



ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
CENTER FOR MATERIALS ENGINEERING

DESIGNING A SOLAR PV POWERED REVERSE OSMOSIS DESALINATION SYSTEM
USING ROSA TO CLEAN LAKE BASAKA WATER

A THESIS SUBMITTED TO THE CENTER FOR MATERIALS ENGINEERING IN ADDIS
ABABA INSTITUTE OF TECHNOLOGY IN PARTIAL COMPLETION OF THE
REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN MATERIALS
ENGINEERING

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JULY, 2023

ADDIS ABABA, ETHIOPIA

Declaration

I declare that this thesis entitled “Analysis of Lake Basaka water by the solar-driven membrane-based reverse osmosis filtration system and membrane design by ROSA software” has been solely the result of my work under the supervision of Georgies Alene (Ph.D.) which is composed of original content I have written, references cited and credits in acknowledgment. Furthermore, it completes all necessary required information and it has not been submitted for any other institution in whole or in part for a degree completion or professional qualification.

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ACKNOWLEDGMENT

First and foremost, I would like to give thanks, glory, and blessing to my Father, Jesus Christ, who is in heaven for his superabundant providence with his everlasting life and invaluable security throughout my life.

I would like to extend my sincere gratitude to my advisor Georgies Alene (Ph.D.) for being tremendous support by guiding me patiently; furthermore for giving me the chance to take part in his project to do my research as well as for all of the tools and assistance he offered from start to finish of my master's degree program.

I am grateful to my family for being next to me by providing cheerful love and care throughout the year.

I am deeply thankful to my mentor Pastor Seife Ejigu and his wife Sister Tigist for tremendous love, care, and prayer.

In closing, I am grateful to the Center of Materials Engineering, my teachers, my classmates, and the installation crew who has been with me during this journey. It would not have been an educational experience without them.

ABSTRACT

The freshwater shortage is an issue concerning safe water supply. The availability and usage of fresh water are critical for human health as well as economic and ecological stability. The continual increase in salinity and alkalinity hindered the utilization of Lake Basaka for drinking, irrigation, and residential purposes. In this study, ROSA software is used to design an appropriate membrane to filter Lake Basaka water at higher rejection and specified recovery, flux, permeate, and feed flow. The ROSA software-designed TW 30-2540 membrane for the RO System provided the required permeate flow rate of 0.21 gpm with an applied pressure of 100.94 psig, recovery of 14.89%, rejection of 99.56 %, flux of 10.80 gfd, salt passage of 0.44% at an adjusted feed pH of 8, and system temperature of 25 °C. As a consequence, ROSA Software designed the TW 30-2540 membrane for solar-powered RO to filter Lake Basaka water without displaying a design warning. In this regard, a solar-driven reverse osmosis system with five filter stages, including three pretreatment filter stages, one membrane stage, and one post-treatment filter stage, was used to filter Lake Basaka water by removing organic and inorganic components such as suspended particles, dissolved solids, and water pollutants from feed water driven by solar energy as an energy source. The samples collected for water quality examination were 4 liters of water in a clean plastic bottle as part of the sampling procedures from Lake Basaka and RO-filtered Lake Basaka water is evaluated by using AAS and MP-AES, respectively. As comparing Lake Basaka water analyzed before and after RO filtration Na, Mg, Ca, K, CO_3^{2-} , HCO_3^- , Cl^- , Barium, Nitrate, Fluoride, Sulfate, Silicon, and Boron all showed a reduction in mg/l after RO filtration.

Keywords: Freshwater scarcity, Reverse Osmosis, Lake Basaka, A solar-driven reverse osmosis system, ROSA Software

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic absorption spectroscopy
APHA	American Public Health Association
ASTM	America Society for Testing and Material
B	Boron
BW	Brackish water
Ba	Barium
CPV	Concentrated Photo Voltaic
Ca	Calcium
Cl ⁻	Chloride
DOW	Dow Jones Industrial Average
EC	Electrical Conductivity
ECAE	Ethiopian Conformity Assessment Enterprise
ED	Electro Dialysis
EPA	Environmental Protection Agency
F ⁻	Fluoride
GAC	Granular activated carbon
gfd	gallon per square foot per day
gpd	gallon per Day
gpm	gallon per minute
HCO ₃	Bicarbonate
HZ	Hertz, the unit of frequency
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
K	Potassium
LSI	Langelier Saturation Index
M ³	Cubic meter
MP-AES	Microwave plasma atomic emission spectroscopy
MSF	Multi-stage flash distillation
Mg	Magnesium
mg/L	milligram per liter
NH ⁺⁴	Ammonium
NO ₃ ⁻	Nitrate
Na	Sodium
PCV	Prescribed Concentration or Value
PP	Polypropylene
PSI	Pounds Per Square Inch
pH	Potential of Hydrogen

ppm	Parts per million
P	Pressure Differential
ROSA	Reverse Osmosis System Analysis
SAMCO	Samco Acceptance Corp
SAR	Sodium adsorption ratio
SDI	Silt Density Index
SO ₄ ²⁻	Sulfate
SPRO	Semipermeable Membrane Reverse Osmosis
Si	Silicon
Sr	Strontium
TDS	Total Dissolved Solids
TW	Tap water
UN	United Nations
UNICEF	United Nations Children's Fund
V	Volt
V	Velocity
Vac	Volts alternating current
W	Power
WHO	World Health Organization
WWF	World Wide Fund for Nature
ZEEnit	Zeeman AAS Spectrometer

1.0. INTRODUCTION

Water is crucial for life and is used throughout the world. The term "freshwater" refers to naturally occurring liquid or frozen water that contains low quantities of dissolved salts and other total dissolved solids. Water demand throughout the world for drinking purposes, agriculture, industry, and food is higher relative to the water supply/inflow. The matter that arises regarding safe water supply is Freshwater scarcity. Fresh water availability and utilization are vital for human health as well as economic and ecosystem stability. However, the growing disparity between human demands and natural freshwater supplies is adding to freshwater scarcity. Freshwater scarcity affects industrial and agricultural productivity, as well as a wide range of social, economic, and political issues such as poverty, deterioration of ecosystem health, and violent confrontations.[1]

1.1 Background of the study

Water covers 71% of the earth's surface, and 96.5% of that water is in the ocean, with the remaining 2.53 % being fresh water. The majority of the water on Earth is found in the ocean, which is extremely saline and cannot be used for freshwater access.

1.1.1 Fresh Water in the World

While water is abundant on the planet Earth, only a small amount of it is fresh water, and an even smaller fraction is accessible to humans. The oceans hold nearly all of the water on Earth, leaving about 2.5% as fresh water. (Refer to Table 1.) Nearly three-quarters of this small percentage is frozen, with the rest present as soil moisture or deep in the subsurface. The primary sources of fresh water available to society are lakes, rivers, wetlands, and shallow groundwater aquifers all of which account for only a minimal percentage (tenths of one percent) of all water on Earth. [2]

Table 1: The major storages, distribution of water, and percentage in the world [2]

Type	Volume (thous.cu.km.)	Fraction Total Volume (%)	Fraction Fresh Water (%)
World Ocean	1,338,000	96.5	–
Groundwater	23,400	1.7	–
- Freshwater	10,530	0.76	30.1
Soil moisture	16.5	0.001	0.05
Glaciers/permanent ice	24,100	1.74	68.7
Ice in permafrost	300	0.022	0.86
Lakes (Fresh)	91	0.007	0.26
Wetlands	11.5	0.0008	0.03
Rivers	2.12	0.0002	0.006
Biological waters	1.12	0.0001	0.003
Atmosphere	12.9	0.001	0.04
Total Hydrosphere	1,386,000	100	–
Total Freshwater	35,029	2.53	100

1.2. Solar desalination technique

In the solar desalination techniques, there are two systems the first one is the solar photo voltaic system which our research focuses on it which directly changes the sunlight into electric energy. And the second one is concentrated photovoltaic (CPV) which needs a mirror for replacing the light from the sun with thermal energy.[3]

This project focuses on solar photovoltaic technology which tackled the expensive power supply cost in common usage of the PV system.

Solar-driven water purification is the method of reducing organic and inorganic compounds such as any suspending solids and gases and removal of water contaminants that are biological such as viruses, bacteria, algae, and several others through different purification techniques by using solar energy as an energy source.

From different water filtration systems, In this project, a solar-driven membrane-based water filtration system is used because solar-powered membrane desalination is a new and efficient option for Ethiopia's existing energy supply and utility needs and it suits best arid, semi-arid, and rural areas and the power source is solar PV. The power supply is no concern since the country gets sunlight throughout the year in all zones of areas. The Solar power supply works for rural areas where there is a shortage of energy supply because the rural area is not connected to the electricity grid. Therefore this method works in rural areas where there is a shortage of power supply and in the city to minimize energy costs.

Solar-powered membrane desalination technique received global views because of its global warming-reducing behavior and energy-efficient character easiest and needs low maintenance complexity and coupling ability with other power supply methods. The need for solar-powered membrane desalination technology is global due to its economic viability and potential to reduce global warming. The most crucial method for water purification in the world is used to meet the urgent demand for water brought on by infrastructural expansion, population growth, and rural development resulting from agricultural activity. [4]

Solar-driven membrane desalination technology is the world's most essential water purification technique in meeting the world's growing water demand in different sectors such as drinking water, agriculture, and infrastructure due to high population increment. Water purification could therefore help to address the problem of freshwater scarcity. [5]

The desalination process is driven by the proposed solar-based RO desalination system, which turns brackish water into fresh (drinking) water by converting solar energy into electric energy. The PV offers a 231V, 50 Hz AC supply that goes through a 5-filter stage process. [6]

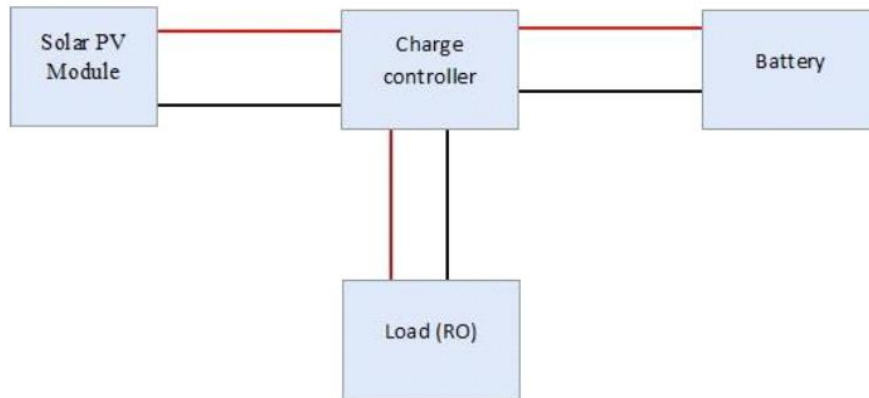


Figure 1: Block diagram of solar RO system[6]

1.2.1. Reverse osmosis

Reverse osmosis is the most well-known and widely used membrane-based desalination process, in which all colloidal or dissolved ions from aqueous solution/water are rejected called concentrate (reject) and practically pure water is delivered as a product (permeate) water. [7]

The principle behind reverse osmosis states that when the applied pressure level exceeds the osmotic pressure, the salt side must exert more pressure for the process to take place and for the water molecules to be propelled directly through the semi-permeable membrane (a membrane that passes a specific species while other is retained while osmosis naturally occurs as water moves from a lower concentration to a higher concentration through a semi-permeable membrane. [6]

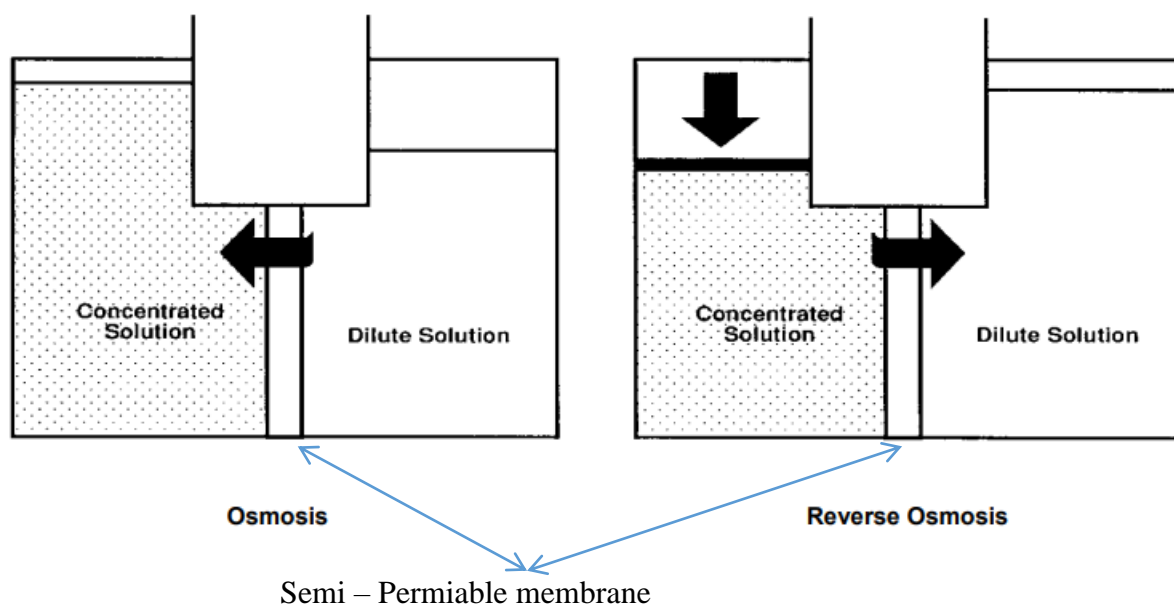


Figure 2: Osmosis and reverse osmosis. [8]

This system will attempt to achieve equilibrium as a basic law of nature. It will attempt to get the same concentration on both sides of the membrane, in other words. The only method to achieve balance is for water to move from the compartment containing only pure water to the compartment containing salt solution, diluting the salt solution. [8] The applied pressure that exceeds natural osmotic pressure must proceed the feed water which has high salinity through a semipermeable membrane into the low concentrated stream by separating the fresh water from the salty water. [9]

1.3. Statement of the problem

The increase in salinity of Lake Basaka over the previous decades has been worrying, resulting in a substantial decrease in the quality of water that is unable to be utilized for drinking, irrigation, and residential purposes. Previous studies demonstrated a deterioration in soil fertility and sugarcane production around Matahara. The Expansion of Lake Basaka is concerning the population in the Awash River basin worrying that it may join the Awash River and have an influence on the irrigational farmlands downstream. Multiple challenges hinder Lake Basaka water from being utilized such as a shortage of Lake Basaka water analysis to prove the appropriate filtration system and a lack of designed high rejection and recovery membrane that filters the Lake Basaka water by Reverse Osmosis.

1.4. Significance of the study

This paper is intended to investigate Lake Basaka water before RO filtration and after RO filtration, comparing the water composition and quality, furthermore, it proves an RO filtration system is a reason for the high rejection of salt and reduction of dissolved solids in the high saline Lake Basaka water. It recommends a designed high salt rejection membrane suitable for Reverse Osmosis filtration of Lake Basaka water for investors and organizations. This study opens the gate to the utilization of Lake Basaka water for irrigation and household and acts as a cornerstone for further investigation regarding Lake Baska water filtration through Reverse Osmosis and its utilization for drinking water.

1.5. General objectives of the study

The general objective of the study was to assess an alternative way to utilize Lake Basaka water.

1.6. Specific Objectives of Study

The specific objectives of the study were:

- To filter Lake Basaka water through a solar-driven membrane-based RO filtration system
- To examine and compare the Lake Basaka water composition and quality before and after RO filtration
- To design the membrane suitable for RO filtration of Lake Basaka water
- To recommend high rejection and recovery membrane for RO filtration of Lake Basaka water

1.7. Scope of the study

The research focuses on the analysis of Lake Basaka water filtration by Reverse Osmosis and an appropriate membrane design that meets better rejection, recovery, product water quality, and lower energy consumption. This research investigates the solar-driven Reverse Osmosis filtration system where the unnecessary and hazardous enormous amount of components have been filtered out by using solar energy. This study analysis compares and discusses the Lake Basaka water before and after Reverse osmosis filtration, designs and suggests a suitable membrane to filter Lake Baska water in higher quality through solar-driven Reverse Osmosis filtration system.

1.8. Limitation of study

To set up the RO System in the entire area surrounding Lake Basaka, the capital should be increased by providing a reverse osmosis filter system with higher solar energy efficiency, a higher permeate flow rate, a larger water tank, and the membrane should be changed into the large scale to increase the product flow rate, which will increase the flow rate and allow for the filtering of a massive amount of gallons per day/gallons per minute. Our ability to offer more freshwater to the shortfall is limited by our expertise and capital but this study could catch the attention of investors and the community to overcome limitations. Furthermore, some water composition tests for specific components are only available at a few testing facilities in Addis Ababa.

1.9. Thesis Organization

This thesis is composed of five chapters subdivided into subsections. Chapter one introduces freshwater scarcity around the world, the source of freshwater shortage, solar desalination technique, reverse osmosis, components of reverse osmosis, and its functions. Furthermore, the significance of the study, general and specific objectives of the study, and the scope and limitation of the study have been included as well. Chapter two presents the literature review on solar-driven water purification/desalination technique, reverse osmosis and its working principles, and solar-driven reverse osmosis. The third chapter is about the materials for study such as ROSA software, RO filter, and methods used to filter the Lake Basaka water. And materials and methods used to analyze Lake Basaka water before and after RO filtration. Chapter four includes detailed results of before and after filtration of the Lake Basaka water and the filtered sample water results and compares it with analysis before and discusses the membrane design and the reports on the membrane designed for Reverse Osmosis Filtration. Chapter five comes to a conclusion of the study and adds up some recommendations and shows direction for future investigation.

2.0. LITERATURE REVIEW

For freshwater availability, water resources should be seen as a source of freshwater deliverance to every human being and seen carefully as a resource and technologically applying different water filtration systems. The driving interest in knowing the freshwater scarcity is due to the benefit of fresh water for the human being and its environmental aspects where its occurrence spatially and temporally differs worldwide. [10]

2.1. Surface water resource

Throughout the world, Africa holds some of the largest freshwater reservoirs appertaining to surface waters, having high dispersal and accessibility but the scarcity of fresh water is a concern due to climate change, environmental deterioration, and instability in several aspects.[11]

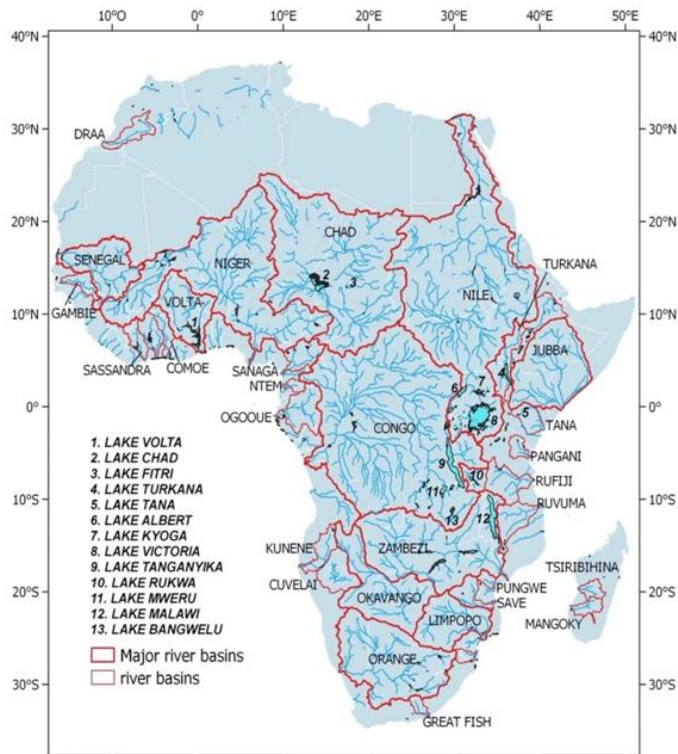


Figure 3: Location of river basins and lakes in Africa [10]

Ethiopia is a landlocked country in East Africa. Ethiopia has enormous water potential, but uneven rainfall distribution, rising demand, and the frequency of droughts have resulted in water scarcity in many sections of the country.[12]

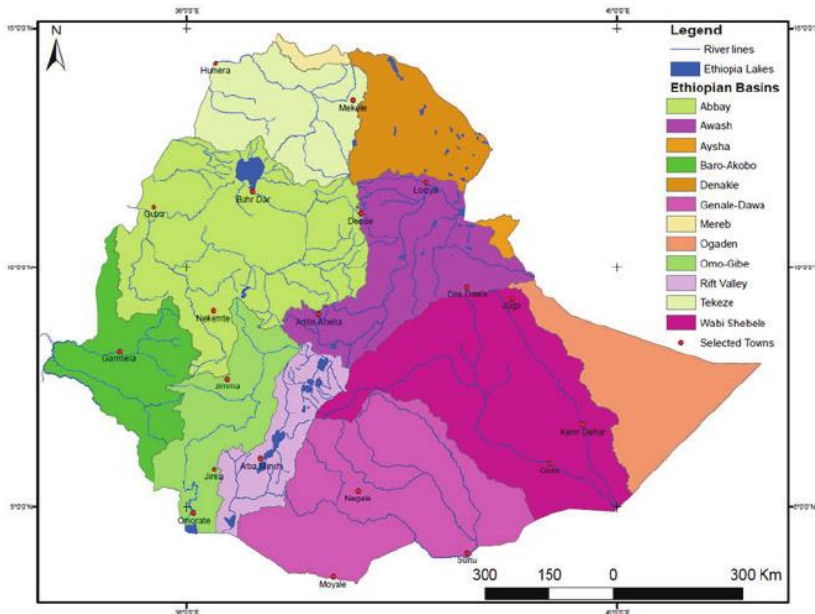


Figure 4: Lakes and river basins in Ethiopia.[13]

Ethiopia has 12 major river basins/valleys, 11 lakes, 9 saline lakes, 4 crater lakes, and over 12 significant swamps. Ethiopia has a complicated topography, a diverse climate, and vast water resources. Although further research is needed, existing understanding indicates that the country contains around 124.4 billion cubic meters (BCM) of river water, 70 BCM of Lake water, and 30 BCM of groundwater resources.[13]

2.1.1. Freshwater scarcity

As United Nations reported Water utilization is heightening at twice the spread of population growth. Two-thirds of the world's population will undergo a state of water stress” by 2025.[14]



Figure 5: Freshwater scarcity in India[15]

14 African countries are already suffering as a result of water constraints, by 2025, an additional 11 countries are scheduled to join. Water scarcity will affect nearly half of Africa's estimated 1.45 billion people by then, according to FAO, AQUASTAT. In Sub-Saharan Africa, over 51% (300 million people) lack access to clean water, and 41% lack sufficient sanitation.[10]



Figure 6: Freshwater scarcity in Africa[15]

The Horn of Africa is seeing more erratic temperature and rainfall patterns due to climate change, a trend that is only predicted to worsen. Many parts of the region will experience decreasing rains, despite the possibility of heavier rainfall in some locations. Extreme rainfall-related flooding is a serious issue that is made worse by the lack of climate-resistant water infrastructure.[16]

Ethiopia, with a population of 120 million people, is a large country with enormous water resources sees variations in rainfall patterns and distribution, combined with catastrophic climate events, have resulted in persistent food insecurity and water scarcity in many sections of the country. As a result, four out of ten people do not have access to clean water, and more children die from diarrhea each year. Even though the majority of rural populations rely on groundwater, they get their water from springs, deep boreholes, and shallow wells.[16]

Reduced rainfall will result in lower surface water levels and less groundwater aquifer replenishment, two crucial sources of water for communities and people deflection. Waterborne diseases like cholera and acute watery diarrhea are brought on by these decreasing water levels as well as poor sanitation and hygiene. Lower water levels result from more water evaporating from land and water surfaces as temperatures rise.[16]



Figure 7: People deflection[17]

The biggest contributing factor to freshwater scarcity was a famine that started about the middle of the 1980s, but there were a lot of other factors, too, like droughts that affected large areas of the country or the world and caused wells to dry up in the winter.

Even if Ethiopia is a water pillar of Africa with major rivers, including the Nile, and the greatest water preserve. Ethiopia is facing water scarcity due to a lack on accessing, indigent infrastructure has halted water management, the settled economic policy, water blossoming project, and stretched-out systems to use the preserves. [18]

Tackling the hazardous consequence of fresh water scarcity which is toxic heavy metals inside the water in the lakes, and rivers by using several filtration systems is feasible and economical rather than dealing with the deadly intoxication and contamination. People in rural areas use water that is unsafe for drinking. As some interviewed testified that just using whatever they find in nearby rivers, lakes, and ponds could be toxic with untreated wastewater, industrial sewage, and contaminants due to several industrial wastes and animal sewage in areas where poor sanitation is afforded.

Despite the abundance of water in nature, economic water scarcity occurs when institutional, financial, and infrastructure limitations restrict access to water therefore water prices increase. It is characterized by a lack of commitment to a system for supplying and distributing water fairly. Poor households struggle to obtain domestic water supplies because they are susceptible to high retail water prices and seasonal availability variations.[19]

2.2. Lake Basaka water salinity

According to Dinka 2017 [20], the water of Lake Basaka has shown salinity (EC ~ 6.3 ds/m), (SAR ~ 300), and alkaline (pH ~ 9.6) and is not used for irrigation and domestic purpose. Water sampling is done by using a clean polyethylene bottle which is half a liter. The water pH, EC, and temperature were measured using a standardized testing method, APHA. The result shows high salinity and alkalinity of water and the study discusses the term by prohibiting the Lake Basaka water for irrigation and domestic use.

The study used physicochemical parameters pH, EC, Soluble cations (Na, Ca, Mg, K), and organic carbon.

EDTA titrimetric method is used to determine calcium and magnesium while a flame photometer was used for the determination of sodium and potassium through this investigation of the water salinity.

Table 2: Methods adopted for water quality analysis[20]

Quality Parameter	Symbol	Method use
Ph	pH	Potentiometric
Electrical Conductivity	EC	Conductometry
Calcium	Ca ²⁺	EDTA titrimetric
Magnesium	Mg ²⁺	EDTA titrimetric
Sodium	Na ⁺	Flame Photometric
Potassium	K ⁺	Flame photometric
Chloride	Cl ⁻	Titration
Carbonate	CO ₃	Titration
Bicarbonate	HCO ₃	Titration (with H ₂ SO ₄)
Sulfate	SO ₄	Specto Photometric

Table 3: Physico-chemical parameters for Lake Basaka water in different years (1961 -2015) [20]

Year	pH	EC	Na ⁺	K ⁺	Ca ⁺²	Mg ⁺²	Cl ⁻	SO ₄ ⁻²	HCO ₃ ⁻²	CO ₃ ⁻²
^a 1961(May)	9.94	7417 0	17800	406	<3	<7.5	5480	4680	580	-
^b 1971		7923 0								
^b 1973		2500 0								
^b 1974		2541 0								
^c 1978		5620	-	-	26	5.0	-	-	-	-
^d 1991 (Mar)	9.4	7440	1810	67	2.2	0.49	450	600	46	-
^e 1993 (Feb)	9.55	-	1900	20	1.0	0.40	572	540	-	-
^b 1996	9.70	6385	882	67.6	4.2	3.7	863	-	515	622
^f 2000	9.71	-	1740	64	3.15	0.70	542	494	-	-
^g 2003 (Jan)	9.54	-	2160	80	2.18	0.38	421	620	-	-
^b 2002 (Jun)	9.6	7335	2449	38	18.2	6.1	1062	1504	2177	385
^b 2003 (Apr)	9.8	7804	1831	15	8.4	12	996	1080	1932	624
^g 2006	9.7	6730	1805	63.8	3.02	1.2	571	540	-	-
^b 2007 (May)	9.57	6280	2583	61.4	7.0	1.7	927	1020	1213	350
^b 2009 (May)	9.52	6170	2579	61.8	4.5	1.1	915	986	1140	340
^h 2010 (May)	9.52	6168	2582	62.1	4.5	1.5	922	987	1174	322
^h 2015 (May)	9.51	6150	2587	62.0	4.2	1.2	937	990	1180	320

The continuous increment of Lake Basaka water throughout several years has brought a big concern and alarm.

2.3. Lake Basaka water expansion bringing soil salinity

The study [21], conducted to reveal the negative consequence of Lake Basaka water expansion on the sugar cane plantation stated that the Matahara sugar estate (MSE) is experiencing salinity towards the plantation and the case is due to the result of the expansion of Lake Basaka water which is saline and alkaline. It negatively impacted crop production such as a decline in the production of Matahara sugar cane, and soil fertility decrease the Lake has the potential to join the awash river to negatively impact all crop production, livestock production, and productivity and livelihood of the people who depends on the Awash river.[21]

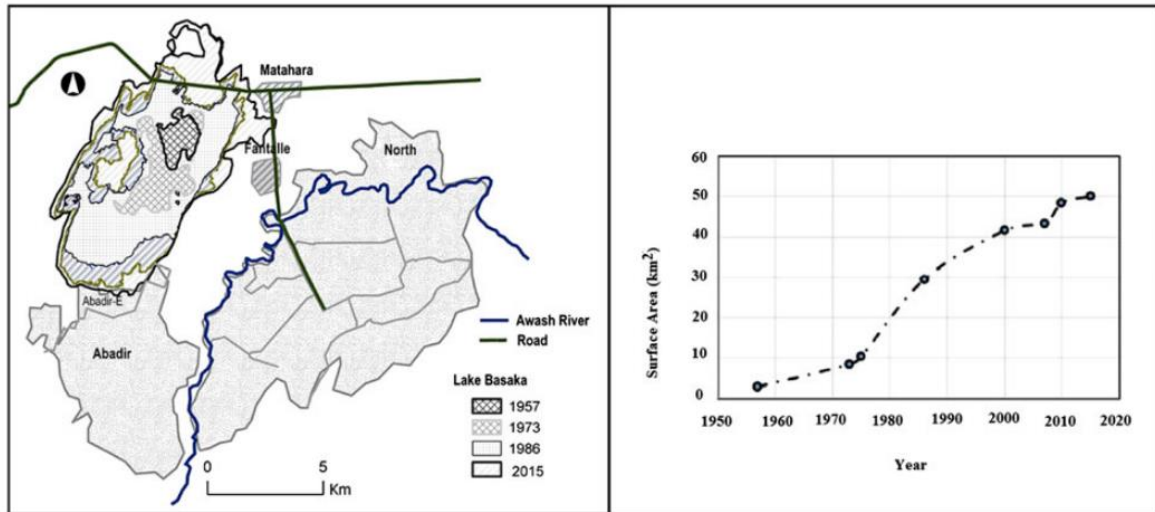


Figure 8: The size of Lake Basaka from (1957–2015) [21]

Figure 8 demonstrates that Lake Basaka increased from 3 KM² in 1957 to around 47.3 km² in 2015 [21]

The highly saline Lake Basaka water has the potential to join the Awash River and have a substantial impact on the river water chemistry and putting further strain on already depleted water supplies. It may also have an impact on the groundwater system and the aquatic ecology downstream. [21] The increase in salinity of the Lake Basaka water could have an impact on the enormous fertile irrigated farmlands located there and by measuring the partial decomposition of parts of cane the result is described as the reduction of OC (organic carbon) with the soil depth which shows the decline in fertility of the soil. [22]

2.4. Solar-driven Reverse osmosis

The ideal solution for the drastically declining subsurface reserves of natural gas and petroleum has been suggested, and it is sustainable energy, also known as renewable energy.

With the source of sunlight, desalination mostly uses solar energy in abundance as the power source for many other desalination techniques such as MF, RO, ED, and NF. [23]

The desalination system is the most known for its major performance in power supply consuming character which decreases the cost and makes it suitable.[3]

To keep the age and efficiency of a semipermeable membrane has to be in line working with pretreatment techniques in priority to that semipermeable membrane and remove other biological contaminants, organic and inorganic compounds mostly the bacteria, waste, and chlorine that reduce the age and efficiency of the semipermeable membrane by closing pore openings for permittivity of pure water.[24]

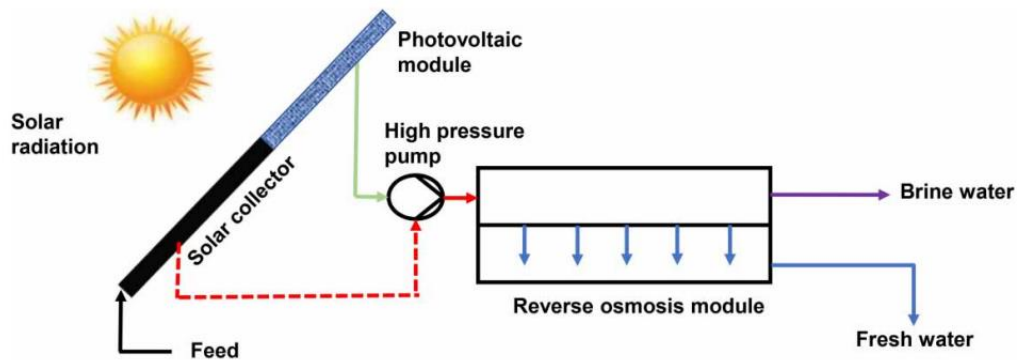


Figure 9: Semipermeable Membrane Reverse Osmosis (SPRO) desalination system [3]



Figure 10: PV – RO Water Desalination Plant[25]

2.5. Reverse osmosis filter and working principle

Reverse osmosis is the most effective method for removing contaminants from different water types. The technique of Reverse osmosis utilizes a reverse osmosis membrane for filtration purposes.

In general, filters are used for the filtration of fine particles. RO water filtration is the process of removing or reducing the concentration of particulate matter from contaminated water, including suspended particles, parasites, bacteria, algae, viruses, and fungi, as well as other undesirable chemical and biological contaminants, to produce safe and clean water for a specific purpose, such as drinking, medical, or pharmaceutical applications by using RO membrane. [26]

2.5.1. RO Filter working principle

To be purified water is provided to a sediment filter in the first filter stage for pre-treatment where the particles of sediments such as sand and clay from the water will be filtered out. And in the second stage, the water flows to the pre-carbon filter from the sediment filter. Little particles, volatile organic compounds, chlorine, taste, and odor are removed by the pre-carbon filter in the third stage. Pre-carbon has 280 grams of silver-impregnated granular activated carbon which is manufactured from the shell of a coconut. The dissolved particles are subsequently removed by the RO membrane filter in the fourth stage, which successfully removes most minerals, metals, and many organic contaminants from the water. Finally, in the fifth stage, the filtered water will flow through a final 'polishing filter,' usually activated carbon, to eliminate any lingering bacterial pollutants as well as the most disagreeable odors and tastes from the water.[27]

Table 4: Five stages of RO filter and its function [26]

Stages	Function	Treatment
First stage	A Pre-filter made of polypropylene that can screen out debris as small as 5 microns	Pre-treatment
Second Stage	Granular activated carbon (GAC) filtration	Pre-treatment
Third stage	A high-density 5-micron carbon block filtration that eliminates chlorine	Pre-treatment
Stage four	A Thin composite membrane that screens out particles as small as 0.0001 micron	Membrane Filtration
Stage five	Post-carbon filtration to enhance flavor and odor	Post-treatment

The semipermeable membrane helps the water to pass through the membrane by rejecting all suspended solids and most dissolved ions. The semipermeable membrane has a property of semi-permeability while they show very low permeability for dissolved substance and high permeability for water. [7] The water in the feed stream flows through a permeable membrane, which then becomes pure water. Consequently, two streams are gathered: permeate stream, nearly clean water with low ion concentration, and concentrate stream with a high concentration of dissolved ions and tiny particles.[6]

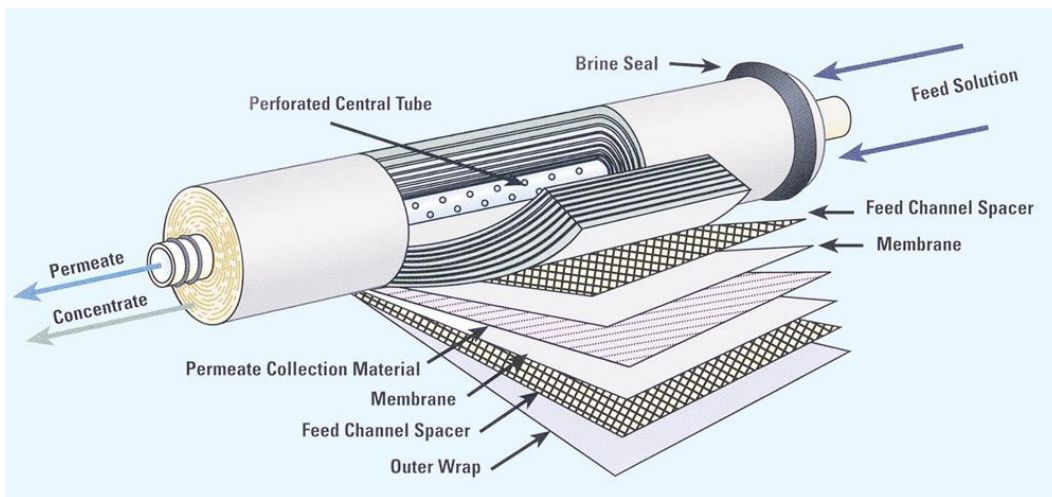


Figure 11: RO Membrane Cross Section[6]

RO system includes an RO membrane which has a feed spacer, and a permeate collection layer is coiled around a perforated central tube before being covered with a fiber vessel. The feed spacer allows feed water to circulate through the vessel, causing the necessary turbulence in the process. The filtered feedwater is then directed to the permeate collection tube via the permeate collecting material.[28]

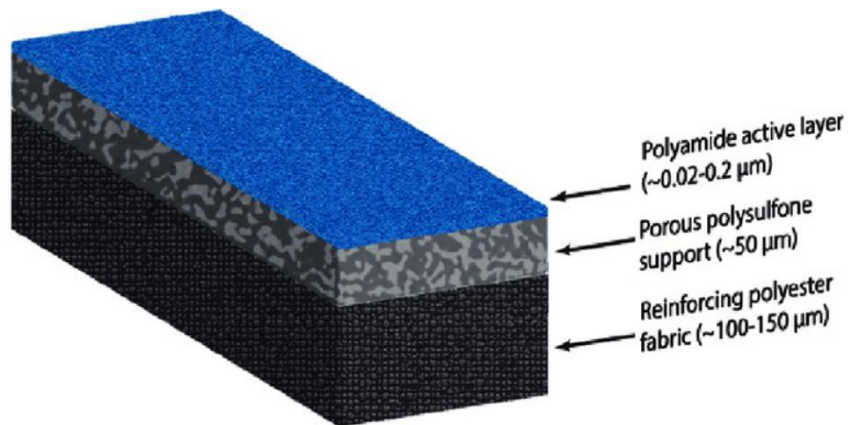


Figure 12: Architecture of a Thin Film Composite[29]

RO membranes are made up of three layers: a polyester layer, a polysulfone layer, and a strong polyamide barrier layer as depicted in Figure 10.

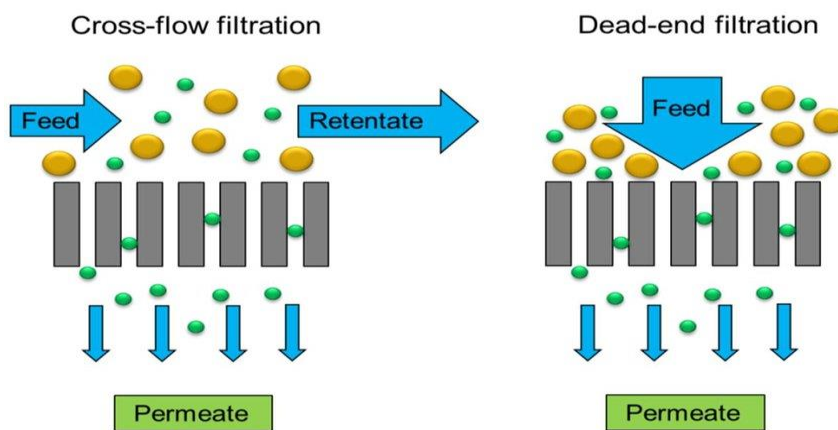


Figure 13: Crossflow and dead-end filtration

There are two types of filtration these are Dead end Filtration which uses dead ends and batch procedure. As a result, the filter will eventually become so clogged with particles that water cannot pass through it. It will be necessary to turn off the filtration system so that the filter can be cleaned or changed. All of the feed water is filtered through the membrane in a dead-end process, leaving the solids on the membrane behind.[30] Another type is Cross-flow filtration in which feed water travels tangentially rather than perpendicularly over the membrane surface. Thus, cross-flow filtration produces two effluent streams the permeate and the concentrate (retentate) from a single influent stream. Cross-flow aids in reducing RO membrane fouling or scaling. [30]

Cross-flow filtration is preferable for RO since it has a low probability of fouling and scaling compared to dead-end filtration.

The definitions of some common terminology used in the Reverse Osmosis System are provided in Table 5 below.

Table 5: Common terminology used in the Reverse Osmosis System[30]

Feed water	Supply water is fed into the RO system to be processed
Permeate	The fraction of feed water that is returned as purified water after passing through a series of membranes.
Concentrate	A fraction of the feed water that the membrane rejects and which contains the impurity solution that has been removed from the permeate.
Recovery Rate:	The ratio of permeate flow to feed water flow, which represents the system's total water efficiency. The quality and composition of the feed water, the kind of membrane, and the system operation all have an impact on the recovery rates of RO systems, which can vary dramatically.
Water Flux:	The rate of permeate production is commonly expressed as the rate of water flow per unit area of the membrane (e.g. gallons per square foot per day).
Rejection:	The term is used to refer to how much percentage of influent species/feed water is retained by the membrane.
Salt Passage	$\% \text{ Salt passage} = (100 - \% \text{ Rejection})$ $\% \text{ Salt passage} = (C_p/C_f) \times 100$

Table 6: The Fundamental RO Components and its Function [31]

RO Component	Function
Pre-filter	Normal practice for pre-filters is to treat feed water supplies before they enter RO systems and post-treat after passing the membrane.
Reverse-osmosis membrane	The center is where the concentrate's pollutants are held captive by the membrane and purified water is generated.
Pressure vessels	A hollow tube that is sealed and contains the components of the RO membrane.
Pumps	Pushes water through RO Membrane
Valves	the flows and pressures controlled by valves
Water Tank	Stores water

Drinking water filtration systems typically use a five-stage filtration process: sediment, mechanical, chemical, mineral, and bacterial.

2.5.2. Fouling and fouling mechanisms

Fouling is a physicochemical phenomenon where the material composition of the membranes and their physicochemical characteristics significantly determine their interaction with feed water and foulants.

Membrane fouling is the main problem in membrane filtration processes since the industry of membrane was invented which is around 1970. Membrane fouling is the consequence of the gathering of particulates, matter, and colloidal molecules, which are organic molecules, and microorganisms on the surface of the membrane.[32]

There are different types of fouling such as; Colloidal, organic, scaling, and biofouling.

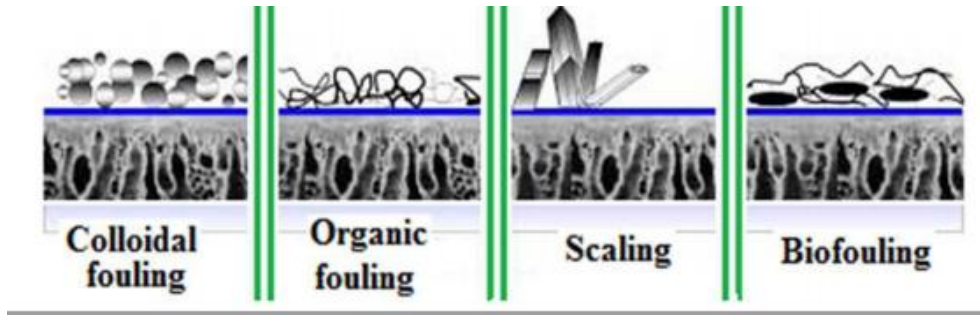


Figure 14: Types of membrane fouling[33]

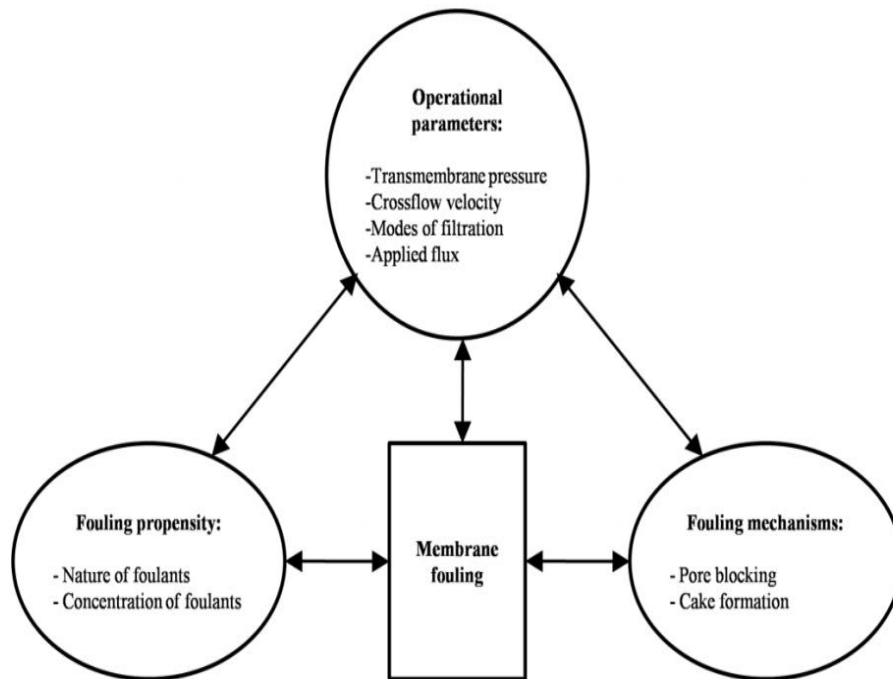


Figure 15: Membrane Fouling[34]

Adsorption of organic species causes organic fouling of membranes. Scale development of sparingly soluble inorganic salts causes inorganic fouling. Pore blockage and cake formation are two possible fouling mechanisms generated by these big particles. Membrane fouling has an impact on separation performance efficiency (low permeate flow and rejection). These impacts may eventually reduce the membrane's economic viability in the separation procedure. If a major fouling problem develops, the membrane's life duration might be drastically reduced. [32]

To eliminate suspended solids, rust, and other particles from the water, all RO systems have particle filters. These filters could be blocked or dirty. The system's throbbing heart, the RO

membrane, which is in charge of removing dissolved impurities, has become tainted. Scale, germs, and other deposits will ultimately clog the membrane. When membranes deteriorate as a result of exposure to system conditions such as scaling, fouling, and harsh chemicals, which have an impact on water flux and recovery rate membrane degradation occurs.

The flow and output of treated water will be reduced by a fouled membrane. Reverse Osmosis membranes should typically be changed every two years. The lifespan of filters might be shortened by turbid water, a high mineral content, or improper maintenance.

CHAI HOON KOO, 2014 discusses that particulate fouling occurs when suspended solids and/or colloidal fabric clog the holes of a membrane or adhere to its floor. As debris accumulates on the membrane, they shape what is known as a “cake” layer that obstructs water from flowing through the membrane’s pores, ensuing in symptoms such as accelerated pressure differential measurements and elevated strength intake.[34]

As a study by CHAI HOON KOO, 2014 to measure the relative hazard of particulate/colloidal fouling, water remedy specialists commonly degree the Silt Density Index (SDI) of a feed flow.

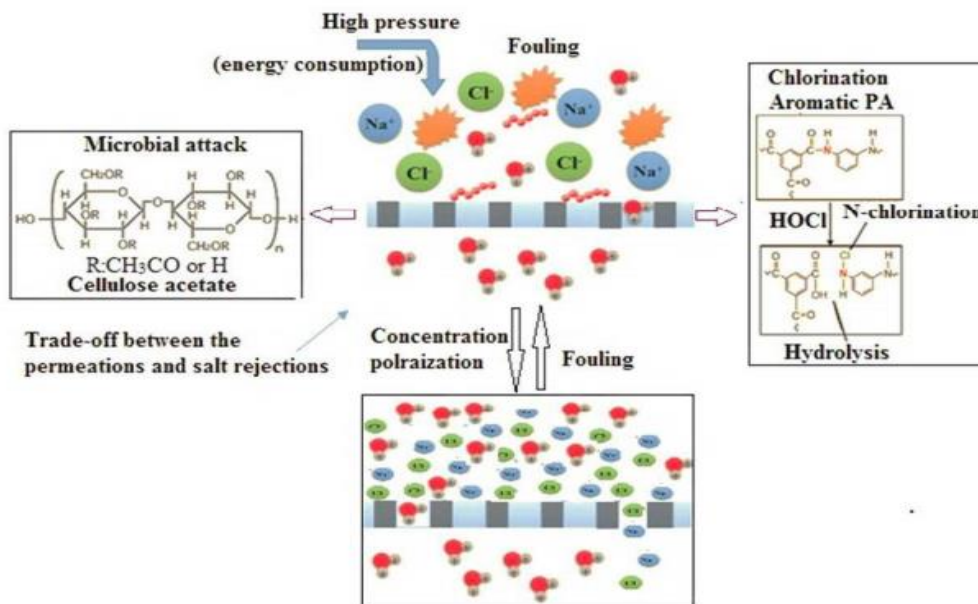


Figure 16: Systematic presentation of challenges to RO membrane[33]

2.5.3. Scaling

In the water treatment and desalination process the main problem that occurs is due to scaling. Scaling, additionally called inorganic or precipitation fouling, is because of the presence of crystallized salts, oxides, and hydroxides in the feed answer.

As a study by SAMCO, 2022, membrane scaling occurs when dissolved constituents precipitate out of solution and collect on the membrane surface or in its pores. Precipitation fouling takes place whilst an answer grows increasingly concentrated towards the feed facet of the membrane, and subsequently surpasses the solution saturation point, inflicting ionic components to fall out of the answer and crystallize and/or bind to the membrane floor.[35]

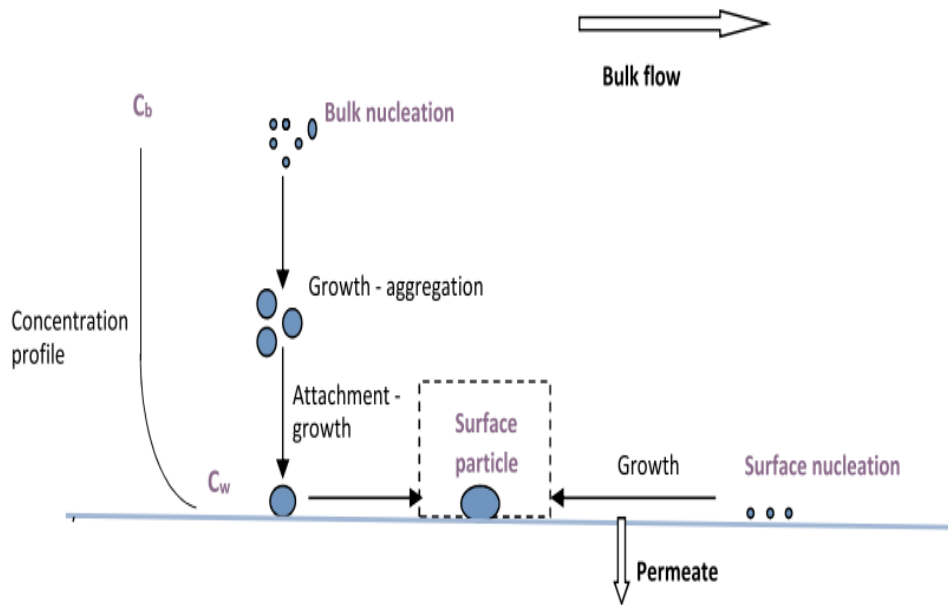


Figure 17: Schematic illustration of mechanisms involved in the early stages of membrane scaling, at low supersaturation.[35]

Inorganic fouling may be averted via treatment techniques that inhibit crystal boom, either through acid injection, softening, and alertness of different chemical scale inhibitors.[33]

2.5.4. Anti-Fouling mechanism

Anti-Fouling is a method to avoid foulants from the surface of the membrane. Physical Cleaning is needed to avoid foulants from the surface of the membrane physical cleaning methods are used as a mechanical force needed for the removal of the cake layer. The mechanical forces are used

for cleaning the membrane by flushing, backwashing, sponge ball cleaning, and CO₂ back permeation.[36]

A study by Asif Matin, 2020, describes that flushing is done by passing the permeate water at high cross-flow velocities along the feed channel of the membrane module. Due to the shear forces caused by increased turbulence in the flow, much particulate matter adsorbed to the surface is removed and washed away[36].

2.6. Membrane Design Consideration

Operating conditions have an impact on the performance of a RO system. Feed water source and quality, temperature, pressure, feed water flow, concentration Flow, Recovery, pH, and flux are among the conditions.

- Quality of Feed Water

The quality of the feed water and its fouling tendency has a considerable impact on the design of a RO system. The feed water quality influences the design flux, feed water and reject fluxes, and salt rejection.

Table 7: Water Type Considering for membrane design

Water Type	RO Permeate
	Well Water
	Surface Water/Brackish Water
	Waste Water
	Sea Water

- Water Supply Source

The feed water source has a significant impact on the water's ability to foul the RO membrane. A high-quality source water, such as well water with an SDI of less than 3, is less likely to foul an RO membrane than a low-quality source water, such as surface water with an SDI < 5.

Table 8: Design guidelines for FILMTEC elements [37]

Feed source	RO Permeate	Well Water	Softened Municipal	Surface Supply
Feed silt density index	SDI < 1	SDI < 3	SDI < 3	SDI < 5
Typical target Flux (gfd)	37	18	16	14
Maximum element recovery %	30	19	17	15

Table 8 shows recommended flux rates as a function of feed water source, as adapted from Dow Water and Process Solutions.

- Flow rate

The amount of water going through a piece of water filtration equipment at any one time is referred to as the flow rate. Typically, this is stated in gallons per minute. (gpm). [38]

Poiseuille's Law states that the flow rate Q changes inversely with pipe length L and directly with the pressure differential (p) between the pipe's ends and the fourth power of the pipe's radius.

It goes like this: $Q = \pi \Delta p r^4 / 8 \mu L$

Equation 1: Flow rate equation[38]

Where Q stands for the flow rate, A stands for a cross-sectional area at a point in the path of the flow and V is the velocity of the liquid at that point.[38].

- Total dissolved solids (TDS)

The total dissolved solids (TDS) content in a RO system influences both the system flow and the salt rejection.

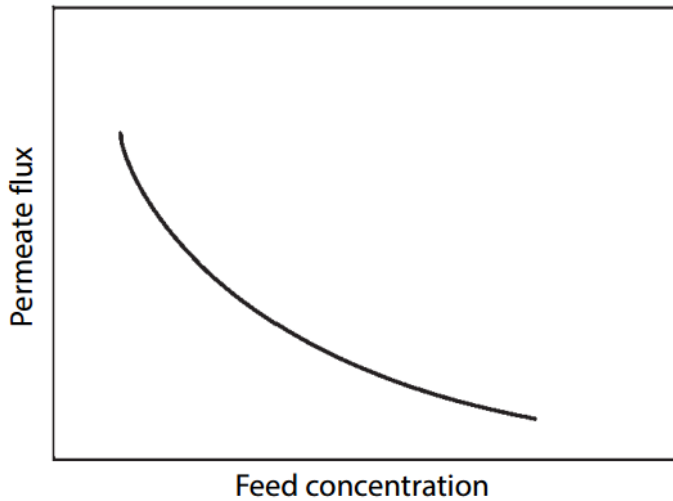


Figure 18: Reverse osmosis membrane flux as a function of feed water total dissolved solids. Assumes constantly applied feed pressure.[30]

The driving force for water drops under constantly applied pressure when feed TDS increases due to Feed osmotic pressure increase resulting in a decrease in system flux, as depicted in Figure 18.

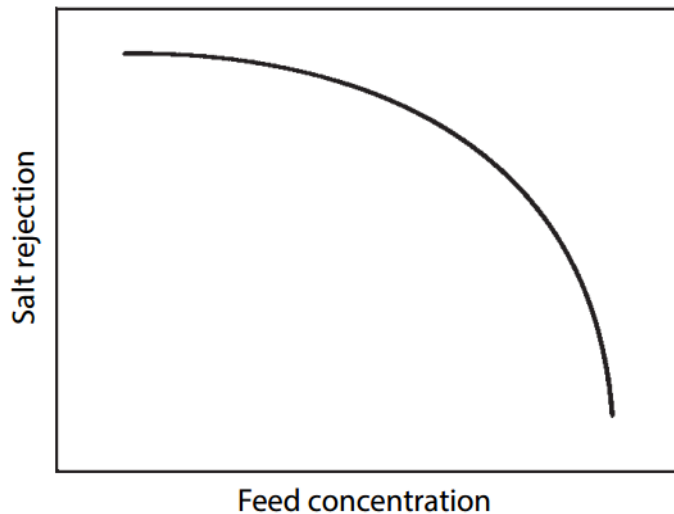


Figure 19: Reverse osmosis membrane rejection as a function of feed water total dissolved solids. Assumes constantly applied pressure.[30]

As the pushing force for water decreases, the volume of water passing through the membrane decreases, resulting in a higher TDS content in the permeate. As shown in Figure 19, as input water TDS increases, rejection decreases which means salt passage increases.

- Temperature

The temperature has an impact on system flux and rejection performance. Figures 20 and 21 depict the influence of temperature on water flux and salt rejection at constant pressure and temperatures less than 45 °C, respectively.

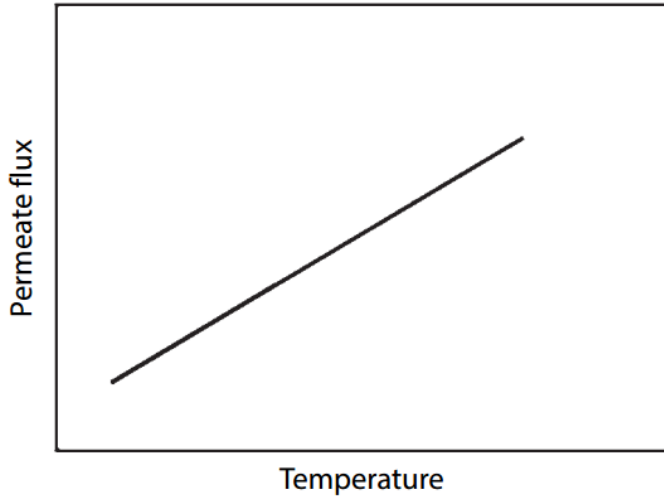


Figure 20: Reverse osmosis membrane water flux as a function of temperature, at constant pressure[30]

Temperature and water flux are interrelated since warmer water has a lower viscosity, making it easier for water to move through membranes, as depicted in Figure 20.

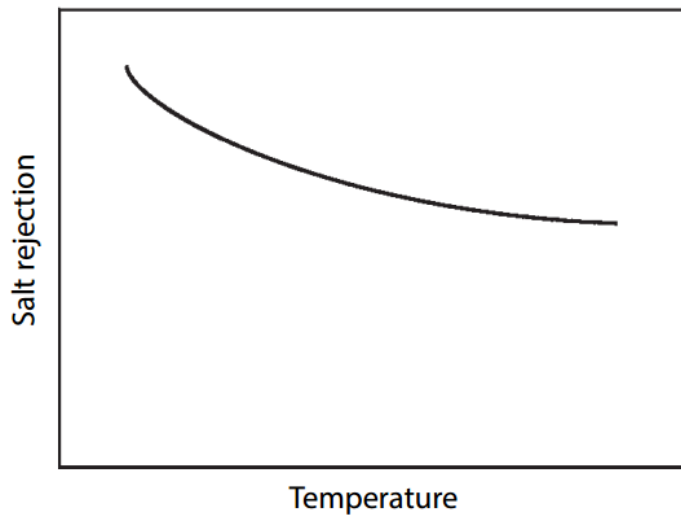


Figure 21: Reverse osmosis membrane salt rejection as a function of temperature, assume constantly applied feed pressure and less than 45°C temperature. [30]

However, when the temperature rises, salt rejection diminishes marginally because higher water temperatures cause more salt to diffuse through the membrane, as depicted in Figure 21.

- Pressure

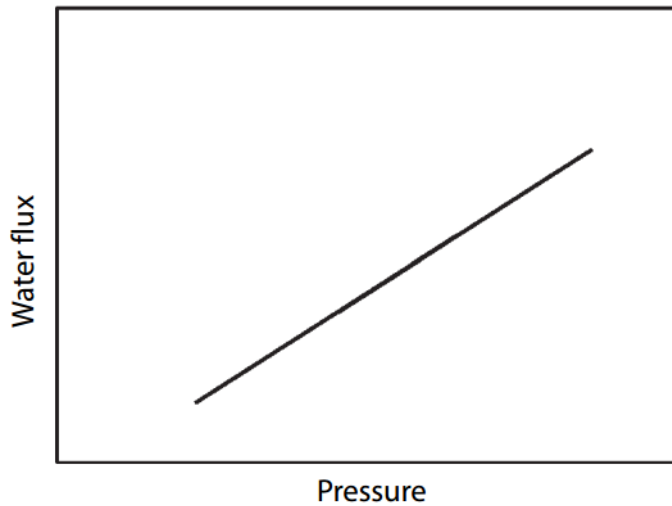


Figure 22: Reverse osmosis membrane water flux as a function of pressure.[30]

Feed water pressure is another element that influences the rate of system recovery. Given that all other variables, including osmotic pressure and water temperature, are kept constant, the amount of water that passes through the membrane increases in direct proportion to increases in feed water pressure. The rejection of dissolved solids is also increased by an increased supply of water pressure.

The quantity and quality of the water generated improve with increasing water pressure within the system's maximum intended pressure range. However, an excessive supply of water pressure can hasten the membranes' early deterioration.[30]

Water flow and salt rejection are affected by operating pressure. Because operating pressure directly affects the force that drives water across the membrane, increasing pressure will result in increased flux as depicted in Figure 22 above.

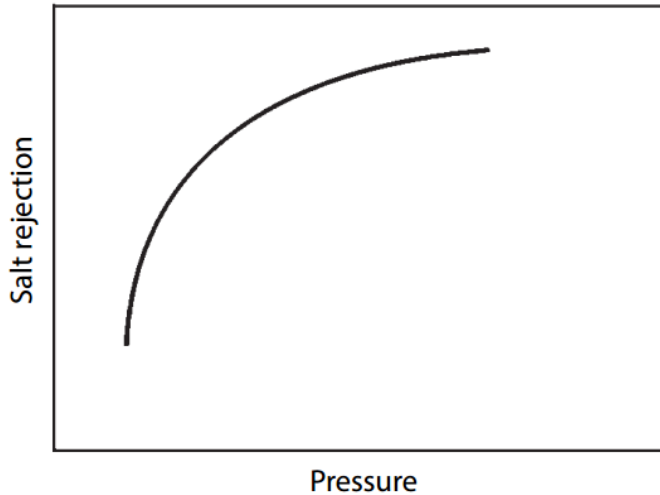


Figure 23: Reverse osmosis membrane salt rejection as a function of pressure.[30]

As illustrated in Figure 23, the salt passage appears to decrease and the salt rejection increases as pressure increases because more water has passed through the membrane at higher pressures, resulting in a lower absolute salt concentration in the permeate.[30]

2.7. ROSA software

ROSA is Software used to estimate stabilized performance for a particular RO or NF machine underneath layout or real conditions. This projected performance is based totally on a nominal overall performance specification for the DOW FILMTEC Membranes.

The manufacturer Dow Water Solutions FilmTec designed a software package called Reverse Osmosis System Analysis (ROSA). In this project, the one which is used to design the membrane is the ROSA9 software program which is the latest version of ROSA that works for RO. ROSA is a tool used to design membranes, and system configurations, and evaluate the performance of a RO system. It is advanced by using DOW organization in the U.S.A. where the membrane type used is film Tec/ Thin Film composite). [39] ROSA has different pages for running the software and different input data should be filled.

Dow Water and Process Solutions-Film Tec's ROSA program version 9 has four input pages and one report page, and cost analysis each tabbed on the bottom of the screen.

The five major tabs are Project Information, Feed water Data, Scaling Information, System Configuration, and Report.

The project information provides space to enter about different cases of the project specifying own set of design information, name of the project, and project preference where the analyzer's name is filled, the company name, balance analysis with and unit set choice is given where to choose the units of measurement for pressure, temperature, and flow rate (Flow: gpm, gpd, m³/h, m³/d or for pressure: psig, bar) and temperature unit either Celsius (°C) or Fahrenheit (°F). For this project the selected unit of Flow is gpm and unit of pressure is psi and the unit of Temperature is °C.

The second screen named feed water data includes where the analyzer selects the feed water type where several choices have been set by the Rosa 9 software the feed water type should be selected from an input selection list that specifies the type of water being treated based on SDI and water source. This is an important input that affects the fouling rate of the membrane and should agree with the overall average flux and should tolerate the product specification for such a specific role. Here to analyze the chosen water type for this project which feed water collected from Lake Basaka therefore the surface supply, SDI < 5.

The third screen where the scaling information is provided this inputs when issuing warnings on concentrate flow rates that are too low. The scaling screen provides the designer with feed and concentrates scaling indices for the recovery and temperature that the designer inputs.

The fourth screen is called system configuration where the number of passes, permeate flow rate, system recovery, and the number of stages. The system array is determined at this point. The designer inputs the number of pressure vessels per stage and the number of membrane elements and the program designs and shows the system configuration. Another important thing that happens here is the membrane product type is selected therefore the membrane product that satisfies certain parameters input in feed water data and system configuration should match with the manufacturer's (DOW Water and Solution) membrane product specification details.

ROSA offers several membrane products including tap water elements, brackish water (surface water), and seawater. Specifications for each membrane type are available by clicking on the Specified button. The pump efficiency is selected where it needs to be between 70% - 80%. The input data is specified in Feed water data. The fifth screen shows the report and the sixth screen shows the cost analysis.

2.8. Spectroscopy used to analyze Lake Basaka water before and after RO filtration

2.8.1. Flame atomic absorption spectroscopy (FAAS) to analyze Lake Basaka water before RO filtration

Flame atomic absorption spectroscopy (FAAS), inductively coupled plasma optical emission spectroscopy (ICP-OES), and microwave plasma atomic emission spectroscopy (MP-AES) are methods for identifying an analyte element based on its electromagnetic spectrum. [40] Flame AAS is known for its reliable trace analysis in troubling matrices and broadly changing clusters of ranges. Atomic absorption spectrometry, or ZEE nit 700 P (Analytikjena)-Flame AAS, is an established method for the identification of elements in the region of medium to low concentrations and compact spectrometers with a high-performance graphite furnace heated transversally. [41]



Figure 24: ZEE nit 700 P (Analytikjena)-Flame AA[41]

- Working principle of AAS:

When a sample solution is inhaled into a flame, the sample element is converted into its atomic vapor. The flame comprises element atoms. Furthermore, some atoms are thermally stimulated by flame while the majority stay in the ground state. The ground state atoms then absorb the exact wavelength radiation emitted by the source, which is a hollow cathode lamp made of that specific metal. Now, the wavelength of radiation emitted by the source or lamp is comparable to that absorbed by the atoms in the flame.

The absorption of ground-state atoms in the gaseous state is quantified using atomic-absorption spectroscopy. Atoms absorb ultraviolet or visible light and change to higher electrical energy levels. The quantity of absorption determines the analyte concentration. [42]

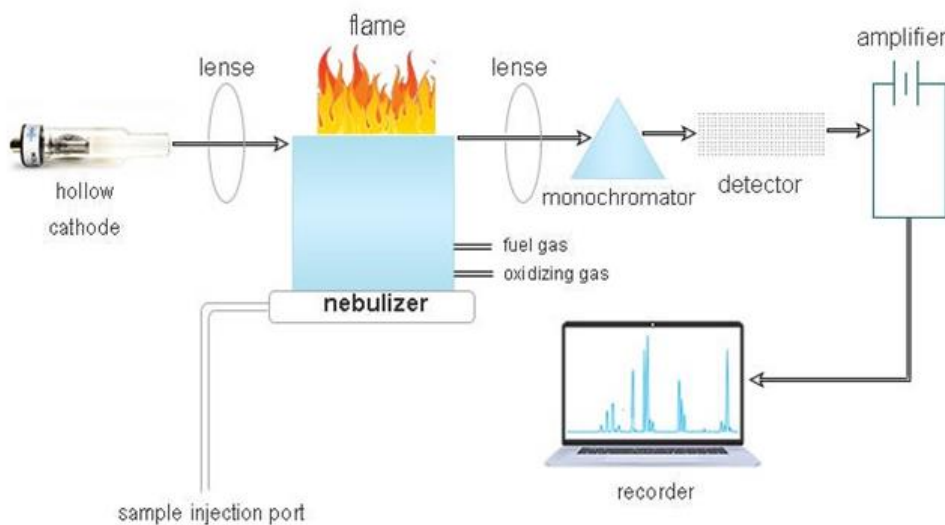


Figure 25: Working principle of AAS[42]

2.8.2. Microwave Plasma Atomic Emission Spectroscopy to analyze Lake Basaka water after RO filtration

Microwave Plasma Atomic Emission Spectroscopy (MP- AES) uses Microwave plasma (MP) as an atomic emission source that is both high temperature and hence ideal excitation source for atomic emission spectroscopy. The microwave plasma powered by nitrogen reaches temperatures close to 5,000 K. Atomic emission is strong at these temperatures, resulting in good detection limits and linear dynamic range for the majority of components.[40]



Figure 26: Microwave Plasma Atomic Emission Spectroscopy

Working principle of MP - AES:

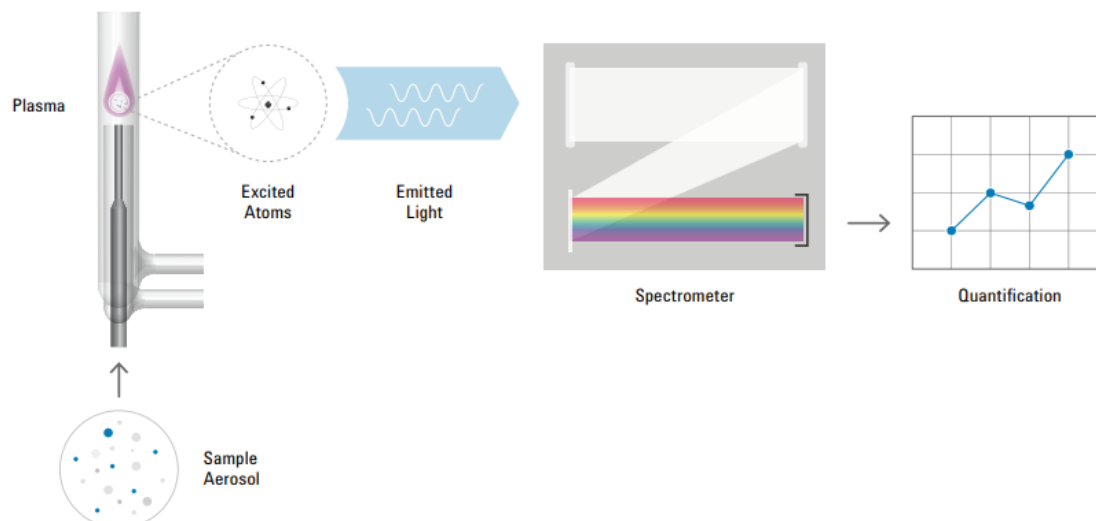


Figure 27: Working principle of MP – AES[43]

Introduction of sample: An aerosol is generated from a liquid sample using a nebulizer and a spray chamber, just as a flame AA instrument. The aerosol is subsequently delivered into the hot plasma's center. As they revert to lower energy levels, the atoms continue to be excited and produce light at wavelengths unique to each element. In the optical system, the plasma emission is channeled into a rapid scanning monochromator. The wavelength range of interest is imaged onto

the high-efficiency CCD detector. For maximum precision, this measures both the spectra and the background at the same time. In the quantification part MP-AES, determines the concentration of an element in a sample by comparing it to a calibration curve, its emission is plotted against that of known amounts of the element. The final result is the element concentration in the sample.[43]

By using the Microwave Plasma Atomic Emission Spectroscopy testing method for Mg, Ca, K, Cl, Boron, and Silicon are analyzed for Lake Basaka water after RO filtration.

2.9. WHO Guideline for drinking water

Table 9: WHO Guideline for drinking water [44]

WHO Guideline For Drinking Water		
No.	Constituent/Characteristic	Guideline value (Maximum)
1	Boron	2.4 mg/l
2	Barium	1.3 mg/l
3	Chloride	250 mg/l
4	Fluoride	1.5 mg/l
5	Nitrate	50.0 mg/l
6	Nitrite	3 mg/l
7	Sulfate	200 mg/l
8	Potassium	1-2 mg/l (min-max)
9	Sodium	200 mg/l
10	Magnesium	50 mg/l
11	Calcium	200 mg/l
12	Chlorine	5 mg/l
13	Sulfate	250 mg/l
14	TDS	< 500 As customer preference
15	pH	6.5 - 8.5

Some WHO drinking water guidelines:[44]

For effective disinfection with chlorine, the pH should preferably be less than 8.0 and above 6.5. The optimum pH will vary in different supplies according to the composition of the water it is below 8.5. The barium guideline value is 1.3 mg/l which states that Reverse osmosis-filtered Lake Basaka water is possible for irrigation purposes with further clearance and post-filtration could be available for drinking. The chloride guideline value is a chloride concentration of more than (250 mg/l) that can give a detectable taste

3.0. MATERIALS AND METHODS

Materials and methods for filtering Basaka Lake water, as well as membrane design software, are employed to achieve the requisite product flow rate, recovery, rejection, and applied pressure. The materials, as well as their roles and procedures, are briefly detailed in this chapter.

3.1. Study Area

Lake Basaka is a salty lake located in Ethiopia's Oromia Region. Lake Basaka is located in Ethiopia's Middle Awash Basin, in the middle rift valley, some 200 kilometers southeast of Addis Ababa. The Matahara region has a bimodal rainfall distribution pattern, with an annual mean rainfall of around 543.7 mm. The average maximum and lowest temperatures over the long term are 32.9 and 17.5 degrees Celsius, respectively.[22]



Figure 28: Lake Basaka catchment, the Location of Ethiopia's Lake Basaka catchment [21]

3.2. Before RO Filtration Lake Basaka water sample collection

A sample of Lake Basaka water was collected from Lake Basaka (the collected amount of water was 25 liters from the site and covered with a safety covering that shields the collected material to keep its status and refrigerated in the compound of Addis Ababa Institute of Technology for better preservation), for the case of analysis 4 liters of sample is collected. Water is collected in a clear plastic bottle (to avoid contamination) and analyzed by FAAS.

3.3. Materials Used for Basaka Lake Water Analysis Before RO Filtration

The sample water was analyzed at Ethiopian Conformity Assessment Enterprise which supplies accreditation services to laboratories (test and calibration) by the requirements of ISO/IEC 17011.

Flame AAS/ ZEE nit 700 P (Analytikjena):-

Atomic Absorption Spectroscopy refers to a group of analytical methods used to assess the elemental makeup of a material by studying its atomic structure. The electromagnetic spectrum is also known as the mass spectrum. [40]

3.3.1. Procedure followed to analyze Lake Basaka Water Sample before RO Filtration by FAAS

Took a determined amount of (50ml) combined water, and acid preserve sample into a beaker, added 5 ml conc. HNO_3 + a few glass beads, slowly boil and evaporate on a hot plate up to 10 - 20 ml. Add conc. HNO_3 (a few ml) until digestion is complete. Washed down the beaker with deionized water three times and filtered and poured the sample into a 100 ml volumetric flask mix thoroughly select and A solution containing the analyte is injected into a flame in AAS. The flame turns samples into excited free ground state atoms. A lamp generating light at the atoms' wavelength is passed through the flame, and when the light energy is absorbed, the electrons in the atoms are activated and prepare a calibration curve for absorbance versus concentration of a standard solution. Took a direct reading of the prepared sample solution from the device.

- Calibration: 4 calibration points for every component.
- Samples were run in triplicate and the average values have been taken
- Na, Mg, Ca, K, CO_3^{2-} , HCO_3^- , and Cl^- are investigated by Flame AAS/ ZEE nit 700 P (Analytikjena).

Before starting the RO filtration process some parameters are selected for the power supply as depicted in the Table (10-11) below.

Before starting RO Basaka Lake water filtration the RO water filter is installed carefully as per the technical manual. The charge controller gives the information of the PV (Power, current, and volt) and battery (power, current, and volt) while the inverter converts DC into AC. Therefore the selected Alternating current from the PV output display is 231 Vac.

In the following Tables (Table 10 - 11) some recorded values of System, Photovoltaic, and Battery outputs for the Solar driven Reverse Osmosis water purification are listed as follows, these results are selected and confirmed at the charge controller. (Annex 1,2)

Table 10: Photovoltaic

Photovoltaic	
Voltage	33.5 V
Current	6.9 A
Power	215 W
Kilowatt-hours	51.91 KwH

Table 11: Battery (output Type)

Battery (Output Type)	
Voltage	231 Vac
Frequency	50 Hz
Load	9%
Battery type	GEZ
Real-time	19:17
Mode	Normal

The above Tables (Table 10-11) describe the recorded data such as the voltage used to operate the RO system, the Copex PV battery provided 231 Vac. After selecting the value from the PV, it becomes efficient to run the RO filtration system.

3.4. Lake Basaka water filtration by RO filtration system

The Lake Basaka water is fed to the tank settled for the feed source with a capacity of 20 liters therefore 20 liters of Lake Basaka water is fed to the feed source tank and the tank is fully fed, and closed tightly as a precaution it needs to be full. The RO filter with 5 filter stages is plugged into the solar battery power inlet and the water pump efficient to pump the water from the feed source into the RO filter is plugged into the power source now the water starts to flow into the RO filtration system due to the pump pressure.

The Lake Basaka water passed into first stage known as polypropylene sediment filter which filters sand, dirt and other suspensions 5 microns and larger and the water has flown into the second stage which is called Granular Activated Carbon Filter where chlorine is removed and the taste and odor is improved and then the waterflows to Carbon Block Filter where chlorine, taste and odor is removed after the sample water is being pre treated to control RO membrane fouling, all organic, colloidal, and biological materials must be eliminated from the RO system's feed water by those three stages now the pretreated water has flown tangentially throw RO Membrane where foreign particles, soluble solids, bacteria and viruses are retained by the membrane with pore size of 0.0005 micron and the concentrate water will flow out of RO system through the drain line and the permeate water has flown into the last filter stage named Post Carbon Filter for improvement of taste and odour and final polishing of the water and the permeate water has flown into the faucet for sample collection but it could hve been stored in storage tank. (Annex 3,4)

3.5. After RO Filtration: Water sample collection

The water is collected in a clear plastic bottle to avoid contamination and is labeled with the type of water collected (Permeate water or Concentrate water) and the correct time and date is labeled, and analyzed by MP-AES. Four liters of water are collected in continuous operation before it gets to the storage tank for the prevention of dirt and other contaminants. To prevent contaminants from entering the collection sample container and the pin of the faucet has not been in contact. Finally, the collected sample water from Lake Basaka is analyzed by MP-AES.

Table 12: After RO Filtration - Sampling Procedure

Sampling Procedures followed	
Sampling Location	AAiT, Center For Materials Engineering Laboratory Addis Ababa, Ethiopia
No. of samples collected	4 liters of filtered water (2 Samples of 2 liters of water)
Date of sampling	August 26, 2022
Time of sampling	06: 30 local time
Temperature	25 °C
For Analysis by	MP-AES
List of Parameters for Analysis at ECAE	pH Value
	Na
	Mg
	Ca
	K
	CO ₃ ²⁻
	HCO ₃ ⁻
	Cl ⁻
	Ammonium
	Strontium
	Barium
	Nitrate
	Fluoride
	Sulfate
Silicic acid	
Silicon	
Boron	

3.6. Materials used for Basaka Lake Water analysis After RO Filtration

MP-AES:

Before sample analysis ensured the gas lines are connected to MP – the AES instrument, checked the USB and power cables are plugged in, and checked that the pre-optics window and torch were. According to the Methods developed by the United State Environmental Protection Agency (USEPA) 3005 a 50 mL of well-mixed water samples was digested in a beaker covered with a watch glass by adding 1 mL of concentrated (69-72%) HNO₃ and 2.5 mL of concentrated (30%) HCl and heated on a hot plate at 90 °C boiled until the solution reached up to the mark (20 mL). Then the beaker was removed and cooled. After cooling to room temperature, transfer the sample to a 50 mL volumetric flask. Rinse the inner wall of the beaker with ultrapure water then add the rinse water to the sample in the volumetric flask. Brought the sample up to volume with ultrapure water.[45] Each of the digested water samples was filtered through Whatman filter paper No.42 into a 100 mL volumetric flask and filled up to the mark with deionized water by the addition of 2 mL of nitric acid to get a clear solution. Analytical solutions are nebulized, and the resulting aerosol is transferred to a plasma, where it undergoes desolvation and excitation.[46] Placed the solution inlet tubing into the wavelength calibration solution and allow the sample to reach the plasma. The torch is aligned and then a wavelength calibration and a calibration check is performed automatically. A grating spectrometer disperses the spectrum, and line intensities are monitored using a light-sensitive detector such as a photomultiplier tube or charge transfer device. A computer system analyzes photocurrents. There it forms calibration line and the sample solution is readed. And the computer reported the result of the elemental analysis. (Annex 5)

3.7. Membrane Design by ROSA Software

3.7.1. Reverse osmosis Membrane Design calculation for TW 30-2540

Before starting to design a specific membrane quality of feed water, feed water source type, temperature, pressure, feed water flow, concentration flow, permeate flow, recovery, pH, and flux, have to be in consideration.

Given:

Feed flow: 1.41 gpm

Permeate flow: 0.21 gpm

Salt rejection for TW 30-2540:

Calculating the system's salt rejection performance will reflect the present performance, and it is critical to keep daily operating data.

$$\text{Salt Rejection} = (\text{TDS Feed} - \text{TDS Product}) / (\text{TDS Feed}) \times 100$$

$$\text{Example: } 2005.54 \text{ ppm} - 88.92 \text{ ppm} / 2005.54 \text{ ppm} \times 100$$

$$= 99.56 \% \text{ Salt rejection}$$

System Recovery %: this term means the amount of water that your system is producing expressed in percent.

$$\text{Permeate Flow} / \text{Feed Flow} \times 100 = \% \text{ Recovery}$$

$$0.21 / 1.41 \times 100 = 14.89 \%$$

Concentration Factor: this term and calculation is used in system design and is focused on the concentrate as it relates to system design and scale probability calculations before antiscalant dose calculations.

$$\text{Concentration Factor} = \frac{1}{1 - \text{Recovery} \%}$$

$$\text{CF} = \frac{1}{1 - 14.28 \%} = 1$$

Water flux:

$$J = \frac{Q_p}{A_m}$$

Where:

J = flux, L/hr/m² (gal/d/ft²) or Lmh (gfd)

Q_p = filtrate flow rate through a membrane, L/hr (gal/d)

A_m = surface area of membrane, m^2 (ft^2)

Where; $Q_p = 0.20$ gpm is converted to 302.4 gfd

$J = \text{Permeate flow rate} / \text{surface area of membrane} = 302.4 \text{ gfd} / 28ft^2 = 10.80 \text{ gfd}$

% Salt passage = (100 - % Rejection)

= $100 - 99.56 = 0.44 \%$

$TDS \text{ (ppm)} = K \times EC(\mu S/cm)$

Notes: The conversion factor k is subject to many factors and varies from region to region. It typically ranges from 0.5 to 0.8 and is often taken as 0.64.

$EC = TDS \text{ (ppm)} / K$

$EC \text{ of feed} = TDS \text{ feed} / 0.64 = 2005.54 / 0.64 = 3133.65 \mu S/cm$

$EC \text{ of Permeate} = TDS \text{ permeate} / 0.64 = 88.92 / 0.64 = 138.94 \mu S/cm$

Table 13: TW 30 – 2540 membrane design specification [47]

Membrane Product	TW 30-2540
Membrane Type	Polyamide Thin film composite
Parameter	Value
Maximum feed flow rate	6 gpm
Maximum permeate flow rate	850 gpd
Maximum Recovery	15 %
Applied pressure	225 psig
Maximum pressure drop	13 psi
Temperature	25 °C
Maximum operating temperature	45 °C
Operating pressure	600 psi
pH range, continuous operation	2 – 11
pH range, Short term cleaning	1 – 13
Active surface area	28 ft ² /2.6 m ²
Stabilized salt rejection	99.5 %
Maximum Silt Density Index (SDI)	< 5
Permeate quality	High permeate quality
Strength	Strong, hard shell to withstand pressure drop
Membrane Lifetime (cleaning must be considered)	More than 3 years

According to Table 13, BW 30-2540 has a maximum feed flow rate of 6 gpm, a maximum feed pressure drop per element is 15 psi, and maximum feed pressure of 600 psig. Therefore the input parameters should not be beyond this.

3.7.2. ROSA membrane design for TW 30-2540

1. Project Information

In the project information menu, the project name is typed and the name of the analyzer, NaCl is chosen to balance the ion (cation and anion) and the unit set is chosen, gpm for flow rate and psig for pressure while for temperature unit Celsius ($^{\circ}\text{C}$) is chosen and the pressure drop for the specified membrane is 13.00 psig.

System Permeate Flow: 0.21 gpm System Feed Flow: 1.41 gpm System Recovery: 14.89%

Project Information

Notes: Project Name: Membrane Design By ROSA Software

Project Cases

Notes for Current Case: Case: 1 Pre-stage ΔP: 13.000 psig

Project Preferences

Analysis By: Bethlehem Terzu Under supervision of Small Commercial System

Company Name:

Balance Analysis With: NaCl

Units Set: Flow: gpm, Pressure: psig

Temperature Unit: Celsius ($^{\circ}\text{C}$)

Default Project Folder: C:\Program Files (x86)\Dow Chemical\ROSA9\MyProjects

DOW
Water & Process Solutions

1) Project Information 2) Feedwater Data 3) Scaling Information 4) System Configuration 5) Report 6) Cost Analysis

Figure 29: Project Information for TW 30-2540

2. Feed Water Data

System Permeate Flow: 0.21 gpm System Feed Flow: 1.41 gpm System Recovery: 14.89%

Water Type: Surface Supply SDI < 5 Open Water Profile Library

Feed Percentage: 100.0 (%) Feed Number: 1 Feed Streams: 1

Ions	mg/l	ppm CaCO3	meq/l	Total Conc.(mg/l)
Ammonium (NH4+ + NH3)	523.246	1450.350	29.007	523.25
Potassium (K)	8.29	10.600	0.212	8.29
Sodium (Na)	25.956	56.450	1.129	25.96
Magnesium (Mg)	13.238	54.450	1.089	13.24
Calcium (Ca)	8.297	20.700	0.414	8.30
Strontium (Sr)	0.044	0.050	0.001	0.044
Barium (Ba)	0.137	0.100	0.002	0.14
Carbonate (CO3)	43.147	71.901	1.438	43.15
Bicarbonate (HCO3)	112.245	91.997	1.840	112.25
Nitrate (NO3)	0.009	0.007	0.000	0.0091
Chloride (Cl)	805.228	1135.627	22.713	805.23
Fluoride (F)	9.502	25.007	0.500	9.50
Sulfate (SO4)	181.295	188.849	3.777	181.29
Silica (SiO2)	56	n.a.	n.a.	56.00
Boron (B)	23.411	n.a.	n.a.	n.a.

Specify Individual Solutes
Total Dissolved Solids: 1,921 mg/l

Feed Parameters
Temperature: 25.0 °C
Flow Rate: 1.41 gpm
pH: 9.5

Charge Balance
Cations: 31.85 Add Sodium
Anions: 31.85 Add Calcium
Balance: 0.00 Adjust Cations
Adjust Anions
Adjust All Ions

System Temp: 25.0 °C System pH: 9.50 Save Water Profile to Library

Note: Any changes in raw feedwater composition will affect scaling calculations. Please review scaling calculations.

1) Project Information 2) Feedwater Data 3) Scaling Information 4) System Configuration 5) Report 6) Cost Analysis

Figure 30: Feed Water Data for TW 30-2540

In the feed water data, First, the water type of the feed source is selected where in this project it is surface supply SDI < 5 which implies that our feed source is surface water thereby Lake water pretreated into SDI < 5 to protect the RO membrane from different kinds of fouling. And the Specify Individual Solutes box is marked. The system temperature is filled to 25 °C. After that, all analyzed values of Lake Basaka water before filtration and pH value of feed water is filled. Charge balance is done by selecting one of the options in the lower right corner where the charge is balanced by adjusting the anions, there the cations and anions become 31.85 and the balance is 0.00, thereby the ions are balanced.

3. Scaling calculation

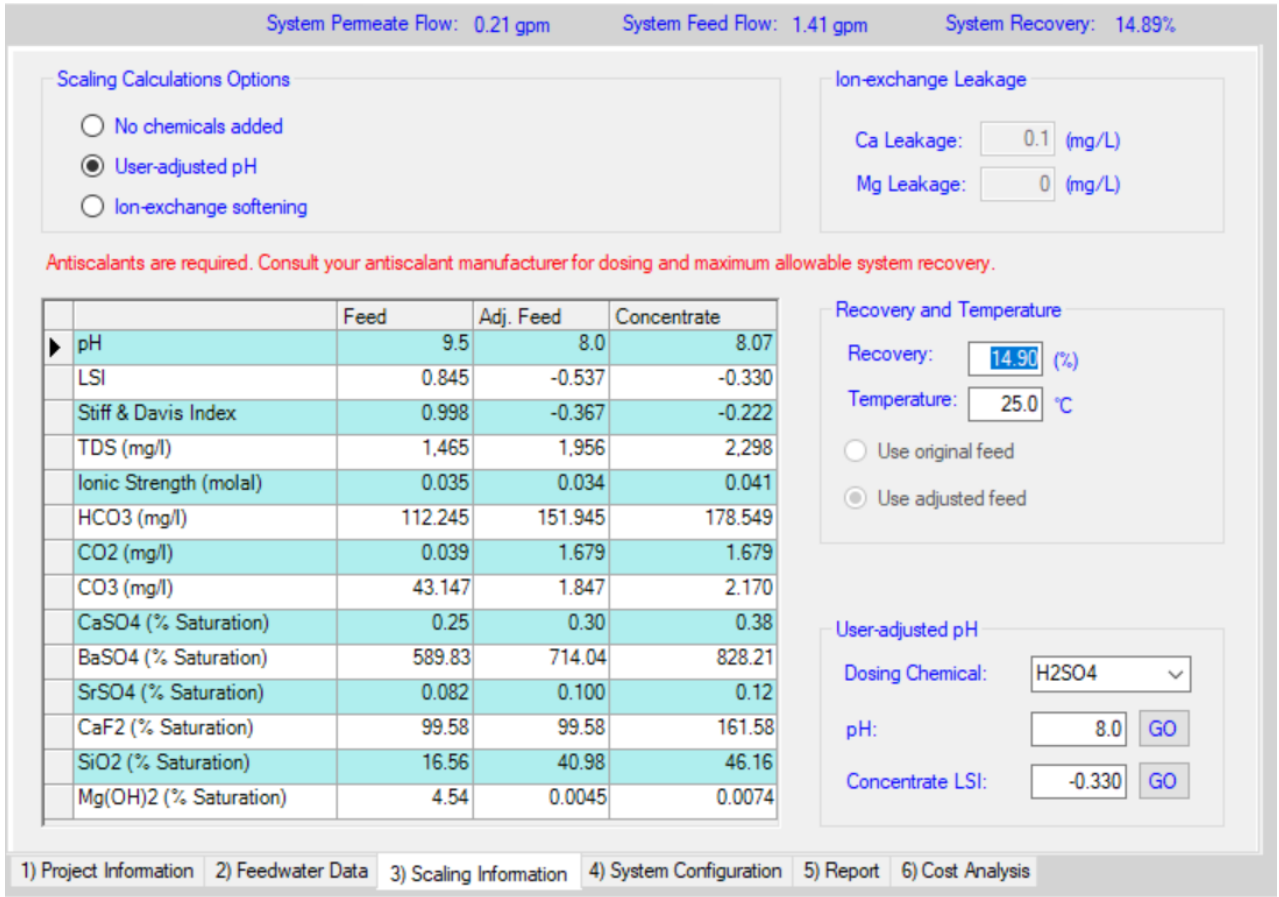


Figure 31: Scaling information for TW 30-2540

In the scaling information menu user-adjusted pH is selected for scaling calculation, and the Feed stream shows a possible scaling of Calcium carbonate [CaCO₃], Calcium sulfate [CaSO₄], Strontium sulfate [SrSO₄], Barium sulfate [BaSO₄], and the LSI value in the feed is positive 0.845 which describes that the water is supersaturated and tends to precipitate a scale layer of CaCO₃. Therefore antiscalant is used to prevent scale formation. Sulfuric acid (H₂SO₄) was chosen as an antiscalant because it has a cheaper operating cost than HCl acid, emits fewer fumes into the environment, resulting in less corrosion of adjacent metal components, and has a better membrane rejection of the sulfate ion than the chloride ion. Therefore the pH is adjusted to 8.0 and the LSI value is targeted LSI to -0.2 because it is aimed for a value that gives a slight negative since LSI < 0 refers that water is under-saturated and tends to dissolve solid CaCO₃. And the concentrate LSI became -0.330.

4. System Configuration

In the system configuration, the system is configured from RO calculation the permeate flow, recovery, feed flow, flow factor, and operating temperature are specified as the RO calculation.

The type of membrane in this menu should be chosen following DOW FILMTEC's specifications therefore membrane type TW 30-2540 is selected after considering membrane specification. Since membrane type TW 30-2540 TDS ranges from 1000 – 3000 ppm, it works for Lake Basaka water with a TDS of around 2000 ppm. [47] Therefore in this project, TW 30-2540 is designed for RO filtration of Lake Basaka water.

Table 14: Require amount of input parameter for TW 30-2540 Membrane design

Require amount input parameter for TW 30-2540 Membrane design	
Feed flow	1.41 gpm
Permeate flow	0.21 gpm
Salt rejection	99.56 %
System recovery	14.89 %
Concentration factor	1
Water flux	10.80 gfd
Salt passage	0.44
EC of Feed	3133.65 $\mu\text{S}/\text{cm}$
EC of permeate	138.94 $\mu\text{S}/\text{cm}$

Table 14 shows the calculated required amount used to feed the system configuration menu, therefore in each box, the required amount calculated is filled. The pump efficiency is selected to 80.0 % and one stage, one pass, and one pressure vessel. And in the product's box, the membrane type TW 30-2540 is selected as the specification of DOW water and solution.

3.7.3. Reverse osmosis Membrane Design calculation for BW 30-2540

Given:

Feed flow: 1.4 gpm

Permeate flow: 0.2 gpm

Salt rejection for BW 30-2540:

Salt rejection = (TDS Feed – TDS Product) / (TDS Feed) X 100

Example: 2025.14 ppm – 96.87 ppm / 2025.14 ppm X 100

= 95.87 % Salt rejection

System Recovery % = Permeate Flow / Feed Flow X 100

% Recovery = 0.20 / 1.4 X 100 = 14.28 %

Concentration Factor:

$$CF = \frac{1}{1 - 14.28 \%} = 1$$

$$1 - 14.28 \% = 1$$

Water flux: J, which is the flow rate of filtrate, i.e., the water passing through the membrane, per unit area of the membrane.

$$J = \frac{Q_p}{A_m}$$

Where:

J = flux, L/hr/m² (gal/d/ft²) or Lmh (gfd)

Q_p = filtrate flow rate through membrane, L/hr (gal/d)

A_m = surface area of membrane, m² (ft²)

Where; Q_p = 0.20 gpm is converted to 288 gfd

J = Permeate flow rate/ surface area of membrane = 302.4 gfd/ 28ft² = 10.28 gfd

% Salt passage = (100 - % Rejection)

= (100 - 95.87 %) = 4.13 %

EC = TDS (ppm) / K

EC of feed = TDS feed/ 0.64 = 2025.14/0.64 = 3164.28 $\mu\text{S}/\text{cm}$

EC of Permeate = TDS permeate/ 0.64 = 96.87/0.64 = 151.35 $\mu\text{S}/\text{cm}$

Table 15: BW 30 – 2540 membrane design specification [47]

Membrane Product	BW 30-2540
Membrane Type	Polyamide Thin film composite
Parameter	Value
Target average flux (gfd)	14 gfd
Maximum feed flow rate	6 gpm
Maximum permeate flow rate	850 gpd
Recovery	15 %
Applied pressure	225 psig
Maximum pressure drop	15 psi
Temperature	25 °C
Maximum operating temperature	45 °C
Operating pressure	600 psi
pH range, continuous operation	2 – 11
pH range, Short term cleaning	1 – 13
Active surface area	28 ft ² /2.6 m ²
Minimum salt rejection	99.5 %
Maximum Silt Density Index (SDI)	< 5

3.7.4. ROSA membrane design for BW 30-2540

1. Project Information

The information is filled regarding the project and the unit of the parameters are selected as referred to in Figure 32 below.

File Options Help

System Permeate Flow: 0.20 gpm System Feed Flow: 1.40 gpm System Recovery: 14.16%

Project Information

Notes: Project Name: MEMBRANE DESIGN BY ROSA SOFTWARE

Project Cases

Notes for Current Case: Case: 1 Add Case Delete Case Manage Pre-stage ΔP: 15,000 psig

Project Preferences

Analysis By: BETHLEHEM TERZUUNDER SUPE Small Commercial System

Company Name: [Empty]

Balance Analysis With: NaCl

Units Set: Flow: gpm, Pressure: psig

Temperature Unit: Celsius (°C)

Default Project Folder: C:\Program Files (x86)\Dow Chemical\ROSA9\MyProjects

DOW Water & Process Solutions

1) Project Information 2) Feedwater Data 3) Scaling Information 4) System Configuration 5) Report 6) Cost Analysis

Figure 32: Project Information for BW 30-2540

2. Feed water data

Surface water type with Silt Density Index is selected on this screen while choosing the right water type is crucial in the RO system design. The water type selected is brackish water which is known as surface supply, conventional pre-treatment Silt Density Index < 5 while surface supply refers to Lake water. The input data collected from the Lake Basaka sample has been filled after being analyzed. All Feed water data is filled in mg/l, and the TDS, feed flow rate, and temperature are filled. The input feed water data (cations and anions) are balanced.

Total dissolved solids (TDS) are the inorganic salts and small amounts of organic matter that are present in solution in water. Calcium, magnesium, sodium, and potassium cations, as well as carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions, are the most common ingredients.[44]

The Input data: pH of the feed is 9.5, the Temperature is 25 °C, the Flow rate is 1.4 gpm.

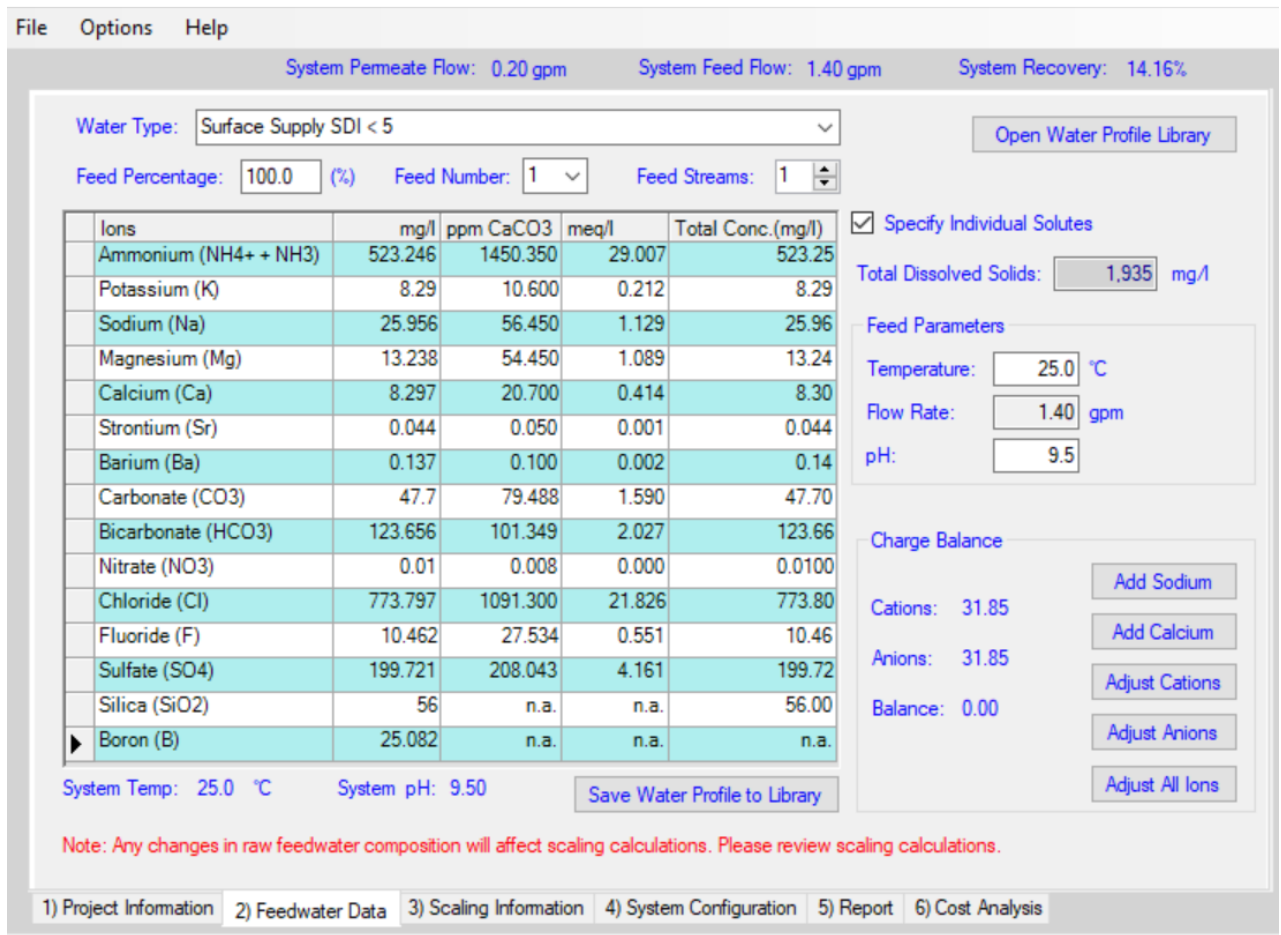


Figure 33: Feed water data for BW 30-2540

Here is the ion balance (the cations and anions are balanced). The operation Temperature is set to 25 °C.

3. Scaling information

Here the input information includes chemicals for scaling and adjusted pH are included. The ions are included and the pH is required for the system to run.

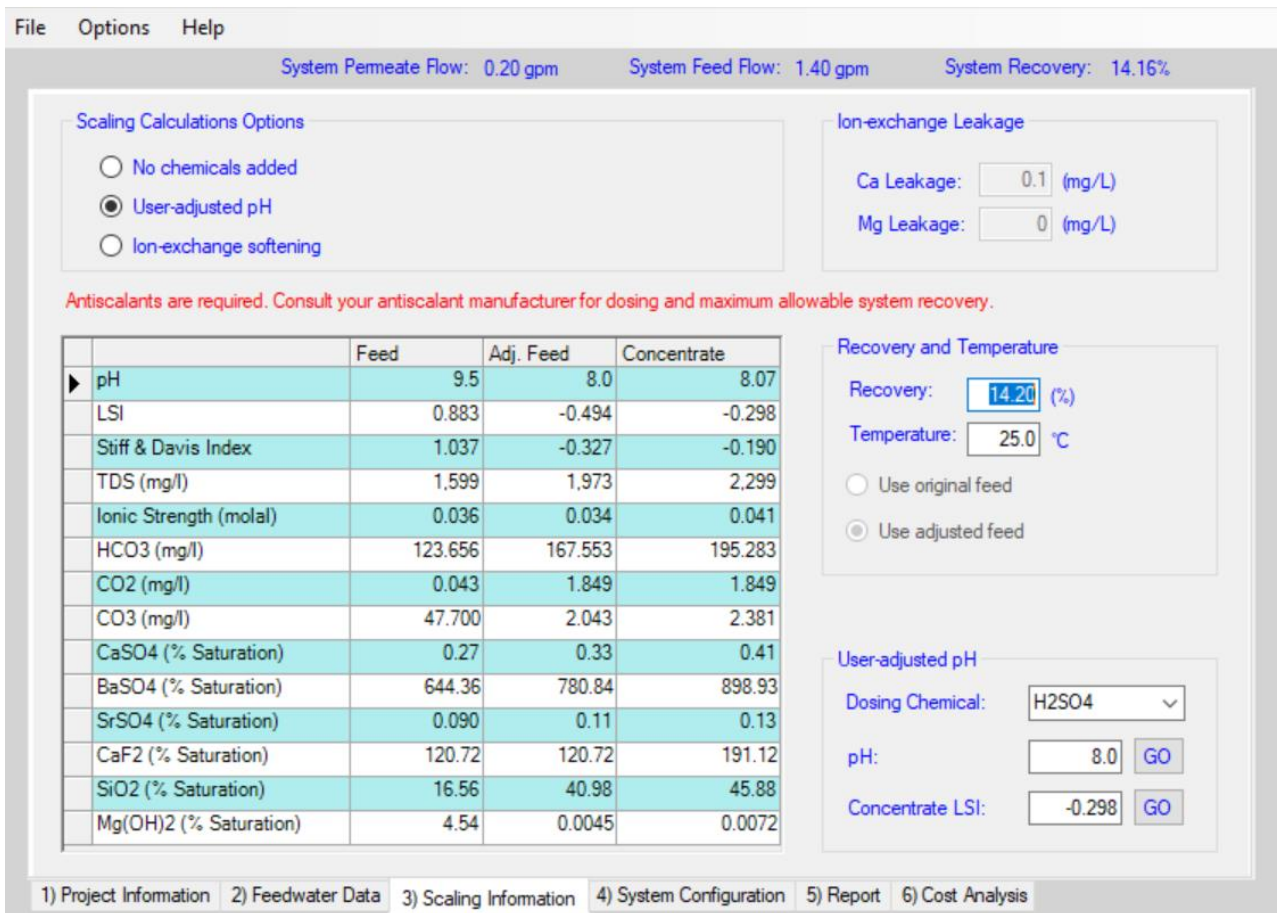


Figure 34: Scaling Information for BW 30-2540

Sulfuric acid (H₂SO₄) is chosen as an antiscalant, the pH was adjusted to 8.0, and the LSI value was set to -0.2 since a value less than indicates that the water is under-saturated and likely to dissolve solid CaCO₃ and the concentrate LSI became -0.298.

4. System Configuration

In the system configuration, the system is configured from RO calculation the permeate flow, recovery, feed flow, flow factor, and operating temperature are specified. as the RO calculation.

The type of membrane in this section is chosen based on DOW FILMTEC specifications, so membrane type BW 30-2540 is chosen for brackish water because brackish water TDS ranges from 1000 to 15,000 ppm and Lake Basaka water TDS is around 2000 ppm, so after considering membrane specification the membrane type has been chosen.

Table 16: Require amount of input parameter for BW 30-2540 Membrane design

Require amount of input parameters for BW 30-2540 Membrane design	
Feed flow	1.40 gpm
Permeate flow	0.20 gpm
Salt rejection	95.56 %
System recovery	14.16 %
Concentration factor	1
Water flux	10.20 gfd
Salt passage	4.44 %
EC of Feed	3164.28 $\mu\text{S}/\text{cm}$
EC of permeate	151.35 $\mu\text{S}/\text{cm}$

Table 16 shows the calculated required amount used to feed the system configuration menu, the pump efficiency is selected to 80.0 % and one stage, one pass, and one pressure vessel, therefore in each box, the required amount calculated is filled.

4.0. RESULT AND DISCUSSION

4.1. Test Result Before RO Filtration

Table 17: Before RO Filtration Test Result

Before RO Filtration - Lake Basaka Water Analysis Result		
No.	Components tested	Test Result (mg/l)
1	pH Value	9.5
2	Na	11.27
3	Mg	5.75
4	Ca	3.6
5	K	55.76
6	CO ₃ ²⁻	96
7	HCO ₃ ⁻	790.5
8	Cl ⁻	227.2
9	Ammonium	< 0.04
10	Strontium	0.06
11	Barium	0.02
12	Nitrate	< 0.5
13	Fluoride	11
14	Sulfate	210
15	Silicic acid	56
16	Silicon	26
17	Boron	1.2

By using the Atomic Absorption Spectroscopy testing method and DIN EN ISO 11885, and DIN EN ISO 10304 specification method the above elements are analyzed, it shows that the pH is 9.5 which is not utilized either for irrigation or for drinking purposes. Table 17 shows the analysis of trace metals such as Na, Mg, Ca, K, CO_3^{2-} , HCO_3^- , Cl^- and non-trace metals such as Ammonium, Strontium, Nitrate, Chloride, Fluoride, Sulfate, Silicic acid, Silicon, and Boron investigated by Flame AAS/ ZEE nit 700 P (Analytikjena)

Bicarbonate (HCO_3^-) is 790.5 mg/l in a high amount which forms scaling and super saturates the water by increasing the water LSI which describes the scale formation due to the high amount of bicarbonate in feed water. The chloride and the sulfate are in high amounts 227.2 and 210 mg/l respectively as depicted in Table 16. Therefore the Lake Basaka Water needs to be pretreated and filtered by membrane-based RO filtration.

4.2. Result of ROSA membrane design for TW 30-2540

In this chapter the result of Basaka Lake Water before and after Reverse Osmosis filtration is discussed. The membrane design by using ROSA Software and how the membrane is designed to fulfill good product water quality and lower energy cost is discussed.

By using the project information in Figure 29, Feed water data in Figure 30, Scaling information in Figure 31, and System configuration inputs in Table 14 the ROSA Software provides the report of membrane design for the feed data as follows.

System Configuration

System Permeate Flow: 0.21 gpm System Feed Flow: 1.41 gpm System Recovery: 14.89%

No. Passes: 1 2 Current Pass: 1 2 Dosing Chemical: None No Degasification
Adjusted pH: None % Carbon Removal: None CO2 Pressure (atm): None

Configuration for Pass 1

Stages in Pass: 1 Permeate Flow: 0.21 gpm Recirculation Loops:
Flow Factor: 0.85 Recovery: 14.89% Blend Permeate: None gpm
Operating Temp: 25.0 °C Feed Flow: 1.41 gpm Pass 1 Conc to Pass 1 Feed: None gpm
Permeate Flux: 10.80 gfd Pass 2 Conc to Pass 1 Feed: 0.0 gpm Max

Configuration for Stage 1 in Pass 1

Stage in Pass: Stage 1 ISD ? Pump Efficiency: 80.0%
Feed Pressure: None psig Boost (2-pass): Calc Back Pressure: None psig
 Same back pressure for all stages
Pressure vessels in each stage: 1
Elements in each vessel: 1
Total elements in stage: 1
Products: TW30-2540 Specs
 Use the same element in the pass

System Configuration

1) Project Information 2) Feedwater Data 3) Scaling Information 4) System Configuration 5) Report 6) Cost Analysis

Figure 35: System Configuration for TW 30-2540

Figure 35 depicts the system configuration by given data such as Permeate flow 0.21 gpm, Recovery 14.89%, Feed flow 1.41 gpm, Permeate flux 10.80 gfd, flow factor 0.85, pump efficiency 80 %, 1 pass, 1 stage, 1 Element, 1 pressure vessel for membrane type TW 30-2540 at 25 °C, the system is configured as the feed water is chemically dosed by an anti scalant H₂SO₄ and passes through the membrane after pretreatment as 80% efficient pump as a driving force for water flow and the product water which is post-treated RO filtered water comes out as a permeate while the reject water leaves the RO membrane as a concentrate.

Table 18: System Details Report-1

System Details					
Feed flow to stage 1	1.41 gpm	Pass 1 Permeate flow	0.21 gpm	Osmotic pressure	
Raw water flow to system	1.41 gpm	Pass 1 Recovery	14.89 %	Feed pressure	20.55 psig
Feed pressure	113.94 psig	Feed Temperature	25 °C	Concentrate Pressure	24.05 psig
Flow factor	0.85	Feed TDS	2004.54 mg/l	Average	22.30 psig
Chemical dose (100% H ₂ SO ₄)	37.06 mg/l	Number of Elements	1	Power	0.09 KW
Total active area	28 ft ²	Average pass 1 Flux	10.80 gfd		6.94 KWh/gal

The feed flow (gpm) is 1.41 and permeate flow (gpm) is 0.21, the average flux (gfd) is 10.80, recovery (%) is 14.89, the feed pressure (psig) is 100.94 and permeate TDS (mg/l) is 88.92. The total active area of TW 30-2540 is 28 ft² and the power to run the RO system is 6.94 KWh/gal. The chemical dose of H₂SO₄ is 37.06 mg/l added for anti-scaling is depicted in Table 18.

Table 19: Report – System details -2 for TW 30-2540

Membrane Type TW 30-2540									
Stage – 1									
Pass – 1									
Number of Elements – 1									
Number of pressure Vessel – 1									
Water classification: Surface supply < 5									
Feed Flow (gpm)	Feed Press (psig)	ReCirc. Flow (gpm)	Conc. Flow (gpm)	Conc. Press (gpm)	Perm. Flow (gpm)	Avg Flux (gfd)	Perm Press. (psig)	Boost Press (psig)	Perm. TDS (mg/l)
1.41	100.94	0.00	1.20	99.63	0.21	10.80	0.00	0.00	88.92

Table 19 depicts the detailed report of the RO system, the design of membrane type TW 30-254 has 1 Stage, 1 Pass, 1 Element, and 1 pressure vessel, and the Water classification is Surface supply < 5.

Table 20: Pass stream for BW 30-2540

Pass Streams (mg/l as Ion)						
Name	Feed	Adjusted Feed		Concentrate	Permeate	
		Initial	After Recycles	Stage 1	Stage 1	Total
NH4+ + NH3	67.12	523.25	523.25	734.84	121.61	121.61
K	8.29	8.29	8.29	9.72	0.14	0.14
Na	25.96	25.96	25.96	30.44	0.33	0.33
Mg	13.24	13.24	13.24	15.54	0.10	0.10
Ca	8.30	8.30	8.30	9.74	0.06	0.06
Sr	0.04	0.04	0.04	0.05	0.00	0.00
Ba	0.14	0.14	0.14	0.16	0.00	0.00
CO3	43.15	1.85	1.85	2.48	0.00	0.00
HCO3	112.25	151.94	151.94	177.87	1.40	1.40
NO3	0.01	0.01	0.01	0.01	0.00	0.00
Cl	805.23	854.51	854.51	1004.01	0.00	0.00
F	9.50	9.50	9.50	11.14	0.12	0.12
SO4	181.29	217.59	217.59	255.04	3.54	3.54
SiO2	56.00	56.00	56.00	65.71	0.49	0.49
Boron	23.69	23.44	23.44	25.05	14.23	14.23
CO2	0.04	1.69	1.68	1.78	1.53	1.53
TDS	1464.95	2004.54	2004.54	2339.58	88.92	88.92
pH	9.50	8.00	8.00	8.03	6.17	6.17

Table 20 depicts the dissolved solids (TDS) in the feed, adjusted feed, concentrate and permeate and pH of Feed water is 9.5 thereby adjusted to 8 to decrease the concentrate LSI value.

System Design Overview

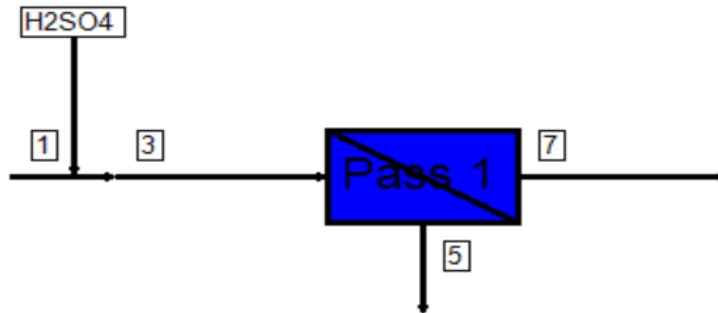


Figure 36: System Design Overview (ROSA) for TW 30-2540

As shown in Figure 36 the RO system is designed as follows:

The feed water at 1 is fed with antiscalant H_2SO_4 in a chemical dose of 37.06 mg/l and at 3 it is pumped and pretreated and passes tangentially through the membrane (the diagonal line inside the blue rectangle shows the membrane) where the dissolved solids and other contaminants are retained by the membrane and filtered water becomes further treated (post-treatment) and comes out at 7 as a permeate water while the concentrate water leaves the RO membrane and the system as a drain at 5.

Table 21: RO System Report – 1 (ROSA)

Raw Water TDS	1464.95 mg/l – Adjusted TDS 2005.54 mg/l
Water Classification	Surface Supply SDI < 5
Operating Temperature	25 °C
% System Recovery	14.89 %
Flow factor (pass 1)	0.85
Feed Flow Rate	1.41 gpm
Permeate flow rate	0.21 gpm
Average flux	10.80 gfd

Table 22: System Design Report- 2 for TW 30-2540

Pass 1			
Stream	Flow (gpm)	Pressure (psig)	TDS (mg/l)
1	1.41	0.00	1464.95
2	1.41	0.00	2004.54 (adjusted)
3	1.41	113.94	2004.54
5	1.20	99.63	2339.58
7	0.20	–	88.92
7/1	% Recovery	14.89	

The system is designed with pass 1 and stage 1, the element type is TW 30-2540, (Pressure vessels per stage, element per pressure vessel is 1), pass average flux is 10.80 gfd, and anti scalant added is H₂SO₄ with a dosage of 37.06 mg/l while the power/Energy consumption is 6.94 KWh/kgal as depicted in Table 23.

Table 23: System Design - Report 3 (ROSA) for TW 30-2540

Pass	Pass 1
Stage	1
Element Type	TW 30 – 2540
Pressure Vessels per Stage	1
Elements per Pressure Vessel	1
Total Number of Elements	1
Pass Average Flux	10.80 gfd
Stage Average Flux	10.80 gfd
Permeate Back Pressure	0.0 psig
Chemical Dose	100% H ₂ SO ₄ 37.06 mg/l
Energy Consumption	6.94 KWh/kgal

Before designing and after designing the TW 30-2540 membrane needs to be cross-checked with the membrane type TW 30-2540 specification. If the design is beyond the specified value of input then ROSA Software will show the design warnings. There were no Design warnings shown since the ROSA Software shows “None” in the design warning section. The designed membrane type TW 30-2540 matches all design specifications and has achieved a “None” design warning on ROSA Software.

Project Information:

Design Warnings:

-None-

ROSA Software showing NO Design warning

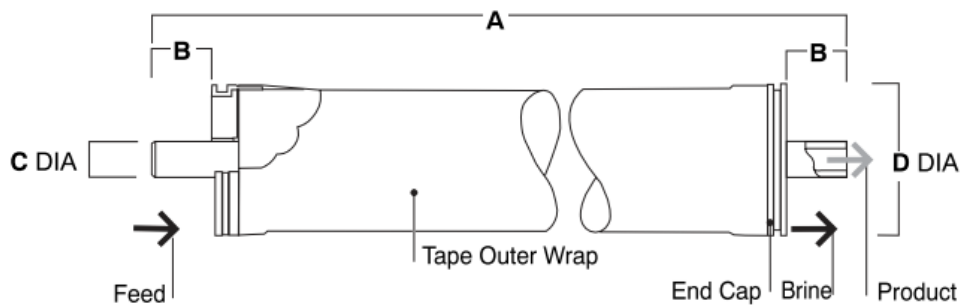


Figure 37: TW 30-2540 Membrane dimensions

Figure 37 describes four dimensions of the TW 30-2540 Membrane where the diameter and length of all four dimensions (A, B, C, D) are depicted in Table 24 below. The arrow at the left shows where the feed water flows into the membrane and the arrow colored grey at the right shows where the permeate comes out as product water and the arrow colored black at the right shows the concentrate water leaving as the brine.

Table 24: Dimension of TW 30-2540 Membrane[47]

Dimension	Unit Value Dimension Inch (mm)
A (Length)	40.0 (1,016)
B	1.19 (30.2)
C	0.75 (19)
D	2.4 (61)



Figure 38: TW 30-2540

Membrane type TW 30 – 2540 is used to filter Lake Basaka water because it has a higher rejection of 99.56 %, a small salt passage of 0.44%, average flux of 10.80 gfd, recovery of 14.89 %, EC of feed is 3133.65 $\mu\text{S}/\text{cm}$ while EC of permeate is 138.94 $\mu\text{S}/\text{cm}$ and membrane type TW 30-2540 is cost-effective. TW 30- 2540 filters the Basaka Lake water in the RO filtration system perfectly even though its range of feed source TDS is below 3000 ppm. Because the TDS range of membrane type TW 30-2540 is 1000 - 3000 ppm, it works for Lake Basaka water with a TDS of around 2000 ppm. [47] Thus TW 30-2540 is used in this project for RO filtration of Lake Basaka water.

4.3. After RO Filtration Lake Basaka Water Test Result

Table 25: RO Filtered Lake Basaka water sample test results

After RO Filtration - Lake Basaka Water Analysis Result		
No.	Components tested	Test Result (mg/l)
1	pH Value	7.6
2	Na	4.59
3	Mg	0.15
4	Ca	0.28
5	K	1.84
6	CO ₃ ²⁻	15.11
7	HCO ₃ ⁻	18.43
8	Cl ⁻	1.72
9	Ammonium	---
10	Strontium	---
11	Barium	< 0.05
12	Nitrate	< 0.5
13	Fluoride	0.08
14	Sulfate	< 0.5
15	Silicic acid	---
16	Silicon	0.64
17	Boron	0.29

Using the Microwave Plasma Atomic Emission Spectroscopy testing method for Mg, Ca, K, Cl⁻, Boron, Silicon, and EPA 300.1 specification methods for Na, CO₃²⁻, HCO₃⁻, Nitrate, Fluoride, and Sulfate are analyzed, the result shows pH is 7.6 which can be utilized either for irrigation or drinking purpose. Bicarbonate (HCO₃⁻) is 18.43 mg/l in low amounts in permeate water. Chloride is 1.72 mg/l and sulfate is less than 0.05 which shows high rejection.

When compared to Flame-AAS, MP-AES offers multi-element capabilities, a wider linear dynamic range, and fast analysis. MP-AES is used to analyze Lake Basaka water after RO filtration because it applies high technology and better performance and is currently applicable in ECAE.

4.4. Comparison of Lake Basaka water before and after RO Filtration

Table 26: Comparison of Lake Basaka water before and after Filtration

	Before RO Filtration		After RO Filtration	
No.	Components tested	Test Result (mg/l)	Test Result (mg/l)	Comment
1	pH Value	9.5	7.6	
2	Na	11.27	4.59	
3	Mg	5.75	0.15	
4	Ca	3.6	0.28	
5	K	55.76	1.84	
6	CO ₃ ²⁻	96	15.11	
7	HCO ₃ ⁻	790.5	18.43	
8	Cl ⁻	227.2	1.72	
9	Ammonium	< 0.04	---	No, outsource
10	Strontium	0.06	---	No, outsource
11	Barium	0.02	< 0.05	
12	Nitrate	< 0.5	< 0.5	

13	Fluoride	11	0.08	
14	Sulfate	210	< 0.5	
15	Silicic acid	56	---	No, outsource
16	Silicon	26	0.64	
17	Boron	1.2	0.29	

Table 26 shows the comparison of the analysis of Lake Basaka water before and after filtration. Bicarbonate (HCO_3^-) is reduced from 790.5 mg/l to 18.43 mg/l in low amounts in permeate water. Chloride is reduced from 227.2 mg/l to 1.72 mg/l, silicon is reduced from 26 mg/l to 0.64, K is reduced from 55.76 mg/l to 1.84 mg/l, CO_3^{2-} reduced from 96 mg/l to 15.11 mg/l and sulfate is reduced from 210 mg/l to less than 0.05 mg/l which shows high rejection. Na, Mg, Ca, K, CO_3^{2-} , HCO_3^- , Cl, Ammonium, Strontium, Barium, Nitrate, Fluoride, Sulfate, Silicic acid, Silicon, and Boron all have shown a reduction in mg/l. Those in the comment referred to as no outsourcing due to the ECAE stopped sending the sample outside of the country for analysis.

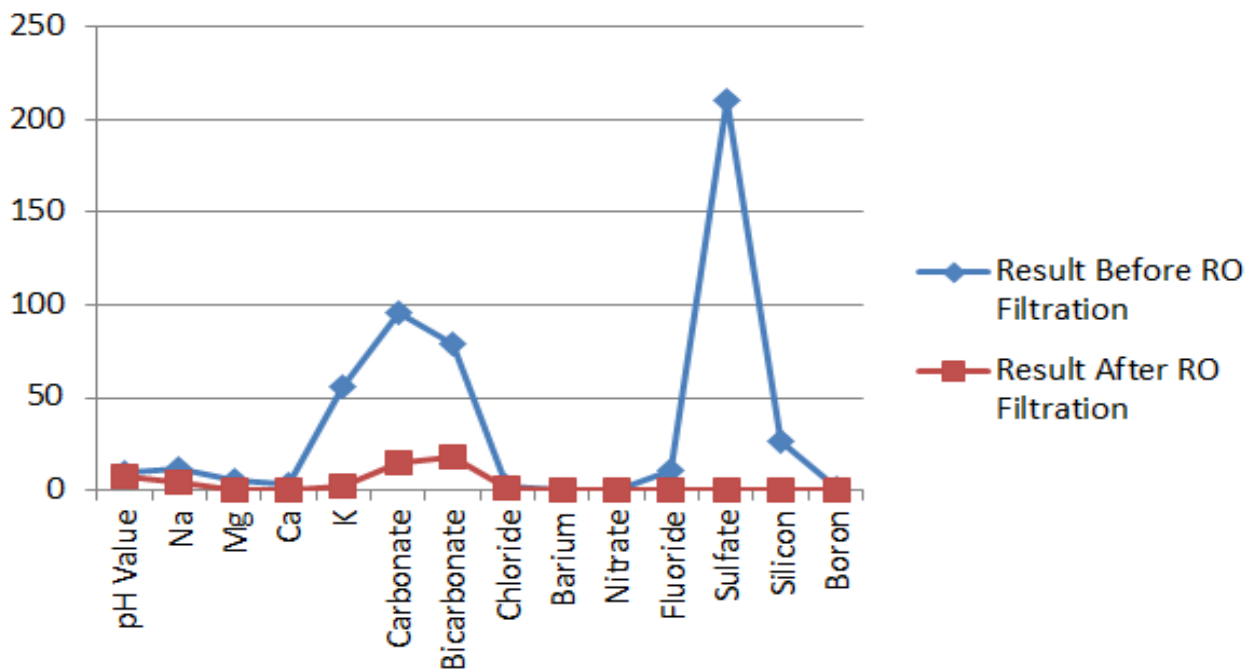


Figure 39: Test results before and after reverse osmosis filtration

[Horizontal axis (pH, and trace and non-trace metal analysis) are shown while perpendicularly amount/concentration in mg/l is shown]

As Figure 39 shows, the Lake Basaka water samples analysis before and after RO filtration result shows a huge difference and rejection which briefly determines that the Reverse osmosis filtration system is perfect for the Lake Basaka water filtration system.

4.4.1 RO Membrane-based Filtration result according to WHO Drinking Water Guidelines

According to the WHO drinking water guidelines, the result shows that the Reverse osmosis filtered Lake Basaka water can be used for irrigation, and from the analysis made by this project all tested elemental analyses fulfills WHO drinking water guideline even though further laboratory tests such as microbiology analysis is needed to conclude if the RO filtered lake basaka water can be used for drinking water purpose. The evaluation after observing the result of the analysis of RO System filtered Basaka Lake water and WHO Drinking Water guideline is stated as follows:

Table 27: After RO Filtration Lake Basaka water sample and WHO Drinking Water Guideline comparison[44]

Check	Components evaluated by WHO guideline	RO test result after Filtration (mg/l except for pH)	WHO Drinking Water Guideline (mg/l except for pH) /Maximum/
Pass	pH Value	7.6	6.5 – 8.5
Pass	Na	4.59	< 20
Pass	Mg	0.15	50
Pass	Ca	0.28	200
Pass	K	1.84	1 – 2 (min- max)
Pass	CO ₃ ²⁻	15.11	< 75 mg/l
Pass	HCO ₃ ⁻	18.43	< 75 mg/l

Pass	Cl ⁻	1.72	250
---	Ammonium	---	1.3
---	Strontium	---	50
Pass	Barium	< 0.05	1.3
Pass	Nitrate	< 0.5	50
---	Fluoride	---	1.5
Pass	Sulfate	0.08	250
Pass	Silicic acid	< 0.5	< 30 mg/l
Pass	Boron	0.6	200
Pass	TDS	< 100	< 500
Pass	Taste and odor	No taste and odor	No taste and odor

After evaluating the filtered water concerning the WHO drinking water guideline as depicted in Table 27, the composition level has passed the evaluation by having smaller concentrations of components in RO Filtered water. Therefore RO membrane-based filtration system filtered Lake Basaka water at higher rejection.

4.5. Result of ROSA membrane design: For BW 30-2540

System Configuration

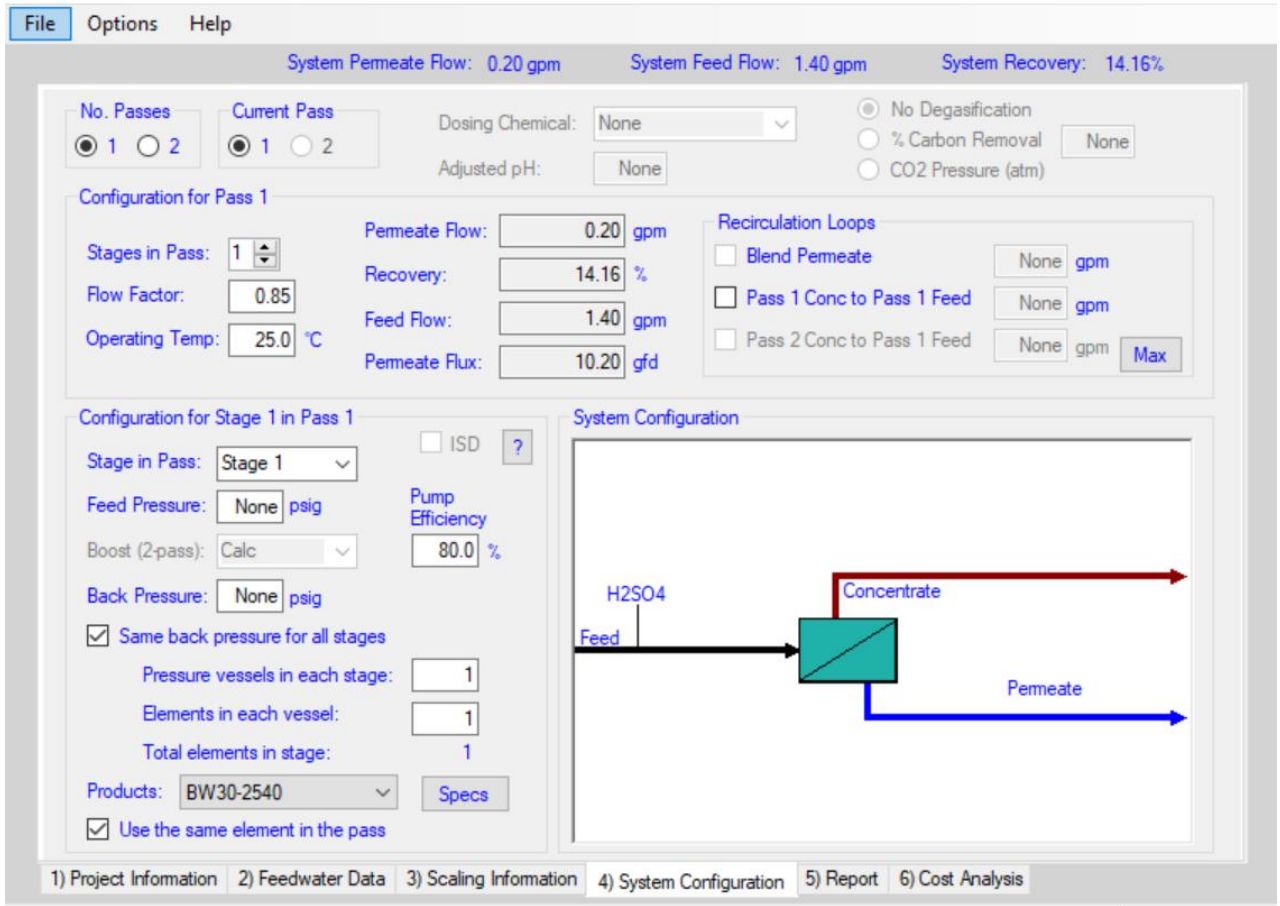


Figure 40: System Configuration for BW 30-2540

The above Figure depicts the system configuration by given data such as Permeate flow 0.21 gpm, Recovery 14.16%, Feed flow 1.40 gpm, Permeate flux 10.20 gfd, flow factor 0.85, pump efficiency 80 %, 1 pass, 1 stage, 1 Element, 1 pressure vessel for membrane type BW 30-2540 at 25 °C, the system is configured as the feed water is chemically dosed by an anti scalant H₂SO₄ and passes through the membrane after pretreatment as efficient pump as a driving force for water flow and the product water which is post-treated RO filtered water comes out as a permeate while the reject water leaves the RO membrane as a concentrate.

Report of ROSA Software for BW 30-2540

The stage, element type, feed flow, and feed pressure of each stage are reported in this stream.

This stream provides us with design information and delivers a signal or warning as it suggests a better method to make the design better.

Table 28: Report System details-1 for BW 30-2540

System Details					
Feed flow to stage 1	1.40 gpm	Pass 1 Permeate flow	0.20 gpm	Osmotic pressure	
Raw water flow to system	1.40 gpm	Pass 1 Recovery	14.6 %	Feed pressure	20.46 psig
Feed pressure	111.09 psig	Feed Temperature	25 °C	Concentrate Pressure	23.10 psig
Flow factor	0.85	Feed TDS	2025.14 mg/l	Average	22.10 psig
Chemical dose (100% H ₂ SO ₄)	40.80 mg/l	Number of Elements	1	Power	0.08 KW
Total active area	28 ft ²	Average pass 1 Flux	10.20 gfd		7.11 KWh/gal

Table 29: Report System details-2 for BW 30-2540

Membrane Type BW 30-2540									
Stage – 1									
Pass – 1									
Number of Elements – 1									
Number of pressure Vessel – 1									
Water classification: Surface supply < 5									
Feed Flow (gpm)	Feed Press (psig)	ReCirc. Flow (gpm)	Conc. Flow (gpm)	Conc. Press (gpm)	Perm. Flow (gpm)	Avg Flux (gpm)	Perm Press. (psig)	Boost Press (psig)	Perm. TDS (mg/l)
1.40	96.09	0.00	1.20	94.79	0.20	10.20	0.00	0.00	96.87

Table 28 depicts The total active area of TW 30-2540 is 28 ft² and the power to run the RO system is 7.11 KWh/gal. The chemical dose of H₂SO₄ is 37.40.80 mg/l added for anti-scaling.

Table 29 depicts the detailed report of the RO system the design of Membrane Type BW 30-2540, 1 Stage, 1 Pass, Number of Elements, and Number of Pressure Vessels is 1 for the Water classification: Surface supply < 5. The feed flow (gpm) is 1.40 and permeate flow (gpm) is 0.20, the average flux (gfd) is 10.20, the feed pressure (psig) is 96.09 and permeate TDS (mg/l) is 96.87.

Table 30: Report – Feed details for BW 30-2540

Pass Streams (mg/l as Ion)					
Name	Feed	Adjusted Feed	Concentrate	Permeate	
			Stage 1	Stage 1	Total
NH ₄ ⁺ + NH ₃	187.41	523.25	945.15	337.37	337.37
K	8.29	8.29	9.63	0.15	0.15
Na	25.96	25.97	30.20	0.35	0.35
Mg	13.24	13.24	15.40	0.10	0.10
Ca	8.30	8.30	9.65	0.06	0.06
Sr	0.04	0.04	0.05	0.00	0.00
Ba	0.14	0.14	0.16	0.00	0.00
CO ₃	47.70	2.04	2.71	0.00	0.00
HCO ₃	123.66	167.55	194.53	1.43	1.43
NO ₃	0.01	0.01	0.01	0.00	0.00
Cl	773.80	826.68	963.06	0.00	0.00
F	10.46	10.46	12.16	0.14	0.14
SO ₄	199.72	239.69	278.55	4.08	4.08
SiO ₂	56.00	56.00	65.15	0.51	0.51
Boron	25.38	25.11	26.70	15.48	15.48
CO ₂	0.04	1.85	1.95	1.69	1.69
TDS	1598.71	2025.14	2343.13	96.87	96.87
pH	9.50	8.00	8.03	6.14	6.14

The above Table depicts the composition of feed water, concentrate and permeate and dissolved solids (TDS) found in Feed water, an adjusted feed where the pH is adjusted to 8 to decrease the concentrate LSI value,

Table 31: Scaling calculation

Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	9.50	8.00	8.03
Langelier Saturation Index	0.88	-0.49	-0.34
Stiff & Davis Stability Index	1.04	-0.33	-0.23
Ionic Strength (Molal)	0.03	0.04	0.04
TDS (mg/l)	1598.71	2025.14	2343.13
HCO ₃	123.66	167.55	194.53
CO ₂	0.04	1.86	1.95
CO ₃	47.70	2.04	2.71
CaSO ₄ (% Saturation)	0.27	0.33	0.41
BaSO ₄ (% Saturation)	644.36	786.39	896.31
SrSO ₄ (% Saturation)	0.09	0.05	0.13
CaF ₂ (% Saturation)	120.72	120.63	189.91
SiO ₂ (% Saturation)	16.56	39.02	46.78
Mg(OH) ₂ (% Saturation)	4.54	0.01	0.01

To balance: 0.01 mg/l Na added to feed.

Table 32: Report of system recovery, TDS, and Temperature (ROSA) for BW 30-2540

Raw Water TDS	1598.71 mg/l–Adjusted feed: 2025.14 mg/l
Water Classification	Surface Supply SDI < 5
Operating Temperature	25 °C
% System Recovery	14.16 %
Flow factor (pass 1)	0.85
Feed Flow Rate	1.40 gpm
Permeate flow rate	0.20 gpm
Average flux	10.20 gfd

Therefore, after adjusting the feed pH to 8.0, the TDS of the raw feed is 2025.14 mg/l.

Another Relevant report from ROSA is listed as follows:

System Design Overview

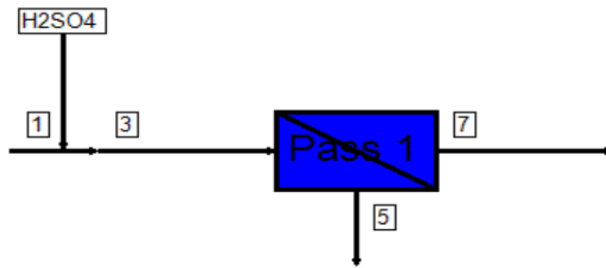


Figure 41: System Design Overview (ROSA) for BW 30-2540

System Design of the RO system is as follows:

The feed water at 1 is fed H₂SO₄ in a chemical dose of 40.80 mg/l and at 3 it is pumped and pretreated and passes tangentially through the membrane where the diagonal line inside the blue rectangle shows the membrane after that as with the RO filtration the permeate water further treated (post-treatment and moves by 7 into the faucet or the storage tank while the concentrate water leaves the RO system from the membrane as a drain at 5.

Table 33: RO System Report – 1 (ROSA) for BW 30-2540

Pass 1			
Stream	Flow (gpm)	Pressure (psig)	TDS (mg/l)
1	1.40	0.00	1598.71
3	1.40	111.09	2025.14 (adjusted)
5	1.20	94.79	2343.13
7	0.20	–	96.87
7/1	% Recovery	14.16	

The system was designed with pass 1 and stage 1, the element type is TW 30-2540, (Pressure vessels per stage, element per pressure vessel is 1), pass average flux is 10.80 gfd, and anti scalant added is H₂SO₄ with a dosage of 40.80 mg/l while the power/Energy consumption is 7.11 KWh/kgal as depicted in Table 34 below.

Table 34: System Design Report- 2 (ROSA) for BW 30-2540

Pass	Pass 1
Stage	1
Element Type	BW 30 – 2540
Pressure Vessels per Stage	1
Elements per Pressure Vessel	1
Total Number of Elements	1
Pass Average Flux	10.20 gfd
Stage Average Flux	10.20 gfd
Permeate Back Pressure	0.0 psig
Booster Pressure	0.00 psig
Chemical Dose	100% H ₂ SO ₄ 40.80 mg/l
Energy Consumption	7.11 KWh/kgal

Before designing and after designing the membrane needs to be cross-checked with the membrane type specification. If the design is beyond the specified value of input then ROSA Software will show the design warnings. There were no Design warnings shown since the ROSA Software shows “None” in the design warning section. The designed membrane type BW 30-2540 matches all design specifications and has achieved a “None” design warning on ROSA Software.

Project Information:

Design Warnings:

-None-

ROSA Software showing NO Design warning

The membrane type BW 30-2540 (BW stands for brackish water) selected by the ROSA membrane design to filter Lake Basaka Water through RO is depicted in Figure 39 below which shows the dimension of the membrane material.

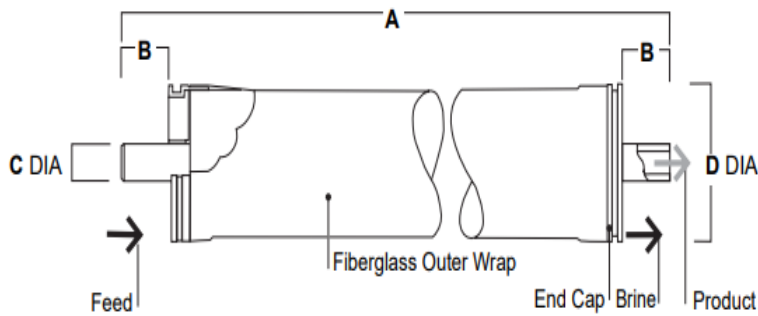


Figure 42: BW 30-2540 Membrane [47]

Figure 42 describes four dimensions of the BW 30-2540 Membrane, It shows that BW 30-2540 is manufactured of fiberglass at the exterior as a hard shell strong enough to withstand high operating pressure. The arrow at the left shows where the feed water flows into the membrane and the arrow colored grey at the right shows where the permeate comes out as a product water and the arrow colored black at the right shows the concentrate water leaving as the brine, where the diameter and length of all four dimensions are depicted in Table 35 below.

Table 35: Dimension of BW 30-2540 Membrane[47]

Dimension	Unit Value Dimension Inch (mm)
A (Length)	40.0 (1,016)
B	1.19 (30.2)
C	0.75 (19)
D	2.4 (61)



Figure 43: BW 30-2540 Membrane

Therefore by using the ROSA Software, the study designed a membrane type BW 30-2540 which provides 0.2 gpm product flow rate from 1.4 gpm feed flow rate, an average flux of 10.20 gfd, 14.16 % recovery, and a high salt rejection which provides a high water quality with less cost of energy with no Design warnings since the ROSA Software shows “None” in the design warning section.

Table 36: Comparison of BW 30-2540 Vs TW 30-2540

TFC Membrane Type	BW 30-2540	TW 30-2540
Parameter	Value	Value
Feed flow rate	1.4 gpm	1.41 gpm
Maximum permeate flow rate	0.20 gpm	0.21 gpm
Average flux	10.20 gfd	10.80 gfd
Recovery	14.16 %	14.89 %
Applied pressure	225 psi	225 psi
Maximum pressure drop	15 psi	13 psi
Temperature	25 °C	25 °C
Maximum operating temperature	45 °C	45 °C
Maximum operating pressure	600 psi	600 psi

pH range,	2 – 11	2 – 11
Minimum salt rejection (Cl ⁻)	99.5 %	99.5 %
TDS	1000 – 15,000	< 3000 ppm
Silt Density Index (SDI)	< 5	< 5

Table 36 shows a significantly close performance of membrane type BW 30-2540 and TW 30 – 2540.

The interrelation between ROSA and RO is that ROSA designed the right membrane and is being utilized for RO filtration of Lake Basaka water therefore, to filter Lake Basaka water by RO filtration system, TW 30-2540 membrane type is designed by ROSA software. In this study, TW 30-2540 is used instead of BW-30-2540 because both membranes can be utilized interchangeably for feed TDS less than 3000 ppm.

TW 30 – 2540 filters the Basaka Lake water in the RO filtration system perfectly however its range of feed source TDS is below 3000 ppm therefore it is recommended for the feed water TDS below 3000 ppm. If the TDS of brackish water is higher than 3000 ppm, the recommended membrane type is BW 30-2540. [47]

BW 30-2540 which is made of fiberglass exterior piece allows for higher operating pressure because of the wider spacer between each membrane type and can achieve a greater crossflow along the surface area and avoid fouling, therefore BW 30-2540 is recommended for RO filtration of Lake Basaka water.

Table 37: Cost analysis of Membrane type TW 30 – 2540 and BW 30 – 2540

Membrane type	TW 30 – 2540	BW 30 – 2540
Pass 1 total element	1	1
Pass 1 pressure vessel	1	1
Pass 1 power cost (KWh)	0.09	0.08
Membrane price (\$)	209.99	285.95
Life time (years)	10	10
Pass 1 projection results		
Pass 1 permeate product (gpm)	0.21	0.20
Pass 1 recovery (%)	14.89	14.16
Pass 1 feed pressure (psi)	113.94	111.09
Pass 1 concentrate pressure (psi)	99.63	94.79
Power consumption		
Pass 1 net energy consumption (KWh/kgal)	6.94	7.11
Pass 1 net energy cost (\$/year)	\$ 61.23	\$ 59. 28
Energy expense NPV (\$)	\$ 376.22	\$ 364.23
Pass 1 energy expense (\$/Kgal)	0.55	0.57
Operating expense subtotal		
Pass 1 operating expense NPV (\$)	\$ 376.22	\$ 364.23
Pass 1 operating expense per Kgal	\$ 0.55	\$ 0.57
Total system capital		
Operating expense NPV (\$)	\$ 376.22	\$ 364.23
Cost of water	\$ 0.35	\$ 0.35

Table 37: Shows a cost analysis of Membrane type TW 30 - 2540 and BW - 2540. The membrane price & net energy cost (\$/year) of Tw 30 - 2540 and BW 30 – 2540 are \$209.99 and \$61.23, \$285.95 and \$59. 28, respectively. Where as the operating expense per Kgal of Tw 30 – 2540 and BW 30 – 2540 are \$ 0.55 and \$ 0.57, respectively.

5.0. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

TW 30-2540 membrane designed by ROSA software for the RO System provided the required permeate flow rate of 0.21 gpm with a lower applied pressure of 100.94 psig, better recovery of 14.89% (since the maximum recovery for this membrane type is 15%), better salt rejection where minimum salt rejection is 99.5 %, flux is 10.80 gfd, salt passage of 0.44 % at an adjusted feed pH of 8, and system temperature of 25 °C. As a result, ROSA Software designed the TW 30-2540 membrane for solar-powered RO to filter Lake Basaka water without displaying a design warning. The membrane type TW 30-2540 produces 0.21 gpm of permeate water which is described in different units as 288 g/d, 45.42 lt/hr, 1090.199 lt/d.

After MP-AES analysis, Na, Mg, Ca, K, CO_3^{2-} , HCO_3^- , Cl⁻, Ammonium, Strontium, Barium, Nitrate, Fluoride, Sulfate, Silicic acid, Silicon, and Boron all have shown a significant reduction in mg/l after RO filtration. Lake Basaka water analysis by MP-AES demonstrated that the solar-powered RO membrane filtered in acceptable quality, which is higher quality due to higher rejection.

Exceeding the design recovery above 15% results lowest purity by allowing more salt passage, therefore the membrane design fulfills the specification by not exceeding the recovery above 15% which is 14.89 %. The pressure drop of the membrane is lower, which is 15 psi which reduces the membrane failure.

The designed membrane type BW 30-2540 by ROSA Software applicable for brackish water ranges 1000 - 15000 ppm has shown the required permeate flow rate of 0.20 gpm, lower applied pressure 96.87 psig, better recovery 14.16% (since the maximum recovery for this membrane type is 15%), better salt rejection, flux 10.20 gfd, at an adjusted feed pH of 8 at 25 °C operating temperature. The membrane type BW 30-2540 produces 0.20 gpm of permeate water which is described in different units such as 47.69 lt/hr, 1144.72 lt/d, and 302.4 g/d.

5.2. Recommendations

Taking the above conclusions into consideration the following recommendations are forwarded:

TW 30 – 2540 membrane is recommended for feed water TDS below 3000 ppm whereas BW 30-2540 membrane is recommended for feed water TDS up to 15000.

Solar-driven reverse osmosis system reduces the salinity and alkalinity of Lake Basaka water therefore, purifying the Lake Basaka water could bring utilization of Lake Basaka water for irrigational and domestic purposes in the welenchity area.

This study demonstrated that RO has successfully filtered Lake Basaka water which complies with WHO drinking water guidelines. However additional tests, such as microbiological analysis must be performed to investigate and to accredit the qualification of the membrane-based RO filtration system.

Future works

Coupling the solar photovoltaic energy source with other energy sources for high energy efficiency to provide a higher permeate flow rate.

Future researches need to focus on new technologies that improve the permeate flow rate, water flux, rejection, and recovery, reduce fouling and scaling, and extend membrane lifetime.

Further studies on Analysis of Lake Basaka water filtered by Solar-Driven Membrane-Based Reverse Osmosis system need to focus on increase of utilization.

REFERENCES

- [1] P. H. Gleick and H. Cooley, “Freshwater Scarcity,” *Annu. Rev. Environ. Resour.*, vol. 46, no. 1, pp. 319–348, 2021, doi: 10.1146/annurev-environ-012220-101319.
- [2] A. W. Conn and G. A. Barker, “Fresh water drowning and near-drowning-an update,” *Can. Anaesth. Soc. J.*, vol. 31, no. 3 Supplement, 1984, doi: 10.1007/BF03007034.
- [3] C. Chen, Y. Jiang, Z. Ye, Y. Yang, and L. Hou, “Sustainably integrating desalination with solar power to overcome future freshwater scarcity in China,” *Glob. Energy Interconnect.*, vol. 2, no. 2, pp. 98–113, 2019, doi: 10.1016/j.gloi.2019.07.009.
- [4] N. Ghaffour, T. M. Missimer, and G. L. Amy, “Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability,” *Desalination*, vol. 309, pp. 197–207, 2013, doi: 10.1016/j.desal.2012.10.015.
- [5] M. Shatat and S. B. Riffat, “Water desalination technologies utilizing conventional and renewable energy sources,” *Int. J. Low-Carbon Technol.*, vol. 9, no. 1, pp. 1–19, 2012, doi: 10.1093/ijlct/cts025.
- [6] A. Shukla, S. Agarwal, and K. Narwat, “Solar-Powered Reverse Osmosis Desalination,” *J. Phys. Conf. Ser.*, vol. 2178, no. 1, 2022, doi: 10.1088/1742-6596/2178/1/012018.
- [7] C. Fritzmann, J. Löwenberg, T. Wintgens, and T. Melin, “State-of-the-art of reverse osmosis desalination,” *Desalination*, vol. 216, no. 1–3, pp. 1–76, 2007, doi: 10.1016/j.desal.2006.12.009.
- [8] “Water & Process Solutions FILMTEC™ Reverse Osmosis Membranes Technical Manual”.
- [9] J. Kucera, “Reverse Osmosis,” in *Kirk-Othmer Encyclopedia of Chemical Technology*, John Wiley & Sons, Inc., 2017, pp. 1–44. doi: 10.1002/0471238961.1805220502080120.a01.pub3.
- [10] F. Papa *et al.*, “Water Resources in Africa under Global Change: Monitoring Surface

- Waters from Space,” *Surv. Geophys.*, vol. 44, no. 1, pp. 43–93, 2023, doi: 10.1007/s10712-022-09700-9.
- [11] F. Papa *et al.*, “Correction to: Water Resources in Africa under Global Change: Monitoring Surface Waters from Space (Surveys in Geophysics, (2023), 44, 1, (43-93), 10.1007/s10712-022-09700-9),” *Surveys in Geophysics*, vol. 44, no. 1. 2023. doi: 10.1007/s10712-022-09729-w.
- [12] T. Woldegebriel, V. Garg, P. K. Gupta, S. K. Srivastav, and R. Ranjan, “Ethiopia’s Water Resources: An Assessment Based on Geospatial Data-Driven Distributed Hydrological Modeling Approach,” *J. Indian Soc. Remote Sens.*, vol. 50, no. 6, pp. 1031–1049, 2022, doi: 10.1007/s12524-022-01511-0.
- [13] B. Berhanu, Y. Seleshi, and A. M. Melesse, “Surface Water and Groundwater Resources of Ethiopia: Potentials and Challenges of Water Resources Development BT - Nile River Basin: Ecohydrological Challenges, Climate Change and Hydropolitics,” A. M. Melesse, W. Abteu, and S. G. Setegn, Eds., Cham: Springer International Publishing, 2014, pp. 97–117. doi: 10.1007/978-3-319-02720-3_6.
- [14] A. K. Biswas and C. Tortajada, “Global crisis in water management: Can a second UN Water Conference help?,” *River*, vol. 2, no. 2, pp. 143–148, 2023, doi: 10.1002/rvr2.40.
- [15] A. Jeff, “Freshwater scarcity in Africa.” 2018.
- [16] UNICEF, “Water crisis in the horn of Africa,” *Water Cris. horn Africa*, pp. 2–8, 2022.
- [17] USAID/Sustainable Water Partnership (SWP), “Ethiopia Water Resources Profile Overview,” *Winrock Int.*, p. 11, 2021.
- [18] M. Hendrix, “Water in Ethiopia”.
- [19] UNICEF, “Wash cpd 2012-2016,” no. June, 2016.
- [20] M. Olumana Dinka, “Analysing the temporal water quality dynamics of Lake Basaka, Central Rift Valley of Ethiopia,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 52, p. 012057, 2017, doi: 10.1088/1742-6596/52/1/012057.
- [21] M. O. Dinka, “Lake Basaka Expansion: Challenges for the Sustainability of the Matahara

- Irrigation Scheme, Awash River Basin (Ethiopia),” *Irrig. Drain.*, vol. 66, no. 3, pp. 305–315, 2017, doi: 10.1002/ird.2114.
- [22] M. Dinka, “Delineating the Drainage Structure and Sources of Groundwater Flux for Lake Basaka, Central Rift Valley Region of Ethiopia,” *Water*, vol. 9, no. 12, p. 797, 2017, doi: 10.3390/w9120797.
- [23] M. Khayet, “Solar desalination by membrane distillation: Dispersion in energy consumption analysis and water production costs (a review),” *Desalination*, vol. 308, pp. 89–101, 2013, doi: 10.1016/j.desal.2012.07.010.
- [24] F. E. Ahmed, R. Hashaikeh, and N. Hilal, “Solar powered desalination – Technology, energy and future outlook,” *Desalination*, vol. 453, no. November 2018, pp. 54–76, 2019, doi: 10.1016/j.desal.2018.12.002.
- [25] H. A. Shawky, A. A. Abdel Fatah, M. M. S. Abo ElFadl, and A. H. M. El-Aassar, “Design of a small mobile PV-driven RO water desalination plant to be deployed at the northwest coast of Egypt,” *Desalin. Water Treat.*, vol. 55, no. 13, pp. 3755–3766, 2015, doi: 10.1080/19443994.2015.1080447.
- [26] S. Information, “Installation and Maintenance Manual Reverse Osmosis Filtration Systems,” pp. 1–22.
- [27] S. G. Salinas-Rodriguez, J. Schippers, and M. Kennedy, “Basic principles of reverse osmosis,” 2021, pp. 29–58. doi: 10.2166/9781780409863_0029.
- [28] W. J. Lau, A. F. Ismail, N. Misdan, and M. A. Kassim, “A recent progress in thin film composite membrane: A review,” *Desalination*, vol. 287, pp. 190–199, 2012, doi: 10.1016/j.desal.2011.04.004.
- [29] A. Sagle and B. Freeman, “Fundamentals of Membranes for Water Treatment,” pp. 1–17.
- [30] J. Kucera, “Reverse osmosis,” *John Wiley&Sons, New Jersey, USA*, p. 416, 2010.
- [31] S. Beardsley, “Reverse Osmosis Design Basics Scott Beardsley”.
- [32] C. H. Koo, A. W. Mohammad, F. Suja’, and M. Z. Meor Talib, “Use and development of fouling index in predicting membrane fouling,” *Sep. Purif. Rev.*, vol. 42, no. 4, pp. 296–

- 339, 2013, doi: 10.1080/15422119.2012.690359.
- [33] R. R. Choudhury, J. M. Gohil, S. Mohanty, and S. K. Nayak, “Antifouling, fouling release and antimicrobial materials for surface modification of reverse osmosis and nanofiltration membranes,” *J. Mater. Chem. A*, vol. 6, no. 2, pp. 313–333, 2018, doi: 10.1039/c7ta08627j.
- [34] C. H. Koo, A. W. Mohammad, F. Suja’, and M. Z. Meor Talib, “Use and Development of Fouling Index in Predicting Membrane Fouling,” *Sep. & Purif. Rev.*, vol. 42, no. 4, pp. 296–339, 2013, doi: 10.1080/15422119.2012.690359.
- [35] A. J. Karabelas, S. T. Mitrouli, and M. Kostoglou, “Scaling in reverse osmosis desalination plants: A perspective focusing on development of comprehensive simulation tools,” *Desalination*, vol. 474, p. 114193, 2020, doi: 10.1016/j.desal.2019.114193.
- [36] A. Matin, T. Laoui, W. Falath, and M. Farooque, “Fouling control in reverse osmosis for water desalination & reuse: Current practices & emerging environment-friendly technologies,” *Sci. Total Environ.*, vol. 765, p. 142721, 2021, doi: 10.1016/j.scitotenv.2020.142721.
- [37] L. Separations, “Dow Liquid Separations”.
- [38] D. Plant, R. Ncube, and F. L. Inambao, “Membrane Modeling and Simulation for a Small Scale Reverse Osmosis Membrane Modeling and Simulation for a Small Scale Reverse Osmosis Desalination Plant,” no. January 2021, 2020.
- [39] “Dow unveils next-generation Filmtec residential RO elements,” *Membr. Technol.*, vol. 2010, no. 4, p. 7, 2010, doi: 10.1016/s0958-2118(10)70071-9.
- [40] “Microwave Plasma Atomic Emission Spectroscopy,” no. January, p. 163, 2021.
- [41] “ZEE nit – Zeeman AAS Spectrometer - Analytik Jena.”
- [42] M. Ahmed, *Atomic Absorption Spectroscopy (AAS)*. 2012. doi: 10.13140/RG.2.2.29580.51844.
- [43] “Elemental Analysis Manual”.
- [44] F. F. O. R. S. Drinking-water, “WHO _ guidelines _ Chp 10 Acceptability aspects”.

- [45] “Sample preparation techniques for AAS , ICP-OES and ICP-MS for regulated testing laboratories Introduction”.
- [46] D. Gerenfes, E. Teju, K. Agricultural, H. Agriculture, and A. Ababa, “Determination of Some Selected Heavy Metals in Water , Oreochromis niloticus and Labeobarbus intermedius Samples from Abaya and Chamo Lakes,” vol. 8, no. 21, pp. 85–95, 2018.
- [47] D. F. Lenntech, “FILMTEC™ Membranes product catalog,” no. 609.

ANNEXES

Annex 1: RO Filtration of Lake Basaka Water: Operation with charge controller



Annex 2: Charge controller, Battery



Annex 3: RO Filtration system setup



Annex 4: Filling Feed water tank of RO Filtration



Annex 5: Collecting RO Filtered water



Annex 6: Analysis of RO Filtered Water by MP-AES



Annex 7: Cost analysis of membrane type BW 30-2540

Project Life (years)	10
Interest rate (%)	10
Power cost (\$/kWh)	0.08
Pass 1	
Projection Results	
Pass 1 permeate production (gpm)	0.20
Pass 1 feed pressure (psi)	111.09
Pass 1 concentrate pressure (psi)	94.79
Pass 1 recovery (%)	14.16
Pass 1 energy recovery efficiency (%)	
Capital Expense	
Pass 1 pressure vessels	1
Pressure vessel cost (\$/vessel)	0
Pass 1 capital for pressure vessels	\$0.00
Product	BW30-2540 (1)
Pass 1 total elements	1
Element cost (\$/element)	\$0.00
Pass 1 capital for elements (\$)	\$0.00
Pass 1 capital (\$)	\$0.00
Pass 1 capital(\$/kgal)	\$0.00
Operating Expense	

Pass 1 net energy consumption (KWh/kgal)	7.11
Pass 1 net energy cost (\$/year)	\$59.28
Energy expense NPV (\$)	364.23
Pass 1 energy expense (\$/kgal)	\$0.57
Membrane replacement cost	
Pass 1 replacement rate (%/year)	13
Replacement price (\$/element)	\$0.00
Pass 1 replacement cost for elements (\$/year)	\$0.00
Pass 1 replacement membrane NPV (\$)	\$0.00
Pass 1 membrane replacement expense (\$/kgal)	\$0.00
Operating expense subtotal	
Pass 1 operating expense NPV (\$)	\$364.23
Pass 1 operating expense per kgal	\$0.57
Pass 1 Total	
Pass 1 cost NPV (\$)	\$0.00
Life Cycle Cost (\$/kgal)	\$0.00
Total System	
Capital	\$0.00
Operating expense NPV (\$)	\$364.23
Cost of water NPV (\$/kgal)	\$0.35

Annex 8: Cost analysis of membrane type TW 30-2540

Project Name		Membrane Design By ROSA Software
Case #		1
Project Overview		
Unit set for economic evaluation		kgal-psi-gpm
System water production (gpm)		0.21
System recovery (%)		14.89
Project Economic Variables		
Project Life (years)		10
Interest rate (%)		10
Power cost (\$/kWh)		0.08
Pass 1		
Projection Results		
Pass 1 permeate production (gpm)		0.21
Pass 1 feed pressure (psi)		113.94
Pass 1 concentrate pressure (psi)		99.63
Pass 1 recovery (%)		14.89
Pass 1 energy recovery efficiency (%)		
Capital Expense		
Pass 1 pressure vessels		1
Pressure vessel cost (\$/vessel)		0

Pass 1 pumping power (kW)	0.09
Pass 1 pump specific energy (kWh/kgal)	6.94
Brine energy recovery (kWh/kgal)	0.00
Pass 1 net energy consumption (KWh/kgal)	6.94
Pass 1 net energy cost (\$/year)	\$61.23
Energy expense NPV (\$)	376.22
Pass 1 energy expense (\$/kgal)	\$0.55
Membrane replacement cost	
Pass 1 replacement rate (%/year)	13
Replacement price (\$/element)	\$0.00
Pass 1 replacement cost for elements (\$/year)	\$0.00
Pass 1 replacement membrane NPV (\$)	\$0.00
Pass 1 membrane replacement expense (\$/kgal)	\$0.00
Operating expense subtotal	
Pass 1 operating expense NPV (\$)	\$376.22
Pass 1 operating expense per kgal	\$0.55
Pass 1 Total	
Pass 1 cost NPV (\$)	\$0.00
Life Cycle Cost (\$/kgal)	\$0.00
Total System	
Capital	\$0.00