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Brackish water demineralization and brine fate. Case study: Ouled Djellal and El-Oued plants.

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Dedication

To my loving mother, whose unwavering support and endless sacrifices have been mysource of strength and inspiration. Your love and guidance have been my anchor throughout this journey.

In the memory of my father. I strive to honor your memory with every achievementand success.

To my fiancé, Radhouane, for your boundless love, patience, and encouragement. Your belief in me has been a constant source of motivation, and I am grateful to haveyou by my side.

To my sister, Ichrak, for your unending support and companionship. Your presencehas always been a source of comfort and joy in my life.

To my two best friends, Rachda and Roufaida, for your unwavering friendship and understanding. Your constant encouragement and laughter have made this journey more enjoyable and bearable.

To my precious family, HAMMADOU and CHIROU, for your unconditional loveand support. Your faith in me has been a driving force behind my efforts and achievements.

This work is dedicated to all of you, with immense gratitude and love.

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Abstract

This research investigated water desalination and demineralization processes for producing fresh water in order to address water shortages, in addition to the management and the disposal of brine (demineralization by product). Two brackish water demineralization plants, Ouled Djellal and El-Oued, were presented and compared. Although both brackish water chemical parameters exceeded Algerian drinking water standards and the demineralization processes are the same, significant differences in operations and environmental management were observed. Ouled Djellal plant lacked laboratory analysis, and exhibited severe environmental impacts by rejecting the brine in the environment. However, El-Oued plant is well equipped and managed brine through sewers for wastewater treatment. In fact, Algeria lacks practices for brine recovery and reuse, leading to brine being discarded as waste, posing environmental risks, and missing resource recoveryopportunities. This research highlighted the need for innovative brine management solutions, including recycling and resource extraction, and calls for the development of regulatory frameworks and advanced treatment technologies. Addressing brine disposal challenges is vital for ensuring desalination, which remains a sustainable and environmentally responsible solution to global freshwater needs.

Keywords

Desalination, demineralization, brine, seawater, brackish water, Demineralization.

Résumé

Cette recherche a étudié les procédés du dessalement et de la déminéralisation des eaux pour la production des eaux potables afin de satisfaire les besoins en eau ainsi que la gestion des sous-produits de déminéralisation (les saumures). Deux stations de déminéralisation des eaux saumâtres (Ouled Djellal and El-Oued) ont été présentées et comparées. Bien que les paramètres physicochimiques des deux eaux saumâtres dépassent largement les normes Algériennes de potabilité et les procédés de déminéralisation sont les mêmes, des importantes différences dans les techniques de traitement et la gestion environnementale ont été remarquées. La station d’Ouled Djellal ne dispose pas d’un laboratoire d’analyse de la qualité physicochimique de l’eau et rejette les saumures dans la nature ce qui peut engendrer des impacts environnementaux. Cependant, la station d’El-Oued est équipée de tous les procédés nécessaires et rejette les saumures dans le réseau d’assainissement pour être traités ultérieurement. En effet, En Algérie, les saumures sont considérées comme des résidus qu’on doit rejeter dans la nature malgré les impacts négatifs de cet acte et pas comme une source qu’il faut récupérer et réutiliser. Cette étude souligne la nécessité de trouver des solutions innovantes pour la gestion de la saumure, notamment en matière de recyclage et d'extraction des ressources, et appelle au développement de cadres réglementaires et de technologies de traitement avancées. Il est essentiel de relever les défis liés à l'élimination des saumures pour que le dessalement reste une solution durable et respectueuse de l'environnement pour répondre aux besoins mondiaux en eau douce.

Mots Clés

Dessalement, saumure, eau de mer, eau saumâtre, déminéralisation.

الملخص

تدرس هذه الأطروحة طرق تحلية المياه للحصول على المياه الصالحة للشرب من أجل سد الاحتياجات المائية بالإضافة إلى تسيير الاملاح الناجمة عن عملية التحلية. وقد تم عرض ومقارنة محطتان للتحلية (محطة أولاد جلال ومحطة الوادي). رغم أن تراكيز الخصائص الفيز وكيمائية لمياه المحطتين تتجاوز معايير الصلاحية الجزائرية وتتسم المحطتان تقريبا بنفس تقنيات التحلية إلا أنه لوحظت اختلافات كثيرة بين المحطتين خصوصا في التسيير البيئي. تفتقر محطة أولاد جلال لمخبر للتحاليل الكيمائية للمياه وترمي الاملاح الناجمة عن التحلية في الطبيعة مما قد ينجم عنه تأثيرات بيئية سلبية. بالمقابل، محطة الوادي مجهزة بكل الوسائل التقنية اللازمة وتوجه أملاح التحلية إلى شبكة الصرف الصحي لتتم معالجتها لاحقا في محطة التصفية. في الواقع تعتبر الأملاح الناجمة عن تحلية المياه في الجزائر مجرد مخلفات يجب التخلص منها وليست مصدر يجب استرجاعه وإعادة استعماله. يسلط هذا البحث الضوء على الحاجة إلى حلول مبتكرة لإدارة المحلول الملحي، بما في ذلك إعادة التدوير واستخراج الموارد، ويدعو إلى تطوير أطر تنظيمية وتقنيات معالجة متقدمة. إن معالجة تحديات التخلص من المحلول الملحي أمر حيوي لضمان بقاء تحلية المياه المالحة حلاً مستداماً ومسؤولاً بيئياً للاحتياجات العالمية من المياه العذبة.

الكلمات المفتاحية

تحلية المياه، المحلول الملحي، مياه البحر، المياه المالحة، نزع المعادن.

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List of abbreviations and Acronyms

ED: Electrodialysis
RO: Reverse Osmosis
HDH: Humidification dehumidification desalination system
SS: Solar Still
MVC: Mechanical vapor compression
MSF: Multi stage flash
MED: Multi effect distillation
ZLD: Zero liquid discharge
ppm: Parts per million
EDTA: Ethylene Diamine Tetra Acetic
HWD: Hamma water desalination plant
AN: Algerian norms
WWTP: Wastewater treatment plant
N.R: Not reported

General Introduction

General introduction

Around 70% of the earth’s surface is covered by water, but more than 97 percent of this water is located in the oceans and seas. Drinking salt water is unhealthy for both people and animals. The amount of freshwater available for use by living beings is very small. The Great Lakes contain 20 percent of the world’s supply of surface freshwater. Other reservoirs of freshwater are not available for use by humans. For instance, more than 2 percent of the Earth’s freshwater is “locked” in ice caps and glaciers (Kherbache, 2020). The available freshwater quantity is threatened by pollution generated by domestic, industrial, and agricultural wastewater, population growthas well as climate change (droughts and floods).

Algeria, one of the largest countries in North Africa, is experiencing rising water scarcity because of several reasons, such as water demand for drinking, industrial and agricultural needs highly exceeding the mobilized water resources, the geographical disparity between needs and resources, the tiny available groundwater and surface water amount threatened by pollution, drought, dams siltation, and leaky distribution system. In addition to these causes, the lack of sustainable development for water resources has exacerbated the situation (Hamiche et al, 2018).

Despite these difficulties, Algeria has heavily invested in water mobilization between 1999 and 2018 and has tried to address these challenges. This era is seen as an exit of the country from economic water shortage, which prevailed before 1999. During this period, Algeria guaranteed that the majority of its population had access to safe drinking water, with a connection rate of 98% in 2016, up from 78% in 1999. Similarly, Algeria reached the sanitation facilities target, with 90% connection rate to the sewage network in 2015 compared to 35% in 1970. Furthermore, water mobilization infrastructure (e.g., dams) has risen significantly over the last 50 years, from 13 operational dams in 1962 to 78 dams in 2018. In 2016, there were 177 WWTPs, up from 12 active stations in 1999 (Kherbache, 2020).

Regardless the improvements in hydraulic sector, the situation in the north of the country remains difficult as reason of an unequal distribution of resources, rainfall and its randomness, imbalances between coastal and interior, the recurrence of drought phenomenon in time and space. To lessen the water shortage, Algeria had to find a sustainable, long-term water supply that could address the expanding urban water demand. With a coastline of 2148 km, seawater is the only abundant new source of water, thus; seawater desalination represents the key solutionto water scarcity (Hamiche et al, 2018).

Algeria's experience with desalination is strongly related to the development of the oil and steel industries. Desalination and demineralization are commonly utilized in industry for boiler

Water, cooling, and treatment purposes. In 1964, three tiny 8-m^3/h blocks were erected at the Arzew liquefied gas plant (a seaside town in the country's west). The method employed is "submerged pipes" that operate at low pressure. In 1969, another factory was developed in Arzew with a production capacity of 4560 m3/d. The procedure employed is MSF (Hamiche et al, 2018).

Since then, more desalination and demineralization units have been established alongside the new complex. Others were placed into service to meet high-purity water needs for power generation (Cap Djenet east of Algiers) as well as industrial liquefaction (Arzew and Skikda). Some facilities, primarily in the south, aim to deliver safe drinking water from petroleum sources. SONELGAZ's energy plants have minor desalination units for internal site purposes (Hamiche et al, 2018).

This research aims to study the brackish water demineralization and brine fate for two plants, Ouled Djellal and El-Oued. The study is structured into three chapters. The first one encompasses an overview on desalination, such as saltwater types,definition of desalination, water desalination plant as well as brine management. The second chapter concerns desalination and demineralization in Algeria. Finally, the last chapter discusses brackish demineralization, areas of study, Ouled Djellal and El-Oued.

Chapter I.

Desalination, demineralization and brine management

I.1. Introduction

Desalination is the technology, which changes seawater into drinking water by removing excess salts and minerals from water. It could be used for municipal, industrial or any commercial uses. The present chapter will contain an overview about saltwater types, history of desalination as well as the main technologies used in the field of desalination.

I.2. Saltwater types

The challenges associated with desalination are primarily focused on two types of saltwater: seawater and brackish water.

I.2.1 Seawater

Seawater in seas open to the great oceans (Atlantic, Channel, North Sea, Pacific) has a salinity of about 35 g/l, considered the standard salinity for seawater. This mean value can vary depending on the balance between precipitation and evaporation. The degree of deviation from this average value varies significantly in closed or only slightly open ocean bodies:

- Mediterranean Sea 36-39 g/l;
- Red Sea 40 g/l;
- Baltic Sea 7 g/l;
- Caspian Sea 13 g/l;
- Dead Sea 270 g/l;
- Arabian Gulf 40-70 g/l;
- Black Sea 20 g/l.

However, in open seas, the proportion of different salts present is relatively constant, as shown in Table I.1. In particular, chloride and sodium ions make up about 85% of the total salts. On the other hand, in enclosed seas or large salt lakes, evaporation from surface water that is slightly dirty but different from seawater may result in highly unusual ionic compositions (Maurel,2006).

Table I.1. The chemical composition of seawater (Maurel, 2006)

		Standard seawater	**Mediterranean Sea (Toulon)**	**Arabic Gulf (Kuwait)**
		ppm	ppm	Ppm
total salinity		35000	39000	45000
Cations	Sodium	10760	11970	13830
	Magnesium	1294	1440	1660
	Calcium	412	450	530
	Potassium	387	440	497
	Total cations	12853	14300	16517
Anions	Chlorides	19353	21570	24900
	Sulfates	2712	2990	3500
	Bicarbonates	142	153	182
	Bromides	67	75	86
	Total cations	22274	24788	28668

I.2.2 Brackish water

In general, brackish water is saline water unsuitable for drinking. Its salinity is lower than seawater's; most brackish water has a salinity of 1 to 10 g/l. It may exist in the form of either ground or surface water (Maurel, 2006).

Their chemical composition varies greatly between regions, and even within the same region, from season to season. Several parameters determine these chemical composition variations. When water penetrates the soil, it dissolves the salts that make up the earth's crust. The main salts that can be dissolved in large quantities are $CaCO_3$, $CaSO_4$, $MgCO_3$, and NaCl, aside from the chemical composition and physical structure of rocks, other factors come into play, among which we will mention:

- The speed of circulation of the water and, as a result, the time of contact;
- The already dissolved materials (the dissolution varies with the ionizing force): thus, chlorinated and gypseous waters can contain in solution quantities of calcium sulfate far exceeding the solubility of calcium sulfate in pure water (in the case of ground waters in

Qatar);

- Evaporation (direct evaporation or evapotranspiration), is a phenomenon primarily associated with climatic conditions but also with the groundwater's depth (irrigation influence) (Maurel,2006).

The table I.2 presents water characteristics through demineralization stages.

Table I.2.Water quality through demineralization treatment stages (ADE Ouargla, 2016)

		Mekhadma station - Ouargla 19-12-2016		
Characteristics	Units	Untreated water	RO water	Treated water
pH	-	NR	NR	NR
Conductivity	µs/cm	6480	555	602
TH	meq/L	29.6	3.4	4.8
TAC (HCO^{3-})	meq/L	1.74	0.29	1.52
Ca^{2+}	mg/L	304.61	24.05	28.05
Mg^{2+}	mg/L	174.99	26.73	41.31
Na^{+}	mg/L	700	50	58
K^{+}	mg/L	30	3	3

I.3. Desalination

Fresh water is scarce around the world; it only makes up 3%, even though water covers 70% of the earth's surface. Around 1.1 billion people around the world do not have access to fresh water, and around 2.7 billion suffer from scarcity at least one month a year. Desalination is commonly adopted nowadays to overcome freshwater scarcity, especially in areas that are very close to the sea or ocean (Wondimu et al, 2023).

I.3.1 Definition

According to Wikipedia, desalination is a process that removes mineral components from saline water. More generally, desalination is the removal of salts and minerals from a substance. It is possible to desalinate saltwater, especially seawater, to produce water for human consumptionor irrigation. Oxford Reference defines desalination as “The removal of dissolved salts and minerals from saline water to produce fresh, drinkable water. The key issues associated with desalination are cost, energy use, and the environmental impacts of brine disposal and feedwater intake” (Trimble et al, 2005).

Desalination is the process of eliminating salts from water to generate water with lower salinity than the source water. Many terms could be used interchangeably with desalination, such as seawater or salty water conversion, desalting, demineralization, and desalinization (Trimble et al, 2005).

Desalination can help to lower salinity in a variety of water sources. The word "source water" refers to the body of water from which water is extracted for useful uses. Surface water, groundwater, and municipal wastewater can all be used as desalination sources. Desalinated water is suitable for potable and non-potable purposes, including municipal drinking water, agricultural irrigation, and industrial activities (Trimble et al, 2005).

I.3.2 Water desalination history

Natural desalination has been occurring on earth since the creation of the seas. Water evaporates from the sea and then condenses to form pure rain water. Desalination has been practiced by man in the form of distillation for over 2000 years. In the history of human civilization, the process dates back to the 4th century B.C. when Greek sailors used an evaporative process to desalinate seawater (Altowayti, et al., 2022)

Historically, the idea behind the desalination process was introduced by the Royal Navy (the United Kingdom’s naval warfare force) at the end of the 18th century with the purpose of increasing navigational autonomy without storing more water on the ships. Since in that period ships were equipped with steam engines, the first desalination technology was single flash distillation, which was improved in the following years into the more efficient MSF. The first type of desalination unit was realized by the G. and J. Weir in 1885 in Glasgow (Scotland). This company, which later became known as Weir Westgarth, practically had a monopoly as a desalination unit builder until World War II (Domenico et al, 2021).

In the following years, desalination plants had been installed around the world for civil purposes, in Saudi Arabian kingdom (1907 and 1928), Qatar (1953), Kuwait (1953 and 1955). From this moment on, desalination plants expanded around the world, with the birth of many companies such as Krupp in Germany, Westinghouse in the USA, and SIR (Società Italiana Resine) in Italy. The other mainstream technique is a reverses osmosis (RO), based on semipermeable membranes. Historically, the phenomenon of osmosis was observed for the first time in 1748 by Jean-Antoine Nollet, without any application for about two centuries. In the USA the first studies were started by the researchers Sidney Loeb and Srinivasa Sourirajan in 1956 at the University of California and the University of Florida, respectively. The first membrane was realized in 1959 whereas the first pilot plant was installed in 1965, with a capacity of 19 m3/day (Domenico et al, 2021).

The slow diffusion of RO was initially due to the high electricity consumption required to produce freshwater in comparison with other techniques, and the limited life of semipermeable membranes. The first applications were related to brackish water, due to its lower osmotic pressure in comparison with seawater. The first desalination plant, based on RO, for a municipality, was realized in 1977 in the USA, with an installed capacity of 11,350 m3/day. Great technological progress occurred in the process of reverse osmosis thanks to the increase in membrane lifetimes and the adoption of energy recovery devices to reduce the energy requirements for the process. By mid-2007, desalination processes in Middle Eastern countries accounted for approximately 75% of the total world capacity of desalinated water (Domenico et al., 2021).

I.3.3 Desalination plant components

In general, a desalination plant includes different processes to obtain fresh water, among which the desalination unit is the most energy-expensive component. A desalination plant normally comprises (Figure I.1) (Maurel, 2006):

- Intake, composed of pumps and pipes to take water from the source (sea or brackish water);
- Pre-treatment, consisting of the filtration of raw water to remove solid components and the addition of chemical substances to reduce the salt’s precipitation and the corrosion inside the desalination unit;
- Desalination, where freshwater is extracted from saltwater;
- Post-treatment, to correct pH by adding selected salts to meet the requirements of the final uses.

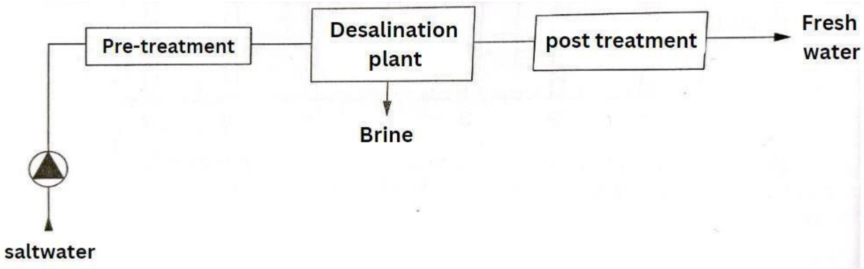


Figure I.1. General diagram of a desalination plant (Maurel, 2006)

I.4. Desalination technologies

Desalination can be realized using variety of technologies, such as reverse osmosis, electrodialysis, vapor compression, solar still and so on. The desalination process represents the most energy-consuming water treatment. Several classifications of desalination techniques are suggested based on different criteria:

- Desalination technologies process-based: It includes thermal process-based and membrane process-based (figure 1.2)
- Desalination technologies working principle based: It comprises evaporation and condensation, filtration, and crystallization (figure 1.3).
- Desalination technologies' main energy input based: It contains thermal energy, mechanical energy, electrical energy, and chemical energy (figure 1.4) (Mohamed et al., 2020)

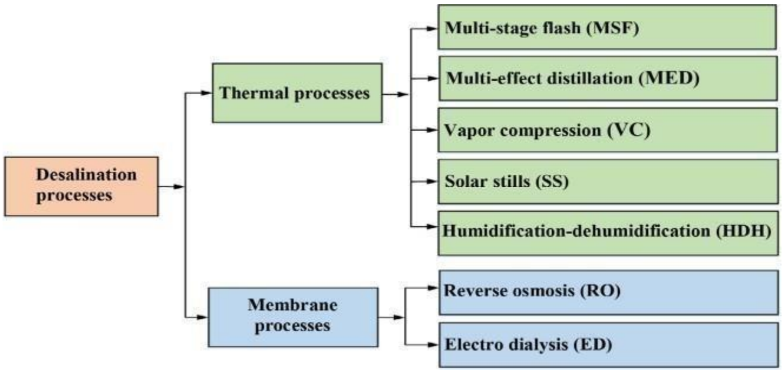


Figure I.2. Desalination technologies process based (Mohamed et al., 2020)

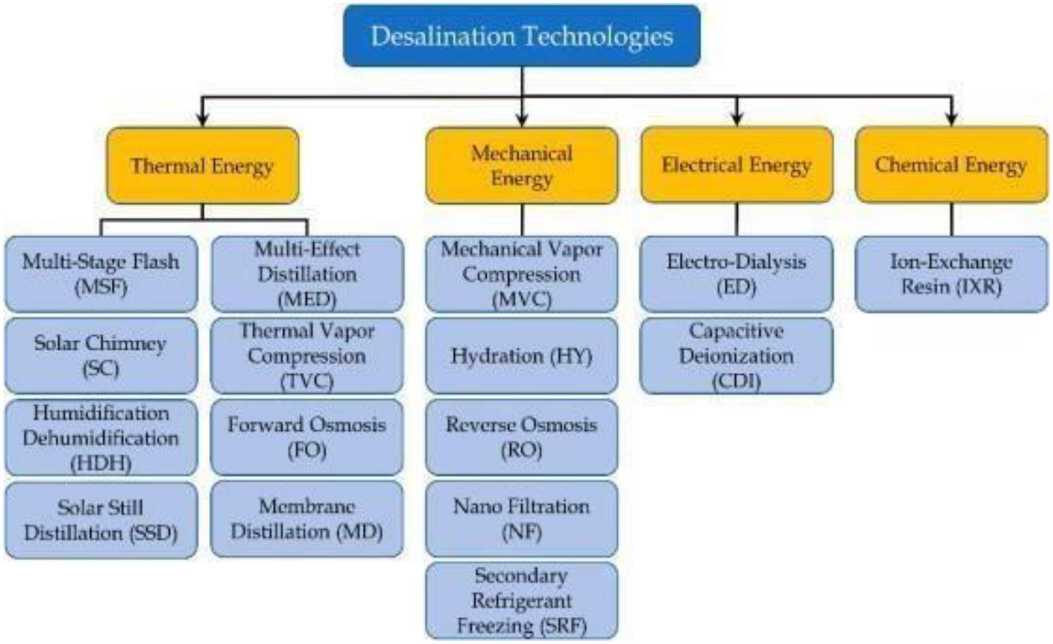


Figure I.3. Desalination technologies working principle based (Domenico et al., 2021)

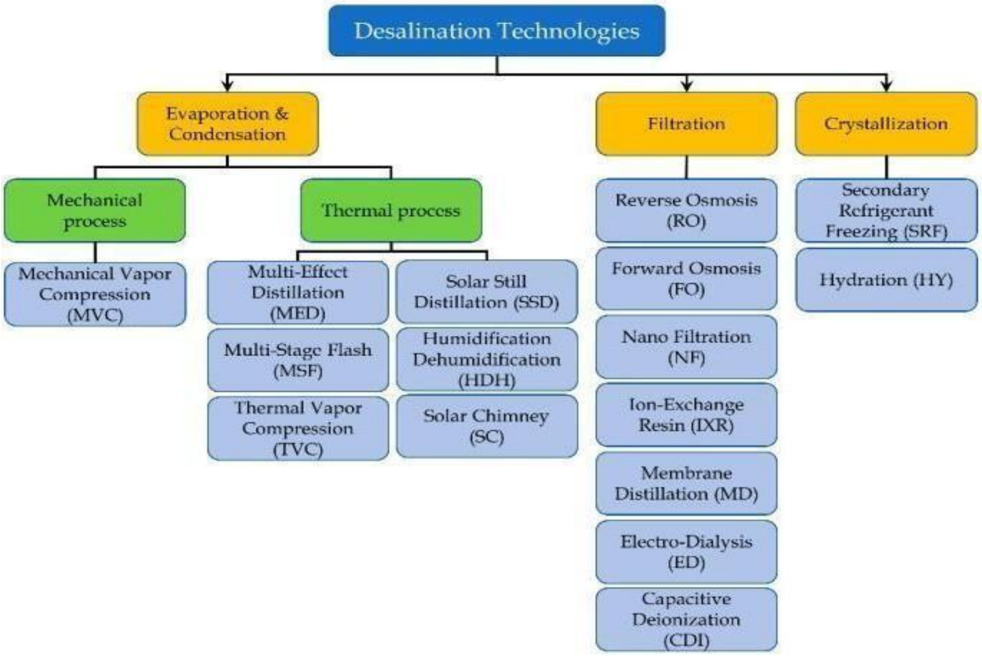


Figure I.4. desalination technologies main energy input based (Domenico et al., 2021)

In this study, the focus will be limited to the first classification because it includes the most used desalination technologies in the world as well as in Algeria.

I.5. Membrane based Desalination

I.5.1 Electrodialysis (ED)

The first electrodialysis (ED) units were introduced in the early 1970s. To prevent salt buildup on the membranes, the polarity of the electrodes is periodically reversed for a few minutes, which changes the direction of ion movement within the unit. During this process, the feedwater channels temporarily become brine channels and vice versa (Figure I.5) (Domenico et al., 2021).

Electrodialysis is an electrochemical desalination process that uses semipermeable membranes and an electric field to remove dissolved ions from water. The electric field, generated by two electrodes supplied with direct current voltage, affects ions based on their charge. Positive ions (cations, such as Na^+ and Ca^{2+}) are attracted to the anode, while negative ions (anions, such as Cl^-, HCO_3^-, and CO_3^{2-}) are attracted to the cathode (Domenico et al., 2021).

Anionic and cationic semipermeable membranes are alternately placed between the electrodes. Anionic membranes allow anions to pass, while cationic membranes allow cations to pass. As ions migrate due to the electric field, cations move toward the anode but are blocked by anionic membranes, and anions move toward the cathode but are blocked by cationic membranes. This selective movement confines ions within the brine channels, thus removing them from the freshwater channels. This technology is currently used to produce freshwater from brackish water with salinity levels up to 2000 ppm (Domenico et al., 2021).

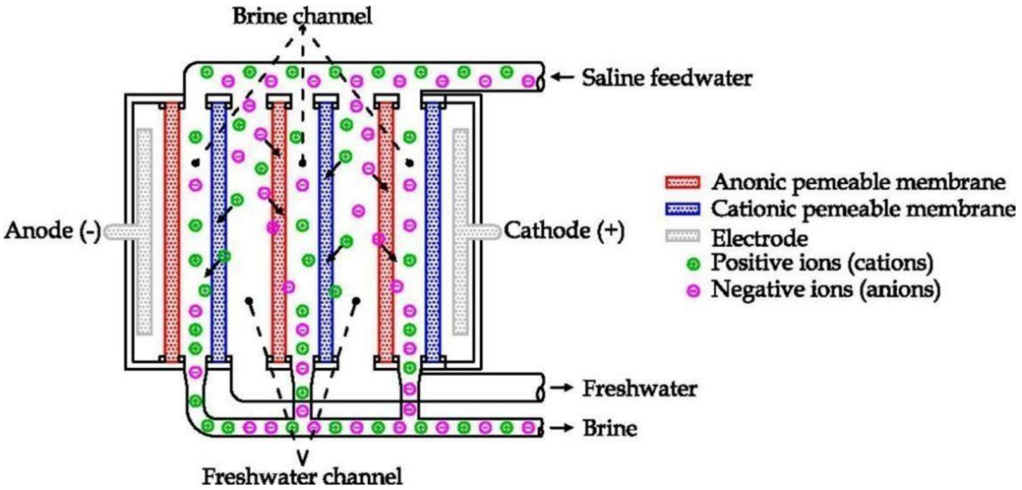


Figure I.5. The working principles of an Electrodialysis desalination unit (Domenico et al., 2021)

I.5.2 Reverse Osmosis (RO)

Reverse osmosis (RO) is a water purification method that uses semipermeable membranes to remove inorganic salts, suspended solids, organic compounds, microorganisms, and gases from water by applying pressure. This desalination technology relies on membranes that selectively allow certain molecules to pass through. In RO, the applied pressure must exceed the natural osmotic pressure of the saline feed water, which otherwise would push the water in the opposite direction. By applying an external pressure greater than the osmotic pressure, freshwater isextracted from saltwater. Typically, an external pressure of 15 to 25 bar is used for brackish water desalination, and 54 to 80 bar for seawater desalination (Domenico et al., 2021).

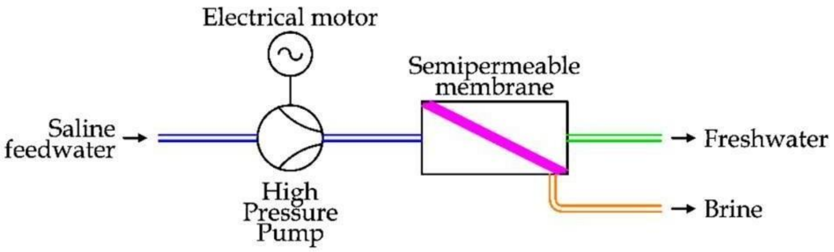


Figure I.6. Reverse Osmosis (RO) desalination unit (Domenico et al., 2021)

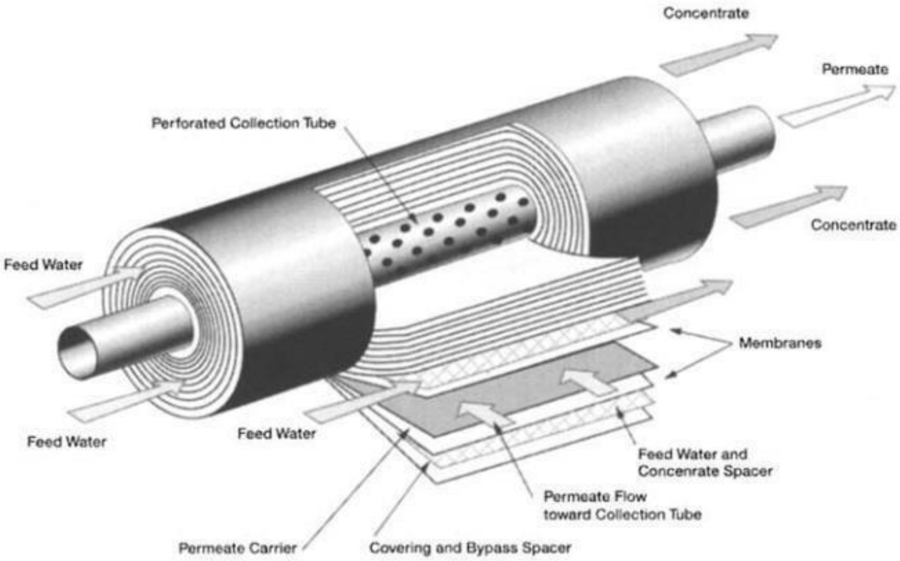


Figure I.7 Deconstructed spiral-wound RO membrane module (Voutchkov, 2013)

I.6. Thermal desalination

I.6.1 Humidification–dehumidification desalination (HDH) system

The HDH desalination process involves converting seawater into vaporized water in a humidifier, which subsequently condenses on condensing coils with an external temperature that's lower than the dew point of the air. To boost the freshwater efficiency of HDH WDS, the process of evaporation is sped up by heating either air, water, or both, allowing the air to carry more vapor from the water while raising its temperature (Mohamed et al., 2020).

Theoretically, 1 kg of dry air can transport 0.5 kg of vapor with an energy cost of 2814 kJ when heated from 30°C to 80°C.41 The humidification method involves flowing air in contact with seawater to remove a specific amount of water vapor. During dehumidification, humid air comes into touch with a cool surface, causing water vapor condensation and receiving new water. The condensation process uses the latent heat of condensation to pre-heat seawater going through the coils (Mohamed et al., 2020).

The HDH desalination technology allows for either an open or closed cycle of seawater. In the open cycle, evaporating 1 kilogram of water causes a 60°C drop in 10 kg of seawater. The recovered freshwater ranges from 5 to 20 percent of the circulated seawater. This results in low freshwater productivity due to significant heat loss. A closed cycle produces more fresh water while consuming less energy (Figure I.8) (Mohamed et al., 2020).

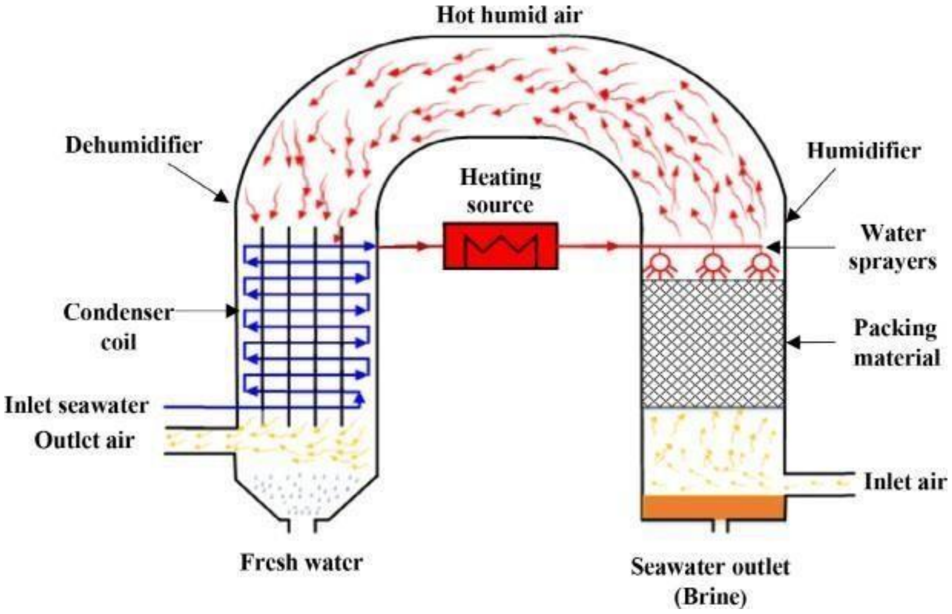


Figure I.8. Simple type of HDH desalination process (Mohamed et al., 2020)

I.6.2 Solar Still

The evaporation of water takes energy. The solar still is powered by the sun's direct, diffuse, and reflected radiation. Additionally, the glass cover, basin, and water absorb and/or reflect radiation. A black basin absorbs solar energy and transmits it to the water, increasing the temperature of both the water and the air inside the still. A certain amount of energy can be wasted through the basin and glass cover due to radiation, convection, and conduction, making the solar system less effective. Solar stills absorb varying amounts of solar radiation depending on characteristics such as latitude, cover slope, orientation, and glass thickness, Solar stills absorb varying amounts of solar radiation according to characteristics such as latitude, cover slope, orientation, glass thickness, time of year, and diffuse radiation. To maximize incoming radiation, align the glass's inclination and latitude. This will provide the highest amount of radiation received over a year. During the summer, the sun's declination angle is maximum due to the earth's tilt upon its axis of rotation (Ren, 2021).

The heat disrupts the connections between water molecules, causing it to evaporate. The vapor moves from the basin to the cooling glass by convection, radiation, and evaporation. Here, the vapor condenses, releasing the latent heat (Ren, 2021).

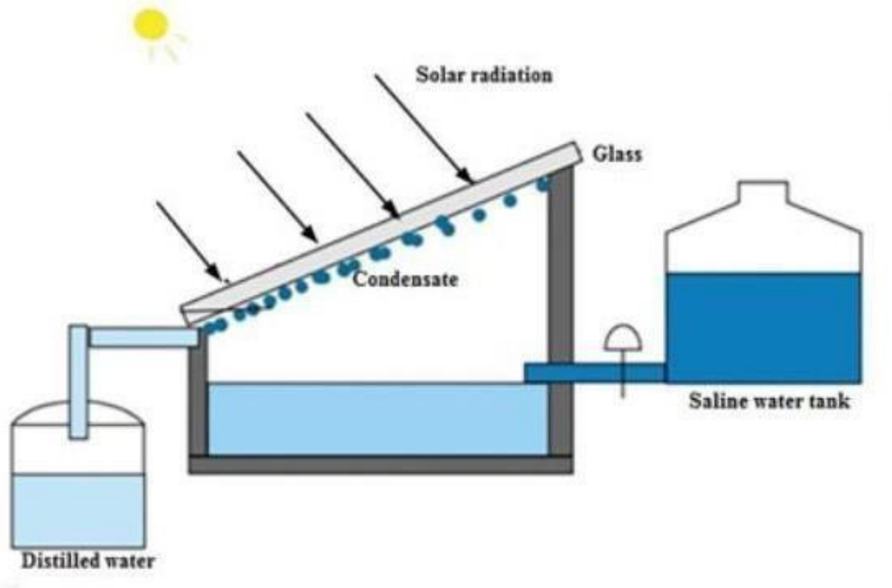


Figure I.9. solar still desalination system diagram (Ren, 2021)

I.6.3 Vapor Compression

The mechanical compressor produces a vacuum in the vessel, compresses the vapor, and condenses it into a tube bundle. Seawater is sprayed outside the heated tube bundle, boiling and partially evaporating to produce more water.

The steam-jet-type VC unit, also known as a thermo-compressor, has a venturi aperture at the steam jet that generates and absorbs water vapor from the main vessel, resulting in a lower ambient pressure. A steam jet compresses the extracted evaporated water. This combination condenses on the tube walls, providing heat energy to evaporate the seawater that has been applied to the vessel's outer tube walls. The mechanical vapor compression (MVC) system is the most appealing since it is compact and does not require an external heating source, unlike other systems. Yet, it requires highly skilled operators and has a more expensive upkeep cost. The system operates at low temperatures ranging from 60 to 70°C, which reduces scale and corrosion. Also, at these low temperatures, losses are minimized, and the need for thermal isolation is reduced (Figure I.10) (Aly, 2003).

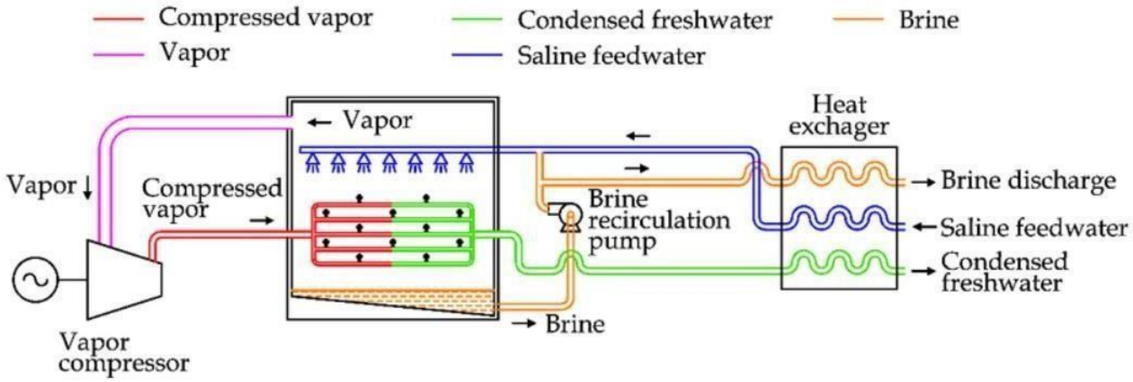


Figure I.10. A schema of a simple Mechanical Vapor Compression desalination unit. (Domenico, Vincenzo, & Andrea, 2021)

I.6.4 Multi-Stage Flash

The MSF distillation process produces the most desalinated urban drinking water produced in the MENA region. Today, it ranks second globally after RO technology and is largely used to desalt saltwater. This technique has been in large-scale commercial production for almost 30 years, and because it is more resistant to scaling than MED technology, it has consistently superseded it since the 1950s. Kuwait erected four MSF plants in 1957, totaling 9084 m^3/day. The Al-Jubail facility (815,120 m^3/day) in Saudi Arabia is the world's largest MSF plant (Ren, 2021).

This method uses seawater feeds that are compressed, heated, and discharged into flashingchambers that are slightly below saturation vapor pressure. As a result, a portion of the feed wateris converted into steam. The flashing steam travels through a mist eliminator before condensing onthe outer surface of the heat transfer tube (condenser) at the top of each step. The condensed liquid drips into trays and collected as freshwater. MSF plants have three sections: heat source, heat recovery, and heat rejection. The heat recovery segment typically has 19 to 28 stages (in larger plants). The heat rejection section typically has three or more steps to regulate the recycled brine temperature and conserve anti-scaling ingredients. The heat input section's peak brine temperature(TBT) normally ranges between 90-110°C but can reach 120-130°C with modifications. Figure I.11 depicts the usual MSF schematic design. For current MSF facilities, the typical pumping powerconsumption ranges from 3.0 to 5.0 kWh/m^3 (Ren, 2021).

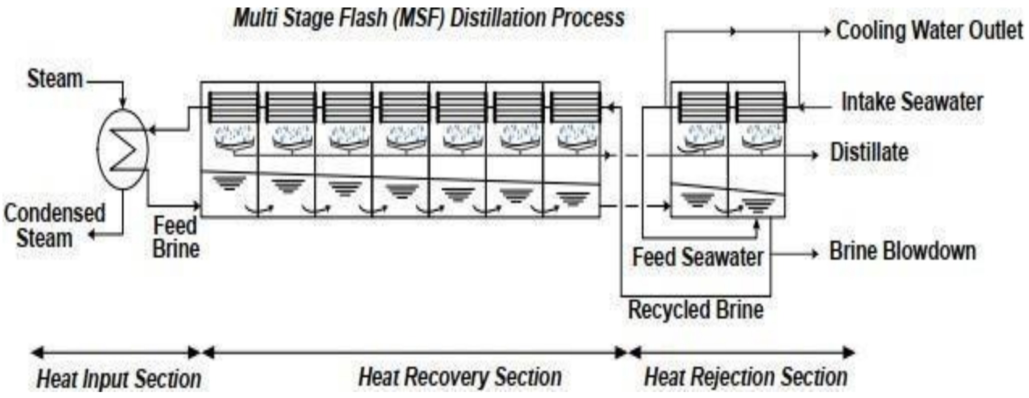


Figure I.11. A standard multi-stage flash schematic design (Bijan, 2017)

I.6.5 Multi-effect distillation

MED, like MSF, works as an evaporative phenomenon. The saline water goes through a series of compartments. Each successive chamber operates at a gradually reduced pressure. The MED method involves condensing vapor from one chamber and using the heat to heat the next room. Additionally, feed water is typically sprayed over the tube bundle at the top of each chamber. (The dark blue track in Figure I.12). External steam (the yellow tube in Figure I.12) is supplied into the first chamber, causing the feedwater to evaporate as it absorbs the heat from the steam. The resultant vapor reaches the second chamber under lower pressure via the tube. The heat created in the second chamber by condensation of the first chamber's vapor causes the feedwater to evaporate partially. The technique is repeated in each successive chamber. In each chamber, vapor condensesinto fresh water and is pumped out (see Figure I.12, sky blue track). The residual brine flows fromchamber to chamber (green line in Figure I.12) and is pumped out at the end of the procedure. MED typically recovers 25-40% of feed seawater as product water (Debele Negewo & Ward, 2019).

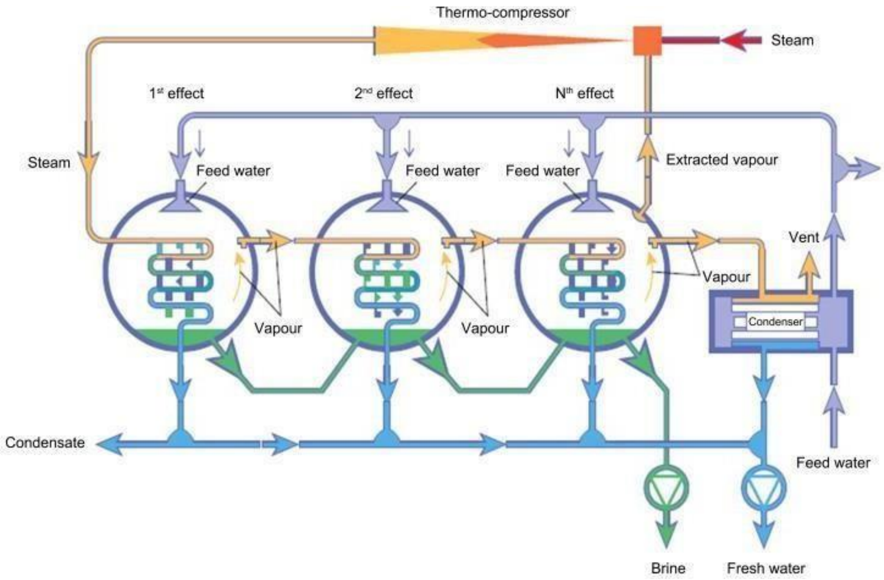


Figure I.12. Illustration of Multiple Effect Distillation (MED) desalination technique.

(Debele Negewo & Ward, 2019)

I.7. Method comparison

I.7.1 Technical comparison

Desalination necessitates energy, primarily in the form of heat for Multi-Effect Distillation (MED) and Multi-Stage Flash (MSF) plants, with a minor requirement for electrical power to operate pumps and auxiliary systems. In contrast, Reverse Osmosis (RO) relies solely on electrical energy. Each method possesses distinctive technical attributes that render it more suitable for particular circumstances. Thermal techniques excel in handling high salinity and temperature environments, while membrane techniques offer cost advantages in scenarios of moderate salinity and lower temperatures, typically around 25°C. Furthermore, energy costs vary significantly between countries. In oil-rich nations, where oil prices are low, thermal techniques are often favored by authorities. Conversely, regions lacking fossil fuel resources tend to lean towards reverse osmosis due to its reliance on electrical energy (Hamiche et al., 2018)

I.7.2 Economical comparison

Tables (I.3) and (I.4) compare the cost of producing water according to technology and capacity, regardless of power source. However, table I.5 presents the advantages and disadvantages of all the desalination technologies mentioned in this research (Hamiche et al., 2018).

Table I.3. Methods' Comparison (membrane) (Hamiche et al., 2018)

	RO	ED
Operating temperature (°C)	<45	<45
Energy used	Mechanical (via electricity)	Electrical
Power consumption (kWh/m3)	4-7	1
Salinity of raw water (g/l)	1-45	0.1-3
Salinity of treated water (mg/l)	<500	<500
Train capacity (m3/d)	1-10.000	1-12.000
Benefits	Modularity	

Table I.4. Methods comparison (thermal) (Hamiche et al., 2018)

	MSF	MED	MVC
Operating temperature (°C)	<120	<70	<70
The principal source of Energy	Thermal	Thermal	Mechanical (via electricity)
Thermal consumption (kWh/m3)	12	6	Not applicable
Power consumption (kWh/m3)	3.5	1.5	8-14
Salinity of raw water (g/l)	30-100	30-100	30-50
Salinity of treated water (mg/l)	<10	<10	<10
Train capacity (m3/j)	5.000-60.000	500-12.000	10-2.500
Benefits	Proven technique	20% cheaper than MSF	Simplicity
Disadvantages	Investment consumption	capacity lower than MSF	Limited capacity

Table I.5. Advantages and disadvantages of the main desalination technologies (Domenico et al., 2021)

Technology	Pros	Cons
RO	- Only electrical demand - Low investments - Couplable with many renewable energy sources - Modular structure of plant	- Lower water quality - High costs for membranes and chemicals - Subject to biofouling
ED	- High purity of freshwater - Energy consumption proportional to salt concentration	- Only for brackish water (up to 2000 ppm) - Bacterial contaminants not removed by system
HDH	- Low operating temperature - Simple operation	Optimization of thermodynamic cycle and flow rates Three circuits: air, water, freon
SS	- Run by solar radiation - Realizable with poor materials	Usable only for small applications
MVC	- High water quality - Low energy consumption	Low production capacity
MSF	- Maintenance operations to remove the scaling are simpler than in MED - High water quality - High rated capacity	- High energy demand - Huge investment - Corrosion problem - Slow start-up - The entire plant is stopped for maintenance
MED	- High water quality - Low energy consumption	Scaling on the pipes

I.8. Brine characteristics

Desalination generates two streams: the product water (freshwater) and brine, which contains excess dissolved particles. Thus, brine is an undesirable byproduct of the desalination process that must be thrown. Brine water can be dangerous due to factors such as salinity, temperature, chemical concentrations, and heavy metals. Table I.6 shows the chemical characteristics of brine from diverse sources. The chemical composition of brine water affects the disposal procedure.

The rejected brine, which is generally dumped back into the sea, can be damaging to aquatic life. For a while now, there has been concern in the Mediterranean region about Posidonia oceanica, which is considered a particularly critical ecosystem and is designated as an environment of priority by the European Habitat Directive (Council). Furthermore, it has one of the most frequent seagrass species in the Mediterranean, covering around 40,000 km^2 of seafloor and forming vast marine meadows from surface level to a depth of 40 m. Unfortunately, due to brine releases, this field has deteriorated in some coastal areas, which are highly sensitive to salty water (Al-Ghouti, 2021).

Recovery is a term used to describe that portion of the input water to a desalination plant that is converted to product fresh water. For example, if a plant produces 100 units of fresh water for every 300 units of seawater input, it is said to have 33% recovery. High recovery minimizes feed water requirements and hence pumping and pretreatment costs. It is also important when the feed water source is limited (IDA, 2011).

Concerning brine concentration, if a desalination plant produces 300 units of seawater input. This means that virtually all of the salts contained in 300 original units of feed water must now be packed into only 200 units of brine. The concentration of the brine must thus be 300/200 = 1.5 times the concentration of the feed water. A high recovery rate implies a high brine concentration factor. This may lead to problems with precipitation, scale formation, and disposal (see following sections) (IDA, 2011).

Concerning salts rejection, if the same plant takes in seawater at 35,000 ppm and produces a fresh water product of only 500 ppm, it is said to have a rejection of (35,000 – 500)/35,000 = 0.9857 or 98.57%. That is to say that 98.57% of the TDS in the incoming feed water has been rejected and remains in the brine (IDA, 2011).

Table I.6. Chemical characteristics of brines from various sources (Al-Ghouti, 2021).

	pH	TDS (mg/l)	COD (mg/l)	K^+ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)
Source 1	9.12	73.75	1554	781	1382	2974	23931
Source 2	9.9-10.1	NR	NR	11300	NR	48.6	67600
Source 3	7.9	55000.0 ± 2500	NR	NR	879 ± 53	1864 ± 56	15270 ± 460
Source 4	8.2	1410	-	32	14	17	6840
Source 5	7.5	54746.86	-	276.38	1086.37	1394.09	17495.27
Source 6	8.34	57400	NR	491	521	1738	18434

I.9. Brine management

Desalination operations generate large amounts of brine water. There are several options for its disposal, including direct disposal, direct reuse, and brine minimization. However, none of these options can be applied on a wide scale for all desalination plants since several parameters must be addressed before determining the best brine disposal strategy. Factors affecting brine storage include its capacity and quality, composition, geological location, available space, acceptability, capital, and operating costs. Efficient brine management is crucial for desalination plants to minimize environmental impact. For a long period, sodium chloride was the most commonly derived salt from the sea. As technology advanced, individuals began researching the prospect of mining rich metals including bromide, gold, magnesium, cesium, and lithium from seawater and brine. Optimizing brine water management involves two approaches: no liquid discharge and volume reduction (Khan, Q. M.- M. 2021).

I.10. Brine disposal strategies

I.10.1 Surface water discharge

Seawater discharge (SWD) involves directly releasing rejected brine into oceans, rivers, bays, lakes, or other suitable open water bodies. Initially, the brine is transported to a disposal site, from where it is discharged into a water body via an outfall structure. Over 90% of seawater desalination plants worldwide use this method. However, it is only viable if the brine's composition is suitable for the receiving water body's ecosystem. As previously mentioned, aquatic organisms are at significant risk from brine disposal due to its high salinity and pollutant levels. This risk can be mitigated by diluting the brine with regular seawater or municipal wastewater. Nevertheless, no comprehensive studies have yet confirmed that aquatic life is unaffected by variations in temperature or salinity caused by brine discharge. Additionally, the increased water volume can reduce dissolved oxygen levels in the marine environment, further harming aquatic life (Al- Ghouti, 2021).

I.10.2 Sewer discharge

The sewer discharge method is typically employed by small-scale brackish water reverse osmosis (BWRO) desalination plants due to the high total dissolved solids (TDS) content in the brine, which can negatively impact wastewater treatment plants (WWTP). This method involves discharging brine into a nearby wastewater collection system. Seawater brine, with TDS levels exceeding 55,000 mg/L, cannot be used in this manner because it would require the WWTP to have at least 20 times more capacity to treat the high TDS concentration, leading to potential environmental and regulatory issues. To mitigate risks, pH neutralization or other pre-treatment processes may be necessary, as the brine can contain significant amounts of metals. Consequently, this method is primarily used for BWRO desalination plants to avoid such complications (Al-Ghouti, 2021; Khan, 2021).

I.10.3 Evaporation ponds

Evaporation ponds are essentially very large-scale artificial ponds designed to evaporate water efficiently through exposure to the sun. As an example, that is used in Tamanrasset demineralization plant in south Algeria, the ponds are located 800 meters from the station and comprise 14 ponds.

The total surface area of these basins is 60 hectares. The depth of each basin is 01 m. These basins receive an average daily brine flow of ≈ 6000 m^3/day (Lakhdari, 2019)

This technology is currently the most widely used by inland-based desalination plants. Evaporation ponds are more practical in arid regions like the Middle East but are less common in Australia's arid areas. The primary concern with evaporation ponds is the risk of aquifer contamination due to potential leakage. Solar ponds offer an alternative for managing brine from desalination plants. Salt gradient solar ponds, while renewable energy sources, have limited applications. In arid and semi-arid regions, they are installed on a small scale for power generation. In Italy and Switzerland, solar ponds are combined with thermal desalination systems, providing heat for small MSF evaporator units (Khan, 2021).

I.10.4 Deep well injection

This method involves discharging by-product water into a deep, isolated subterranean aquifer. A major environmental concern is the potential contamination of nearby drinking water sources. Therefore, extensive testing, including deep drilling, hydrological assessments, pilot testing, and environmental reviews, is conducted before construction. This method is commonly used when other disposal options are ineffective and is suitable for all sizes of brackish water desalination facilities. The process involves injecting brine into a well with multiple layers of casing and filling, using permeable rocks to contain the brine and clay to prevent water pollution (Khan, 2021).

Table I.7. A summary of brine disposal methods (Al-Ghouti, 2021).

Disposal method	**Primary operational method**	**Cost**	**Advantages**	**Disadvantages**
Surface water discharge	Brine water is directly discharged to the surface of water bodies	USD ($) 0.050–0.300/m^3 of rejected brine	• Cost-effective Operated by medium and largescale plants • Handles large water volume • High dilution rate • Natural process • Promotes degradation	• Can have limited availability of dissolved oxygen in the receiving water bodies Causes an increase in water pH as well as eutrophication and toxicity • Can cause adverse effects to the marine water, if water is not treated appropriately. • Can cause thermal pollution
Sewage discharge	The brine is discharged to an existing sewage collecting system	USD ($)0.320–0.660/m^3	• Cost-effective, as it uses an existing infrastructure • Easily implemented • Brine is diluted • Low capital and operational cost are required	• Can cause bacterial growth • Overload the existing capacity of the wastewater treatment plant • Not commonly used for the seawater desalination plant
Evaporation ponds	Salt can be accumulated at the bottom, while the brine water is evaporated in the pond	USD ($) 3.280–10.040/m^3 of brine rejected	• A feasible option for inland plants in a dry region • Easy construction and maintenance • No apparent marine life threat	• Requires large area • Restricted to capacity • Climate dependent, suitable for dry arid countries • High construction and operational cost required • Risk of the underlying soil and groundwater.
Deep well injection	Brine water is introduced to a porous subsurface structure rock formation	USD ($) 0.320–2.650/m^3 of rejected brine	• Best suited for inland desalination plants • Does not affect marine life • No pretreatment is required prior to brine disposal • Oil wells that are not active or being used can be optimized, which reduces drilling cost	• Dependent on the suitability of isolated aquifer structure • Not appropriate for areas near geologic faults or areas that are susceptive to seismic activities • Regulatory compliance cost

I.11. Brine recycling

I.11.1 Land application and reuse

Several researchers have looked into the use of rejected brine in irrigation and aquaculture. Phyto-desalination uses concentrated brine to irrigate salt-tolerant crops. These crops, known as halophytes, are still in the experimental stage. Improvements include identifying plants with halophyte features and modifying existing plants through genetics (Khan, 2021).

Reject brine can also be used to raise fish. Tilapia is a unique fish species that thrive in high salinity environments. A scheme called Agua Doce, started in Brazil, provides the use of rejected brine in fish farming. The water exiting the pond is infused with organic fertilizer and is then pumped to irrigate halophyte shrub plantations (Khan, 2021).

I.11.2 Zero liquid discharge

Zero Liquid Discharge (ZLD) technology reduces brine to a dry, crystalline residue by using various methods such as vacuum evaporators, reverse osmosis (RO), evaporation ponds, crystallizers, and spray dryers. ZLD is particularly beneficial for inland areas with limited disposal options due to its environmental advantages. However, it is expensive and energy-intensive, making it more practical for small-scale brackish water desalination plants. ZLD systems involve multiple processes, which increase costs, but they are more cost-effective than other disposal methods and help address strict brine disposal regulations and groundwater preservation efforts (Al-Ghouti, 2021; Khan, 2021).

I.11.3 Salt recovering

The recovery of salts from a ZLD system for commercial use has been researched. This strategy may be profitable if the desalination plant is located in an area with high industrial demand for recovered chemicals. The recovery of sodium, potassium, magnesium, rubidium, phosphorus, indium, germanium, and cesium from rejected brine is commercially viable. However, a feasibility evaluation is required to evaluate whether the salt recovery method is economical or not (Al-Ghouti, 2021).

Sodium hypochlorite is a chemical that can be recovered from rejected brine. This chemical is commonly used as a disinfectant and could replace costly dry disinfectants and toxic chlorine gas. Extracted sodium hypochlorite could be a cost-effective solution for chlorinating cooling water systems in the power and desalination sectors, preventing microbial growth (Al-Ghouti, 2021).

I.11.4 Acid and caustic production

Caustic soda (sodium hydroxide) and chlorine, extensively used in various industries, are produced through the electrolysis of a sodium chloride brine solution, an energy-intensive process. To improve efficiency, many acid and caustic producers have implemented brine electrolysis recovery strategies, allowing for the reuse of brine waste through multiple cycles. Similarly, mining and metals industry brines can be reclaimed for acid and caustic production. This reduces brine waste volumes while producing chlor-alkali products for internal use or sale (SAMCO, 2024).

I.11.5 Softener brine recycling

Brines produced by both ion exchange (IX) softeners and reverse osmosis (RO) systems can be treated and reused for multiple treatment cycles. This can help minimize total water and salt intake. Brine waste reclamation arrangements collect a part of used brine, treat it (if necessary), and restore it to the brine tank during the IX resin regeneration process. While brine recycling can be an effective technique to enhance softener efficiency, it is often only practical for softeners that use a high salt dose and have a relatively high sodium chloride content after an active cycle. Furthermore, brine reuse might produce a more concentrated effluent, which may be moredifficult or expensive to discharge (SAMCO,2024).

I.11.6 Deicing and dust control

In an effort to reduce discharge costs, several facilities have begun providing waste brines to towns and municipalities to control ice, snow, and dust on roads. Different regions or municipalities may be more or less ready to accept waste brines for road treatment due to concerns about hazardous elements or the risk of harm to the local environment or water supply. Local governments have been known to take waste brines from food and beverage manufacturing, mining and gas extraction, and other businesses. The amount of treatment required prior to usage for road treatment applications varies depending on the stream contents, but in some situations, towns may go beyond mere acceptance and compensate industrial facilities for their waste brines (SAMCO,2024).

I.11.7 Cooling

While cooling towers are extensively used in power plants, oil refineries, chemical plants, and other facilities, they use a lot of water. With proper treatment, recycled brine can be an excellent option for lowering water consumption in cooling and thermal equipment. Recycling brine for this purpose will typically necessitate some type of cooling tower water treatment to reduce corrosion and scaling, which may involve lowering salt content, chlorides, phosphates, sulfates, and oxidizing microorganisms. Recycling for cooling purposes is limited due to salt content and other contaminants, which inhibit heat transfer and may produce foaming (SAMCO,2024).

I.12. Conclusion

Numerous promising desalination systems, which vary in form, production, efficiency, and operating conditions, have been displayed in this chapter. In addition to several factors that affect distillation systems. Choosing a good desalination technique requires empirical study under all the conditions and criteria that may influence desalination effectiveness. Moreover, almost all technologies that were discussed in the review comprehensively have the ability to recover resources from brine water in a sustainable manner these resources have both high and low economic.

Chapter II.

Desalination and demineralization in Algeria

II.1. Introduction

Water scarcity is a major issue in many arid and semi-arid regions around the world, including Algeria. Thus, creative solutions are crucial for ensuring a reliable and sustainable water supply. Desalination and demineralization technologies are critical answers to the country's acute water scarcity and rising demand for freshwater resources. With a largely desert climate and increasing urbanization, these technologies are critical in diversifying water sources beyond conventional reservoirs and groundwater, assuring a consistent and sustainable water supply for urban populations, industrial operations, and agricultural needs. Desalination and demineralization use seawater and brackish water resources to increase water quantity, improve water quality, reduce the risk of waterborne infections, and protect public health.

II.2. Current water resources situation in Algeria

Algeria, one of the largest countries in North Africa, is experiencing rising water stress due to numerous reasons. First, water needs (demand for drinking, industrial, and agricultural water) highly exceed the mobilized water resources. Second, there is a geographical disparity between needs and resources, especially in the north because of the high concentration of water needs in the coastal strip (60%). Third, the available groundwater and surface water resources are threatened by pollution due to domestic, industrial, and agricultural waste. Besides, the weakness of our resources is overused as reason of the poor spatial and temporal distribution of these resources, the soil erosion, and the siltation of dams. In addition to these causes, the lack of sustainable development for water resources has exacerbated the situation (Hamiche et al., 2018; Kherbache, 2020).

Despite these difficulties, Algeria has successfully addressed the challenge of water mobilization between 1999 and 2018. This era is seen as an exit of the country from economic water shortage, which prevailed before 1999. During this period, Algeria guaranteed that the majority of its population had access to safe drinking water, with a connection rate of 98% in 2016, up from 78% in 1999. Similarly, Algeria reached the sanitation facilities target, with a 90% connection rate to the sewage network in 2015 compared to 35% in 1970. Furthermore, water mobilization infrastructure (e.g., dams) has risen significantly over the last 50 years, from 13 operational dams in 1962 to 78 dams in 2018. In 2016, there were 177 WWTPs, up from 12 active stations in 1999 (Kherbache, 2020).

II.3. Desalination and demineralization in Algeria

Even though, the major investments carried out by Algerian authorities in the hydraulic sector, the present situation of water supply and irrigation in the north of the country remains difficult due to unequal distribution of resources, rainfall and its randomness, Imbalances between coastal and interior, the recurrence of drought phenomenon in time and space, and the overexploitation of groundwater. Therefore, the use of nonconventional water has become vital to curbing the negative effects of climate hazards on water availability, regulating the distribution and providing certainty in the drinking water of major cities in coastal areas, and ensuring the regular and stable development of irrigation water. Seawater is the most available non-conventional (renewable) water in Algeria with a coastline of 2148 km, thus; seawater desalination represents the key solution to water scarcity (Hamiche et al., 2018).

II.3.1 Seawater desalination

Algeria's experience with desalination is strongly tied to the development of the oil and steel industries. There is almost no desalination for the sole purpose of providing drinking water to the population. In the demineralization unit of Ouled Djellal, one station was tried due to a lack of alternative solutions. Desalination and demineralization are commonly utilized in industry for boiler water, cooling, and treatment purposes. In 1964, three tiny 8-m^3/h blocks were erected at the Arzew liquefied gas plant (a seaside town in the country's west). The method employed is "submerged pipes" that operate at low pressure. In 1969, another factory was developed in Arzew with a production capacity of 4560 m^3/d. The procedure employed is MSF (Hamiche et al., 2018).

Since then, more desalination and demineralization units have been established alongside the new complex. Others were placed into service to meet high-purity water needs for power generation (Cap Djenet east of Algiers) as well as industrial liquefaction (Arzew and Skikda). Some facilities, primarily in the south, aim to deliver safe drinking water from petroleum sources. SONELGAZ's energy plants have minor desalination units for internal site purposes (Table II1) (Hamiche et al., 2018).

Table II.1. Some Desalination Stations in Algeria (Hamiche et al., 2018)

Site	Number of units	Capacity (m^3/d)	Process	Commissioning
Skikda	1	1440	Flash	1971
Skikda	2	720	Flash	1971
Skikda	/	1440	Ion Exchanger	1971
Annaba	2	960	Ion Exchanger	1971
Annaba	2	3600	Ion Exchanger	1973
Ghazaouat	1	840	Ion Exchanger	1974
Arzew	6	3888	Electrodialysis	1975
Arzew	/	960	/	1975
Hassi Messaoud	6	1000	Electrodialysis	1975
Hassi Messaoud	2	110	Electrodialysis	1976
Hassi Touil	1	55	Electrodialysis	1977
Arzew	1	350		1978
Annaba	3	14,180	Multiflash	1978
Hassi Messaoud	2	350	Electrodialysis	1978
Bel Abbes	/	1500	Ion Exchanger	1978
Haoud Bercaoui	1	55	Electrodialysis	1979
Hassi Messaoud	2	30	Electrodialysis	1979

Table II.2. Desalination seawater management and downstream (big stations) (Hamiche et al., 2018)

Region	Localization	Capacity (m^3/d)	Linear (km) $a \leq \Phi < b$	Status	Investors (SDEM)
West	Arzew/Oran	90,000	37km $\Phi = 1250$	Operating (August 2005)	Black-Veatch (South Africa)
	Souk Tleta/ Tlemcen	200,000	157 km $250 \leq \Phi < 1400$	Operating (May 2011)	Hyflux-Malakoff (Singapore)
	Honaine/ Tlemcen	200,000	160 km $500 \leq \Phi < 1200$	Operating (July 2012)	Geida (Spain)
	Mostaganem	200,000	117 km $200 \leq \Phi < 1400$	Operating (September 2011)	Inima-Aqualia (Spain)
	Sidi djelloul/ Ain Temouchent	200,000	160 km $250 \leq \Phi < 1400$	Operating (December 2009)	Geida (Spain)
	Mactaa/Oran	500,000	21 km $700 \leq \Phi < 1800$	Operating (February 2013)	Hyflux-Malakoff (Singapore)

Center	Hamma/Alger	200,000	12 km $700 \le \Phi < 900$	Operating (February 2008)	GE Ionix (USA)
	Cap Djinet/ Boumerdes	100,000	30 km $900 \le \Phi < 1000$	Operating August 2012)	Inima-Aqualia (Spain)
	Fouka/Tipaza	120,000	15km $350 \le \Phi < 900$	Operating (July 2011)	SNC Lavalin-Predisa (Canada-Spain)
	Oued Sebt/ Tipaza	100,000	127 km $200 \le \Phi < 1000$	SDE Mnot launched	Biwater (England)
	Tenes/Chlef	200,000	254 km $200 \le \Phi < 1400$	Work in progress	Befsa Agua (Spain)
East	Echatt/Tarf	100,000	20 km $\Phi = 800$	SDE Mnot launched	-
	Skikda	100,000	54 km $400 \le \Phi < 1000$	Operating (March 2009)	Geida (Spain)
Total		2,310,000	1164km		

Table II.3. Seawater Desalination (small stations) (Hamiche et al., 2018)

Stations	Capacity (m^3/d)
Mono-block desalination plants managed by the ADE	
Ghazaouet 1	2500
Ghazaouet 2	2500
Bou Ismail	5000
Tigzirt	2500
Skikda 1	2000
Skikda 2	5000
Bouzedjar	5000
Chatt El ward	5000
Tenes	5000
Total	34500
Mono-block desalination stations managed by SEAAL	
Zeralda 1	2500
Zeralda 2	2500
Ain Benian 1	2500

Ain Benian 2	2500
Palm Beach	2500
Total	12500
Mono-block desalination stations managed by SEOR	
Bousfer	5500
Les dunes	5000
Total	10500

II.3.2 Demineralization

In southern Algeria, the overall capacity of brackish water demineralization plants (BWDP) is 91.5 hm3/year. The total flow mobilized upstream exceeds 428.9 hm^3/year. The situation is as follows:

- Understudy: 06 stations (Tamanrasset 4. El Oued 2), including 04 BWDP for which studies have been completed (El Oued 2 and Tamanrasset 2).

- Study and construction: 01 station (Béchar).

- Under construction: 12 stations (Ouargla 10, El Oued, and Tamanrasset (ADE)).

- Work in progress: 02 stations for ADE (Tindouf and Illizi).

- Installation of BWDP Monoblocs: 15 stations (El Oued) of which: 01 station is completed and commissioned and 14 stations are being installed (Zeghidi, 2020).

II.4. Government policies and initiatives

Water resources are the subject of a development drive that has always been at the heart of the concerns of the State's highest authorities, and they illustrate better than any other sector the spectacular leap Algeria has made since the early 2000s. Indeed, the water stress that affected the country during the 90s led the public authorities to launch an emergency program to secure the supply of drinking water to coastal areas through the use of seawater desalination. To strengthen and secure the population's drinking water supply, the public authorities have decided to exploit non-conventional resources, in particular seawater desalination, by building two new plants in addition to the existing ones. Two new desalination plants, each with a capacity of 300,000 m^3/day, will be built: the first in the wilaya of El Tarf, and the second to the west of Algiers. The plant in the wilaya of El Tarf will strengthen and secure the drinking water supply to a large geographical area in the east of the country (Hadjoumi, 2017).

The West Algiers plant is intended to meet the demand for drinking water in the western part of Algiers and Blida. These two plants, together with those already in operation, will account for 25% of the country's overall drinking water production, compared with 17% at present. The construction of the West Algiers plant is all the more necessary given that the vagaries of theclimate are causing a drastic fall in dam reserves and a lowering of groundwater levels, including those in the Mitidja, Mazafran, and Hamiz. The two plants will be built in BOT (Build Operate and Transfer) mode, under the management of Algerian Energy Company (AEC), a subsidiary of Sonatrach and Sonelgaz (Hadjoumi, 2017).

As a reminder, the desalination program, implemented from 2003 onwards, provides for the construction of 13 desalination plants with a total nominal capacity of 2.31 million m^3/d, representing almost 850 million m^3/year, to serve 8 million inhabitants (Hadjoumi, 2017).

To date, eleven (11) plants with an installed capacity of 2.1 million m3/day have been built and commissioned. These are Arzew (Oran: 86,000 m^3/d), Hamma (Algiers: 200,000 m^3/d), Skikda (100,000 m^3/d), Beni Saf (Ain Temouchent: 200,000 m^3/d), Mostaganem (200,000 m^3/d), Fouka (Tipaza: 120. 000m^3/d), Souk Tlala-(Tlemcen: 200.000 m^3/d), Honein (Tlemcen : (200.000 m^3/d), Cap Djinet (Boumerdès: 100.000 m^3/d), Tenes (Chlef: 200.000 m^3/d) and Maacta (Oran: 500.00 m^3/d) (Hadjoumi, 2017).

II.5. Analysis of the Desalination situation in Algeria

This analysis seeks to adapt the experience of operating stations to future stations. The investigated themes can be categorized into three categories: technological aspects, environmental impacts, and desalination costs (Hamiche, et al., 2018).

- **Technical Aspects**: They are closely related to the desalination stages. For seawater intake, using coastal wells instead of a submarine outfall is more cost-effective, especially for small or medium production (approximately 50,000 m^3/day). Filtration represents the pretreatment phase that ensures the quality of the raw water that reaches the reverse osmosis membrane. It is achieved either with closed filters or with open ones. To increase feedwater quality, membranes for micro- and ultra-filtration may be used in the future. Concerning desalination technology, it seems that distillation is a more energy-intensive process than reverse osmosis, which leads to its annual dominance. In Algeria, all plants built or under construction after 2000 are based on the reverse osmosis process. The posttreatment of the desalination plant is related to the addition of hardness and alkalinity to the RO water, which is accomplished by two technologies saturators of lime and the beds of calcite.

- **Environmental impacts**: They are associated to the discharge of brine on the marine ecosystem and the increase in energy consumption compared to alternative drinking water resources. The effects of the difference between brine and seawater salinity as well as the residues of chemicals used in the pretreatment on the marine environment are indicated by several studies, such as anoxia at the seabed, reduction of light, and affection of marine species.
- **Desalination costs**: Estimating desalination costs is of paramount importance in order to determine the feasibility of desalination plants compared to other drinking water techniques, including surface water, groundwater, transfer, recycling solutions for wastewater, and water conservation. For instance, the current total cost of the desalination plant of (El Magtaa) of Oran in 2014, was 75 DA/, including investment, operating, and financial costs.

II.6. Case studies

II.6.1 Desalination case studies

a) Hamma Water Desalination (HWD) plant

It is Africa’s largest seawater desalination plant. Hamma Water Desalination SpA, a special project company, led by GE Water & Process Technologies, was selected to design, build, own, and operate the 200,000m^3 /day, Hamma Seawater Desalination Plant (SWDP), a reverse osmosis seawater desalination facility that would significantly feed approximate 1.5 million residents and alleviate water scarcity in Algiers. The plant was built on a brown-field site just east of the Port ofAlgiers. Although ship traffic and port activities can have an impact on the water quality in this part of the bay, the site is ideal for its proximity to the city’s water distribution network, power grid, and transit links. The facility will draw seawater through two 550-meter direct intake pipesto a pre- treatment system. The pretreatment stage of the plant comprises flocculation, settling (lamella clarifier), and filtration (media filter and five-micron cartridge filters) in order to remove suspended solids and lessen biological problems in the raw water caused by seasonal dynamics, biological blooms, and turbidity effects from a working port. The stage of desalination is equipped with an advanced membrane process that offers operational and economic advantages over alternatives like thermal desalination processes, including reduced energy consumption and lower chemical requirements. The finished water is guaranteed to meet the following parameters:

Total Dissolved Solids of less than 500 mg/L, Alkalinity of up to 65 ppm, Total Hardness of between 50 – 65 ppm, and pH of 8– 8.5 (www.gwater.com).

Figure II.1. El-Hamma station's RO units (spa, 2024)

'Honaïne' desalination station

In north-western Algeria, a seawater desalination plant has been installed in the Wilaya of Tlemcen, in the "Honaïne" region. It has a production capacity of 200,000 m^3/d, supplying drinking water to 23 communes and the urban agglomerations of Greater Tlemcen (Tlemcen, Mansourah, and Chetouane), with a population of around 555,000. The Honaïne seawater desalination plant, the second in the wilaya after Souk Tleta, was commissioned on 19 September 2006 by the Spanish consortium GEIDA (comprising the companies COBRA, SADYT, BEFESA, and CODESA) 51% and AEC 49%, and became operational in July 2012, with an investment of investment of 250 million dollars (Hadjoumi, 2017).

Seawater characteristics

The characteristics of the seawater to be desalinated are presented in Table II-4. These are the basic conditions for starting the desalination operation.

Table II.4. Characteristics of Honaine seawater (Hadjoumi, 2017).

Characteristics	Unit	BASIC CONDITIONS OF THE DESALINATION PLANT OF 'HONAÏNE
Temperature	° C	24
Total dissolved solids	g/l	40.074
Suspended solids	g/l	0.004
Chloride	g/l	22.289
Calcium	g/l	1.047
Sulfate	g/l	2.978
Magnesium	g/l	1.545
Sodium	g/l	11.472
Potassium	g/l	0.583
Bicarbonate	g/l	0.13
pH	-	8.2

The municipality of Honaïne, located 60km from the administrative center, has a total area of 6,385 hectares and borders the Trara Orientales to the east, the daïra of Béni Saf in the wilaya of Ain-Temouchent to the north, the sea to the west, the daïras of Nedroma and Ghazaouet to the south, and the daïra of Remchi to the south (Hadjoumi, 2017).

Station plan

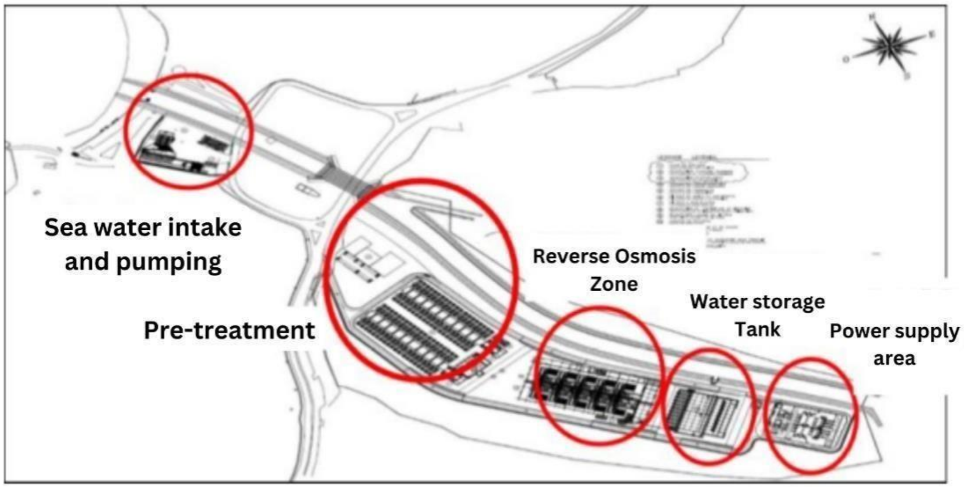


Figure II.2. Station plant (Hadjoumi, 2017)

Desalination process applied in the Honaïne desalination plant

The seawater desalination process comprises four main stages:

- Capture of seawater
- Pre-treatment
- Reverse osmosis
- Post-treatment

'Mostaganem' desalination station

The Mostaganem Desalination Plant, located at Cheliff Beach (Mostaganem), has a drinking water production capacity of 200,000 m^3/day (Hadjoumi, 2017).

This station includes:

- A seawater collection and pumping system,
- A seawater pre-treatment system using filtration and microfiltration,
- A system for demineralizing micro-filtered water by reverse osmosis,
- A remineralization and conditioning system for demineralized water,
- A remineralized water pumping system,
- A system for removing brine and by-products. (Hadjoumi, 2017)

Seawater characteristics

The characteristics of the seawater used for desalination are presented in the table below.

Table II.5. Seawater characteristics - Mostaganem (Basic site conditions) (Hadjoumi, 2017)

Characteristics	**Unit**	**BASIC CONDITIONS OF THE DESALINATION PLANT OF 'Mostaganem'**
Temperature	° C	24
Total dissolved solids	mg/l	39,040.000
Suspended solids	mg/l	5,000
Chloride	mg/l	21,001,000
Calcium	mg/l	345,000

Sulfate	mg/l	2,200,000
Magnesium	mg/l	1,466,000
Sodium	mg/l	11,332,000
Potassium	mg/l	437,200
Bicarbonate	mg/l	159,900
pH	-	7,5 to 8,5
Total hardness	ppm	65 as $CaCO_3$
Alkalinity	ppm	50 to 65 as $CaCO_3$

II.6.2 Demineralization case studies

a) Ouargla demineralization station

The province of Ouargla is exclusively supplied with drinking water from aquifers. It also has 138 wells, of which 116 are in service for domestic water supply, in addition to 93 reservoirs with a storage capacity of 56,590 m^3. The 9 stations involved in the Ouargla city project are currently supplied with raw water from 27 exploited wells, including 2 Albian wells. The project aims to improve the quality of the currently distributed drinking water in Ouargla and reduce its salinity, which currently ranges from 3 to 6 g/l, to be reduced after desalination to 0.8 g/l. The various stations will be able to treat 70,500 m^3/day to provide 75% demineralized water, approximately 53,000 m^3/day (Zeghidi, 2020).

Table II.6. Characteristics of water demineralization plants in Ouargla (Zeghidi, 2020)

Station's name	Raw water capacity (m^3/d)	Target quantity of treated water per day (m^3/d)	Average number of residents served (150 liters/person/day).	Well
GHARBOUZ (S1)	3000	2250	15000	2
AIN EL KHEIR (S2)	9000	6750	45000	5
HAI BOUZID (S3)	4500	3375	22500	3
MEKHADMA (S4)	3000	2250	15000	3
IFRI-GARA (S5)	10500	7850	52333	4
ZYAYNA (S6)	3000	2250	15000	2 (1 Albian)
EL KHAFDI (S7)	7500	5625	37500	3

BAMENDIL VILLAGE (S8)	3000	2250	15000	2
EL HADEB (S9)	27000	20250	13500	3 (Albians)

'Tamanrasset' demineralization station

Some data on the reverse osmosis demineralization plant, designed to supply drinking water to the towns of Tamanrasset and In Salah supply drinking water to the town of Tamanrasset and In Salah. The plant covers a total area of 81831.00 m^2 (Lakhdari, 2019)

- Built-up area: 6298, 00 m^2.

- Undeveloped area: 75633, 00 m^2.

- Area of evaporation basins (14 basins): 60 hectares.

The plant is one of the main components of a drinking water supply system planned for the town of Tamanrasset and the town of in Salah, which is located around 700 km to the south-east in Algeria's Saharan region (Lakhdari, 2019)

The system is designed to meet the water needs of the town of Tamanrasset and the communities along the supply route until 2050.

The data relating to the commissioning and operation of the demineralization plant are as follows:

- Start of works: 10 May 2015.

- Semi-industrial commissioning and testing: 19 July 2017.

- Provisional partial acceptance of the demineralization plant: 01 November 2017.

- Current production (as required):
  - Raw water: Between 33,000 m3/day and 34,000 m3.
  - Treated water: Between 29,000 m3/day and 30,000 m3.

- Measured mineralization: At the plant outlet: 0.6 g/l. In Tamanrasset: 0.8 g/l.

- Cost per cubic meter of treated water: 36.48 DA including VAT (Lakhdari, 2019).

We can see a summary of the treatment processes in the figure below (Figure II.3).

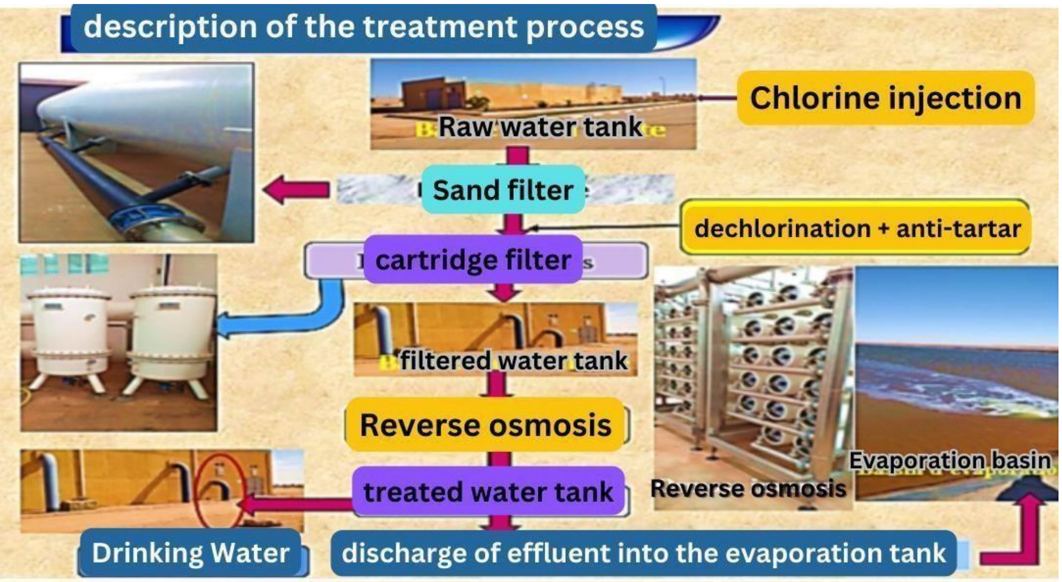


Figure II.3. The treatment process at the Tamanrasset-In Salah water demineralization plant (Lakhdari, 2019).

II. 7. Future prospects

Since 2021, the Algerian government has embarked on the swift construction of five major desalination facilities across significant states: TARF, Bejaia, Boumerdes, Tipaza, and Oran. Each of these plants has the capacity to generate 300,000 m^3/day. This urgent endeavor is aimed at alleviating water scarcity issues in these regions, particularly in densely populated urban centers and vital industrial zones. Through the strategic placement of these facilities, Algeria is ensuring a more reliable and fair distribution of water resources, catering to both present demands and future requirements. This initiative underscores the government's dedication to providing its citizens with access to clean water (table II.7) (Lakehal, 2023).

Algeria is witnessing a profound change in its water infrastructure, driven by substantial investments in desalination endeavors. According to official statistics, desalinated water presently accounts for 17% of the country's total water supply. However, the National Water Strategy (2021-2030) charts an ambitious course for the future. By 2022, this proportion is expected to surge to 22%, signaling a swift expansion of desalination capabilities across the nation. The National Water Strategy aims to meet 60% of Algeria's drinking water needs through desalination by 2030, reflecting the government's dedication to water security amidst climate change, population growth, and urbanization. This comprehensive strategy integrates advanced technology, sustainability, and environmental awareness. Desalination has become central to Algeria's water security, with 42% of water needs projected to be met through desalination by 2024, promising a transformative shift in water accessibility and availability (Lakehal, 2023).

Table II.7. Development in Production between 2020 & 2024 (Lakehal, 2023)

	%	**Production (m^3/day)**
2020	30	2 100 000
2022	40	2 310 000
2024	60	3 300 000

II. 8. Conclusion

During this chapter, the water scarcity issue in Algeria has been discussed, in addition to the solutions proposed by the authorities in which seawater desalination seems to be the suitable key. Case studies of Algerian seawater desalination and brackish water demineralization were displayed with some water characteristics and treatment stages.

Chapter III.

Brackish water demineralization, areas of study “Ouled Djellal” and “El Oued”

III.1. Introduction

This chapter will describe the two brackish water demineralization plants, Ouled Djellal and El-Oued, from the intake water stage to the final treatment step. The chemical characteristics of the feed water, treated water, and brine solution for both plants will be presented, in addition to the brine fate.

III.2. Description of the drinking water production plant of Ouled Djellal

III.2.1 Geographical location

The wilaya of Ouled Djellal was officially established on 2021. Previously, it was part of the Biskra wilaya territory. It is delimited (Fig.III.1):

- To the north: the wilaya of Msila
- To the west: the wilaya of Biskra
- To the south: the wilayas of El Oued and Ouargla.
- To the east: the wilaya of Djelfa

Figure III.1. Ouled Djellal location (satellite image)

III.2.2 Objectives of installing the demineralization plant

Raw water arrives at the plant via an internal borehole. The water is then stored in a raw water tank. As we can see in the table III.1, the feed water is characterized by high hardness (high content of magnesium and calcium), high chloride, sulfate, sodium, and potassium levels. Because of its poor quality, the demineralization of this water using reverse osmosis is required.

The water demineralization station concerns the Bir Naam region, and it is built as part of the project to improve the town's drinking water supply. The station is managed by the ADE, and has not yet been commissioned.

The plant supplies the town with a flow rate of 1,200 m^3/day, distributed via a single water tower, which ensures the reinforcement and improvement of the produced water.

Table III.1. Raw water characteristics

Characteristics	Units	Value	Algerian standard (2011)
pH	-	7.02	6.5-8.5
Conductivity	µs/cm	3230	2800
TAC	meq/L	76	25
HCO_3^-	mg/L	305	/
TA	meq/L	0	/
Ca^{2+}	mg/L	736	200
Mg^{2+}	mg/L	470.4	150
Na^+	mg/L	275	200
K^+	mg/L	44	20
Cl^-	mg/L	364.88	500
SO_4^{2-}	mg/L	1280	400

(for the Algerian standard look at annex)

III.2.3 Description of the treatment process

a) The borehole

The demineralization plant is supplied from a single internal Albian borehole (Fig III.2) with depth of 2km. The water temperature in this borehole is 54°C.

Figure III2. The internal borehole of the station

Pre-treatment

The pretreatment of brackish water prior to reverse osmosis is absolutely necessary because these membranes are very sensitive to clogging.

The pretreatment stage consists of two operations:

- First operation: water cooling.
- Second operation: filtering system.

Water Cooling

The water is cooled from 54°C to 25°C by a cooling tower (Figure III.3). This consists of three big cooling fans with a drip system.

Figure III.3. Water cooling system

Feed pumps for sand filters

Just before the sand filters, there are two high-pressure water pumps (Figure III.4).

Figure III.4. The sand filter feed pumps

Filtering system

To filter the cooled raw water, four sand filters (Figures III.5) will be used to remove suspended matter. Each filter is in fact composed of several layers of sand and carbon.

The sand filter is backwashed by stored filtered water.

Figure III.5. Sand filters

Pressure pump

Two high-pressure pumps are used to feed the reverse osmosis unit (one pump for each unit). The main characteristics of pressure pump are presented in table III.2.

Table III.2. High pressure pumps characteristics

Flow	**F= 25*2 m^3/h**
Manometric head	Hmt=153m
Pressure	P=10-12bar

Reverse Osmosis:

A sequestrant and sulphuric acid are injected to eliminate free chlorine and prevent the formation of limescale and algae in the osmosis system.

After the high-pressure pump, the feed water enters the membranes. The diaphragm assembly can be referred to as a single pressure vessel system or as a parallel pressure vessel system. These can be arranged as multiple modules in a multi-stage configuration (Figures III.6).

Figure III.6. Reverse osmosis modules at the station

Water physico-chemical analysis

Ouled Djellal Station is not equipped with a laboratory where water analysis should be conducted. For this reason, a sample of each of the three stages (raw water, treated water, and the rejected brine) will be analyzed in the LARHYSS lab.

Water samples

Water sampling at the demineralization station is carried out manually at three points:

1- At the outlet of the raw water reservoir.

2- At the reverse osmosis outlet.

3- At the discharge outlet.

Physico-chemical analyses

In the LARHYSS laboratory, the following parameters, pH, conductivity, sodium (Na^+), potassium (K^+), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulphates (SO_4^{2-}) and TAC were analyzed.

Conductivity

Electrical conductivity is a regularly used technique for determining a substance's ability to conduct electricity. Conductivity is directly proportional to the presence of ions in solution, making it a useful indication of water quality, dissolved salt levels, and other chemical characteristics (Rodier, 2005).

It was measured using a “Biobloc scientific LF 315” as shown in Figure III.7, electrical conductivity meter, giving measurements in µS/cm and mS/cm (Lakhdari, 2019).

Figure III.7. Conductivity meter used to measure the conductivity of water samples.

pH

The pH of a water represents its acidity or alkalinity, it is linked to the geological nature of the terrain crossed. The pH of the water samples was measured using a CONSORT instruments pH meter (P800) (Figure III.8).

Figure III.8. pH meter used in the tests.

The Complete Alkalimetric Title (TAC)

The TAC (Complete Alkalimetric Title) represents the basic character of water (HCO_3^- + CO_3^{2-} + OH^-). It is controlled by pH and the amount of bicarbonate HCO_3^- that can be measured by titration (Rodier, 2005).

A few drops of methyl orange are added to the water sample to be analyzed, followed by titration with sulfuric acid until the color changes from yellow to orange. The TAC is measured in milliequivalents per liter or French degree.

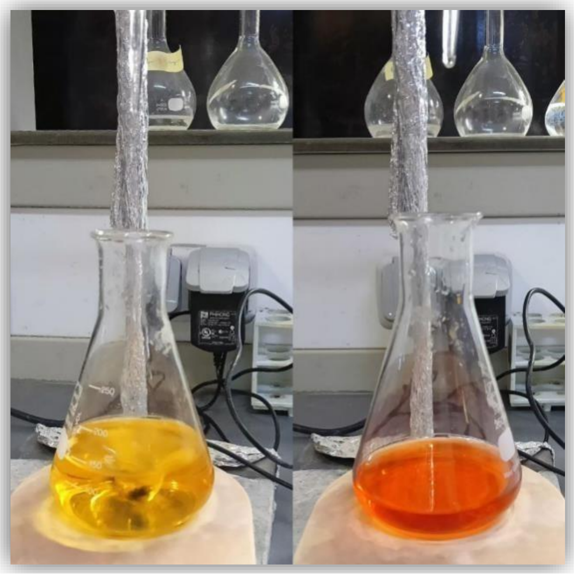


Figure III.9. Alcalinity determination

TH

Total hardness is naturally determined by the leaching of the earth and correlates with calcium and magnesium levels. This metric exhibits significant variance, which could be attributed to the lithological nature of the aquifer formation (Rodier, 2005).

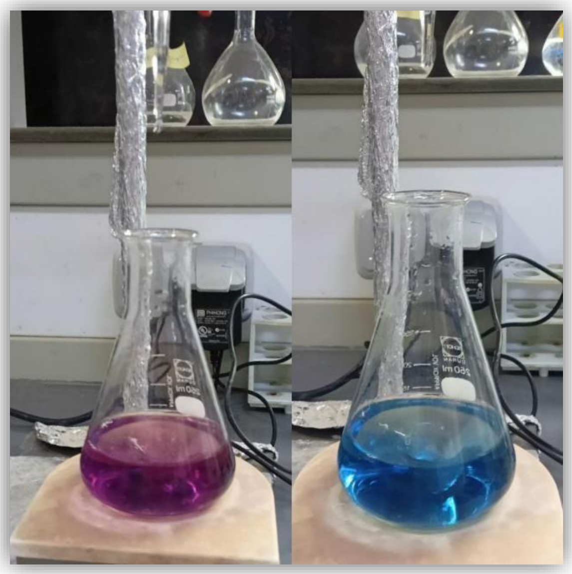


Figure III.10. TH determination

Place 100 ml (10 ml raw water + 90 ml distilled water) of the water to be analyzed in an Erlenmeyer flask and add 2 ml of the pH10 and the N.E.T (Eriochrome Black) color indicator. At this stage, titration with the E.D.T.A solution (0.02 N), by stirring until it turns blue, allows the TH to be measured (Figure III.10).

$TH = ((C_{E.D.T.A} \times V_{E.D.T.A}) \times V_{Sample}) / 1000$

C_{EDTA}: Normal value of the EDTA solution

V_{EDTA}: Volume in milliliters of EDTA solution used for the assay

Vs_{ample}: Volume, in milliliters, of sample assayed

Calcium

It is an important component of water hardness. It is typically the dominating element in drinking water. Its content varies significantly depending on the nature of the traveled land (Rodier, 2005).

Fill a burette with a standard EDTA solution and slowly add the EDTA solution to the water sample while continuously stirring. The EDTA binds with the calcium ions in the water to form a stable complex. Continue adding EDTA until a color change indicates that all the calcium ions have reacted. For instance, if using Eriochrome Black T, the solution will change from red to blue when all the calcium ions are chelated by the EDTA (Fig III.11).

Figure III.11. Calcium determination

Magnesium

Magnesium (Mg^{2+}) is a significant component of water's durability, causing unpleasant taste at concentrations of 100 mg/L. Its concentration in water depends on the makeup of the sedimentary rocks encountered. Its origins are similar to those of calcium, as it comes from the breakdown of carbonated rocks with high magnesium concentrations, such as magnesite and dolomite (Rodier, 2005).

Magnesium durability is calculated using the following formula:

$$\mathbf{Mg\ (mg/L) = (TH\ (meq/L) - Calcium\ (meq/L))*12}$$

Chloride

Water almost always contains chlorides but in varying amounts. The chloride ions originate from clay-like lenses in sedimentation. Their presence ingroundwater is caused by the dissolving of natural salts, specifically sylvite (KC) and halite (NaCl) (Rodier, 2005).

The method consists of measuring chlorides with silver nitrate in the presence of potassium chromate (Figure III.12). By silver nitrate, Cl- ions are mobilized to form silver chloride. When all the chloride ions have precipitated as AgCl, the silver nitrate reacts with the potassium chromate and a brick-red precipitate appears.

Figure III.12. Chloride determination

Sodium

Sodium Na^+ is the most dominant cation and is present in all waters because the solubility of its salts is very high. (Rodier, 2005)

Sulphate

Sulfates are natural compounds in water, linked to the major cations: calcium, potassium, and sodium. They mainly come from the dissolution of gypsum ($CaSO_4$, $2H_2O$) where the sulfides entrained oxidize into sulfates on contact with air (Rodier, 2005).

The assay was carried out on a “PALINTEST” photometer (Figure III.13) at a specific wavelength set on the “PALINTEST” photometer after the addition of a suitable reagent (Figure III.14) according to the instrument catalog.

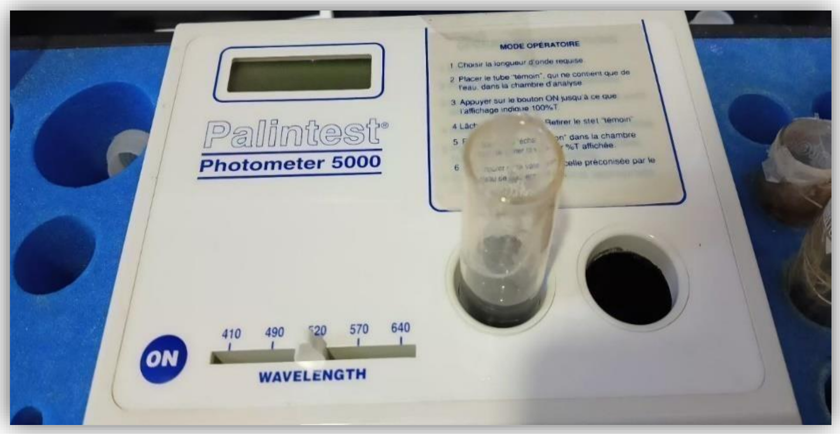


Figure III.13. photometer

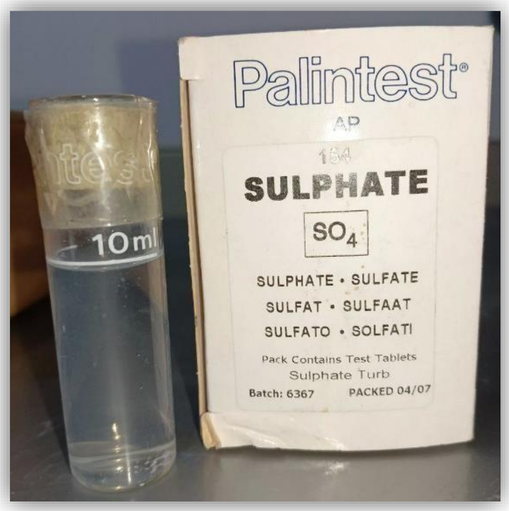


Figure III.14. Sulphate determination (via photometer)

Potassium

Potassium is the least abundant major element in water after sodium, calcium, and magnesium, ranking just third among cations. It is necessary for life, particularly vegetative growth. In agriculture, potassium is used as fertilizer in the form of sulfate, chloride, or nitrate (Rodier, 2005).

The operation method for Potassium is the same as that for Sulfate, but it uses a different wavelength. (Figure III.15)

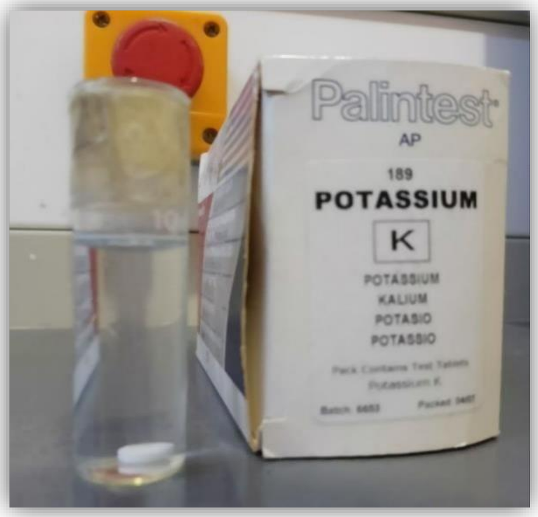


Figure III.15. Potassium determination (via spectrophotometer)

Results and discussion

After all the tests taken on “April 29th, 2024”, we can summarize the results in the table below:

Table III.3. Water characteristics through demineralization stages.

Characteristics	**Units**	**Untreated water**	**RO water**	**Brine**	**A.N**
pH	-	7.02	7.02	7.97	6.5-8.5
Conductivity	µs/cm	3230	696	6210	2800
TH	meq/L	76	8.5	116	25
TAC	meq/L	4.96	0.98	4.5	/
Ta	meq/L	0	0	0	/
Ca^{2+}	mg/L	736	80	1280	200
Mg^{2+}	mg/L	470.4	54	624	150
Na^+	mg/L	275	60	500	200
K^+	mg/L	44	8.2	53	20
Cl^-	mg/L	346.88	62.48	11199.62	500
HCO_3^-	mg/L	302.56	59.78	274.5	/
SO_4^{2-}	mg/L	1280	148	2400	400

According to table III.3 presenting the chemical characteristics of raw, treated, and brine water, one can notice that all raw water parameter contents are greater than Algerian drinking standards, except pH and chloride. Water with high conductivity and high total hardness is not enjoyable for consumption or use (bitter taste and scale deposit), so it must be treated to increase the acceptance to fit usage. One can also notice that total hardness (TH) is highly greater than TAC, which represents the temporal hardness. This means that permanent hardness (TH- TAC) related to chloride and sulfate, is present in this water with high level. In contrast, the treated water quality seems to be improved using demineralization processes. All treated water parameter concentrations fit Algerian drinking guidelines. It appears that the quality of treated water is similar to mineral water bottled and sold at supermarkets. Concerning the brine solution, the extraction of soft fresh water from the brackish water seems to concentrate the salts, the metals, and the chemicals added during the demineralization stages. According to the literature (IDA,2011), 78,45% of the TDS in the raw water has been rejected and remains in the brine.

- ***The Brine***

The demineralization station in question is currently releasing brine waste onto the surface without treatment or containment, a technique known as direct disposal. This method includes releasing concentrated brine, a byproduct of the demineralization process, straight into the environment.

Figure III.16. Demineralization by-product

III.3. Description of the drinking water production plant of El-Oued

Station “19 MARS OTHMEN GUEDIRI” is a demineralization station located in the wilaya of El Oued (Figure III.17). provided us with All statistics, data, and technical drawings were provided by the station's managers, in addition to the digital photographs that were taken to get a better idea of the facility. The “19 MARS OTHMEN GUEDIRI” desalination station (Figure III.18) is fully operational since April 2020, with a production capacity of 30000 m^3/j using reverse osmosis. This ensures a potable water supply as well as four other plants for the EL OUED commune, which has a population of approximately 198,700 people.

Figure III.17. Satellite image of the station

Figure III.18. "19 MARS OTHMEN GUEDIRI" Demineralization station

III.3.1 Geographical location

El Oued city is located in the center of the wilaya, south of the Chott Melrhir, 101 km north-east of Touggourt, 222 km from Biskra4, 212 km north-east of Ouargla, 700 km south-east of Algiers, and near the Algerian-Tunisian border3. It is the capital of Souf (Khaldi, 2005).

Figure III.19. Communes bordering El Oued

III.3.2 Description of the treatment process

a) The borehole

The demineralization plant in the town of EL OUED is supplied by three boreholes in the Albian aquifer:

- “ECHOUHADA”: Flow rate= 490m^3/h.
- “Route de Touggourt”: Flow rate = 485 m^3/h.
- “19 MARS”: Flow rate=300m^3/h.

The average water temperature for the three boreholes is 60°C.

b) Pre-treatment

Same as the previous station, we have two operations, a water cooling, and a filtration system.

<u>Water Cooling</u>

The water temperature will be reduced from 60°C to 30°C after passing through a two-cell cooling tower. It will have two counter-current ventilated cells. The tower outlet will be outfitted with a differential pressure flowmeter to monitor the flow of cooled water exiting the tower (Fig III.20).

Figure III.20. Cooling tower

Filtering System

Sand filter

Using sand and anthracite layers (Fig III.22), six pressure sand filters (Fig III.21) will be utilized for cooling raw water filtering in order to eliminate suspended solids. These horizontal filters have a metal floor with distribution nozzles and are made of gravel, sand, and anthracite. They have three manholes, strainers (50 units/m^2), and the required pipework. They run automatically for the production and backwash cycles at filtration rates of 10 to 15 mm/h, guaranteeing a low Silt Density Index (SDI) for feedwater used in reverse osmosis.

Wash pumps and air blowers are used to backwash with filtered water at a rate of 25 m^3/h, which can be manually operated or controlled via a PLC control. The filter material is loosened by pressurized air that is delivered counter currently, and the backwash effluent is sent into the brine tank.

Figure III.22. Sand filters

Figure III.21. Sand filter's layers sample

Mixing pump

Its job is to replenish the sand filters' water supply in order to adjust the 3+1 (three on and one standby) operating mode parameters (Figure III.23).

Figure III.23. Mixing pumps

Low-pressure supply pumps

Water filtered by four (3+1) 420 m3/h low-pressure feed pumps powers cartridge filters (Figure III.24).

Figure III.24. Low pressure supply pumps

Cartridge filters

Six units; each filter has 39 cartridges (figure III.27).

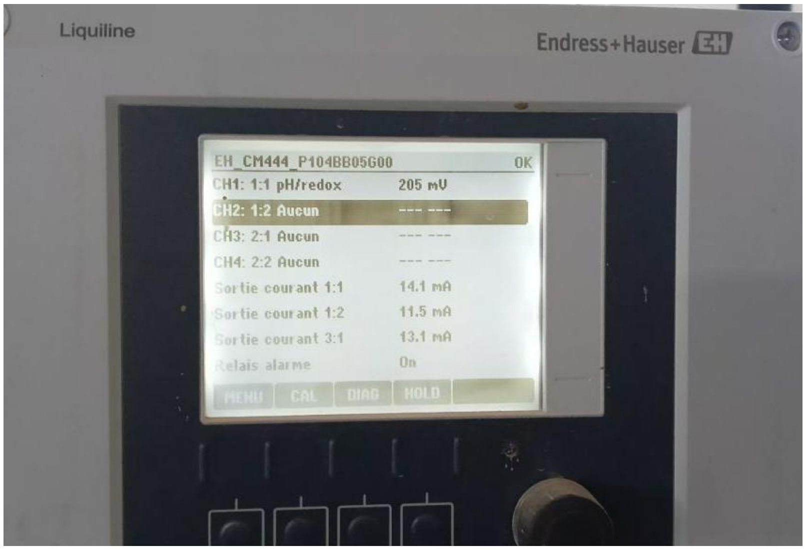
To prevent large particles or fine sand from entering the membrane system, a replaceable cartridge filter system is planned. The cartridges are composed of polypropylene filaments with a helicoidal enrollment and a nominal retention threshold of 5 microns. It is planned to have measurement stations for various operational parameters, such as temperature, pH, and redox potential, at the microfilters. (figure III.25)

A discharge valve located downstream of the microfilter can be opened to release the water until the membranes' operating conditions are restored following the demineralization unit's startup if the water quality isn't meeting their requirements.

- Before the cartridge filters there are two injection points:

Injection of sodium metabisulphite (SMBS) to eliminate free chlorine and injection of anti-scalant to prevent the formation of limescale and algae in the osmosis system. (figure III.26)

Figure III.27. A cartridge filter unit



```
EH_CM444_P104BB05G00          OK
CH1: 1:1 pH/redox             205 mV
CH2: 1:2 Aucun                --- ---
CH3: 2:1 Aucun                --- ---
CH4: 2:2 Aucun                --- ---
Sortie courant 1:1            14.1 mA
Sortie courant 1:2            11.5 mA
Sortie courant 3:1            13.1 mA
Relais alarme                 On
```

Figure III.25. Measuring point

Figure III.26. Injection points

High-pressure feed pumps

Four (3+1) high-pressure feed pumps to power the reverse osmosis machine (420 m^3/h) (Figure III.28).

Figure III.28. high-pressure feed pumps.

Reverse Osmosis

Reverse osmosis (Figure III.29) works by applying pressure to the solution to be desalinated. This pressure is greater than the osmotic pressure of the solution, due to the flow of water in the opposite direction across the semi-permeable membrane (from the salt water to the fresh water chamber). A reverse osmosis system consists of three lines, ventilated by position at average temperatures, with a total production capacity of 22500 m^3/d and a conversion rate of 75%.

Each reverse osmosis line is configured in two stages, depending on the proportion of pipes.The balance between the first and second stages is determined by a first-order pressure relief valve.The final product with three reverse osmosis lines mixed with filtered water is located on a tank with a capacity of 2 x 5000 m3. After mineralization, the mixture does not exceed 600 mg/l. Caustic soda is added for pH adjustment, and calcium hypochlorite for disinfectant injection. The process is simple, but presents a real problem in terms of membrane clogging, which requires extensive pre-treatment of the brackish water.

Figure III.29. The station's Reverse Osmosis plant

Post-treatment

The Mixing Principle

Osmosis water is not suitable for human consumption since it does not meet drinking water quality standards. As a result, partially extracted dissolved salts must be restored. This phase is known as remineralization. Remineralization can be done in two ways.

- By adding salts (lime, calcium carbonate, etc.) into the RO water.
- By combining some of the pre-treated water with the osmotic water.

Treated water pumping station

The pumps (Figure III.30) supplying 11 water towers (Figure III.31).

Figure III.30. Treated water pumps

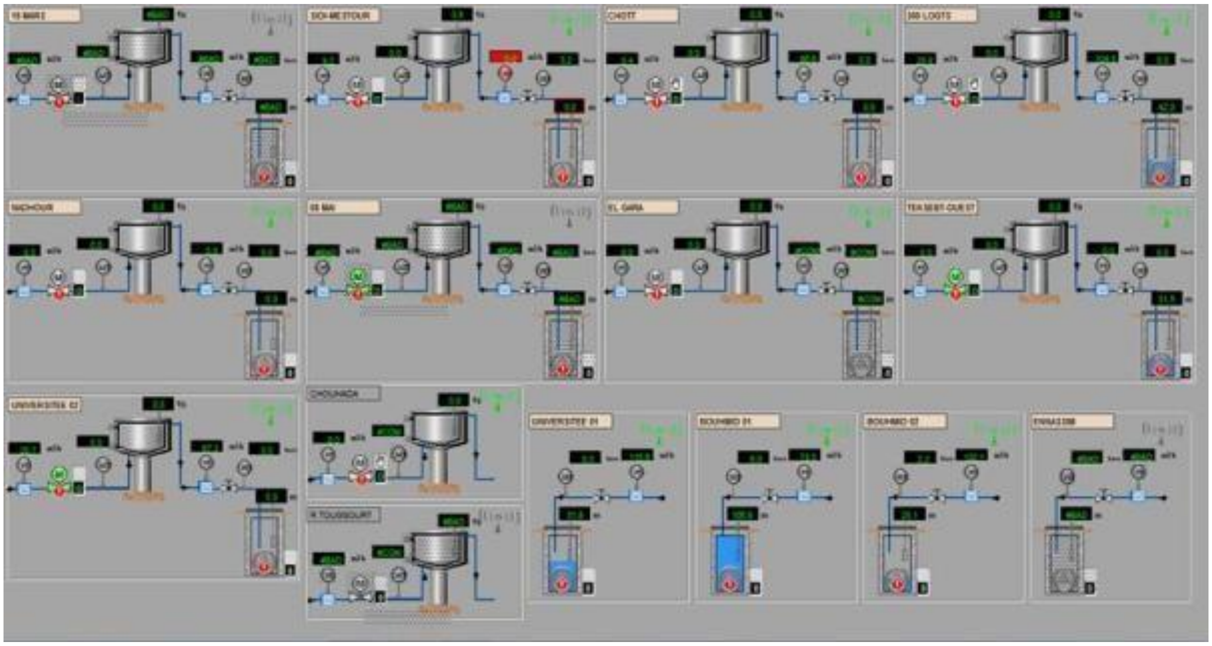


Figure III.31. Water towers supplied by the station.

Discharge evacuation station

Description of the discharge station:

The discharge station consists of (3+1) pumps. A 250 m^3 discharge tank (Figure III.32).

Figure III.32. Discharge pumps

III.3.3 Physico-chemical treatment

Following our one-day visit to the station, we were only able to obtain past water analysis results (Annex).The results are from May 2023.

Table III.4. El-Oued station water analysis

Characteristics	Units	Untreated water	RO water	Brine	A.N
pH	-	7.43	7.9	7.74	6.5-8.5
Conductivity	µs/cm	2730	1072	9703	2800
TH	meq/L	18.24	6.56	68.2	25
TAC	meq/L	4.39	0.19	6.45	/
Ta	meq/L	0	0	0	/
Ca^{2+}	mg/L	179.55	57.71	845.68	200
Mg^{2+}	mg/L	112.75	44.72	313	150
Na^{+}	mg/L	/	/	/	200
K^{+}	mg/L	/	/	/	20
Cl^{-}	mg/L	795.2	305.3	/	500
HCO_3^{-}	mg/L	268.4	122	701.5	/
SO_4^{2-}	mg/L	464	332	2400	400

According to table III.4, which displays the chemical characteristics of raw, treated, and brine water, one can remark that El-Oued plant feed water parameter contents are less than Algerian drinking standards, except for chlorides and sulfates. Water with a conductivity of 2730 µs/cm and a total hardness of 18,24 is not pleasant for consumption or use (bitter taste and scale deposit); improving its quality seems to be required. In contrast, demineralization methods appear to increase the quality of treated water. All treated water parameter concentrations are within Algerian drinking guidelines. The grade of treated water looks to be equivalent to mineral water bottled and sold in supermarkets. Regarding the brine solution, the extraction of soft fresh water from the brackish water appears to concentrate the salts, metals, and compounds added throughout the demineralization steps.

III.3.4 The Brine

The station disposes of its demineralization by-products through sewer discharge. This method involves channeling the waste directly into the sewer system. While it offers a straightforward disposal solution, it requires careful monitoring to ensure compliance with environmental regulations. This practice can have significant implications for wastewater treatment processes.

III.4. Comparison and comments

Table III.5. Demineralization plants characteristics assembly

		Ouled djellal plant			EL-Oued plant			
Characteristics	**Units**	**Untreatd water**	**RO water**	**Brine**	**Untreated water**	**RO water**	**Brine**	AN
pH	-	7.02	7.02	7.97	7.43	7.9	7.74	6.5-8.5
Conductivity	µS/cm	3230	696	6210	2730	1072	9703	2800
TH	meq/L	76	8.5	116	18.24	6.56	68.2	25
TAC	meq/L	4.96	0.98	4.5	4.39	0.19	6.45	/
Ta	meq/L	0	0	0	0	0	0	/
Ca^{2+}	mg/L	736	80	1280	179.55	57.71	845.68	200
Mg^{2+}	mg/L	470.4	54	624	112.75	44.72	313	150
Na^{+}	mg/L	275	60	500	/	/	/	200
K^{+}	mg/L	44	8.2	53	/	/	/	20
Cl^{-}	mg/L	346.88	62.48	11199.62	795.2	305.3	/	500
HCO_3^{-}	mg/L	302.56	59.78	274.5	268.4	122	701.5	/
SO_4^{2-}	mg/L	1280	148	2400	464	332	2400	400

The comparative analysis of the two desalination stations provides insights into their operational efficiency, treatment effectiveness, and brine management practices. The following sectionsdetail the differences and similarities between the two stations based on their water samples. The comparative analysis of the two desalination stations provides insights into their operational efficiency, treatment effectiveness, and brine management practices. Examining table III.4, we can notice the following:

- Both brackish water chemical parameter concentrations exceeded Algerian drinkingwater standards.
- It appears also that all Ouled Djellal raw water parameter contents, such as conductivity, TH, Ca^{2+}, Mg^{2+}, HCO_3^-, and SO_4^{2-}, are greater than El-Oued raw water ones, except chloride (Cl^-).
- After demineralization processes, it seems that both treated water parameters are adequate with Algerian drinking standards, and some Ouled Djellal treated water parameters became less than El-Oued treated water ones, such as HCO_3^-, SO_4^{2-}, and Cl^-.
- One can also notice that Ouled Djellal-treated water is softer than El-Oued-treated water.
- The same remark can be noticed concerning the conductivity.
- Comparing the treatment effectiveness of the two stations is challenging because the first station provided osmotically treated water without any further remineralization, whereas the second station required additional laboratory adjustments to make the water potable. This difference in treatment processes makes a direct comparison between the stations' performance difficult.
- The brine from both stations is highly concentrated. The second station's brine has particularly high conductivity and total hardness, indicating the need for advanced brine management.
- **Operational Differences**: Differences in raw water chemistry significantly affect treatment outcomes. The second station faces greater challenges due to higher initial concentrations of bicarbonates and total hardness.
- **Management Practices**: Effective brine disposal and treatment are critical. The second station, with more concentrated brine, highlights the necessity for innovative brine management strategies.

Disposing of brine directly into the environment poses significant risks such as harming aquatic ecosystems, reducing biodiversity, and contaminating soil and freshwater resources. In contrast, discharging brine into the sewage system can lead to infrastructure corrosion, overloading of treatment plants, and potential non-compliance with regulatory standards. While both methods have severe drawbacks, discharging into the sewage system can at least offer some level of treatment, albeit insufficient, compared to direct environmental discharge which can cause more immediate and widespread ecological damage. Sustainable brine management strategies are essential to mitigate these issues.

III.5. Conclusion

In this chapter, two different stations that utilize the same demineralization system, but manage their by-products in distinct ways, were observed. El-Oued station opts for sewer discharge to dispose of its waste, while Ouled Djellal plant employs a surface disposal method. This comparison highlights the diverse approaches to handling demineralization by-products and underscores the environmental and regulatory implications of each method.

General Conclusion

General Conclusion

This study investigated brackish water demineralization processes for producing fresh water in order to address water shortages, in addition to the management of demineralization by product(brine). The thesis is structured into three main chapters. The first chapter presented an overview of desalination and demineralization in addition to brine management, including saltwater types, the definition and history of desalination, water desalination plants, desalination technologies, andbrine management techniques. The second chapter concerned desalination and demineralization in Algeria. The core chapter of this study is chapter three, which discusses the brackish water demineralization plants of Ouled Djellal and El-Oued.

Two brackish water demineralization plants, Ouled Djellal and El-Oued, were presented and compared. Both brackish water chemical parameter concentrations exceeded Algerian drinking water standards. It appears also that all Ouled Djellal raw water parameter contents, such as conductivity, TH, Ca^{2+}, Mg^{2+}, HCO_3^-, and SO_4^{2-}, are greater than El-Oued raw water ones, except chloride (Cl^-). After demineralization processes, it seems that both treated water parameters are adequate with Algerian drinking standards, and some Ouled Djellal treated water parameters became less than El-Oued treated water ones, such as HCO_3^-, SO_4^{2-}, and Cl^-. One can also notice that Ouled Djellal-treated water is less hard than El-Oued-treated water.

Concerning brine management, the Ouled Djellal demineralization plant is currently releasing brine waste into the environment without treatment or containment, a technique known as direct disposal. This method includes releasing concentrated brine, a byproduct of the demineralization process, straight into the environment. In contrast, the El-Oued plant approach to brine management involved rejecting the brine through sewers as wastewater in order to be treated via a wastewater treatment plant (WWTP). Even this type of management may negatively affect the efficiency of WWTP, especially those based on biological treatment.

However, it is important to note that brine recovery and reuse are not currently practiced in the country. As a result, brine is simply discarded as waste without any attempts at resource recovery or recycling. This highlights a critical area for improvement, as adopting brine recovery and reuse strategies could significantly enhance the sustainability and environmental responsibility of desalination operations.

A key finding of this research is the lack of brine recovery and reuse strategies within the country. Current practices result in brine being discarded as waste, which not only represents a lost opportunity for resource recovery but also poses substantial environmental risks. This thesis underscores the necessity for adopting innovative solutions for brine management, including the potential for recycling and resource extraction from brine.

In conclusion, addressing the environmental impact of brine disposal is crucial for the sustainable expansion of desalination technology. The findings of this thesis advocate for the development and implementation of effective brine management strategies, regulatory frameworks, and technological innovations that can transform brine from a waste product into a valuable resource.

Study limitation

One can notice that the title of the study does not greatly match the content of the dissertation because, in the beginning, the student planned to visit study, Zeralda desalination plant (the only plant that sends its by-product for industrial re-use), which releases massive amounts of brine, and try to figure out its management. Unfortunately, she was unable to do this because of administrative issues; at the end, the study was limited to brackish water demineralization

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Annexes

Nature de l’échantillon :Eau rejet

Lieu de prélèvement : Station el oued **Date d’analyse : 03/05/2023**

Commune: EL-oued

Paramètres Organoleptiques	**Unité**	**Résultat**	**N.A (E.T)**	**Minéralisation Globale**	**Unité**	**Résultat**	**N.A (E.T)**
Couleur	mg/l platine	-	15	Calcium (Ca^{++})	mg/l	**845.688**	200
Odeur à 25 °C	Taux dilution	-	04	Magnésium (Mg^{++})	mg/l	**313.534**	--
Saveur à 25 °C	Taux dilution	-	04	Dureté totale (TH)	mg/l $CaCO_3$	**3410**	500
Chlore résiduel libre	mg /l		>0,1	Sodium (Na^+)	mg/l	-	200
Paramètres Physico-Chimiques	**Unité**	**Résultat**	**N.A (E.T)**	Potassium (K^+)	mg/l	-	12
Concentration en ions hydrogène	Unité pH	**7.74**	≥ 6,5 et ≤ 9	Chlorures (Cl^-)	mg/l	**1283.398**	500
Conductivité à 25°C	µS/cm	**9307**	2800	Sulfates (SO_4^{2-})	mg/l		400
Température	°C	**28.6**	25	Nitrates (NO_3^-)	mg/l	**2.968**	50
Turbidité	NTU	**0.339**	5	Bicarbonate (HCO_3^-)	mg/l	**406.26**	--
Oxygène dissous	mg/l		--	Titre Alcalimétrique Complet (TAC)	mg/l $CaCO_3$	**333**	--
T D S	mg/l	**5956**	--	Slica (SiO_2)	mg/l	-	
Résidu sec à 105°C	mg/l	**7420**	--				
Paramètres de pollution	**Unité**	**Résultat**	**N.A (E.T)**	**Paramètres Indésirables**	**Unité**	**Résultat**	**N.A (E.T)**
Ammonium (NH_4^+)	mg/l	**0.444**	0.5	Fer	mg/l	-	0.3
Nitrites (NO_2^-)	mg/l	**0.059**	0.2	Manganese	mg/l	-	0.05
Orthophosphate (PO^{-3}_4)	mg/l		5	Aluminium	mg/l	-	0.2
Oxydabilité	mg/l	-	5				
Paramètres Bactériologiques	**Unité**	**Résultat**	**N.A (E.T)**	**Paramètres ioniques**	**Unité**	**Résultat**	**N.A (E.T)**
Coliformes totaux	/	**ABS**	/	Fluorures (F^-)	mg/l	-	1,5
Escherichia Coli	n/100ml	**ABS**	00	Cyanures (CN^-)	µg/l	-	70
Entérocoques	n/100ml	**ABS**	00	Bromures (Br^-)	mg/l	-	--
Bactéries sulfito-réductrices	n/20ml	**ABS**	00	Sulfure d’hydrogène (H_2S)	mg/l	-	--
Observation							

Nature de l'échantillon :Eau brute

Lieu de prélèvement : Station el oued **Date d'analyse : 03/01/2023**

Commune: EL-oued

Paramètres Organoleptiques	**Unité**	**Résultat**	**N.A (E.B)**		**Minéralisation Globale**	**Unité**	**Résultat**	**N.A (E.B)**	
			SURF	**SOUT**				**SURF**	**SOUT**
Couleur	mg/l Echelle Pt-co	-	200	20	Calcium (Ca^{++})	mg/l	**179.558**	--	--
Odeur à 25 °C	-	-	20	3	Magnésium (Mg^{++})	mg/l	**112.75**	--	--
Paramètres Physico-Chimiques	**Unité**	**Résultat**	**N.A (E.B)**		Dureté totale (TH)	mg/l $CaCO_3$	**912**	--	--
			SURF	**SOUT**					
Concentration en ions hydrogène	Unité pH	**7.43**	≥ 6,5 et ≤ 9		Sodium (Na^+)	mg/l	**-**	--	--
Conductivité à 25°C	µS/cm	**2730**	2800		Potassium (K^+)	mg/l	**-**	--	--
Température	°C	**51.4**	25		Chlorures (Cl^-)	mg/l	**795.2**	600	500
Turbidité	NTU	**0.985**	--		Sulfates (SO_4^{2-})	mg/l	**464**	400	400
Oxygène dissous	mg/l	-	30	>70	Nitrates (NO_3^-)	mg/l	**0.9**	50	50
Résidu sec à 105°C	mg/l	**1329**	..	..	Bicarbonates (HCO_3^-)	mg/l	**268.4**	--	--
Taux De Salinité (TDS)	mg/l	**2109**	--		Titre Alcalimétrique Complet (TAC)	mg/l $CaCO_3$	**220**	--	--
Paramètres de pollution	**Unité**	**Résultat**	**N.A (E.B)**		**Paramètres Indésirables**	**Unité**	**Résultat**	**N.A (E.B)**	
			SURF	**SOUT**				**SURF**	**SOUT**
Ammonium (NH_4^+)	mg/l	-	4	0.5	Fer	mg/l	**0.237**	1	0.3
Nitrites (NO_2^-)	mg/l	**0.010**	--		Manganese	mg/l	-	1	0.05
Orthophosphate (Po^{-3}_4)	mg/l	-	10	5	**Paramètres ioniques**	**Unité**	**Résultat**	**N.A (E.B)**	
Matières Organiques	mg/l	**-**	--					**SURF**	**SOUT**
Demande Biochimique en Oxygène (DBO_5)	mg/l O_2	**-**	7	< 3	Fluorures (F^-)	mg/l	-	2	1,5
Demande Chimique en Oxygène (DCO)	mg/l O_2	**-**	30	--	Cyanures (CN^-)	µg/l	-	100	50
Azote Total Kjeldhal (NTK)	mg/l	**-**	3	1	Bromures (Br^-)	mg/l	-	--	--
Paramètres Bactériologiques	**Unité**	**Résultat**	**N.A (E.B)**		Iodures (I^-)	mg/l	**-**	**--**	**--**
			SURF	**SOUT**					
Coliformes totaux	/	**00**	/		Sulfure d'hydrogène (H_2S)	mg/l	**-**	**--**	**--**
Escherichia Coli	n/100 ml	**00**	20.000	20					
Entérocoques	n/100 ml	**00**	10.000	20					
Observation									

Nature de l'échantillon :Eau Traitée
Lieu de prélèvement : Station el oued **Date d'analyse : 03/01/2023**
Commune: EL-oued

Paramètres Organoleptiques	**Unité**	**Résultat**	**N.A (E.T)**	**Minéralisation Globale**	**Unité**	**Résultat**	**N.A (E.T)**
Couleur	mg/l platine	-	15	Calcium (Ca^{++})	mg/l	**57.71**	200
Odeur à 25 °C	Taux dilution	-	04	Magnésium (Mg^{++})	mg/l	**44.72**	--
Saveur à 25 °C	Taux dilution	-	04	Dureté totale (TH)	mg/l $CaCO_3$	**328**	500
Chlore résiduel libre	mg /l	**0.97**	>0,1	Sodium (Na^+)	mg/l	-	200
Paramètres Physico-Chimiques	**Unité**	**Résultat**	**N.A (E.T)**	Potassium (K^+)	mg/l	-	12
Concentration en ions hydrogène	Unité pH	**.790**	≥ 6,5 et ≤ 9	Chlorures (Cl^-)	mg/l	**305.3**	500
Conductivité à 25°C	µS/cm	**1072**	2800	Sulfates (SO_4^{2-})	mg/l	**332**	400
Température	°C	**24.6**	25	Nitrates (NO_3^-)	mg/l	**0.8**	50
Turbidité	NTU	**0.52**	5	Bicarbonate (HCO_3^-)	mg/l	**122**	--
Oxygène dissous	mg/l	-	--	Titre Alcalimétrique Complet (TAC)	(°F)$CaCO_3$	**10**	--
T D S	mg/l	**590**	--	Silica (SiO_2)	mg/l	**11.6**	
Résidu sec à 105°C	mg/l	**308**	--				
Paramètres de pollution	**Unité**	**Résultat**	**N.A (E.T)**	**Paramètres Indésirables**	**Unité**	**Résultat**	**N.A (E.T)**
Ammonium (NH_4^+)	mg/l	-	0.5	Fer	mg/l	**0.220**	0.3
Nitrites (NO_2^-)	mg/l	**0.004**	0.2	Manganese	mg/l	-	0.05
Orthophosphate (Po^{-3}_4)	mg/l		5	Aluminium	mg/l	-	0.2
Oxydabilité	mg/l	-	5				
Paramètres Bactériologiques	**Unité**	**Résultat**	**N.A (E.T)**	**Paramètres ioniques**	**Unité**	**Résultat**	**N.A (E.T)**
Coliformes totaux	/	**ABS**	/	Fluorures (F^-)	mg/l	-	1,5
Escherichia Coli	n/100ml	**ABS**	00	Cyanures (CN^-)	µg/l	-	70
Entérocoques	n/100ml	**ABS**	00	Bromures (Br^-)	mg/l	-	--
Bactéries sulfito-réductrices	n/20ml	**ABS**	00	Sulfure d'hydrogène (H_2S)	mg/l	-	--
Observation							

ANNEXE

PARAMETRES DE QUALITE DE L'EAU DE CONSOMMATION HUMAINE

Tableau 1 : PARAMETRES AVEC VALEURS LIMITES

GROUPE DE PARAMETRES	PARAMETRES	UNITES	VALEURS LIMITES
Paramètres chimiques	Aluminium	mg/l	0,2
	Ammonium	mg/l	0,5
	Baryum	mg/l	0,7
	Bore	mg/l	1
	Fer total	mg/l	0,3
	Fluorures	mg/l	1,5
	Manganèse	µg/l	50
	Nitrates	mg/l	50
	Nitrites	mg/l	0,2
	Oxydabilité	mg/l O2	5
	Phosphore	mg/l	5
	Acrylamide	µg/l	0,5
	Antimoine	µg/l	20
	Argent	µg/l	100
	Arsenic	µg/l	10
	Cadmium	µg/l	3
	Chrome total	µg/l	50
	Cuivre	mg/l	2
	Cyanure	µg/l	70
	Mercure	µg/l	6
	Nickel	µg/l	70
	Plomb	µg/l	10
	Sélénium	µg/l	10
	Zinc	mg/l	5

ANNEXE (suite)

GROUPE DE PARAMETRES	PARAMETRES	UNITES	VALEURS LIMITES
Paramètres chimiques	Hydrocarbures polycycliques aromatiques (H.P.A) totaux fluoranthène, benzo (3,4) fluoranthène, benzo (11,12) fluoranthène, benzo (3,4) pyrène, benzo (1,12) pérylène, indéno (1 ,2,3-cd) pyrène. benzo (3,4) pyrène	µg/l µg/l	0,2 0,01
	Hydrocarbures dissous ou émulsionnés extraits au CCl_4	µg/l	10
	Phénols	µg/l	0,5
	Benzène	µg/l	10
	Toluène	µg/l	700
	Ethylbenzène	µg/l	300
	Xylènes	µg/l	500
	Styréne	µg/l	100
	Agents de surface réagissant au bleu de méthylène	mg/l	0,2
	Epychlorehydrine	µg/l	0,4
	Microcystine LR	µg/l	0,1
	Pesticides par substance individualisée - Insecticides organochlorés persistants, organophosphorés et carbamates, les herbicides, les fongicides, les P.C.B. et PC.T à l'exception de aldrine et dieldrine	µg/l	0,1 0,03
	Pesticides (Totaux)	µg/l	0,5
	Bromates	µg/l	10
	Chlore	mg/l	5
	Chlorite	mg/l	0,07
	Trihalométhanes (THM) (Total) Chloroforme, Bromoforme, Dibromochlorométhane, Bromodichlorométhane	µg/l	100

ANNEXE (suite)

GROUPE DE PARAMETRES	PARAMETRES	UNITES	VALEURS LIMITES
Paramètres chimiques (suite)	Chlorure de vinyle	µg/l	0,3
	1,2 - Dichloroéthane	µg/l	30
	1,2 - Dichlorobenzène	µg/l	1000
	1,4 - Dichlorobenzène	µg/l	300
	Trichloroéthylène	µg/l	20
	Tetrachloroéthylène	µg/l	40
Radionucléides	Particules alpha	Picocurie/l	15
	Particules béta	Millirems/an	4
	Tritium	Bequerel/l	100
	Uranium	µg/l	15
	Dose totale indicative (DTI)	(mSv/an)	0,1
Paramètres microbiologiques	Escherichia Coli	n/100ml	0
	Entérocoques	n/100ml	0
	Bactéries sulfitoréductrices y compris les spores	n/20ml	0

Tableau 2 : PARAMETRES AVEC VALEURS INDICATIVES

GROUPE DE PARAMETRES	PARAMETRES	UNITES	VALEURS INDICATIVES
Paramètres organoleptiques	Couleur	mg/l Platine	15
	Turbidité	NTU	5
	Odeur à 12°C	Taux dilution	4
	Saveur à 25°C	Taux dilution	4
Paramètres physico-chimiques en relation avec la structure naturelle des eaux	Alcalinité	mg/l en CaC03	500
	Calcium	mg/l en CaC03	200
	Chlorures	mg/l	500
	Concentration en ions hydrogène	Unité pH	≥ 6,5 et ≤ 9
	Conductivité à 20°C	µS/cm	2800
	Dureté	mg/l en CaC03	200
	Potassium	mg/l	12
	Résidu sec	mg/l	1500
	Sodium	mg/l	200
	Sulfates	mg/l	400
	Température	°C	25