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Comparative Study of Conventional and Ultrafiltration Pretreatment Methods in Desalination Plants: Case of Beni Saf and El Mactaa Stations, Algeria

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Abstract. Pretreatment is a critical phase in the reverse osmosis desalination process, ensuring the compatibility of feed water with membrane specifications and preventing fouling caused by suspended solids, microorganisms, or scaling. This study presents a comparative analysis between conventional pretreatment using sand, anthracite, and cartridge filters and ultrafiltration-based membrane pretreatment, with a specific focus on the Silt Density Index (SDI) as an indicator of performance. The findings reveal that while ultrafiltration provides higher unit availability, conventional treatment offers more stable SDI values and reduced operational complexity. These insights are based on data collected from two large desalination plants in Algeria: Beni Saf and El Mactaa. Ultimately, the results suggest that conventional pretreatment remains more effective under variable raw water conditions common in Algerian coastal regions.

Keywords. Desalination, Pretreatment, Ultrafiltration, Reverse osmosis, SDI clogging index.

INTRODUCTION

The lack of access to drinking water and the scarcity of its natural resources pose serious challenges to human life in many regions around the world. In several regions, freshwater resources suitable for drinking water production are either nonexistent or insufficient to support population growth and industrial activities (Kettab, 2001).

Over the past two decades, faced with the growing needs for fresh water and the impossibility of being satisfied with natural resources, efforts have been made to develop and implement various seawater and brackish water desalination processes, provided they are economically viable (Drouiche, Ghaffour, Naceur, Mahmoudi, & Ouslimane, 2011).

Desalination is emerged as a complementary and alternative resource that meets specific needs (Linninge, Ahrné, & Molin, 2015; Neumann, Pesante, Venegas, & Vidal, 2016).

Water desalination is a programmatic approach that makes it possible to increase the available freshwater resource, to provide a solution in the event of droughts and to cope with situations of sustainability and crises (Gorjian & Ghobadian, 2015).

In Algeria, the most widely used desalination process in is reverse osmosis (RO) which requires good quality raw water and therefore adequate pretreatment to protect reverse osmosis modules against clogging and increase their longevity (Kim et al., 2022; Li et al., 2023).

RO has become the predominant technology for seawater desalination due to its superior operational efficiency, relatively low energy demand, and reduced capital investment compared to thermal methods such as multi-stage flash (MSF) and multi-effect distillation (MED) (Al Bloushi, Giwa, Mezher, & Hasan, 2018). RO systems typically require around 40% of the total energy input to counteract the high osmotic pressure of saline water (Kalogirou, 2005). To mitigate this energy burden, advanced energy recovery devices are commonly integrated into the brine stream, recovering a substantial portion of the consumed energy (Harby et al., 2024).

Despite its advantages, the RO process generates a concentrated brine stream laden with residual salts and chemicals from pretreatment stages, posing serious environmental discharge challenges (Goh, Kang, Ismail, & Hilal, 2021). Proper treatment and disposal of this brine are not only environmentally critical but also financially significant, accounting for nearly 25% of the overall operational cost of desalination (Reddy & Ghaffour, 2007). Although RO consumes significantly less energy than thermal desalination estimated at approximately one-quarter of the energy consumed by MSF and MED systems the process entails considerable expenses in membrane replacement and chemical pretreatment, which can substantially elevate total costs (Reddy & Ghaffour, 2007; Said, Emtir, & Mujtaba, 2013).

In this context, the present study conducts a comparative analysis of two desalination plants in Algeria Beni Saf and El Mactaa each employing a different pretreatment strategy. While Beni Saf utilizes a conventional approach based on sand, anthracite, and cartridge filtration, El Mactaa employs ultrafiltration membranes as its primary pretreatment method. By focusing on the SDI as a key performance indicator, this work aims to evaluate the operational efficiency, chemical consumption, maintenance needs, and water quality outcomes associated with each system. The results provide valuable insights into the suitability and cost-effectiveness of pretreatment technologies under varying raw water conditions.

MATERIALS AND METHODS

Presentation of the stations

Beni Saf seawater desalination station

The Chatt El Hilal desalination plant is designed with a production capacity of 200,000 m³ per day (Fig. 1). It began operations in November 2009 to supply drinking water to the wilaya of Ain Temouchent (Ouadi et al., 2024). Table 1 presents the technical specifications of the facility, which is operated by the Beni Saf Water Company.

Table 1. Specifications of the desalination station of Wilaya Ain Temouchent (STATION - Beni Saf Water Company).

Location	El Hillal beach (formerly Oued el Hallouf) Beni Saf wilaya of Ain-Témouchent.
Owner	Beni Saf Water Company SPA.
Constructor	Ute desaladora beni saf construction
Treatment process	Reverse Osmosis
Capacity of production	200,000 m^3/d
Energy consumption	4.15 kwh/m^3
Project amount	240 million $
Composition of the station	10 desalination units
Product water quality	alkalinity < 65 mg, hardness 50- 65 mg, pH 8- 8.5, loin index 0.4
Commissioning date	March 2010

Fig.1. Station Beni Saf Water Company.

Fig. 2. Location of the desalination station Beni Saf of Wilaya Ain Temouchent. (Google Maps).

El Mactaa seawater desalination station

El Mactaa desalination station is located approximately 45 kilometers east of the city of Oran, within the coastal municipality of Mers El Hadjadj (Hamiche, Stambouli, Flazi, Tahri, & Koinuma, 2018). Table 2 outlines the technical specifications of this facility, which operates under the management of the Algerian Energy Company (AEC). Figure 3 illustrates different reverse osmosis compartments in this desalination station.

Table 2. Specifications of the desalination station of wilaya Oran (Algerian Energy Company (AEC)).

Location	Municipality of Mers El Hadjadj wilaya of Oran
Capacity of production	500,000 m^3/d
Destination of produced water	Wilaya of Oran
Number of modules	25 units of 20,000 m^3/d each
Treatment process	Reverse osmosis
Electricity consumption	$\leq$ 4.15 kwh/m^3
Mechanical pretreatments	Ultrafiltration
Chemical pre-treatments	Sodium hypochlorite, sulfuric acid, sodium metabisulphite, dispersant.
Product treatment post	Calcium carbonate- sodium hypochlorite
Project amount	492 million $
Commissioning date	July 10, 2016

Fig.3. Different reverse osmosis compartments of the El Mactaa desalination plant.

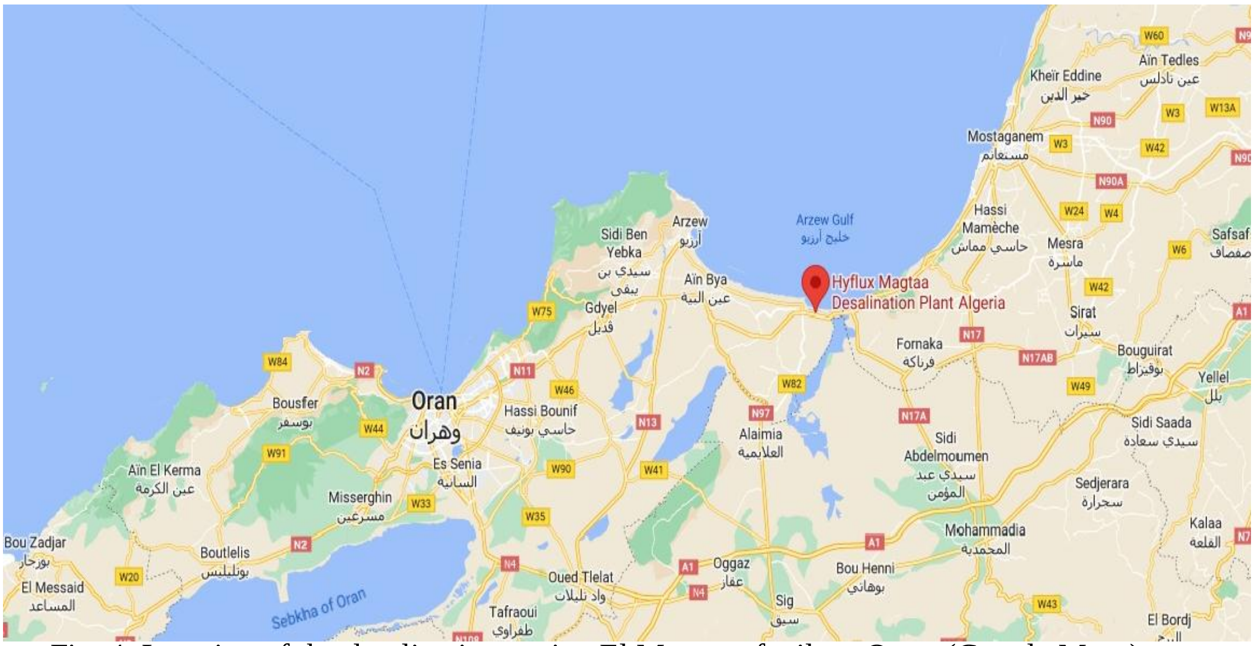

Fig. 4. Location of the desalination station El Mactaa of wilaya Oran. (Google Maps).

Methods used

SDI control (clogging index)

The Silt Density Index (SDI) is a commonly used indicator for assessing the concentration of suspended solids in water. Typically monitored from the control room, the SDI provides valuable information about the quality of filtered water after the pretreatment stage and serves as an early warning for potential membrane fouling in reverse osmosis systems. While a high SDI value does not directly confirm membrane fouling, it remains the most practical and widely accepted method for predicting the likelihood of such events (Alhadidi et al., 2011; Zhang, Zhao, Zhang, & Jegatheesan, 2021).

The SDI test involves measuring the flow rate of water passing through a 0.45 µm filter by recording the initial time (T_i) required to collect a defined volume of water, and the final time (T_f) after 15 minutes. The SDI value is then calculated according to the equation (1) proposed by (Mosset, Bonnelye, Petry, & Sanz, 2008).

$$SDI_T = \frac{\left[1-\frac{t_i}{t_f}\right]\cdot 100}{T} \qquad (1)$$

T : the total time. t_i : first time required for filling the 500ml for t = 15 minutes. t_f : second time required for filling the 500ml.

Materials Used

Several equipment's have been used, the most important are the following:

- Electronic chronometer.
- Erlenmeyer graduated 100 or 500 ml.
- 0.45µm filter.
- Fouling Index measurement kit (clogging index), set comprising (connection tips, pressure regulator, pressure gauge, isolation valve, filter support)

Figure 5 illustrate the measurement process of SDI.

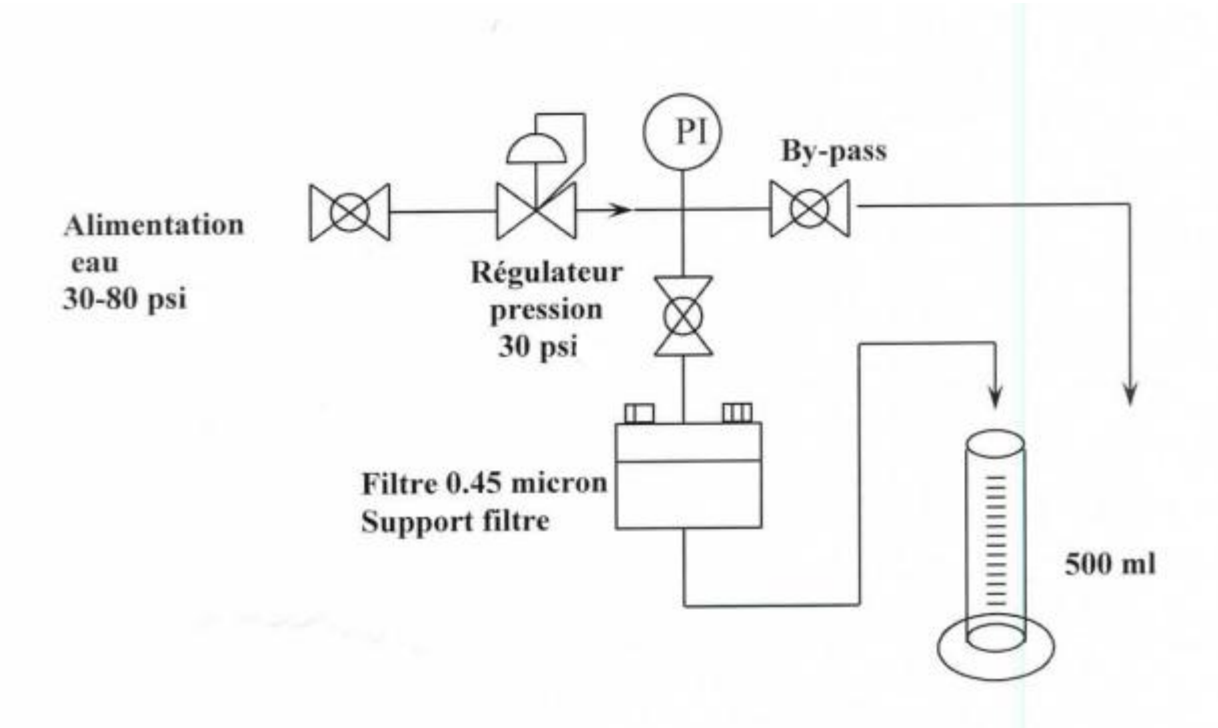

Fig.5. SDI measurement process.

RESULTS AND DISCUSSIONS

To evaluate the efficiency of the pretreatment processes. Variations in the SDI are monitored at two desalination plants.: the Beni Saf and El Mactaa seawater desalination stations. Figures 6 and 7 illustrate the SDI values recorded during January 2020 for the El Mactaa and Beni Saf stations, respectively. The El Mactaa facility operates at full production capacity 500,000 m^3/day only during scheduled performance tests. Under normal operating conditions, the plant typically functions at approximately 70% of its nominal capacity, depending on daily water demand from the regional Water and Sanitation Company.

Significant fluctuations were observed in SDI values at El Mactaa, ranging from 0.99 to 2.74, indicating a high sensitivity to variations in feedwater quality. In contrast, the Beni Saf station exhibited a narrower SDI range, from 1.5 to 1.9, suggesting more stable pretreatment performance. Over the study period, the average SDI at Beni Saf was approximately 1.8 at the beginning of January and slightly decreased to 1.7 by the end of the month. This station generally operates at full capacity throughout the year, except during periods of increased turbidity caused by the discharge of wadis into the sea, particularly in winter. Additionally, algal blooms during this season contribute to a reduction in production, with output dropping from 432,000 m³/day to 350,000 m³/day a decrease of about 20%.

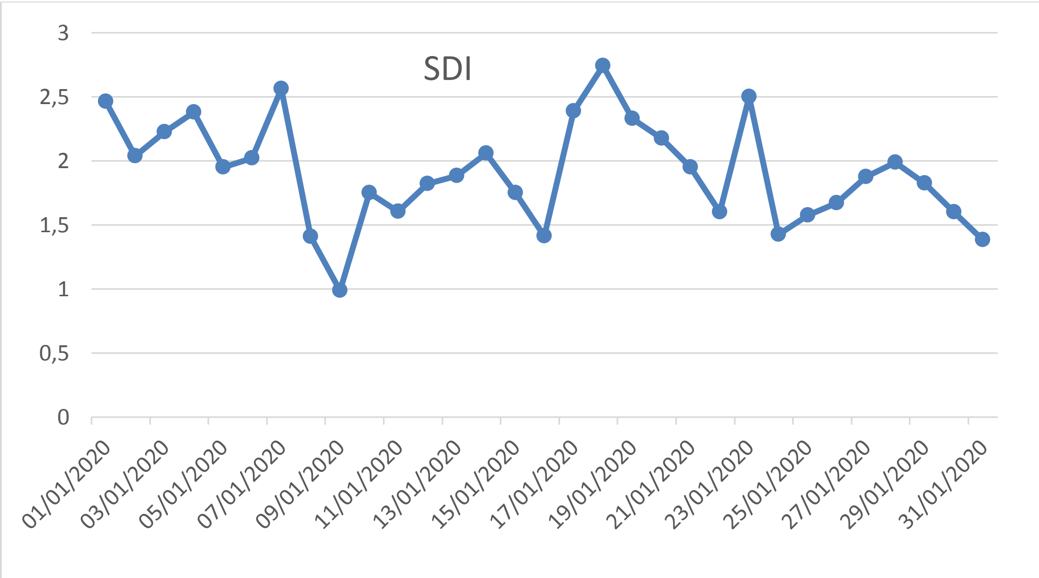

Fig.6. SDI values for the El Mactaa station month of January 2020.

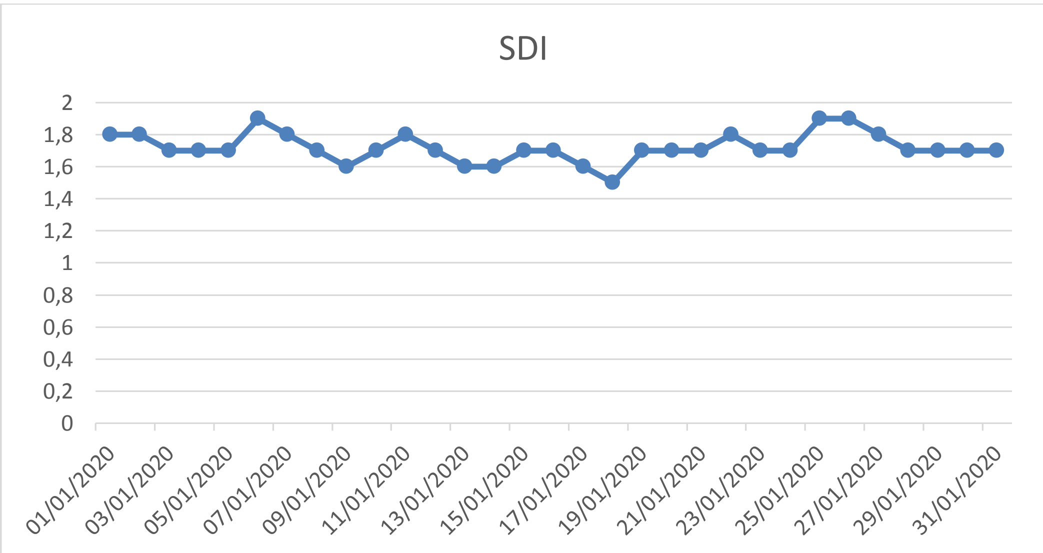

Fig. 7. SDI value for the Beni-Saf station month of January 2020.

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Consumption of chemicals

The consumption of chemicals will be the same for the same flow and according to the characteristic of the water Except for the addition of the ferric chloride coagulant FeCl3. This consumption concerning the conventional pretreatment in the station of Beni-Saf during periods when there is an increase in turbidity and suspended matter (Drouiche et al. 2011). Note that this consumption of chemicals is almost replaced or converted by the use of washing chemicals.

$$\text{Qmp} = \frac{\text{Q .(R.dosage) .100}}{\text{perc (\%) .(conc.commer.)}} \quad (2)$$

where Q_{mp} denotes metering pump flow rate (l/h), Q_{water} is the water flow to be treated (m^3/h), *R.dosage* denotes reagent dosage rate, expressed as pure product (g/m^3) (nota:g/m^3 = mg/l), *Perc* is the product purity percentage, and *conc. Comm* denotes a concentration of the reagent in commercial product for a powder product (g/l) , density x 1000 for a liquid product (g/l).

Q_{mp} = 83.75 (l / h)

Half-yearly consumption (considering that the dosage of ferric chloride is only done during autumn and winter):

c = 83.75 * 24 * 30 * 6 = 361800 l

Table 3. Characteristics of the ferric chloride coagulant $FeCl_3$.

Q_{water} (m^3 / J)	432000
Dosage rate	(Determined in the laboratory)
Percent (%)	40% (20% after dilution)
Concentration commercial (g/l)	1425

Maintenance intervention

- ***Beni-Saf Station:***

Based on the data collected from the Beni-Saf desalination plant, it was observed that maintenance operations are predominantly preventive in nature. Corrective maintenance is rarely required, which reflects an efficient maintenance management strategy aimed at minimizing unexpected breakdowns and ensuring continuous operation. This proactive approach contributes to the overall reliability of the station's processes and limits production downtime.

- ***El Mactaa Station:***

At the Macta station, there is a particular emphasis on the continuous monitoring and maintenance of the membrane system, which serves as the plant's sole pre-treatment stage. The membranes are critical components, and their performance directly affects the plant's overall efficiency and water quality. As a result, maintenance interventions are more frequent, especially during periods of peak production when the plant operates at or near full capacity. This increased maintenance activity ensures membrane integrity, prevents fouling, and sustains optimal operational output.

Availability of units

The availability of the units is determined by their operational and maintenance schedules. It is important to note that maintenance time primarily refers to the duration allocated for cleaning or backwashing procedures. Washing time can be determined by the following equation (3):

$$A = \frac{Usage\ and\ standby\ time}{Usage\ and\ Standby\ Time + Maintenance\ Time} \quad (3)$$

<u>Availability of a UF module for one day</u>

A backwash is performed for 30 seconds after every 40 minutes of use. So the maintenance time for 24 hours will be 18 min:

A = (1422) / 1440 = 0.9875

<u>Availability of a sand and anthracite filter for one day</u>

A backwash is performed, lasting up to 40 minutes — corresponding to the daily maintenance period — using water with properties favorable to the operation. As a result, an improvement in the availability of the UF membranes is observed.

Advantages, Problems and solutions

<u>El-Mactaa station case</u>

<u>Advantages</u>

- A good ratio between surface area occupied and flow treated.
- Compact frames that support the modules.
- Pre-determined backwashing sequence in the operating system.
- A low SDI with good quality raw water (low in suspended matter).
- A single pre-treatment step.

<u>Problems with this type of installation</u>

- Complex system with several pipes for backwashing, recirculation and chemical washing of ultrafiltration modules and several accessories (membrane connection and joint) which complicates maintenance and requires a lot of intervention.
- For a production of less than 70% of the installed capacity, the operator has a large number of stand-by modules which gives him leeway in the event of rapid clogging with raw water moderately loaded with suspended matter.
- Risk of tearing of the ultrafiltration membrane and intrusion of untreated water into the reverse osmosis system which may subsequently induce, if the phenomenon is frequent, an irreversible clogging and a pressure drop of around 5 bars if the operator does not intervene in time.

<u>Suggested solutions</u>

- Invest in an installation upstream with a spectrum of filtration which varies gradually between 200mm up to ultrafiltration and this to avoid having water in the presence of particles exceeding the admissible threshold at the entrance of ultrafiltration.
- If the operator wishes to continue producing without investing in new installations, then he must adapt his production with the seawater to be captured because only water with a low suspended solids allows a "full capacity" without major problems.

Classic pretreatment case of Beni Saf station

<u>Advantages</u>

- Conventional systems are weakly influenced by variations in the quality of the water to be treated and allow working over a wide range of suspended matter load and consequently more production days in the year.
- It provides satisfactory and fairly regular water quality for reverse osmosis.
- It has only one pumping.

Disadvantages

- The installation does not support heavy suspended matter load, which leads to shutdowns during the flood season.
- This type of pretreatment is without load break and therefore without intermediate pumping, so the operator must pay attention to the excessive pressure drop in the circuit caused mainly by the clogging of the filters, in order to ensure an acceptable flow in the circuit (entry of reverse osmosis).
- Length preprocessing chain with several stages therefore several equipment and annex equipment which requires more effort from the labor teams.

Suggested solutions

- Installation of a new system upstream of the sand filters to absorb the heavy load caused by the overflow of the river.
- Include a refining treatment such as ultrafiltration after cartridge filters to obtain water with a lower SDI.

CONCLUSION

Pretreatment is a critical stage in the treatment of surface and seawater, playing a decisive role in the effectiveness and longevity of RO systems. Since RO membranes are costly, their protection through efficient pretreatment directly impacts both system reliability and the cost of desalinated water production.

The findings indicate that while ultrafiltration offers superior unit availability, it is highly sensitive to variations in raw water quality. This sensitivity results in fluctuating SDI values and necessitates frequent maintenance, along with increased consumption of chemical agents. In contrast, the conventional pretreatment system demonstrated more stable SDI values and consistently high water quality, with minimal dependence on raw water conditions and no need for corrective maintenance.

Specifically, SDI values at the El Mactaa station (ultrafiltration) ranged from 0.99 to 2.74, highlighting significant fluctuations. Meanwhile, the Beni Saf station (conventional filtration) maintained a narrower and more consistent SDI range of 1.5 to 1.9.

Given the high cost of ultrafiltration modules — approximately $900 per unit — and the requirement for specialized supervision and chemical inputs, the operational and economic burden is considerably higher. Based on these findings, conventional pretreatment systems are strongly recommended for desalination plants operating under variable raw water conditions, as they provide greater stability, lower maintenance requirements, and more cost-effective operation.

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