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Pretreatment Performance Evaluation of the Seawater Desalination Plant of Beni Saf BWC

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Abstract: The BENI SAF Seawater Desalination Plant is one of the largest projects undertaken by the Algerian state for supplying drinking water, with a capacity of 200,000 m^3 per day. The plant uses the Reverse Osmosis technique as a desalination process. The performance of such systems requires the production of pretreated, good-quality feed water. Moreover, a number of large-scale experiments have shown that pretreatment of seawater before reverse osmosis (RO) desalination is key to retard fouling in osmosis membranes. This work aims to study the performance of the pretreatment selected by the BENI SAF Desalination Plant. To achieve this, we determined the physico-chemical and bacteriological parameters of the raw seawater used by the Plant. Variation of SDI, which is a key parameter in controlling fouling potential, was monitored during the year 2019. The pretreatment performance was investigated by monitoring the efficiency of each stage of the pretreatment process. The results obtained show the efficiency of the pretreatment adopted by this desalination plant.

Keywords: Desalination; fouling; pretreatment; retarding.

1. INTRODUCTION

To address water shortage, Algeria has reinforced its water resources by waste water treatment and seawater desalination plants. The desalination plant of BENI SAF produces 200,000 m^3/d of water to meet the needs of the region of Ain Temouchent and Oran. Located on the Mediterranean coast of Algeria in the wilaya of Ain Temouchent, the plant covers an area of 65700 m^2. The desalination process adopted for this plant is the reverse osmosis (RO) technique. A major challenge experienced by the plant is the poor quality of the raw seawater and therefore the rapid fouling of the reverse osmosis membranes. Feed water is characterised by turbidity, bacterial content and TDS (total dissolved solids), which causes fouling and results in the degradation of the membrane performance. When a membrane is affected by fouling, there is deterioration of its basic functions; this includes salt passage, decreased permeate flow and pressure drop across the membrane. On the other hand, inorganic scaling caused by exceeding the solubility limit of soluble salts is considered less problematic since it can be controlled by pH and addition of antiscalants [7].

Deposits on the membrane or on the pores leads to a decrease in the performance of the membrane [5], and to prevent rapid formation of these deposits, the seawater desalination plant of Beni Saf adopted a conventional physico-chemical treatment. The objectives of the pretreatment are as follows: * improving the quality of water, enhancing the performance of the membranes (reducing membrane fouling). Pretreatment has proved to be efficient in improving the performance of the membrane and reducing the cost of its replacement since it eliminates turbidity, bacteria and TDS (Total Dissolved Solids). Without pretreatment, RO

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membranes are prone to rapid fouling which results in frequent replacement with the consequential increase in operational costs. To address this issue, a pretreatment method must be integrated before feed water enters the RO system to help reduce membrane fouling and improve thereby its performance [1].

2. MATERIALS AND METHODS

2.1. Physico-chemical and biological characteristics of the raw seawater from the desalination plant of Beni Saf

The raw seawater of the Beni Saf plant was characterized by taking a sample of raw seawater and analyzing the physico-chemical and bacteriological parameters. Water sampling is a sensitive operation. It allows defining the quality of water at a given time or over a more or less long specified period. Therefore, it should be handled with the greatest care [3]. Table 1 shows the results of the physico-chemical and bacteriological analyses performed on a sample taken on 27/11/2019.

Table 1. Results of the physico-chemical and bacteriological analyses of the raw seawater from Beni Saf plant

	Physico-chemical analysis of raw water
Turbidity (NTU)	1.76
Temperature (°C)	19
pH	8.12
Conductivity ms.cm^{-1}	54.85
TDS (mg.l^{-})	39.55
DBO_5	5.00
DCO	10.00
Alkalinity (mg.l^{-}de $CaCO_3$)	142.7
Hardness (mg.l^{-} de $CaCO_3$)	7158.4
	Ionic Balance
Ca^{++} (mg.l^{-})	417.20
Mg^{++} (mg.l^{-})	1487.93
Na^{++} (mg.l^{-})	12165
K^{+} (mg.l^{-})	420.71
Sr^{++} (mg.l^{-})	11.25
Fe^{++} (mg.l^{-})	0.03
Ag+ (mg.l^{-})	0.11
SO_4^{2-} (mg.l^{-})	2,950.00
Cl^{-} (mg.l^{-})	21,950.12
HCO_3^{-} (mg.l^{-})	158.92
F^{-} (mg.l^{-})	1.25
CO_3^{2-} (mg.l^{-})	8.62
	Bacteriological analyses
Total califorms	3/100ml
Fecal califorms	0
Total Streptococci	0
Fecal streptococci	0
Aerobic germs22°C	2/100ml
Salmonella	Abs

Compared to other parameters such as turbidity or suspended solids, the Silt Density Index (SDI) is key in controlling the fouling potential of seawater, and therefore, requires continuous monitoring [2]. To this end, the evolution of the SDI of the seawater from this desalination plant was monitored over a certain period. SDI tests were performed as per ASTM D 4189-95 standard by filtrating a water sample through a membrane of 0.45 µm (microfiltration) and 47mm of diameter at a constant transmembrane pressure (2.1 bars). The SDI is determined by comparing filtration times, t_1 and t_2 required to achieve a fixed filtration volume at time 0 and after time t respectively. SDI_{15} (t = 15 minutes) is defined by the ASTM as the time required for accurate and standardized testing. SDI_{15} (t = 15 minutes). Figure 1 represents the variation of the raw seawater SDI_3 of the desalination plant of Beni Saf as a function of time for 2019.

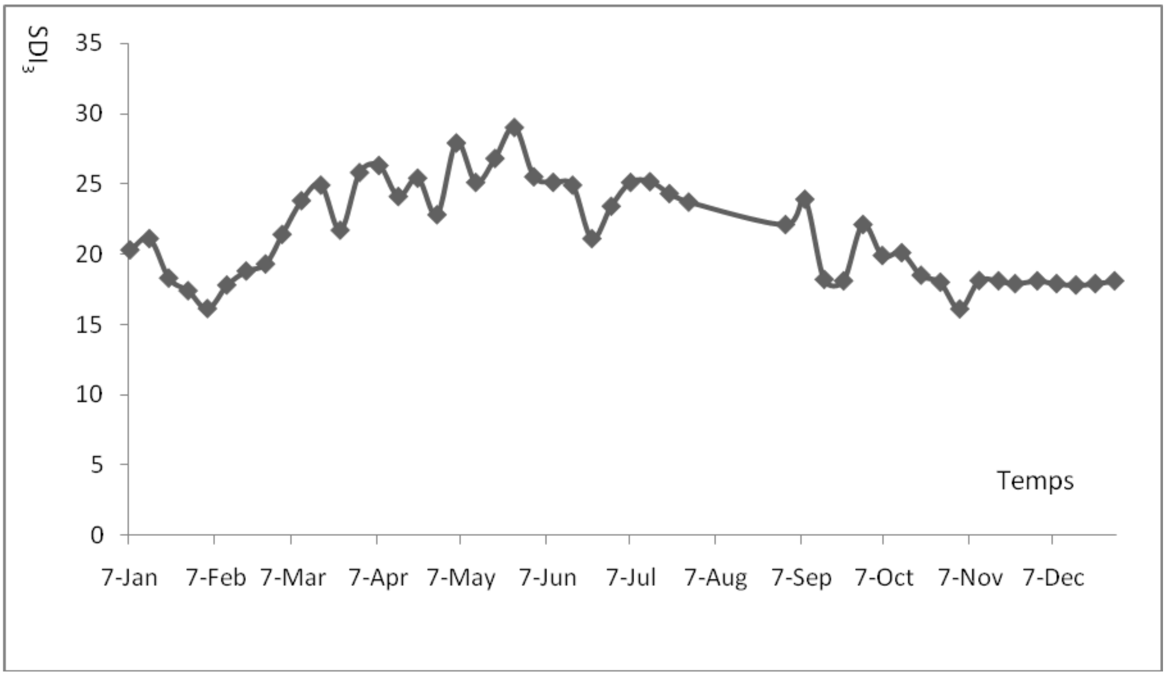

Fig.1. Variation of the raw seawater SDI of the desalination plant of Beni Saf as a function of time for 2019

From the SDI_3 versus time plot, one can see that the average SDI_3 in autumn and winter is low with little evolution but then increases in spring and summer.

2.2. Selection of pretreatment for the desalination plant of Beni Saf

Knowledge of the physico-chemical characteristics of the raw seawater requires the selection of the most adapted pretreatment technology to produce good quality supply water, and delay fouling of RO membranes. The pretreatment selected by the desalination plant of Beni Saf is a conventional physical and chemical treatment.

Figure 2 illustrates the different pretreatment stages used by the plant.

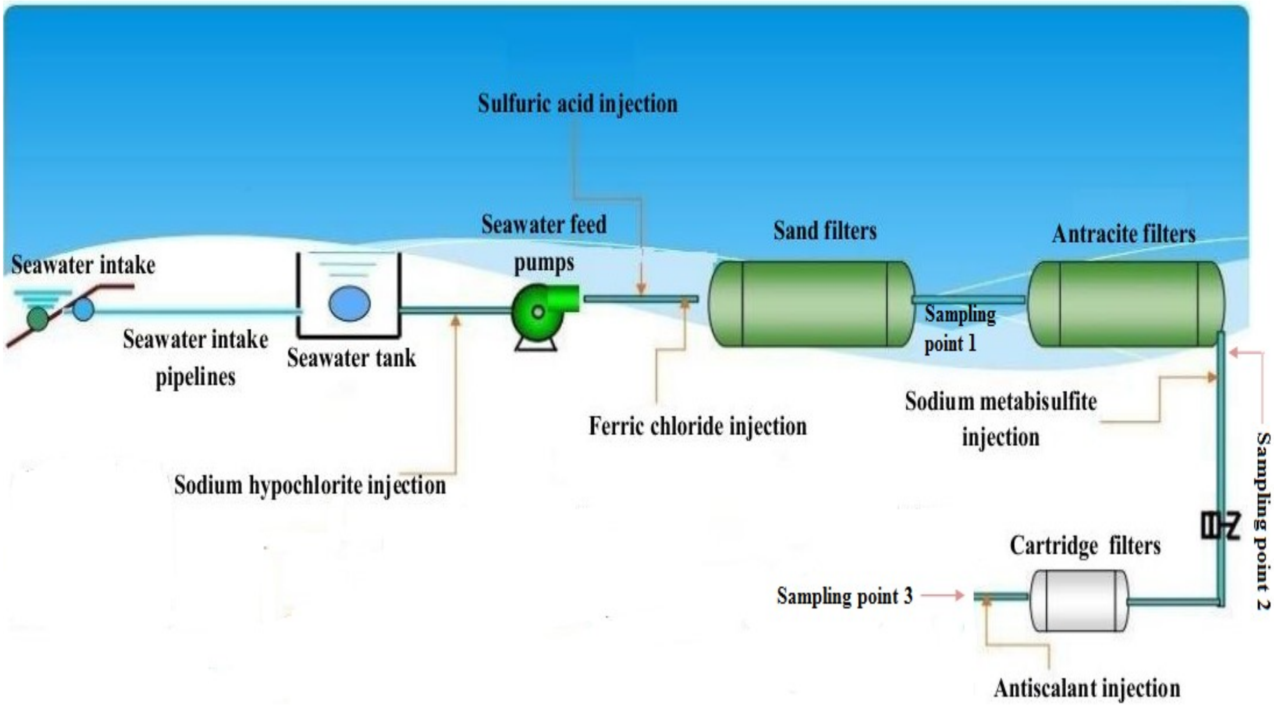

Fig .2. The pretreatment process used by the desalination plant of Beni Saf

2.2 Performance evaluation of the pretreatment adopted by Beni Saf plant

To monitor the performance of the pretreatment used in this plant, the pretreatment process was subdivided into three systems. Then samples were taken downstream of each system (sampling points represented in the diagram fig.2) at regular time intervals, and the parameters most influenced at this stage were measured (SDI_{15}, turbidity, temperature, pH). Samples were taken during the daily the production over a one-year period (2019).

System 1: Description of the system

Injection of sodium hypochlorite into seawater (pre-chlorination)

For pre-chlorination, the plant uses commercial sodium hypochlorite as a biocide. Hypochlorite is dosed automatically and continuously into the seawater collection tank to remove organic matter. This operation is handled by three dosing pumps with a rate of 25%, i.e., 187.51 l/h under a pressure of 2 bars.

Sulfuric acid dosing

Concentrated sulfuric acid (98%) is dosed upstream of the sand filters, to set the pH and prevent precipitation of carbonates and bicarbonates on the RO membranes. This operation is handled by three dosing pumps with 25% rate, i.e., 83.75l/h under a pressure of 6 bars.

Ferric chloride dosing (Coagulation)

Coagulation is the most popular treatment process used for the elimination of potential impurities such as colloidal and particulate matter. The purpose of coagulation is to combine small particles into larger aggregates/flocs (i.e. large groups of loosely bound suspended particles) by neutralizing the charges of the particles [6] . Performed upstream of the sand filters, the coagulation serves to destabilize colloids and suspended solids so that these substances are retained during filtration. Beni Saf desalination plant uses 40% commercial iron chloride as coagulant. Ferric chloride is automatically dosed into the discharge manifold of the seawater intake pump upstream of the sand filters at a rate that depends on the seawater flow rate. Five dosing pumps with 25% rate, i.e., 83.75 l/h are dedicated to this operation.

Sand filtration

A filtration bed constituted of sand and silica with two different sizes (dual layer) is employed in this plant. This dual layer filtration is sufficient to achieve an SDI < 4 and effectively eliminate the pigments of algae if the installation is fed with good quality raw seawater [4]. The layer of coarse sand (base layer) at the bottom of the filter is topped by a finer sand layer (filtration layer). The 1000 mm thick filtration layer (upper layer) with its low granulometry serves to trap particles.

The filtration sand has the following characteristics:

Table 2. Characteristics of the filtration sand (upper layer)

Sio_2 content	>99,5
Effective size (mm)	0.9
Uniformity coefficient	1.4
Absolute density (kg/m^3)	2650
Bulk density (kg/m^3)	1600
Grain size (micron)	139

The thickness of the coarse sand bed (base layer) is ~300 mm. The sand has the following characteristics:

Table 3. Characteristics of the filtration sand (base layer)

Sio_2 content	>99,5
Effective size (mm)	2
Uniformitycoefficient	1.4
Absolute density	2650
Bulk density (kg/m^3)	1600
Grain size (micron)	309

The turbidity analyzer console of each train includes a sampling device (sampling point 1) for the measurement of SDI and turbidity together with other parameters.

System 2: Description of the system

Anthracite filtration was added to this system.

The anthracite filtration system consists of two filter trains comprising seven modules or filter pairs, making up a total of twenty-eight filters. Each module comprises two identical filters operating as a single filtration unit. In normal operation, the flow rate required to feed the anthracite filter system is 18,000 m^3/hour.

The desalination plant of BENI SAF employs anthracite filters with a filtration bed of 1000 mm. The anthracite used has the following characteristics:

Table 4. The characteristics of the anthracite used in the desalination plant of BENI SAF

Rate of charcoal %	>90
Effective size (mm)	1.2
Uniformity coefficient	1.4
Absolute density	1400
Bulk density (kg/m^3)	1050
Grain size (micron)	186

The turbidity analyzer console of each train comprises a sampling device, intended for measuring the rate of SDI matter, turbidity together with other parameters (sampling point 2).

System 3: Description of the system

Physico-chemical treatments were added to this system

Antisclants dosing

This chemical treatment is carried out upstream of the cartridge filters. A commercial dispersant with a concentration of 95% diluted to 10% is dosed using 5 pumps with a flow rate of 25%, i.e., 56.75l/h under a pressure of 6 bars.

Sodium bisulphite dosing

Chemical treatment is performed downstream of the cartridge filters using commercial sodium bisulphate 61% diluted to 10%. The operation is handled by five pumps with a flow rate of 25%, i.e., 133.51 l/h under 6 bars of pressure for dosing sodium bisulphite

Cartridge filtration

This is the first pretreatment stage aimed at retaining particulate <5 µg and ensuring the protection of the reverse osmosis installation. The filter cartridges used are made of polypropylene because of its low water absorption. Each filter contains 380 cartridges type PP-5, with an outer diameter of 61 mm and a length of 1270 mm with a rating of 5 microns. At the end of this process, a connection for taking samples is placed on the filtered water outlet line to measure the SDI fouling index, turbidity and other parameters (sampling point 3).

3. RESULTS AND DISCUSSION

3.1. Study of the pretreatment

Temperature, pH, turbidity and SDI measurements were taken after each pre-treatment system for the year 2019 by computing the monthly average. The results are consolidated in the following tables.

Table.5. Results of analyses after sand filtration at BWC plant for 2019

Physical characteristics	*PH*	*Temperature (°C)*	*SDI_{15} (%/min)*	*Turbidity*
Standard	7-8	16-25	5-6	0.7-1
January	7.45	18.77	5.2	0.76
February	7.61	17.3	5.25	0.76
March	7.71	15.73	5.6	0.77
April	7.51	17.28	5.7	0.8
May	7.45	18.85	5.73	0.86
June	7.40	21.03	5.63	0.87
July	7.67	24.5	5.95	0.85
August	7.52	24.4	5.75	0.88
September	7.63	22.3	5.5	0.78
October	7.76	23.2	5.4	0.77
November	7.61	19.44	5.3	0.75
December	7.64	16.9	5.1	0.71

Figure 3 shows the evolution of these parameters as a function of time for the first system

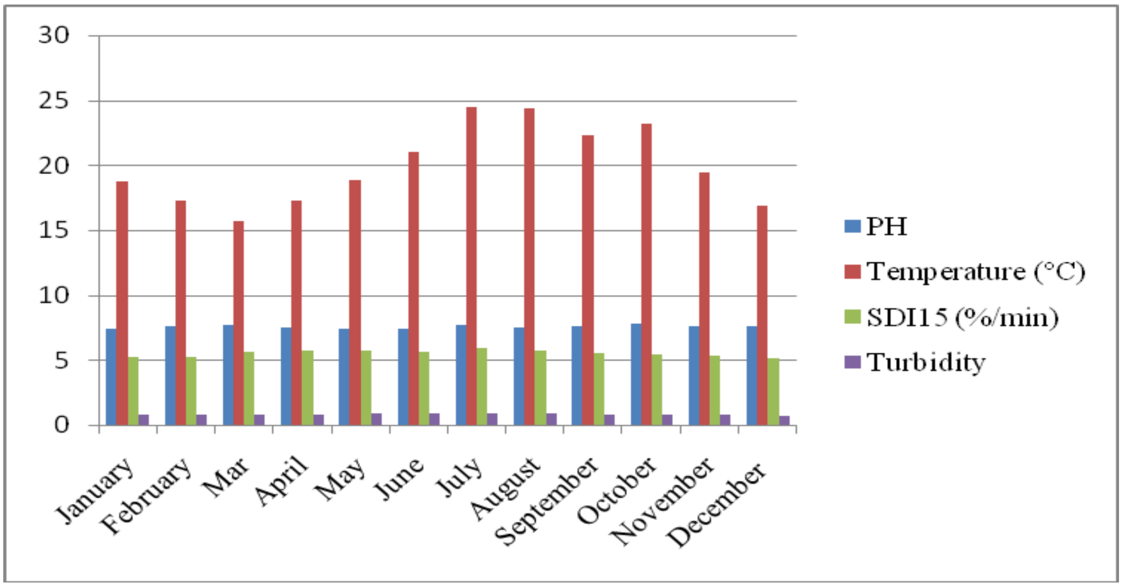

Fig. 3. Evolution of temperature, pH, SDI_{15}, turbidity after the 1st filtration system of the plant for 2019.

By comparing the results found and those of the raw seawater, a significant reduction in turbidity and SDI_{15} was observed with a difference of 10-15% and 0.7-1 NTU for the SDI_{15} and turbidity respectively, which shows the effectiveness of the system (coagulation+ sand filtration). The sand-based filtration aims at retaining suspended solids present in the seawater and flocs that formed at the preliminary stage of coagulation. The filter medium used by the plant is of two sizes (dual layer); a layer of coarse sand (base layer) located at the bottom of the filter is topped by a layer of finer sand (filtration layer) that serves to retain finer particles. An increase in SDI_{15} and turbidity was observed. This increase is caused by the fouling of the filtration bed by trapped particles. Therefore, the filters must be washed when the head loss reaches a limit value, which results in a drop in filters output.

Table 6. Analyses results after anthracite filter at BWC plant

Physical characteristics	*PH*	*Temperature (°C)*	*SDI_{15}(%/min)*	*Turbidity*
Standard	7-8	16-25	4- 4,5	0.7- 0,5
January	7.45	18.77	44	0.65
February	7.61	17.3	4.45	0.6
March	7.71	15.73	4.3	0.53
April	7.51	17.28	4.25	0.55
May	7.45	18.85	4.15	0.50
June	7.40	21.03	4.13	0.52
July	7.67	24.5	4.1	0.51
August	7.52	24.4	4	0.5
September	7.63	22.3	4.2	0.58
October	7.76	23.2	4.39	0.6
November	7.61	19.44	4.5	0.68
December	7.64	16.9	4.45	0.7

Figure 4 shows the evolution of these parameters as a function of time for the 2nd filtration system.

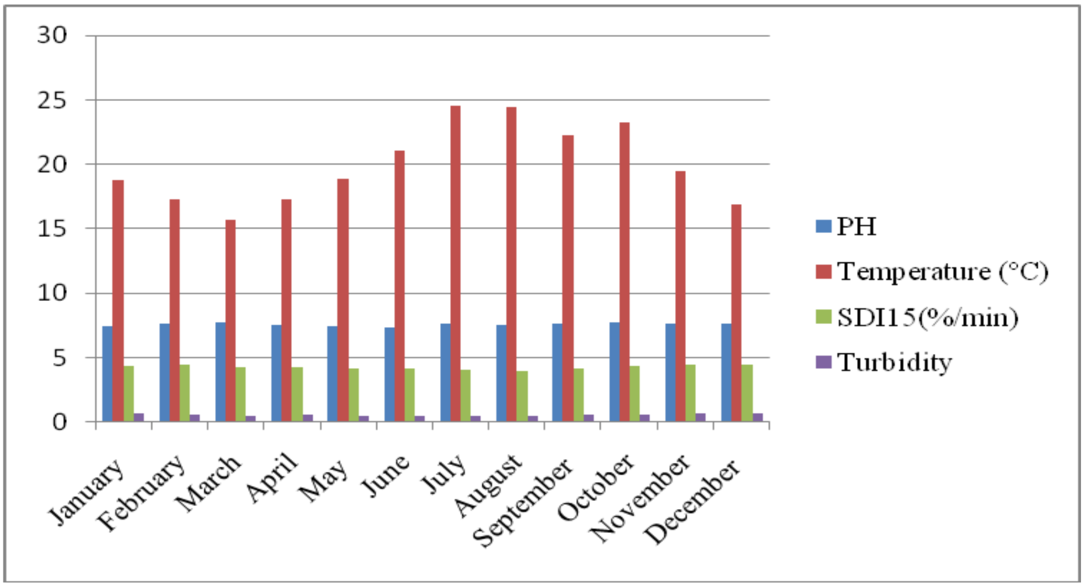

Fig. 4. Evolution of temperature, pH, SDI_{15}, turbidity after the 2nd filtration system of BWC plant for 2019

Figure 4 shows the filtration performance of the 2nd system in the elimination of SDI_{15} and turbidity. The SDI_{15} recorded after filtration by anthracite filters fares better than that recorded after a single filter (sand filter only). A discrepancy of 0.5-1.5 was observed between the two configurations (system 1 & 2).The second system shows that anthracite filtration operates as an adsorbent. The anthracite fulfils a number of functions among which the elimination of residual concentrations of oxidant agents such as chlorine and ozone, together with other carcinogenic derivatives resulting from the treatments. Anthracite adsorbs these substances or reduces them by catalysis to benign forms It also traps organic matter, algae, pesticides and generally any compounds that may alter the odour or taste of the drinking water. Therefore, the anthracite filters are necessary after the sand filters in order to produce water with good quality.

Table7. Results of the analyses after the cartridge filters (pretreated water) at BWC plan for 2019

Physical characteristics	*PH*	*Temperature (°C)*	*SDI_{15}(%/min)*	*Turbidity*
Standard	7- 8	16- 25	<4	<0.5
January	7.45	18.77	3.6	0.35
February	7.61	17.3	3.4	0.38
March	7.71	15.73	3.45	0.4
April	7.51	17.28	3.2	0.42
May	7.45	18.85	3.1	0.35
June	7.40	21.03	3	0.3
July	7.67	24.5	3.12	0.35
August	7.52	24.4	3.15	0.30
September	7.63	22.3	3.25	0.38
October	7.76	23.2	3.3	0.35
November	7.61	19.44	3.4	0.4
December	7.64	16.9	3.48	0.38

Figure 5 below shows the evolution of these parameters as a function of time for the 3rd system.

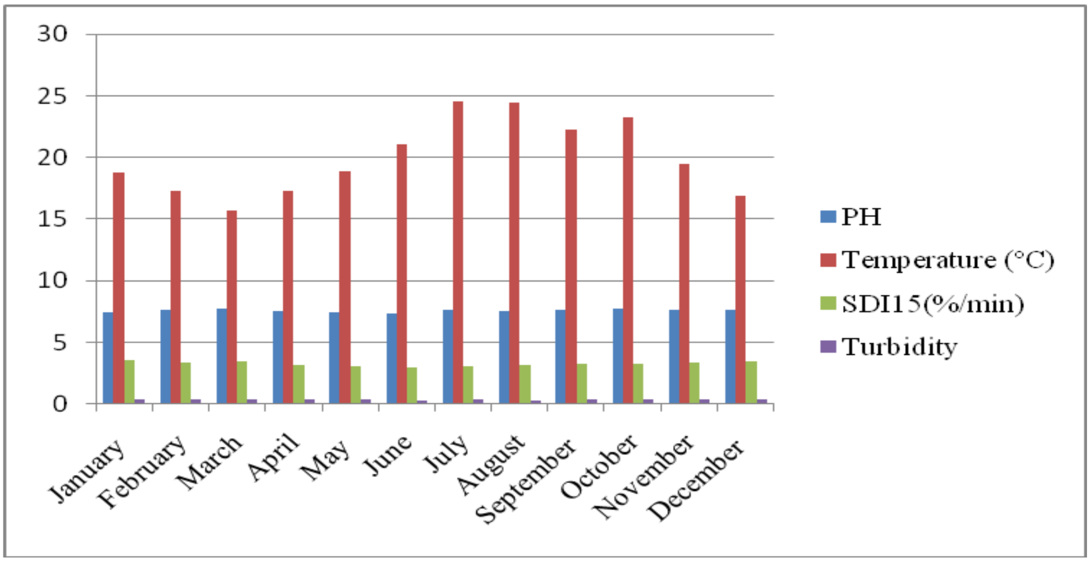

Fig. 5. Evolution of temperature, pH, SDI_{15}, turbidity after the 3rd filtration system of BWC plant for 2019.

The recommended limit values for SDI and turbidity, upstream of the RO membranes, are < 4 (95 % of the time), and<0.5 NTU respectively [5]. Figure 5 shows variation in turbidity and SDI_{15} as a function of time. As can be seen, the recorded SDI_{15} and turbidity values are below the recommended limits upstream of the reverse osmosis system, confirming thereby the efficiency of the pretreatment used by the desalination plant. Filtration by cartridge filters is the final pretreatment stage; it serves to protect the high-pressure unit as well as the RO membranes, and retain smaller particles that may cause damage to equipment. It also serves to reduce subsequently the SDI_{15} and turbidity to produce water ready for passage through the RO membranes. Upstream of the cartridge filters, antiscalant dosing allows for avoiding salts precipitation on the RO membranes. Down the cartridge filters, the dosing of sodium bisulphite allows for the elimination of residual chlorine resulting from the sodium hypochlorite employed for the disinfection of seawater.

3.2. Study of the influence of the pretreatment used by the desalination plant of BENI SAF on the performance of reverse osmosis

The desalination process is carried out by passing pretreated seawater through semi-permeable membrane modules (Hydranautics SWC5). These modules require the following conditions (Table 8).

Table 8. Operating conditions

Conditions	*Recommended values*
Maximum pressure applied	82,73 bars
Maximum chlorine concentration	< 0.1 PPM
Maximum operating temperature	113 °F (45 °C)
pH range, continuous (cleaning)	2-11 (1-13)*
Maximum Feed water Turbidity	1.0 NTU
Maximum Feed water SDI (15 min)	5.0
Maximum Feed Flow	17.0 m^3 /h
Maximum Pressure Drop for Each Element	1,03 bar

These requirements must be fulfilled by the plant to ensure stable membrane performance. To investigate the influence of pretreatment on the performance of RO, variation of the pressure drop of both stages of line no. 1 together with its permeate flow rate were monitored. The following figures show the variation of permeate flow and head losses as a function of time (line 1). Les measurements were taken during the daily production.

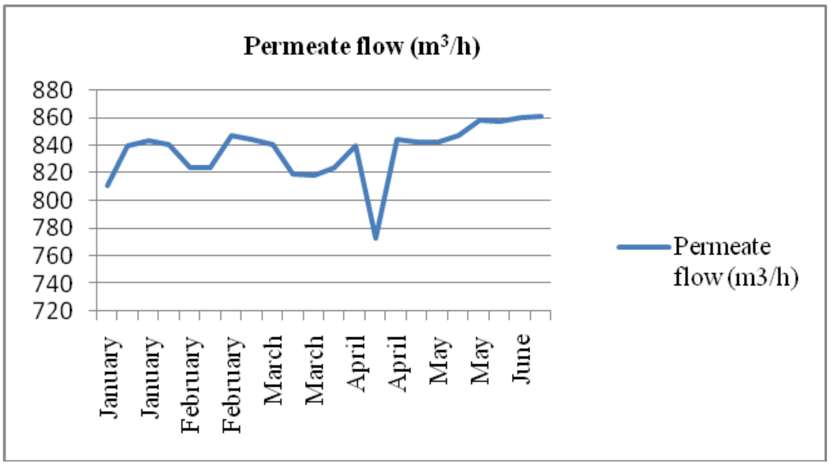

Fig .6. Evolution of permeate flow as a function of time

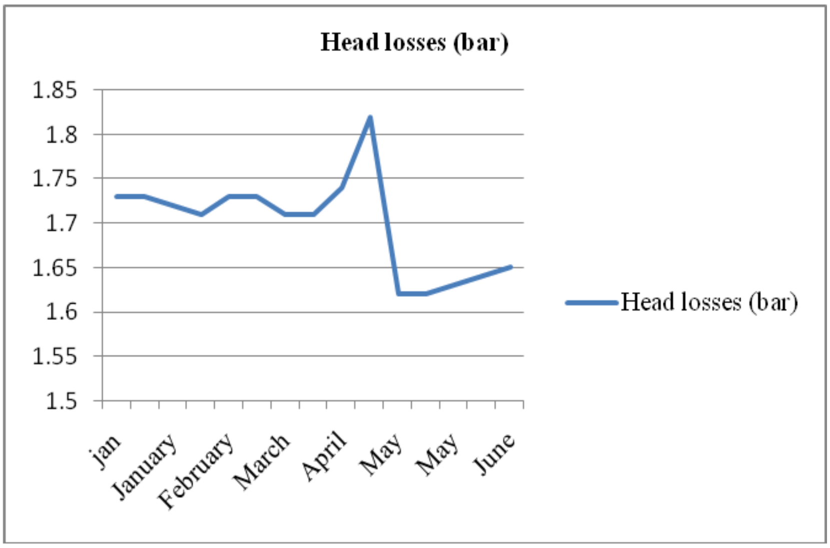

Fig.7. Evolution of head losses as a function of time

As can be seen from figure 3, which illustrates permeate flow variation (line 1), there is a quasi-stability of the permeate flow during for January-March. For April, one can observe a decline in flow rate (~10%) attributable to the fouling phenomenon, which necessitates a chemical cleaning of the membranes. As shown in figure 7, the variation curve of head losses illustrates the stability of both the first and second stages for Jan-March, which can be explained by the absence of the fouling phenomenon. By contrast, April sees an increase in head loss due to fouling. The results found show that albeit the seawater of the desalination plant of BENI SAF is properly pretreated, there is yet a persistent fouling. Currently, a very noteworthy trend includes the use of membrane pretreatment (Microfiltration- Ultrafiltration), to improve the quality of the pretreated water and consequently the performance of the RO installation.

4. CONCLUSION

The main challenges faced by the desalination plant of BENI SAF is the rapid fouling of RO membranes associated to particulate/colloids (deposit), organic compounds (scaling) and to biological growth (biofilm).

Results of physico-chemical and bacteriological analyses on the raw seawater of the desalination plant show that this seawater necessitates a pretreatment to eliminate the materials responsible for fouling.Poor feed water leads inevitalby to shorter life cycle of the RO membrane.

For this reason, the desalination plant of BENI SAF employs a conventional pretreatment (physico-chemical treatment) to fight the formation of deposits on the RO membrane.

Our study shows that each stage of pretreatment used by the plant leads to significant improvement in the quality of the feed water.

The first system shows that pre-chlorination, coagulation, and sand filtration reduces SDI_{15} by 10-15% /min whereas the second pretreatment system shows the effectiveness of the anthracite filtration, and a discrepancy in SDI_{15} between the two systems (1 & 2) of 0.5-1.5. Whereas the last system shows the effectiveness of the filtration based on cartridges (0.5 µm) and addition of antiscalants.SDI_{15} and turbidity values were found to be in the range < 4 (95 % of the time), and <0.5 NTU, respectively. These results demonstrate the effectiveness of the pretreatment used by the desalination plant of BENI SAF. In spite of the effectiveness of the pretreatment employed by the plant, the fouling phenomenon persists, which requires an additional pretreatment process such as membrane pretreatment (desalination plant of MAKTAA) to improve the quality of pretreated seawater and increase the life cycle of RO membranes.

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