International Journal of Chemical and Biochemical Sciences
(ISSN 2226-9614)

Journal Home page: www.iscientific.org/Journal.html

Performances analysis of the reverse osmosis desalination plant of brackish water used for drinking water: Case study

A. Lachheb[1], M. Hafsi[2], M.Taky[1], M. El Amrani[1], A. Elmidaoui[1]

[1]Laboratory of Separation Processes, Department of Chemistry, University Ibn Tofail Kenitra, Morocco BP 1246 Kenitra
[2]Office National of Electricity and Drinking Water (ONEE), Rabat, Morocco

Abstract

Reverse osmosis (RO) desalination systems are being increasingly used in the world as an efficient, reliable and cost-effective technology. It is widely used for the production of municipal and industrial grade water treating seawater and brackish water. Due to the continuously increasing demand for fresh water in the desert and remote areas. The most advanced and promising desalination system is the reverse osmosis (RO) system. In this paper, a 252m3/day RO desalination plant in the city of Tagounite, Morocco is taken as a case study. The measured data of the plant are recorded during 1 years of its normal operation. Also, experimental tests are carried out on site to investigate the influence of the main design and -operating parameters on the plant performance. The RO system is found to be sensitive to the variation in the feed water temperature, pressure and salinity. The used maintenance schedule is also seen to be suitable for the plant, since the change in plant performance during the operation period is not noticeable. On the other hand, a cost analysis is carried out on the RO plant components. The major factors affecting the cost of product water of this plant are the power consumption and capital cost. Surprisingly, the chemical treatment cost is one of the lowest in percentage. In this case, the power consumption cost is 35.1% and the capital cost is 33.6% and that of maintenance and repairs represent only 4.9% while the chemical treatment represents 10.6% of the total cost.

Keywords: Brackish water; Reverse osmosis; Desalination; Drinking water; Performance

Full length article **Corresponding Author*, e-mail: lachheb.ae@gmail.com

1. Introduction

Water, a limited finite resource, vital for the very existence of life on earth and a necessity for economic and social development and for environmental sustainability, is becoming a scarce commodity [1]. This is caused by the population growth, the change of lifestyle, water pollution, and inefficient use of water and climatic changes with more frequent extreme events such as droughts and floods. Where the availability of water cannot be increased by using conventional resources or by recycling or cannot be made available by demand management methods, the desalination of sea or brackish water offers an alternative solution [2]. Despite its long history, desalination remained largely untapped due to technological hurdles, excessive capital investments, and substantial energy demands, and very high unit cost when compared to conventional water [3]. New technological advances in the last 30 years tremendously reduced the capital cost and the energy consumption so that desalination projects can be considered as alternative solutions to water development [4]. The southern provinces of Morocco are suffering from water shortage. This is due to the population growth and climate changes. However, some areas in Zagora province have brackish water with significant water resources to mobilize after recovery operations, with salinity from 3 to 6g/l [5].

2. Materials and Methods

2.1. Presentation of the demineralization station

In North-West Morocco, the province of Zagora has seen the installation of a brackish water demineralization station, in the Tagounite region. Its production capacity is 18m3/h, ensuring the supply of drinking water to several municipalities as well as urban areas, the number of the population approximately 6000 habitants according to 2018 statistics. The brackish water demineralization station is the first installed in the province of Zagora.

2.2. Raw Water Characterization

The raw water, captured via a well catchment system and driven to the desalination plant, [6] has the following average physical, chemical and microbiological characteristics which are typical of water of well and are summarized in **Table 1**. As can be seen in Table1, a number of water quality parameters exceed the WHO and Moroccan drinking water standards. In particular the salinity (TDS 3.3-4 g/L) and ion concentration Cl-, Mg^{2+} and Ca^{2+} was high and thus needs desalination. In the Moroccan Drinking Water Standards, TDS is set at two distinct limits: the permitted limit 1000 ppm and the maximum allowable limit of 2000 ppm, where no better source is available [7].

2.3. Description of the Reverse Osmosis plant

Brackish Water Reverse Osmosis Plant (BWRO), has a production capacity of 252m^3/d. This desalination plant is in the municipality of Zagora in the South east of the Morocco. The plant is feed with brackish water from wells located at 1 km far from Reverse Osmosis Plant. **Figure. 2.** Shows the diagram of the plant. As shown in this Figure, the raw brackish water coming from the wells flows into a Raw water Tank, then it is sent to the pretreatment unit (Sand filters followed by cartridge filters), and then to the RO modules using high pressure pumps. After, the permeate water is mixed with the raw brackish water. This mixture is stored in a reservoir [8].

- ✓ **Pretreatment unit:** The raw brackish water is pretreated through the following stages:
- ✓ **Prechlorination:** A prechlorination station is located 50 km upstream of the plant (chlorine dosing up to 3 mg/L). Due to the occurrence of biofouling on the RO membranes when using prechlorination at the beginning of operation, it was decided to stop the use of prechlorination [9].
- ✓ **Acidification**: Sulphuric acid is injected at the inlet of the plant to prevent carbonate precipitation. The pH level is adjusted at 6.9. After acidification, the water is split in two similar process streams [10].
- ✓ **Sand filters**: Each stream is composed of one pressure filter. Each filter can treat a flowrate of 12 m3/hr corresponding to a filtration velocity of 12m/hr.
- ✓ **Antiscalant**: Antiscalant (polyphosphate 3 mg.L^{-1}) is injected to prevent scaling of calcium sulphate and barium sulphate as well metallic oxides [11].
- ✓ **Microfiltration**: Each RO skid is equipped with 5µm cartridge filters.
- ✓ **Dechlorination**: Dechlorination with sodium metabisulfite can be performed upstream of the high-pressure pump. Since continuous chlorination has been stopped, the use of sodium metabisulfite was stopped as well. Moreover, the injection point was initially located upstream of the cartridge filters which led to extensive biological growth onto
- ✓ **Reverse Osmosis Unit**: The pre-treated water is pumped to the RO group by high-pressure pump (19 bars). The RO group is composed of two stages. The first stage consists of two modules containing 12 RO TORAY spiral membranes (TM20-370). The second stage has one module containing 6 RO TORAYspiral membranes (TM20-370). The membrane is made of aromatic polyamide composite and each one has 34 m^2 /area. The average conversion rate is about 64% to 70% [12].
- ✓ **The post-treatment:** The post-treatment of permeate water to re-establish its calco-carbonic equilibrium includes the mixture of the permeate water with an equivalent quantity of the raw brackish water. This water is disinfected by calcium hypochlorite injection before put in reservoir of 200m^3 capacity (Distributed water).

3. Results and discussion

In this part, the results of the performances of the plant was described, the plant operations were monitored continuously and the values of selected indicators were recorded every day in order to optimize the performances of the plant and to detected the trends and the potential problems for long-term. The analysis below covered an operational period of one year beginning from plant start-up.

3.1. Analysis performances of Reverse Osmosis Plant

The table: 2, 3, and 4, present the monthly variations of the physico-chemical parameters of the raw water, permeate water and distributed water during the one year of 2020.

3.1.1. Physico-chemical quality of the feed water and treated water

Figures. 3, 4, 5, 6, 7, 8 and 9, present the monthly variations of the physico-chemical parameters of the raw water permeate water and distributed water during the one year of 2020. After demineralization by reverse osmosis, the overall rejection rate is high resulting in a conductivity of the treated water of the variations of 259-424 µS/ cm and TDS 196-321 mg/l (figure.3&4). The demineralization by reverse osmosis has also an effect on the change in pH, which takes values 5.66 to 5.67. (Figure.5) [13]. The water treated by reverse osmosis unit is mineralized with fresh water of the well to make a water treated its calco-carbonic equilibrium. As showed Figure .7, the turbidity of the permeate and distributed water has the rate 0.13 – 0.40 NTU. This value respects the Moroccan standards of drinking water. The silt density index (SDI) of pretreated water has a value < 1, indicate the good pretreatment of the raw water and prevent the fouling of membrane [14]. In addition, the MLSLI negative of the variations of -0.4 to -0.79 indicates that the distributed water is slightly aggressive (table 4). The results show that the quality of the distributed water after demineralization by reverse osmosis is satisfactory in term of the physic-chemical parameters such as the conductivity, pH, turbidity, cholorure, calcium and magnesium level (shown figure 3, 4, 5, 6, 7, 8, and 9). In addition, the distributed water respects the Moroccan standards of drinking water.

3.1.2. Microbiological quality of the feed water pretreated and distributed water

Figures 10, 11, and 12, present the monthly variations of the microbiological feed water, pretreated water and distributed water [15-16]. The analysis of the results bacteriological of distributed water shows in figure 9,10, and 11.The average load in total coliform is 0 UFC / 100 ml, 0 UFC / 100 ml of fecal coliform, 0 UFC / 100ml of fecal streptococci and 0-3 UFC/100ml of microorganisms (at 22°C and 37°c) [17]. On the one hand, this result is consistent with the Moroccan standards of drinking water for human consumption and the distributed water have good qualities bacteriological. On the other hand, it confirms that there is a good disinfection, a pathogen destruction [18].

Table 1. Characteristics of the raw brackish water

	Physical-chemical characteristics	Moroccan standards of drinking water
T(°C)	23-30	-
PH	7,12-7,28	6.5-8.5
Turbidity NTU		5
Conductivity µS/cm	4840 -5300	2700
TA méq/l	0	-
TAC méq/l	4-5,1	-
Oxydabilité mg/l	0,92-1,72	5
Fer mg/l	<0,1	0.3
Chlorure mg/l	1178 - 1526 / l	750
TH méq/l	36-42	-
Ca^{2+} mg/l	344-366	500
Mg^{2+}mg/l	227-293	200
TDS mg/l	3702 – 4040	1000-2000
Langelier index MLSI		-0.2<MLSI<0.2
Microbiological characteristics		
Total colliforms UFC /100ml	0	0 /100 ml
fecal colliforms UFC /100ml	0	0 /100 ml
Fecal Streptococci UFC /100ml	0	0 /100 ml
Microorganisms at 22°C and 37 °C	0-3	20 /1 ml at 37°C 100 /1 ml at 22°C
Total colliforms UFC /100ml	0	0 /100 ml
fecal colliforms UFC /100ml	0	0 /100 ml

Table 2. Characteristics physico-chemical parameters of the raw water

	Jan	Fab	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T(°C)	20	20.40	23	24	26	28.7	29	29	27.9	26.45	24.75	24.75
PH	7.17	7.19	7.18	7.17	7.24	7.17	7.10	7.14	7.12	7.1	7.08	7.07
Turbidity NTU	0.23	0.22	0.23	0.25	0.21	0.23	0.23	0.23	0.22	0.23	0.22	0.21
Conductivity µS/cm	5045	5032	5060	5077	5099	5034	5014	5012	5033	5076	5015	5023
TA méq/l	0	0	0	0	0	0	0	0	0	0	0	0
TAC méq/l	4.5	4.75	4.95	4.85	4.7	4.8	5.00	5.05	5.05	4.95	4.95	4.7
Oxydabilité mg/l	1.28	1.48	1.4	1.36	1.36	1.16	1.12	1.08	1.44	1.2	1.46	1.40
Fer mg/l	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Chlorure mg/l	1033	1029	1011	1123	1045	1027	1038	1020	1024	1055	1036	1038
TH méq/l	40.3	38	37.1	36.2	36.0	36.0	36.1	36.4	37.5	39	39.7	40.6
Ca^{2+} mg/l	366	358	354	344	326	334	350	338	348	362	372	360
TH an °F	8,5	8,06	7,6	7,42	7,24	7,2	7,2	7,22	7,28	7,5	7,8	7,94
Mg^{2+} mg/l	268	245	236	231	240	235	226	237	245	254	257	257
TDS mg/l	3824	3774	3748	3691	3642	3630	3657	3661	3653	3642	3668	3691

Table 3. Characteristics physico-chemical parameters of the permeate water

	Jan	Fab	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T(°C)	21,3	21,6	22,45	23,55	25.2	27.2	28.6	29.1	28.67	27.7	27.75	23.45
PH	6.39	6.41	6.39	6.39	6.38	6.38	6.37	6.37	6.35	6.33	6.38	6.25
Turbidity NTU	0.17	0.17	0.17	0.16	0.17	0.17	0.17	0.17	0.16	0.18	0.16	0.15
Conductivity µS/cm	445	467	455	432	437.5	437.5	483.5	496.5	481.5	479.5	486	463
TDS (mg /l)	307,6	307,6	315,29	324,51	336,43	336,43	371,81	381,80	377,96	368,73	373,73	356,04

Table 4. Characteristics physico-chemical parameters of the distributed water

	Jan	**Fab**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
T(°C)	19.72	21.25	23.05	25.4	27.6	29.2	30.8	31.35	28.9	28.3	24.3	19.4
PH	7.20	7.20	7.19	7.20	7.21	7.25	7.23	7.23	7.28	7.18	7.22	7.27
Turbidity NTU	0.29	0.36	0.27	0.40	1.45	0.23	0.19	0.19	0.33	0.28	0.26	0.24
Conductivity µS/cm	955	965	971	908	1064	971	975	927	1193	1050	962	1038
TA méq/l	0	0	0	0	0	0	0	0	0	0	0	0
TAC méq/l	2.00	2.20	2.20	2.00	2.65	2.7	2.7	2.75	2.55	2.5	2.5	2.55
Oxydabilité (mg/l)	0. 7	0. 52	0. 68	0. 72	1.00	0.8	1.04	0.56	0.56	0.68	0.84	0.48
Fer mg/l	<0.1	<0.1	<0.1	<0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Chlorure (mg/l)	193	188	198	188	181	175	179	169	184	193	181	183
TH méq/l	4.86	5.14	4.58	3.9	5.22	4.88	5.00	4.76	5.00	5.04	4.92	5.3
Ca2+ mg/l	63	61	62	59	65.2	60.8	61	59.6	60.4	60.0	62	62.8
pHs	7.98	7.86	7.95	7.94	7,77	7,67	7,67	7,67	7,57	7,70	7,78	7,75
TACs	2.45	2.55	2.6	2.4	2.9	3.15	2.85	3.1	2.8	2.8	2.8	2.8
Cl résiduelle mg/l	0.75	0.75	0.75	0.7	0.75	0.75	0.8	0.85	0.75	0.75	0.75	0.8
Mg2+ (mg/l)	24	27	25	24	23	24	24	26	24	24	23	24
TDS mg/l	723	731	736	688	806	736	739	702	904	795	799	800
ISL	-0,78	-0,66	-0,76	-0,74	-0,56	-0,42	-0,44	-0,44	-0,29	-0,52	-0,56	-0,48

Table 5: Cost of chemical pretreatment

Product Cost	$/m3 Cost	$/ yr
Sodium hypochlorite- NaCl	50 274	0.30
Sodium Metabisulfit- $NaHSO_3$	0.03	4 570
Antiscalant	0.57	95 297

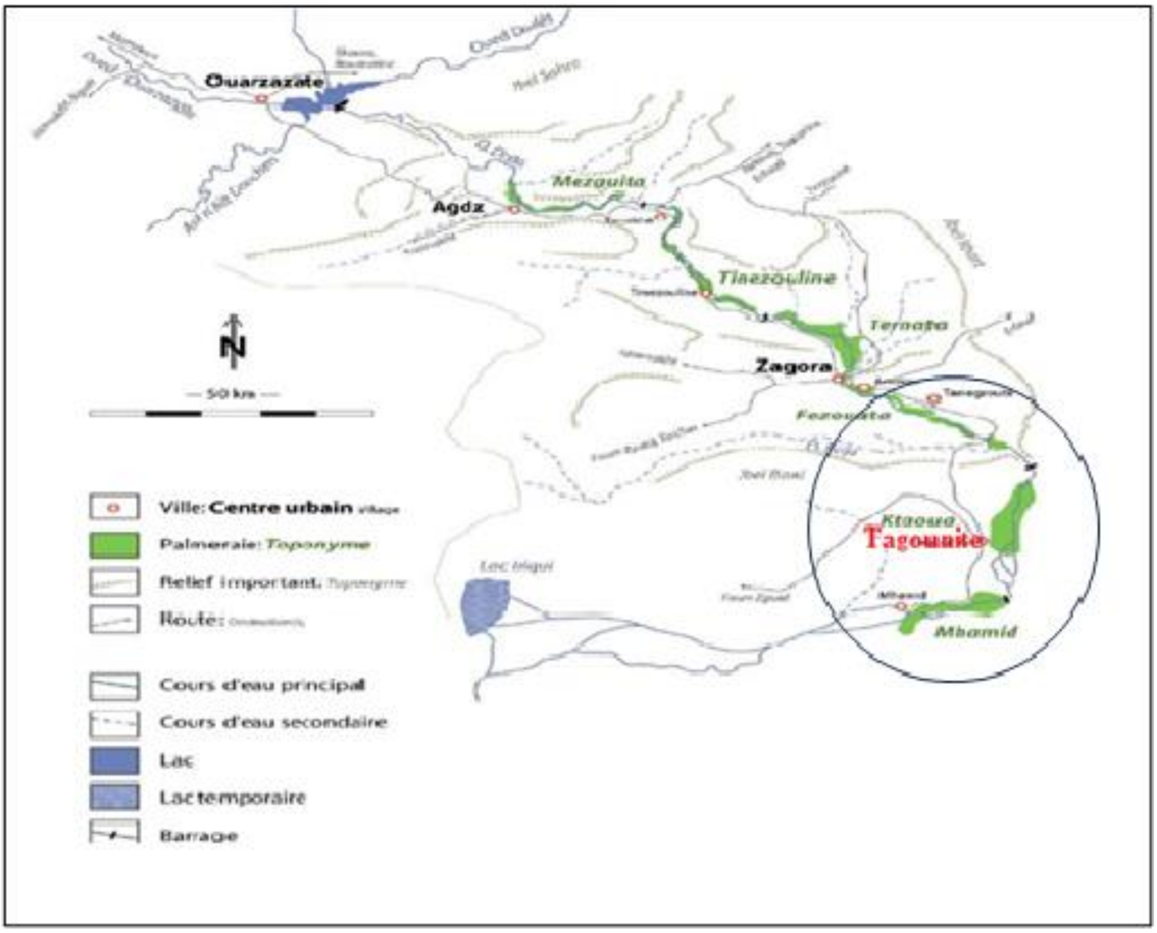

Figure 1. Geographical location the brackish water demineralization station

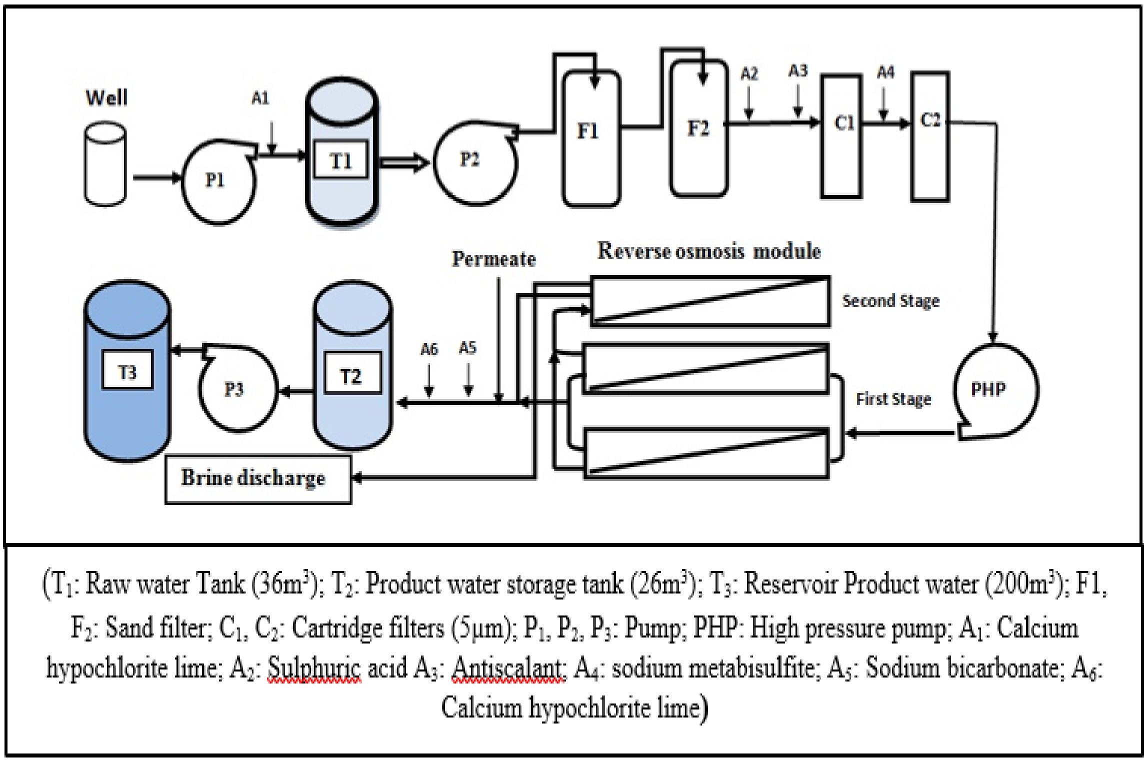

Figure 2. Flow diagram for the brackish water desalination plant

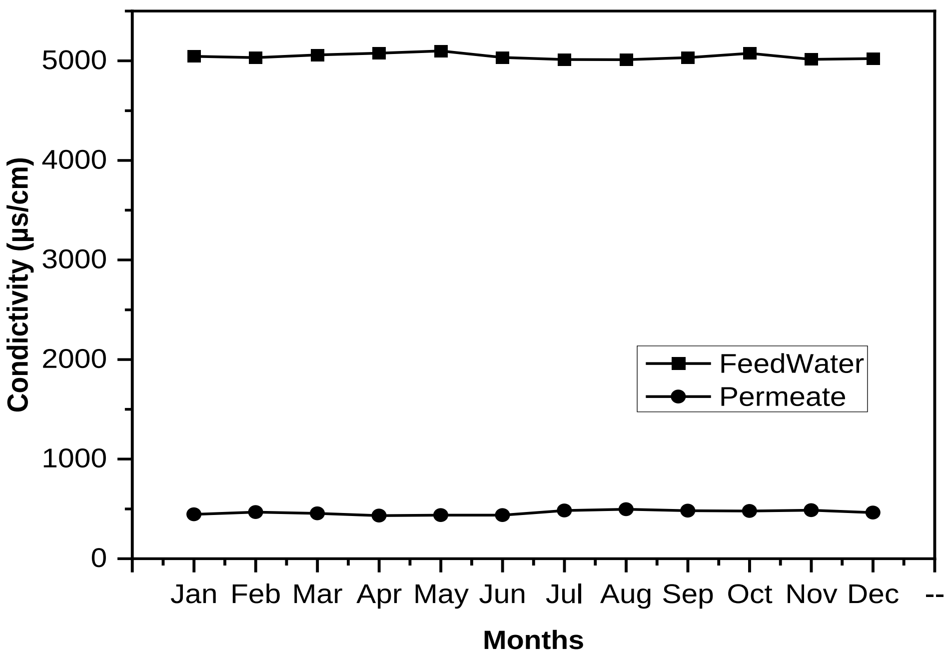

Figure 3. Variations of water conductivity during one year

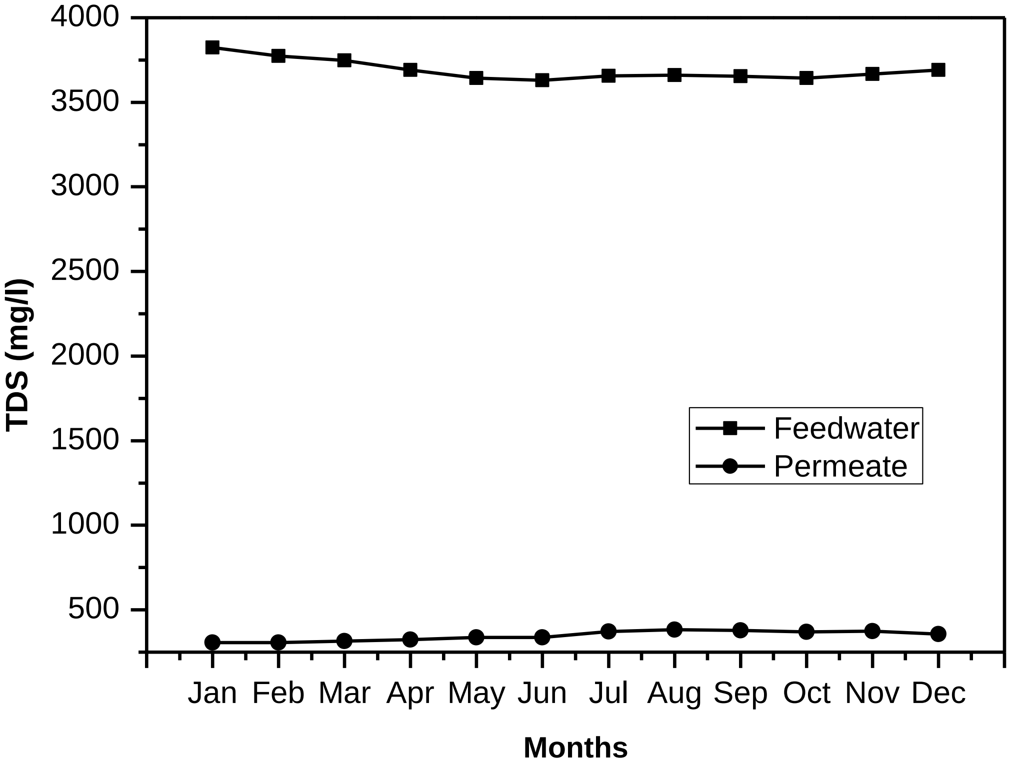

Figure 4. Variations of water TDS during one year

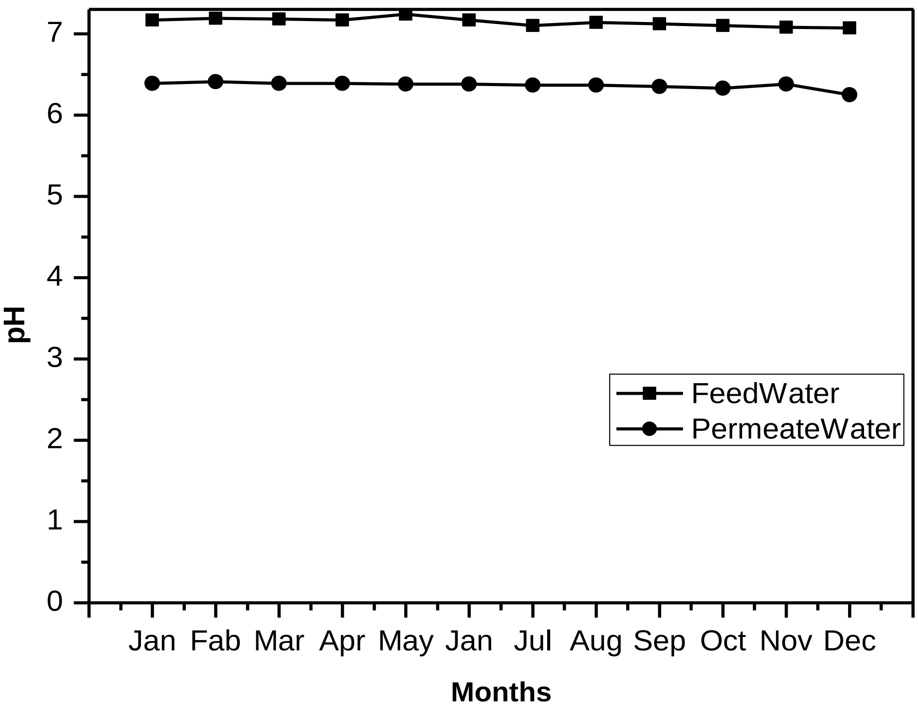

Figure 5. Variations of water PH during one year.

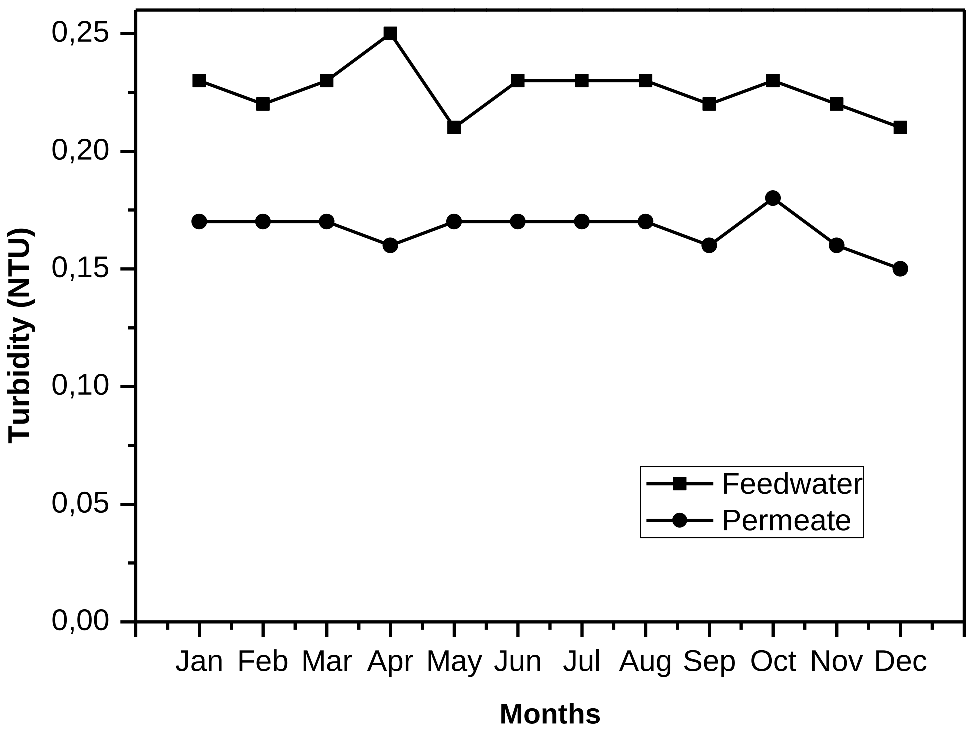

Figure 6. Variations of water turbidity during one year.

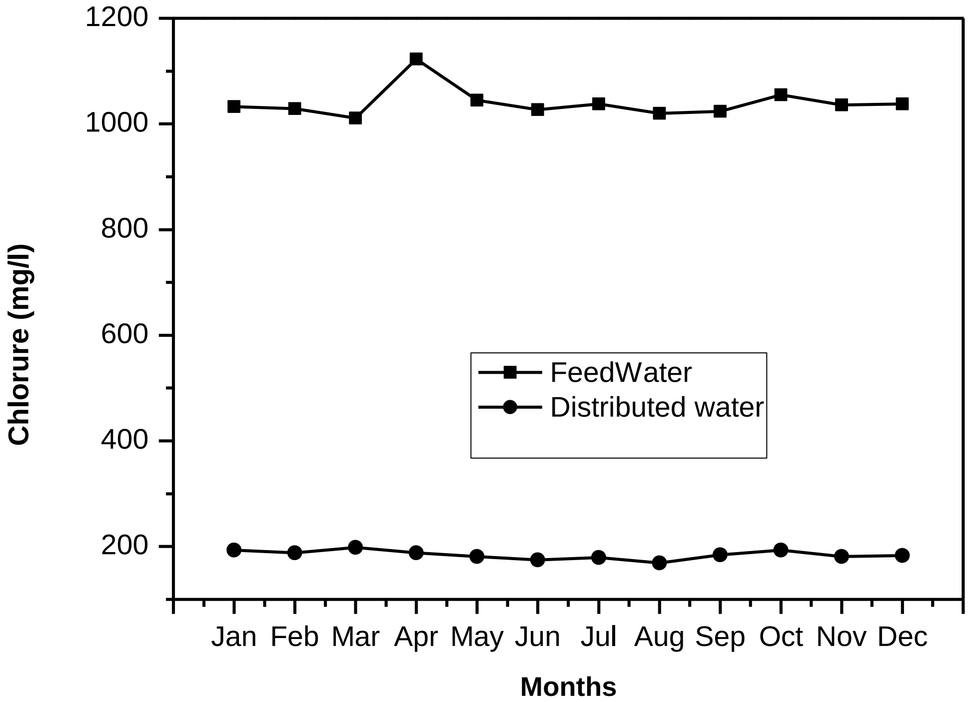

Figure 7. Variations of water Chlorure during one year.

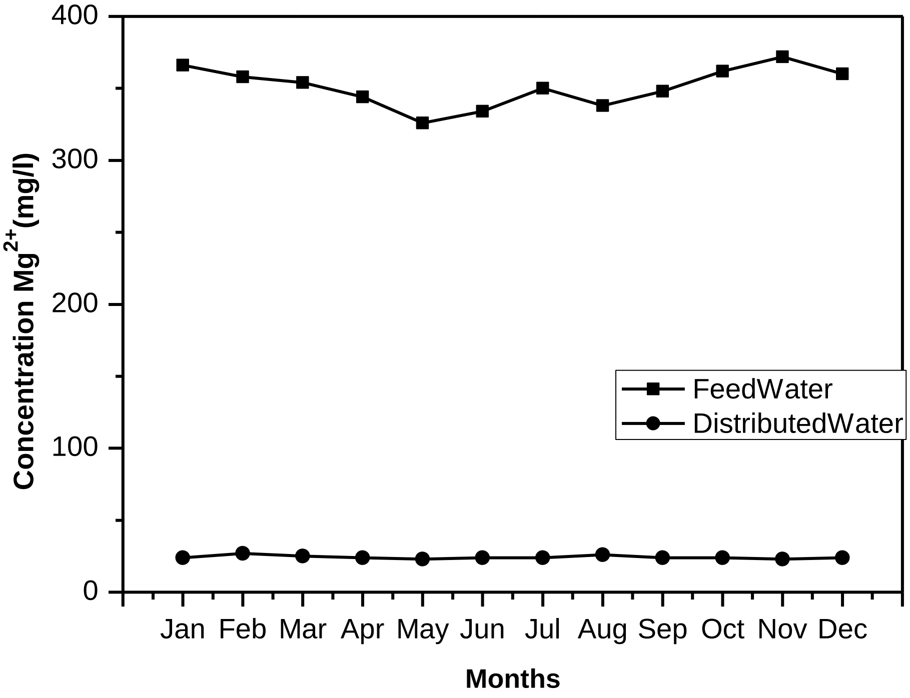

Figure 8. Variations of water concentration Mg^{2+} during one year.

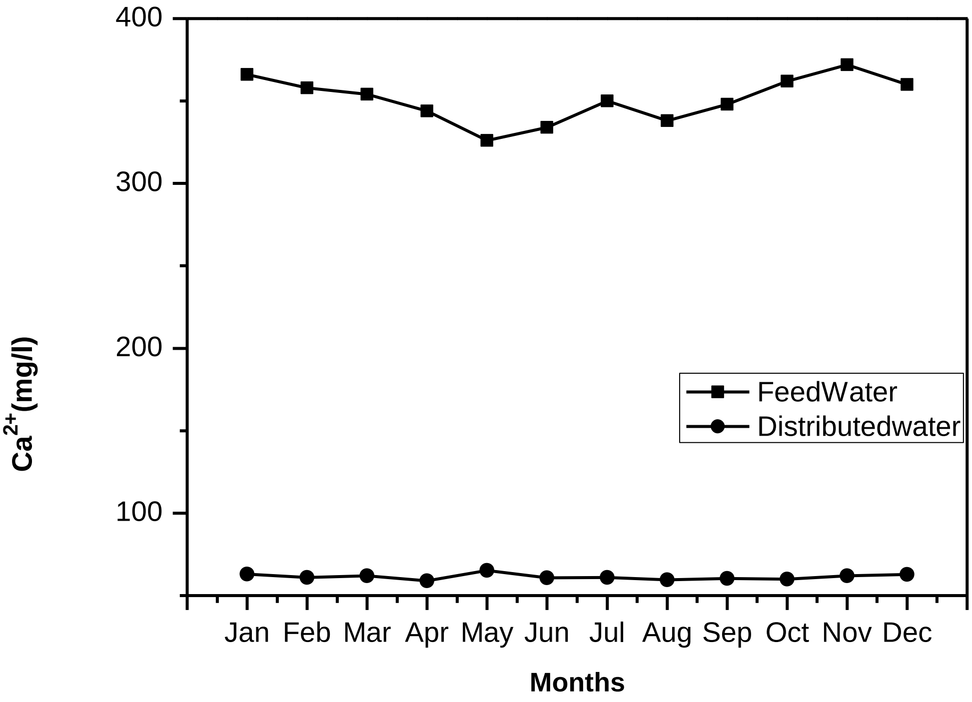

Figure 9. Variations of water concentration Ca^{2+} during one year

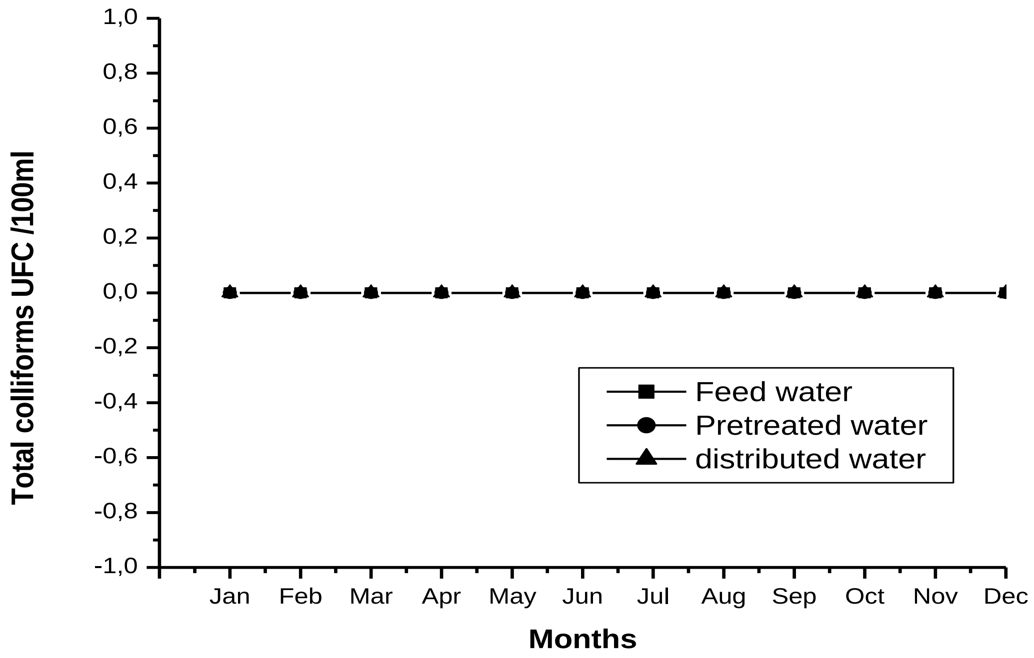

Figure 10. Variations of water the total coliforms during one year

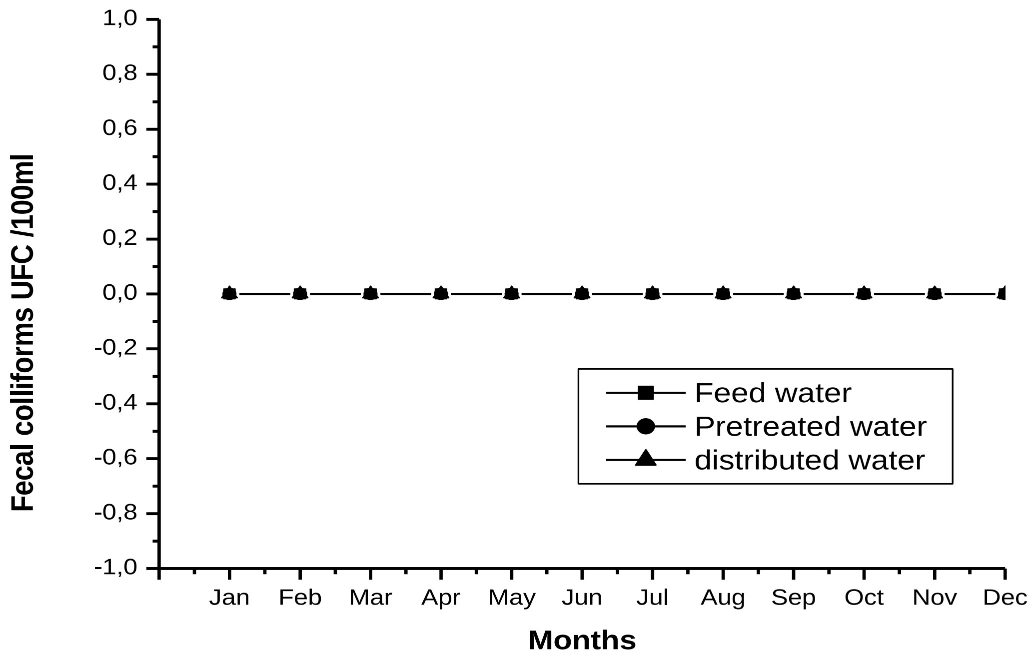

Figure 11. Variations of water the fecal coliforms during one year

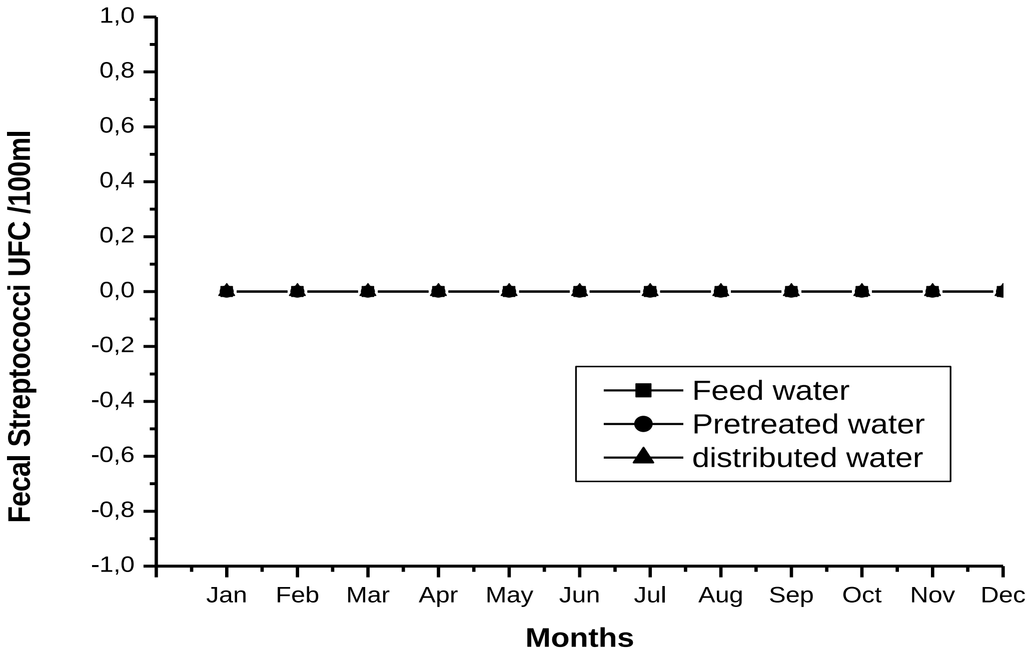

Figure 12. Variations of water the fecal streptococci during one year

3.2. Economic Evaluation

Several factors affect the cost of reverse osmosis desalination plant [19]. The total cost of the plant consists of two terms: capital cost and operation/maintenance cost. The Capital Cost includes all expenditures associated with the implementation for construction (equipment, piping, service utilities, etc.), engineering efforts, and administrative/financing activities. The operation and maintenance (O&M) costs consist of plant operation costs (energy, chemicals, replacement of consumables, and labor) and maintenance costs for plant equipment, buildings, and utilities. The O&M costs are typically expressed as either all operational expenditures per year (e.g., $/y) or operational costs for desalinated product water per volume (e.g., $/m3) [20]. In this study case and in terms of the economic point of view, economical evaluation was done concerning the chemicals cost. Table 5 gives the cost of chemical pretreatment. The removal of Sodium hypochlorite and sodium metabisulfite from pretreatment step, cause the saving cost of 54 800 $/year in operation unit cost.

4. Conclusions

The water produced by the desalination plant has a satisfactory quality, and respects the Moroccan drinking water standards. In addition, the plant displays a better performance and the satisfactory reproducibility. This result shows clearly the interest of the implementation of this desalination plant to solve the problem of the shortage of drinking water for the Southeast region of Morocco.

Acknowledgements

ONEE (MOROCCO) and laboratory of separation process, Department of Chemistry, Ibn Tofail University, supported this work. The authors express his gratitude for this support.

References

[1] M.F. Idrees. (2020). Performance analysis and treatment technologies of reverse osmosis plant–a case study. Case studies in Chemical and environmental engineering. 2 100007.

[2] M.Q. Gubari, H.M. Zwain, W.H. Hassan, M. Vakili, A. Majdi. (2023). Desalination of pigment industry wastewater by reverse osmosis using OPM-K membrane. Case Studies in Chemical and Environmental Engineering. 100401.

[3] F. Elazhar, M. Tahaikt, A. Achatei, F. Elmidaoui, M. Taky, F. El Hannouni, A. Elmidaoui. (2009). Economical evaluation of the fluoride removal by nanofiltration. Desalination. 249 (1) 154-157.

[4] N.E.L. Harrak, F. Elazhar, S. Belhamidi, M. Elazhar, J. Touir, A. Elmidaoui. (2015). Performances comparison of two membranes processes: Nanofiltration and Reverse Osmosis in brackish water Desalination. Materials and Environmental Science Journal. 6 (2) 383-390.

[5] F. Elazhar, M. Tahaikt, A. Achatei, F. Elmidaoui, M. Taky, F. El Hannouni, A. Elmidaoui. (2009). Economical evaluation of the fluoride removal by nanofiltration. Desalination. 249 (1) 154-157.

[6] S.A. Avlonitis. (2002). Operational water cost and productivity improvements for small-size RO desalination plants. Desalination. 142 (3) 295-304.

[7] Y.M. Kim, S.J. Kim, Y.S. Kim, S. Lee, I.S. Kim, J.H. Kim. (2009). Overview of systems engineering approaches for a large-scale seawater desalination plant with a reverse osmosis network. Desalination. 238 (1-3) 312-332.

[8] S. Lotfi, M. Chakit, D. Belghyti. (2020). Groundwater quality and pollution index for heavy metals in Saïs plain, Morocco. Journal of Health and Pollution. 10 (26) 200603.

[9] G.S. Mittal. (2006). Treatment of wastewater from abattoirs before land application—a review. Bioresource technology. 97 (9) 1119-1135.

[10] X. Zhao, J. Chen, M. Guo, C. Li, N. Hou, S. Bai. (2022). Constructed wetlands treating synthetic wastewater in response to day-night alterations: performance and mechanisms. Chemical Engineering Journal. 446 137460.

[11] S. Ait Messaad, M. Chakit, S. Lotfi, D. Belghyti. (2022). Contamination of Beach Sand by Cutaneous Larva Migrans in Rabat-Sale Area (Morocco) and their Health-Related Problems. Egyptian Journal of Aquatic Biology and Fisheries. 26 (6):173-183.

[12] Y. Asfers, H. Taouil, A.S. Ibn, M. Chakit. (2016). Evaluation metallic pollution caused by iron, copper, lead and cadmium of Oum-Rabia river water. Journal of Bio Innovation. 5 59-67.

[13] Y. Asfers, H. Taouil, S. Ibn Ahmed, M. Chakit. (2016). Metallic Pollution of Aquatic Ecosystems: Water of Oum Er-Rbia River. American Journal of Engineering Research. 5 (9) 111-115.

[14] K. Azam, N. Shezad, I. Shafiq, P. Akhter, F. Akhtar, F. Jamil, M. Hussain. (2022). A review on activated carbon modifications for the treatment of wastewater containing anionic dyes. Chemosphere. 135566.

[15] G. Wang, D. Wang, Y. Xu, Z. Li, L. Huang. (2020). Study on optimization and performance of biological enhanced activated sludge process for pharmaceutical wastewater treatment. Science of The Total Environment. 739 140166.

[16] M.A. Fulazzaky. (2009). Carbonaceous, nitrogenous and phosphorus matters removal from domestic wastewater by an activated sludge reactor of nitrification-denitrification type. Journal of Engineering Science and Technology. 4 (1) 69-80.

[17] S. Waqas, M.R. Bilad, Z. Man, Y. Wibisono,J. Jaafar, T.M.I. Mahlia, M. Aslam. (2020). Recent progress in integrated fixed-film activated sludge process for wastewater treatment: A review. Journal of environmental management. 268 110718.

[18] H. Awad, M. Mossad, H. Mahanna, M. Foad, M.G. Alalm. (2024). Comparative assessment of different scenarios for upgrading activated sludge wastewater treatment plants in developing countries. Science of The Total Environment. 907 168022.

[19] W.Q. Guo, S.S. Yang, W.S. Xiang, X.J. Wang, N.Q. Ren. (2013). Minimization of excess sludge production by in-situ activated sludge treatment processes—A comprehensive review. Biotechnology advances. 31 (8) 1386-1396.

[20] A.Lachheb, M. Taky, M. El Amrani, A. Elmidaoui. (2024). performances analysis of Treatment of Urban Wastewater at the Laboratory Scale by Activated Sludge.

[21] A. Lachheb, S. Belhamidi, N. Zouhri1, Y. A. Idrissi, M. Hafsi, M. Taky, M. El Amrani, A. Elmidaoui. (20016). Journal of Chemical and Pharmaceutical Research. 8(4):119-129.