

Wastewater Treatment at Cement Industry – Transfer State of the Art Techniques to Selected Jordan Cement Industry Companies

Master's Thesis

at the Hof University of Applied Sciences, Faculty of Engineering, degree program in Sustainable Water Management and Engineering

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List of Abbreviations

MCA	Multicriteria
SA	Sustainability Assessment
MCM	Million cubic meter
MWI	National Water budget
WAJ	Water authority Jordan
JVA	Jordan valley authority
WCA	World cement Association
DMF	Dual media filter
CTBD	Cooling tower blow down
CTW	Cooling tower water
NF	Nanofiltration
EO	electrochemical oxidation
TN	Total nitrogen

1. Introduction

1.1. Scope

Water is used throughout various phases involved with cement production, including cooling systems and washing processes. The majority of the water utilized is in non-contact operations such as kiln bearings, grinding devices, heat pipes, and compressors, which are mainly cooling operations and called dry processes, where water is used only for cooling, and at the same time, water is used in a process called wet production to effectively grind the components in a contact form where water is sprayed on the raw material (Xinghan Zhu, 2022). According to the (COMMISSION, Reference Document on Best Available Techniques in the, 2001), waste water discharge is mostly limited to cooling water and has no significant impact on water pollution. On the other hand, water consumption is relatively high in the cement industry, which raises the issue of water shortages and sustainable water practices, especially in countries that face water scarcity. Wastewater has gotten the least attention in comparison to other polluting materials generated from cement plants due to its environmental hazards throughout the manufacturing process, especially in the dry processes (Faisal, Jaeel, & Al-Gasham, 2020).

Accordingly, this thesis will study wastewater treatment in the cement industry for water reuse and transfer state-of-the-art techniques to selected Jordan Cement Industry companies. The project is outlined as per:

- Literature research on the cement industry, water sector in Jordan, challenges, and correlation with the industrial sector
- Literature research on selected cement industries and a comparison of cement industry water treatment techniques
- A Comprehensive Literature Review on cooling towers, and wastewater key parameters

1.2. Aims and Objectives

The aim of this study is to transfer state-of-the-art techniques in water treatment and water quality monitoring to selected Jordan cement industry companies using the most innovative and applicable approach.

1.3. Limitations

- Factory turn off for maintenance purposes in the period of 01.12.2023 to 15.01.2024 which lead to a delay of first draft submission. Due to the turn-off, there were no available water quality test results in this period, which led to a delay in the conduct

of Section 3.4 in this study. As a solution, the author decided to use the last quality test results that were conducted before the turn-off.

- Access is denied to the water quality lab facilities for safety reasons, and photography documentation is not allowed in the water quality lab. As a result of this limitation, the documentation of the water sampling and water quality analysis procedures is not included in this study. Consequently, the data available from the water quality test results is based on the author's understanding of the lab's engineer description.

2. Literature research on the Cement industry, water sector in Jordan, challenges, and correlation with the industrial sector

2.1 Introduction to cement industry

Cement is a fundamental building and civil engineering material. The cement industry's output is directly tied to the state of the construction industry in general, and so closely reflects the broader economic situation.

After mining, grinding, and homogenization of raw materials, the first step in cement production is calcination of calcium carbonate, followed by high-temperature burning of the resulting calcium oxide with silica, alumina, and ferrous oxide to generate clinker. Clinker is then mixed or milled with gypsum and other ingredients to make cement (COMMISSION, Reference Document on Best Available Techniques in the, 2001). Calcium carbonate is derived from naturally existing calcareous deposits such as limestone, marl, or chalk. Silica, iron oxide, and alumina can be found in a wide range of ores and minerals, including sand, shale, clay, and iron ore. As a partial replacement for natural raw materials, power station ash, blast furnace slag, and other process leftovers can be utilized. The clinker burning takes place in a rotary kiln which can be part of a wet or dry long kiln system, a semi-wet or semi-dry grate preheater kiln system, a dry suspension preheater kiln system or a preheater/"Precalciner" kiln system (COMMISSION, Reference Document on Best Available Techniques in the, 2001).

A deeper look at the basic chemistry basic chemistry of the cement manufacturing process begins with the breakdown of calcium carbonate (CaCO_3) at around 900°C to calcium oxide ("CaO", lime) and freed gaseous carbon dioxide (CO_2). This is followed by the clinkering process, in which calcium oxide combines with silica, alumina, and ferrous oxide at high temperatures (usually $1400\text{-}1500^\circ\text{C}$) to generate the calcium silicates, aluminates, and ferrites that comprise the clinker. To make cement, the clinker is ground or milled with gypsum and other ingredients (Frauke Schorcht, Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide, 2013). The accompanying image displays a simplified schematic flowchart of the dry process of making Portland cement (see Figure 1).

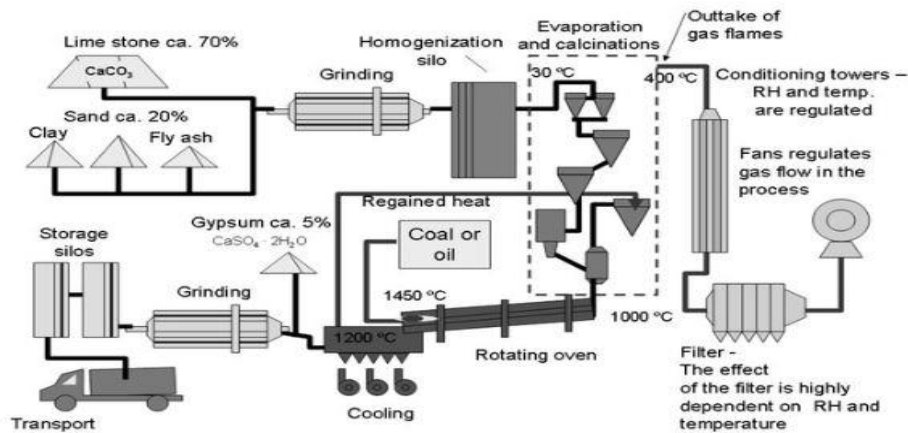


Figure 1, simplified schematic flowchart of the dry process of making Portland cement, (Addassi, 2018)

According to the European Commission, "Reference Document for the Production of Cement, Lime and Magnesium Oxide", World-wide cement production is manufactured using four different processes: dry, semi-dry, semi-wet, and wet. Those classifications are based on the water used throughout the process. For example, the dry process uses water only for cooling purposes; on the other hand, the wet process involves water from extracting the raw material to the finished product, for example, the raw material washing process, crushing, and mixing stages.

In Jordan and according to the author perspective, the main processes are used in Jordan's cement industries are limited to dry and semi-wet processes.

According to the (COMMISSION, Reference Document on Best Available Techniques in the, 2001) the cement production four different processes outlined as per:

- The dry process of grinding and drying raw materials to produce raw meal in the form of a flow-able powder. The dry raw food is fed into a preheater or Precalciner kiln, or, in exceptional cases, a long dry kiln.
- The semi-dry technique, in which dry raw food is pelletized with water and fed into a grate preheater prior to the kiln or a long kiln outfitted with crosses.
- The semi-wet method of dewatering the slurry in filter presses. The resulting filter cake is extruded into pellets, which are then fed to either a grate preheater or a filter cake dryer for raw meal manufacture.
- The wet process in which raw ingredients are ground in water to generate a pump-able slurry (typically with a high moisture content). The slurry is then either injected directly into the kiln or sent via a slurry dryer first.

2.2 Cement industry in Jordan

Jordan has a well-established cement sector that has grown throughout time to satisfy the expanding need for construction materials, contributing to Jordan's industrial and economic development. The industry operates inside a government-mandated regulatory framework, requiring adherence to environmental standards, safety laws, and other criteria (Al-kharabsheh, 2021). According to the author Jordan's cement business, like any other, confronts issues such as market volatility, regulatory changes, and environmental concerns. Opportunities may exist as a result of ongoing infrastructure development, regional demand, and sustainable practice innovation.

According to the author research Jordan's Cement Factories are listed as per:

- Arab Co. for White Cement Industry (Arab Co For White Cement Industry ACWCI, n.d.)
- Qatrana Cement (Qatrana Cement, n.d.)
- Cementra Jordan (cementra Jordan, n.d.)
- LafargeHolcim Group (Lafarge Jordan, n.d.)
- Northern Cement Factory (Northern Cement Factory, n.d.)
- Manaseer Group (Manaseer Group, n.d.)

Water consumption is an important part of the cement manufacturing process, encompassing many phases ranging from raw material preparation to cement manufacturing. Water consumption varies depending on factors such as the type of manufacturing process, technology used, and the specific practices of different cement plants (COMMISSION, Reference Document on Best Available Techniques in the, 2001).

Because of the economic and technological benefits of cement products, interest in improving cement characteristics and addressing any issues related with cement production has grown. Heightened public awareness of the difficulties posed by global warming has recently heightened concern about the environmental impact of cement manufacturing (Deborah N. Huntzinger, 2009). Cement manufacture requires a considerable amount of energy, and energy generation necessitates a large amount of water use, for example cooling down power plants (Ronald C. Pate, 2007). According to the author, this problem represents a problem for power plants and cement manufacturers, where the pre-heating stage in cement production requires a large amount of energy, also according to Cementra Jordan, a small power plant based on coal is used to generate power, which needs a large amount of water for cooling purposes. In addition to the pre-heating towers, they consume water for cooling purposes.

Typically, the amount of direct fresh water used to produce one ton of cement is used to calculate water consumption in the cement industry. The word 'fresh water' refers to fresh

tap water, groundwater, or surface water added to a cement plant's water system, excluding the circulating water necessary for cooling. This statistic, known as the direct water consumption intensity, which does not include recycled and reclaimed water, is mostly determined by the cement manufacturing process and the equipment utilized (Deborah N. Huntzinger, 2009).

Jordan's large-scale businesses include phosphate and potash mining, cement production, fertilizers, and petroleum refining (Al-Najjar, 2023). According to the (Azzam Hamaideh, 2013) in 2008 Lafarge cement Jordan, Al-Fuhais plant, is one of the largest industrial water consumers in Jordan consumed about 1140 m³ /day, in comparison with water consumption in Cementra Jordan, Cementra Jordan consume in 2023 approx. 857 m³ /Day (according to the water demand engineer in Cementra). After a breakdown and a deeper look on the consumption numbers Lafarge cement Jordan water resources are divided into 2 categories, first is fresh water and second is Treated wastewater and Collection pool, where the reused water source provide a total of 260 m³ /day, according to (Azzam Hamaideh, 2013). In comparison to Lafarge cement Jordan, Cementra Jordan depends totally on fresh water as a resource and does not apply treatment techniques for reuse the water resources. This comparison shows the need for water treatment techniques to reuse the water in the production process by Cementra and other cement manufacturers in Jordan, whereas Lafarge Cement Jordan has a treatment process to reuse water in order to lower its freshwater footprint. In addition, the cement industry in Jordan needs to adapt a sustainable water management strategy in accordance with the National Water Strategy 2023–2040 of Jordan (Al-Najjar, 2023). The need of a water reuse system in such a high water demand industry is a must in such a scarce resources country, where Jordan is one of the most water-scarce countries in the world (Al-Najjar, 2023), according to the National Water Strategy 2023-2040, industrial sector in Jordan depends mainly in Freshwater resources.

In the author's opinion, transferring the best art techniques in waste water treatment will help and enhance the cement production industry in Jordan to lower their fresh water footprint.

2.3 Water scarcity in Jordan

Jordan, tucked in the center of the dry Middle East, has a difficult issue that extends beyond its ancient landscapes and modern aspirations: water scarcity. As one of the world's most water-stressed countries, the Hashemite Kingdom of Jordan must strike a delicate balance between its naturally limited water resources and the rising demands of a growing population. The convergence of geographical, climatic, political, and socioeconomic factors creates a complex tapestry of challenges that define Jordan's quest for sustainable water management. Jordan has embarked on a multifaceted journey to navigate the intricate web of water scarcity, which threatens its socioeconomic stability and environmental resilience.

This investigation digs into the complex dynamics of water scarcity in Jordan, revealing insight on the country's efforts to overcome adversity and ensure a more water-secure future (Al-Najjar, 2023). Water security has been defined as "the reliable availability of an acceptable quantity and quality of water for health, livelihood and production, at an acceptable level of water-related risks" (Grey & Sadoff, 2007). Jordan's water risks have skyrocketed owing to both natural and human factors, making it difficult to achieve water security in recent decades. Jordan's limited groundwater resources, dwindling surface water flows, and climate change have all contributed to rising temperatures, evaporation, aridity, flooding, and droughts. Over-pumping of groundwater and exploitation of surface water are the primary human causes, negatively impacting water quality, and quantity, pollution, and aquifer/basin catchment systems (Al-Najjar, 2023).

The primary problems and considerations for obtaining water security in the water sector are as follows (Al-Najjar, 2023):

- Population increase and demographic changes are significantly impacting water allocation for various uses, exceeding previous forecasts.
- Water sources, including large-scale seawater desalination, have not been developed as planned, causing a significant impact on water supply capacity.
- Climate change is causing decreases in rainfall, distribution, and pattern across the Kingdom, leading to decreased water storage in dams and groundwater recharge.
- Drought consequences exacerbate water and food security concerns.
- In recent years, relying on international sources for water has increased supply vulnerabilities.
- The escalating cost of water and wastewater services has raised concerns about financial viability.
- Jordan's water sector should stay inventive and up-to-date with new technologies to meet local demands and contribute to their development.

According to those tremendous challenges the water sector in Jordan, stakeholders need to emphasize the following main points according to (Al-Najjar, 2023):

- The importance of technological innovation to address water issues
- Identifying the total amount of water loss and overcoming this critical issue
- Actions to treat and reuse water in agriculture and industry can mitigate the impact of climate change on the water sector.

2.4 Current Situation of Jordan's Water Sector

Jordan's water sector is struggling to meet rising demand and limited supply. Demand is always rising due to population expansion and the frequent influx of migrants escaping insecurity in neighboring countries. The demand for economic development activities is also

increasing, as is the push to expand agricultural regions. In 2021, the total water use from all resources was around 109, 300, 000 m³, which included groundwater, surface water, reclaimed water, and desalination (Al-Najjar, 2023).

In 2021, renewable freshwater resources totaled approximately 680, 000, 000 m³ which equates to only 61 m³ per person for all purposes. Reclaimed water accounted for approximately 167, 000, 000 m³ while desalinated seawater accounted for less than 1, 000, 000 m³ (Al-Najjar, 2023).

Jordan is among the poorest countries in terms of conventional renewable water resources (excluding reclaimed and desalinated seawater), no available data on the reclaimed water and Jordan does not have a seawater desalination system. Which lead to falls significantly below the absolute water scarcity of 500 m³ per capita and the Middle East and North Africa (MENA) median of 800 m³ per capita in 2019. (See Figure 2).

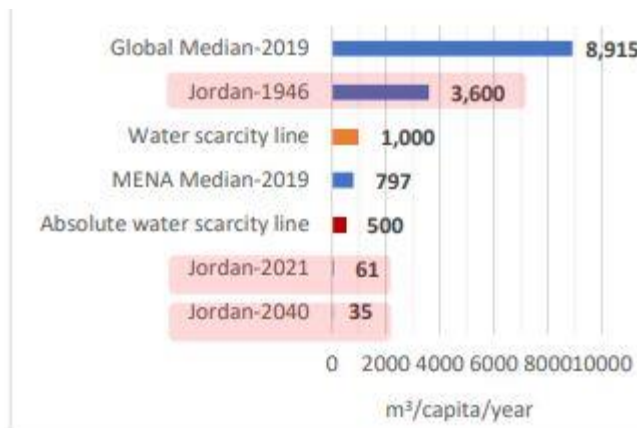


Figure 2, Jordan's Annual Renewable Freshwater Resources Per Capita vs. Water Scarcity Lines, (FAO, FAO's Global Information System on Water and Agriculture, n.d.)

Jordan's population growth and limited surface and groundwater resources will result in just 35 m³ of renewable water per capita by 2040, despite a large increase in reclaimed water (excluding desalinated water). According to the Minister of Water and Irrigation statistics, to approach absolute water scarcity in 2021, Jordan's total water resources must be 5.5 billion cubic meters. This is eight times the existing renewable water resources and five times the total water amount used from all resources.

The groundwater accounts for more than half of Jordan's yearly water budget, but it is quickly decreasing. Groundwater supplies totaled approximately 619 million cubic meters in 2021. The Disi and Jafer Basins extracted around 450 million cubic meters from renewable aquifers and 169 million cubic meters from non-renewable resources per year. The safe yield for renewable groundwater extraction is around 280 million cubic meters per year, ensuring stability and sustainability.

The surface water includes baseflows from wadis and springs, runoff, and transboundary water from the Tiberias and Yarmouk rivers. Dams are the primary structures used to hold and utilize surface water. There are 13 dams on the main wadis, with a total storage capacity of around 280 million cubic meters (excluding Karameh Dam and sediment deposit). Dam sediment deposition poses a significant difficulty, lowering storage capacity. Since construction, four main dams have lost 39 million cubic meters of storage capacity, or 27% of their original capacity according to MWI (2021) National Water Budget. Sediment accumulation in dams will continue hindering surface water use until sediment removal programs are adopted. In 2020, dams received barely 30% of their capacity due to low rainfall (Al-Najjar, 2023).

Water collected at dams is mostly utilized for agriculture, with some being mixed with treated wastewater effluent and used only for irrigation. The total surface water consumed in 2021 reached roughly 307 million cubic meters, compared to the overall discharge of surface water, including Tran’s boundary water, is 470 million cubic meters, representing 65% usage. Surface water with excessive salinity is typically desalinated and treated before being supplied (Al-Najjar, 2023).

2.5 Industrial sector water demand in Jordan

Most businesses rely on groundwater from privately licensed wells that are regulated by WAJ. Licensed wells serve as the exclusive means of interaction between the water and industrial sectors. There's also Coordination between the JVA and the potash and bromine businesses to oversee surface water in Southern Ghor. Reclaimed or small-scale desalination water is only used in the Aqaba area for industrial purposes. According to the 2021 National Water Master Plan, industrial consumption is expected to increase by around 72 million cubic meters by 2040, based on a simple trend analysis and a percentage increase assumption (Al-Najjar, 2023). (See Figure 3) depicts predicted demand, which includes planned expansions and new projects.

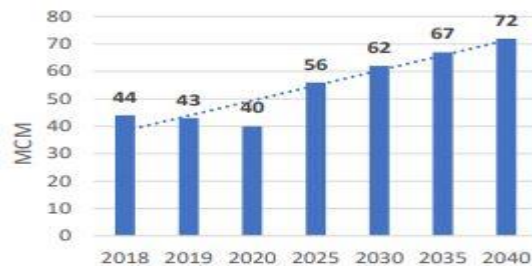


Figure 3, Water Use and Projected Demand for Industrial Sector 2021 (Ahmad Abuhijlehm, 2021)

Heavy industry, which lacks access to municipal water, relies significantly on groundwater resources, accounting for around 80% of industrial water supply in 2021. The remaining resources include surface water and recovered water in minor quantities. Industry may not be able to use the same amount of groundwater in the future due to declining groundwater levels and decreasing surface water availability due to climate change (Al-Najjar, 2023). To meet industrial sector demand, water resources will be primarily sourced from recycling, saltwater desalination, and reclaimed water (see Figure 4).



Figure 4, Current and Future Water Resources for Industrial Sector (Al-Najjar, 2023)

2.6 Current Situation of Jordan's Groundwater

Groundwater is Jordan's primary source of water, accounting for over half of total consumption (Al-Najjar, 2023) (see Figure 5).

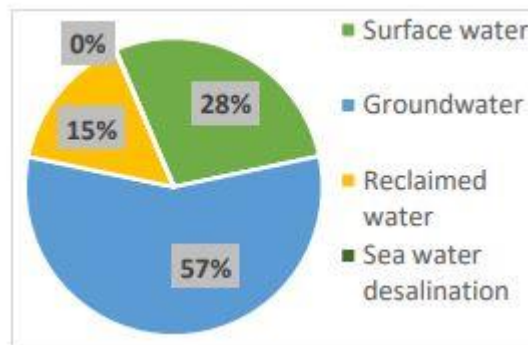


Figure 5, Water Source Shares in Jordan (2021), (Al-Najjar, 2023)

Figure 5 shows that groundwater accounts for 57% of Jordan's total water supply (619 million cubic meters), with 169 million cubic meters of non-renewable groundwater and 450 million cubic meters from renewable groundwater resources. This is nearly more than double the groundwater average annual recharge rate, or safe yield of 280 million cubic meters, as illustrated in (see Figure 6). Groundwater levels can decrease by up to 10 meters per year in some locations and 4-5 meters in others (Al-Najjar, 2023).

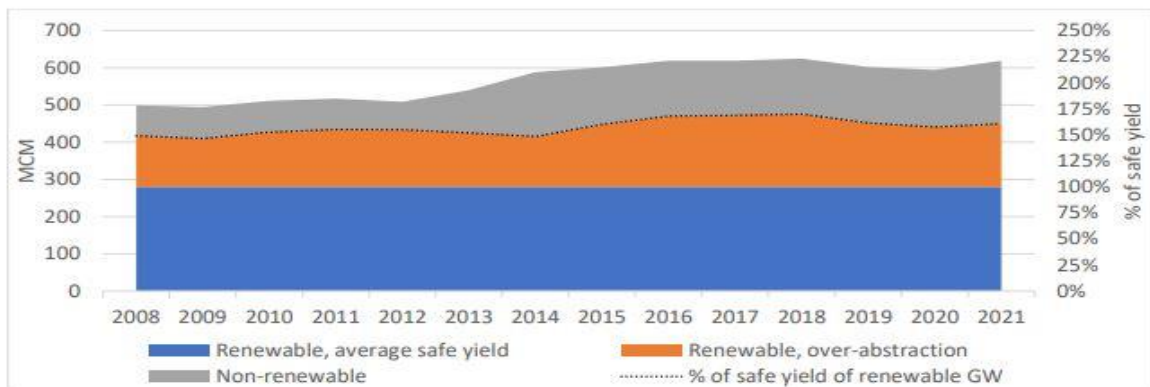


Figure 6, Renewable and Non-Renewable Groundwater Abstraction to Safe Yield, (Al-Najjar, 2023)

Figure 7 depicts the variations in groundwater use patterns over the past 14 years. The growth in municipal consumption since 2014 is due to the functioning of several resources, most notably the Disi aquifer, and their transfer to Amman and other governorates. WAJ is responsible for groundwater management, including developing bulk water sources, licensing private wells, and monitoring their abstraction volumes. The Groundwater Monitoring Bylaw, enacted in 2002 to conserve and protect groundwater from illicit use and over abstraction, has been in existence since then. The 2002 Bylaw outlined the roles of responsible authorities, updated license conditions and abstraction costs for private wells, and enforced them. Following this, a comprehensive groundwater sustainability policy was approved in 2016 brought with it new restrictions for managing Jordan Valley groundwater. In 2016, an e-Groundwater Monitoring System and Telemetric Gauging Station platform were implemented to input into the National Water Information System (NWIS). A mechanism to monitor groundwater quality is also being developed (Al-Najjar, 2023).



Figure 7, Groundwater Use over 2008-2021, (Al-Najjar, 2023)

Groundwater levels have steadily decreased due to over-abstraction techniques, as seen in Figure 8. In certain regions, the loss has exceeded 100 m, indicating that the aquifers are either out of production or nearing it.

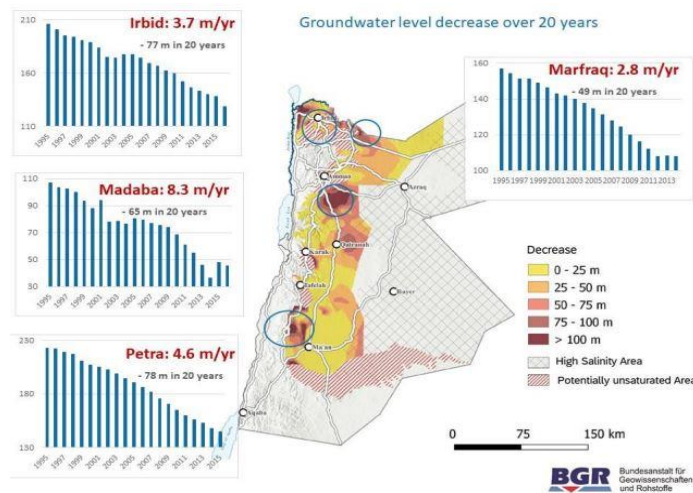


Figure 8, Groundwater Level Decrease between 1995 and 2017, (Jokisch, 2021)

As shown in the preceding sections of this study. In the author's opinion Jordan is a country dealing with chronic water scarcity and increasing demands on its limited water resources. Water treatment and reuse in the industrial sector emerge as a critical solution to solve the pressing concerns of water sustainability. The advantages of incorporating water treatment and reuse technologies into industrial operations go far beyond simple conservation; they play an important role in promoting environmental stewardship, economic resilience, and social well-being.

In the author's opinion, one of the primary benefits of treating and reusing water in Jordan's industrial sector is the preservation of the country's limited water supplies. Jordan's arid climate and limited freshwater supplies pose a persistent threat of water scarcity, which is

worsened by population expansion and climate change. By using sophisticated water treatment technology, enterprises can minimize their dependency on traditional water sources, relieving strain on the country's freshwater supply and contributing to the general preservation of this valuable resource.

In conclusion, and in the author's opinion the alliance between the National Water Strategy 2023 and the management board of the cement industries in Jordan should be strengthened is to invest in water treatment and reuse technology where it is a critical step toward ensuring a water-secure and thriving industrial landscape. Where using water treatment and reuse technologies in Jordan's industrial sector provides numerous benefits. These initiatives, which range from conserving finite water resources and promoting environmental sustainability, are critical in leading the country toward a more resilient and sustainable future. Transferring the best art techniques in wastewater treatment will help the industrial sector in Jordan, especially the cement production factories, lower their freshwater footprint as Jordan deals with water scarcity issues.

3. Literature research on selected Cement industries and a comparison on the Cement Industry Water Treatment Techniques

3.1 Introduction of Cementra Jordan

Cementra Jordan, a major actor in the Jordanian industrial scene, is a cornerstone of the country's construction and building materials industry. Cementra, founded on a commitment to excellence and innovation, has emerged as Jordan's premier cement producer, making important contributions to infrastructure development. With a long history and a consistent commitment to quality, sustainability, and community engagement, Cementra has become synonymous with dependability and progress in the construction sector.

Cementra was founded on the ideals of technological innovation and environmental responsibility, and it has consistently invested in cutting-edge manufacturing techniques to ensure the creation of high-quality cement products that meet and surpass worldwide standards. Cementra's commitment to innovation is demonstrated in its use of cutting-edge technologies and sustainable practices, which position the company as a pioneer in Jordan's construction materials sector progress (cementra jordan, n.d.).

Cementra's large product line meets a wide range of construction needs, including cement types intended for maximum performance in a variety of applications. Cementra's products, whether used in the construction of residential structures, infrastructure projects, or commercial buildings, are designed to deliver strength, durability, and sustainability, matching with the changing demands of the construction sector (cementra jordan, n.d.).

Aside from its role as a renowned cement producer, Cembra places a high value on corporate social responsibility and community engagement. The corporation actively supports efforts that promote environmental protection, resource efficiency, and the well-being of the communities where it operates. Cembra's commitment to sustainable development extends beyond its production methods to include a comprehensive approach that takes into account the social and environmental impacts of its activities (cembra jordan, n.d.).

Cembra Jordan's location is carefully selected for logistical effectiveness, enabling for seamless transportation of its goods to various construction projects across the country. The manufacturing plant's location allows for quick and cost-effective distribution, which is critical in meeting the building industry's demand for reliable and readily available cement solutions.



Figure 9, Mafraq Cement Plant and Headquarters location, (cembra jordan, n.d.)

Mafraq Cement Plant is located in Mafraq Governorate, 60 km northeast of Amman. And Headquarters located at Al-Abdali Boulevard, Cembra was the first company to locate its headquarter in Amman's new downtown (see Figure 9).

Cembra is considered as a strategic partner in the sustainable development plan and contributes to the national economy growth; being one of the key manufacturers and suppliers of high quality cement and clinker in the Hashemite Kingdom of Jordan and the region.

The company aims to constantly raise its efficiency, productivity and quality to support the construction and infrastructure development sector, which is an integral pillar of sustainable development, through its strategically located plant in the governorate of Mafraq, which prides itself on utilizing the latest machinery and state-of-the-art technologies, supplied by renowned European & other international companies such as IKN, GEHR PFEIFFER, H&B, CMD, BEUMER, SIEMENS, ABB. The company supplies local and regional markets with high

quality cement according to the global cement standards with clinker production capacity of 2 million tons / year and cement production capacity of 2.4 million tons / year (cementra jordan, n.d.). Cementra supplies a significant portion of the cement demand in Jordan and the neighboring markets, as one of the most dependable cement firms in the Hashemite Kingdom of Jordan and the area, and is the preferred choice for most contractors and end-users due to its continuous high quality products (cementra jordan, n.d.).

The company has developed and evolved tremendously over the last decade, and it remains committed to achieving its vision through comprehensive sustainable development (cementra jordan, n.d.).

Cementra Jordan is a member of the World Cement Association (WCA) (see Figure 10), a global forum and important body at the vanguard of the cement industry, bringing together major participants from across the world in a common commitment to promoting sustainable growth, innovation, and quality in cement manufacturing. Established as a vital organization, the WCA acts as a unifying force, bringing together industry executives, policymakers, and stakeholders to address the issues and opportunities confronting the global cement industry (WCA, n.d.).

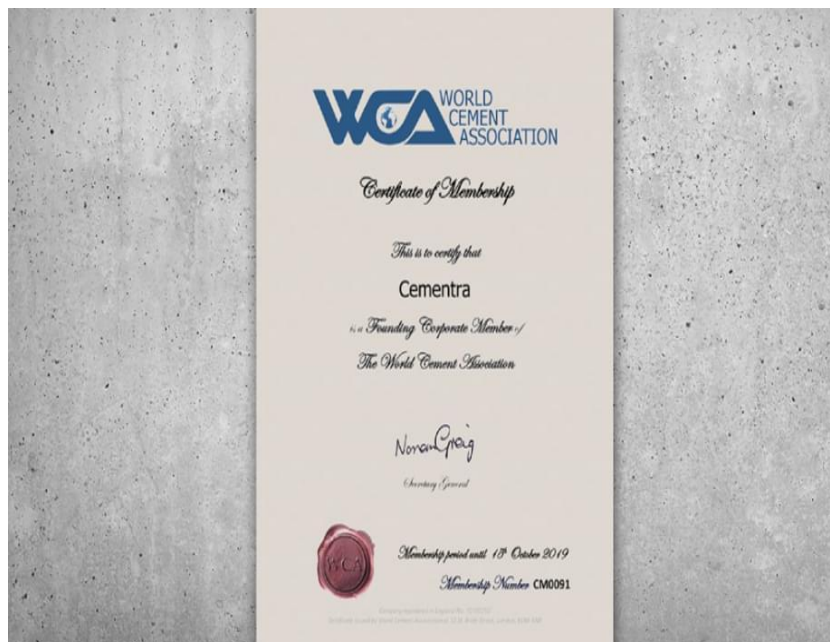


Figure 10, Cementra certificate of membership The World Cement Association, (cementra jordan, n.d.)

The World Cement Association, founded on the values of collaboration, knowledge sharing, and collective action, serves as a forum for the exchange of ideas, expertise, and best practices among its diverse membership. The WCA's objective is to promote sustainable

growth, environmental stewardship, and social responsibility in the cement industry, and it plays an important role in shaping the sector's future (WCA, n.d.).

Cementra Jordan is certified with TÜV Austria ISO 14001(see Figure 11), which is a certification that demonstrates an organization's commitment to good environmental management practices is a mark of quality. The ISO 14001 standard, developed by the International Organization for Standardization (ISO), provides a systematic framework for enterprises to build, implement, maintain, and continuously improve an environmental management system. TÜV Austria, known for its stringent certification processes, is critical in evaluating and endorsing ISO 14001-compliant enterprises (cementra jordan, n.d.).



Figure 11, TÜV Austria ISO 14001, (cementra jordan, n.d.)

The ISO 14001 accreditation represents a global benchmark for environmental responsibility and sustainability. Organizations who earn this accreditation demonstrate a commitment to assessing and controlling the environmental implications of their activities, products, and services. TÜV Austria, as an accredited certification authority, evaluates whether an organization's environmental management system meets the strict ISO 14001 requirements, giving reliable and internationally recognized proof of an organization's commitment to environmental stewardship (family, n.d.).

The certification process entails a detailed examination of an organization's environmental management practices, including its dedication to meeting applicable regulatory requirements, pollution prevention, resource efficiency, and continual development. TÜV Austria's auditing and certification expertise guarantees that firms seeking ISO 14001 certification receive a thorough review that validates the efficacy of their environmental management systems (AUSTRIA, n.d.).

Cementra's commitment to sustainable practices is reflected in its efforts to minimize environmental impact at its location. The company incorporates eco-friendly measures, resource-efficient technologies, and rigorous environmental management protocols, demonstrating a dedication to Sustainability (cementra jordan, n.d.).

3.2 Cement production process at Cementra Jordan

According to (COMMISSION, Reference Document on Best Available Techniques in the, 2001) there are four main process routes for the manufacture of cement: dry, semi-dry, semi-wet and wet processes. Where Cementra Jordan adopt the dry processes in which the raw materials are ground and dried to raw meal in the form of a flowable powder. The dry raw meal is fed to the preheater or precalciner kiln or, more rarely, to a long dry kiln (cementra jordan, n.d.). The dry processes have the following sub-processes:

- Raw materials–storage and preparation
- The kiln systems – kiln firing processes
- Products–storage and preparation
- Packaging and dispatch

In the initial stages as a dry process, water is not used in the extract and transport raw materials (cementra jordan, n.d.), as the dry cement production process progresses, water becomes increasingly important during the cooling of clinker, a critical intermediate product. Clinker is generated by calcining the raw material in high-temperature kilns. Efficient cooling is required to maintain the quality of the clinker, and water is used in cooling systems to attain appropriate temperatures (cementra jordan, n.d.).

According to (COMMISSION, Reference Document on Best Available Techniques in the, 2001) the initial stage of extraction of nearly all of the natural raw minerals entails mining and quarrying operations (see Figure 12). The materials are often acquired from open surface quarries. This usually includes rock drilling, blasting, excavation, hauling, and crushing. Quarrying is the primary source of raw materials, including limestone, chalk, marl, shale, and clay. In most situations, the quarry is near the plant. Following first crushing, the raw materials are transferred to the cement factory for storage and subsequent processing. Additional raw materials, such as bauxite, iron ore, blast furnace slag, and foundry sand, are sourced abroad. Where Cementra Jordan follows the same procedure of (COMMISSION, Reference Document on Best Available Techniques in the, 2001)



Figure 12, Raw Materials Extraction, (cementra jordan, n.d.)

This sophisticated process includes the intricate art of mining and quarrying operations, which are required for procuring a diverse range of minerals that serve as the fundamental building blocks for cement making. From limestone and clay to gypsum and silica, the extraction of these raw materials is a critical precursor that influences the quality and composition of the final cement product (cementra jordan, n.d.).

Figure 13, shows the Following of the extraction process, where the raw materials are transferred to the cement factory for storage and subsequent processing.



Figure 13, Raw materials transfer, (cementra jordan, n.d.)

According to Cementra Jordan and (COMMISSION, Reference Document on Best Available Techniques in the, 2001) Covered storage is recommended based on climatic conditions and the amount of fines in raw material leaving the crushing facility. For a 3000 tons/day

operation, these buildings might house between 20,000 and 40,000 tonnes of material. Figure 14 illustrates an example of covered raw material storage.

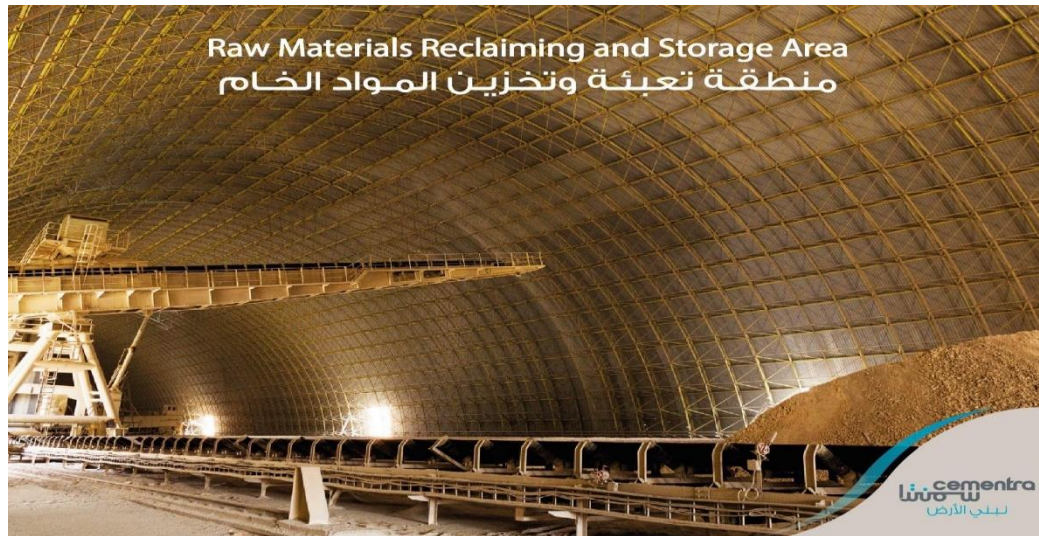


Figure 14, covered raw material storage in Cementra Jordan, (cementra jordan, n.d.)

The raw material fed into a kiln system should be as chemically homogenous as possible according to (COMMISSION, Reference Document on Best Available Techniques in the, 2001). This is accomplished by regulating the feed to the raw grinding plant. To pre-blend varying quality quarry material, arrange it in rows or columns. Extraction involves layering along the store's length or circumference and taking cross-sections. Simpler stacking and recovering processes can be used with somewhat uniform quarry material (see Figure 15).



Figure 15, raw grinding plant, (cementra jordan, n.d.)

According to (cementra jordan, n.d.) Accurate metering and proportioning of mill feed components by weight is crucial for maintaining consistent chemical composition. This is crucial for consistent kiln operation and high-quality output. Metering and proportioning are also significant aspects in the grinding system's energy efficiency. The apron feeder is the primary metering and proportioning device for raw material feed to mills, followed by belt

weigh feeders (COMMISSION, Reference Document on Best Available Techniques in the, 2001) (see Figure 16).



Figure 16, primary metering and proportioning device followed by belt weigh feeders, (cementra jordan, n.d.)

The next step is clinker burning according to (cementra jordan, n.d.), which is the most essential aspect of the process in terms of emissions, product quality, and cost. Clinker burning involves feeding raw meal into the rotary kiln system, where it is dried, warmed, calcined, and sintered to generate cement clinker. Clinker burning requires high temperatures to turn the raw material mix into cement clinker. It is critical to keep kiln charge temperatures in the sintering zone of rotary kilns between 1400 and 1500°C, and the flame temperature about 2000°C. Additionally, the clinker must be burned under oxidizing circumstances. As a result, an excessive amount of air is required in the sintering zone of a cement clinker kiln (COMMISSION, Reference Document on Best Available Techniques in the, 2001).

Since its introduction about 1895 (COMMISSION, Reference Document on Best Available Techniques in the, 2001), the rotary kiln has been an integral feature of all current clinker production facilities. The vertical shaft kiln is still used to produce lime, but only in a few countries for cement clinker manufacture, and then only at small-scale plants (see Figure 17).

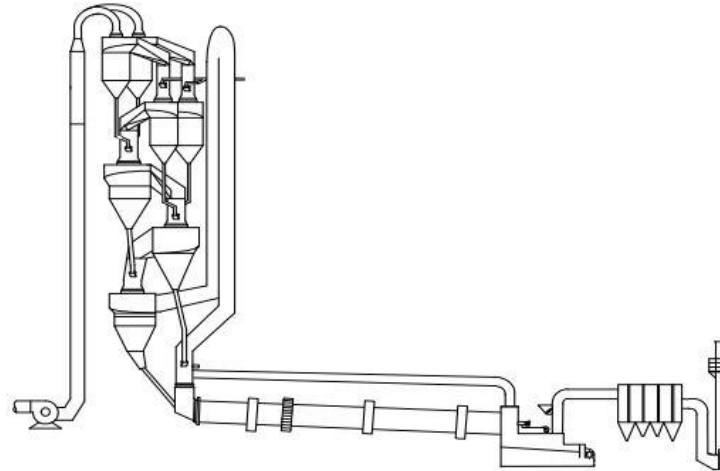


Figure 17, rotary kiln, (COMMISSION, Reference Document on Best Available Techniques in the, 2001)

According to Cementra Jordan the rotary kiln manufacturing module is used (see Figure 18)



Figure 18, Rotary Kiln, (cementra jordan, n.d.)

The rotating kiln uses steel tubes with length-to-diameter ratios ranging from 10:1 to 38:1. The kiln is supported by two to seven (or more) support stations, rotates at 0.5 to 5.0 revolutions per minute, and has an inclination ranging from 2.5 to 4.5%. The tube's slope and spin lead stuff to move slowly along it. To endure high peak temperatures, the rotating kiln is coated with heat-resistant bricks (refractories). Internal heat transfer is enhanced by the use of chains, crosses, and lifters in both long and short kilns (cementra jordan, n.d.) (COMMISSION, Reference Document on Best Available Techniques in the, 2001).

This approach involves dividing the heat input between two sites. Primary fuel combustion takes place in the kiln burning zone. Secondary burning occurs in a specialized combustion

chamber between the Rotary kiln and preheater (see Figure 19) (COMMISSION, Reference Document on Best Available Techniques in the, 2001).



Figure 19, preheater tower, (cementra jordan, n.d.)

According to Cementra Jordan the precalciner kiln can burn up to 65% of its fuel in this chamber. The prolonged retention duration of hot meal, kiln exhaust gases in the bottom part of the cyclone preheater, and more tertiary air all contribute to this outcome. The energy is primarily utilized to calcine the raw meal, which is virtually totally calcined upon entering the kiln. Calcination levels can reach far over 90%. The cooler provides hot air for the calciner's combustion process. The material leaves the calciner at around 870 °C (COMMISSION, Reference Document on Best Available Techniques in the, 2001).

In dry production process the water use is needed in cooling towers work on the principle of evaporative cooling. The clinker cooling process generates hot water, which is piped to the cooling tower and spread over the fill material. The water then pours down over the fill, while air is drawn via the tower. This causes some of the water to evaporate, absorbing heat from the remaining water and lowering its temperature (COMMISSION, Reference Document on Best Available Techniques in the, 2001).

The water used in cooling towers undergoes a continuous cycle according to (cementra jordan, n.d.). It is initially circulated over the clinker and fill media for cooling. A portion of this water evaporates, carrying away heat, while the rest is recirculated through the system. To compensate for water loss due to evaporation, a makeup water supply is often integrated into the cooling tower system.

Cooling towers are used to remove surplus heat produced during the clinker producing process. The heat is generated mostly during the clinker generation process in the kiln, which heats raw materials to high temperatures. Efficient cooling is vital for preventing equipment overheating, maintaining product quality, and complying with environmental standards. The quality of water used in the cooling tower is crucial to prevent scaling, corrosion, and other issues that may affect efficiency (COMMISSION, Reference Document on Best Available Techniques in the, 2001).

3.3 Water cycle and water treatment in Cementra Jordan

The source of water that is used by Cementra Jordan is a groundwater well (see Figure 20) located in the facility area of the production plant. The groundwater well is 300m deep, and a submerged pump is used to extract the water from the well to the first step of treatment.



Figure 20, Groundwater well, (cementra jordan, n.d.)

The extracted amount of water is sent directly to a sedimentation reservoir with a volume of 5000 m³ (see Figure 21)

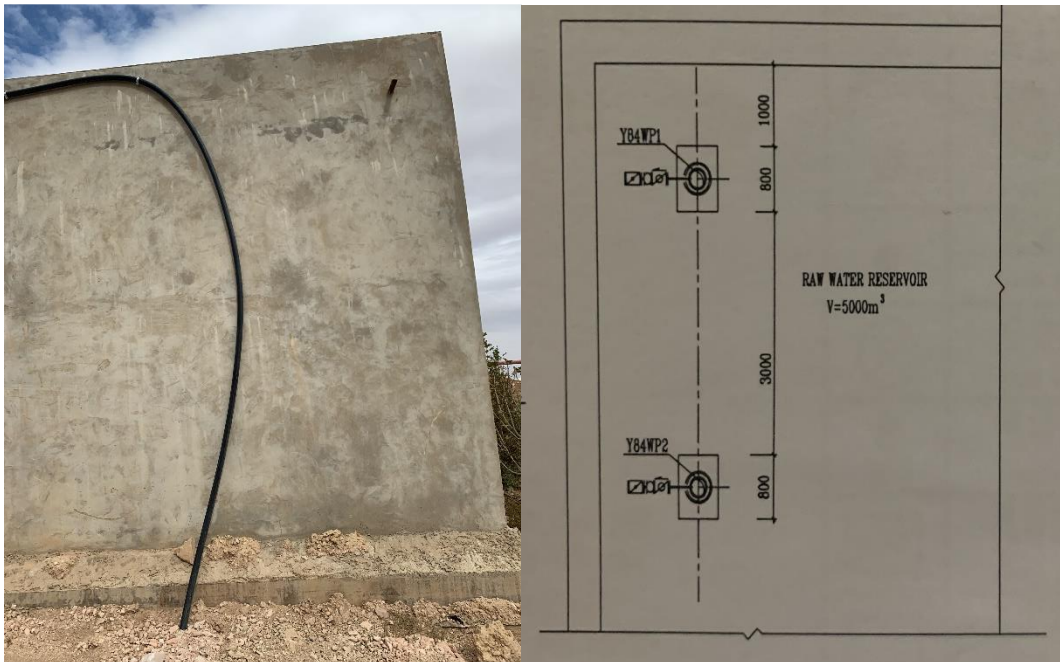


Figure 21, sedimentation reservoir, (cementra jordan, n.d.)

According to (Sperling, 2007) Sedimentation is a natural process that occurs when particles suspended in water settle to the bottom due to gravity. This process is critical in many

environmental, industrial, and geological situations. Sedimentation is an important part of the water treatment process.

The sedimentation process uses gravity to separate solid particles from liquids. When particles are placed into a fluid, they encounter a buoyant force that is counterbalanced by gravity. If the gravitational pull outweighs the buoyant force, particles fall to the bottom and form a layer of silt (Sperling, 2007). As a sustainable decision, the required cooling water should go through the process of waste particle sedimentation and be filtrated prior to demineralization to eliminate harmful elements and reuse them in the cooling cycle. (Nanda & Berruti, 2020) (Berner, 1992) (Batchelor, 2006). High quantities of suspended particles can abrasively wear industrial equipment like pumps, valves, and pipes. This can increase maintenance expenses and shorten the operational lifespan of equipment. Suspended particles can build up on heat exchange surfaces, limiting heat transmission efficiency. This can lead to lower performance in industrial operations that rely on efficient heat exchange, such as cooling systems. Suspended particles can clog filters and membranes in water treatment systems, lowering their efficiency. This requires more frequent maintenance and may raise running costs (Steinemann, 2001). Suspended solids may include corrosive chemicals, hastening corrosion in metallic components of industrial systems. This can lead to infrastructure degradation and higher maintenance expenses.

To lessen the effects of suspended solids in industrial water, organizations frequently use pretreatment techniques like sedimentation, filtration, or centrifugation to remove or reduce solid particles before the water reaches industrial operations. Regular monitoring and compliance with water quality regulations are required to maintain the efficiency and lifespan of industrial systems (Batchelor, 2006).

After the settling reservoir, the water is filtered through a dual-media filter and an activated carbon filter (see Figure 22).

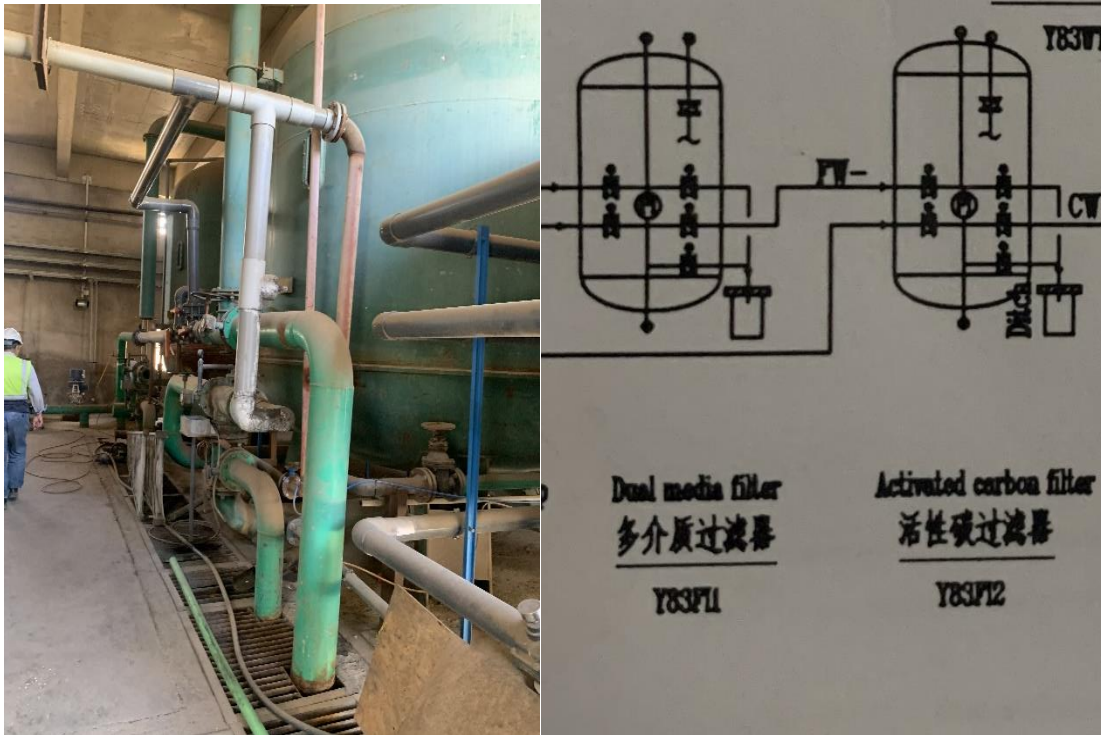


Figure 22, Dual media filter and activated carbon filter, (cementra jordan, n.d.)

Dual media filtration is a water treatment procedure that uses two different types of filter media to improve particle removal from water. The combination usually consists of a coarser material, such as anthracite or sand, on top of a finer substance, such as garnet or silica sand (Abushaban, 2022). This dual-layered design enables the removal of a greater variety of pollutants and particles from water. According to (Abushaban, 2022) DMF filters are often built with a 0.4-0.8 m layer of anthracite over a 0.8-1.2 m sand substrate. They operate at velocities ranging from 8 to 15 m/h, depending on the feed water quality and treatment aim. Dual media filtration is utilized to guarantee that the particle matter present in the water is properly removed before reaching the RO units, targeting criteria such as turbidity.

Activated carbon filters are critical components in water treatment systems, helping to remove organic pollutants, dissolved compounds, and other impurities from contaminated water. Activated carbon, recognized for its high surface area and adsorption properties, is an effective adsorbent for absorbing and retaining a wide range of pollutants. The use of activated carbon filters is especially efficient in improving the quality of treated water by the removal of various organic and inorganic contaminants (Fundneider, 2021).

Activated carbon serves as the heart of the filtration system. It is a porous type of carbon with a large surface area, making it ideal for adsorption. This activated carbon can come from a variety of sources, including coconut shells, wood, and coal. Activated carbon is often placed in a filter bed through which wastewater runs. The bed can be set up as a single-stage or multiple-stage filtration system, depending on the treatment needs (Fundneider, 2021).

After the filtration procedure, a reverse osmosis filtration process is used to obtain the desired water quality (see Figure 23).

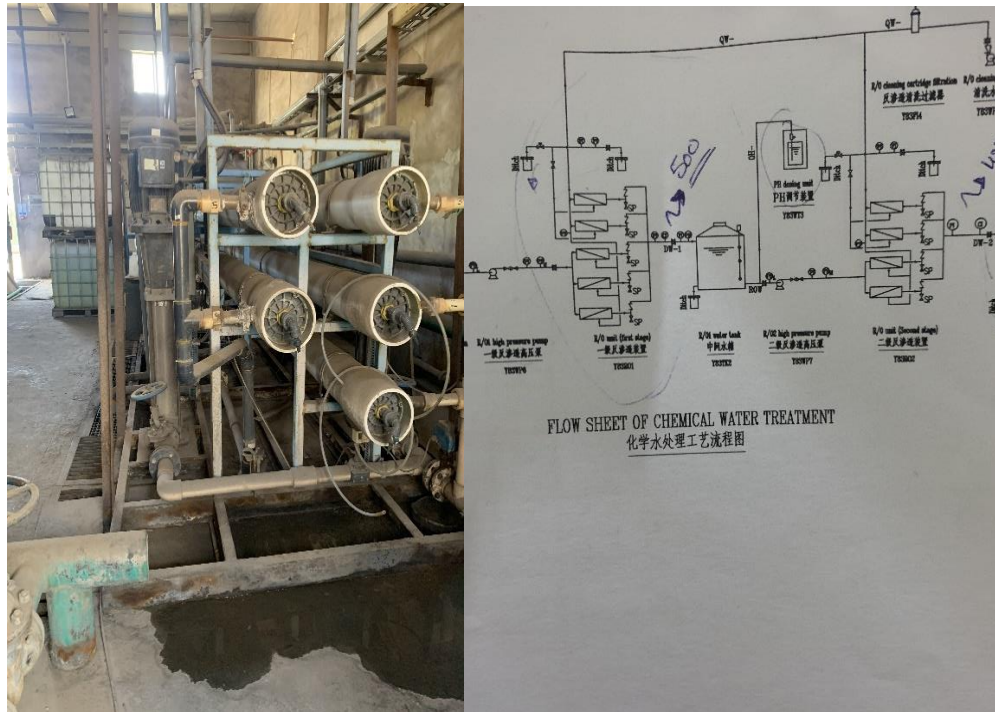


Figure 23, reverse osmosis filtration, (cementra jordan, n.d.)

According to (Gang Liu, 2022) RO is a water purification system that uses a semipermeable membrane to filter out ions, molecules, and bigger particles from drinking water. Reverse osmosis involves applying pressure to counteract osmotic pressure, which is caused by chemical potential differences in the solvent. Reverse osmosis removes bacteria and other dissolved and suspended species from water, making it useful for industrial processes and potable water production. The pressured side of the membrane retains the solute, while the pure solvent passes through. A "selective" membrane should not allow big molecules or ions to pass through its pores. However, smaller components of the solution, including solvent molecules, should be allowed to move freely. During osmosis, a solvent travels from a low solute concentration (high water potential) location to another through a membrane.

A high solute concentration (with a low water potential). When the difference in solvent concentration on each side of a membrane is minimized, the system's free energy decreases, resulting in osmotic pressure as the solvent moves into a more concentrated solution. Reverse osmosis occurs when an external pressure reverses the natural flow of a pure solution. The process is comparable to other membrane-based applications.

The water produced from the treatment process is used in the cooling tower process (see Figure 24)

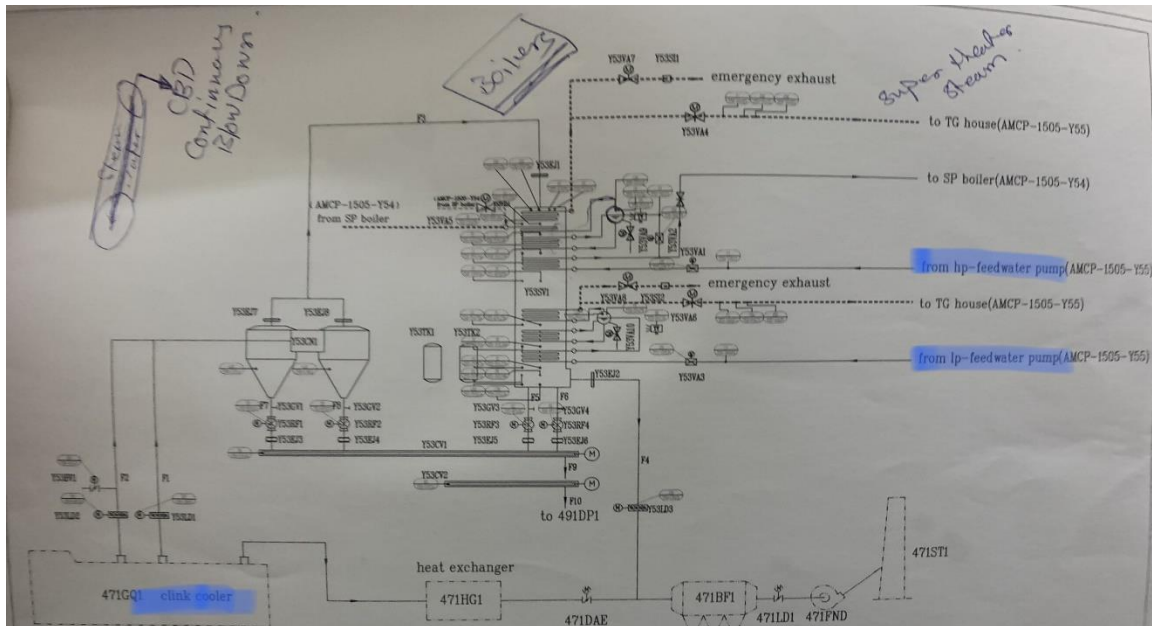


Figure 24, treated water feed for cooling system, (cementra jordan, n.d.)

The treated water is pumped to the cooling system from a low-pressure bump and a high-pressure pump (see Figure 23) in a method called the cooling tower blow down (CTBD).

According to Cementra Jordan, the cooling tower employed is known as an open recirculating cooling system (see Figure 25).



Figure 25, open recirculating cooling tower system, (Water, 2024)

Because of its great cooling efficiency, open recirculating cooling is one of the most widely utilized wet cooling systems for releasing heat from industrial fluids and processes around the world. This technology takes advantage of water's ability to alter state when subjected to heat (COMMISSION, Reference Document on the application of Best Available, Integrated Pollution Prevention and Control, 2001).

According to (cementra jordan, n.d.) The effluent water from the open recirculating cooling tower is used for dust control. (See Figure 26), as (Frauke Schorcht, Best Available

Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide, 2010) describe that diffuse dust emissions can occur while storing and moving commodities and solid fuels, including open storage, raw material conveyors, and road surfaces during transit. Dust generated during the packaging and shipment of clinker/cement might also be considerable.

Diffuse emissions can cause a local rise in dust levels, while process dust emissions from high stacks might affect air quality over a greater area. Conveyors and elevators are closed systems that prevent dust emissions from dusty materials. Lorry roads are regularly paved and maintained to minimize dust emissions. In addition, water is sprayed at the installation location to avoid these emissions.



Figure 26, air-and-water spraying for dust control, (cementra jordan, n.d.)

As according to (Prostański, 2013) the use of air-and-water spraying systems can reduce dust concentration by up to 80%, contributing to a significant reduction in dust concentration in the air.

The water treatment and quality monitoring processes are applied only to the raw water before it is used for cooling purposes. The effluent from the cooling tower and the blow-down process are not monitored, and no test results are available. As mentioned in Sec. 3.2, the resulted water is used for dust control purposes. The water management strategy needs to be changed, and a more sustainable strategy should be adopted, especially in a scarce country as described in Sec. 2.3. Also, as described in Sec. 2.5–2.6, the high demand on fresh water resources and the high dependence on ground water in Figure 8 show the groundwater level decline between 1995 and 2017 across Jordan. The sustainable water

strategy must be in alignment with the national water strategy to decrease the dependence on groundwater, increase the use of recycled water, and adapt new treatment technologies.

According to (COMMISSION, Reference Document on the application of Best Available, Integrated Pollution Prevention and Control, 2001), Reducing water use for cooling is especially important in areas with limited water availability due to natural or environmental factors. This can include drought-stricken areas as well as locations with little rainfall during the season. The risk of groundwater depletion and circumstances with relatively high cooling water demand.

3.4 Water quality and monitoring techniques in Cementra Jordan

The water cooling system is a way of eliminating heat from the component. Water is employed as a heat transmitter. Typically, water cooling is obtained from rivers, lakes, and ground water, but there are issues with the water itself, such as hardness and pollutants. Water impurities can be in the form of gases (such as oxygen and carbon dioxide) or solids (suspended and dissolved). Suspended form includes any impurities that are not dissolve (sand, silt), whereas dissolved solid include any pollutants that are dissolved in the water supply (Hamzah, 2008).

Accordingly Cementra Jordan is using the water treatment techniques described in (Sec. 3.3), is used to prevent scaling and corrosion as they are regarded as important issues in water cooling systems. Scale deposition is a chemical precipitation process in which dissolved salts in cooling water "out" surfaces in contact with the water because their solubility limitations are surpassed. Previous research has shown that temperature, water hardness, and pH all influence the scale (Moriarty, 2001). Corrosion is an electrochemical process in which a metal returns to its native state, forming oxide when in contact with oxygen. Chlorine, total dissolved solids (TDS), conductivity, and temperature are all elements that influence corrosion. Chlorine and conductivity can be combined with TDS or total suspended solids (TSS) to create corrosion. The greater the TDS or TSS readings, the higher the conductivity of water and the higher the risk that corrosion will develop (Moriarty, 2001).

Cementra Jordan conduct a laboratory tests to monitor water quality (see Figure 27), where PH, conductivity, dissolved oxygen, and Hardness are tested. According to the lab engineer the measurement of dissolved oxygen was carried out on-site using portable oxygen meters, the water was collected using a sampling bottle, and the dissolved oxygen concentration was immediately measured using a handheld oxygen meter. The PH and conductivity where measured by taking a water sample and transported to the lab to be tested using PH and conductivity meter, 5 minutes was the time period from sampling the water and transport it to the lab to minimize temperature changes, sample aeration. Also according to the lab engineer the total hardness is measured by the titration method the total hardness is defined as the sum of the calcium and magnesium concentrations, both expressed as

calcium carbonate in mg/L. When hardness (numerically) is greater than the sum of carbonate and bicarbonate alkalinity, amount of hardness equivalent to the total alkalinity is called “Carbonate hardness”. When the hardness is numerically equal to or less than the sum of carbonate and bicarbonate alkalinity all of the hardness is carbonate hardness and there is no non carbonate hardness. The hardness may range from zero to hundreds of milligrams per liter in terms of calcium carbonate, depending on the source and treatment to which the water has been subjected. Ethylenediamine tetra-acetic acid and its sodium salts (EDTA) form a chelated soluble complex when added to a solution of certain metal cations. If a small amount of a dye such as Eriochrome black T is added to an aqueous solution containing calcium and magnesium ions at a pH of 10 ± 0.1 , the solution will become wine red. If EDTA is then added as a titrant, the calcium and magnesium will be complexes. After sufficient EDTA has been added to complex all the magnesium and calcium, the solution will turn from wine red to blue. This is the end point of the titration.

Boilers Feed Water					
Time	PH	Cond. uS/cm ₂	DO ppb	Hardness ppm	PH
	8-9.2	<30	<50	<0.03	7.5-9.0
8:30	7.43	8.53	-	mg 0.31 ca 0.84	7.32
9:00	7.78	10.81	-	-	6.81
9:30	8.50	10.1	-	-	8.54

Figure 27, laboratory tests to monitor water quality, (cembra jordan, n.d.)

- PH has a significant impact on scale and corrosion in industrial systems. Controlling and maintaining pH within a certain range, based on system and water properties, is critical for reducing scaling and corrosion hazards and assuring infrastructure's long-term integrity (Moriarty, 2001). Scaling is the deposition and buildup of mineral salts (such as calcium carbonate, calcium sulfate, and silica) on surfaces within a system, which frequently results in hard, crystalline deposits. Water pH impacts mineral solubility. In scaling, the pH level regulates mineral precipitation. Water with a higher pH (alkaline conditions) promotes the production of scale, specifically calcium carbonate (Moriarty, 2001). On the other side, low pH (acidic conditions) can hasten metal corrosion. Acidic water includes hydrogen ions (H^+) that can react with metals,

causing dissolution and corrosion. Carbonic acid (produced by dissolved carbon dioxide) and mineral acids are two common acids found in water. Corrosion is the deterioration of materials, particularly metals, caused by chemical reactions with the environment. It can lead to metal loss, structural deterioration, and system (Moriarty, 2001). To control scaling and corrosion the PH is adjusted within the range of 7-9 as shown in figure 25.

- Conductivity is a measure of a solution's ability to carry an electric current and is affected by the concentration of ions in the solution. Conductivity in industrial systems can significantly affect scale and corrosion. Higher conductivity suggests a higher concentration of dissolved salts, which contribute to scaling. Common scaling ions are calcium (Ca^{2+}), magnesium (Mg^{2+}), and bicarbonate (HCO_3^-) (Moriarty, 2001). As shown in figure 25 the results are in the range of (8-10 $\mu\text{S}/\text{cm}^2$) which is within the safe range (less than 30) as recommended by (Moriarty, 2001).
- The concentration of dissolved oxygen (DO) in water has a significant impact on scaling and corrosion in industrial systems. The presence of oxygen in water has complex impacts on metal corrosion and scale development. As shown in figure 25 results are not available.
- Water hardness is mostly caused by the presence of calcium and magnesium ions. Water hardness is an important component that affects scaling and corrosion in industrial systems. Water hardness is determined by the concentration of divalent metal ions, particularly calcium (Ca^{2+}) and magnesium (Mg^{2+}). These ions can interact with carbonate and bicarbonate ions to produce insoluble salts, resulting in the formation of scale. CaCO_3 and CaSO_4 are the most prevalent scale-forming chemicals related with hardness. Magnesium compounds can also promote scale development (Moriarty, 2001). The hardness of water, primarily caused by calcium and magnesium ions, has a substantial impact on scaling and corrosion in industrial systems. Managing water hardness with appropriate treatment procedures is vital for preventing scale deposition and reducing corrosion concerns. As shown in figure 25 the test resulted a magnesium concentration of 0.31 ppm and calcium concentration of 0.84 ppm which is relatively high than the recommended in (Moriarty, 2001).

According to the Food and Agriculture Organization (FAO, WATER QUALITY MONITORING, STANDARDS AND TREATMENT, n.d.), qualitative and quantitative measurements are required on a regular basis to continuously check the quality of water from various sources of supply. The following is a general overview of the significance of commonly performed water quality tests.

- Water sampling and analysis should be performed by ISO-certified laboratories. Where local laboratories are not ISO-certified, it is recommended that their quality be assessed by an ISO-certified laboratory through collaborative testing to guarantee

that the variation in the accuracy of results is sufficiently modest. Unreliable results increase pollution issues when corrective action is not implemented in a timely manner. Only qualified technicians should conduct sampling and monitoring tests.

- Physical tests reveal qualities that are detectable with the senses.
- Chemical testing measure the concentrations of mineral and organic components that influence water quality.

Which is the same procedure that is used in Cementra Jordan laboratory. Even though the traditional testing methodology is used worldwide, there are new methodologies that are more efficient and accurate, which are recognized as areas for improvement by the Cemntra Jordan Management Board and will be discussed in further sections of this study.

4. A Comprehensive Literature Review on cooling towers, and wastewater key parameters

According to (COMMISSION, Reference Document on the application of Best Available, Integrated Pollution Prevention and Control, 2001), there are different types of cooling systems that can be classified by different criteria. This study will consider the open recirculating cooling tower system, as, in the author's opinion, it is mainly used by the cement industry in Jordan.

Open recirculating cooling systems recirculate water through a secondary circuit. Cooling water is pushed via heat exchangers to absorb heat from main processes. It is then sprayed from the top of a tower, where some of the warm water evaporates with an upward air flow. The tower's packing fill materials promote efficient cooling by ensuring excellent air-water interaction. Drift eliminators mounted above spray nozzles prevent droplets from departing the system. Cooled water is collected in a basin at the bottom of the tower and then pushed back to the heat exchangers. A simplified schematic (see Figure 28) depicts the operation of a cooling tower (COMMISSION, Reference Document on the application of Best Available, Integrated Pollution Prevention and Control, 2001). The extra energy is dissipated from the system via evaporation.

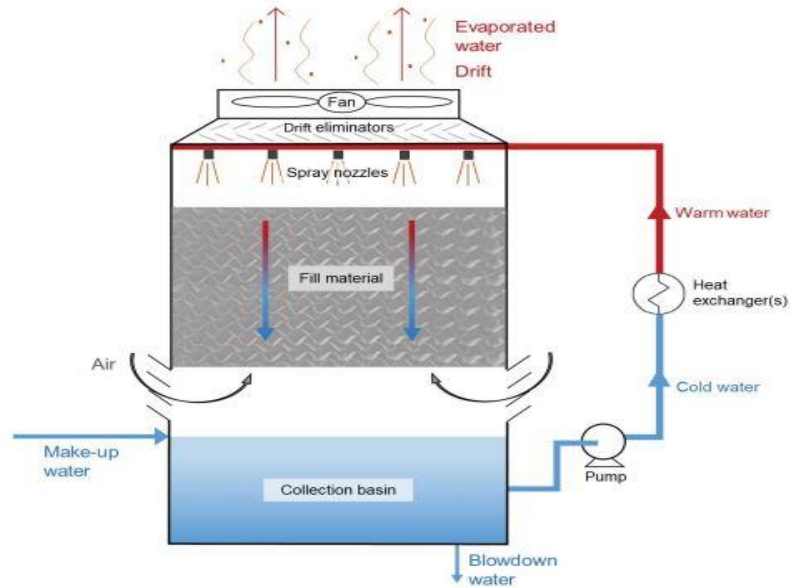


Figure 28, Open recirculating cooling system, (Pinel, 2021)

Some of the tower's cooled water is recirculated and reused for cooling. The primary causes of water loss are evaporation, blowdown, purge, and leaks. Intentional blowdown involves removing water from a circuit to prevent thickening of cooling water. To compensate for blowdown and evaporation, water is added, which is known as make-up. An open recirculating system typically requires 1-3% more make-up water flow than a once-through system with the same cooling capacity (COMMISSION, Reference Document on the application of Best Available, Integrated Pollution Prevention and Control, 2001). This system requires constant water supply and cooling water treatment.

Open recirculating cooling systems have issues such as evaporation from cooling towers, which can concentrate minerals and organic materials in the recirculating water. Figure 29 shows several quality metrics.

Parameter	Unit	CT1	CT2
Temp.	°C	9-29	15-25
pH	-	8.2-8.9	7.5-7.9
COD	mg/L	-	-
TOC	mg/L	6-41	34-56
EC	µS/cm	600-1400	3000-3500
Turbidity	NTU	1-58	1-13
TSS	mg/L	<100	-
Alkalinity	mg _{CaCO3} /L	-	800-1300
Chloride	mg/L	-	400-550
Phosphate	mg/L	<3	6-9

Figure 29, Open recirculating cooling systems several quality metrics, CT1 (Paranjape K. B., 2020a), CT2 (Paranjape K. B., 2020b)

Also according to (COMMISSION, Reference Document on the application of Best Available, Integrated Pollution Prevention and Control, 2001), common problems related to water quality include:

- Corrosion of cooling water equipment may lead to leakage of heat exchangers, spills of process fluids into the environment, or loss of vacuum in condensers.
- Scaling is primarily caused by the precipitation of calcium carbonates, sulphates, phosphates, zinc, and magnesium.
- Bio fouling of conduits and heat exchangers, as well as wet cooling towers, can cause obstruction of heat exchanger tubes with big particles shells and air emissions.

4.1 Exploring Key Parameters: A Deeper Dive into effluent parameters

The total nitrogen (TN) content of water can have a variety of effects on scaling and corrosion, while its direct impact is typically thought to be negligible when compared to other parameters such as pH, alkalinity, hardness, dissolved oxygen, and chlorine concentration. However, nitrogen compounds can have an indirect impact on corrosion and scaling processes in water systems due to interactions with other constituents and microbes. Nitrate (NO₃) and nitrite (NO₂) are typical nitrogen molecules present in water. While they are generally not corrosive, they can promote microbial development in water systems. Microorganisms, such as bacteria, can use nitrogen molecules as nutrition, and their metabolic activities can speed up corrosion processes and lead to biofilm development. Excess nitrogen in water can also increase the growth of some bacteria, such as sulfate-reducing bacteria and iron-oxidizing bacteria, which are known to cause corrosion in pipes and metal surfaces. These bacteria can produce corrosive byproducts and form localized corrosion cells, resulting in rapid metal loss. Nitrogen compounds can also impact the pH and alkalinity of water, influencing mineral solubility and scaling tendency. Elevated pH values can encourage the formation of carbonate and hydroxide scales, especially in hard water settings (Bhandari, 2014) (T.V. Wagner J. P., J. Hazard Mater, 2020) (Thomas Wagner, 2022).

Total Organic Carbon (TOC) in water can significantly influence scale and corrosion in water systems. TOC is a measure of the carbon-containing organic compounds found in water. The effect of TOC on scale and corrosion is determined by the specific organic molecules present as well as the general water chemistry. High TOC levels may lead to scaling in water systems, particularly if the organic compounds present may react with minerals in the water. Some organic compounds can also act as complexing agents, combining with minerals and generating insoluble precipitates. This can result in the deposition of scale on surfaces such

as pipes, heat exchangers, and other system components. Additionally, scale development can lower the efficiency of heat transfer in equipment, resulting in decreased water flow. While certain organic substances in water may either increase or inhibit corrosion depending on their composition, microbial activity linked with organic matter can produce corrosive byproducts. For example, the metabolism of some bacteria can create acids that speed up rusting. On the other hand, some organic chemicals can act as corrosion inhibitors by creating a protective coating on metal surfaces. Also TOC is often associated with the presence of organic material that can support microbial growth in water systems and Microbial activity can contribute to both scaling and corrosion. Some bacteria can produce biofilms that lead to scale formation, while others may produce corrosive byproducts (Bhandari, 2014) (T.V. Wagner J. P., J. Hazard Mater, 2020) (Thomas Wagner, 2022).

Total Inorganic Carbon (TIC) in water can have a substantial impact on scale and corrosion difficulties. As the research reveals the influence of Calcium Carbonate (CaCO_3) Scaling occurs when water containing calcium ions (Ca^{2+}) and bicarbonate ions (HCO_3^-) is heated or the pH rises. Calcium carbonate can precipitate out of the water and create scale deposits. This is a typical problem with water-based appliances and industrial equipment. Magnesium Carbonate (MgCO_3), like calcium carbonate, can precipitate out of water in certain conditions, resulting in scale formation. Carbon dioxide (CO_2) dissolved in water can produce carbonic acid (H_2CO_3), which is corrosive to metals. This type of corrosion is very prevalent in systems with carbon steel components. In addition to Bicarbonate (HCO_3^-) concentrations in water can contribute to corrosion, especially in the presence of dissolved oxygen. Bicarbonate ions can act as a buffer and influence the pH of the water, affecting the corrosion rate of metals (J. Löwenberg, 2015) (T.V. Wagner J. P., J. Hazard Mater, 2020) (Thomas Wagner, 2022).

Phosphate (PO_4^{3-}) act as scale and corrosion inhibitors. Phosphates can operate as a scale inhibitor in water systems. They form compounds with calcium and magnesium ions, which prevent these ions from precipitating as scale (calcium carbonate or magnesium hydroxide) on surfaces such as pipes and equipment. Scale buildup is a major problem in water systems because it reduces heat transfer and flow through pipes. Phosphates can help prevent scaling by retaining calcium and magnesium ions in solution. Also Phosphates may have a corrosion-inhibiting effect in some situations. They can build a protective layer on metal surfaces, lowering corrosion rates. The protective layer may impede the electrochemical reactions that cause metal corrosion, particularly in systems containing water (C.K. Groot, Water Sci. Technol., 2015) (Thomas Wagner, 2022) (J. Löwenberg, 2015). According to Cementra Jordan (cementra jordan, n.d.), phosphates are used as anti-scaling and corrosion inhibitors (see Figure 30).

PH	Alkalinity mmol/L	PO ₄ ppm	Cond. uS/cm ²	iron ppm
9-11	<8.0	5-30	<3500	<0.1
10.81	—	26.6	508	—

Figure 30, Concentration of Phosphate, (cementra jordan, n.d.)

According to table 1, the concentration was 2.2 mg/L, which is equivalent to 2.2 ppm. The water sample tested by Cementra Jordan showed a concentration of 26.6 ppm, as shown in figure 26, as the studies stated that excessive phosphate concentrations can lead to environmental concerns, such as eutrophication in natural water bodies, which is the over-enrichment of water with nutrients.

Potassium ions (K⁺) and sodium ions (Na⁺), when potassium ions (K⁺) are present in water, they do not often contribute significantly to scale or corrosion difficulties. Potassium salts are often extremely soluble in water, and the ions remain in solution rather than precipitating and creating scale. As a result, potassium does not contribute significantly to scaling problems in water systems. Potassium is not regarded a particularly corrosive element, and its presence in water is not usually associated with corrosion problems. The presence of sodium ions (Na⁺) in water can have a variety of impacts on scale and corrosion, depending on the water's chemistry and the materials in contact with it. Sodium ions alone do not usually contribute to scale development. Calcium (Ca²⁺) and carbonate (CO₃²⁻) ions in water can combine to create scale, typically in the form of CaCO₃ or other salts. While large concentrations of sodium ions may boost water conductivity, certain metals may experience faster corrosion (Thomas Wagner, 2022) (T.V. Wagner J. P., J. Hazard Mater, 2020) (C.K. Groot, Water Sci. Technol, 2015).

Na⁺, Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻, are considered as common ions contributing to water conductivity, High conductivity in water is frequently related with increased concentrations of dissolved minerals such as calcium, magnesium, and bicarbonates. When high conductivity water evaporates or temperatures rise, these minerals precipitate and form scale deposits on surfaces. In addition, water conductivity is directly proportional to its hardness. Hard water, which contains a high concentration of minerals, is more likely to scale. Scale deposits can build up on the internal surfaces of pipes, heat exchangers, and other equipment, lowering efficiency and perhaps causing damage over time. While

Corrosion is the process by which metals decay in response to reactions with their surroundings. The conductivity of water can influence the rate of corrosion, and high conductivity water, which is frequently associated with the presence of dissolved salts, can make water more corrosive. The ions in the water stimulate electrochemical processes that accelerate metal corrosion, as well as Corrosion can degrade pipes and equipment, resulting in leaks, lower system efficiency, and potentially costly repairs or replacements (Thomas Wagner, 2022) (T.V. Wagner J. P., J. Hazard Mater, 2020) (J. Löwenberg, 2015) (C.K. Groot, Water Sci. Technol., 2015).

4.2 Best available water treatment technology for cooling towers in cement industry

Nanofiltration was carried out on a Mexplorer lab-scale nanofiltration setup (NXFiltration, Enschede, The Netherlands), which included a rotary vane pump (Fluid-o-Tech PO211, Milan, Italy) with a flowrate of 73-292 L/h at 0 bar and an operating pressure of 0-10 barg at 20 °C. A dNF40 membrane (NXFiltration, Enschede, and The Netherlands) was installed, which is a hollow-fiber negatively charged polyelectrolyte multilayer membrane unit with 120 fibers, an inner diameter of 0.7 mm, a length of 30 cm, a nominal membrane area of 0.065 m², and a molecular weight cutoff of 400 Da. Before usage, the membrane was cleansed from its storage solution with 150 L of tap water per the manufacturer's recommendations. The membrane's pure-water permeance (PWP) was evaluated using demineralized water according to Eq. 1, (J. Löwenberg, 2015)

$$PWP = \frac{V_{permeate}}{A \cdot t \cdot \Delta P}$$

Eq.1

Permeate (L) represents the collected permeate volume, A (m²) represents membrane area, t (h) represents permeate collection period, and ΔP represents trans-membrane pressure. The membrane has a PWP of 7.0 L m⁻²h⁻¹bar⁻¹, comparable to the pure-water presence of the same type of membrane measured by (A. Bona, 2020). During NF of CW-treated and untreated CTW, a 100 μm filter (Amiad Water Systems Europe, Bochum, Germany) was employed to avoid particulates entering the system.

Several methods were used to evaluate the membrane's performance and the impact of CW-pretreatment:

- By comparing the effects of different trans-membrane pressures on the retention of target solutes and the time necessary for the NF membrane to produce 30 mL of permeate from both pre-treated and untreated CTW. Trans-membrane pressures of

1, 2, and 3 bars were measured at a constant cross-flow velocity of 0.5 m/s. The tests were performed in duplicate.

- By evaluating the effect of altering cross-flow velocity on target solute retention and the time necessary for the NF membrane to produce 30 mL of permeate from both pre-treated and untreated CTW. Cross-flow velocities of 0.5, 0.75, and 1.0 m/s were measured under a constant trans-membrane pressure of one bar. The tests were performed in duplicate.
- By evaluating the effect of pre-treatment on target solutes by the membrane across four consecutive concentration runs with an 80% permeate recovery, a cross flow velocity of 0.5 m/s, and a trans-membrane pressure of 2 bar. 10 L batches of pre-treated and untreated CTW were recirculated until 80% of the-permeate was recovered, with samples taken at regular intervals for target solute measurement and trans-membrane pressure and feed flow rate monitoring.

The EO experiments were carried out as stated previously (P. Saha H. B., 2020) in an electrochemical cell in batch recirculation mode utilizing 350 mL NF concentrate of either CW pre-treated or untreated CTW that had been concentrated four times. The electrochemical cell included a single-flow chambered flat plate reactor assembly with an active electrode surface area of 22.4 cm² and an inter-electrode distance of 1.5 cm, as well as sensors for measuring pH, EC, and temperature in real time. The CTW was pumped through the electrochemical cell using a peristaltic pump, with the system kept at a temperature of 21-23 °C. The working anode was a boron-doped diamond (BDD) electrode from Magnetic Special Anodes in Schiedam, Netherlands, while the cathode was a platinum-coated titanium electrode. A silver/silver chloride (Ag/AgCl) electrode (QM711X/Gel, Prosense, The Netherlands) was utilized to The reference electrode was ionically inserted into the EO cell by Haber-Lugging capillaries and filled with a 1 M potassium nitrate solution. The experimental electrochemical data was recorded and analyzed using the Iviumstat software. To assess the EO performance, the instantaneous current efficiency (% ICE) was calculated using equation (2) (P. Saha H. B., 2020).

$$\% \text{ ICE} = FV_S \left(\frac{COD_0 - COD_t}{8I\Delta t} \right) \times 100$$

Eq. 2

Where: COD₀ and COD_t is the COD concentration at the beginning and time interval t, respectively, in go₂/l, Faraday's constant F (96485 C/mol), electrolyte volume V_s (L), oxygen equivalent mass 8 (gO₂eq/mol), applied current I (A) and the electrolysis time interval t(S).

Pre-treatment with NF resulted in a much greater removal of organic compounds at varied current densities compared to untreated CTW due to the varying ions-ratios of the starting solutions. (see Figure 31)

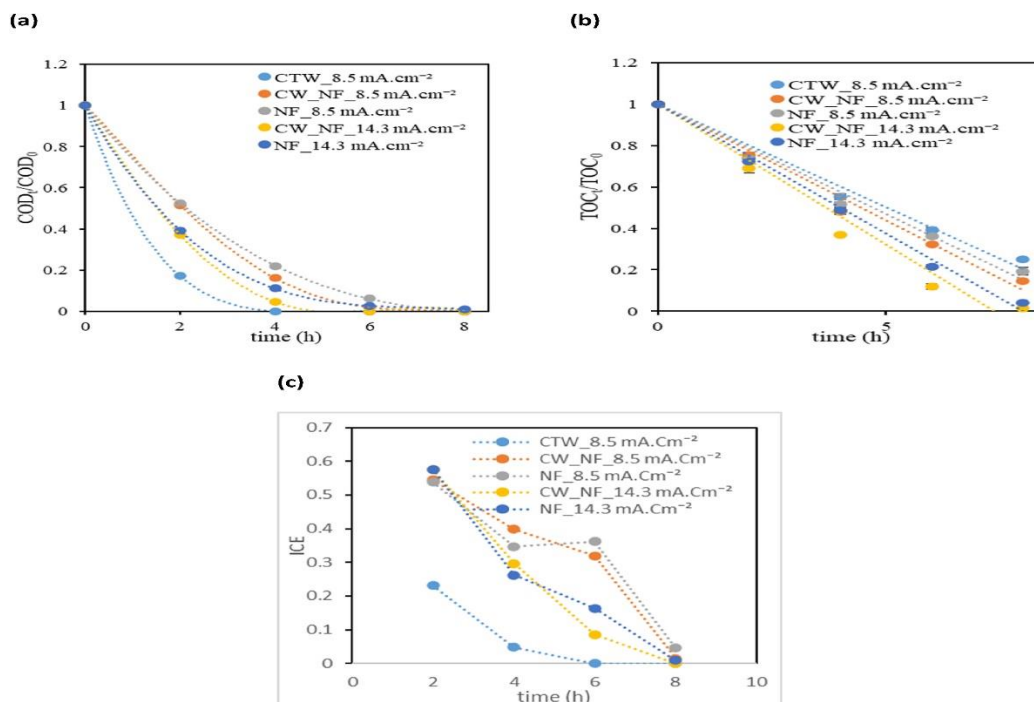


Figure 31, (a) COD_t/COD₀, (b) TOC_t/TOC₀ and (c) Instantaneous current efficiency (ICE) over time (h). Experimental conditions: 350 mL CTW (without treatment (CTW)); treated by constructed wetland and nanofiltration with 80% recovery (CW_NF); treated by nanofiltration with 80% recovery (NF)), T = 25–30 °C, current density = 8.5 or 14.3 mA/cm², conductivity = 3.63 (CTW) and 6.36 (NF/CW_NF) mS/cm, flow rate = 580 mL/min, reaction time = 8 h., (P. Saha H. B., 2020)

The study shows a remarkable removal of water contamination, where both NF and EO are effective techniques to treat the effluents of cooling towers.

Nano filtration membranes are now widely used for selectively separating multivalent ions. Nano filtration membranes are a pressure-driven membrane process. Dissolved components are separated using a molecular weight cut-off of 200-1,000 Da and a molecular size of 1 nm (Oluranti Agboola, 2015). The Nano filtration process is sophisticated in its core. Nano filtration membranes' ionic transport and selectivity are influenced by three factors: charge (Donnan effect), steric, and dielectric effects. The first effect is created by charge polarities between the membrane and solutes, followed by the second effect by ion size relative to membrane pores, and finally by the third effect. According to (Oluranti Agboola, 2015), the difference in dielectric constant between bulk and membrane pores causes this phenomenon. These effects enhance membrane separation capabilities and apply to a wide spectrum of liquid-liquid separation systems. Research indicates that selecting appropriate membrane parameters for a process can increase efficiency and improve performance.

Clarifying the relationship between the aforementioned impacts and rejection behavior is crucial for optimizing process parameters and lowering the cost of Nano filtration membranes in industries (Oluranti Agboola, 2015). Nano filtration is a pressure-driven membrane technique that, in terms of molecular or ionic species rejection, falls in between ultrafiltration and reverse osmosis. Nano filtration membranes, organic membranes, and ceramic membranes may be dense or porous. Nano filtration membranes may have more free space, smaller holes, or Nano voids (Baker, 2004; Van der Bruggen, 2009; Crespo, 2010; Schafer et al., 2005) for transport. These Nano voids constitute a transition between micro porous and dense membranes, with sizes ranging from 0.5 to 1 nm (Baker, 2004). Nano filtration membranes are typically thought to have a nominal cutoff of 1000–200 Da. In the Nano filtration process, the pore size range is typically 1 to 10 nm. Nano filtration has always been more difficult to define and describe than ultrafiltration and reverse osmosis (Van der Bruggen et al., 2008; Geens et al., 2006). Nano filtration membranes are distinguished by very high rejections for multivalent ions (>99%), low to moderate rejections for monovalent ions (about 70%), and strong rejection (>90%) of organic molecules with molecular weight over the molecular weight of the membrane. The method of mass transport is heavily influenced by membrane structure as well as interactions between membrane and transported molecules. Separation efficiency can be determined by the sieving effect (when the size of the Nano pores and the size of the solute molecules have the greatest influence) or by the solute molecules' solubility and diffusion properties. In the case of charged molecules, the electrical field plays an important role in transportation. A Nano filtration unit's operation depends on three parameters: solvent permeability or flux through the membrane, solute rejection, and yield or recovery. Let's look at the most crucial expressions for predicting separation efficiency during Nano filtration.

Electro-oxidation is a relatively new technique, comparable to electro-coagulation, in which anodic oxidation on the anode surface replaces direct chemical/photochemical oxidation. An alternative form of this process involves merely the electrochemical production of an oxidizing species, followed by direct oxidation by the resulting oxidizing agents. Thus, the essential mechanism remains the same, but the location and nature of the oxidation reaction varies slightly. Common oxidizing agents, similar to those used in conventional oxidation, include the hydroxyl radical, hydrogen peroxide, chlorine, and ozone. The design of the electrochemical cell, electrode selection, operational parameters, and power cost are all important considerations when using electro-oxidation in wastewater treatment. Typically, the existing electro-oxidation techniques are thought to be successful at degrading refractory pollutants that would be difficult to degrade otherwise. These mostly comprise hazardous chemicals and ammoniacal nitrogen. However, knowledge on practical applications in this field is limited, necessitating extensive research and development for

industrial wastewater treatment, particularly in terms of effluent/pollutant type and concentrations (Bhandari, 2014).

Electro-oxidation is a potential technology for wastewater treatment that uses electric current to trigger oxidation reactions, which result in the breakdown of organic and inorganic contaminants. This method is especially successful for treating industrial effluents that contain a variety of pollutants (Bhandari, 2014). The Principle of Electro-oxidation:

1) Electro-oxidation involves the application of an electric current to electrodes immersed in wastewater. Electrodes can be formed of a variety of materials, including graphite, platinum, and other conductive materials.

2) When a potential difference is supplied, electrochemical processes occur at the electrode surfaces, resulting in the formation of reactive species such as hydroxyl radicals (OH), which are effective oxidizing agents.

Pollutant Degradation involved Organic and inorganic contaminants in wastewater undergo oxidation processes driven by reactive species. Electro-oxidation can successfully decompose a variety of pollutants, including organic dyes, phenols, insecticides, and heavy metals (Bhandari, 2014).

Advantages of Electro oxidation:

- High removal efficiency: Electro-oxidation can effectively remove a wide range of contaminants.
- Versatility: The approach is adaptable and can be used to treat wastewater from various businesses.
- No extra chemicals: Unlike some other treatment processes, electro-oxidation rarely requires the addition of chemicals.

The efficiency of electro-oxidation is determined by a variety of operational parameters, including current density, electrode potential, pH, temperature, and the type of pollutants present (Bhandari, 2014).

Ultrafiltration, The UF membrane, a low-pressure-driven membrane technique, is widely employed in many industrial applications and water treatment processes (Rouzan Shoshaa, 2023) due to (Wenten I.G., 2020):

- Its ability to produce high-quality effluent
- Its cost-effectiveness in terms of capital cost and operation cost which makes it suitable for large scale application
- Its high potential for macromolecule removal, lower footprint, and low energy consumption

UF membranes can remove contaminants at low operating pressures of 1-2 bar, with pore sizes ranging from 0.005-0 (AiCHE, 2013). Furthermore, UF membranes can eradicate pathogenic germs and viruses, enable the passage of most ionic inorganic substances, and retain ionic and particulate matter (Drioli E., 2008). In addition, the UF membrane can remove both water-soluble organic waste and bacteria in a single step. Thus, it has a strong potential to replace the standard treatment chain (Peter-Varbanets M., 2009). Traditional water treatment plants typically include several processes such as media filtration, coagulation, flocculation, flotation, and adsorption; however, the use of UF in the water treatment process can simplify and replace multiple steps due to the benefits mentioned earlier. UF has been widely used to treat and reuse secondary effluent from wastewater treatment plants (WWTPs) (Huang W., 2022) (Zheng Y.M., 2011). Overall, UF membrane technology is most commonly utilized to treat drinking water (60%), followed by substantial industrial water treatment (18%) and wastewater treatment (15%). However, the lack of high-performance UF membranes remains a long-term barrier, despite significant developments in membrane materials and technology during the last few decades.

Recently, there are several review articles published in a similar topic to explore the removal of heavy metals via Nano filtration examined the development of Nano composite adsorptive membranes for heavy metals (Damiri F., 2022). And highlighted the most current advancements and problems of adsorptive membranes for various contaminants. However, no recent research has focused on both hazardous metal rejection and anti-fouling techniques for UF membranes simultaneously. This paper examines and discusses organic and inorganic materials, as well as composites, utilized to increase UF performance. Based on that conversation, several materials were compared using certain criteria to establish the most important materials for future research and implementation. Furthermore, this study brings together the major problems and constraints to establish the future direction of research in the field of UF membrane development and applications (Qalyoubi L., 2021).

Potentially dangerous elements, often known as heavy metals or trace elements, including mercury (Hg), chromium (Cr), nickel (Ni), copper (Cu), cadmium (Cd), cobalt (Co), and arsenic (Li W., 2016). High concentrations of potentially harmful substances in water bodies cause major environmental and health problems, as well as a huge increase in wastewater treatment costs (Ogoyi D.O., 2011). Potentially harmful materials may develop naturally in the environment as a result of rock leaching, forest fires, or airborne dust. However, human activities such as agricultural, industrial, and home applications, directly and indirectly affect the presence and accumulation of heavy metals in water bodies (Gardea-Torresdey J.I., 2005). To safeguard the environment, most countries have adopted restrictions limiting the release of effluents containing potentially harmful substances. In Canada, the Metal Mining Effluent Regulations limit metal concentrations in effluents to less than 1 mg/L. The European Community has rigorous restrictions for drinkable water, limiting the maximum nickel concentration to 50 g/L (Danis U., 2009). As a result, it is critical to develop low-cost

and efficient methods for eliminating potentially harmful components from wastewater. Adsorption and chemical precipitation are the most often utilized procedures for removing potentially harmful components from wastewater. However, these procedures are low-selective and relatively expensive (Rana D., 2014). Membrane processes are modern procedures that are substantially cheaper and more practical for treating metal-containing wastewater since membranes may be retrofitted into existing plants. Nano-filtration and reverse osmosis are effective processes for potentially toxic elements removal from aqueous solution; however, more energy consumption and higher operating pressure are the disadvantages, particularly when treating large volumes of wastewater with low levels of potentially toxic elements (Yang Y., 2007). UF offers certain advantages over other membranes because it requires less pressure to function. However, the UF membrane separates contaminants using a size exclusion method, which leads to poor decontamination effectiveness for potentially harmful components. Furthermore, treating a substantial amount of water may result in a big volume of sludge, a high energy demand, a lack of selectivity, and insufficient contaminant removal. As a result, researchers are still working to develop new types of UF membranes that will be more effective at removing possibly hazardous substances (Landaburu-Aguirre J., 2009).

Membrane fouling is the process by which particles and compounds in feed water accumulate on the membrane's surface, partially or totally clogging the membrane pores. This leads to a decrease in permeate flux and salt rejection of the membranes, necessitating frequent cleaning or replacements (Ashfaq M.Y., 2022). Adsorption and accumulation of material on the surface of a membrane and through its pores are the results of mass transport, in which chemical and physical interactions occur between the components of the membrane surface and those of feed water (Guo W., A mini-review on membrane fouling, 2012). Membrane fouling can be classed as either reversible or irreversible, depending on the system's operating circumstances and how it is cleaned (Chang W.W., 2012). Reversible fouling occurs at the membrane rejection surface, and it can be restored through physical washing if the membrane is back washable; otherwise, fouling can be eradicated with chemical cleaning. However, irreversible fouling can occur by pore clogging and chemisorption processes. To restore the membrane's, the membrane is either thoroughly cleaned with chemicals or replaced (A., 2005).

In the context of this review, which is all about UF fouling control, the rapid drop in permeate flux caused by membrane fouling is regarded as a major issue in UF membrane applications in water treatment. The lowering of membrane flow occurs primarily for two reasons. The first is concentration polarization, which is a reversible event that has no effect on the membrane's properties. These molecules that accumulated near the membrane's surface are hardly reversible in the bulk solution, and their concentration could be 50 times higher than in the bulk solution, resulting in a decrease in the solvent flow through the membrane and reducing its membrane's permeability (Humbert H., 2007). The main modes

of membrane fouling in UF membranes include pore blockage, gel formation, cake formation, and adsorption. However, multiple fouling mechanisms can be active at the same time. Fouling caused by pore-blocking happens when particles and colloids settle on the membrane surface, completely or partially closing the pores. This mechanism is most active during the early phases of the filtering process, when the particles are in direct contact with the pores. The second fouling mechanism that can occur on the UF membrane is gel-layer development, which is a dense coating of solutes that considerably blocks membrane pores and reduces permeate flux. Cake formation is a third possible fouling mechanism, defined as the buildup of particles layer by layer on the membrane's outer surface, preventing fluid flow through it. The interaction between the membrane surface and cake layer determines fouling reversibility, whereas the morphology governs flux decline. Fouling caused by cake formation can progress to over clogging and become irreversible when the created cake's interstices are loaded with tiny macromolecules, which increase hydraulic resistance (Humbert H., 2007).

A module is used to physically seal and separate the feed and permeate streams. The most common module designs for UF membranes are hollow fiber modules and flat-sheet plate and frame modules. Researchers evaluated the effect of innovative spacers with varied designs, angles, forms, and types (non-woven or woven) on membrane fouling, because the spacers not only offer mechanical strength to the membrane but also alter the hydrodynamics of the feed flow (Ilyas A., 2023). Thus, the innovative spacers are intended to improve flow turbulence, resulting in decreased pressure drop (or dead zones) and foulant accumulation on the surface. Vibrating spacers and turbo-spacers, for example, were developed to improve UF membrane performance and reduce fouling. Turbo-spacers in PFMs improved flow turbulence by utilizing the feed flow's kinetic energy. The experimental results demonstrated less buildup on membranes with turbo-spacers than with conventional spacers since the conventional ones had very little impact on flow unsteadiness (Ali S.M., 2020). In addition, several turbulence promoters are used to improve fluid hydrodynamics near the membrane surface. However, the majority of these turbulence promotion approaches are used to membrane bioreactors and RO. In UF, a spinning basket membrane module was utilized to produce turbulence. It was similar to the rotating disk module, which rotated flat sheet membranes around a hollow shaft. The application of the novel turbulence promoter greatly reduced the fouling propensity, with just a 5% drop in flux observed for the study time (Sarkar A., 2012). Various pre-treatment procedures are utilized to create hybrid membrane processes (HMP) and integrated membrane processes (IMP). HMPs/IMPs are used to minimize the amount of foulants (organics, inorganics, and bacteria) in the feed water, which helps to manage membrane fouling and improves performance. HMP incorporates traditional pretreatment processes (physical, chemical, and biological) into the membrane unit, whereas IMP integrates two or more membrane units. Physical approaches allow for the elimination of chemicals by increasing the size of the foulants and

sedimentation, or by filtering through a microfiltration membrane. Using chemical procedures, the feed water chemistry is altered to increase the foulant's size and decrease its attraction for the membrane. Biological procedures mostly entail disinfection processes that are used to kill microorganisms and reduce bio fouling. Other methods that aim to mitigate membrane fouling are membrane cleaning techniques and membrane characterization techniques. These techniques do not prevent membrane fouling directly. Instead, cleaning techniques help to remove the fouling layer from the membrane surface so that its performance can be restored. And the novel characterization techniques allow in-situ monitoring of the fouling phenomenon and process so that on-time measures can be adopted, and cleaning procedures can be implemented. It has been discovered that UF can eliminate compounds as small as 3 nm, but MF membranes can only remove pollutants as large as 50 nm. As a result, the UF membrane can accomplish better bacterial elimination while still being a low-cost approach in comparison to other membranes (Vrouwenvelder J.S., 2011). However, this makes the UF membrane very sensitive to bio fouling, which significantly reduces penetration rates during operation and limits the use of UF membranes in the water filtration process. As a result, the researchers have focused their efforts on investigating alternative membrane changes to improve fouling resistance and membrane performance. Based on the findings of many investigations, two membrane approaches may be created to prevent bio fouling. The first way involves the incorporation of additives within the membrane matrix or on its surface, such as Nano composite structures, which are also known as mix matrix membranes (Hu C., 2019). The MMM has been found to be particularly effective in increasing membrane performance, and a range of nanoparticles have been employed, such as Al₂O₃, Cu, SiO₂, and TiO₂ (Mollahosseini A., 2012). The second way alters the bulk and surface properties of membranes by modifying their chemical structure. This review focuses on the change of the membrane surface, which affects the membrane's physiochemical properties. Surface membrane modification is considered one of the most successful strategies for antibacterial applications; to improve membrane bacteriostatic performance, overcome flux retention challenges, and lessen bio-fouling issues (Guo W., A mini-review on membrane fouling, 2012). It has been claimed that when an input comes into contact with the surface of the integrated membranes, the antibacterial chemicals release and change the bacterial cell wall, resulting in both disinfection and filtration. Previous studies have investigated the antibacterial activity of several modified UF membranes (Moslehyani A., Effect of HNTs modification in nanocomposite membrane enhancement for bacterial removal by cross-flow ultrafiltration system, 2015). For example, (Zodrow K., 2009) investigated the ability of silver nanoparticles coated with polysulfide UF membrane to remove germs. This study shown that this modified membrane is very successful at removing E. coli K12 and P. Mendocino KR1. Furthermore, the modified membrane not only filtered out bacteria but also prevented these strains from attaching to the membrane surface, reducing bio fouling. One downside of this technology is that nanomaterials may be depleted quickly over long-term use. As a result, it was strongly advised to investigate other

strategies that focused on the attachment of antimicrobial compounds to the membrane's surface in order to limit their release. More modern approaches, such as employing a "immobilize agent" on inorganic or organic fillers that are completely compatible with the polymer matrix, have shown promise in eliminating the leaching issue. For example, (Moslehiani A., Effect of HNTs modification in nanocomposite membrane enhancement for bacterial removal by cross-flow ultrafiltration system, 2015) studied the efficiency of silver lactate halo site nanotube (HNT) clay Nano-filler linked to a PVDF polymer matrix as a bacterial separator. The primary goal of this research was to create fouling-resistant membranes with a high penetration flux. The goal of utilizing HNTs was to prevent antibacterial compounds from leaching off the membrane's surface, specifically silver lactate (SL) in this investigation. (Geng X., 2021) Created a PVDF UF membrane functionalized with imidazole graphene oxide via one-step grafting (Im-GO as an antibacterial agent). Previous research has established that imidazole groups retain significant antibacterial activity by releasing autolytic enzymes that break bacterial cell walls, resulting in component leakage and cell death. PVDF was modified using GO nanosheets to improve its hydrophilicity. This work shown that increasing Im-GO concentrations reduces bacterial adherence on the Im-GO/PVDF membrane. Im-GO 0.2 wt% showed the highest antibacterial efficacy against E. coli colonies, at 96.4%, damaging the cell membrane and releasing intracellular chemicals.

UF is a low-pressure membrane process that has been widely employed in various industrial and water treatment operations. However, the UF membrane performs poorly in removing potentially harmful substances and is prone to fouling by bacteria and NOM. These are the most frequent foulants that have harmed the performance of UF membranes. As a result, this study covers recent research advances in the development of UF membranes for greater heavy metal removal capacity and improved anti-fouling performance. The bibliometric research revealed consistent upward trends in the number of publications in the analyzed topic areas. Several researchers have developed advanced and novel UF membranes for better performance, including the incorporation of various materials such as organic, inorganic, carbon-based, and composite-based substances into the polymeric UF membrane to improve separation performance and fouling control. These materials include zeolites, metal-organic frameworks (MOFs), graphene oxide (GO), and zinc-doped aluminum oxide (ZnAl₂O₃). Functionalizing the membrane's surface with these materials resulted in strong separation performance for various heavy metal ions, as well as promising membrane fouling management findings. However, based on the overall evaluation conducted in this review, composite-based nanomaterial shown remarkable performance in various aspects such as separation performance and antifouling, leaching, research popularity, and cost efficiency, making them more advantageous than other materials.

Several research have demonstrated the production of UF membranes modified with organic, inorganic, and hybrid materials for the removal of hazardous elements. Nonetheless, there are some obstacles in the general use of these UF membranes.

The (figure 32) depicts 12 significant problems and constraints to the use of UF membranes for the removal of hazardous substances. The first three problems pertain to the materials (nanoparticles, inorganic filters, and nanocomposites) used in the construction of modified membranes. To begin with, there is minimal data on the toxicity of these components. If they detach or leach from the membranes, they may end up in the product water. As a result, it is recommended that toxicity studies be required for the products under consideration.

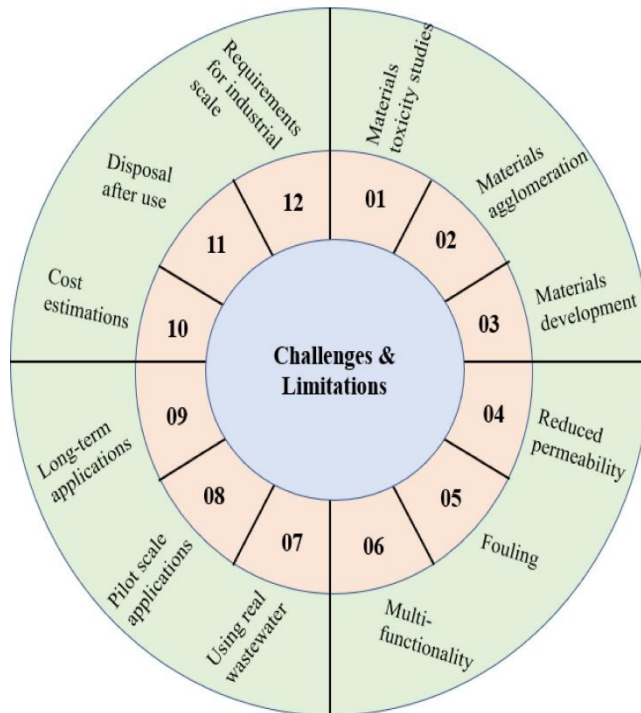


Figure 32, problems and constraints to the use of UF membranes for the removal of hazardous substances, (Gunta Grinberga, 2022)

Illustration 1 shows that the obstacles and limits indicated in numbers 4-6 are related to membranes. The loss of permeability (and sometimes selectivity) upon alteration is typical, jeopardizing the membrane system's operational costs. Furthermore, the majority of the research focus on the development of modified membranes for the removal of harmful substances and do not address membrane fouling. However, membrane fouling is one of the biggest disadvantages of using membrane technology. As a result, future research should concentrate on the creation of multifunctional membranes with strong rejection capabilities and resistance to membrane fouling. The following three restrictions are relevant to the scope of the research work. Data on the performance of modified UF membranes while treating real wastewater is rare. Furthermore, most studies lack a transformation perspective, which suggests that lab-scale research should be executed on a pilot scale over a longer period of time. This will aid in the collection of further information on the membranes' sustainability and durability, as well as bridging the gap between lab-scale

research and industrial applications. Finally, pricing estimates for the modified membranes and their applications must be performed, as well as methods for their regeneration and disposal after use, as well as any technical requirements for the modified membranes' industrial scale application.

Ultrafiltration membranes can be manufactured from either organic (polymer) or inorganic materials. UF membranes are made from several materials, including polymers. Polymers are chosen for their specific features, including molecular weight, chain flexibility, and chain interaction, when used as membrane materials. These materials include polysulfone, polyethersulfone, sulfonated polysulfone, polyvinylidene fluoride, polyacrylonitrile, cellulose, polyimide, polyetherimide, aliphatic polyamides, and polyetherketone. Alumina and zirconia are examples of inorganic materials that have been employed (Mulder, 1996). The structure of the UF membrane can be either symmetric or asymmetric. Symmetric membranes, whether porous or non-porous, range in thickness from 10 to 200 μm . The resistance to mass transfer is governed by the total membrane thickness. A decrease in membrane thickness increases permeability rate. Ultrafiltration Membranes have an asymmetric structure consisting of a dense top layer or skin (0.1-0.5 μm) and a porous sublayer (50-150 μm). These membranes offer great selectivity and penetration rates, combining the benefits of dense and thin membranes. Thin top layers significantly impact mass transfer resistance. The separation properties of porous membranes are mostly determined by the size of the pores. The kind of membrane material affects chemical, thermal, and mechanical stability but not flux or rejection. Therefore, the purpose of membrane preparation is to change the material using an appropriate approach. To create a membrane structure with a morphology appropriate for a certain separation. The key processes include sintering, stretching, track-etching, phase-inversion, sol-gel process, vapour deposition, and solution coating. UF membranes are typically prepared by phase-inversion or sol-gel processes (Mulder, 1996). Porous membranes can be characterized using structural characteristics (pore size, distribution, top layer thickness, surface porosity) and permeation parameters (cut-off measurements). The molecular weight cut-off (MWCO) is a specification used by membrane suppliers to describe the retention capabilities of UF membranes. It refers to the molecular mass of a macro solute (usually polyethylene glycol, dextran, or protein) for which the membrane has a retention capability of more than 90%. The MWCO can thus be interpreted as a measure of membrane pore diameters. UF includes particles and molecules with molecular weights ranging from 1000 to 500,000 Daltons (Mulder, 1996). Ultrafiltration (UF) is a low-pressure process with Tran's membrane pressures typically ranging from 0.5 to 5 bars. This not only enables the use of no positive displacement pumps, but also allows for the construction of membrane installations using synthetic components, resulting in cost savings. UF membranes can be made in one of two shapes: tubular or flat sheet. These membranes are often made on porous substrates. Membranes are engineered into a single functioning unit, known as a module. The

operational unit includes membranes, pressure support structures, feed inlet, concentrate output ports, and permeate draw-off points. There are two main varieties of UF modules in the market: hollow fibers (capillary) and spiral wound (see Figure 33).

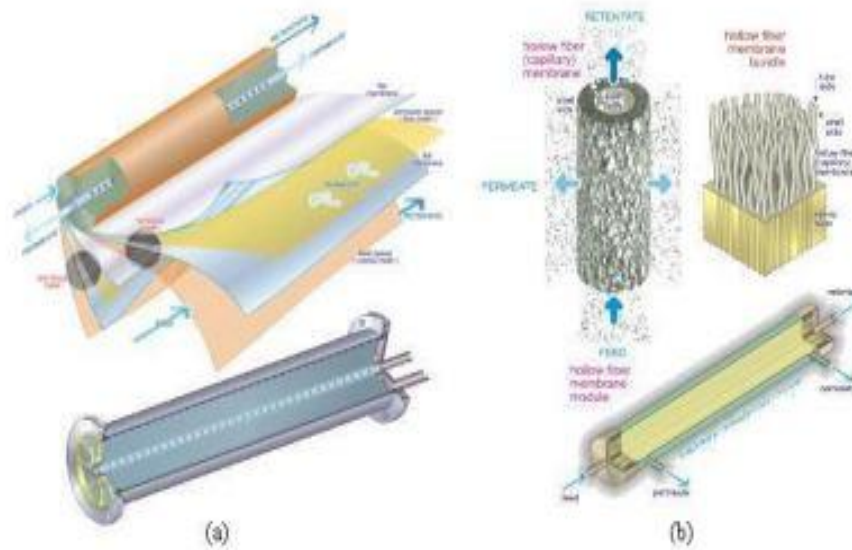


Figure 33, Major types of UF modules: (a) spiral wound and (b) hollow fiber, (Mulder, 1996)

Module types differ in packing density, cleaning ease, cost, pressure drop, hold-up volume, and pre-treatment quality. Hollow fiber modules offer higher packing density, are easy to clean, and are cost-effective. Additionally, there is a spiral wound module. The tubular module and revolving disc/cylinder have the lowest pressure drop compared to the others. The hollow fiber module has the highest holding volume, followed by plate and frame, spiral wound, tubular, and rotating disc/cylinder modules. Tubular and spinning disc/cylinder modules require minimal pre-treatment (Aptel, 1996).

Reverse osmosis (RO), the earliest application of membrane technology was to convert seawater to drinking water using reverse osmosis. The RO system separates dissolved solutes (even single charged ions like Na^+ and Cl^-) from water via a semipermeable membrane that preferentially flows water over the solute. RO is a diffusion-controlled mechanism that regulates the mass transfer of ions through membranes. RO membranes differ from other filtration systems due to their lack of physical pores. The RO membrane's hydrophilicity allows water to easily permeate into and out of its polymer structure. RO membranes come in four modules: plate and frame, tubular, hollow fiber, and spiral wrapped. However, the spiral-wound element is by far the most commonly used in the generation of drinking water. RO configurations include single, two, and two-pass systems. The option between these configurations relies on the desired quality of the product water. The pass system produces high-purity water, making it ideal for preparing boiler water. The single-stage method is widely used in desalination applications because to its simplicity. The

two-stage technique is commonly used for brackish water treatment to improve overall recovery ratio (Fawzi, 2002). RO systems are widely used in industries to separate dissolved solutes from water, including desalination. They can also be used in homes to improve water taste and remove harmful chemicals. RO has expanded water supply by enabling the use of brackish waters for potable water production. RO desalination is a popular method for producing fresh water in arid environments, particularly in rural areas where fresh water is scarce. Recent advancements in membrane materials and pre-treatment have made RO desalination economically viable, even at high saltwater concentration. Membrane uses have grown significantly, with systems capable of processing over 19,000 m³/d (Buckley, 1996). RO technology's success has been attributed mostly to its low operating costs and simplicity. RO membranes have evolved from the original cellulose acetate membrane requiring 28 bar to current polyamide thin-film membranes with only 7 bar net driving pressure, resulting in increased salt rejection. Salt rejection of RO membrane has increased from 97 to 99.5%, with some specific membrane varieties displaying even better separation efficiency (Nicolaisen, 2002). RO membranes are more vulnerable than thermal desalination methods to scale, fouling, chemical, and biological attacks. One of the most significant shortcomings of RO membranes is their sensitivity to fouling. Although RO is a more energy-efficient alternative to thermal processes, it still faces competition due to pre-treatment requirements.

According to (Ebrahim, 2001), an effective RO system consists of pre-treatment filtration with a dual-media filter and an activated carbon filter (see Figure 34).

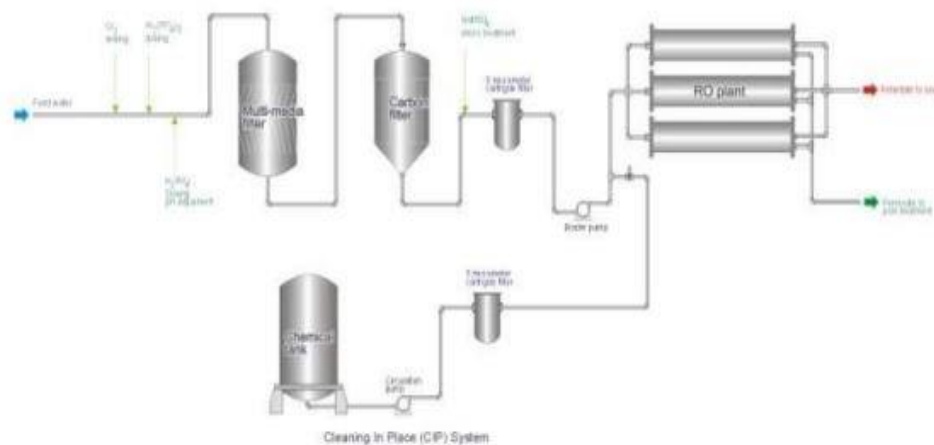


Figure 34, RO system with extensive pre-treatment, (Ebrahim, 2001)

An Integrated Membrane System (IMS) refers to a system that uses a UF membrane as a pre-treatment before RO (Nederlof, 2000). IMS combines the advantages of UF particle removal with RO selectivity (Glucina, 2000) Several studies are now being conducted to assess the

viability of a dual membrane system for achieving water quality targets (Lainé, 2000). The IMS design approach to water treatment systems offers some notable advantages over RO systems developed with traditional pretreatment. UF pre-treatment has several advantages, including continuous and automated operation, no breakthrough like granular media filtration, effective RO membrane protection, no chemical additions, simple chemical shock disinfection, and compact equipment design (Heyden).

5. List of the best available state-of-the-art NF technology

5.1 The dizzer XL 0.9 MB 80 WT ultrafiltration technology by inge GmbH

Inge GmbH, situated in Greifenberg, Germany, is the world's largest provider of ultrafiltration technology. This membrane process treats drinking water, process water, waste water, and seawater. The company's global reach and partner network have resulted in successful reference projects showcasing its cutting-edge technologies. In August 2011, inge GmbH joined BASF, the world's biggest chemical corporation (SE, 2016). At IFAT 2016 in Munich, Germany. Inge GmbH introduced the dizzer XL series' new UF module has an active filtering area of 80 m², resulting in a 14% increase in production compared to the old 70 m² version. Inge and BASF collaborated to refine the structure and stability of the Multibore membrane throughout production, resulting in a UF fiber with optimum geometry that does not require chemical modifications and maintains mechanical stability (SE, 2016). The collaboration resulted in a new innovation membrane materials that form the dizzer XL 0.9 MB 80 WT ultrafiltration membranes. The new innovative material introduced as "Ultrason E, S, and P" (SE, 2016).

Ultrason resins are amorphous thermoplastics made from polyethersulfone (PESU), polysulfone (PSU), and polyphenylsulfone (PPSU) with great heat resistance. Their diverse set of favorable qualities enables them to be molded into high-quality engineering parts and heavy-duty mass-produced goods. They can be treated using practically any technique used for thermoplastics. Ultrason is suitable for applications where conventional plastics such as polyamide, polycarbonate, polyoxymethylene, and polyalkylene terephthalates do not match the criteria. Ultrason resins are extremely versatile and can be used to replace thermosets, metals, and ceramics. Furthermore, ultrason can be utilized to build membranes. The range of innovative, cost-effective membrane processes is always expanding. Applications include water purification, food processing, biomedical, and manufacturing, wastewater treatment, and gas separation. Membrane devices and membrane materials employed in new separation processes are significant driving forces. In this area, high performance thermoplastics such as polyethersulfone (PESU), polysulfone (PSU), and polyphenylsulfone (PPSU) are widely used due to their demanding process conditions, high separation selectivity, and efficiency (SE, 2016).

BASF's trademark name Ultrason refers to the polymer class of polyarylene ethersulfones. The product range includes clear, high-temperature, and high-performance thermoplastics with superior chemical and hydrolytic stability, continuous-service temperatures of ≥ 160 °C, and high mechanical strength. Our membrane materials are available in granules (PSU, PPSU) and porous flakes (PESU) with varying molecular weights for quick dissolution. Ultrason stands out from other polymers due to its exceptional mechanical qualities, as well as its heat and chemical resilience. Ultrason produces membranes with high flux and UF pore-size rating, while maintaining a narrow pore-size dispersion. Many Ultrason grades meet FDA and European requirements for food contact applications (SE, 2016).

Ultrason E (Polyethersulfone, PESU), has stronger intrinsic hydrophilicity and chemical stability than PSU, including resistance to oxidizing agents such as sodium hypochlorite. Additionally, it has exceptional mechanical and thermal qualities. Ultrason E has become a standard for technical membranes used in UF water treatment due to its high permeability, long lifespan, low fouling, and chemical resistance (SE, 2016).

Ultrason S (Polysulfone, or PSU), is a widely established membrane standard. Its high purity (low gel and oligomer content) ensures process stability and pore size control during membrane fabrication. It is the primary material for single-use membranes or Thin Film Composite (TFC) membranes (SE, 2016).

Ultrason P (Polyphenylenesulfone, PPSU), outperforms the other three polymers in terms of chemical resistance and molecular weight degradation. It tends to create denser coatings or membranes (SE, 2016).

Advantages of Ultrason Technology:

- 1) Excellent chemical resistance to water, acids, NaOCl, and caustic soda.
- 2) Can be utilized throughout a broad pH range (0-13)
- 3) Repeated sterilization is achievable with superheated steam (134°C), ethylene oxide, and γ -radiation.
- 4) Meets FDA and European regulations for food contact (repeated usage).
- 5) Soluble in solvents frequently used for membrane manufacturing.
- 6) Effective pore size regulation
- 7) High flux.

		Polymer	Nominal type	Max. flux [lmh]	MS2 virus LRV	Max. TMP [bar]
Hydranautics	HYDRAcap 60	PESU	UF	119	>4	1.2
Inge	Dizzer	PESU	UF	156	3.5	2.0
Norit	SXL 225	PESU	UF	127	>4	2.1
GE-Zenon	ZW 1000	PVDF	UF	93	3.5	0.8
DOW	SFX 2860	PVDF	UF	102	2.5	2.1
Pall	Microza	PVDF	MF	204	0.5	3.0
Siemens Memcor	S10 V, L10 V, L20 V	PVDF	UF	88	1.5	1.5
Toray	HF S -2020	PVDF	UF	202	1.5	2.0

Figure 35, Virus removal of commercial UF membranes, (SE, 2016)

As shown in figure 35, the dizzer UF membranes by Inge GmbH are made from the polymer PESU. Dizzer modules with Multibore® 0.9 membrane specifications are listed in (see Figure 36) and technical information (see Figure 37).

Module data			dizzer® XL 0.9 MB 60 W		dizzer® XL 0.9 MB 38 W	
Part number			VK-0069		VK-0070	
Membrane area	m ²	sq.ft.	60	645	38	410
Length with end cap (L)	mm	inch	1680 ± 3	66 1/8	1180 ± 3	46 1/2
Length without end cap (L1)	mm	inch	1486 ± 1.5	58 1/2	986 ± 1.5	38 3/4
Distance feed connectors (L2)	mm	inch	1600 ± 3	63	1100 ± 3	43 1/2
Distance feed – module center axis (A)	mm	inch	165	6 1/2	165	6 1/2
Distance feed – filtrate connector (B)	mm	inch	190 ± 1.5	7 1/2	190 ± 1.5	7 1/2
Outer diameter end cap coupling max. (C)	mm	inch	295	11 5/8	295	11 5/8
Outer diameter module (D)	mm	inch	250	9 7/8	250	9 7/8
Connector flexible victaulic (d1)		inch		2		
Weight* (wet)	kg	lbs.	55	120	40	90

Figure 36, Dizzer modules with Multibore® 0.9 membrane specifications, (inge, n.d.)

Technical information

Cleaning/disinfection chemicals		Multibore® 0.9 and 1.5 membrane		
Free chlorine	ppm ppm x h	max. 200 max. 200,000 (at pH ≥ 9.5)		
H ₂ O ₂ (Hydrogenperoxide)	ppm	max. 500		
Caustic Soda pH		max. 13		
Acid pH		min. 1		
Flux rate				
Filtration*	l/(m ² h)	gfd	60 – 180	35 – 105
Backwash standard	l/(m ² h)	gfd	230	135
Backwash range	l/(m ² h)	gfd	230 – 300	135 – 175
Transmembrane pressure (TMP)				
Filtration*	bar	psi	0.1 – 1.5	1.5 – 20
Backwash standard*	bar	psi	0.3 – 3.0	5 – 40
Burst pressure membrane	bar	psi	> 10	> 150

Figure 37, Dizzer modules technical information, (inge, n.d.)

Dizzer XL - Ultrafiltration modules provide (inge, n.d.):

- Excellent efficiency and high output
- Easy installation, plug-and-play operation
- Compact design
- Low operating costs

5.2 The SFX-2860 ultrafiltration technology by DOW Water & Process Solutions

Dow Water & Process Solutions, a business unit of The Dow Chemical Company which is an American multinational corporation headquartered in Midland, Michigan, United States. The company is among the three largest chemical producers in the world. It is the operating subsidiary of Dow Inc., where it represent a major leader in water treatment technology. Dow Water & Process products provided a variety of water treatment products, including nanofiltration membranes for desalination, purification, and industrial operations (Dow, n.d.).

DOW Ultrafiltration modules use high-strength hollow fiber membranes with the following features:

- 0.03 µm nominal pore diameter for removal of bacteria, viruses, and particulates including colloids
- PVDF polymeric hollow fibers for high strength and chemical resistance

- Hydrophilic PVDF fibers for easy cleaning and wettability that help maintain long term performance
- Outside-In flow configuration for high tolerance to feed solids and the use of air scour cleaning
- U-PVC housings eliminate the need for pressure vessels and are resistant to UV light

The outside-in flow design tolerates a wide range of feed water quality and enables for air scour cleaning. The dead-end flow maximizes recovery and energy savings. The pressurized vertical shell-and-tube design avoids the need for separate pressure vessels and facilitates air removal during cleaning and testing. Hollow fiber membranes composed of PVDF polymer have a diameter of 1.3 mm outside and 0.7 mm inside. The fibers are strong due to an asymmetrically dense PVDF polymer mixture. The 0.03µm nominal pore size provides both strong filtering performance and high flux. In comparison to microfiltration, the smaller pore size provides more stable long-term filtration efficacy. Spongy layer, and skins produced on both sides of the fiber. PVDF membranes have great chemical resistance and can withstand temperatures up to 40°C. Using a unique treatment during manufacture increases the hydrophilicity of the PVDF fibers (Offices).

The basic operating conditions for the DOW Ultrafiltration modules are shown in figure 38.

Operating Conditions	SI	US
Feed Pressure, Maximum at Inlet at 20 °C	6.25 Bar	93.75 psi
Operating TMP (Maximum)	2.1 Bar	30 psi
Filtrate Flux @25C	40 - 120 L/m ² /hr	24 - 70 gfd
Temperature (UPVC limited)	1 – 40 °C	34 - 104 °F
Operating pH Range	2 - 11	
NaOCl, Cleaning Maximum	2,000 ppm	

Figure 38, the basic operating conditions for the DOW Ultrafiltration, (Offices)

5.3 The HFUG-2020AN ultrafiltration technology by Toray

Toray is a Japanese multinational conglomerate founded in 1926 in Japan. It operates in a variety of industries, including chemicals, fibers and textiles, plastics, and information technology-related products. It also provides solutions for environmental issues and engineering challenges, such as water treatment, air purification, and other environmental technologies. Toray Industries, Inc. has developed water treatment membranes since 1968. Today, they offer a complete array of membranes, supported by our sixty years of

experience. Their innovative membrane technologies and global operations guarantee the success of every project. Toray Group prioritizes sustainability as the top global problem of the 21st century. Toray's Sustainability Vision for water treatment seeks to treble the amount of water treated annually using membranes by 2030 (compared to 2013). They offer superior membrane technology, including RO membranes, strengthen their technical services, and contribute to solving global water concerns (toray).

Toray's PVDF membrane is resistant to chlorine and strong acids, enabling effective chemical cleaning without compromising membrane life. Toray UF Modules effectively remove suspended particulates, viruses, and bacteria and are approved for use in drinking water applications. Toray's PVDF hollow fiber membranes are created using thermally-induced phase separation, resulting in the industry's strongest fiber. Their production technique optimizes membrane pore distribution and size, resulting in superior filtrate quality and reduced fouling potential, the HFUG-2020AN modules technical information are described in (see Figure 39) (toray).

Dimensions and Weight		Unit	Value
Diameter		mm (in)	216 (8.5)
Length		mm (ft)	2,160 (7.087)
Weight	Full of Water	kg (lbs)	92 (203)
	After Draining	kg (lbs)	49 (108)
Connections		Value	
(1) Filtrate / Backwash		Housing type joint, 80A	
(2) Air Out		Housing type joint, 65A	
(3) Feed Drain / Air In		Housing type joint, 80A	
Material Composition			
Casing		uPVC	
Cap		uPVC	
Potting		Epoxy resin	
O-ring		EPDM	

Figure 39, the HFUG-2020AN modules technical information, (toray)

5.4 The L10V MEMCOR ultrafiltration technology by Siemens Water Technologies group

Memcor is the world leader in microfiltration and ultrafiltration membrane treatment, with over 1000 membrane plants deployed throughout the world. Memcor is a membrane

manufacturer and seller of water treatment systems inside the Siemens Water Technologies division. Membranes treat a wide range of water sources for potable use, as well as municipal wastewater for reuse. One of the growing uses of membrane applications is using a strong ultrafiltration membrane prior to reverse osmosis treatment (RO) for both desalination and industrial processes. The Memcor L10V UF membrane module is part of the Memcor XP series of products. The module is 4.7 inches in diameter and 45.5 inches in length. The membrane fibers are composed of polyvinylidene fluoride (PVDF). The flow of water through the membrane fibers is from outside to inside. The modules run in a dead-end mode, with no reject streams. The nominal pore size is 0.04 μm . Siemens provided five modules from five separate production runs for testing. Siemens delivered a pilot unit for testing the modules (dupont). The Memcor L10V UF technical sheet (see Figure 40).

Module Model	L10V
Membrane Material	PVDF
Backwash Type	Air Scour Liquid B/W
Nominal Pore Size (μm)	0.04
Surface Area (m ²)	23.4
Maximum Temp (°C)	45
pH Range	2-10
Average Free Chlorine (ppm)	< 5
Maximum Free Chlorine (ppm)	1000
Module Weight Wet (kg)	6.5
Nominal Module Length (mm)	1157
Nominal Module Diameter (mm)	119
Typical Applications	General Applications

Figure 40, The Memcor L10V UF technical sheet, (dupont)

The modules were set to run at a target flux of 80 gallons per square foot per day (gfd), equivalent to 14 gallons per minute for the L10V. The results are shown in (see Figure 41)

Module Model	L10V
Membrane Material	PVDF
Chlorinated Secondary Effluent	
Module Flow (kL/day)	30.3
Recovery	93%
Clear Surface Water	
Module Flow (kL/day)	38.5
Recovery	95%
Turbid Surface Water	
Module Flow (kL/day)	30.3
Recovery	94%
Surface Water - with Algae or coagulant	
Module Flow (kL/day)	
Recovery	
Sea Water	
Module Flow (kL/day)	35.7
Recovery	95%
Chlorinated Municipal Water	
Module Flow (kL/day)	55.0
Recovery	> 96%

Figure 41, The Memcor L10V UF test result, (dupont)

6. Results and Discussion

According to the previous sections, the research was conducted based on RO, NF, UF, and RO treatment techniques, while electro-oxidation shows potential in wastewater treatment, there is a lack of study into EO treatment technologies and the challenges that involve scaling up where implementing electro-oxidation on a wider scale can be difficult, and its high energy consumption, which can be a disadvantage, making it an unsuitable treatment technology for this study. Also according to the research, nanofiltration is considered an effective solution in most cases. But ultrafiltration represents a more suitable treatment technology for this specific case, where ultrafiltration is compatible with the existing treatment system in Cementra Jordan by the explained method “Integrated Membrane System (IMS)” and also considering the water source as ground water, where the results show nanofiltration is considered the best available technology for ground water pre-treatment in a RO system, especially when the water is filtered with activated carbon, which is used in the Cementra treatment system.

A list of the best available NF technology was provided in section 5, and the Dizzer XL 0.9 MB 80 WT ultrafiltration technology by Inge GmbH represents the best art technique and the most suitable solution for this project. The technique was chosen based on the used filtration material. The Dizzer XL 0.9 MB 80 WT ultrafiltration membrane is designed using polyethersulfone (PESU), while the other technologies listed are designed using PVDF (polyvinylidene difluoride) membranes. A technical comparison between PESU and PVDF is shown in (see Figure 42).

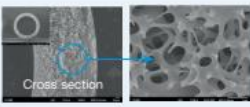
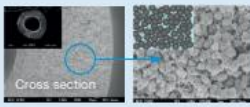
Polymer	PESU		PVDF	
Processing	Non-solvent induced phase separation (NIPS)		Temperature induced phase separation (TIPS)	
Configuration	Hollow fiber			
Membrane morphology	 <p>Strong fiber – high porosity with interconnected pores</p>		 <p>Weak fiber – spherulitic globules due to crystallinity</p>	
Porosity	75-80%		60-70%	
Water permeability [LMH/bar]	UF: >1,000		UF: 500-600	
Pore size [µm]	0.02 and below (narrow)		0.015 – 0.2 (broader distribution, not exactly UF rating)	
Virus removal (LRV) ₁₀	≥ 4		0.5-3.5 (lower than drinking water LRV requirement = 4)	

Figure 42, a technical comparison between PESU and PVDF, (Membr., 2009)

According to the figure 42, the PESU polymer has a porosity range of 75-80%, while the PVDF polymer has a lower range of 60-70%, in addition to the virus removal and water

permeability in PESU represent a perfect chose. Membrane efficacy for viral elimination is heavily influenced by pore size and distribution. The conventional PESU formulation has a smaller pore size distribution and a greater log virus removal value (LRV ≥ 4) than PVDF (see Figure 43).

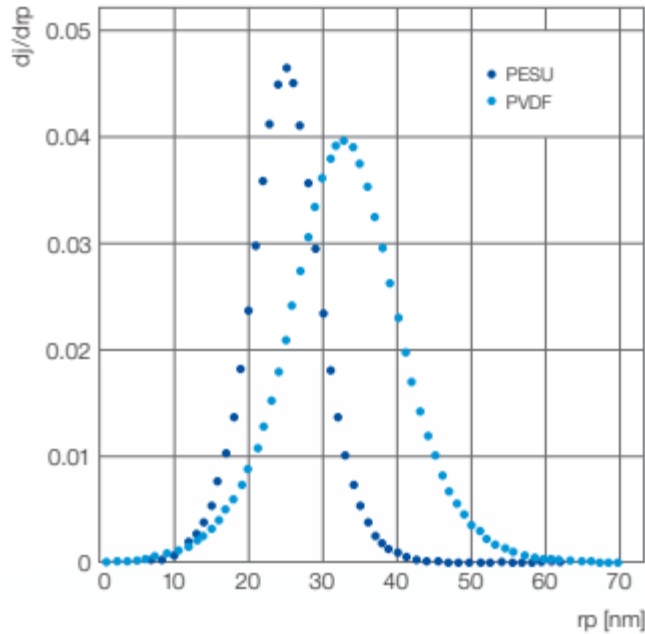


Figure 43, PESU higher virus removal as compared to PVDF, (Services, 2009)

UF membranes manufactured with PESU have a narrower pore size distribution compared to PVDF, resulting in greater RO feed water quality, less fouling, and increased productivity. PESU holds a 70% market share in UF pre-treatment for the RO process (see Figure 44).

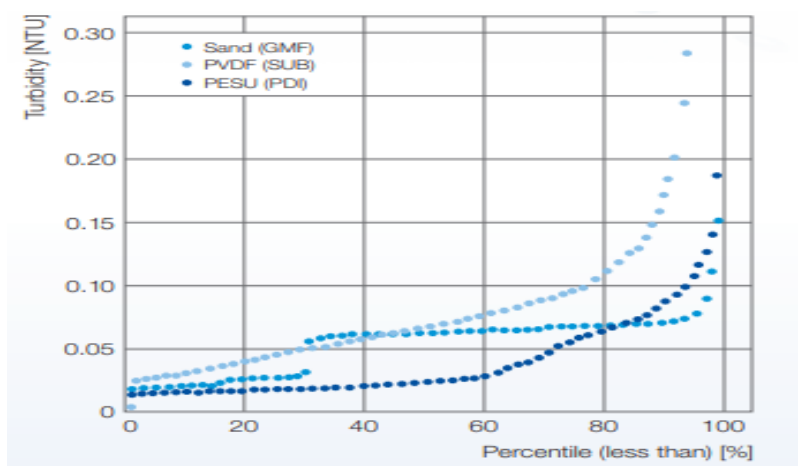


Figure 44, PESU membranes provide lower water turbidity during ultrafiltration pre-treatment for reverse osmosis compared to PVDF membranes (al, 2007).

Sulfone polymers are very resistant to alkali, which are commonly employed for membrane cleaning. After 1,000 hours of exposure to 10% caustic soda at 40°C, the molecular weight of PSU, PESU, and PPSU membranes remained unchanged. PVDF's molecular weight reduces by 35% at alkaline circumstances (see Figure 45).

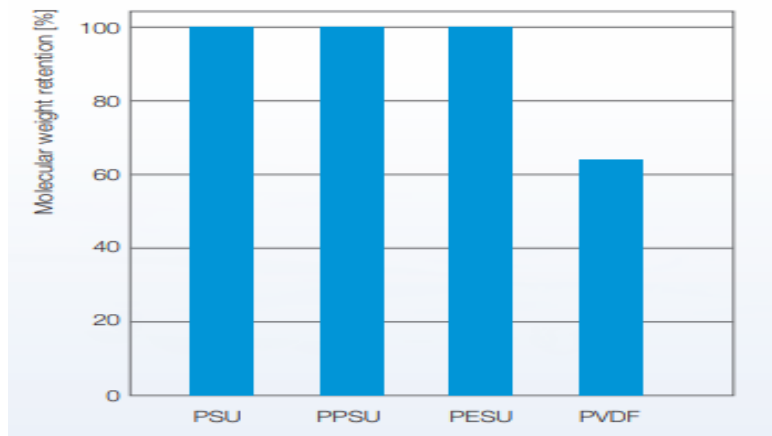


Figure 45, Retention of molecular weight of PSU, PPSU, PESU and PVDF membranes after 1,000 h immersion in caustic soda (NaOH, 10%, 40 °C), (Membr., 2009)

7. Methodology

Environmental decisions involve biophysical, sociocultural, and economic challenges that require adequate knowledge synthesis and stakeholder interaction, as well as the ability to handle increasingly complicated and vast data sets. It might be claimed that all environmental decision-making processes should analyze and compare many types of alternatives.

Alternatives encompass all options, choices, or courses of action for achieving specific goals (Steinemann, 2001). These alternatives can be related to 'different possible purposes, different locations and designs, different general approaches to serving the selected purpose, different packages of mitigation and enhancement components, and different implementation plans, for example. Alternatives in environmental decisions are weighed against diverse and competing aims, such as safeguarding nature, meeting community needs, and supporting economic growth (Lindfors, 2021).

Sustainable development, possibly the most influential vision of future civilization, tries to combine the most important and demanding concerns that societies around the world are currently facing. Social struggles, environmental degradation, and economic development all fall under the umbrella of sustainable development. Furthermore, these issues should be tackled as a unified and difficult challenge (Lindfors, 2021).

Many methodologies from various disciplinary backgrounds can be used to perform integrated sustainability assessments. Multi-criteria assessment is a popular approach family. MCA methods originated within the field of operations research as a way to handle decision-making in management based on multiple competing criteria and dimensions, but their application in SA is a continuously growing area with high methodological diversity (Lindfors, 2021).

In this thesis, MCA is used as an umbrella term for methods that are used to support decision-making based on multiple criteria. In the MCA methodology, the target of the assessment is to transfer the best art techniques in the first dimension and the most cost-efficient in the second dimension.

8. Conclusion

According to the research, Jordan is one of the most scarce water resource countries in the world due to several reasons, such as the lack of seawater desalination practices to increase the water budget in Jordan, the high dependence on ground water for domestic supply, agricultural, and most importantly in the industrial sector, where the industrial sector depends mainly on ground water, especially the concrete industry. The water use in the concrete industry in Jordan consumes water mainly for cooling purposes, where waste water treatment practices are not developed or do not exist in the first place. As an example, Cementra Jordan was discussed in this study, from extracting water through the pre-treatment of the ground water to be used in cooling towers to discharging the water by using it as a dust control method. Other manufacturers, such as Lafarge, use wastewater treatment to recycle the water and reuse it in the cooling processes, but only a small amount of water is being recycled. The main component in the cooling process is the cooling towers. According to the research, several types of cooling towers exist, but only the open recirculating cooling systems are discussed. In the author's opinion, they are the main cooling system in the cement industry in Jordan. The cooling system consumes a large amount of water with specific water quality in order to avoid scaling and corrosion problems. Water parameters were discussed as key parameters that affect the quality of water that needs to be achieved in order to ensure safe recycled water reuse. Several water treatment techniques were discussed to improve the waste water quality and enhance the reuse of waste water, such as electro-oxidation treatment techniques that show potential in wastewater treatment, but due to the lack of study into EO treatment technologies and the challenges that involve scaling up where Implementing electro-oxidation on a wider scale can be difficult, and its high energy consumption is a disadvantage. According to the author, it is an unsuitable treatment technology for this study. On the other hand, findings on Nano filtration and RO provide a great solution for this study. A method called "Integrated

Membrane System (IMS)’ was discussed, which is a multi-step treatment consisting of a dual media filter, an activated carbon filter, Nano filtration, and RO. Also, a list of the best available Nano filtration innovative technologies was discussed, and a finding on the PVDF membrane material showed great results in waste water treatment.

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