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Theme

Reverse Osmosis

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Defended on 25/06/2025 before the jury composed of:

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I thank God Almighty for His infinite blessings, His constant guidance that illuminates my path, and the countless blessings He has bestowed upon me at every stage of this journey.

This work is dedicated with gratitude and affection to my dear parents. Their unwavering support, silent sacrifices, constant encouragement, and the education they provided me are the very foundations of the individual I am today. This work is the result of their passion and mutual trust.

This dedication is dedicated to my dear brother. The presence of the subject in question, the wise advice offered, the attentive listening, and the unwavering support have been a great comfort and a precious motivation throughout this journey. The recipient's consistent presence is acknowledged and appreciated.

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Dedication

I dedicate this work, the fruit of my hard work and perseverance, to my dear parents, my support and help in life, and the source of endless love and giving. Without your sincere prayers and great sacrifices, this achievement would not have been possible.

To my brother, my companion and loyal friend, whom I thank for his constant support and encouragement.

To the pure souls of my departed ancestors, whose fragrant memory continues to illuminate my path and inspire me with wisdom and patience.

To the soul of my dear friend who has departed from our world, your pure memory will remain engraved deep within me and forever inspire me.

I extend my sincere thanks and gratitude to everyone who supported me and prayed for my success in my career. Your prayers have been my sustenance on this educational journey.

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RO	Reverse osmosis
UCLA	University of California, Los Angeles
Ie	is a Latin abbreviation that stands for "id est," which translates to "that is" or "in other words."
Eg	is a Latin abbreviation, and it stands for "exempli gratia," which means "for example.
MED	Multi-effect distillation
C°	Degrees celsius
m^3	Cubic meter
MSF	Multi-flash distillation
bar	Baros it a Greek word means weight
Q_p	Flow of permeate
Q_c	Flow of concentrate
USA	United States of America
ERI	Industrial water
BRM	Membrane bioreactor
nm	Nanometer
µm	Micrometer
mm	Millimeter
Km	Killometer
mce	Meters of water column
pH	Potential hydrogen
SDI	Salt density index
m	Meter
ppm	Parts per million
Px	Pressure exchanger
TDS	Total dissolved solids
LSI	Langelier saturation index
ADE	Algerian Water Company
CIP	Clean in place
min	Minute
h	Hour
sec	Seconde
TH	Total hardness
EDTA	Ethylenediaminetetraacetic acid
EBT	Eriochrome black T
NTU	Nephelometric Turbidity Unit
WHO	World Health Organization

ملخص

يُمثل التناضح العكسي تقنيةً محوريةً لمعالجة المياه، وتزداد أهميتها في ظل التحديات التي يفرضها تناقص هطول الأمطار وندرة موارد المياه العذبة. تدفع هذه الظروف البحث عن حلول مستدامة، ولذلك يُنظر في تحلية مياه البحر وهي موردٌ يكاد يكون غير محدود. تتضمن عملية التناضح العكسي تطبيق ضغط عالٍ على مياه البحر، ثم تُعرَّض لغشاء شبه نفاذ يتميز بمسام دقيقة للغاية. صُمم هذا الغشاء للسماح بنفاذ جزيئات الماء النقي فقط، مع الاحتفاظ بالأملاح والمعادن والملوثات الأخرى بشكل انتقائي. تتميز المياه الناتجة بنضارتها ونقائها، مما يجعلها مناسبةً لتطبيقات متنوعة بما في ذلك مياه الشرب والزراعة والاستخدام الصناعي. وبالتالي، يُعد التناضح العكسي استراتيجيةً محوريةً لضمان الأمن المائي، لا سيما في الدول التي تُعاني من ندرة المياه، كما هو الحال في الجزائر والمناطق الأخرى المتأثرة بالجفاف وتغير المناخ.

الكلمات المفتاحية :التناضح العكسي**,**تحلية مياه البحر**,**الأغشية .

Summary

Reverse osmosis represents a pivotal water treatment technology, its importance being compounded by the challenges posed by diminishing rainfall and the scarcity of freshwater resources. These conditions drive the search for sustainable solutions, which is why desalination of seawater, a virtually unlimited resource, is being considered. The reverse osmosis process entails the application of high pressure to seawater, which is then subjected to a semi-permeable membrane characterised by exceedingly fine pores. This membrane has been engineered to permit the permeation of pure water molecules alone, while selectively retaining salts, minerals, and other contaminants. The resultant water is characterised by its freshness and purity, making it suitable for various applications including drinking water agriculture, and industrial use. Consequently, reverse osmosis is a pivotal strategy in ensuring water security, particularly for countries grappling with water scarcity, as evidenced by Algeria and other regions affected by drought and climate change.

Keywords: Reverse osmosis,seawater desalination,membranes.

Résumé

L'osmose inverse représente une technologie essentielle de traitement de l'eau, son importance étant renforcée par les défis posés par la diminution des précipitations et la raréfaction des ressources en eau douce. Ces conditions incitent à la recherche de solutions durables, c'est pourquoi le dessalement de l'eau de mer, une ressource quasi illimitée, est envisagé. Le procédé d'osmose inverse consiste à appliquer une haute pression à l'eau de mer qui est ensuite soumise à une membrane semi-perméable aux pores extrêmement fins. Cette membrane a été conçue pour permettre la perméation des molécules d'eau pure, tout en retenant sélectivement les sels, les minéraux et autres contaminants. L'eau ainsi obtenue se caractérise par sa fraîcheur et sa pureté, la rendant adaptée à diverses applications notamment l'eau potable, l'agriculture et l'industrie. Par conséquent, l'osmose inverse est une stratégie essentielle pour garantir la sécurité hydrique, en particulier pour les pays confrontés à une pénurie d'eau, comme en témoignent l'Algérie et d'autres régions touchées par la sécheresse et le changement climatique.

Mots clés : Osmose inverse,dessalement de l'eau de mer,membranes.

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General introduction

Water is widely regarded as one of the most significant renewable natural resources on the planet. Its chemical stability is perhaps its most notable characteristic, in that the quantities of water on the earth's surface have remained relatively constant for many centuries. Current estimates put the total volume of water on the planet at around 1360 billion cubic meters (m^3). It is estimated that 97% of this volume is in the seas and oceans, with the remaining 2% found as ice sheets. The hydrological cycle, which involves the movement of water between different phases, is a crucial factor in the transformation of salt water into fresh water. It is estimated that 875 billion cubic meters (m^3) of water evaporates from water surfaces every day due to the thermal energy that reaches the earth with the sun's rays. The wind moves the moist air filled with steam to other places with lower temperatures, where it condenses again and falls as rain and snow, thus compensating for the part that humans consume [1].

Algeria's water resources are categorised as follows:

- Surface resources, which include 17 water basins located in three groups: the Mediterranean basins, the High Plains basins, and the Saharan basins. These basins contain 12.7 billion cubic meters per year.
- Underground resources, including the renewable reservoirs of northern Algeria and the basins of the poorly recharged desert regions. These reservoirs comprise 9.3 billion cubic meters per year.

Algeria’s water resources, amounting to 17.25 billion cubic meters, satisfy 4.36 billion cubic meters of the country’s water needs. The primary source of water in Algeria is rainfall, of which 13.50 billion cubic meters are accounted for by surface runoff. The second most significant source of water for the sea is groundwater [2].

It is important to acknowledge that many regions of the Arab world are confronted with challenges related to water scarcity, largely due to their geographical location within the arid and semi-arid regions of the globe. As the population in the Arab world grows, it is reasonable to assume that the issue of scarcity will be exacerbated as a logical consequence of the increasing demand for water to meet domestic, industrial, and agricultural needs.

It is understood that reverse osmosis desalination technology involves the separation of salts from water without any change in its natural (physical) state. It is believed that this is achieved by using semi-permeable membranes that allow the passage of small water molecules but do not allow the passage of relatively large salt molecules.

It is fair to say that Reverse Osmosis (RO) technology has become a common feature in desalination processes involving groundwater and seawater. There is no doubt that this process has attracted increased global attention in recent times due to its ease of operation and low costs, as well as the continuous progress in the production of effective RO membranes. It is estimated that approximately 30% of the world's desalination plants are currently operating with this technology. The first laboratory beginnings of reverse osmosis desalination were in 1953, followed by the development of cellulose acetate membranes at UCLA in 1960 and 1965 saw the emergence of commercial reverse osmosis water purification units on the market, and the reverse osmosis desalination industry underwent a major leap after the commercial availability of hollow microfiber reverse osmosis units and spiral-wound units in 1976 [1].

Our work is structured into four main chapters. The first chapter is titled "Desalination Techniques", where we present and compare the most commonly used methods for seawater desalination. The second chapter focuses on a detailed description of the desalination plant and the process used, with emphasis on reverse osmosis technology. In the third chapter, we explain the materials and methods applied during our study, including the tools, procedures and sampling techniques. The fourth chapter presents the results and discussion, where we analyze the findings, interpret the data, and assess the quality of the produced water in light of World Health Organization standards. Finally, the work concludes with a general conclusion that summarizes the main results and highlights the key points of our study.

CHAPTER I

DESALINATION TECHNIQUES

I.1- Introduction

Algeria faces severe water scarcity, especially in coastal areas, due to factors like population growth and climate change. Seawater desalination is emerging as a key solution to provide potable water. A study assesses the feasibility, technological advancements, environmental impacts, and socio-economic aspects of desalination, focusing on sustainable and energy-efficient methods to address water security challenges in Algeria [3].

I.2- Definition of desalination

Water desalination, also referred to as desalting or desalination, is a process that enables the production of potable water from brackish or salty water sources, with seawater being a primary example. The fundamental premise is that sourcing water for treatment (surface water, e.g., lakes and rivers, or groundwater) is more straightforward and cost-effective than desalination.

However, in many regions of the world, including Algeria, freshwater resources are limited. Consequently, the desalination of seawater is the prevailing choice [4].

I.3- Water desalination

I.3.1- Seawater

The most essential characteristic of seawater is its salinity, i.e., its overall salt content(sodium and magnesium chlorides, sulphates, and carbonates). The salinity of seas open to the ocean masses (Atlantic, Channel, North Sea, Pacific) is of the order of 35 $g.L^{-1}$,which is considered to be the standard salinity of seawater. It is acknowledged that there exists variation around this mean value, which is contingent on the precipitation-evaporation balance. As demonstrated in Table I.1, salinity can vary significantly in seas that are closed or only slightly open to oceanic masses [5].

Table I.1: Salinity of seawater and oceans [5].

Sea or ocean	Salinity ($mg.L^{-1}$)
Baltic Sea	7000
Caspian Sea	13500
Black Sea	20000
Adriatic Sea	25000
Pacific Ocean	33600
Atlantic Ocean	33800
Mediterranean Sea	39000
Arabian Gulf	43000
Red Sea	43000
Dead Sea	270000

I.3.2 - Brackish water

Brackish water is defined as non-drinking salt water with a salinity lower than that of seawater. The salinity of most brackish waters ranges from 1 to 10 g of salts per liter($g.L^{-1}$). Brackish water can be found in two primary forms surface water and groundwater. The latter is of particular interest due to its ability to become loaded with salts through the dissolution of certain salts present in the soils through which it has passed. The composition of brackish water is thus determined by the nature of the soil through which it flows and the rate of its circulation. The predominant dissolved salts include $CaCO_3$, $CaSO_4$, $MgCO_3$, and NaCl.

Additionally, $MgCO_3$ and NaCl have been identified as contributing elements [5].

I.4 - Different desalination processes

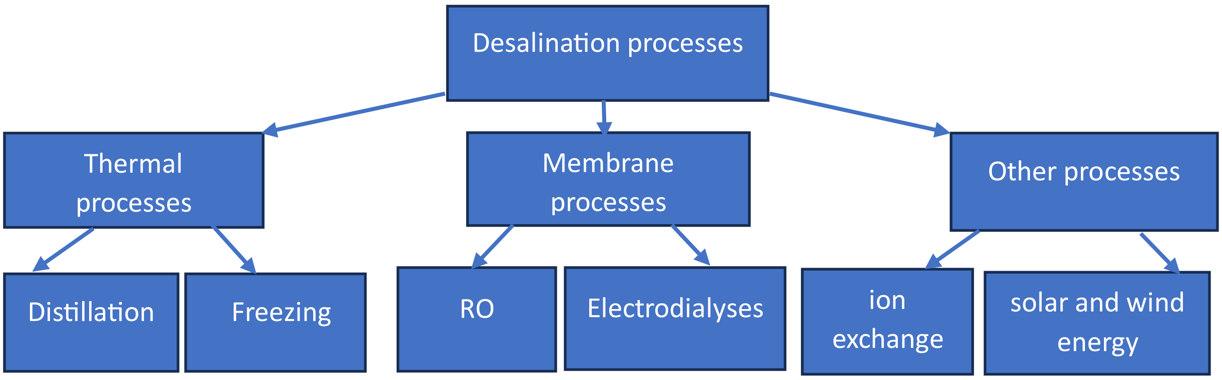

Figure I-1: Different desalination processes.

I.4.1- Thermal processes

I.4.1.1- The distillation process

Distillation processes involve the application of heat to seawater to vaporise a portion of it. The vapour obtained contains no salt, and so condensation of this vapour is used to obtain liquid fresh water. The objective is to accelerate the natural water cycle. In the natural environment, water evaporates from the oceans, where it accumulates to form clouds, and subsequently falls back to earth through precipitation. This desalination process has been employed since ancient times to generate minute quantities of fresh water on seafaring vessels[6].

I.4.1.1.1- Single distillation

The principle is straightforward. It reproduces the natural water cycle (see Figure I.2):

1. Within a closed chamber, a heating coil is employed to raise seawater to its boiling point.

2. The steam produced as a result of this process subsequently condenses on contact with a second coil, which is fed by cold seawater.

3. An electric pump then extracts the condensed water, and a second pump extracts a concentrated seawater or brine.

This initial solution is straightforward to implement, but it exhibits low efficiency. Consequently, it is primarily employed on vessels equipped with a thermal energy source [6].

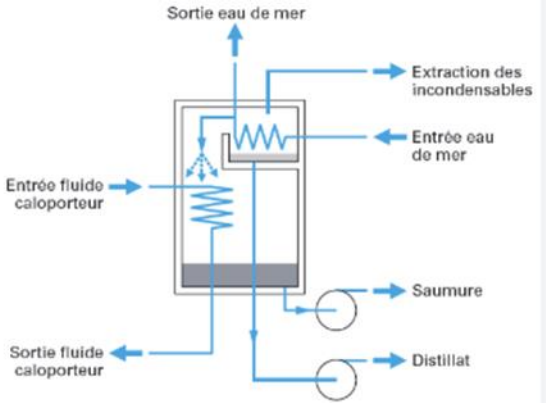

Figure I.2: Single-acting distiller.

I.4.1.1.2- Multi Effect Distillation (MED)

The process is based on the principle of evaporation, under reduced pressure, of a portion of preheated seawater at a temperature of between 70 and 80 C°. The process of evaporation occurs on an exchange surface, a departure from the prior process in which evaporation transpired within the successive stages by expansion. The heat transferred across this surface is provided by steam produced by a boiler or by hot water from a heat recovery unit. The steam produced in the initial effect is condensed to produce fresh water in the secondary effect where the pressure is lower, allowing the heat of condensation to evaporate part of the seawater contained in the secondary effect. This process continues recursively, as illustrated in Figure I.3. Consequently, the energy required for evaporation in the initial effect is solely of external origin. It can thus be concluded that the number of effects can be multiplied, thereby reducing the specific consumption (energy/m³ of fresh water produced) [7].

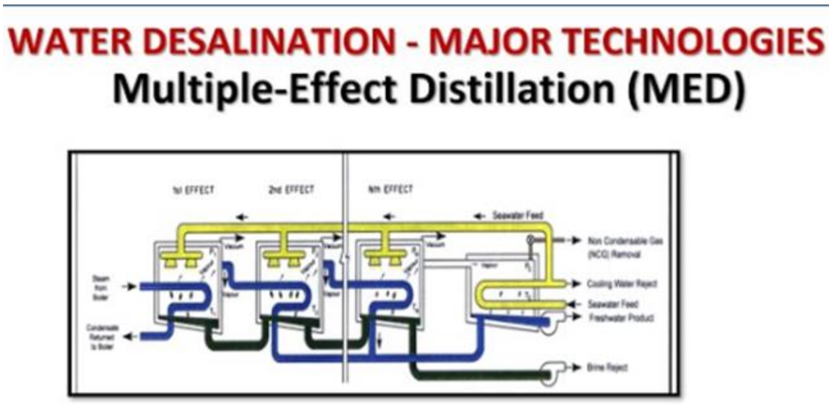

Figure I.3: Multi-Effect distillation.

I.4.1.1.3- Steam compression

The process entails the recovery of water vapour from the effect through the utilisation of a mechanical compressor or an ejector. This process is referred to as thermo-compression. It is also important to note that the ejector-based compression process necessitates the presence of steam (see Figure I.4) [8].

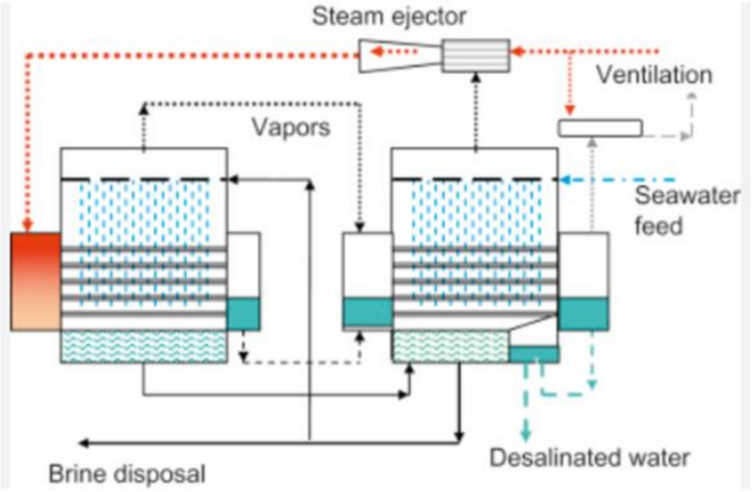

Figure I.4: Steam compressor.

I.4.1.1.4- Multi-flash distillation (MSF)

This process, known as Flash, maintains water pressure throughout the heating process. At a temperature of approximately 120 C°, the water is introduced into an enclosure (or stage) where the pressure is reduced. The result is instantaneous vaporisation using an expansion called Flash. A portion of the water evaporates and subsequently condenses on the condenser tubes positioned at the upper extremity of the chamber. The liquid water is then collected in receptacles situated beneath the tubes. The process is then reversed, with the hot seawater cooling down to provide the heat required for vaporisation. The boiling point of seawater is reached when the temperature equals the pressure within the vessel.

The flash phenomenon is then reproduced in a second stage where the pressure is even lower.

The water is thus vaporised by successive expansion in a series of stages where the pressures are increasingly reduced. It is noteworthy that up to 40 such stages can occur in an industrial MSF unit [6].

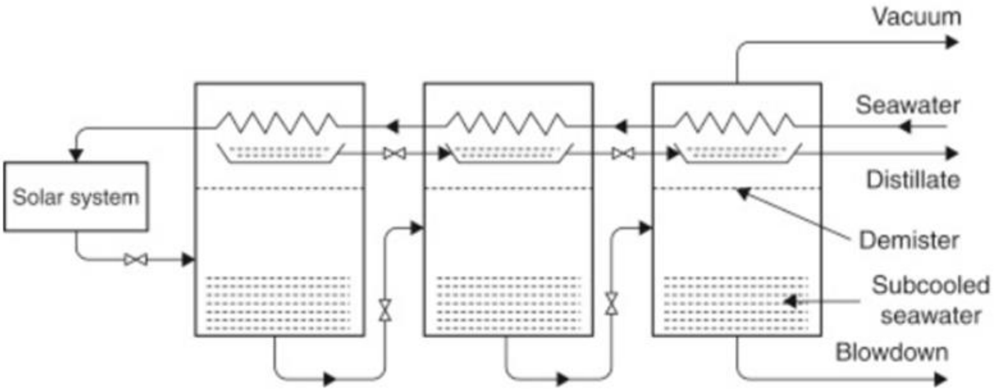

Figure I.5: Multi-flash distiller.

I.4.1.2 - Freezing process

Freeze desalination technology has been proposed as an alternative to distillation and reverse osmosis for the desalination of seawater in several works. Distillation and reverse osmosis for seawater desalination.

It is noteworthy that this technology can also be applied to wastewater treatment. Freezing desalination technology can be categorised into two distinct processes: 'direct' and 'indirect'[9].

I.4.1.2.1 - Desalination by direct freezing

The principle of direct freezing is predicated on the formation of ice crystals by direct contact between a refrigerant and seawater [9].

I.4.1.2.2 - Desalination by indirect freezing

In the process of indirect freezing, the cooling is facilitated by a heat exchanger, resulting in the formation of a layer of ice on the cold walls of the exchanger [9].

I.4.2 – Membrane processes

All membrane processes are distinguished by the fact that separation is achieved via a membrane. The following assertion is made:

Membrane can be regarded as a selective barrier that is permeable to some substances but not to others, and which is located between two homogeneous substances.

The phenomenon under investigation can be subdivided into phases. The transportation of components through the membrane is initiated by the application of a driving force.

The feed has been incorporated. In most cases, the processes in question are membrane-related.

The driving force is defined as the pressure difference or concentration (or activity) difference across.

The membrane is the subject of this study. The parameters under consideration are pressure, concentration (or activity), and temperature.

It is conceivable that the chemical potential may be incorporated within a single parameter[10].

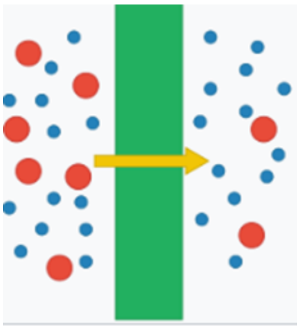

Figure I.6: The reverse osmosis membrane.

I.4.2.1 – Electrodialysis

Electrodialysis is a process that functions on the principle of rejecting ions at their charge. This method is predicated on the separation of salt and water through a semi-permeable membrane.

Ions present within the salt solution migrate through water-impermeable membranes, known as selective membranes, when subjected to the action of an electric field. An electrodialyser is composed of multiple compartments, alternating between anionic and cationic membranes. The movement of ions is driven by an electric field, with cations migrating in the direction of the electric current and passing exclusively through the cationic membrane. Anions, in contrast, flow in the opposite direction to the current and can only traverse the anionic membrane [7].

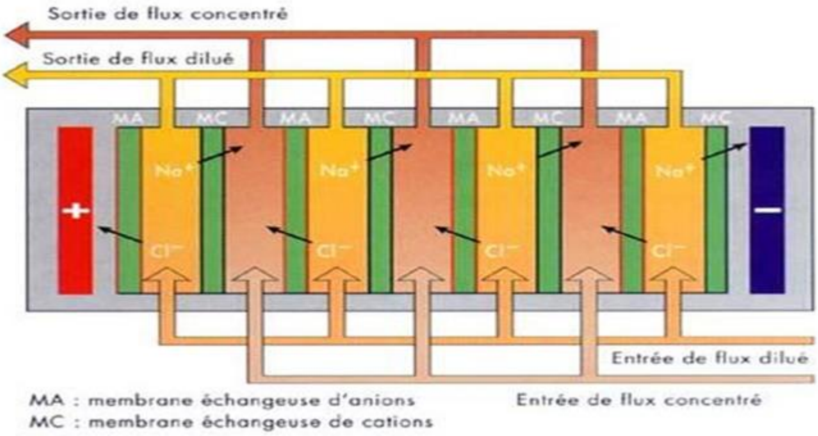

Figure I.7: Principle of operation of electrodialysis.

I.4.2.2 – Reverse osmosis

The reverse osmosis desalination technology is predicated on the separation of salts from water without causing any change in its natural (physical) state. In this process, salts are separated using semi-permeable membranes that allow the passage of small water molecules but do not allow the passage of relatively large salt molecules [2].

I.4.3 - Other processes

I.4.3.1 - Ion exchange

Ion exchange technology is an ideal solution for the removal of specific contaminants from drinking water. In comparison with alternative processes, ion exchange is distinguished by its high level of selectivity, which renders it a highly effective solution for the precise removal of specific contaminants.

Ion exchange is employed in numerous large-scale applications, including the targeted removal of hardness, nitrates, natural organic matter, perchlorates, chromates, uranium, and chlorine. It is also used in the removal of various other metals [11].

Ion exchange is defined as the reversible process of permutations between structural ions in a material known as an 'ion exchanger' and ions in solution. The latter solution is in contact with the ion exchanger [12].

I.4.3.2 - Desalination using solar and wind energy

It is estimated that approximately one hundred desalination plants utilizing renewable energies have been constructed globally over the past two decades. The majority of these facilities are of a small scale, serving either as experimental or demonstration sites, with a capacity ranging from 0.5 to 200 $m^3.d^{-1}$. A significant number of these facilities are situated within the Mediterranean region, including countries such as Egypt, Algeria, Tunisia, and Spain. These facilities typically utilize energy storage systems, which are costly, and face challenges due to a paucity of local expertise, particularly in the realm of maintenance. However experience shows that small-scale desalination units, when properly designed and operated can provide water for a wide range of isolated supply sites with good quality water, at costs that are already attractive. However, to circumvent operational challenges over time and ensure optimal maintenance and durability, the installations must be designed with simplicity and reliability as paramount [13].

I.5 - Desalination plants in Algeria

In response to the evolving dynamics of water supply and demand, the Algerian government has significantly augmented its investments in the desalination industry, a strategic imperative dictated by the exigencies of the situation (Algerian Government, 2021). Between 2005 and 2021, a total of 14 desalination facilities were commissioned, fostering a collaboration between governmental entities and private investors. In response to the evolving dynamics of water supply and demand, the Algerian government has significantly increased its investments in the desalination industry. This strategic imperative is dictated by the exigencies of the situation (Algerian Ministry of Water, 2021). Between 2005 and 2021, a total of 14 desalination facilities were commissioned, fostering a collaboration between governmental entities and private investors (Algerian Ministry of Water, 2021). These facilities boast a combined production capacity of 2,090,000 cubic meters per day ($m^3.d^{-1}$) and represent a concerted effort to address the escalating demands for fresh water through technologically advanced and sustainable means (Algerian Ministry of Water, 2021).

Table I.2: Desalination plants in Algeria between 2005-2021.

Location	m³/ Day	Process	Commissioning
Chlef (Tenes)	200 000	RO	2015
Tlemecen (Souk Tleta)	200 000	RO	2011
Tlemecen (Honaine)	200 000	RO	2012
Alger (Hamma)	200 000	RO	2008
Alger (Staouali)	5 000	RO	2021
Alger (Ain El Benian)	10 000	RO	2021
Ain Temouchent (Benisaf)	200 000	RO	2009
Oran (Kahrama)	90 000	MSF	2005
Oran (Bousfer)	5500	RO	2005
Oran (Maktaa)	500 000	RO	2016
Skikda	100 000	RO	2009
Mostaganem	200 000	RO	2010
Boumerdes (Cap Djinet)	100 000	RO	2010
Tipaza (DouaoudaFouka 1)	200 000	RO	2008

The strategic deployment of desalination infrastructure in Algeria exhibits a clear correlation with the magnitude of damage inflicted, primarily by drought-induced conditions. It is estimated that approximately 70% of these plants

The western regions are characterized by a particular set of circumstances.

Historically, the region has suffered significant damage as a result of prolonged periods of dry weather. A further 20% of the budget is allocated to central areas, where the impact of drought is particularly evident.

It has been observed that this phenomenon has been notable, albeit to a lesser extent. The remaining 10% of desalination plants are concentrated in the eastern part of the country indicating the efforts [14].

CHAPTER II

DESCRIPTION OF THE STATION AND PROCESS USED

II.1- Introduction

In natural settings, osmosis plays a pivotal role in maintaining biological equilibrium However within the industrial context, the process is referred to as “reverse osmosis” due to its application of elevated pressure (surpassing the osmotic pressure) of approximately 80 bars which serves to propel salt water from the compartment of higher salt concentration to the compartment containing fresh water. The separation of these two compartments is facilitated by a membrane, resulting in the enrichment of the freshwater compartment with freshwater. In the absence of an artificial membrane or external pressure, the process would be unidirectional, leading to the dilution of the saline water and the accumulation of fresh water in the compartment [15].

Reverse osmosis is a process that utilizes dense membranes to permit the movement of water while impeding the passage of salts. This technique finds application in the following contexts:

- Seawater desalination.
- Desalination of brackish water.
- Production of ultrapure water.
- Process water production [16].

II.2 –Difference between osmosis and reverse osmosis

II.2.1- Osmosis

Osmosis is based on the fundamental principle of equilibrium, whereby two liquids with different concentrations of dissolved solids are brought into contact and gradually mix until the concentrations are equalized. If these two liquids are separated by a semi-permeable membrane that allows the liquids to pass through while the dissolved solids remain in their respective compartments, the liquid with the lower concentration of dissolved solids will cross the membrane and enter the liquid with the higher concentration of dissolved solids. This process continues until a state of equilibrium is achieved, resulting in a difference in water level on either side of the membrane. This difference in water level is known as osmotic pressure [17].

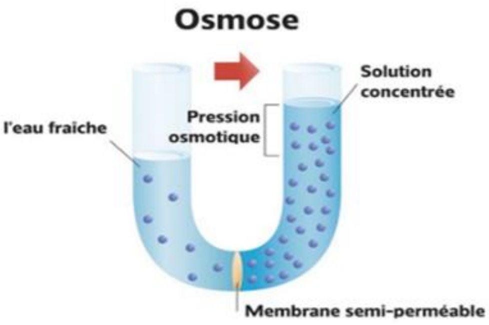

Figure II.1: The phenomenon of osmosis.

II.2.2- Reverse osmosis

Reverse osmosis is a process that involves the movement of water through semi-permeable membranes, driven by a pressure differential between a concentrated and a diluted solution. The rate of removal is expressed as a percentage of the total salt content. The salinity reduction of brackish water is typically greater than 92%, while that of seawater can reach over 98.5%[18].

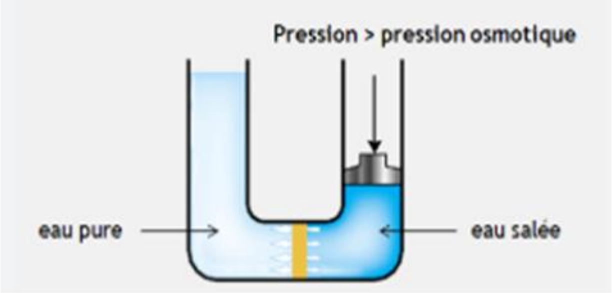

Figure II.2: Reverse osmosis process.

The flow is distinguished by its uninterrupted nature and its tangential orientation concerning the membrane. A proportion of the solution to be treated is separated at the membrane into two parts of differing concentrations:

- The component that traverses the membrane or permeates (flow rate Q_p).
- The term 'concentrate' or 'retentate' (flow rate Q_c) is used to describe a part that does not pass through the membrane. The concentrate contains the molecules or particles retained by the membrane [16].

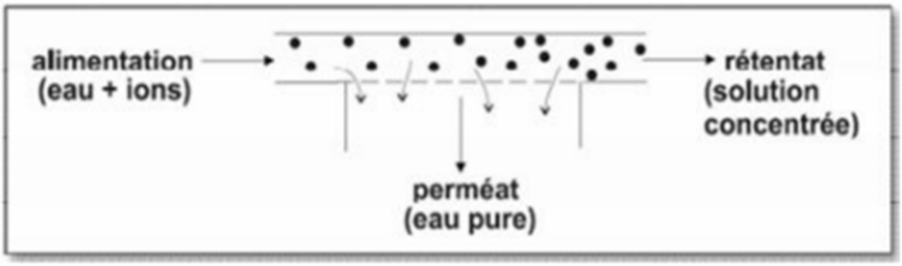

Figure II.3: Separation of liquid phases by permeation through a membrane.

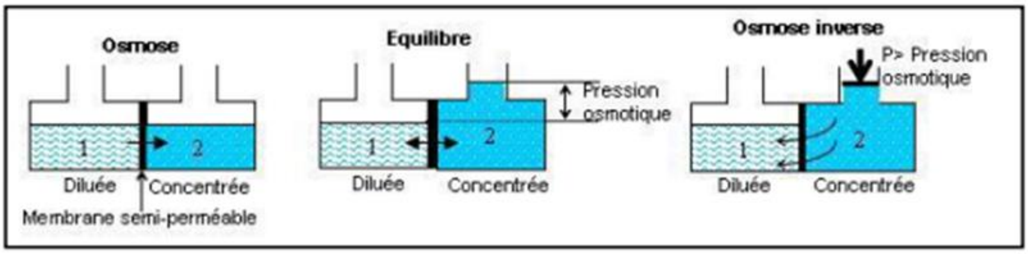

Figure II.4: Osmosis and reverse osmosis processes.

II.2.3- Principle of reverse osmosis

It is important to recall the definition of osmosis as the transfer of a solvent (most commonly water) across a membrane under the action of a concentration gradient.

It is imperative to consider a two-compartment system that is separated by a permselective membrane containing two solutions of different concentrations (see Figure II.5).

The phenomenon of osmosis is defined as the movement of water molecules from a dilute solution to a concentrated solution.

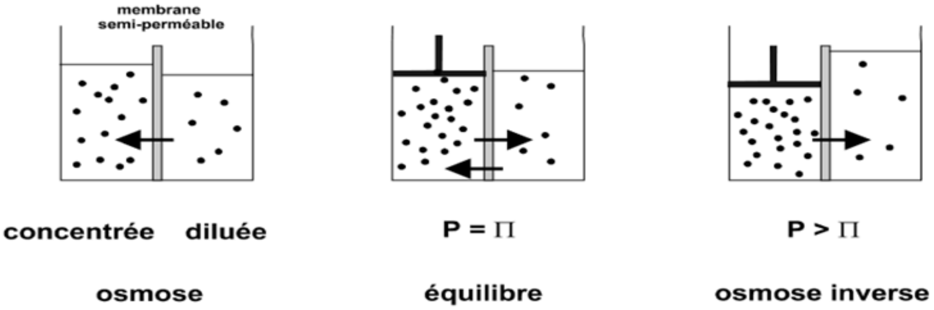

Figure II.5: Principle of reverse osmosis.

Should an attempt be made to impede the flow of water by exerting pressure on the concentrated solution, this would be an effective method of achieving the desired outcome. The magnitude of water transferred by osmosis will diminish. There will come a point when the pressure exerted is such that the flow of water is counterbalanced. Assuming, for the sake of simplicity, that the dilute solution is pure water, this equilibrium pressure is referred to as the osmotic pressure.

Should the pressure be increased beyond the osmotic pressure, this will result in water flowing in the opposite direction to the osmotic flow.

The phenomenon of reverse osmosis was discovered in 1950 by Reid at the University of Florida (USA) in the context of studies on the desalination of seawater. The development of reverse osmosis as a technology took place in the 1960s, when Loeb and Sourirajan at the University of California (USA) succeeded in obtaining highly permeable asymmetric membranes (cellulose acetate-based membranes) [19].

II.3– Osmotic pressure

The calculation of osmotic pressure is facilitated by Van’t Hof’s law, which stipulates that the osmotic pressure exerted by a solute is equivalent to the pressure that the solute would exert in the perfect gas state, assuming the same volume (V) and temperature (T). In the event of the solute dissociating into i ions, the osmotic pressure is elevated by i times [20].

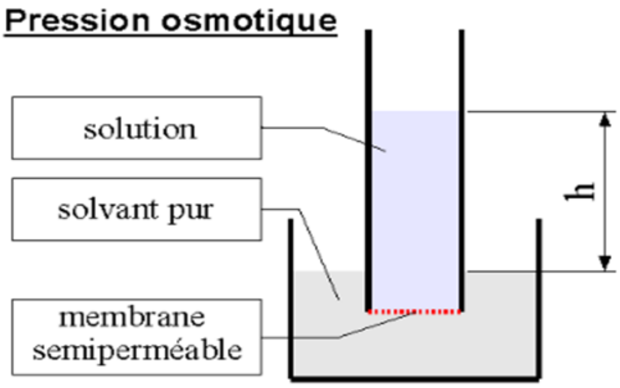

Figure II.6: Osmotic pressure.

The osmotic pressure of a solution is directly proportional to the concentration of the solute.

$$\Pi = i.C.R.T$$

The following variables are to be considered:

P: Osmotic pressure (bar).

i: Number of dissociated ions in the case of an electrolyte.

C: Molar concentration (mol.L^{-1}).

R: Ideal gas constant (0.082 L.bar. $mol^{-1}.k^{-1}$)

T: Absolute temperature (K) [21].

II.4– Transfer mechanism

In the context of reverse osmosis, the transfer of solvent and solute through a semi- permeable membrane is facilitated by a process known as solubilisation-diffusion. This process involves the dissolution of all the molecular species (solute and solvent) within the membrane resulting in their subsequent diffusion through its structure. This diffusion occurs under the influence of a concentration and pressure gradient, akin to the movement of a liquid or solid through a given medium [22].

II.5– Reverse osmosis modules

II.5.1– Definition of modules

The modules under consideration consist of a stack of membranes and support plates. Any(flat) membrane can be adapted to this process, ranging from microfiltration to high-pressure reverse osmosis. The utilization of these modules is predominantly observed in the context of loaded liquids, particularly within industrial processes, ERI, and BRM applications. The principles of filter presses inspire the design of these devices. The fluid under consideration is subject to treatment and is observed to be in motion between the membranes of two adjacent plates. These plates offer a dual function, providing both mechanical support for the membrane and drainage for the permeate. The plates can be arranged in either a parallel or serial configuration [23].

II.5.2– Types of modules

II.5.2.1– Tubular modules

The membranes are placed or formed inside a support tube, which may be porous or have drainage holes, with a diameter varying from 10 to 40 nm. These tubes are then placed in parallel or in series in a cylindrical envelope to form the unitary module. The hydrodynamics of the flow are well-defined, and circulation speeds of up to 6 m.s^{-1} are attainable if a high turbulence regime is required. These modules do not necessitate fine pre-filtration of the liquid to be treated and are easily cleaned. Their primary disadvantage is their low compactness and a high cost per m^2 installed [24].

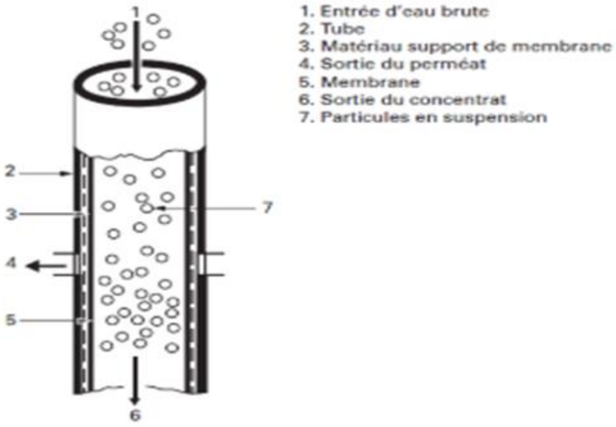

Figure II.7: Tubular module.

II.5.2.2– Hollow fiber modules

These modules consist of a set of hollow fibers, with lengths ranging from a few centimeters to a meter and a thickness of 100 to 200 µm. The fibers are bundled together with a diameter of less than 3mm [25].

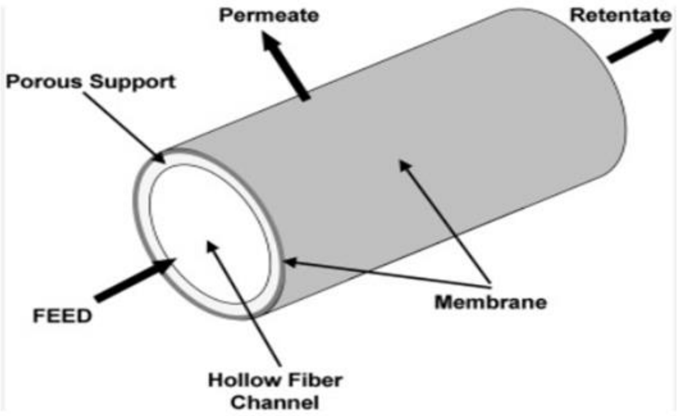

Figure II.8: Hollow fiber module.

II.5.2.3– Plate modules

The system utilizes membranes in the form of sheets. This configuration is the simplest type of filter press. The filter surface remains small about the space requirement [26].

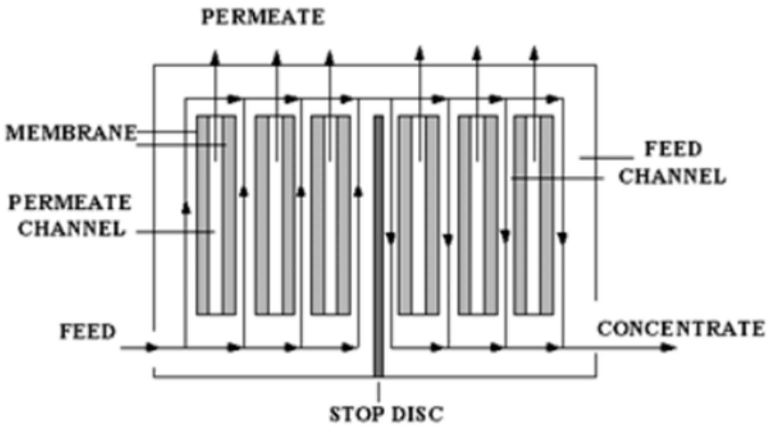

Figure II.9: Plate module.

II.5.2.4– Spiral modules

The flat membranes are wound in a spiral around a hollow, perforated tube intended to collect the permeate. Between the membranes is placed a plastic mesh of 0.8 to 1.2 mm thick, the purpose of which is to create turbulence in the circulation of the fluid. This configuration results in a multi-layer cylinder, wherein the permeate flows along a spiral path towards the porous tube while the feed circulates axially within the channels [27].

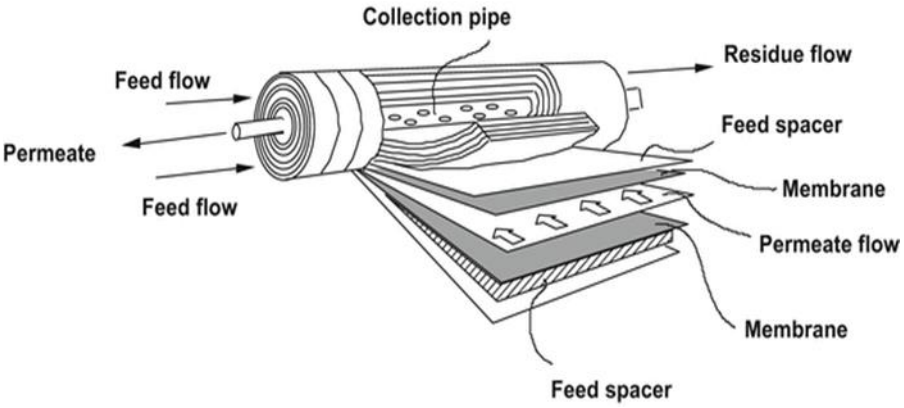

Figure II.10: Spiral module.

II.6– Description of Sonachter desalination plant

The Mostaganem desalination plant has been found to have a drinking water production capacity of 200,000 $m^3.d^{-1}$ [28].

Situated in proximity to the renowned Sidi l'Adjel beach, within the administrative boundaries of the commune of Khadra, 72 km east of the wilaya of Mostaganem, this location provides not only convenient access to marine resources but also offers a safeguard against the potential hazards associated with rising sea levels [29].

The plant's water treatment process consists of the following:

- Firstly, a seawater collection and pumping system is employed.
- The seawater is then subjected to a pre-treatment system that utilizes filtration and microfiltration techniques.
- The micro-filtered water is then subjected to demineralization by reverse osmosis.
- A remineralisation and conditioning system for demineralized water is in place.
- Finally, a system for pumping the remineralised water (marketable water) to the distribution network (external water transport network) is in place.
- The following system is also required: a system for removing brine and by-products[28].

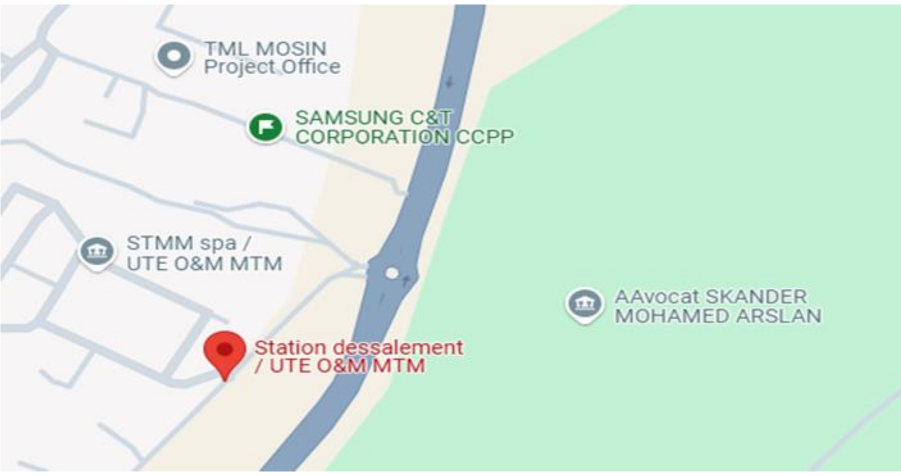

Figure II.11: Geographical location of Sonachter desalination plant.

II.7– Description and normal operation of process installations

II.7.1- Seawater collection and pumping

The collection system’s function is to supply seawater to the pretreatment facility in the requisite quantity and at the necessary pressure to produce the desired volume of drinking water.

The collection system is comprised of the following sub-systems:

The collection system consists of the following components:

- Towers and intake pipes.
- An anti-medusa sub-system.
- A seawater pumping sub-system [28].

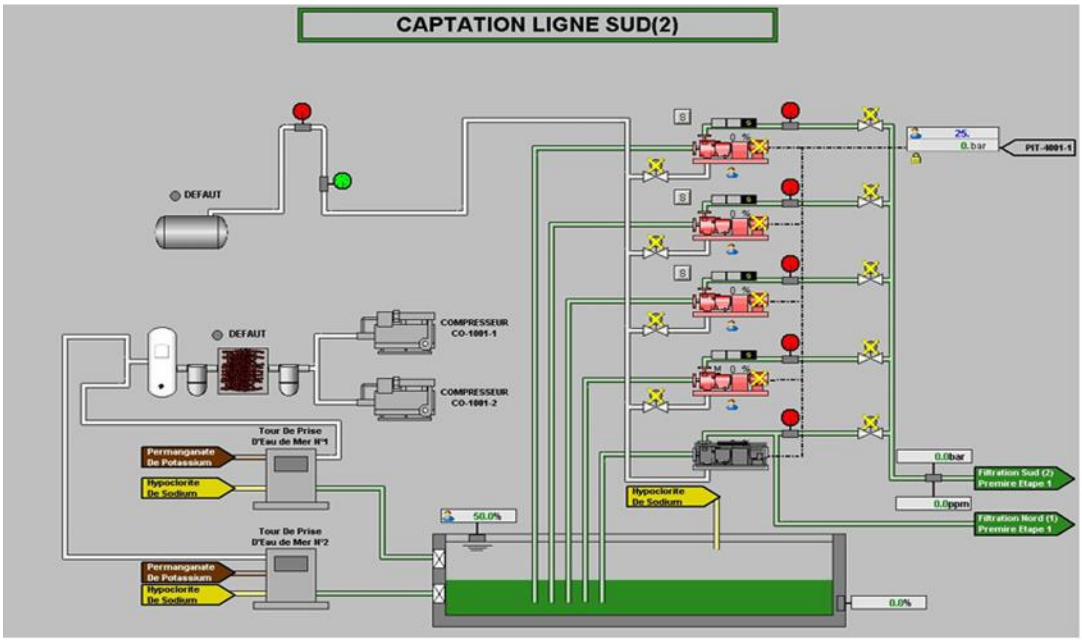

Figure II.12: Seawater capture.

II.7.1.1- Catchment towers and piping

The seawater is collected via two intake towers connected to the seawater pumping tank which is connected to two high-density polyethylene pipes (1,800 mm in diameter). Through these pipes, the water must flow at a speed of around 1 $m.s^{-1}$. The pumping towers are submerged at approximately 2,500 meters from the coast and a depth of 16.5 meters [28].

II.7.1.2- Anti-medusa system

The level in the seawater catchment tank may eventually become too low for several reasons. One such reason is if the grids of the collection towers are blocked by jellyfish, algae, and/or fish. The anti-jellyfish system has been designed to generate a curtain of air around the screens that floats these animals and/or elements towards the surface [28].

II.7.1.3- Seawater pumping system

The purpose of the seawater pumping system is to provide seawater pre-treatment in the requisite quantity and at the requisite pressure to produce the desired quantity of drinking water.

The seawater collection pumps have been meticulously engineered to achieve a flow rate of2,380 $m^3.h^{-1}$ at a pressure of 67 m.c.e [28].

II.7.2- Pre-treatment system

The purpose of the pretreatment system is to condition the seawater physically, biologically and chemically. The overarching aim of this process is to protect and maximise the performance of the reverse osmosis system.

The pre-treatment system comprises the following sub-systems:

- Chemical conditioning subsystem
- Filtration subsystem
- Micro-filtration subsystem [28].

Chemical pretreatment focuses on bacteria, hardness scale, and oxidising agents. Chemicals are used to remove, destroy, inhibit, or chemically reduce these species [30].

Table II.1: Chemical RO pretreatment techniques and the species each technique treats [30].

Chemical Pretreatment	Species Addressed
Chlorine	Microbes, Total Organic Carbon, Color
Ozone	Microbes, Total Organic Carbon, Color
Antiscalants	Hardness, Silica
Sodium Metabisulfite	Oxidizers (free chlorine)
Non-Oxidizing Biocides	Microbes

II.7.2.1- Chemical conditioning

The water is successfully conditioned by adding the following reagents:

II.7.2.1.1- Dosage of sodium hypochlorite

The system under consideration is a dosing system for disinfecting seawater. It consists of three tanks with a capacity of 60,000 liters each, as well as a dosing skid with two diaphragm pumps and one diaphragm pump. The purpose of the dosing skid is to dose sodium hypochlorite into the catchment towers and the catchment tank, as well as into the collection tank [28].

II.7.2.1.2- Dosing of potassium permanganate

This is a dosing system for oxidizing and disinfecting seawater.

Typically, hypochlorite is the more effective option however, macro-incrustations have been observed in the catchment towers and/or intake pipes, and certain types of mules may, at specific stages of development, develop resistance to the effects of sodium hypochlorite. In such cases, the utilization of permanganate may prove more efficacious [28].

II.7.2.1.3- Dosing sulphuric acid

The function of the sulphuric acid dosing system is to reduce the pH of seawater with a view to optimizing yield.

The precise dosage of sulphuric acid required is determined by laboratory analysis of the pH of the seawater in the reservoir [28].

II.7.2.1.4- Dosage of coagulant (ferric chloride)

The system has been designed to administer a coagulant to raw water to prepare it for filtration.

The precise quantity of ferric chloride required is determined by measuring SDI [28].

II.7.2.1.5- Dosage of flocculant (Poly electrolyte)

The system is designed for the administration of flocculant to raw water.

The precise dosage of polyelectrolyte required is determined by measuring SDI [28].

II.7.2.1.6- Antiscalants

Sequestering agents, otherwise referred to as scale inhibitors or antiscalants, are employed to reduce the likelihood of the formation of scale on the surface of an RO membrane. Antiscalants are typically administered as a standalone solution for most applications. In certain instances however, acid feed is utilized in conjunction with an antiscalant. This approach is employed to regulate both the levels of calcium carbonate scale and calcium phosphate scale, thereby ensuring optimal performance and efficiency [30].

II.7.2.1.7- Dosage of sodium metabisulphite

This is a dosing system for the reduction and elimination of chlorine residues in the water entering the membranes. The precise dosage of sodium metabisulphite is determined by measuring the chlorine content of the water, which is facilitated by a chlorine content meter[28].

II.7.2.2- Filtration System

The plant is equipped with two filtration stages. The first stage employs mixed sand and anthracite filters, while the second stage utilizes sand filters.

To optimize the durability of the osmosis membranes and micro-filter cartridges, it is recommended to maintain the SDI downstream of the filtration system and upstream of the microfiltration system below 3.

If the recommended SDI value is reached at the end of the first filtration stage, the second stage can be bypassed [28].

II.7.2.2.1- First stage filtration

The plant is equipped with two first-stage filtration lines, each comprising twelve horizontal pressure filters.

Each filter possesses an average filtration area of 91.39m², a diameter of 4.00m, and a total length of 24.04m. Manufactured from carbon steel, the filters are lined with 3.00 mm-thick natural rubber.

The filters are cleaned using air and brine from the osmosis process [28].

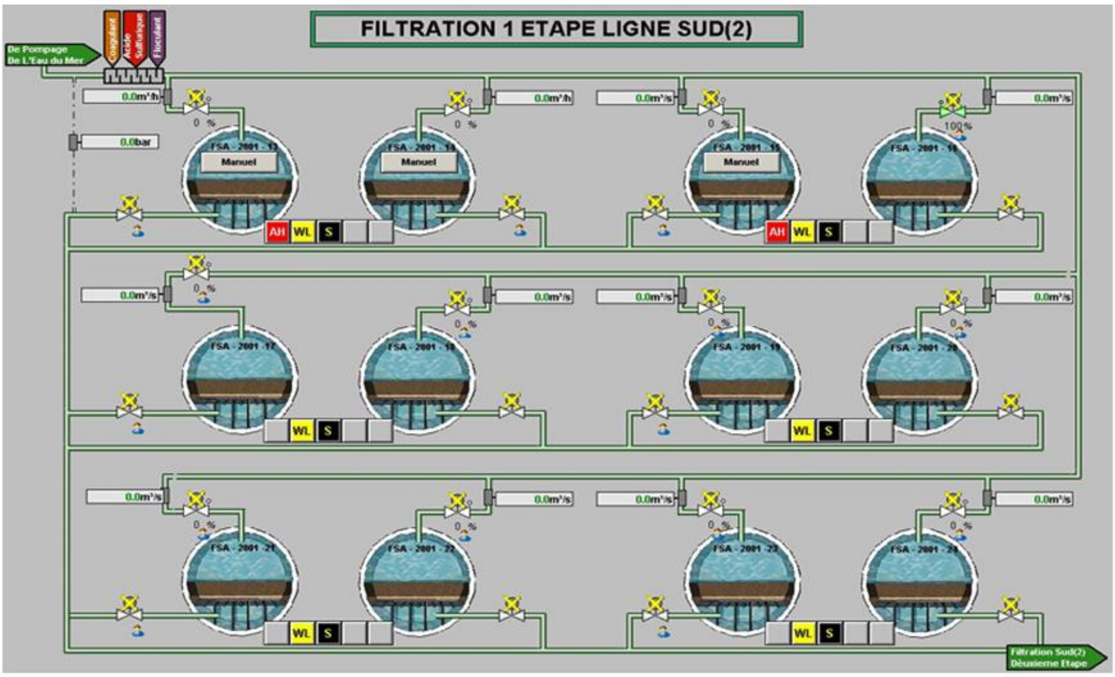

Figure II.13: First stage filtration.

II.7.2.2.2- Second stage filtration

The apparatus is equipped with two batteries, each comprising eight horizontal pressure filters.

It has been determined that each filter possesses an average filter surface area of 90.04 m². Furthermore, their dimensions and characteristics are identical to those of the sand and anthracite filters in the first stage.

Sand is composed of clean, free grains of clay, dust, and organic matter.

Notably, the presence of iron and manganese in sand is negligible, and their levels and morphologies do not such as having a deleterious effect on the quality of filtered water [28].

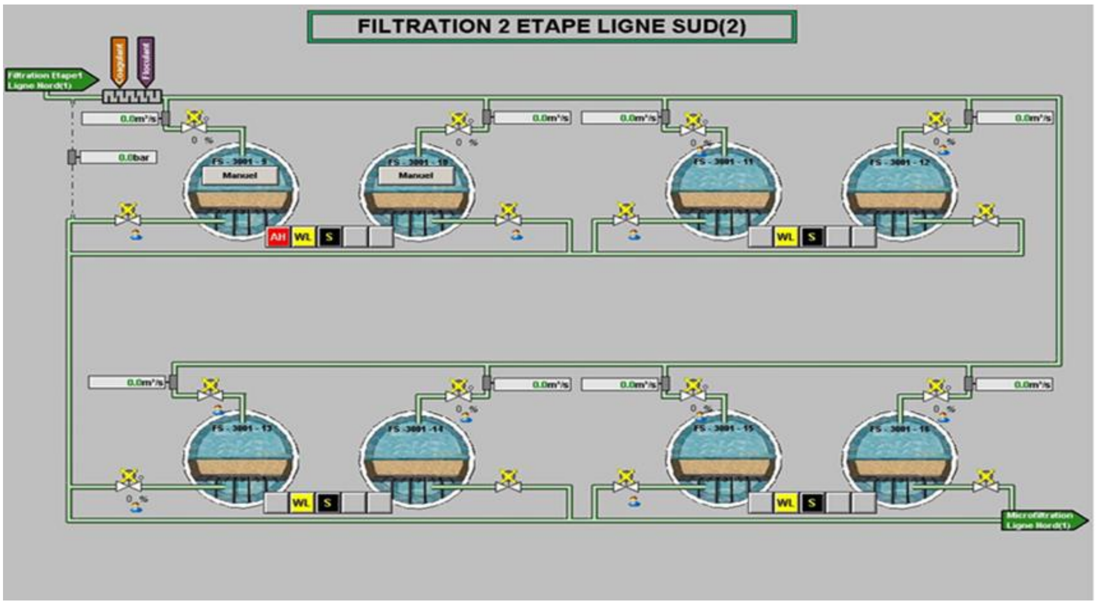

Figure II.14: Second stage filtration.

II.7.2.2.3- Microfiltration system

The purpose of the microfiltration system is to safeguard the reverse osmosis system by impeding the movement of particles suspended in the filtered water and not retained by the filters, thereby preventing their entry into the high-pressure pumping system. The microfiltration system is designed to ensure the integrity of the reverse osmosis process by selectively permitting the movement of particles with a diameter smaller than 5 microns thereby ensuring the efficient removal of suspended particulates and contaminants from the water.

Each filter is equipped with 360 cartridges, each measuring 1250 mm in length. The unit's flow rate per cartridge is 2.85 cubic meters per hour when the nine cartridges are in operation [28].

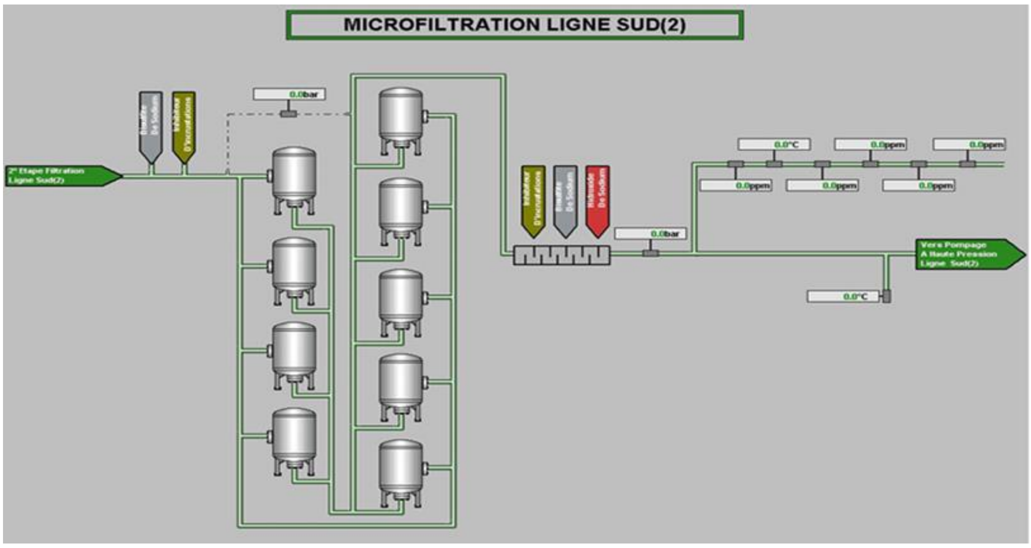

Figure II.15: Microfiltration system.

II.7.2.2.4- Filter cleaning system

It is to be expected that the porosity of the filter media will undergo a progressive reduction. The present situation is liable to give rise to the following consequences:

- It has been demonstrated that there is a direct correlation between an increase in system load losses and an increase in the plant's electricity consumption.
- It has been demonstrated that an increase in the speed of seawater passing through the rest of the filters will result in a reduction in the efficiency of the filtration process.

It is imperative that filters are subject to periodic cleansing to maintain optimal functionality and ensure the integrity of the system. This procedure should be initiated in the event of a substantial increase in pressure differential and/or a significant decrease in the flow rate through the respective filter.

The filters are subjected to a process of filtration that involves the introduction of air to enhance their spongy texture, and the backwashing of the filter mass with brine derived from the reverse osmosis process.

The cleaning system has been configured to allow for the simultaneous cleaning of two filters with one filter dedicated to each of the pre-treatment lines [28].

II.7.3– Reverse osmosis system

The reverse osmosis system constitutes the core of the plant, with the function of reducing the salt content of the micro-filtered water [28].

II.7.3.1– The elements of reverse osmosis

Reverse osmosis represents the core of the desalination process. It comprises a high- pressure pump, an energy recovery system, and reverse osmosis membranes.

II.7.3.1.1- High pressure pump

The effectiveness of the RO process is contingent upon the controlled flow of water through a semi-permeable membrane, which is achieved by maintaining the correct water pressure. This is where pumps become essential. Pumps play a key role in maintaining the required pressure levels within the RO system. They facilitate the pressurisation of the incoming feed water thereby generating the necessary force to propel it through the membrane and subsequently enable the separation of pure water from contaminants. The absence of efficient and reliable pumps would result in the complete cessation of the RO process, consequently rendering the plant ineffective in its mission to produce clean, purified water [31].

II.7.3.1.2- Booster pump

A reverse osmosis booster pump serves to increase the water pressure within a reverse osmosis system, thereby optimizing its performance. in instances where the water pressure entering an RO system is inadequate, the system's productivity is significantly diminished, and its effectiveness is compromised. While municipal water supplies generally possess sufficient water pressure to facilitate the operation of an RO, the incorporation of a reverse osmosis booster pump ensures that the system functions optimally, irrespective of the incoming water pressure. RO booster pumps are concentrated over 500 ppm [32].

II.7.3.1.3- The pressure exchanger PX (an energy harvester)

The pressure drops across the RO membranes is approximately 1.5 to 2 bar, depending on the number of elements per pressure tube, resulting in the concentrate being expelled at high pressure.

The energy recovery system enables the reuse of energy from the concentrate. The concentrate is directed to the energy recovery system, where it transfers its energy directly to a portion of the feed water [33].

II.7.3.1.4- Membrane

The reverse osmosis membrane constitutes a thin, semi-permeable layer that enables the filtration of water by the removal of dissolved solids, ions, and organic matter. It is composed of synthetic polymers that form a physical barrier to contaminants larger than water molecules[34].

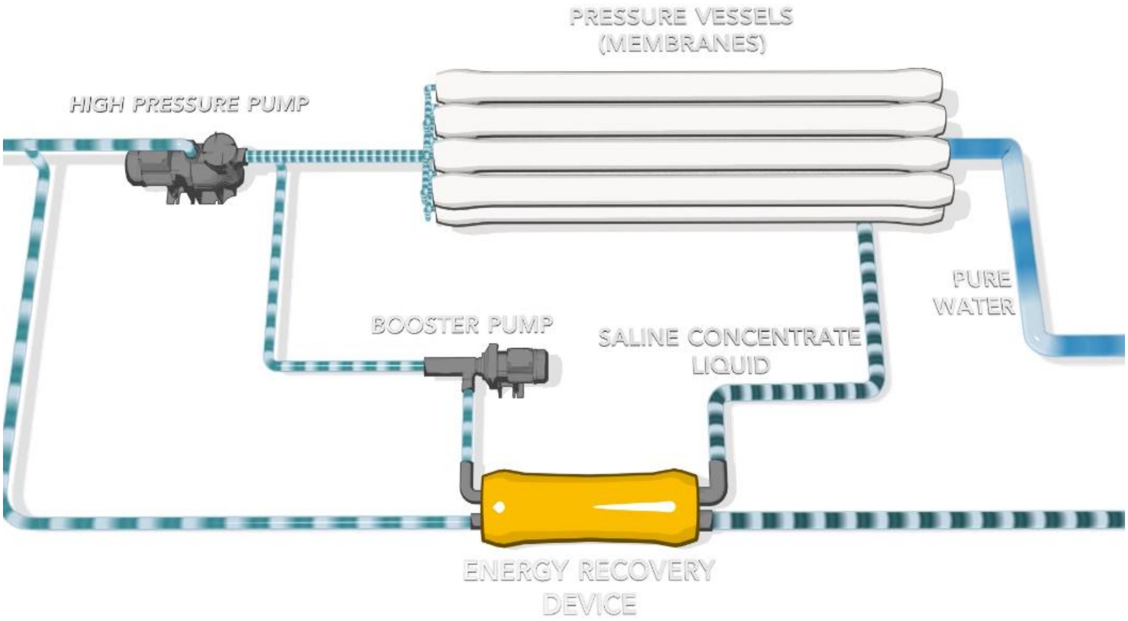

Figure II.16: The elements of reverse osmosis.

II.7.4– Remineralisation and conditioning system for osmosis water

Following the culmination of the reverse osmosis process, the osmotic water is subjected to a process of remineralisation with a view to reducing the aggressiveness of the water and achieving a guaranteed level of alkalinity and hardness.

The following data is provided: pH, Langelier index and TDS values.

The osmotically-sourced water from each reverse osmosis line is directed towards the remineraliser through an independent channel.

This text concerns the practice of collecting. Each manifold is responsible for the transportation of flow from each production line.

The water is stored in a tank with a height of 6 metres. This height is sufficient to allow the osmotic water to pass through.The calcite beds are subject to the effects of gravity, which results in their movement towards the storage tank where the produced water is stored.

The administration of CO_2 is achieved through the implementation of a sparger within the connecting pipe that links the osmotic water tank and the calcite bed tank.The water enters at the base of the cells and is distributed through the false bottoms of the calcite beds.

The reaction of the carbon dioxide dissolved in the water with the calcium carbonate present in the bed results in the formation of soluble calcium bicarbonate, thereby increasing the pH level.

Following the occurrence of the remineralisation reaction, there will be an enhancement in the hardness and alkalinity of the water. Concurrently, the presence of a residual CO_2 in equilibrium with HCO_3 will be observed.

The determination of the pH of the treated water will be facilitated by this process [28].

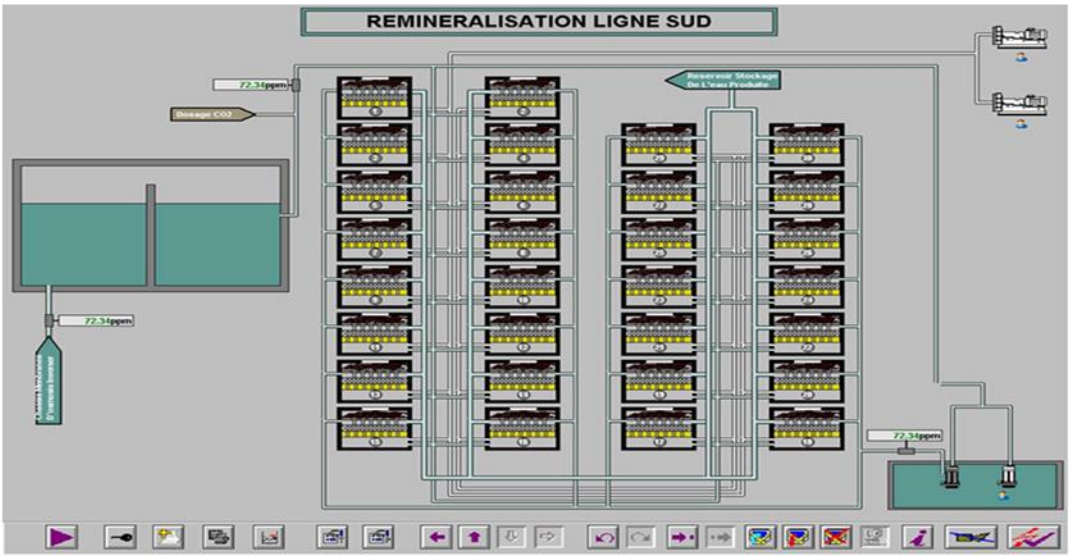

Figure II.17: Remineralisation for osmosis water.

II.7.5 - Storage and impulse of produced water

The system’s function is the storage and pumping of marketable water. The water produced is pumped to the distribution network through the External Water Transport Network, which is managed by Algerian Water Company (ADE) [28].

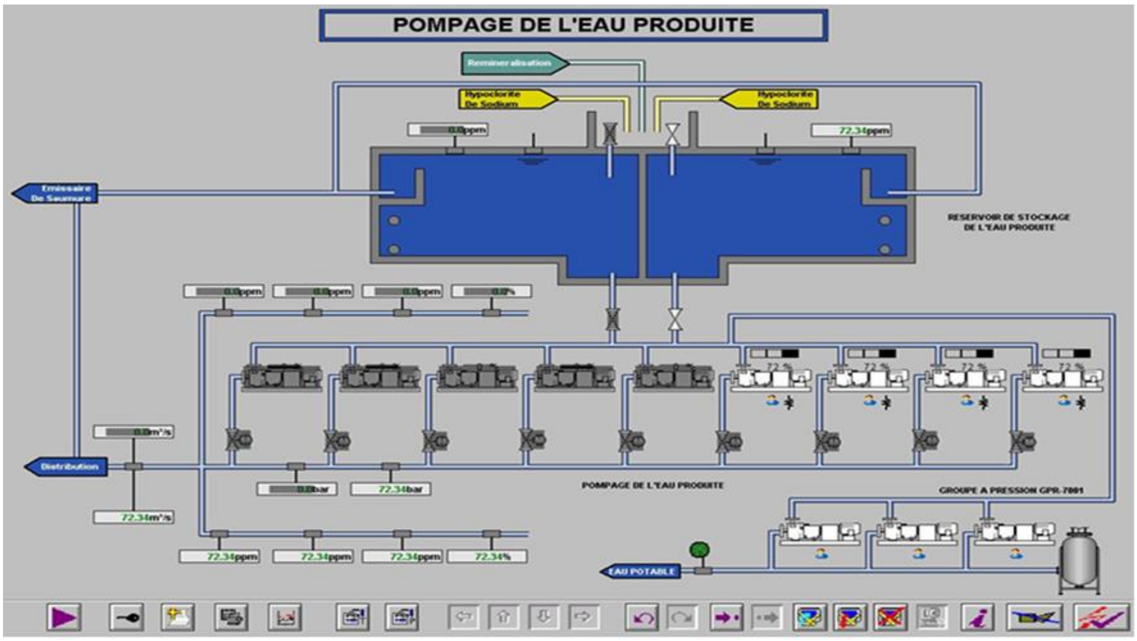

Figure II.18: Pumping of produced water.

II.8– Membrane cleaning

The utilization of reverse osmosis membranes invariably results in the gradual accumulation of particulate matter, thereby diminishing the flow rate produced by the membranes.

The accumulation of particulate matter can be attributed to colloidal materials or small precipitates. To maintain the integrity of the membranes and restore their functionality, it is imperative to subject them to periodic cleansing procedures.

The following conditions must be met in order to initiate the washing process:

- A pressure loss of more than 20% in comparison to the initial value must be observed in the membranes.
- A passage of salt from the module that exceeds 30% of the initial value must be recorded.
- A flow rate that is less than 15% of the initial flow rate must be produced.

The system under consideration is composed of the following components:

- An 80 m^3 tank in which the cleaning solution is prepared.
- Resistors that serve to heat the solution.
- Level switches.
- A thermometer and a temperature transmitter.

The system has been designed to facilitate the cleaning of the pipes of a complete chassis in a single process, thus reducing the necessity for repeated cleaning operations.

The chemical cleaning circuit functions at low pressure and is isolated from all the frames by manually operated ball valves equipped with limit switches. There are eight units for supplying the chemical cleaning solution for the frame of line number 1, and eight other units for the discharge of the solution for line number 2, there are also 8 supply valves and 8 others for the discharge. It is imperative to note that, during the execution of chemical cleaning operations it is crucial to ensure that there is no contact between the pressure exchangers and the chemical solution. To this end, a manually operated ball valve is installed in the discharge collector for each frame, equipped with limit switches. The water outlet from the reverse osmosis frames, from both the discharge and the permeate, is discharged to the chemical cleaning tank. It is recommended to reject 10% of the volume of the solution pumped out, as its fouling rate may have increased [28].

II.8.1– Clean-In-Place (CIP) Equipment

Membrane cleaning can be carried out in situ, otherwise known as clean-in-place (CIP), or ex-situ, typically off-site. As illustrated in Table II.2, a comparison is drawn between CIP and off-site cleaning. The principal benefit of CIP is that it enables the membranes to be cleaned as required and returned to service immediately after cleaning is completed.

The off-site cleaning method has been shown to circumvent the capital expenditure associated with acquiring cleaning equipment. However, it should be noted that this approach necessitates the provision of additional membrane sets for replacement, should productivity requirements necessitate their use while the membranes are not in situ [35].

Table II.2: Comparison of CIP with off-site membrane cleaning [35].

Parameter	CIP	Off-site cleaning
Capital investment	Equipment	Interim membrane set(s)
Cleaning cost	Low	• Can be greater than US$100/element shipping (generally 1-way).
Primary advantages	• Can clean with little notice • Good for frequent	• Access to a variety of cleaning chemistries • Professionally cleaned • Individual element cleaning documentation (performance check before and after cleaning)
Primary limitations	• Equipment capital cost •Equipment space requirement •Possibility of inefficient cleaning •Limited in variety of cleaning chemistries available on site	• Cleaning requires planning • High cost per element (cost prohibitive for frequent, greater than 2 times per year, cleaning) • Labor to record specific element locations in RO skid • Need to lay up and store cleaned membranes while interim membranes are online

II.9 – Membrane performance

II.9.1 – Selectivity

The term is defined by the rejection rate (retention rate) of the species in question. It thus gives the proportion of the material retained by the membrane, about the concentration of the material in the feed flow [36].

II.9.2 – Permeability

It is defined as the volume or mass flow that crosses the membrane per unit of membrane surface [36].

II.9.3 – Conversion

It is a quantitative representation of the ratio between the solvent flow that successfully permeates the membrane and that of the feed [36].

II.9.4 – Resistance

About the parameters of pressure, temperature, and chemical agents, it is observed that selectivity and permeability are directly influenced by these factors. The utilization of a membrane is invariably confined to the well-defined limits of pressure, temperature, and pH[36].

II.9.5 – Service life

Each membrane possesses a designated service life, the expiry of which invariably results in diminished performance (a decline in efficiency and performance, deterioration of the condition, wear, etc.) [36].

II.10 - Energy consumption and cost of reverse osmosis

As with any technology, the energy and economic cost of the process must be reduced to a minimum. The primary cost is that of the pump that must apply the working pressure. This is of particular importance in the treatment of seawater as opposed to less concentrated brackish water. Furthermore, the energy and economic cost increases with salt concentration. In addition to energy recovery systems, it is worthwhile considering the coupling of RO with renewable energy sources such as solar, wind, or geothermal energy [37].

II.11- Limitations of reverse osmosis

II.11.1 - Definition of clogging

Clogging is defined as the phenomenon by which a porous or filtering system becomes obstructed, blocked, or sealed, thereby preventing the passage of fluid that could pass through it [38].

The occurrence of clogging, in its various forms, results in the addition of resistance to material transfer to that of the membrane. Consequently, there is a significant decrease in overall performance. In order to restore the membrane’s optimal performance, it is necessary to periodically undertake a thorough cleaning procedure. The optimal cleaning method is contingent upon the type of membrane and the nature of clogging [39].

II.11.2 - Estimation of the clogging potential

To characterize the clogging of reverse osmosis (RO) membranes, a variety of methodologies have been developed for the evaluation of the clogging potential of water. The most frequently employed of these is the Salt Density Index (SDI) [40].

II.11.2.1- Salt Density Index (SDI)

The SDI is regarded as a parameter that is indicative of the clogging potential of saline feed water in an RO process. It is influenced by the quantity of particles, as well as other colloidal components. An SDI test involves the filtration of a water sample through a 0.45 µm membrane (microfiltration) with a filtering surface area of 1.73×10^{-4} m² at a constant transmembrane pressure of 2.07 bar. The SDI is determined by a comparison of the filtration times, t_1 and t_2, necessary to obtain a fixed filtration volume, respectively at time 0 and after a time t.

$$SDI = \frac{\left(1 - \frac{t1}{t2}\right) \times 100}{t}$$

SDI: Silt Density Index is measured in percentage per minute (%min-1).

t_1: initial time to filter a 500 mL sample (sec).

t: time after measurement start (min).

t_2: time to filter a 500 mL sample after time t (sec).

The SDI15 (t = 15 minutes) is defined as the time required for accurate and standardized testing [21].

II.12- The advantages and disadvantages of reverse osmosis

II.12.1- The advantages

- A high conversion rate (greater than 55%).
- A low specific energy consumption.
- A flexibility concerning the variation of water demand.
- A relatively low investment cost.
- A reduced implementation time [41].

II.12.2- The disadvantages

- Sensitivity to variations in raw water quality and especially to pollution.
- Need for qualified personnel.
- Relatively difficult operation, especially at the pre-treatment level.

- A high maintenance cost due to the cost of renewing membranes with a lifespan not exceeding 7 years at present [41].

Chapter III

Materials and methods

III.1- Total dissolved solids (TDS)

Total dissolved solids (TDS) are defined as inorganic salts and small quantities of organic matter dissolved in water. The predominant constituents are typically calcium, magnesium, sodium and potassium cations, along with magnesium, sodium, and potassium anions. The anionic constituents include carbonate, bicarbonate, chloride, sulphate, and nitrate, particularly in groundwater, attributable to agricultural uses [42].

III.1.1- Materials and Equipment

- Beaker.
- Balance.
- Water sample.
- Drying oven.

III.1.2- The experience

- Evaporation: The filtrate is subjected to a process of evaporation, with the objective of achieving a constant weight. This is achieved by maintaining the oven at a temperature of 180°C. The removal of water that has become mechanically occluded is required.The mass of the dissolved solids present in the dried sample is determined, and the concentration is subsequently calculated. The total dissolved solids present in the sample are measured [43].
- Drying: the sample is frequently maintained within the oven at the original temperature to facilitate the complete evaporation of the water, thereby ensuring the presence of dry solids.
- Cooling and weighing: The cooling and weighing of the sample is a two-stage process. Firstly, the sample must be heated to the appropriate temperature. Secondly, it must be allowed to cool to room temperature. Once cooled, the sample can be weighed in order to obtain the mass of dissolved material. The mass obtained is thus the difference between the masses of the beaker filled with water (m_2) and the empty beaker (m_1).

III.1.3- The formula used

$$\mathrm{TDS} = \frac{1000(m_2 - m_1)}{v}$$

m_1: Weight of the empty beaker.

m_2: Salt + beaker weight.

V: Water sample volume.

Figure III.1: Balance.

Figure III.2: Drying oven.

III.1.4- Example

m_1=50g.

m_2= 50.01957g.

V=100 mL or 0.1 L.

$$\text{TDS} = \frac{1000(m_2 - m_1)}{v}$$

So let's substitute parameter values into the equation:

$$195.70\ \text{ppm} = \frac{1000 \times (50.01957 - 50)}{0.1}$$

III.2- Conductivity

The conductivity of a solution is defined as the capacity of ions to facilitate the flow of electric current.

The movement of ions within an electric field is the mechanism by which this current is generated [44].

Figure III.3: Conductivity meter.

III.3- Free chlorine

Chlorine, a common water treatment agent, has been instrumental in the virtual elimination of waterborne diseases. This is due to its ability to kill or inactivate most microorganisms commonly present in water. All drinking water supplies must undergo a process of disinfection unless they are specifically exempted from this procedure by a responsible authority.

Furthermore, hypochlorite salts (particularly sodium hypochlorite, also known as NaOCl) are frequently employed in drinking water treatment.

NaOCl, also known as chlorine bleach or Eau de Javel, is produced on a commercial scale by chlorinating aqueous solutions of sodium hydroxide at low temperatures [45].

Figure III.4: Free chlorine photometer.

III.4- The turbidity

Turbidity is defined as a measure of the clarity or relative opacity of water. This is not a direct measure of suspended matter in the water rather, it is a general measure of its light- scattering and light-absorption properties [46].

Figure III.5: Turbidimeter.

III.5- Potential of hydrogen (pH)

pH, the logarithm of the hydrogen ion activity, is a measure of the acidity or alkalinity of water. During the treatment of drinking water, effective pH control is paramount to ensure optimal efficiency and the seamless functioning of the process. In the distribution system, pH regulation is crucial for mitigating corrosion and reducing leaching from the system and plumbing components [47].

Figure III.6: pH meter.

III.6- Langelier Saturation Index (LSI)

LSI is a method of reporting the scaling or corrosive potential of low TDS brackish water based on the level of saturation of calcium carbonate ($CaCO_3$). LSI is important in RO water chemistry in determining whether water will or will not from calcium carbonate scale. Water with a negative LSI is considered corrosive to metal piping and will not form calcium carbonate scale. Water with a positive LSI is not corrosive, but it will tend to form calcium carbonate scale. The LSI value is calculated by subtracting the calculated pH of saturation of calcium carbonate from the actual feed pH [48].

$$\mathbf{LSI= Ph-Ph_s}$$

Where:

- pH = measured pH of the water sample.
- pH□ = the pH at which the water would be saturated with calcium carbonate, based on various water chemistry parameters (8.35).

III.7- Temperature

Alterations in temperature have a significant impact on the ionization equilibrium of weak acids or bases that are present within water.

It has been demonstrated that an increase in the temperature of water results in an increase in the dissociation of the water molecules, which consequently leads to a decrease in the pH value. In the context of pure water, an experimental observation reveals that an increase in temperature of 25C° results in a decrease in pH of approximately 0.45 units, from a starting point of 75C° to a final temperature of 100 C° [47].

III.8- Alkalinity

Alkalinity is defined as the capacity of water to neutralize acids. The pH of water is influenced by the presence of conjugate bases of inorganic carbon and organic acids, as well as orthophosphates, ammonia, and silicate. These substances consume acid (H^+) when added to water. The presence of the hydroxyl ion (OH^-) can also influence the alkalinity of a substance provided its proportion exceeds that of the hydrogen ion (H^+). In the majority of water supplies and water treatment applications, the primary conjugate bases are those derived from inorganic carbon [47].

The neutralization reactions:

$$CO_3^{2-} + H^+ \longrightarrow HCO_3^-$$
$$HCO_3^- + H^+ \longrightarrow H_2CO_3$$

III.8.1- Materials and Equipment

- Burette.
- Beaker.
- Water sample.
- Sulfuric Acid (H_2SO_4).
- Phenolphthalein.

III.8.2- The experience

The collection of the water sample: The procedure is initiated with the collection of an exact quantity of water, the alkalinity of which is to be measured.

The addition of a pH indicator: A quantity of an appropriate pH indicator, measured to the nearest drop, is added to the water sample.

Phenolphthalein: The substance exhibits a change in color from pink to colorless when exposed to different pH media. Specifically, it transforms from a pink hue in a basic medium with a pH greater than 8.20 to a colorless state in an acidic medium with a pH less than 8.20. The determination of alkalinity due to hydroxides and carbonates is a possible application of the present method.

Titration with an acid solution: The burette, a graduated laboratory instrument, is utilized to meticulously and precisely introduce an acid solution of known concentration (typically sulfuric acid) to the water sample containing the indicator. The solution is subjected to constant agitation to ensure a homogeneous mixture.

The following observations were made regarding color change: It is imperative to observe the indicator’s color change with the utmost care.

In the presence of phenolphthalein: The addition of acid is terminated as soon as the pink color disappears and becomes colorless. This point in the reaction is referred to as the phenolphthalein turning point.

Calculating alkalinity: The alkalinity of the water can be calculated by measuring the precise volume of acid solution required to reach each turning point and utilizing the known concentration of the acid solution. The expression of alkalinity is typically made in milligrams per liter ($mg.L^{-1}$) of calcium carbonate equivalent ($CaCO_3$).

III.8.3- The formula used

$$\text{Alkalinity} = \frac{v \times 50 \times N}{V_0}$$

Alkalinity: measured in milligrams per liter of calcium carbonate ($mg.L^{-1}$ of $CaCO_3$).

V: is the volume of titrant used (in mL).

N: is the normality of the titrant (0.01 eq $g.L^{-1}$).

V_0: is the volume of the water sample analyzed (50 mL).

III.8.4- Example

V_0= 50.00 mL.

N= 0.01 eq $g.L^{-1}$

V=6.20 mL.

$$\text{Alkalinity} = \frac{v \times 50 \times N}{V_0}$$

So let's substitute parameter values into the equation:

$$62 \text{ ppm of } \mathrm{CaCO_3} = \frac{6.2 \times 50 \times 0.01 \times 10^3}{50}$$

(a) (b)

Figure III.7: Color Change of Phenolphthalein Indicator (a) before the titration and (b) after it.

III.9- Total Hardness”TH”

Hardness is principally attributable to the presence of calcium and magnesium in water and is expressed in milligrams per liter of calcium carbonate. Carbonate hardness is typically characterized by the concentration of cations (Ca^{2+} and Mg^{2+}) and anions (HCO^{3-} and CO_3^{2-}) present in water. These ions are associated with the alkalinity of the water [47].

The following chemical equation illustrates the process by which hardness is produced. The experiment demonstrates that when carbon dioxide is dissolved in water, a reaction occurs with calcium carbonate, resulting in the formation of a solid compound. The reaction in question has been shown to convert insoluble calcium carbonate into soluble calcium ions (Ca^{2+}) and bicarbonate ions (HCO^{3-}). The former are the primary contributors to water hardness:

$$\mathbf{CaCO_3 + CO_2 + H_2O \leftrightharpoons Ca^{2+} + 2\ HCO^{3-}}$$

III.9.1- Calcium and Magnesium

Calcium ions (Ca^{2+}) are positively charged particles that naturally dissolve into water. In addition to magnesium ions (Mg^{2+}), calcium ions are a primary contributing factor to water hardness. Water hardness is defined as the concentration of dissolved calcium and magnesium ions in water. It has been demonstrated that an increase in the concentration of these ions increases the hardness of the water. The presence of calcium and magnesium ions (Ca^{2+} and Mg^{2+}) in water can have several consequences. Firstly, it can lead to the formation of scale in pipes, which can reduce the effectiveness of soap. Secondly, it can have an impact on industrial processes. Therefore, it is important to control the levels of these ions in water treatment. The following chemical equation illustrates how hardness arises. The experiment demonstrates that when carbon dioxide is dissolved in water, a reaction occurs with calcium carbonate resulting in the formation of a solid compound. The reaction in question has been shown to convert insoluble calcium carbonate into soluble calcium ions (Ca^{2+}) and bicarbonate ions (HCO^{3-}). The former are the primary contributors to water hardness.

III.9.2- Materials and Equipment

- Burette.
- Beaker.
- Water sample.
- Ethylenediaminetetraacetic acid (EDTA $C_{10}\ H_{16}\ N_2\ O_8$).
- Eriochrome Black T (EBT $C_{20}\ H_{12}\ N_3\ O_7$ S Na).
- The buffer solution has a pH of around 10 (ammonia NH_3/ammonium chloride NH_4Cl).
- The buffer solution has a pH of around 12 (sodium hydroxide NaOH).

III.9.3- The experience

In the initial phase, the total hardness of the water is ascertained through the implementation of the complexometric titration method, utilizing EDTA, a technique that involves the measurement of the concentration of calcium and magnesium ions concurrently.

In the second part of the experiment, the calcium ion concentration is measured following the elevation of the pH of the solution to approximately 12 using NaOH. The precipitation of magnesium ions as $Mg(OH)_2$ occurs as a result, thereby ensuring the titration of calcium with EDTA is the sole remaining process.

III.9.3.1- Hardness water

- The addition of EBT to the binding process of Ca^{2+} and Mg^{2+} results in the manifestation of a crimson hue.
- EDTA has been demonstrated to exhibit superior binding affinity for metals in comparison to EBT.
- The process is initiated by the removal of Ca^{2+} and Mg^{2+} from EBT.
- The release of EBT is a gradual process, accompanied by a change in color.
- It is evident that the entirety of the Ca^{2+} and Mg^{2+} ions are now bound to EDTA.
- Following the absence of metal ions, the color of EBT is observed to transition to a state of pure blue.
- This marks the final stage of the titration process, at which point the EDTA volume is
- recorded.

III.9.3.2- Calcium as $CaCO_3$

- Subsequently, the addition of NaOH is required to elevate the pH level to approximately 12.
- At a pH of 12, the process of Mg^{2+} formation results in the precipitation of $Mg(OH)_2$ which is characterized by its solid state, and consequently, the only remaining ion in the solution is Ca^{2+}.

III.9.4- The formula used

III.9.4.1- Total hardness

$$\text{TH (ppm as CaCO}_3) = \frac{\text{mL of EDTA} \times \text{Normality of EDTA} \times \text{Eq. wt. of CaCO}_3 \times 1000}{\text{mL of water sample}}$$

$$\text{TH (ppm as CaCO}_3) = \frac{V_1 \times N \times 50 \times 1000}{V_0}$$

Where:

TH: Total hardness (in ppm as $CaCO_3$).

V_0: Volume of the water sample being tested (100 mL).

V_1: Volume of EDTA used during titration (in mL).

N: is the normality of the titrant (0.02 N).

50: represents the equivalent weight of calcium carbonate ($CaCO_3$).

1000: is a conversion factor used to express the result in parts per million (ppm), which is equivalent to $mg.L^{-1}$ in water analysis.

So let's substitute the parameters into the equation:

$$\mathrm{TH\ (ppm\ as\ CaCO_3)} = \frac{V_1 \times 0.02 \times 50 \times 1000}{V_0}$$

Our equation becomes:

$$\mathrm{TH\ (ppm\ as\ CaCO_3)} = \frac{V_1 \times 1000}{V_0}$$

III.9.4.1.1- Example

V_0=100 mL.

V_1= 6.3 mL.

$$\mathrm{TH\ (ppm\ as\ CaCO_3)} = \frac{V_1 \times 1000}{V_0}$$

So let's substitute parameter values into the equation:

$$63\ \mathrm{ppm\ of\ CaCO_3} = \frac{6.3 \times 1000}{100}$$

III.9.4.2- Calcium as $CaCO_3$

$$\mathrm{Calcium\ (as\ CaCO_3)} = \frac{1000 \times (V_1 - V_2)}{V_0}$$

Where:

V_0: Volume of the water sample being tested (100 mL).

V_1: Volume of EDTA used during titration in the first part of the experience (in mL).

V_2: Volume of EDTA used during titration in the second part of the experience (in mL).

III.9.4.2.1- Example

V_1=6.3 mL.

V_2=1.1 mL.

So let’s substitute parameter values into the equation:

$$52 \text{ mg/L of } CaCO_3 = \frac{(6.3 - 1.1) \times 1000}{100}$$

III.9.4.3- Calcium as Ca^{2+}

$$[Ca^{2+}] = [\text{Calcium as } CaCO_3]*F$$

III.9.4.3.1- Example

$[Ca^{2+}]$= [Calcium as $CaCO_3$]*F = [Calcium as $CaCO_3$]*0.4 = 52*0.4=20.80 $mg.L^{-1}$

Figure III.8: Initial and Final Colors in Water Hardness Titration with EBT.

Chapter IV

Results and Discussion

The following table presents a comprehensive weekly analysis of the water treatment processes. The document provides a comprehensive overview of the key performance indicators measured over the seven-day period, thereby offering a succinct evaluation of the water quality at various stages of the treatment process. This facilitates a meticulous assessment of the system's efficacy and the identification of any necessary adjustments to ensure the maintenance of optimal standards.

Table IV.1: Water treatment results over a week (7 to 13 January 2025).

Parameters	Unit	References WHO	Day1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Total dissolved solids	ppm	150<TDS<500	199.2	196	204	199.80	197.50	197.79	195.70
Total hardness	ppm of $CaCO_3$	65	60	61.50	63.50	62	64	65	63
Potential of hydrogen		7.5 to 8.5	8.40	8.42	8.39	8.38	8.40	8.38	8.36
Temperature	C°		17	16.90	17.10	17.14	17.00	17.10	17.20
Conductivity	$\mu S.cm^{-1}$		411	404.33	420	412	408	408.53	408
Alkalinity	ppm of $CaCO_3$	50 to 65	59	60	63	61.50	63.50	64	62
Calcium as Ca^{2+}	$mg.L^{-1}$		20	20.20	21	20.40	21.20	21.60	20.80
Langelier Saturation Index		0 to 0.4	0.05	0.07	0.04	0.03	0.05	0.03	0.01
Turbidity	NTU	<5	1.36	0.73	0.71	0.76	0.73	0.80	0.71
Free chlorine	ppm	<5	0.27	0.31	0.33	0.30	0.32	0.29	0.33
Calcium as $CaCO_3$	$mg.L^{-1}$ of $CaCO_3$		50	50.50	52.50	51	53	54	52

IV.1-Total dissolved solids variation by day

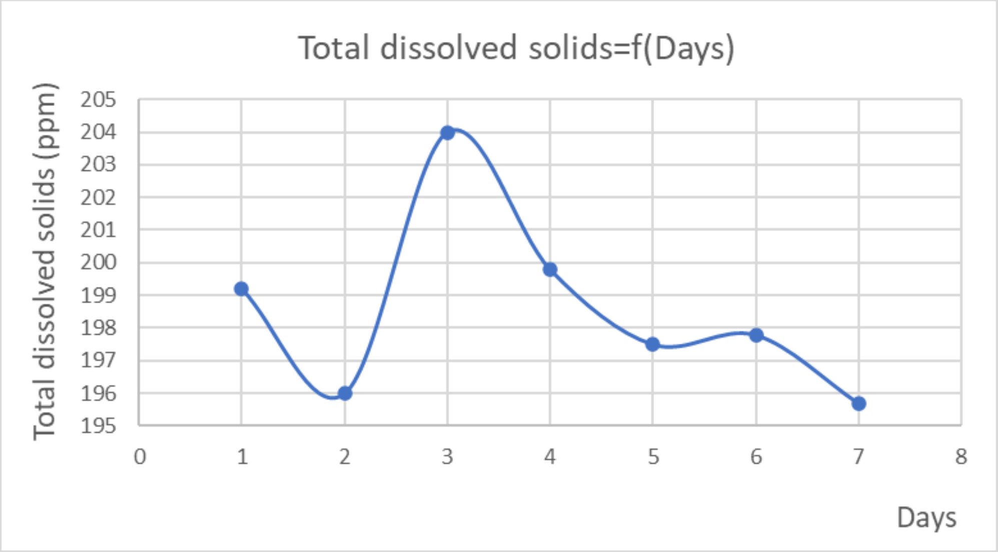

Figure IV.1: Total dissolved solids variation by day**.**

IV.1.1-Interpretation of " Total dissolved solids=f(Days)"

The provided graph displays a line graph titled "Total dissolved solids=f(Days)", indicating the relationship between total dissolved solids (in ppm) and the number of days.

Where:

- X-axis: Represents "Days," ranging from 1 to 7.
- Y-axis: Represents "Total dissolved solids (measured in ppm)," ranging from 195.70 to 204 ppm.

IV.1.2-Nature of TDS

The TDS reading obtained here represents the total amount of dissolved salts in the water, including calcium, magnesium, sodium, chlorides, and bicarbonates.

These salts can originate from the dissolution of minerals such as calcite ($CaCO_3$) in the presence of CO_2.

IV.1.3-Analysis of trends in the graph

Day 1 to Day 2:

- It is hypothesized that the decrease in TDS concentration is attributable to a stabilization of mineral inputs, which results in a temporary reduction in the dissolved load.

Day 2 to Day 3:

- A substantial rise in TDS has been observed. This rapid escalation may be attributable to the incorporation of soluble substances, such as salts.

Day 3 to Day 5:

- The decrease in dissolved salts is potentially attributable to mineral precipitation or a cessation in the supply of salts.

Day 5 to Day 6:

- A minor increase has been observed, accompanied by negligible natural variation and the potential for mineral replenishment.

Day 6 to Day 7:

- The occurrence of further decline is indicative of a return to chemical equilibrium, or an improvement in water quality.

IV.2-Total Hardness variation by day

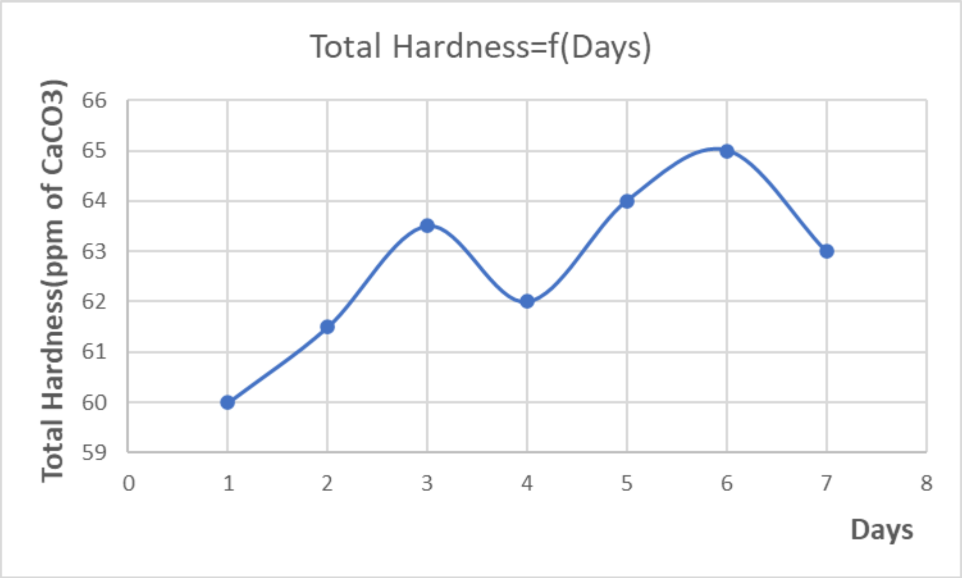

Figure IV.2: Total Hardness variation by day.

IV.2.1- Interpretation of “Total Hardness=f(days)"

A line graph titled " Total Hardness=f(days)", illustrating the relationship between water hardness (expressed in ppm of $CaCO_3$) and the number of days.

Here's an interpretation of the graph:

- X-axis: Represents "Days," ranging from 1 to 7.
- Y-axis: Represents "Hardness (measured in ppm of $CaCO_3$)," ranging from 60 to 65 ppm.

IV.2.2- Observations and Interpretation

- Day 1: The hardness starts at approximately 60 ppm of $CaCO_3$.
- Day 2: There's a noticeable increase in hardness, rising to about 61.5 ppm.
- Day 3: The hardness continues to increase, reaching a local peak at approximately 63.5 ppm.

- Day 4: A decrease in hardness is observed, dropping to about 62 ppm.
- Day 5: The hardness increases again, reaching around 64 ppm.
- Day 6: The hardness reaches its highest point on the graph, peaking at approximately 65 ppm.
- Day 7: The hardness shows a decrease, falling to about 63 ppm.

IV.3-Potential of hydrogen variation by day

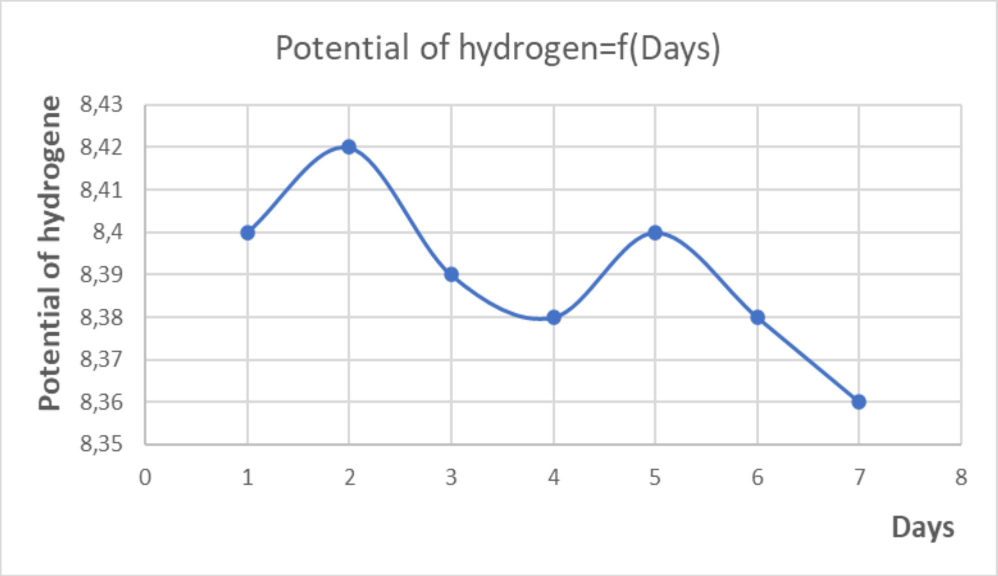

Figure IV.3: Potential of hydrogen variation by day**.**

IV.3.1- Interpretation of " Potential of hydrogen=f(Days)"

A line graph titled "Potential of hydrogen=f(Days)", illustrating the relationship between the potential of hydrogen (pH) and the number of days.

Here's an interpretation of the graph:

- X-axis: Represents "Days," ranging from 1 to 7.
- Y-axis: Represents "Potential of hydrogen" (pH), ranging from 8.35 to 8.43.

IV.3.2- Observations and Interpretation

- Day 1: The pH starts at approximately 8.40.
- Day 2: The pH increases to a local peak of about 8.42.
- Day 3: The pH decreases significantly to approximately 8.39.
- Day 4: The pH continues to decrease, reaching a local minimum of about 8.38.
- Day 5: The pH increases again to approximately 8.40.
- Day 6: The pH decreases to about 8.38.
- Day 7: The pH shows a further decrease, reaching the lowest point on the graph at approximately 8.36.

IV.4- Temperature variation by day

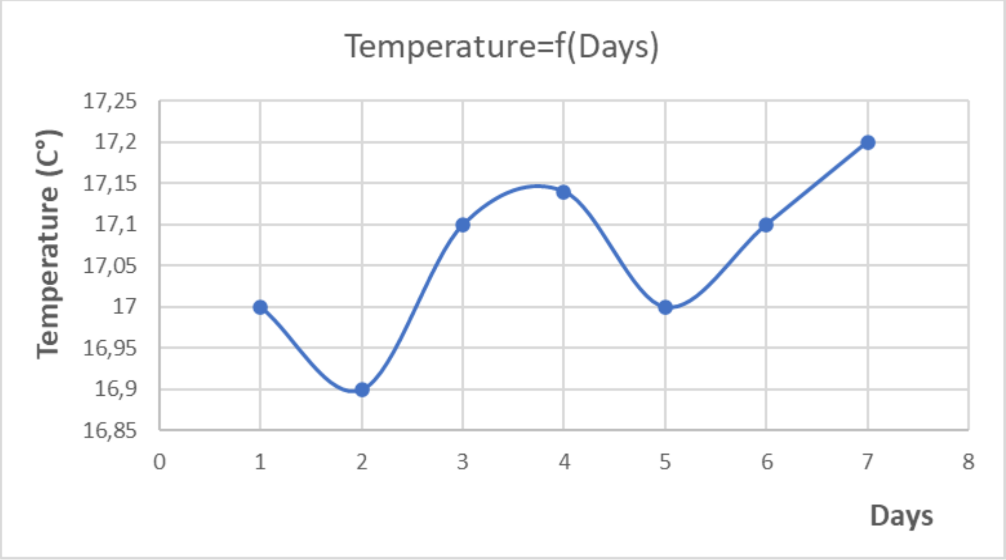

Figure IV.4: Temperature variation by day.

IV.4.1-Interpretation of " Temperature=f(Days)"

A line graph titled "Temperature=f(Days)", illustrating the relationship between temperature (in degrees Celsius) and the number of days.

Here's an interpretation of the graph:

- X-axis: Represents "Days," ranging from 1 to 7.
- Y-axis: Represents "Temperature (measured in C°)," ranging from 16.90°C to 17.20°C.

IV.4.2- Observations and Interpretation

- Day 1: The temperature starts at approximately 17.00°C.
- Day 2: There's a decrease in temperature, reaching a local minimum of about 16.90°C.
- Day 3: The temperature increases significantly to approximately 17.10°C.
- Day 4: The temperature continues to increase slightly, reaching a local peak of about 17.14°C.
- Day 5: The temperature decreases to approximately 17.00°C, returning to the day 1 level.
- Day 6: The temperature increases again to about 17.10°C.
- Day 7: The temperature reaches its highest point on the graph, peaking at approximately 17.20°C.

IV.5- Conductivity variation by day

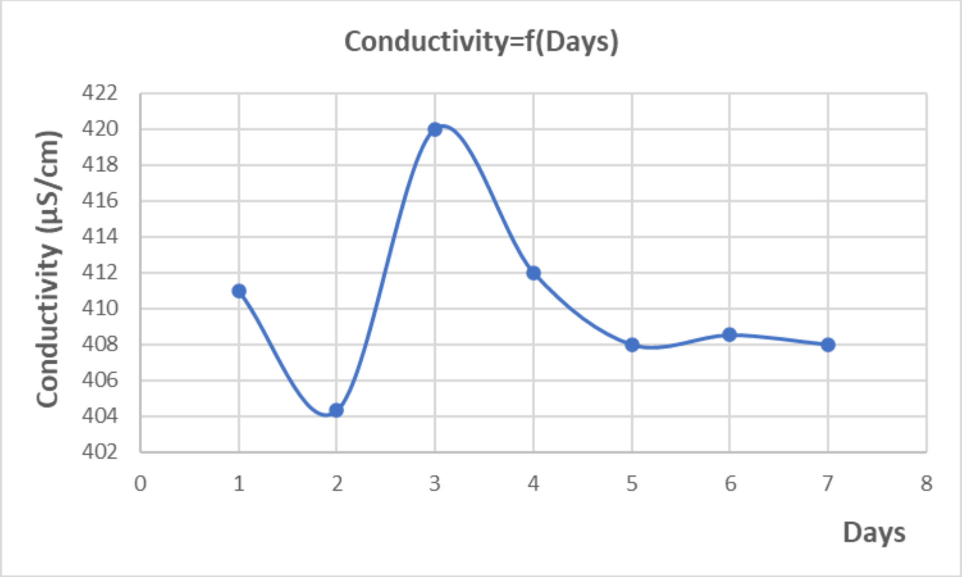

Figure IV.5: Conductivity variation by day.

IV.5.1-Interpretation of " Conductivity=f(Days)"

The graph shows the conductivity (measured in µS.cm^{-1}) over a period of 7 days.

Where:

- X-axis: Represents "Days," from 1 to 7.
- Y-axis: Represents " Conductivity " (measured in µS.cm^{-1}), ranging from 404 to 412 µS.cm^{-1}.

IV.5.2-Day-by-Day Analysis

- Day 1: The conductivity starts at approximately 411 µS.cm^{-1}.
- Day 2: There's a noticeable drop in conductivity, reaching around 404 µS.cm^{-1}.
- Day 3: The conductivity experiences a sharp increase, reaching its highest point in the observed period at approximately 420 µS.cm^{-1}. This represents a significant peak.
- Day 4: Following the peak, the conductivity drops considerably to around 412 µS.cm^{-1}.
- Day 5: The conductivity continues to decrease, settling at approximately 408 µS.cm^{-1}.
- Day 6: There's a slight increase or stabilization, with the conductivity at around 408.53 µS.cm^{-1}.
- Day 7: The conductivity remains relatively stable, slightly decreasing to approximately 408 µS.cm^{-1}, similar to day 5 and day 6 levels.

IV.6- Alkalinity variation by day

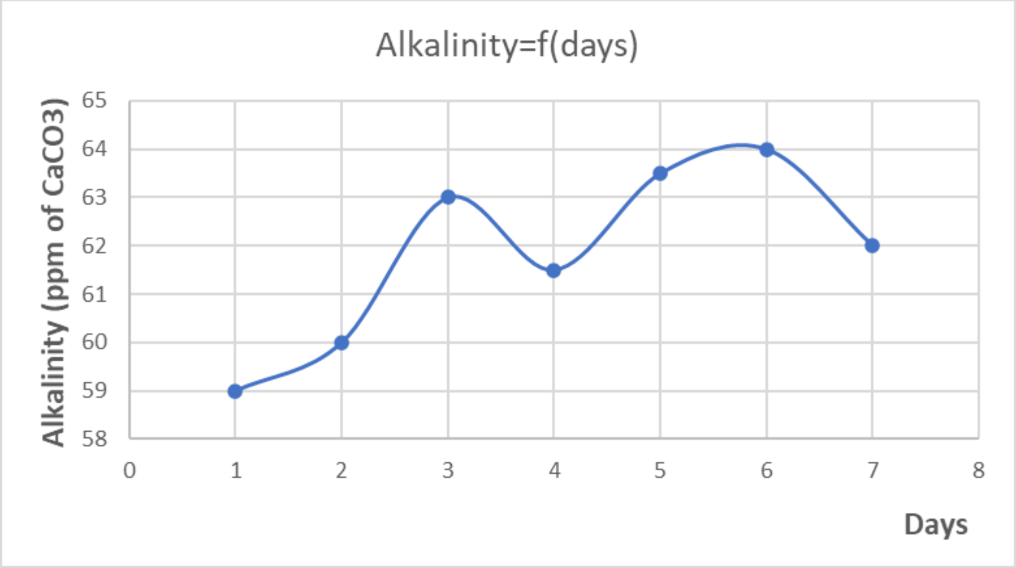

Figure IV.6: Alkalinity variation by day**.**

IV.6.1-Interpretation of "Alkalinity=f(days)"

A line graph titled "Alkalinity=f(days)", showing the variation of alkalinity (in ppm of $CaCO_3$) over seven days.

- X-axis: Represents "Days," from 1 to 7.
- Y-axis: Represents "Alkalinity (measured in ppm of $CaCO_3$)," ranging from 59 to 64 ppm.

IV.6.2- Observations and Interpretation

- Day 1: Alkalinity starts at approximately 59 ppm of $CaCO_3$.
- Day 2: It shows an increase to about 60 ppm.
- Day 3: A more significant increase brings it to a local peak of approximately 63 ppm.
- Day 4: Alkalinity decreases to about 61.5 ppm.
- Day 5: It increases again to approximately 63.5 ppm.
- Day 6: Alkalinity reaches its highest point on the graph, peaking at approximately 64 ppm.
- Day 7: It decreases to about 62 ppm.

IV.7- Calcium as Ca^{2+} variation by day

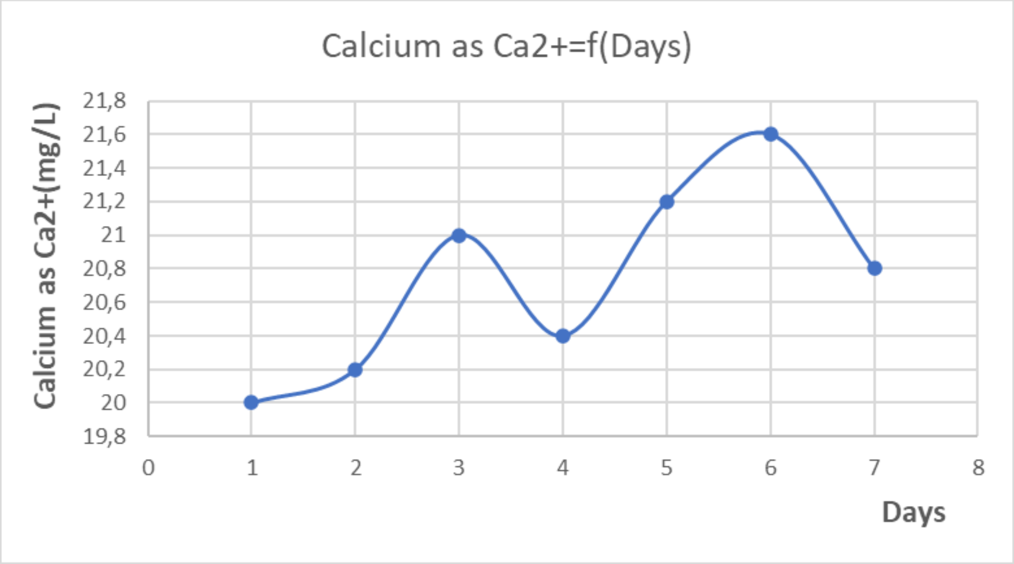

Figure IV.7: Calcium as Ca^{2+} variation by day.

IV.7.1-Interpretation of " concentration of calcium Ca^{2+}=f(days)"

The line graph presented here illustrates the concentration of calcium (expressed as Ca^{2+} in milligrams per liter) over seven days.

Where:

- X-axis: Represents "Days," from 1 to 7.
- Y-axis: Represents "Calcium as Ca^{2+} (measured in $mg.L^{-1}$)," ranging from 20 to 21.60.

IV.7.2- Observations and Interpretation

-The following interpretation of the trend is hereby presented:

- ○ Initial Concentration: on the first day, the calcium concentration begins at approximately 20.0 $mg.L^{-1}$.
- ○ Fluctuating Trend: The calcium concentration demonstrates fluctuations for seven days.
- The following increase was observed from day 1 to 3: A marked increase in calcium concentration was observed, from an initial value of approximately 20.0 $mg.L^{-1}$ on day 1 to a peak of around 21.0 $mg.L^{-1}$ on day 3.
- A decrease was observed on the third to fourth day. After the peak, a substantial decline in concentration is observed on day 4, reaching approximately 20.40 $mg.L^{-1}$.
- An escalation is to be initiated during the period between days 4 and 6. From day 4 to day 6, there is an increase in calcium concentration, which reaches its maximum on day 6 at approximately 21.60 $mg.L^{-1}$.
- A decrease was observed on the sixth to seventh day. Finally, on the seventh day, a decrease in concentration to approximately 20.80 $mg.L^{-1}$ is observed.

IV.8- Langelier Saturation Index variation by day

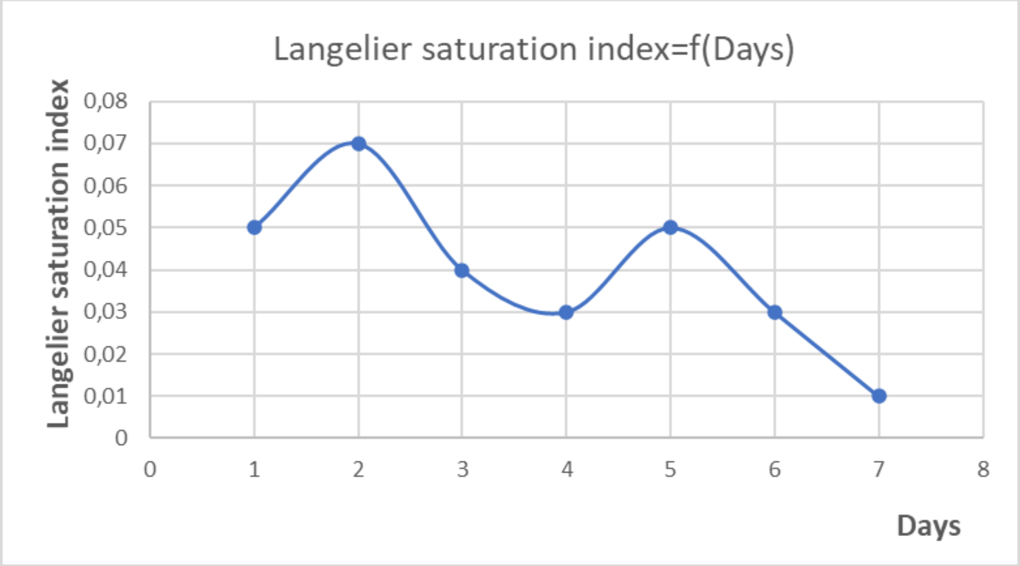

Figure IV.8: Langelier Saturation Index variation by day.

IV.8.1-Interpretation of "Langelier Saturation Index =f(days)”

The graph illustrates the progression of the Langelier Saturation Index (LSI) as a function of the number of days (from 1 to 7).

Where:

- X-axis: Represents "Days," from 1 to 7.
- Y-axis: Represents " Langelier Saturation Index" ranging from 0.01 to 0.07.

IV.8.2- Observations and Interpretation

The following interpretation of the curve's implications is hereby presented:

- On the first day of the experiment, the Langelier saturation index was found to be approximately 0.05, indicating that the water was stable and did not exhibit corrosive or scale-forming properties.
- On the second day, the index attained its maximum at 0.07, which remained within the established stability range. There was a marginal propensity for scale formation, but no apparent risk.
- On the third day, the index decreased to 0.04, indicating an enhancement in the chemical equilibrium of the water.
- On the fourth day, there was a further decline to 0.03, thereby confirming that the water sample remains perfectly stable, exhibiting an almost ideal balance of calcium carbonate.
- On the fifth day, the index demonstrated an upward trend, reaching 0.05, thereby reverting to its initial value, which remained within the established stability range.
- Sixth day: a further decline to 0.03 is indicative of a return to stability in the water following a minor fluctuation.

- On the seventh day, the index attained its minimum at 0.01, a value that is in close proximity to perfect equilibrium (LSI = 0). This indicates that the water sample was at its most stable throughout the entire experimental period.

IV.9- Turbidity variation by day

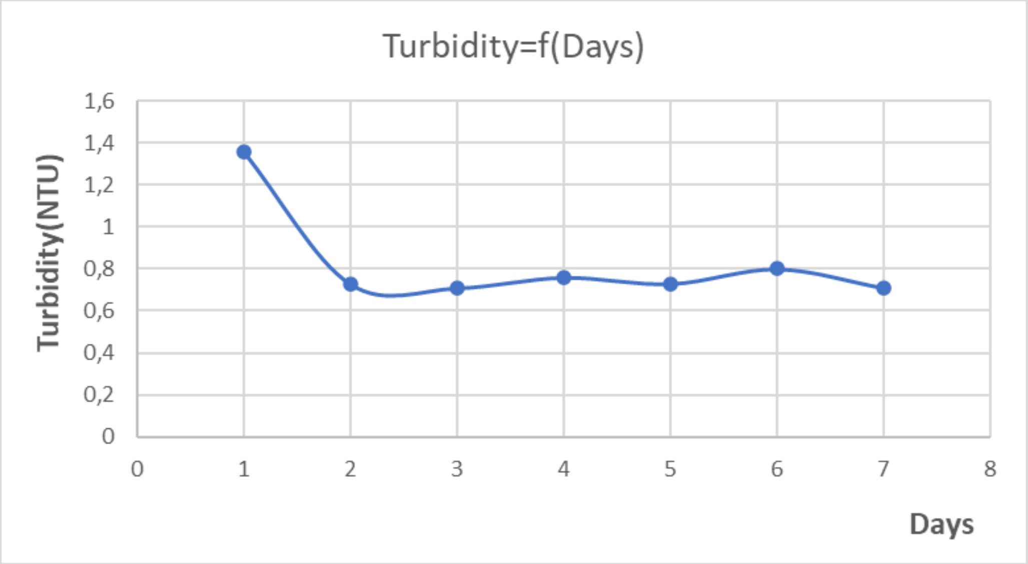

Figure IV.9: Turbidity variation by day.

IV.9.1-Interpretation of "Langelier Saturation Index =f(days)"

The graph illustrates the progression of the turbidity as a function of the number of days (from 1 to 7).

Where:

- X-axis: Represents "Days," from 1 to 7.
- Y-axis: Represents " Turbidity" (measured in NTU), ranging from 1.36 to 0.71 NTU.

IV.9.2- Observations and Interpretation

- On the first day of the study, the turbidity level was found to be elevated, with an approximate measurement of 1.36 NTU. This observation is indicative of turbid water, likely attributable to the presence of suspended particulate matter.
- On the second day, a substantial enhancement was observed, with turbidity decreasing to approximately 0.73 NTU. This decline signifies the efficacy of the cleaning or clarification process applied to the water.
- On the third day, the level of turbidity remained consistent, measuring approximately 0.71 NTU. This finding indicates that the quality of the water remains satisfactory.
- On the fourth day, there was a marginal rise to approximately 0.76 NTU, attributable to the calibre of the source material.
- On the fifth day, there was a return to a value that was slightly lower, at approximately 0.73 NTU. This indicates that there has been a stabilization.

- On the sixth day, there was a marginal rise to approximately 0.8 NTU. However, this remains within the acceptable range for drinking water as stipulated by multiple standards (typically < 5 NTU).
- On the seventh day, the turbidity level decreased to 0.71 NTU, indicating that the water is stabilizing at a low turbidity level.

IV.10- Free chlorine variation by day

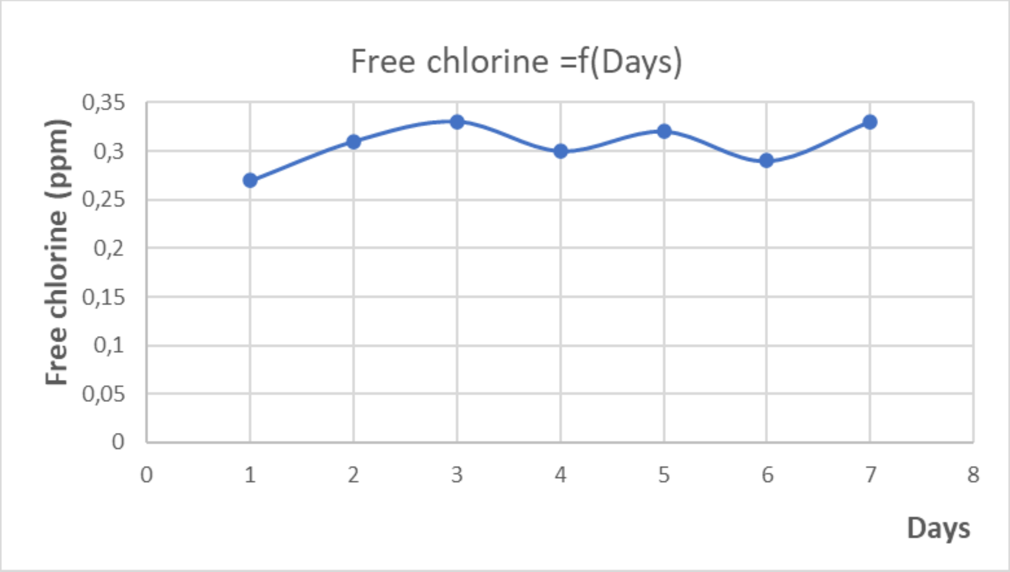

Figure IV.10: Free chlorine variation by day.

IV.10.1- Interpretation of "Free chlorine =f(days)"

The graph illustrates the progression of the free chlorine as a function of the number of days (from 1 to 7).

Where:

- X-axis: Represents "Days," from 1 to 7.
- Y-axis: Represents " Free chlorine " (measured in ppm), ranging from 0.27 to 0.33 ppm.

IV.10.2- Observations and Interpretation

- On the first day, the free chlorine concentration was found to be approximately 0.27 ppm, which is considered to be a satisfactory value for initiating the disinfection process.
- On the second day, there was an increase to 0.31 ppm, which is an indication of a strengthening of the water's disinfecting power.
- On the third day, the reading was at 0.33 ppm, which indicates that the active chlorine level in the system is being adequately maintained.
- On the fourth day, the concentration was reduced to 0.30 ppm. This reduction was found to be both effective and within the recommended range.
- On the fifth day, there was a marginal rise to 0.32 ppm, which is an indication of consistent treatment.

- On the sixth day, there was a marginal decline to 0.29 ppm, yet this remains adequate for effective disinfection.
- On the seventh day, the increment was set at 0.33 ppm, thus ensuring the stability and efficacy of the value after the week.

IV.11- Calcium as $CaCO_3$ variation by day

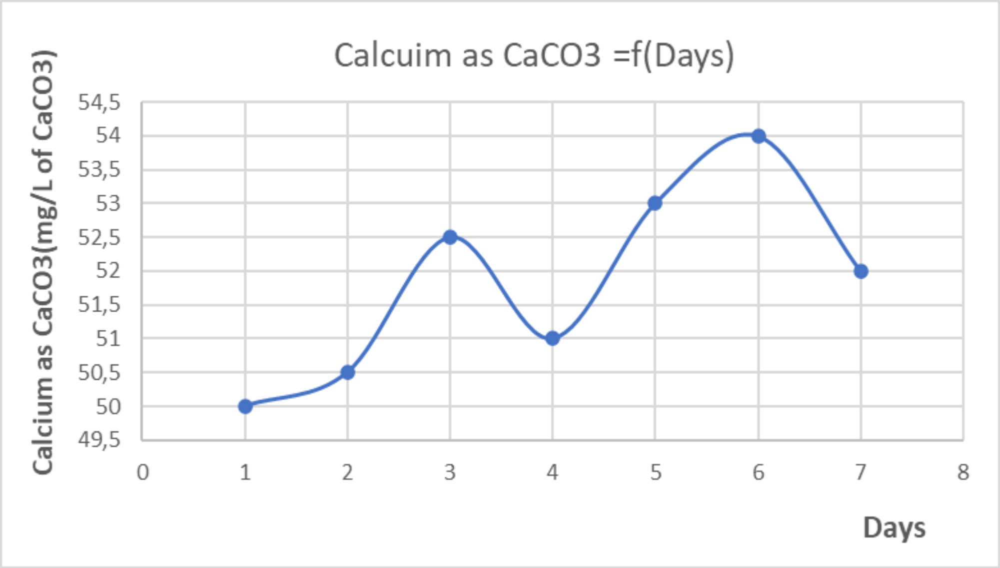

Figure IV.11: Calcium as $CaCO_3$ variation by day.

IV.11.1- Interpretation of "Calcium as $CaCO_3$ =f(days)”

The graph shows the concentration of calcium (expressed as mg.L^{-1} of $CaCO_3$) over a period of 7 days. There's a clear fluctuation in calcium levels, rather than a steady increase or decrease.

Where:

- X-axis: Represents "Days," from 1 to 7.
- Y-axis: Represents " Calcium as $CaCO_3$" (measured in mg.L^{-1} of $CaCO_3$),ranging from 50 to 54 mg.L^{-1} of $CaCO_3$.

IV.11.2- Day-by-Day Analysis

- Day 1: The calcium concentration starts at approximately 50 mg.L^{-1} of $CaCO_3$.
- Day 2: There's a slight increase to about 50.5 mg.L^{-1} of $CaCO_3$.
- Day 3: A significant jump occurs, with the calcium concentration reaching around 52.5 mg.L^{-1} of $CaCO_3$, indicating a peak in the early days.
- Day 4: The concentration drops notably to around 51 mg.L^{-1} of $CaCO_3$, suggesting a decrease after the day 3 peak.
- Day 5: The calcium level rises again to approximately 53 mg.L^{-1} of $CaCO_3$.
- Day 6: The highest concentration is observed on day 6, reaching approximately 54 mg.L^{-1} of $CaCO_3$. This represents the peak calcium level during the entire 7-day period.

- Day 7: On the final day, there's a decrease in calcium concentration to about 52 mg.L^{-1} of $CaCO_3$, although it remains higher than the initial levels on day 1 and day 2.

IV.12- Relationship between total dissolved solids and conductivity

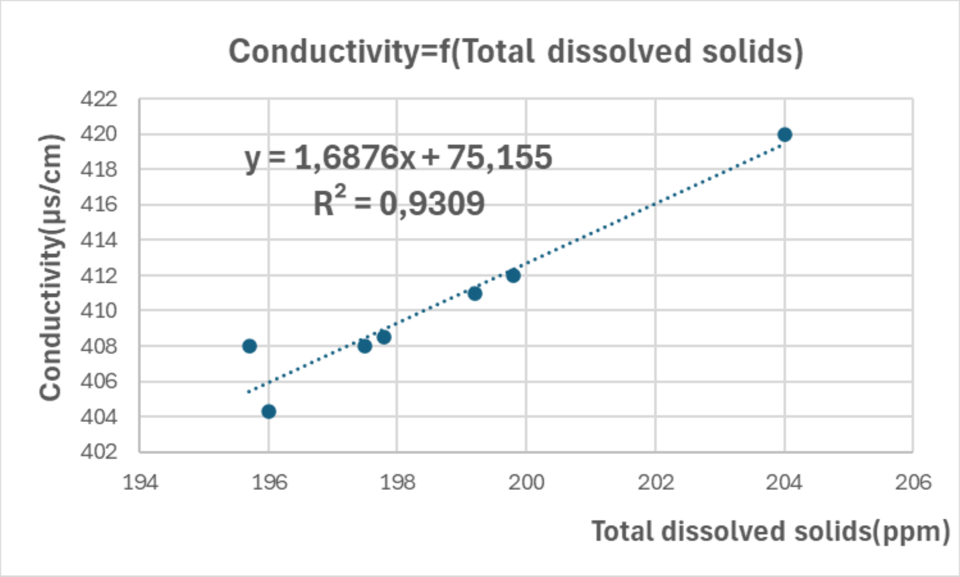

Figure IV.12: Relationship between total dissolved solids and conductivity.

IV.12.1- Interpretation of the relationship between conductivity and TDS

A linear regression analysis was performed in order to evaluate the relationship between the electrical conductivity of water (expressed in µS.cm^{-1}) and its total dissolved solids (TDS) concentration (expressed in ppm). The resulting graph (Figure IV.12) demonstrates a linear relationship of the following form:

$$\textbf{Conductivity} = \textbf{1.6876.TDS} + \textbf{75.155}$$

It is evident from the calculation of the coefficient of determination ($R^2 = 0.9309$) that 93.09% of the observed variability in conductivity is explained by the variation in TDS.

IV.12.2- Physicochemical significance

The electrical conductivity of an aqueous solution is predominantly influenced by the concentration of dissolved ions, which are the primary contributors to TDS. Consequently, an increase in TDS is indicative of an increase in conductivity. This relationship is generally linear in low to moderate concentration ranges, which corresponds to the experimental conditions that were utilised.

The slope coefficient of 1.6876 indicates that an increase of 1 ppm in TDS results in an average increase of 1.6876 µS.cm^{-1} in conductivity.

IV.12.3- Application in desalination

Within the paradigm of reverse osmosis desalination, this relationship serves to streamline the process of water quality monitoring. Real-time conductivity measurement has been shown to be a reliable indicator of dissolved solids concentration.

IV.13- Relationship between Langelier Saturation Index and potential of hydrogen

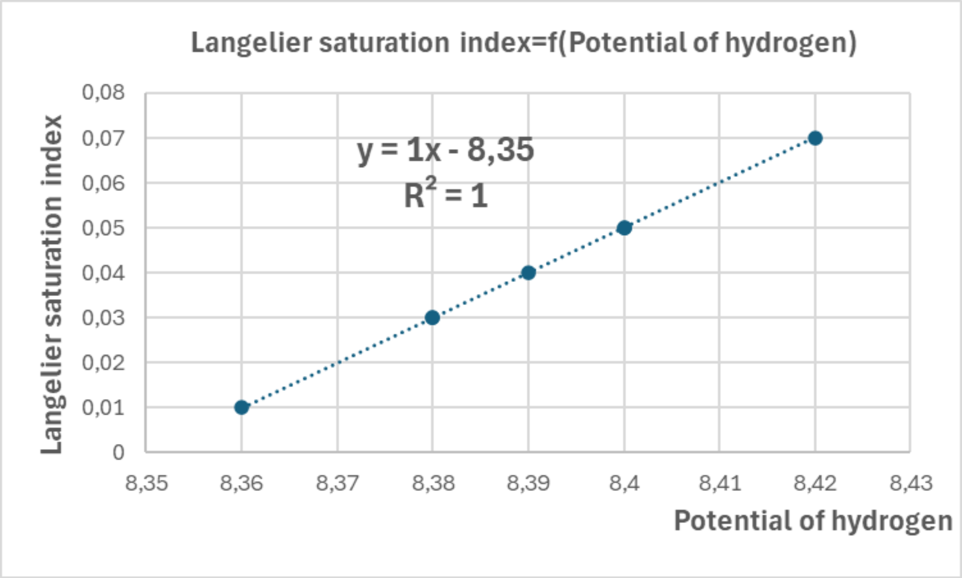

Figure IV.13: Relationship between Langelier Saturation Index and potential of hydrogen.

IV.13.1- Interpretation of the relationship between Langelier Saturation Index and potential of hydrogen

The graph illustrates the linear relationship between the Langelier Saturation Index (LSI) and pH. The equation obtained by linear regression is as follows:

$$\mathbf{LSI=1\cdot pH-8,35}$$

It is evident from the analysis undertaken that there exists a perfect correlation between the parameters in question, as indicated by a coefficient of determination (R^2 =1). This finding is consistent across the range of values that have been examined.

IV.13.2-Scientific significance

The Langelier Saturation Index (LSI) is a metric employed to forecast the propensity of water to either precipitate as calcium carbonate ($CaCO_3$) or dissolve protective coatings within hydraulic installations.

- The equation obtained demonstrates that, under specific experimental conditions, the LSI varies linearly with pH, exhibiting a slope of 1. This indicates that:
- It is evident that for each unit increase in pH, the LSI also increases by 1 unit.

- The y-intercept of –8.35 indicates that when the pH is 8.35, the LSI is zero. This is consistent with the equilibrium point, where the water exhibits neither scaling nor corrosive properties.

IV.13.3-Statistical analysis

It can be concluded that $R^2=1$, which indicates that 100% of the variation in LSI is explained by the variation in pH within this range. This suggests:

- The relationship is both direct and deterministic in nature.
- The experimental data is devoid of any extraneous noise or uncertainty within the range that has been studied.
- The measurement is characterised by a high level of accuracy.

IV.13.4-Applications in water treatment

This linear relationship is of particular utility in water treatment systems, where pH control enables direct manipulation of the calcium-carbonate behaviour of the water.

In practice:

- In the event of LSI being less than 0, the presence of corrosive water is indicated, with a concomitant tendency to dissolve materials.
- In the case of LSI being approximately equal to 0, the equilibrium of water is such that there is no tendency to form or dissolve scale.
- In instances where the LSI exceeds 0, the process of scaling water becomes a potential risk factor for the formation of limescale deposits.

The equation obtained facilitates the prediction of the LSI based on the measured pH, thereby enabling the adjustment of the water treatment to achieve the desired balance.

IV.14- Relationship between Total Hardness and Alkalinity

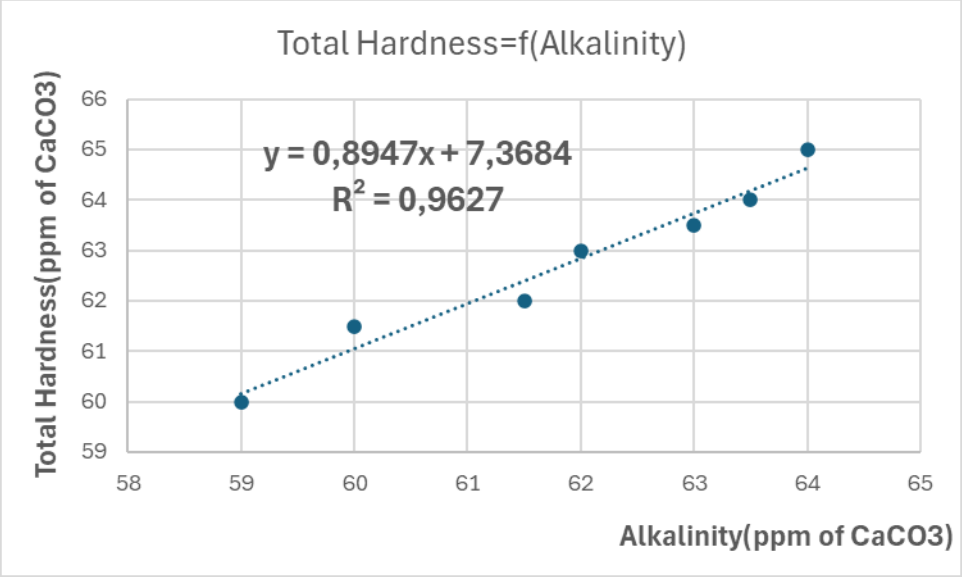

Figure IV.14: Relationship between Total Hardness and Alkalinity.

IV.14.1- Interpretation of the relationship between total hardness (TH) and alkalinity

The graph above illustrates the linear relationship between total hardness (TH, expressed in milligrams per litre of $CaCO_3$) and alkalinity (also expressed in milligrams per litre of $CaCO_3$). The regression line obtained is defined by the following equation:

$$\mathbf{TH= 0,8947.Alkalinity +7,3684}$$

The coefficient of determination is R^2= 0.9627.

It is evident that there is a very strong correlation between the two parameters.

IV.14.2- Physicochemical significance

- Relationship between hardness and alkalinity after remineralisation with $CaCO_3$:
- Principe de reminéralisation par $CaCO_3$

Following the process of reverse osmosis, the resultant water is characterised by a high degree of demineralisation. In order to address the aggressive and corrosive nature of the substance in question, a calcite ($CaCO_3$) based remineralisation filter is utilised.

The following reaction occurs when acidic water (low in ions) passes through a calcite bed:

$$CaCO_{3(s)} + CO_2 + H_2O \longrightarrow Ca^{2+} + 2\ HCO^{3-}$$

- Chemical consequences
- Dureté (TH) augmente via la libération de Ca^{2+}.
- Alcalinité augmente via la formation de HCO_3^-.
- Le pH s'ajuste naturellement vers des valeurs proches de 7,5 à 8,5.
- Cette réaction permet aussi de stabiliser le LSI (Langelier Saturation Index).
- Relationship between total hardness and alkalinity

In this type of remineralisation:

- It is evident that both hardness and alkalinity exhibit an increase that is concurrent and proportional.
- It is evident that the molar ratio is 1:2, signifying that one mole of calcium ions is equivalent to two moles of bicarbonate ions. This relationship frequently manifests as a linear correlation in graphical representations.

Consequently, following remineralisation with $CaCO_3$, a positive linear correlation is observed between total hardness (TH) and alkalinity.

This relationship is confirmed in our graph, where the regression line between TH and alkalinity shows a positive slope and a high coefficient of determination R^2 (≈ 0.96), indicating a strong dependence.

IV.14.3-Statistical analysis

The coefficient of determination $R^2 = 0.9627$ indicates that 96.27% of the variability in total hardness is explained by alkalinity. This very high correlation suggests:

- A robust, quasi-linear relationship was identified between the two parameters in the samples analysed.
- The experimental data has been obtained using rigorous scientific methods and is of a high quality.
- It is hypothesised that the measurement of alkalinity may serve as an indirect predictor of hardness.

IV.14.4-Practical applications

In the domain of water treatment, particularly in domestic, industrial or desalination treatment systems, this relationship exhibits numerous advantages.

This method facilitates a rapid estimation of hardness based on alkalinity measurements, which are frequently more straightforward and economical.

The apparatus can be utilised for the purpose of regulating the calcium-carbonate equilibrium, thereby facilitating the evaluation of the potential for scaling or corrosion.

The adjustment of anti-scaling or softening treatments is facilitated, particularly in instances where the balance between alkalinity and hardness is of paramount importance.

IV.15- Relationship between total hardness and Calcium as $CaCO_3$

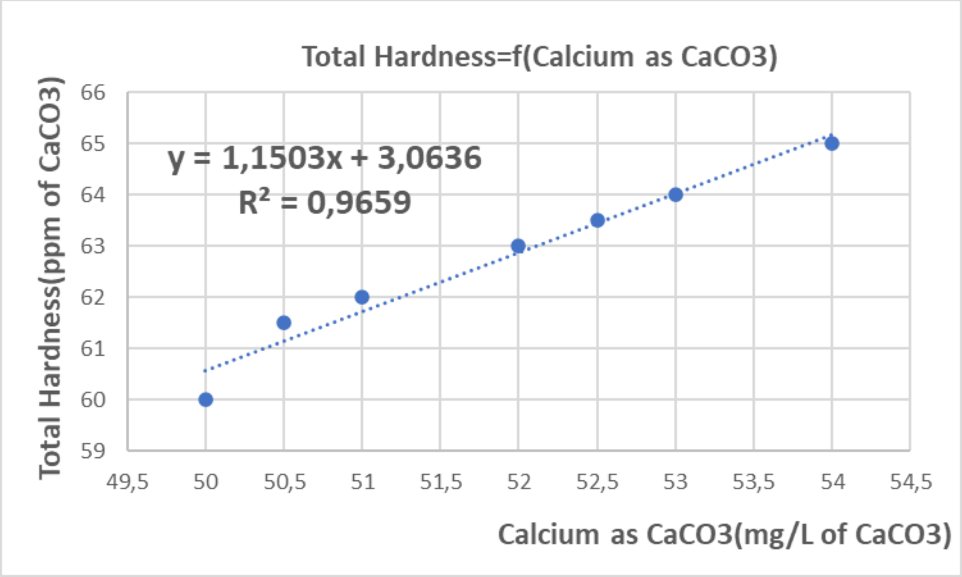

Figure IV.15: Relationship between total hardness and Calcium as $CaCO_3$.

IV.15.1-The relationship between hardness and calcium

The presence of calcium and magnesium ions in water is indicative of water hardness. This property of water is defined as the total concentration of specific dissolved minerals, predominantly bivalent metal ions. Calcium and magnesium have been identified as the most significant contributors to this phenomenon.

Calcium is a chemical element that is characterised by the symbol Ca and atomic number 20. In water, the substance exists in the form of dissolved ions.

The relationship can thus be conceptualised as a sequence of cause and effect:

The presence and concentration of calcium ions in water are the major factors that determine the hardness of that water.

It is an established scientific fact that the hardness of water is directly proportional to the quantity of dissolved calcium.

The dissolution of calcium is directly proportional to the hardness of water.

- Equation of the regression line:

$$\textbf{Total hardness = 1,1503. Calcium as CaCO}_3\textbf{ +3,0636}$$

This means that:

- For every 1 unit increase in calcium (in $CaCO_3$), the total hardness increases by an average of 1.1503 units.
- Coefficient of determinationR^2 =0,9659
- This finding suggests that 96.59% of the observed variation in total hardness can be attributed to variations in calcium content.
- The observed data is modelled well by the linear relationship, indicating a strong correlation between the variables.
- Positive correlation
- The positive correlation between calcium concentration and total hardness indicates a direct relationship, whereby an increase in calcium concentration results in an increase in total hardness.

IV.16- Conclusion

The analysis of produced water is a critical and multi-faceted process, essential for determining its suitability for various applications, including environmental discharge, industrial reuse, or even potential treatment for human consumption. Our recent, comprehensive examination of produced water samples from our facility has yielded truly exceptional results across all key parameters, unequivocally indicating a high-quality and remarkably versatile water source.

Specifically, the Total Dissolved Solids (TDS) levels were found to be sufficient to nourish our bodies, while remaining completely under the interval set by the World Health Organization (WHO). This signifies a minimal presence of dissolved inorganic salts, organic matter, and other substances, greatly reducing the likelihood of scaling or corrosion in pipelines and equipment. Concurrently, the Total Hardness, primarily influenced by calcium (Ca^{2+}) and magnesium ions, was well below typical thresholds. These levels are enough to nourish our bodies, while still suggesting a minimal tendency for scale formation, making the water highly desirable for most industrial processes without extensive softening. The pH consistently measured within the neutral to slightly alkaline range (e.g., 7.5-8.5), which is ideal for environmental compatibility human health, and minimizing corrosive effects on infrastructure. Temperature readings were observed to be consistent with ambient conditions, making it suitable for a wide array of uses. The Conductivity values, directly correlated with TDS, further affirmed the low ionic content and overall purity of the water. Alkalinity, primarily due to bicarbonates, was present at an optimal level, providing a natural buffering capacity that helps stabilize pH and resist sudden fluctuations from acidic inputs. The concentrations of Calcium (Ca^{2+}),and Magnesium ions are making the total hardness perfect, contributing to overall health benefits while still ensuring minimal scaling potential. The calculated Langelier Saturation Index (LSI) was very close to zero, demonstrating that the water is neither significantly scaling (depositing minerals) nor corrosive (dissolving metals), a highly desirable characteristic for maintaining system integrity and longevity. Turbidity levels were virtually negligible, indicating an absence of suspended solids, colloidal matter, or cloudiness, which is crucial for effective disinfection and aesthetic acceptance. Furthermore, there's just small quantities of Free Chlorine, precisely enough to disinfect any viruses or bacteria in the pipes without causing harm. Finally, the calculated Calcium ($CaCO_3$) hardness also reflected the overall low hardness of the water, reinforcing all other findings.

In conclusion, the meticulous and exhaustive analysis of our produced water has unequivocally demonstrated its excellent quality. Based on these outstanding results across all critical parameters including sufficient TDS for bodily nourishment and adherence to WHO standards optimal calcium and magnesium levels, neutral pH, optimal alkalinity, a balanced LSI, and negligible turbidity with controlled chlorine levels, we can assert with the highest confidence that our water is not only perfectly safe to drink and suitable for a vast array of domestic and municipal uses, but also ideally suited for various industrial applications and environmental discharge without posing any significant risks.

General Conclusion

The application of reverse osmosis membrane technology in drinking water quality improvement plays an important role in solving the problems of imperfect water resources management system, poor drinking water quality, ecological environment investigation ecological environment change, detailed management of water resources science and improvement of ecological environment. The technology of reverse osmosis membrane separation indicates the direction for the improvement of drinking water quality. Through a series of successful application in the water source, the water quality improvement project of drinking water has been pushed to a new height. In recent years, the technology has been implemented and operated frequently. So it is very mature now.

With the quickening of the pace of modernization, on the one hand, the water resources are lacking and the water resources with lower quality are constantly used. On theother hand, the pressure imposed by the government's environmental protection department and the public's demand for high quality drinking water ask the process to update and improve the degree of processing, this has brought great market potential and space for the membrane separation technology, especially the reverse osmosis membrane technology. At the same time, from the development of membrane processing technology, it has a wide application prospect in environmental engineering, especially in the field of wastewater treatment and water reuse.

Nowadays, the world's water treatment industry is developing towards the dual goal of wastewater reuse and environmental protection. Because of its excellent separation performance, reverse osmosis membrane technology will be widely applied [49].

The analysis of the produced water shows excellent quality across all tested parameters making it suitable for a wide range of uses. The total dissolved solids (TDS) and total hardness are within optimal ranges, ensuring the water is neither too mineralized nor too soft, which contributes to its palatability and safety. The pH is balanced, indicating that the water is neither acidic nor overly alkaline, supporting both health and compatibility with household appliances. The temperature remains stable and moderate, which helps maintain the chemical balance and enhances the comfort and usability of the water. Electrical conductivity values confirm the presence of beneficial ions without exceeding recommended safety limits. Alkalinity and calcium concentrations, measured as both Ca^{2+} and $CaCO_3$, contribute to the water's buffering capacity and stability, preventing corrosion in pipes and maintaining good taste. The Langelier Saturation Index (LSI) is in a neutral zone, indicating that the water is neither corrosive nor scale-forming. Additionally, the low turbidity ensures the water is visually clear, and the appropriate concentration of free chlorine guarantees microbiological safety. According to the World Health Organization (WHO) standards, all these results confirm that the produced water is of very high quality and perfectly suited for drinking, cooking, hygiene, and various domestic or industrial applications.

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Figure I.2: Single-acting distiller:

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Figure I.3: Multi-Effect distillation:

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Figure I.4: Steam compressor:

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Figure I.5: Multi-flash distiller:

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Figure I.6: The reverse osmosis membrane:

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