# Desalinated water quality: Remineralization technique at the Al-Hoceima desalination plant (northern Morocco)

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**Abstract.** One solution to the shortage of drinking water in Morocco is the development of reverse osmosis (RO) desalination plants. However, the quality of the permeate produced is corrosive, unbalanced, and does not meet the standards required for its use. The post-treatment process at the Al-Hoceima desalination plant in northern Morocco consists of the addition of carbon dioxide ($CO_2$) and hydrated lime ($Ca(OH)_2$). In this study, various analyses were utilized to assess the physical-chemical quality parameters of the water produced after remineralization. The results revealed that the remineralization method adopted by the plant is relatively complex and associated with difficulties in maintaining optimal remineralized water parameters such as pH, TAC, TH, and $Ca^{2+}$. However, the water produced re-establishes its calcocarbonic balance and is of satisfactory quality for human consumption. ***Keywords.*** Desalination, remineralization, permeate, quality, Al Hoceima.

## 1 Introduction

The depletion of water resources due to climate change, population growth, and the unprecedented increase in human activity present some challenges to water resource management in urban areas [1]. 40% of the world's population lives in arid regions or on islands where freshwater is scarce. Moreover, droughts are multiplying worldwide, reducing resilience to climate change [2].

Like many countries, Morocco has faced an unprecedented water shortage in recent years due to a dry climate and a lack of conventional water resources. To alleviate this shortage and to satisfy the needs of the population.

The Office National of Electricity and Drinking Water (ONEE) has implemented several projects involving the construction of desalination plants. Among the most widely used technologies is the reverse osmosis desalination process due to its ability to remove over 99% of salts while consuming less energy than traditional thermal processes [3].

The permeate generated by the RO process generally has very low salinity and high aggressiveness and corrosivity. As a result, demineralized water needs to be corrected, particularly about the water's buffering capacity of total hardness components ($Ca^{2+}$ and $Mg^{2+}$) and corrosion-dependent parameters. For these improvements, desalinated water will require remineralization [4]. The water after remineralization is periodically analyzed by measuring several parameters such as pH, turbidity, TAC, TH, $Ca^{2+}$ content, and Langelier index. In all desalination plants, the water produced after remineralization must meet the following characteristics Provided it is to be balanced [5]:

- ✓ TH ≥ 8 °F
- ✓ TAC ≥ 8 °F
- ✓ 7.5 <pH< 8.5
- ✓ -0.3 < LSI< 0.3

Post-treatment plays a crucial role in seawater reverse osmosis desalination plants. Indeed, several remineralization methods are suggested by previous research [6].

### 1.1 Study area

The Al Hoceima desalination plant is located 8 km south-east of Al Hoceima (north-east Morocco) on a coastal site close to the SFIHA beach in the commune of Ajdir, with a surface area of 3.2 ha (land Confiscated on behalf of ONEE Branche eau). This seawater desalination plant, currently in the trial phase, will be supplied with seawater via pumps located six kilometers away. The plant will produce 17280 $m^3$/day of drinking water for the city of Al Hoceima, which has a population of around 140,000.

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# 2 Materials and methods

During the sampling campaign, regular samples were taken from the permeable water at the osmosis plant outlet, from the water after remineralization, and from the lime water at the saturator, at a frequency of 12 months (January to May, December 2023).

To obtain a complete and accurate representation of the composition of each sampling point. Samples were taken in clean 1-liter polyethylene bottles and rinsed three times with sample water. After each sampling, the samples were stored at 4 (°C) and transported to the laboratory for analysis.

The samples were subjected to a series of physical-chemical analyses in accordance with Rodier's water analysis method (9th edition) [7], namely, HACH pH meter (Sension+) and HACH Turbidimeter (TU5200). The measurement of total Total Alkalinity (TAC) is based on the determination of the bases present in water, such as [$OH^-$], [$CO_3^{2-}$], and [$HCO_3^-$]. It is measured using the volumetric 0.1 N silver nitrate method (NF EN ISO 9963-1), Volumetric calcium ion titration using Ethylenediaminetetraacetic acid (EDTA) disodium salt solution at pH = 10 (AFNOR NF T90-003). The Langelier saturation index (LSI) is determined by the following relationship:

$$LSI = pH - pH_{saturation} \quad (1)$$

With $pH_{saturation}$ is the saturation pH of the water is measured after the marble test.

# 3 post-pretreatment

The plant's operating principle is based on reverse osmosis, a process that separates water from its dissolved salts utilizing the power of pressure inside semi-permeable membranes.

Desalination using this technique requires highly efficient pre-treatment of the raw water to avoid the deposition of suspended solids on the membranes, which would rapidly lead to a reduction in throughput.

## 3.1 Raw water collection

The Al Hoceima seawater catchment system consists of six boreholes. Vertical centrifugal pumps, each with a flow rate of 417 $m^3$/h, are installed inside these boreholes. Water is thus pumped from the boreholes to the raw water reservoir.

The raw water pumping station is equipped with a raw water reservoir divided into two tanks, each with a capacity of 1021.41 $m^3$.

## 3.2 Filtration

Filtration is the pre-treatment stage before the reverse osmosis process. Raw water is filtered in its entirety to reduce turbidity and suspended solids using horizontal triple-layer sand filters, coarse sand (10 cm), fine sand (40 cm), and anthracite (50 cm). Eight filters operate in parallel and identically, with a flow rate of 1664 $m^3$/h, a diameter of 3 m, a length of 10.5 m, and a capacity of 67 $m^3$.

## 3.3 Cartridge filter

Before installation of the membranes, eight cartridge filters were installed, each with a flow rate of 208 m3/h and a selectivity of 5 µm. The cartridges provide safety filtration to protect the reverse osmosis membranes.

Osmose inverse. The membranes used are thin-film nano-composites (TFN), which reduce water treatment costs while improving energy efficiency (Table 2).

These composite membranes consist of nanomaterials incorporated into the thin-film polyamide layer. This innovative technology considerably increases membrane permeability and improves salt rejection [8].

The Al Hoceima reverse osmosis plant comprises two parallel lines, with three pumping systems, each consisting of : (i) High-pressure pump with a flow rate of 365.70 $m^3$/h; (ii) ERI's PX-Exchanger energy recovery system, and (iii) a booster pump at the outlet of the pressure exchanger.

Each osmosis line comprises 94 pressure tubes. Each pressure tube contains 07 membranes. Reverse osmosis membranes operate hydraulically with tangential water circulation. As a result, only around 45% of the flow is produced per element in the form of permeate, while most of the feed water flows along the membrane surface is discharged as concentrate. As the flux is high, the flow velocity over the membrane surface is high, reducing the conditions for deposition layer formation [9].

Water post-treatment is essential to maintain optimum conditions and prevent fouling of reverse osmosis membranes. It helps to ensure the long-term durability and efficiency of the desalination system by ensuring that the treated water remains of high quality and that the membrane functions optimally. On the other hand, the main disadvantages of this type of thin-film membrane (TFN) are low chlorine resistance and susceptibility to fouling, leading to deterioration and reduced efficiency. High temperatures can also damage the membrane pores [10]. Membrane deterioration or malfunction can be minimized by monitoring the evolution of pressure drop across the reverse osmosis system [11]. The table below (table 1) shows the characteristics of the reverse osmosis membranes at the Al-Hoceima plant.

**Table 1.** Al-Hoceima plant reverse osmosis membrane features

| Parameters | Unit | Value |
|---|---|---|
| Active area | ($m^2$) | 41 |
| Max. applied pressure | (bar) | 82.7 |
| Chlorine concentration limit | (ppm) | <0.1 |
| Maximum temperature | (°C) | 45 |
| pH range | - | 2-11 |
| Recovery | (%) | 47 |

# 4 post-treatment

The process adopted by the Al-Hoceima desalination plant for remineralization consists of adding lime water and ($CO_2$) carbon dioxide so that the water regains its calco-carbonic balance, as shown in the following equation (1):

$$2CO_2 + Ca\,(OH)_2 \leftrightarrow Ca^{2+} + 2HCO_3^- \quad (1)$$

This method lowers the pH of treated water by adding ($CO_2$). Lime (Ca $(OH)_2$) is then pumped into the water to achieve the required hardness and alkalinity, enriching the water with hardness TH and alkalinity TAC at a ratio of 1:1. In equivalent units [12]. Thus, the simple addition of hydrated lime does not contribute to the buffering capacity (carbonate) of the water to accomplish this, $CO_2$ is dissolved in water before hydrated lime gets added. The $CO_2$ is stored in liquid form in insulated tanks at -18̊C, and the vaporized $CO_2$ Gets injected into the osmosis water header before being dosed with calcium hydroxide.

# 5 Results and discussion

## 5.1 Permeate quality

Table 2 shows the main characteristics of permeate water from the Al-Hoceima desalination plant and the values of these parameters according to Moroccan drinking water standards.

**Table 2.** Permeate characteristics of the Al-Hoceima desalination plant

| Parameters | Permeate | Moroccan standard |
|---|---|---|
| pH | 5.48 | 6.5-8.5 |
| TAC (mg/L) | 2.1 | 200 |
| Ca2+ (mg/L) | 3 | 500 |
| Langelier saturation index (LSI) | -0.97 | -0.2<LSI<0.2 |

From the results in Table 2, the permeate produced is low in the minerals essential for calco-carbonic balance, making this desalinated water very aggressive and corrosive. Indeed, this water Becomes characterized by a relatively low pH value and lower hardness. As a result, problems of corrosion of traditional metal pipes can induced when RO permeate gets transported into the drinking water distribution network [13].

In addition, calcium and magnesium are two elements that play a fundamental role in human health. The World Health Organization in 2009 summary examined the health effects of calcium and magnesium content in drinking water. The most recent WHO drinking water quality standards of 2017 [14,15] do not contain minimum concentrations of magnesium and calcium. On the other hand, post-treatment is necessary to improve water mineralization to correct its corrosive tendency. Indeed, corrosivity is linked to numerous water constituents, such as pH, hardness, alkalinity, sulfate, chloride, and TDS [16,17].

## 5.2 Remineralization stage

### 5.2.1 Lime water characteristics

Lime milk is produced by mixing 38 kg/h of lime with permeate water (3 $m^3$/h). Preparation takes place automatically in a tank. The milk of lime Became mixed with 24 m3/h of permeate in a static mixer. The saturator receives a commercial solution of polyelectrolyte at a concentration of 1.350 g/m³ gets injected to reduce the turbidity of the lime water, which considerably reduces the probability of finding undesirable molecules in the remineralized water. The figure 1 below shows the annual physical-chemical characteristics of lime water obtained in the saturator.

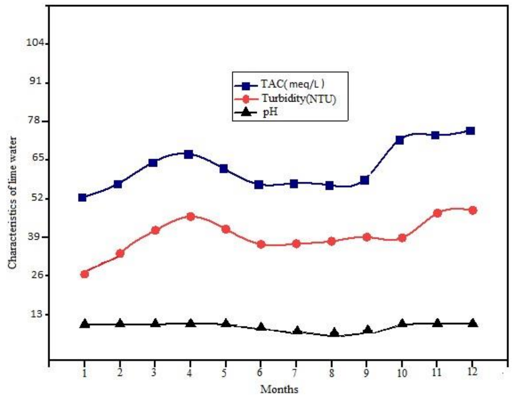


**Fig. 1.** Annual variation in lime water characteristics.

Figure 1 shows a decrease in the TAC value at the saturator level during the dry months of the year (months 6, 7 and 8). This demonstrates that lime has inverse solubility properties and tends not to dissolve easily with increasing temperature [18]. Decreasing TAC reduces the concentration of alkaline species, namely [$OH^-$], [$CO_3^{2-}$] and [$HCO_3^-$] ions, in limewater and diminishes its buffering capacity, which promotes acidification of the solution, resulting in a lower pH value in the saturator (figure 1). On the other hand, the results revealed that the turbidity of limewater (Figure 1) decreases with decreasing TAC. This is probably due to the fact that when TAC decreases, limewater becomes less effective at flocculating suspended particles and favoring their sedimentation or removal by filtration. This can increase the turbidity of the treated water. As lime solubility decreases, less lime dissolves in the water. This can lead to an accumulation of particles (solid precipitates) of undissolved lime at the bottom, causing saturator clogging. Indeed, the El Azhar study showed that the lime remineralization method and ($CO_2$) lead to increased turbidity in drinking water, and the formation of scale and calcium deposits in the injection equipment [5].

### 5.2.2 Water characteristics after remineralization

Demineralized water lacks the minerals required for human health. In addition, calcium and magnesium are added during post-treatment processes. The calcium/magnesium ratio should be between 2 and 3

[19]. The taste of water generally comes from cations such as sodium, calcium, and magnesium, and anions such as chloride, nitrate, and sulfate help modify its strength [20]. The following table (table 3) shows the different characteristics of treated water after the remineralization stage.

**Table 3.** Characteristics of treated water after remineralization

| Parameters | Characteristics |
|---|---|
| pH | 6.75-7.98 |
| TAC (F) | 7.7-8.00 |
| TH (F) | 7.8-8.00 |
| Ca2+ (F) | 6.7-8.00 |
| Langelier saturation index (LSI) | 0.15- 0.19 |

According to Table 3, the recorded values for TH, TAC, and $Ca^{2+}$ concentration are sometimes below 8°F, Although the addition of the "theoretically adequate" amount of Ca $(OH)_2$ lime for remineralization. Indeed, remineralization using carbon dioxide ($CO_2$) and lime in the Al-Hoceima desalination plant presents some difficulties, as the use of hydrated lime is relatively complex from a technical point of view, precisely if the permeate is hot, which reduces the solubility of the lime [21,22]. Lime is a relatively affordable and widely accessible option, but its use for remineralization presents various problems, including the risk of pipe clogging due to lime deposition on the injection equipment [23]. In addition, maintaining the optimum parameters of the water to be remineralized, such as TAC, $Ca^{2+}$, pH, and TH, proves to be a complex task.
The results also revealed that Langelier saturation index values were within the recommended norm, showing that the water regained its calco-carbonic balance after the remineralization stage. In 2007, Lahav and Birnhack published an article on quality criteria for desalinated water in the post-treatment in Israel. The following specific water quality criteria for desalinated water are illustrated in the following table 4:

**Table 4.** Water quality parameters recommended by the Israeli authority [24].

| Parameters | Values defined by the Israeli authority |
|---|---|
| pH | < 8.5 |
| $[Ca^{2+}]$ | 32–48 (mg/l) |
| $[Mg^{2+}]$ | 12-18(mg/l) |
| Alcalinité | > 80 (mg/l as CaCO3 |
| $[Cl^{-}]$ | <20(mg/l) |
| $[Na^{+}]$ | <20(mg/l) |

According to another study by Kozisek, the minimum values recommended by European Union regulations for calcium, magnesium, and TDS are respectively 30 (mg/L), 20 (mg/L), and 100 (mg/L) [25]. However, other minerals are also virtually absent from desalinated water. Martínez's study of several desalination plants in Spain revealed that no sulfate values were added [26]. Research carried out at the Ashkelon desalination plant in Israel showed that magnesium was not added during post-treatment. Indeed, most desalination plants fail to supply at least one of the required mineral values regulated by the Israeli authorities: calcium, magnesium, or sulfate [27].

## 6 Conclusion

Seawater desalination is becoming a practical alternative in many countries, for drinking water supply as well as industrial needs., for drinking water supply as well as industrial needs. The Al Hoceima seawater desalination plant uses the reverse osmosis process. Great importance was taken to ensuring the quality of the permeate leaving the desalination plant, limiting corrosion of pipes and equipment, and complying with drinking water standards. Water from the desalination process (osmosis water) is unbalanced due to its lack of minerals from the desalination process (osmosis water) is unbalanced due to a lack of minerals, making it aggressive and corrosive. Post-treatment remineralization is essential to restore the water's calcium-carbonate balance and protect the distribution network against corrosion. In our study, the results of the analyses confirm the difficulties that influence the efficiency of the remineralization process with the addition of $Ca(OH)_2$ hydrated lime and $CO_2$, particularly in terms of maintaining optimum parameters such as TH, $Ca^{2+}$, TAC, and pH. After remineralization, the water produced has a level of mineralization in line with the recommended standard for human consumption.

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