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Journal of Chemical and Pharmaceutical Research, 2022, 14(9):01-10

Research Article

ISSN: 0975-7384
CODEN (USA): JCPRC5

The First Experiment in Morocco to Demineralize Brackish Surface Water by Reverse Osmosis

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Received: *12-Nov-2019, Manuscript No. JOCPR-19-4515;* ***Editor assigned:*** *15-Nov-2019, PreQC No. JOCPR-19-4515 (PQ);* ***Reviewed:*** *29-Nov-2019, QC No. JOCPR-19-4515;* ***Revised:*** *06-Sep-2022, Manuscript No. JOCPR-19-4515 (R);* ***Published:*** *04-Oct-2022, DOI: 10.37532/0975-7384.2022.14(7).006.*

ABSTRACT

The Khenifra reverse osmosis plant is the first water treatment plant in Morocco, which combines conventional treatment with RO process. The plant will cover production of 36,290 m^3/d drinking water by 2030. This brackish water. The RO plant was commissioned in June 2013 and since then the performance of the RO installation unit has gone through several highs and lows. In this study, certain design factors and operating conditions of the brackish water demineralization unit of the Khenifra Oum Er-Rabie River (OER) are reviewed and their evolution during its first year of operation to assess the unit's performance. He follow-up of the physical-chemical analyses (chloride, magnesium, conductivity and calcium) supplemented by bacteriological analyses indicates the proper functioning of the treatment unit. In this study, certain design factors and operating conditions of the brackish water demineralization unit of the Khenifra Oum Er-Rbia River (OER) are reviewed and their evolution during its first year of operation to assess the unit's performance. The follow-up of the physical-chemical analyses (chloride, magnesium, conductivity and calcium) supplemented by bacteriological analyses indicates the proper functioning of the treatment unit.

Keywords: Reverse osmosis; Desalination; Drinking water; Performance

INTRODUCTION

Water is a vital element for life on earth and a necessity for the continuity of the economic, social and environmental life [1].

According to the World Health Organization (WHO), around 2.1 billion individuals in the world lack drinking water, although in 2025, we predict that half world population will live in crisis regions [2].

To produce drinking water, raw water is characterized and then treated in a treatment facility which must produce, in all circumstances, Water with quality that meets all current standards. In fact, clotting-flocculation is the most widely used treatment to eliminate suspended materials and colloids in water [3].

MATERIALS AND METHODS

Raw water characterization

Reverse osmosis membrane treatment is used to eliminate salinity from the water. Oued Oum Er-Rabie is the main water resource in Khenifra province. This surface water is characterized by large variations in suspended materials and high concentrations of chlorides that leave an unacceptable taste to the consumer. Given the high salinity of the raw water of Oued Oum Er-Rabie which in some cases exceeds the Maximum Allowable Value (MAV) of the Moroccan standard on the quality of human food water in terms of chlorides, a osmosis demineralization unit reverse is added to the traditional treatment unit of the city of Khenifra; to produce water that meets the standards of potabilization. This is the first surface water demineralization experiment in Morocco to be carried out. This study focuses on treatment process evaluation of the treatment station based on physical-chemical and bacteriological analyses (Table 1) [4].

Table 1: Characteristics of Oued Om Er-Rabie raw water in 2013.

Chemical composition	**Physical-chemical characteristics**	**Moroccan standards of drinking water**
pH	8.5	6.5-8.5
Conductivité µs/cm^2	2700-1333	2700
Chlorure mg/l	650-800	750
Alkalinity (°F)	17.6	-
Total dissolved solids TDS (mg/L)	1800	1000-2000
Oxydabilité	1-0.6	5
Magnésium mg/l	32.5	100
Calcium mg/l	95	<500
Aluminium mg/l	<0.2	0.2
Sulfate mg/l	117	200
Microbiological characteristics		
Total colliforms NPP /100 ml	150	0/100 ml

Khenifra, a city with 117510 population, located in Middle Atlas of Morocco, with an area of 41.033 km^2 (5.77% of Morocco's area). It occupies a strategic position at the crossroads of two important collars that connect the high pond of Om Er-Rabie to the high ponds of Melouiya and Beht/Sebou [5]. The raw water supply at the treatment plant comes from the Tanfnit El Borj, located 15 km from the treatment plant. These surface waters are distinguished by the physical, chemical and microbiological characteristics that are summarized in the following chart [6]. Description of the treatment plant in Khenifra for the water-fertilization of the Khenifra treatment plant, the treatment put in place consists of;

Pretreatment Process

Undisbursement unit: There are two independent disbursers, designed to handle a level of suspended solids up to 20 g/L, to the unit at a nominal flow of 1250 m^3/h. Their function is necessary when the concentration of suspended solids exceeds 2 g/L, otherwise they serve as a contact tank for prechlorination [7].

Lamella clarifiers: There are two independent clarifiers; their role is to remove suspended solids upstream of the dual media filters. They include the following steps:

Coagulation with aluminium sulphate: Aluminium-based coagulants have been the most widely used. They can modify the surface loading properties to promote agglomeration and/or entanglement of smaller particles into larger flocs.

- **Flocculation with anionic polymer:** The role of flocculation is to promote contact between destabilized particles by means of a slow mixture. These particles agglomerate to form a floc that can be easily removed by sedimentation.
- **Lamellar settling:** Technique used to separate suspended matter and colloids collected in the flocs during the coagulation flocculation stage.

Dual media filtration: There are seven 36 m² parallel double filters containing 0.1 m of gravel, 0.8 m of very fine sand and 0.8 m of pumice stone to trap fine particles, obtain a turbidity of the filtered water of less than 0.5 NTU and thus improve the Silt Density Index (SDI). All cells are washed back in sequence with filtered water and air (Figure 1).

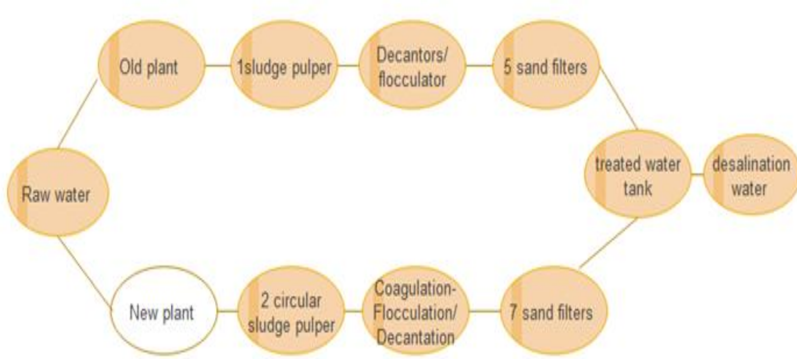

Figure 1: Block flow diagram for the pretreatment system. Note: FWT: Filtered Water Tank.

Sludge Recirculation

At different stages, the Khenifra water treatment plant produces different wastes:

- Purifier sludge.
- Sludge from lamellar clarifiers.
- Clarifier for dirty water from sand filters.

This sludge cannot be released directly into the natural environment. In addition, in order to minimize water losses from the plant, some of the dirty water washing will be recycled. The sludge extracted from the lamellar clarifiers, one part was used as a coagulant aid in the coagulation flocculation step, the other part of the clarifier and the sludge from the dirty water filter are sent according to their concentration either to the sludge tank or directly to the natural environment [8,9].

A Reverse Osmosis Process

Low pressure pumps and microfiltration: A group of three-micron cartridge filters (MCFs) with a 5 µm mesh installed on the common discharge manifold of low pressure pumps, each containing 224 cartridges (PALL Claris 50 reference). After pumping at low pressure, the filtered water receives three additional treatments: Acidification pH adjustment by injection of H_2SO_4 to 98%. Injection reagent sequestering up stream of microfiltration to prevent precipitation of calcium carbonate ($CaCO_3$) and calcium sulfate ($CaSO_4$) at the membrane level. Injection of sodium bisulfate to neutralize the residual chlorine remaining in the feed water.

FilmTecTM Reverse Osmosis for Brackish Water

The membrane used in this plant is called XLE440 and belongs to the FILMTEC membrane family FT30. It is composed of a thin film composite membrane composed of three layers, each layer is adapted to specific requirements: A polyester support strip, A microporous polysulfone intermediate layer An ultra-thin polyamide barrier layer on the upper surface.

The pretreated water is pumped to the RO group by a high-pressure pump. The pretreated water is divided into three identical flows to supply the three reverse osmosis units, each reverse osmosis unit consists of 75 pressure tubes divided into two stages, namely 56 tubes on the first stage and 19 tubes on the second stage. Each tube is loaded with 7 membranes, giving a total of 525 membranes per osmosis plant [10]. The association mode of the two pressure tube stages is the so-called "series-release" mode, i.e. the concentrate from the first stage is fed to the second stage. The average conversion rate is about 80%. The pretreated water is pumped up to a pressure of 12 bar. The maximum nominal pressure is 14.5 bar (Figure 2).

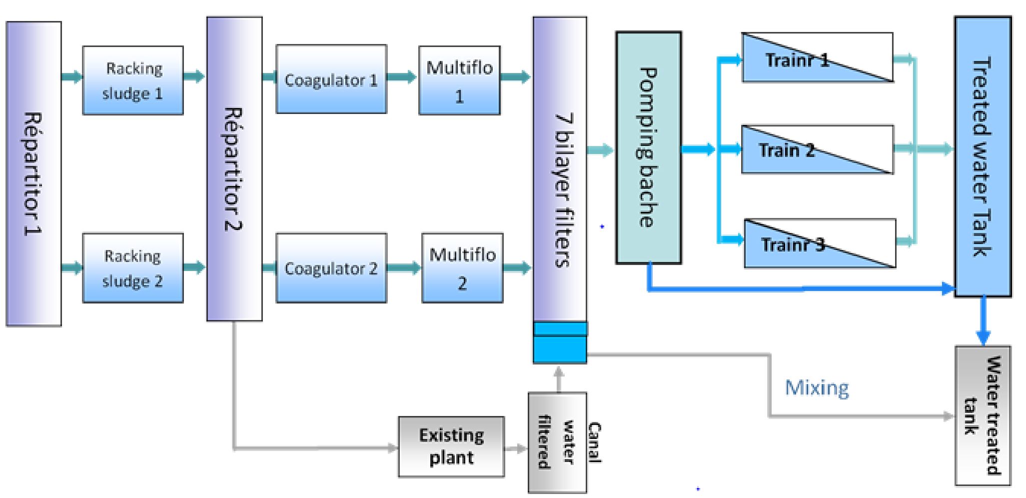

Figure 2: Block flow diagram for the reverse osmosis process.

Osmosis and Blending Water

The return of osmosis water from the 3 anti-drying tanks is placed above the treated water tank to ensure mixing between the demineralized water and the filtered water used for the final mixture. The osmosis water is therefore discharged directly into the filtered water. The treated water and blending water are therefore mixed at the inlet of the 3,000 m^3 reservoir (Distributed water). In this section, the performance results of the Khenifra plant have been described, the plant's operations have been continuously monitored and the values of the selected indicators have been recorded daily in order to optimize the plant's performance and to detect trends and potential problems for the long term [11]. The analysis below covers an operational period from 2013 of the plant start-up.

The Evolution of Operating Parameters

SDI: The Clogging Density Index (SDI) is an indicator of colloids and suspended particles in water. The evolution of the Clogging Density Index (SDI) of filtered water from dual media filters and micro-filtered water after 5 µm cartridge filters the SDI values after microfiltration are always below <3 even if water quality changes seasonally, which leads to deduce the efficiency of the pre-treatment process. The results obtained show that the reverse osmosis section at the inlet of the pre-treatment process works correctly and that microfiltration improves the quality of the filtered water in terms of SDI (Figure 3) [12].

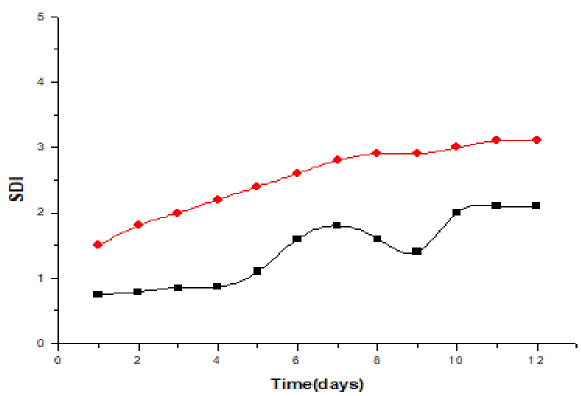

Figure 3: SDI values at the inlet and outlet of the microfiltration. Note: Micro-filtered water, Filtered water.

RESULTS

Conductivity

The raw water supplied to the demineralization plant undergoes significant seasonal variations in conductivity. It increases during the summer to 2512.3 µS/cm; Due to water evaporation causing a high salt concentration and a decrease during the winter to 1333.8 µS/cm, due to the precipitation dilution. This increase will have a significant impact on the membrane's performance in the short and long term. In the short term, permeate quality will gradually decrease, as will productivity. In the long term, if the recovery and dosage of the antiscalant agent are not adjusted, the membranes would suffer from severe scale or even irreversible fouling, resulting in a decrease in the performance of the membrane plant. Conductivity remained stable on the first in addition, it increased in the second stage due to the increased salt passage generated by the deposition of salts on the membrane surface, particularly NaCl, $CaCO_3$ and $CaSO_4$ contained in the feed water (Figure 4).

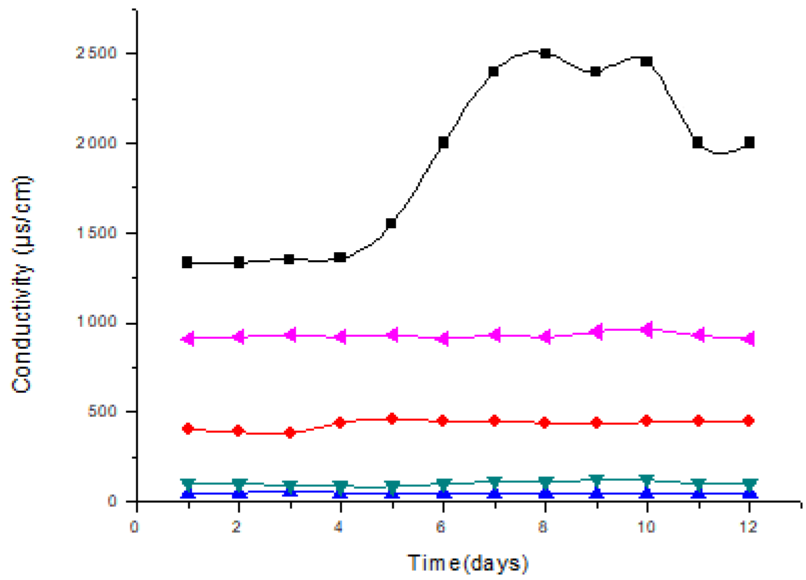

Figure 4: Variation in water conductivity over a Year 2013. Note: Feed Water, Permeate, 1 st Stage RO, 2nd Stage RO, Distributed water.

Permeate Flow Rate

At the beginning of the operation of the RO system permeate flow of the first stage decreased from 300 m^3 to 252 m^3 /h. This decrease is due to system settings during the commissioning period. Permeate flow increased during the first few days and stabilized after almost two weeks. This stabilization of membrane flow is known as membrane wetting. The wetting process ended after almost 13 days of operation. The progressive increase in the salinity of the permeate of the 2nd floor indicates mineral clogging. However, the decrease in the permeate flow rate of the first stage indicates organic fouling (Figure 5) [13].

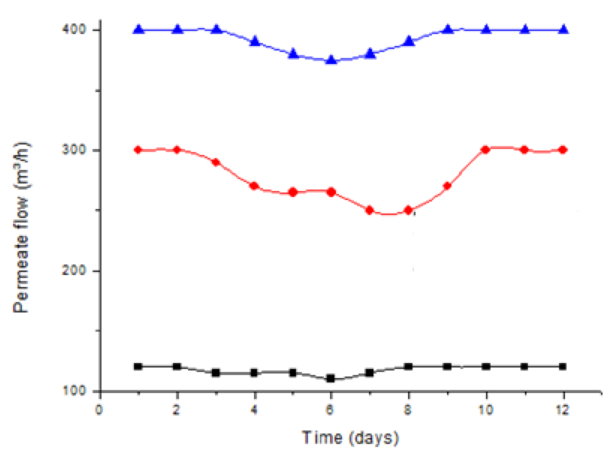

Figure 5: 1st stage, 2nd stage and RO unit permeate flow evolution 2013. Note: 1st stage R, 2nd Stage RO, RO Unit.

Physico-chemical parameters: The data represented on the graphs corresponding to the evolution of the physio-chemical parameters that were monitored on a daily basis. The following graphs show the evolution of these parameters during the first year of operation (Figures 6 to 9) [14].

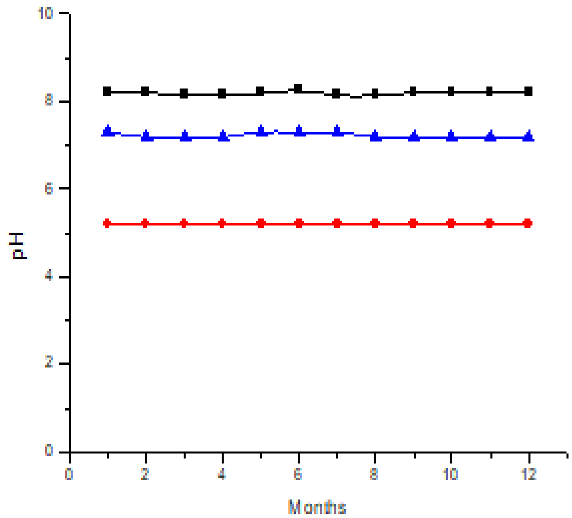

Figure 6: Change in pH during 2013. Note: Feed water, permeate, Distributed water.

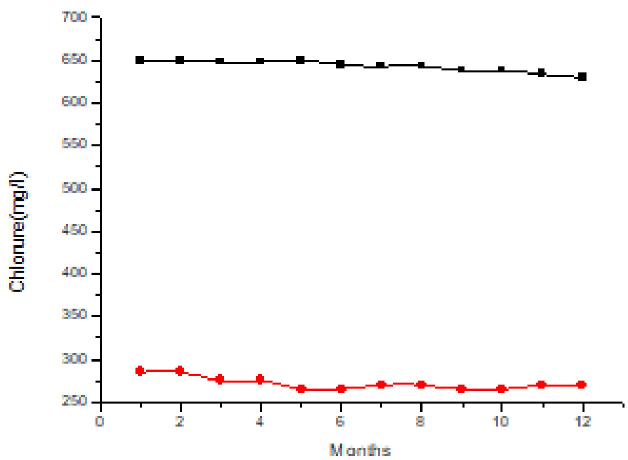

Figure 7: Chloride variation in water during 2013. Note: Feed water, Distributed water.

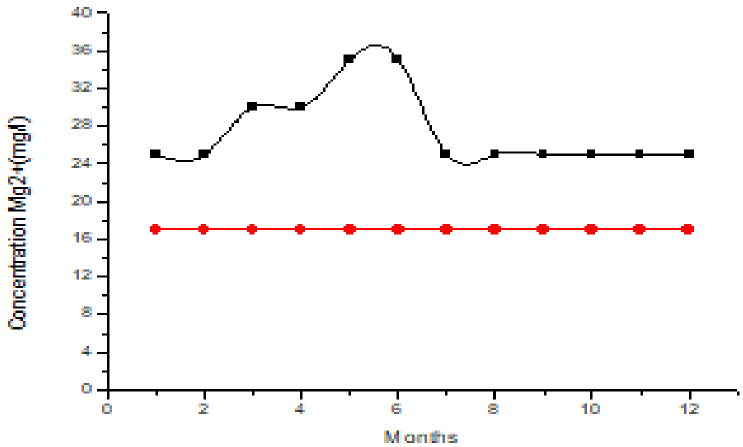

Figure 8: Change in Magnesium content during 2013 Note: —■— Feed water, —●— Distributed water.

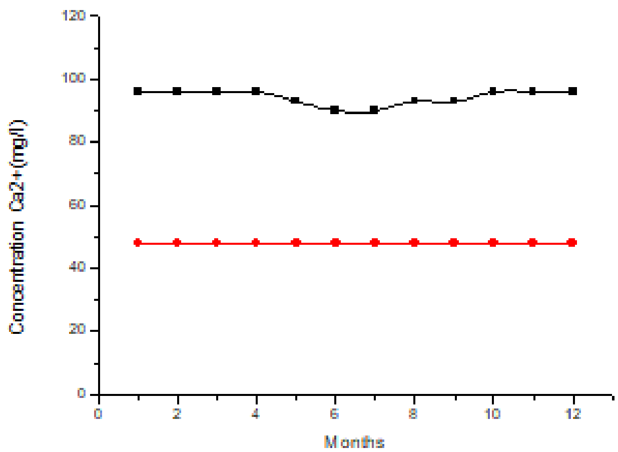

Figure 9: Change in Calcium content during 2013 Note: —■— Feed water, —●— Distributed water.

The performance of the reverse osmosis installation, in particular the variation in the concentration of chlorides, magnesium, pH and calcium in the raw and treated water during the year 2013. The pH of the water distributed at a rate ranging from 7.2 to 7.8. This value complies with Moroccan drinking water standards. The calcium, magnesium and chloride content comply with Moroccan standards for drinking water. The clogging index (IDS) of the pretreated water has a value <3, indicating the good pre-treatment of the raw water and preventing membrane fouling. The results show that the quality of the water distributed after demineralization by reverse osmosis is satisfactory in terms of physical and chemical parameters.

Microbiological quality of the supply water Pre-treated and distributed water: The monthly variations in microbiological feed water, pre-treated water and distributed water (Figures 10 to 12).

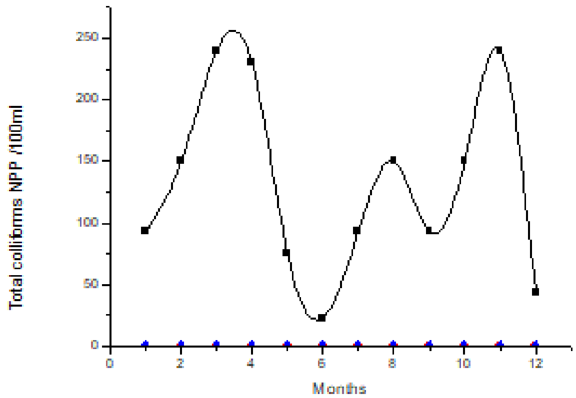

Figure 10: Variation of total coliforms in water during 2013 Note: —■— Feed water, —▲— Distributed water.

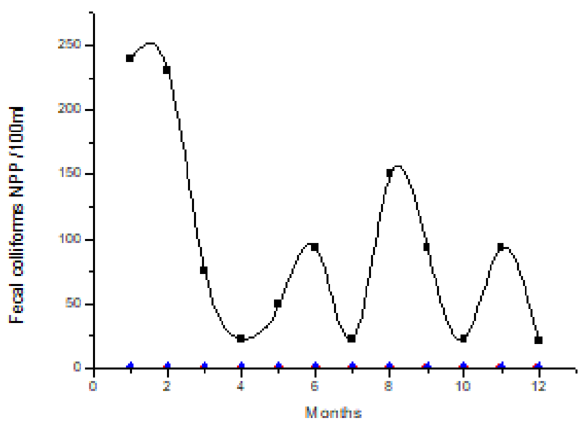

Figure 11: Fecal coliform variation in water during 2013 Note: —■— Feed water, —▲— Distributed water.

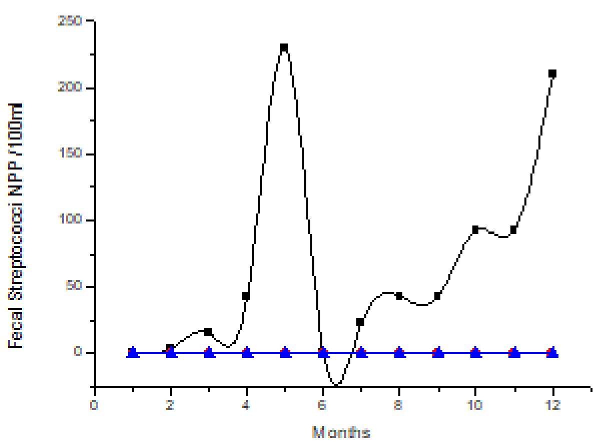

Figure 12: Fecal Streptococci variation in water during 2013 Note: —■— Feed water, —▲— Distributed water.

The analysis of the bacteriological results of the distributed waters is illustrated. The average total coliform load is 0 MPN/100 ml and 0 MPN/100 ml fecal coliforms, 0 MPN/100 ml fecal streptococci. On the one hand, these results comply with the bacteriological requirements of drinking water and meet Moroccan standards relating to the quality of the water produced and distributed for human consumption. On the other hand, it confirms that there is good disinfection; destruction of the pathogen [15].

DISSCUSSION

The monitoring of the operating parameters of the new treatment plant in the city of Khenifra and particularly the Reverse Osmosis unit shows the stability and reproducibility of these parameters. The water produced by the Khenifra desalination plant is of good quality and complies with Moroccan standards for the quality of drinking water produced and distributed.

CONCLUSION

In addition, the installation has improved performance and satisfactory reproducibility of operating parameters, although the quality of the raw water used to supply the plant varies seasonally. These results clearly show the interest of setting up this desalination plant to solve the problem of drinking water shortage for the city of Khenifra while improving the taste quality of the drinking water distributed.

ACKNOWLEDGEMENT

This work was supported by Onee (Morocco) and Laboratory of Separation Process, Department of Chemistry, Rabat University. The authors express his gratitude for this support.

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