entail a consumption of 104 m^3 , with an associated economic loss due to the consumption of the osmosis water produced and which is used in the displacement of the chemical products.

- **Rehearsal nº 5: Mini CIP 30'.**

In this case, the consumption of sodium hypochlorite in the mini CIP's was 3.1 ppm, obtaining a reduction in the consumption of this (47 %, with respect to the operation mode in which CEB's are carried out). In addition, the result was a water production similar to that obtained with case 1, although with a slightly higher recovery. However, as for the consumption of chemical products as a whole used in the mini CIP's such as sodium hypochlorite at 0.1%, sodium hydroxide at 0.1% and oxalic acid at 2%, this was 12 ppm per cubic meter produced, and whose increase reached 60% with respect to the normal operation mode (performing CEB's). As for the amount of osmosis water consumed in the displacements of the mini CIP's during a year of operation under these conditions, it would entail a consumption of 2,500 m^3 .

- **Rehearsal nº 6: Mini CIP 60'.**

The consumption of sodium hypochlorite in the mini CIP's was very similar to case 5 (3.2 ppm). . In addition, this mode of operation resulted in the greatest reduction in the amount of sodium hypochlorite used in the mini CIP's, 60%. However, production was affected, being reduced by 27%. In addition, chemical consumption increased by 64%, as did the operating cost associated with the UF process. As for the amount of osmosis water consumed in the displacements of the mini CIP's, this was 2,000 m^3 .

- **Rehearsal nº7: Mini CIP 90'.**

Finally, with regard to the time required to perform a mini CIP with its basic and acid cleaning stages, and its corresponding chemical product displacements, it was found that performing a mini CIP every 72 hours with a duration of 30, 60 and 90 minutes in each stage of basic and acid cleaning, entailed the following hours of work.

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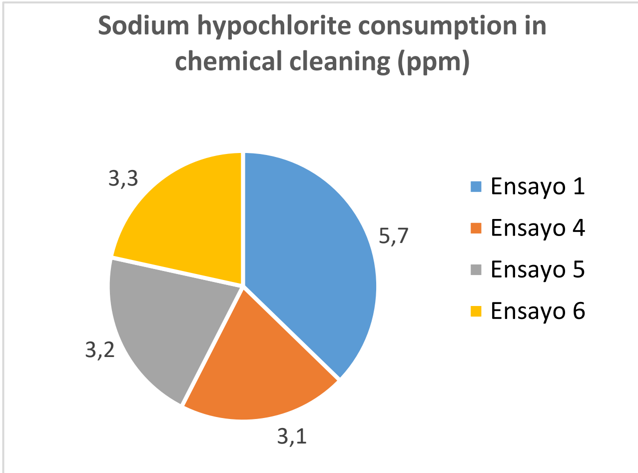
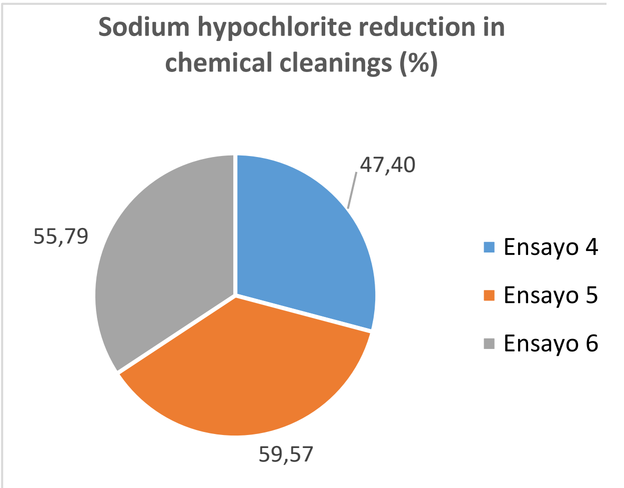


Figure 6: Sodium hypochlorite consumption in each trial.



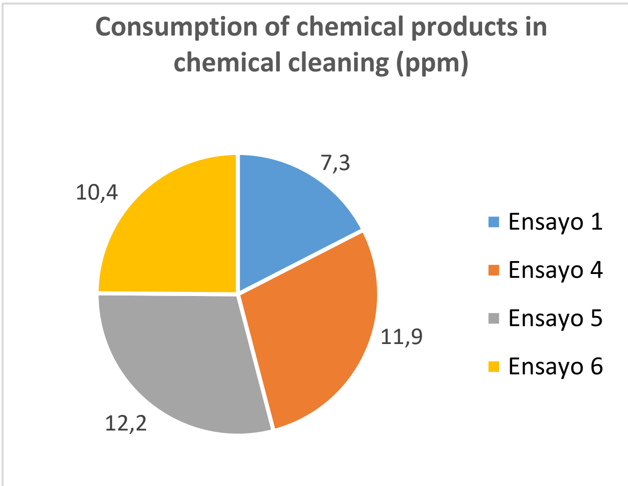
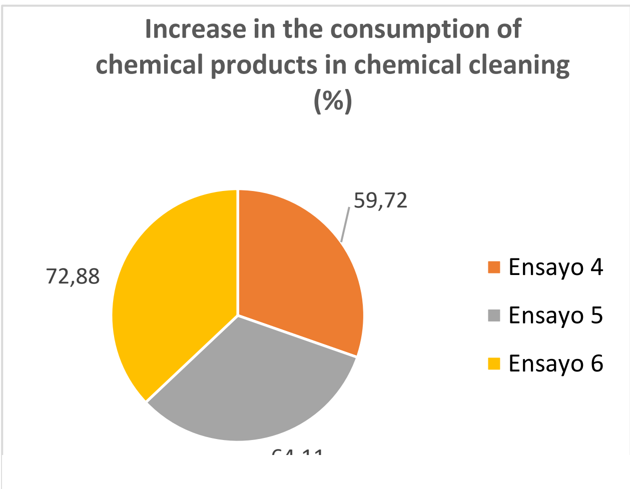


Figure 7: Chemical consumption in BECs, mini-IPCs and IPCs.



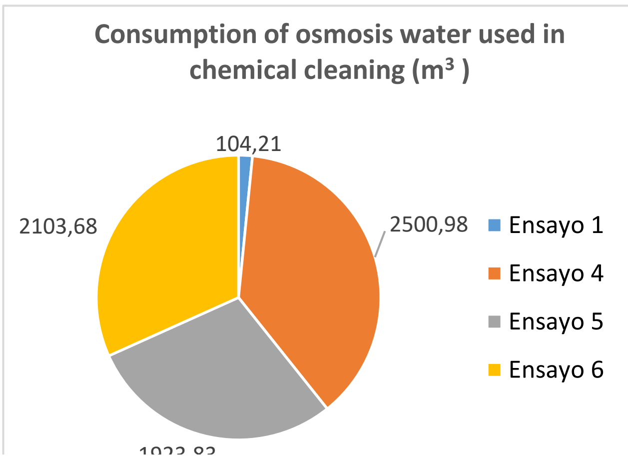


Figure 8: Consumption of osmosis water used in the displacement of the different tests of the study.

ESSAY	Work hours required to perform a mini CIP	Number of mini CIP's or CEB's performed per year	Number of CIP's performed per year	Labor hours required to perform mini CIP's per year
	(hours)	NO.	No. CIP's /year	(hours/year)
1	0,74	359		
5	5			1.387
				980
		114		1.266

Table 5: Annual work hours required by the CEB's, mini CIP's and CIP'S of the different case studies.

In this study, we have also taken into account the CIP's that would be necessary to perform in a year of operation with the membrane studied, where a CIP requires about 14 hours of work of an operator to perform the necessary maneuvers and control the operating parameters of the intensive chemical cleaning process. Therefore, taking into account the time required to perform the CIP's, the case study that would require the least number of working hours is case 1, while case 5 is the one that requires the highest number of working hours per year. There is the possibility of automating the process, with the cost of investment and personnel specialized in programming and automation that this entails, but this alternative has not been the subject of this study.

6. CONCLUSIONS

The results revealed that a 60% reduction in the amount of sodium hypochlorite per cubic meter of water produced can be achieved in both maintenance chemical cleaning (CEB's or mini CIP's) and intensive cleaning (CIP). However, the consumption of other chemical reagents and the operating cost of chemical cleaning of the UF membrane increased significantly.

On the other hand, in test No. 5, a production loss of 20 to 27% was observed, as well as a high consumption of osmosis water used in the displacement of the chemical products, increasing by 96%, compared to the operation mode with CEB's with a daily frequency.

Regarding the working hours required by the mini CIP's carried out in the case studies, it is observed that from 1,000 to 1,400 hours per year are required for an operator to carry out the process of the mini CIP's with their corresponding maneuvers, so it would be necessary to hire a person exclusively for this task, or otherwise automate the process, with the cost of investment and personnel specialized in programming and automation that this entails.

Therefore, based on the results obtained, it can be deduced that the alternatives proposed, a priori, make it possible to reduce the consumption of sodium hypochlorite in the chemical cleaning required by the UF technology by up to 60%, as indicated in test No. 6 of the study. However, this measure would imply an increase in costs in the operation of the technology as pretreatment to the RO in the Maspalomas 1 seawater desalination plant, as a consequence of the increase in the consumption of other chemical products that are also used in the mini CIP's and CIP's, such as sodium hydroxide and oxalic acid.

ACRONYMS AND ANGLICISMS

UF: Ultrafiltration

Biofouling. Biological fouling

TMP: Transmembrane pressure

SDI: Soiling index

CEB's: Daily maintenance cleanings

CIP's: Intensive Chemical Cleanings

EDAM: Seawater Desalination Station

RO: Reverse Osmosis

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