EGE UNIVERSITY GRADUATE SCHOOL OF
APPLIED AND NATURAL SCIENCES

(MASTER OF SCIENCE THESIS)

QUALITY ANALYSIS OF WATER PRODUCED FROM SEAWATER BY REVERSE OSMOSIS METHOD-STUDYING THE EFFECT OF MEMBRANE TYPE ON WATER QUALITY

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ÖZET

TERS OZMOS YÖNTEMİYLE DENİZ SUYUNDAN ÜRETİLEN TATLI SUYUN KALİTE ANALİZİ-MEMBRAN TÜRÜNÜN SU KALİTESİNE ETKİSİNİN İNCELENMESİ

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Tüm canlılar için su, en önemli yaşam kaynağıdır. Günümüzde, birçok ülke, artan nüfus yoğunluğu, gelişen endüstri ve açığa çıkan atıkların oluşturduğu çevre kirliliği nedenlerinden dolayı temiz su sıkıntısı çekmektedir. Gittikçe artan bu sıkıntı nedeniyle, alternatif su kaynaklarına olan ilgi artmaktadır. Son yıllarda, içme ve kullanma suyu olarak, ters ozmos yöntemi ile deniz suyundan elde edilen suyun kulanımı büyük önem kazanmıştır.

Ters ozmos yöntemi ile elde edilen suyun, içme ve kullanma suyu olarak kullanılabilmesi için, içme ve kullanma suyu kriterlerine (Dünya Sağlık Örgütü-WHO, Türk Standartları Enstitüsü-TSE, Avrupa Çevre Koruma Ajansı-EPA tarafından belirlenen) uyması gerekir.

Bu çalışmada, Kimya Mühendisliği Bölümü öğretim üyesi Prof. Dr. Nalan Kabay'ın çalışma grubu tarafından Su Ürünleri Fakültesi'nin Urla'daki laboratuarlarında, kurulu olan ters ozmos sistemiyle deniz suyundan elde edilen suyun kalitesi çeşitli analitik yöntemler kullanılarak incelenmiş ve su kriterlerine uygunluğu değerlendirilmiştir. Ayrıca, ters ozmos sisteminde kullanılan iki ayrı membranın performansları karşılaştırılmış, suyun üretimine ve kalitesine etki edebilecek ters ozmos parametreleri incelenmiştir.

Çalışmada, su örneklerinin katyon analizleri Varian 10 Plus Model Atomik Absorpsiyon Spektroskopisi kullanılarak yapılmıştır. Anyon derişimleri Shimadzu IC-Ai model İyon Kromotografi cihazı kullanılarak saptanmıştır. Su örneklerindeki karbonat ve bikarbonat iyonlarının analizlerinde titrasyon yöntemi kullanılmıştır. Bulanıklık ölçümleri, arazi tipi Micro TPI türbidimetre cihazı kullanılarak yapılmıştır.

Anahtar sözcükler: Deniz Suyu, Desalinasyon, İçme Suyu, Sulama Suyu, Ters ozmos.

ABSTRACT

QUALITY ANALYSIS OF WATER PRODUCED FROM SEAWATER BY REVERSE OSMOSIS METHOD-STUDYING THE EFFECT OF MEMBRANE TYPE ON WATER QUALITY

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Water is the most important life sources for all of the living organizms. Nowadays, many countries have fresh water problems because of environmental pollution which occurs due to increasing population, improved industry and contaminants. Because of these problems which increase day by day, attention has increased to alternative water resources. Recently, using water produced from seawater by reverse osmosis method as drinking and irrigation water, has been popular.

In order to use water produced from seawater by reverse osmosis, this water should be suitable according to drinking and irrigation water criteria (which is determined by World Health Organization-WHO, Turkish Standards Institute-TSE and Environmental Protection Agency-EPA)

In this study, quality of water produced from RO system established by Prof.Dr. Nalan Kabay's research group at the laboratories of Faculty of Fisheries of Ege University at Urla, was investigated using various analytical methods and evaluated according to water criteria. Additionally, two different membranes which were used at reverse osmosis system, were compared for their performances. Reverse osmosis parameters such as applied pressure and temperature which affect performances of water production and water quality were investigated.

In this study, cation analyses of water samples were analyzed by Varian 10 Plus Model Atomic Absorption Spectrophotometer. Anion concentrations of water samples were determined with Shimadzu IC-Ai model ion chromatography equipment. For the analyses of carbonate and bicarbonate ions in water samples, titration method was used. Turbidity measurement were performed by Micro TPI Field Portable Turbidimeter.

Keywords: Desalination, Drinking Water, Irrigation water, Reverse Osmosis, Seawater.

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Seyhan SOLAK

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CHAPTER ONE

1. INTRODUCTION

1.1 Water

Water covers about three-quarters of Earth's surface and is a necessary element for our life. During their constant cycling between land, the oceans, and the atmosphere, water molecules pass repeatedly through solid, liquid, and gaseous phases (ice, liquid water, and water vapor), but the total supply remains fairly constant. A water molecule can travel to many parts of the globe as it cycles (Adekalu et al., 2002)

Water, one of the most common substances in the world, covers a substantial part of the earth’s surface. It fills the oceans, rivers and lakes. It is in the ground and in the air. It is interesting to note that there is hardly enough water to drink and meet other basic needs such as washing, cooking, bathing, etc. Wilson (1978) gives the total amount of water on earth as 1360 million km^3 but only 4 million km^3 (or 0.3%) is available for human use as fresh water in rivers, streams, springs and aquifers. The remaining 1356 million km^3 (or 99.7%) is locked in seas and oceans (Adekalu et al., 2002).

Water makes up approximately two thirds of the body’s weight and approximately 75 percent of the brain’s weight. Nearly 4 percent of the water in the body is lost through the skin, lungs and through urine and stools each day. This water loss must be replaced continually by beverage and food consumption. Sweating causes greater water loss and increases the need to consume more fluids. Water loss resulting in as little as 1 percent decrease in body weight is called dehydration. Dehydration will reduce the body’s ability to perform physically and mentally. Infants and children can quickly become dehydrated; therefore, it is critical they consume adequate fluids. Water is so important to well-being that you can only live a few days without it (Convertino et al., 1996).

Why Is Water So Important? It makes up a large part of the body and plays a role in nearly every function of the body:

- Water is essential for the body to cool itself. The inability of the body to cool itself will result in heat cramps, heat exhaustion or a heat stroke.
- Water is needed for digesting, absorbing and transporting nutrients.
- Water is a lubricant for joints and cushions vital organs and tissues. It is important for healthy mucus membranes in the lining of the mouth, lungs, nose and intestines.
- Water helps prevent constipation (and possibly reduce the risk of colon cancer) by adding bulk to feces and moving it through the colon faster. Getting enough fluid is critical with a high-fiber diet to keep the bowels functioning properly.
- Water is critical for health because it carries waste products from cells so the waste can be excreted from the body (Convertino et al., 1996).

1.2 Water Scarcity in the World

One of the most important problems nowadays, which is becoming more and more acute, is the scarcity of fresh water of adequate quality for human consumption, and for industrial and agricultural use (Raluy et al., 2006). Agriculture uses two-third of available fresh water. The proportion of irrigated surface should increase by 1/3 in 2010 and by 50% in 2025. Industrial and domestic water use increases at twice the rate of population increase. Water consumption increased sevenfold since 1900. In total, water demand doubles every 20-year. Fresh water resources are almost completely exhausted in many Middle-East countries (Eltawil et al., 2009).

The World Health Organization has stated that 80% of all known diseases are related to water borne diseases, and more than 1 billion people worldwide lack safe drinking water. The increasing world population, together with increasing industrial and agricultural activities, has led to excessive exploitation of available water resources and pollution of fresh water resources. Hence, although the total quantity of water on the earth remains constant, the fresh water supply is becoming more and more scarce (Raluy et al., 2006). Owing to the foreseen growth of population worldwide (especially in the developing countries), the above situation will be more and more critical over the next two decades or so (Eltawil et al., 2009).

Freshwater is a scarce resource in many parts of the world (Figure 1.1) and its future availability is predicted to be even more limited, posing a serious concern for future generations. The United Nation's World Health Organisation estimates that at least 1.1 billion people do not have access to clean drinking water and this could potentially rise up to 3 billion by 2025, posing an even greater threat for future generations (Forstmeier et al., 2007).

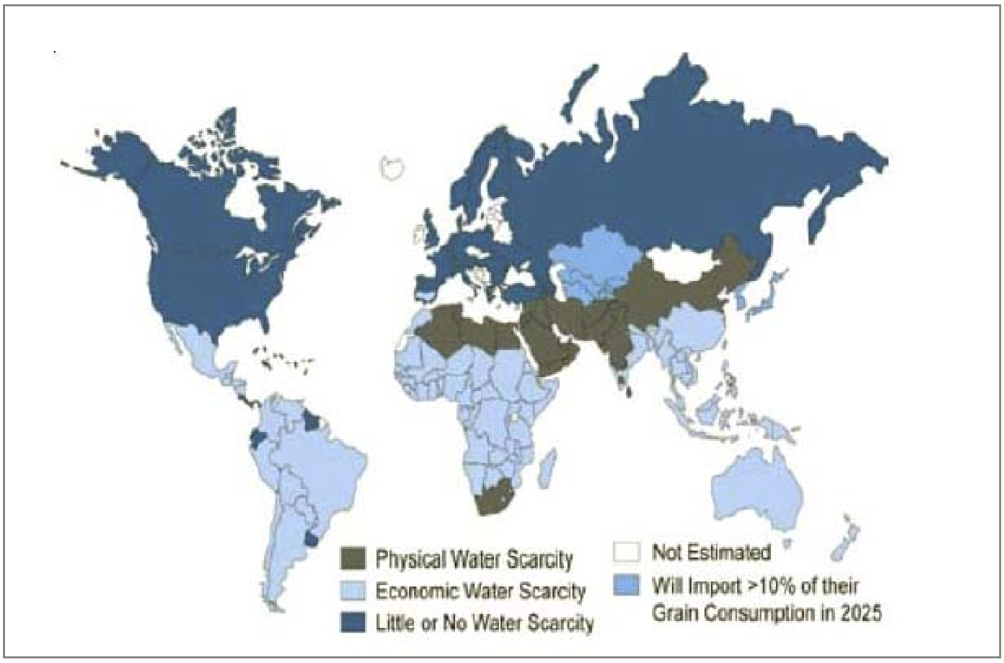

Figure 1. 1 Worldwide water scarcity issues (Forstmeier et al., 2007)

Today, about three billion people around the world have no access to clean drinking water. According to the World Water Council, by 2020, the world will be about 17% short of the fresh water needed to sustain the world population. Moreover, about 1.76 billion people live in areas already facing a high degree of lacking water. The need for fresh water is at the top of the international agenda of critical problems, at least as firmly as climate change. As a consequence of the growing scarcity of freshwater, the implementation of desalination plants is increasing on a large scale (Charcosset, 2009).

1.3 Water Sources

Water is a basic need for life on Earth and is used for many purposes. In recent years awareness has risen that the “precious blue” is a finite and vulnerable resource and is likely to have a decisive impact on the future development of human societies. The total amount of renewable freshwater available from precipitation on the earth surface stayed roughly constant over the last hundred years, whereas the water use for human needs multiplied sixfold, mainly due to raising water demand for food production and industrial activities (Zehnder et al., 2003).

Water is one of the most abundant resources on earth, covering three fourths of the planet’s surface. About 97% of the earth’s water is salt water in the oceans and 3% (about 36 million km^3) is fresh water contained in the poles (in the form of ice), ground water, lakes and rivers, which supply most of human and animal needs. Nearly, 70% from this tiny 3% of the world’s fresh water is frozen in glaciers, permanent snow cover, ice and permafrost. Thirty percent of all fresh water is underground, most of it in deep, hard-to-reach aquifers. Lakes and rivers together contain just a little more than 0.25% of all fresh water; lakes contain most of it (Kalogirou, 2005).

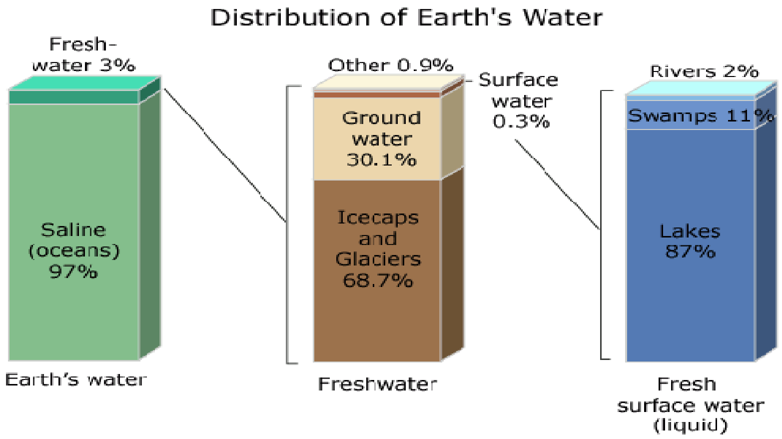

Figure 1. 2 Distribution of Earth’s Water (http://ga.water.usgs.gov)

1.3.1 Ground Water

Groundwater is water located beneath the ground surface in soil pore spaces and in the fractures of lithologic formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table. Groundwater is recharged from, and eventually flows to, the surface naturally; natural discharge often occurs at springs and seeps, and can form oases or wetlands. Groundwater is also often withdrawn for agricultural, municipal and industrial use by constructing and operating extraction wells. The study of the distribution and movement of groundwater is hydrogeology, also called groundwater hydrology. (Sophocleous, 2002).

Typically, groundwater is thought as liquid water flowing through shallow aquifers, but technically it can also include soil moisture, permafrost (frozen soil), immobile water in very low permeability bedrock, and deep geothermal or oil formation water. Groundwater is hypothesized to provide lubrication that can possibly influence the movement of faults. It is likely that much of the Earth's subsurface contains some water, which may be mixed with other fluids in some instances. Groundwater may not be confined only to the Earth. The formation of some of the landforms observed on Mars may have been influenced by groundwater. There is also evidence that liquid water may also exist in the subsurface of Jupiter (Sophocleous, 2002).

1.3.2 Surface Water

Surface water refers to water found on the surface of the earth. Lakes, rivers, streams and wetlands are all examples of surface water. Surface waters are one of the most important natural resources to humans, wildlife, and the environment. Because they are open, easily accessible, and heavily used in industry, agriculture and municipal facilities, surface waters are vulnerable to pollution, particularly contamination from chemical spills (www.wikipedia.com).

1.3.3 Seawater

The oceans represent the earth's major water reservoir. About 97% of the earth's water is seawater while another 2% is locked in icecaps and glaciers. Available fresh water accounts for less than 0.5 % of the earth's total water supply. Vast reserves of fresh water underlie the earth's surface, but much of it is too deep to access in an economically efficient manner. Additionally, seawater is unsuitable for human consumption and for industrial and agricultural uses. By removing salt from the virtually unlimited supply of seawater, desalination has emerged as an important source of fresh water (Khawaji et al., 2008).

Seawater contains almost all elements from hydrogen far down to uranium and is composed of 96.7% water and 3.3% dissolved salts. Seven elements (Na, Mg, Ca, K, CI, S) for 93.5% of the dissolved salts (Ohya et al., 2001).

Seawater contains high concentrations of salts. It has electrical conductivity (EC) levels of around 55 dSm^{-1} (total dissolved solids 35,000 mg L^{-1}) and sodium (Na^{+}) concentration of more than 450 mmol L^{-1} (10,400 mg L^{-1}). Without treatment to reduce its salt content, humans or animals cannot use seawater directly for consumption, as this would severely affect their health; nor can untreated seawater be used to produce crops. The same is true of highly brackish groundwater containing elevated levels of various types of salts (Qadir et al., 2007).

1.3.3.1 Salinity of seawater

The fact that more than 70% of the Earth surface is covered by seawater has long made man aware of its properties and uses, namely the considerable amount of dissolved salts, which is economically exploited from evaporation of seawater under the action of wind and sun. Since Robert Boyle published "Observations and Experiments on the Saltiness of the Sea" in 1674 scientific information has progressively increased. In 1865 George Forchammer introduced the term salinity (S) for the total amount of dissolved salts as grams in one kilogram of seawater. Unrefined sea salt contains 98.0% sodium chloride (NaCl) with the remaining 2.0% of other salts, mostly below levels detectable by chemical analysis. In 1884

Wilhelm Dittmar advanced the law of constant proportions of the seven major elements of seawater, besides hydrogen and oxygen, i.e. sodium, calcium, magnesium, potassium, chloride, bromide and sulphate (Table 1.1) (Gros et al., 2008).

Table 1. 1 Relative proportions of dissolved salts in water (Castro and Huber's, 2008)

Chemical Ion Contributing to Seawater Salinity	**Concentration in ‰ (parts per thousand) in average seawater**	**Proportion of Total Salinity (no matter what the salinity)**
Chloride	19.345	55.03
Sodium	10.752	30.59
Sulfate	2.701	7.68
Magnesium	1.295	3.68
Calcium	0.416	1.18
Potassium	0.390	1.11
Bicarbonate	0.145	0.41
Bromide	0.066	0.19
Borate	0.027	0.08
Strontium	0.013	0.04
Fluoride	0.001	0.003
Other	less than 0.001	less than 0.001

Most of the water available on earth has the salinity up to 10,000 ppm whereas seawater normally has salinity in the range of 35,000–45,000 ppm in the form of total dissolved salts. According to World Health Organization (WHO), the permissible limit of salinity in water is 500 mg/L and for special cases it goes up to 1000 mg/L (Eltawil et al., 2009)

In Table 1.2, salt concentration of seas change depends on position of the seas.

Table 1. 2 Salt concentrations of the seas in the world (Uludağ Universitesi, Mühendislik-Mimarlık Fakültesi Dergisi, 2002)

SEA	Salt Concentration (‰)
Standard sea water	35
Baltic Sea	7
The Caspian Sea	13
Pacific Ocean	34
Atlantic Ocean	36
Red Sea	43
Persian Gulf	43
Black Sea	18
Marmara Sea	22
Aegean Sea	38
Mediterranean Sea	43

1.3.3.2 Desalination of seawater in the world

Water shortage has become a big problem in many parts of the world. Following an increase in population and consumption, the fast growth of the economy and the serious situation of water pollution, the conflict between water supply and demand is aggravated day by day. The scarcity of fresh water is a serious threat to the socioeconomic development of the world. More and more people begin to pay attention to the ocean, which covers about 70% surface of our earth and contains the largest resource of fresh water. Desalination technologies, can be utilized to produce fresh water for industry, agriculture and human consumption (Xie et al., 2009).

Desalination is increasingly used worldwide to supplement (or replace) existing conventional water sources in water scarce areas. Currently, less than 3% of the world's total water requirements are met by desalination. Given the World Water Council's prediction of water shortages by 2025 there exists potential for increased use of this process (Wittholz et al., 2008). Over the past 20 years or so, desalination has become a reliable and convenient method for water production in many arid regions around the world. A number of trends in technologies for desalination has resulted in a significantly lower cost for the water that is produced (Bruggen, 2003).

The first countries to use desalination on a large scale for municipal drinking water production were in the Middle East (Greenlee et al., 2009). Desalination has become a major source of fresh water in the Middle East and North Africa, especially in the Arabian Gulf countries. Many other countries utilize or will utilize desalination to obtain fresh water due to the limited natural resources of potable water and the rapid increase in water consumption. Recently about 65% of desalination plants that are in operation worldwide are located in the Arabian Gulf countries (Al-Mutaz, 2001).

Today, over 15,000 desalination plants are in operation worldwide, and approximately 50% of those are reverse osmosis (RO) plants. The Middle East holds approximately 50% of the world's production capacity (and 2.9% of the world's population) and has forged ahead as the leader in large-scale seawater desalination. In 2005, Israel opened the world's largest seawater RO desalination plant, with a production capacity of 330,000 m^3/day, or 100 million m^3/yr (Greenlee et al., 2009).

1.4 Desalination Processes

Desalination is a water treatment process that removes salts or other dissolved minerals and contaminants such as dissolved metals, radionuclides, bacterial and organic matter from high salinity water to produce fresh water. Desalination is used to improve the quality of hard waters (high in concentrations of magnesium and calcium), brackish waters (moderate levels of salt) or seawater (Alghoul et al., 2009).

Desalination processes involve saline feed water (brine), low-salinity product water (fresh water) and very saline concentrate (reject water). Saline feed water (water before the desalination process) will be separated into two products:

fresh water and water with high concentration of salts or brine, after it goes through the desalination process (Alghoul et al., 2009).

Desalination processes fall into two main categories, thermal processes and membrane processes. Besides, there are ion exchange method, evaporation, as shown in Figure 1.3. Thermal desalination includes multi-stage flash (MSF), multi-effect distillation (MED), vapor compression (VC) and membrane distillation (MD). In the membrane desalination, the reverse osmosis (RO) and electrodialysis (ED) are technologies used frequently (He and Yan, 2009).

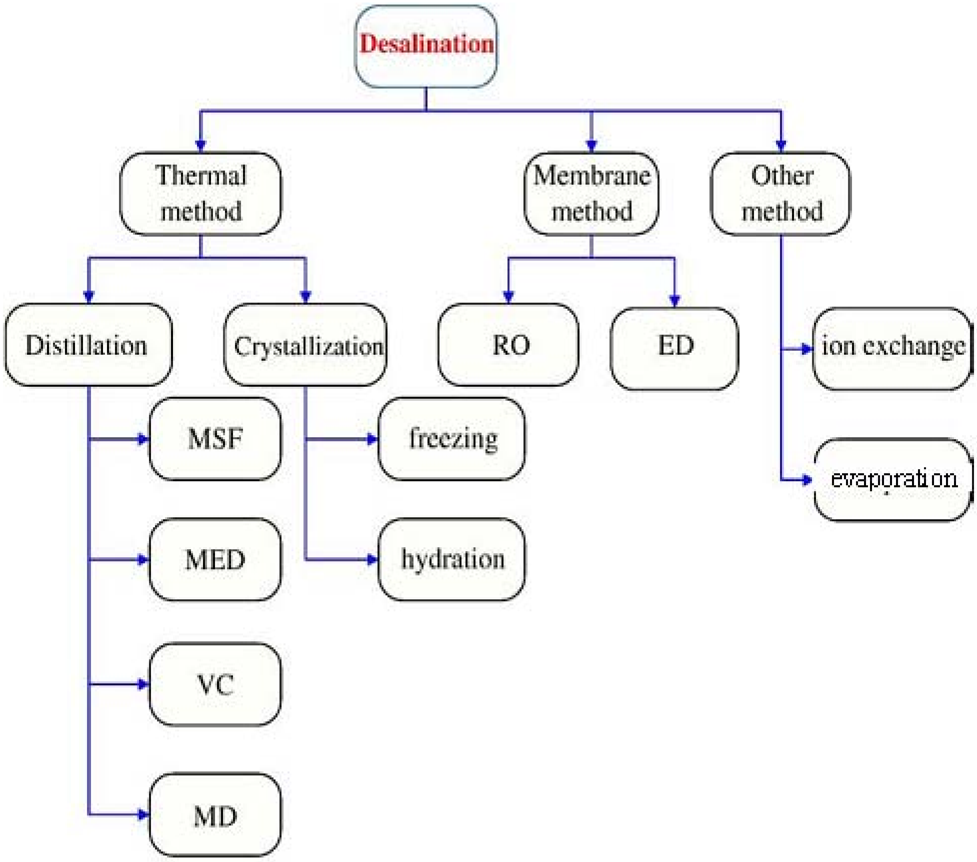

Figure 1. 3 Schematic diagram of the main desalination processes (He and Yan, 2009).

Both membrane and thermal processes appear to be equally popular. However, the extent of popularity differs among various technology variants under these basic processes, i.e. among thermal processes, multi-stage flash evaporation technology is most popular, while among membrane processes, Reverse Osmosis (RO) is the most preferred technology as shown in Figure 1.4 (Water Desalination project, 2009).

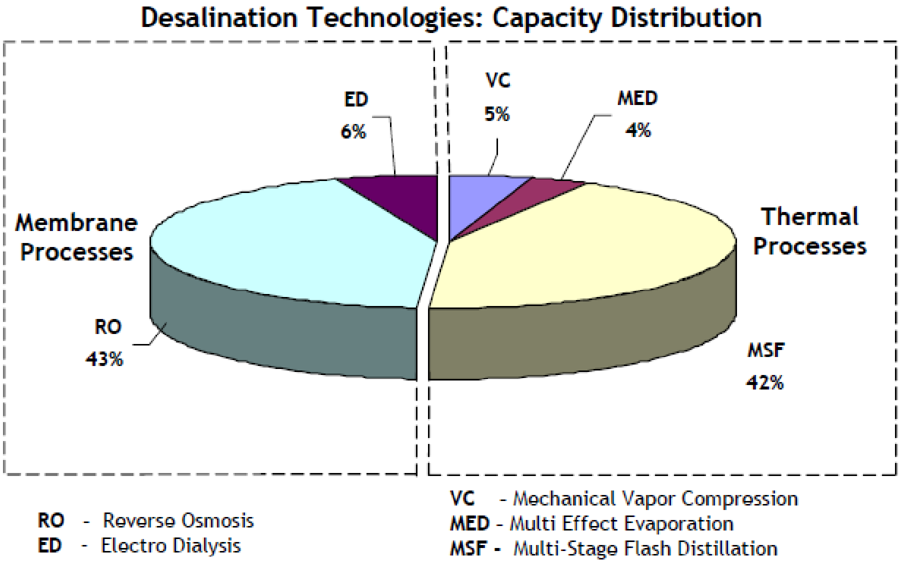

Figure 1.4 Global distribution of installed desalination capacity by technology (Macdonald, 2009).

Desalination has been a practical solution to the water shortage problems encountered in many countries of the world, in particular, in semi-arid regions as well as in countries with high population density. Over the decades, numerous commercial-scale desalination plants have been designed, built and operated, such as the multi-stage flash (MSF) type, the multi-effect desalination type, the membrane-based reverse osmosis (RO) plants. More recent improvements include the hybrid plants, which combine the RO and MSF processes, could recover higher quality and yield of water with typical dissolved solids of less than 500 mg/L as required by the World Health Organization (WHO) standards. Ion exchange is another method whereby ions of dissolved inorganic salts are chemically replaced with the more desirable ions, and such a process has been used to minimize the fouling and carry-over to the water. Electrodialysis (ED) or electrodialysis reversal (EDR) is deemed as one of the most promising techniques; however, the expected breakthrough has yet been realized (Wang and Choon Ng, 2005)

1.4.1 Membrane Desalination Process

Reverse osmosis (RO), nanofiltration (NF), and electrodialysis (ED) are the three membrane processes available for desalination. ED membranes operate under an electric current that causes ions to move through parallel membranes and are typically only used for brackish water desalination. NF is a new technology developed in the mid-1980s and has been tested on a range of salt concentrations. Research has shown that NF, as a singular process, cannot reduce seawater salinity to drinking water standards, but NF has been used successfully to treat mildly brackish feed water. Reverse osmosis is employed for seawater and brackish water desalination while electrodialysis is used only for brackish water desalination. Coupled with RO, NF can be used to treat seawater. In particular, NF membranes are used to remove divalent ions, such as calcium and magnesium that contribute to water hardness, as well as dissolved organic material (Greenlee et al., 2009).

The major challenge in the membrane desalination processes is the scaling and fouling of membranes. More efforts are needed to overcome this problem by understanding the basic mechanism that is responsible for their formation. There is a need to develop improved membranes, which would be less susceptible for scaling and fouling with high salt rejection. Parameters that are responsible for scaling and fouling must be identified to develop better feed pretreatment processes and to establish better operating conditions. Improved anti-scaling and anti-fouling chemicals are thus required. Other challenges include developing membranes that can withstand high-pressure operation and tolerate chlorine (Quteishat et al., 2003).

Devices for recovering the energy from the reject brine of reverse osmosis process play a major role in lowering the energy consumption of this process. Recently, highly efficient pressure exchangers have been introduced in the commercial plants in place of conventional turbines for energy recovery, which resulted in significant reduction in the energy consumption. However, they are yet to prove their robustness and service life. A current topic of interest is the application of membrane filtration processes in place of the conventional pretreatment for the pretreatment of feed to reverse osmosis process. But this alternative has still to prove its technical and economical benefits. There is also a scope to improve module and process design of membrane desalination processes (Quteishat et al., 2003).

1.4.1.1 Reverse Osmosis

Reverse osmosis (RO) membrane processes are among the most important and versatile water treatment technologies for the 21st century. Reverse osmosis technology is used around the world for production of ultra-pure, potable, and process waters in addition to water recycling and resource recovery (Hoek et al., 2008).

Reverse osmosis is capable of rejecting nearly all colloidal or dissolved matter from an aqueous solution, producing a concentrate brine and a permeate which consists of almost pure water. Although reverse osmosis has also been used to concentrate organic substances, its most frequent use lies in seawater desalination applications. Reverse osmosis is based on a property of certain polymers called semi-permeability. While they are very permeable for water, their permeability for dissolved substances is low. By applying a pressure difference across the membranes the water contained in the feed is forced to permeate through the membrane. In order to overcome the feed side osmotic pressure, fairly high feed pressure is required. In seawater desalination, it commonly ranges from 55 to 68 bar (Fritzmann et al., 2007).

In recent years, reverse osmosis (RO) has gained considerable importance because of the advantages this technology offers compared to the thermal water desalination techniques. They include low energy requirements, low operating temperature, modular design and low water production costs (Abbas, 2006). Its ability to reject nearly all contaminant ions and most dissolved non-ions, small space requirements, modular type construction. The removal of most of the total dissolved solids (TDS) gives RO the broadest treatment range and the best water quality (Ozturk et al., 2008).

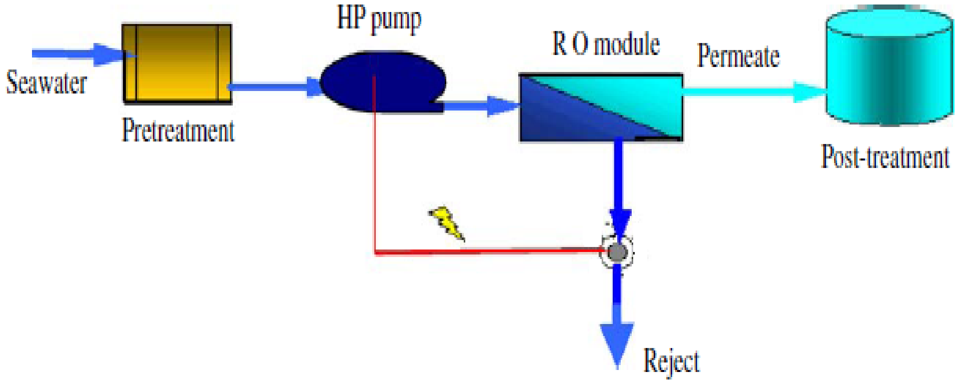

Figure 1. 5 Block diagram of reverse osmosis operations (HP:high pressure pump) (Raluy et al., 2006)

A typical RO plant is shown in Figure 1.5. The seawater passing through the modules is not completely desalted, part is rejected as brine. Before being returned to sea, the mechanical energy of brine is used in energy recovery systems, which achieved a significant energy saving.

RO has more and more extensive application in the desalination process of water treatment. Advanced RO facilities recently developed for energy recovery or minimizing RO energy consumption using the pressure exchange and system design of operate condition optimization technology.

The disadvantages of RO are (1) high power costs; (2) high maintenance expenses; (3) frequent membrane monitoring (the membranes can lose approximately 30–50% of their flux capacity during the operating period) (Bick and Oron, 2005).

Principle of Reverse Osmosis

Osmosis occurs when a semi-permeable membrane (permeable to water and not to the solute) separates two aqueous solutions of different concentration. At equal pressure and temperature on both sides of the membrane, water will diffuse (“permeate”) through the membrane resulting in a net flow from the dilute to the more concentrated solution until the concentrations on both sides of the membrane become equal. (Fritzmann et al., 2007) (Figure 1.6).

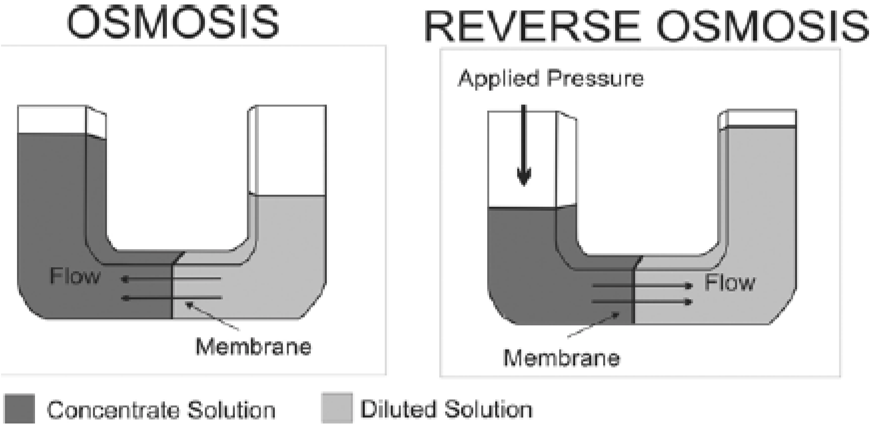

Figure 1. 6 Schematic presentation of osmosis and reverse osmosis. Left: osmosis;right: reverse osmosis (Fritzmann et al., 2007)

This process will also take place if the pressures on both sides are different, as long as the pressure difference Δp between the concentrated side and the dilute side is not larger than a certain value that depends upon the difference of the respective concentrations and is called the osmotic pressure difference $\Delta\Pi$. If the differential pressure Δp is larger than $\Delta\Pi$, the direction of flow is reversed and water flows from the concentrate to the dilute side. This process is called RO. In water desalination, the feed side is operated under elevated pressure and the solute concentration on the permeate (dilute) side is negligible compared to the feed concentration. In this case, permeate flow is observed, as long as the differential pressure exceeds the osmotic pressure Π_F of the feed solution (Fritzmann et al., 2007).

Osmotic pressure:

Thermodynamically, the osmotic pressure is defined as:

$$\pi = -\frac{R \cdot T}{V_b} \ln(x_w) \tag{1.1}$$

with the osmotic pressure π, the molar volume of water *Vb,* the mole fraction of water *xW* and the ideal gas constant *R*. In dilute solutions, the osmotic pressure can be estimated using van t'Hoff's law, which is of the same form as the ideal gas law:

$$\pi = \frac{n_s}{V} R \cdot T \qquad \text{or} \qquad \pi = C \cdot R \cdot T \tag{1.2}$$

with the total amount of solutes in solution *ns* [moles], total concentration of solutes *C* [moles/L] and the volume of solvent *V.*

Taking into account non-ideality and dissociation of the ions in solution, vant'Hoff's law can be rewritten as

$$\pi = i\phi C \cdot R \cdot T \tag{1.3}$$

with *i* representing the dissociation parameter, which is equal to the number of ions and molecules per mole of solute produced by dissolution of the solute and Φ representing a correction factor that takes into account non-idealities (Fritzmann et al., 2007).

The Stage of Reverse Osmosis

The process includes the following stages: (Fritzmann et al., 2007).

- Water abstraction
- Pre-treatment
- Pumping system
- Membrane separation unit
- Energy recovery system
- Post-treatment
- Control-system

The abstraction of feed water can be realised either through coast- and beach wells or through open seawater intake systems. Coast and beach wells provide better quality water with less turbidity, algae and total dissolved solids than open seawater intakes, but require more space. In brackish water desalination, wells areused to abstract feed water. Pre-treatment includes all activities to adjust the intake water in constitution and pH-value. Particulate matter is removed from the feed-water and chemicals are added to prevent scaling and fouling. The pumping system is required to overcome height differences within the distribution chain and to apply the necessary pressure to the feed. The membrane is capable of separating salt from water with a rejection of 98–99.5%, depending on the membranes in use. The energy recovery system is responsible for the transfer of potential energy from the concentrate to the feed. Current energy recovery systems such as work exchangers operate with efficiencies of up to 96%. In post-treatment permeate is re-mineralised, re-hardened, disinfected by chlorination and adjusted to drinking water standards. A control system maintains a continuous and reliable production (Fritzmann et al., 2007).

Reverse osmosis membranes

RO membranes are able to reject monovalent ions, such as sodium and chloride. Today, seawater RO membranes have salt rejections greater than 99%; some membranes, when operated under standard test conditions (32,000 mg/L NaCl, 5.5 MPa, 25°C, pH 8, 8% recovery), can achieve as high as 99.7–99.8% salt rejection. Although most seawater sources contain 30,000–45,000 mg/L TDS, seawater reverse osmosis membranes are used to treat waters within the TDS range 10,000 – 60,000 mg/L. RO membrane technology has been developed for seawater applications. Seawater RO membranes require maximum salt rejection. Membranes designed for higher salt rejection, have lower permeate fluxes, due to the trade-off between membrane selectivity (salt rejection) and membrane permeability (permeate flux). In addition, seawater RO membranes must operate at higher pressures to compensate for the higher osmotic pressure of seawater. (Greenlee et al, 2009).

The new high rejection and high flow membranes made conversions to 55-60% economically feasible. This can be ascribed to the permitted operating at high pressures (up to 80–90 bars). Hydraulic efficiency of this type of equipment ranged from 90–94%. All of these technologies have resulted in minimizing RO system capital and operating costs (He and Yan, 2009).

RO membranes for desalination generally come in two types: Spiral wound (Figure 1.7) and hollow fiber. Spiral wound elements are actually constructed from flat sheet membranes. Membrane materials may be made of cellulose acetate or other composite polymers. Another type of membrane is the hollow fiber design which places a large number of hollow fiber membranes in a pressure vessel. The pressurized saline water is introduced into the vessel along the outside of the hollow fibers. Under pressure, desalinated water passes through the fiber walls, and flows in the hollow fibers for collection. This type of design is not as widely used now as the spiral wound membranes for desalination.

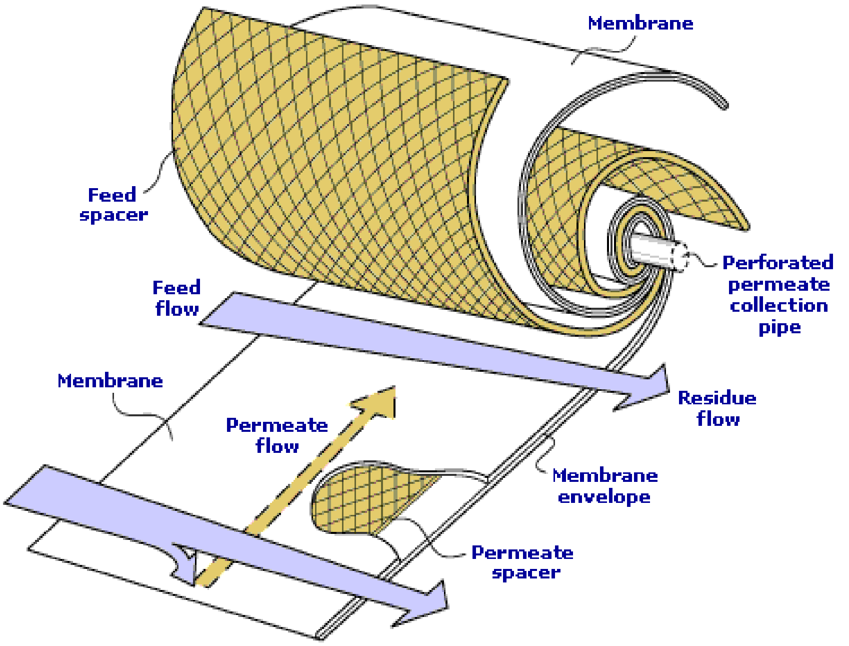

Figure 1.7 Flow through a spiral wound module (Membrane Technology and Research-www.mtrinc.com)

1.5 Using seawater as irrigation water

Agriculture is the largest single user of water, with about 75% of the world's freshwater being currently used for irrigation. In some countries, irrigation accounts for as much as 90% of the total amount of water available. Given that water productivity in agriculture continues to be low and that improvements are only being made very slowly, and that freshwater has always been an integral component of food production, it is obvious that huge amounts of water will be required to produce enough food for the future population of the world. In addition, urbanization and increasing populations in water-deficient countries increase the demand for freshwater. This results in competition among different water-use sectors and, often, in less freshwater being allocated to agriculture. Such priority-setting results from the fact that, at all times, public needs and people's health have to be protected through the use of the best quality water available. The phenomenon of agriculture having to yield part of its share of the freshwater available is expected to intensify in those less-developed, arid and semi-arid countries and regions that are already suffering water, food, sanitation, and health problems (Qadir et al., 2007).

Besides drinking, hygiene and shelter, food is also an essential need of people. Food production needs much more water than is generally appreciated. During growth, the plant consumes water. Most of it is evapotranspired. For the production of about two kilograms of dry wheat plant material roughly 1 m^3 of water is needed under optimally controlled conditions with all nutrient supplied in sufficient amounts. Two kilograms of dry wheat plant contains approximately one kilogram of grains. Thus, based on grain weight, the water-use efficiency or water productivity is 1 kg m^{-3}. The water-use efficiency varies from plant to plant but is for other cereals on the average similar to wheat (Zehnder et al., 2003).

1.5.1 Quality of irrigation water

Water is one of the most important inputs for realising and sustaining high agricultural production. However, its management (transportation to the farm, method and frequency of irrigation) and quality are intimately related to the development of waterlgging and soil salinity (Chhabra, 1996).

In most cases, excess salts, leading to soil salinisation, may be attributed to the weathering products accumulated in the soil (primary salinisation). However, under arid and semi-arid conditions, irrigation water may be instrumental in accumulation of salts in the rootzone that were originally equally distributed in the soil profile or localised in deeper layers, thus causing development of soil salinity. This phenomenon, known as secondary salinisations, is the major cause of decreased production on introduction of irrigation in many parts of the world (Chhabra, 1996).

Under certain situations, such as near the sea coast or where underground water is used for irrigation, water itself can be a source of salt and leads to development of soil salinity. In general, the assessment of water quality criteria is based on the consideration of two related aspects, i.e., the possible effects on the physico-chemical properties of soil and the impact on the crop yield. The main criteria for assessing the quality of water irrigation are salinity (Table 1.3), sodicity hazards and specific ion effects (Chhabra, 1996).

The most important criterion regarding salinity and therefore of water availability to the plant is the total salt concentration. From the EC (electricial conductivity) values, the total salt concentration can be calculated using the following formula, equation: (me/L:miliequivalent per liter)

$$\text{Salt concentration me/L} = \frac{\text{EC}(\mu\text{S/m})}{100} \tag{1.4}$$

Table 1. 3 Salinity Hazards of Irrigation Waters (Chhabra, 1996).

EC of irrigation waters, µS/m	**Salinity**	**Salinity hazards**
100-250	C_1	very low
250-750	C_2	Low
750-2250	C_3	Medium
2250-5000	C_4	High
>5000	C_5	Very high

In addition to total salinity, the tendecy of irrigation water to generate excessive levels of exchangeable sodium, which adversely affect the soil physicochemical properties, needs to be considered. The useful parameter for expressing the sodium hazards of irrigation wters, sodium adsorption ratio (SAR) is calculated from following equation: (Chhabra, 1996).

$$\text{SAR}= \frac{\text{Na}^+}{\sqrt{[(\text{Ca}^{2+}+\text{Mg}^{2+})/2]}} \tag{1.5}$$

In addition to salinity and sodicity hazards, crops may get affected by low to moderate and high concentration of certain ions (such as calcium, potassium, magnesium, chloride, sulphate, lithium, boron…) that may cause specific toxic symptoms and/or nutritional disorders (Chhabra, 1996). Classification of saline irrigation water quality levels are given in Tables 1.4.

Table 1.4 Irrigation Water Quality Classes (Gokçay, ODTÜ, Çevre Mühendisliği Bölümü)

Irrigation Water Quality Criteria	**Water Quality Class**				
	Class 1 (excellent)	**Class 2 (good)**	**Class 3 (permissible)**	**Class 4 (doubtful)**	**Class 5 (unsuitable)**
Conductivity	0-250	250-750	750-2000	2000-3000	>3000
pH	5.8-6.5	6.5-8.5	6.5-8.5	6.5-9	<6.0 or >9.0
Temperature(˚C)	30	30	35	40	>40
TDS(mg/L)	500	1500	5000	>5000	No guideline
Sodium Adsorbtion Ratio(SAR)*	3	3-5	5-10	10-15	>15
Chloride (mg/L)	0-140	140-250	250-420	420-710	>710
Sulphate (mg/L)	0-190	190-330	330-575	575-960	>960
Total Salts (mg/L)	0-175	175-525	525-1400	1400-2100	>2100
Boron	0-0.5	0.5-1.12	1.12-2	>2	No guideline
F^- (mg/L)	1	1.5	2	>2	No guideline
% Na	<20	20-40	40-60	60-80	>80
Fekal Koliforms/100 mL	0-2	2-20	20-100	100-1000	>1000
BOD (mg/L)	0-25	25-50	50-100	100-200	>200
NO_3^- or NH_4^+ (mg/L)	0-5	5-10	10-30	30-50	>50
Na^+ (mg/L)	50-125	125	250	>250	No guideline
Ca^{2+} (mg/L)	40-100	No guideline	No guideline	No guideline	No guideline
Mg^{2+} (mg/L)	30-50	No guideline	No guideline	No guideline	No guideline

1.6 Using Seawater as Drinking Water

Drinking water is a basic requirement. The daily need for a person is between 3 and 9 liter, depending on the climatic conditions. As a consequence each person needs annually between 1 m^3 and 3 m^3 of highest quality water. This water has to be free of pathogenic organisms, harmful chemicals, low in inorganic salts, and should not contain odorous compounds. The detailed quality is defined by the World Health Organization in its Guidelines for Drinking-Water Quality (1993, 1998) (Zehnder et al., 2003).

Drinking water requirements according to different drinking water legislations (WHO,EPA,TSE) are listed in Table 1.5.

Table 1. 4 Drinking water requirements (WHO's Guidelines for Drinking-water Quality, EPA, Europe Polution Agency drinking water standards, Turkish Standards Institute drinking water standards, 2010)

Parameters	**WHO**	**EPA**	**TSE**
Total Dissolved Solids (mg/L)	1000	500	1500
Electrical conductivity (µS/cm)	500–800	No guideline	2500
pH	6.5-8.8	6.5-8.5	6.5-9.2
Turbidity (NTU)	<0.5	<1	<1
SO_4^{2-} (mg/L)	250	250	250
Boron (mg/L)	0.5	No guideline	No guideline
Cl^- (mg/L)	250	250	600
Ca^{2+} (mg/L)	75	No guideline	100-200
Mg^{2+} (mg/L)	30	No guideline	50
K^+ (mg/L)	No guideline	No guideline	12
Na^{2+} (mg/L)	200	No guideline	175
Arsenic (µg/L)	10	10	10
Iron (mg/L)	No guideline	0.3	0.3
Manganese(mg/L)	No guideline	0.05	0.05
Aluminum (mg/L)	No guideline	0.05 to 0.2	0.2
Nitrate (mg/L)	50	10	25

2. EXPERIMENTAL

2.1 Materials

2.1.1 Seawater

The seawater sample which is used for desalination by reverse osmosis method was obtained from seashore of Urla Bay, İzmir, Turkey. Characteristics of seawater were shown in Tables 2.1 and 2.2.

Table 2. 1 Characteristics of the feed seawater

Test Number	Seawater Temperature (°C)	Applied pressure (bar)	Conductivity (mS/cm)	TDS (mg/L)	Flow rate (L/h)	pH	Salinity (‰)
1	18.8	55	57.2	38715	269.4	8.1	37.9
2	17.5	55	57.5	38817	268.8	8.2	38.0
3	17.7	55	57.1	38613	270.0	8.1	37.8
4	17.5	55	57.2	38613	273.0	8.1	37.8
5	16.0	55	57.4	38408	271.2	8.1	37.6
6	10.8	55	57.7	38408	270.6	8.1	37.6
7	12.6	55	59.4	39532	264.6	8.2	38.7
8	12.3	55	59.0	39328	266.4	8.1	38.5
9	13.5	55	58.9	39430	268.8	8.2	38.6
10	13.9	55	58.7	39328	268.4	8.1	38.5
11	12.8	55	58.7	39226	267.6	8.1	38.4
12	13.2	55	58.4	39021	264.6	8.3	38.2
13	16.0	60	56.6	37796	276.6	8.4	37.0
14	16.0	62	56.8	38000	283.2	8.4	37.2
15	15.8	55	57.8	38715	268.2	8.4	37.9
16	20.4	55	57.4	38715	274.8	8.4	37.9
17	25.5	55	57.5	39124	276.0	8.3	38.3
18	25.6	55	58.0	39532	275.4	8.4	38.7
19	27.0	55	57.9	39634	276.0	8.4	38.8
20	24.8	55	58.6	39941	271.2	8.4	39.1
21	24.3	55	58.6	39941	270.6	8.4	39.1
22	22.0	55	58.8	39941	256.8	8.3	39.1
23	18.1	55	58.6	39430	265.2	8.1	38.8
24	15.0	55	58.5	39328	261.0	8.1	38.5

Table 2. 2 Ion concentrations of feed seawater

Test Number	**Seawater Temp. (°C)**	**Na^+ (mg/L)**	**Ca^{2+} (mg/L)**	**Mg^{2+} (mg/L)**	**K^+ (mg/L)**	**Cl^- (mg/L)**	**SO_4^{2-} (mg/L)**	**HCO_3^- (mg/L)**	**CO_3^{2-} (mg/L)**	**Turbidity (NTU)**
1	18.8	10110	514	745	840	24275.95	2877.07	123.34	0	0.34
2	17.5	11280	569	905	890	29970.93	3462.10	148.01	0	0.34
3	17.7	9920	451	976	522	22795.17	2798.46	180.70	0	0.36
4	17.5	10240	479	855	780	27606.67	3229.8	160.34	0	0.34
5	16.0	18330	500	955	719.5	23058.42	3169.74	160.34	0	0.27
6	10.8	10850	514.5	998	777	22855.93	2757.72	160.34	0	0.30
7	12.6	13960	415.5	789	605	27094.42	3438.87	135.57	0	0.29
8	12.3	10190	970.5	1351	658.5	28669.34	3605.30	148.01	0	0.51
9	13.5	10290	579	1309	705.5	23351.23	2995.52	123.34	0	0.46
10	13.9	13320	609.5	1365	756.5	27828.2	3617.12	135.68	0	0.54
11	12.8	17610	718	1008	943	26162.16	3368.46	129.51	0	0.43
12	13.2	11375	522	1088	619	28177.33	3624.86	160.34	0	0.44
13	16.0	14565	509.5	1479	702	26782.77	3500.89	154.18	0	0.46
14	16.0	16170	548	1364	617.5	27100.03	3576.92	148.01	0	0.47
15	15.8	17160	569	1251	679	24630.85	3005.54	148.01	0	0.52
16	20.4	12180	880	1072	595	24880.27	3082.51	154.18	0	0.60
17	25.5	10740	444.5	1211	620	27590.29	3443.42	172.68	0	0.31
18	25.6	13620	519	1536	714	25173.30	3013.7	160.34	0	0.30
19	27.0	12415	480	1424	711	26505.62	3037.20	172.68	0	0.35
20	24.8	13000	896	1584	831	27479.29	3697.36	166.51	0	0.34
21	24.3	18200	651	1325	712	24891.64	3336.76	172.68	0	0.31
22	22.0	14700	737	1043	762	23720.55	2770.93	172.68	0	0.42
23	18.1	16800	580	928	996	26183.26	3131.44	170.21	0	0.43
24	15.0	17850	510	776	670	25962.48	3042.23	175.15	0	0.34

2.1.2 Chemicals

All reagent used were analytical grade and high quality ultra pure water was used for preparing all solutions.

For cation analyses, standard solutions of Na^+, K^+, Mg^{2+}, Ca^{2+} were prepared from their salts in deionization water.

- NaCl (Merck)
- $CaCl_2$. $2H_2O$ (Merck)
- KCl (J.T.Baker)
- $MgCl_2.6H_2O$ (J.T.Baker)

Na_2SO_4 and NaCl were dissolved in ultra pure water for sulfate and chloride analyses.

- Na_2SO_4 (ANALAR)
- NaCl (Baker)
- Ultra pure water

Phenolphthalein and methyl orange indicator, HCl solution were used for carbonate and bicarbonate determination.

2.1.3 Membranes

The membranes used for reverse osmosis were SW30-2540 type Filmtec spiral-wound polyamide thin film composite membrane and high rejection membrane Filmtech XUS SW30XHR-2540. Properties of SW30-2540 membrane are shown in Table 2.3. The characteristics of high rejection SWRO membrane XUS SW30XHR-2540 were not provided by Dow Chem.Co.

Table 2.3 Properties of Filmtec SW30-2540 membrane

Membrane Type (SW30-2540)	Polyamide Thin-Film Composite
Maximum Operating Temperature	113°F (45°C)
Maximum Operating Pressure	1000 psi (69 bar)
Maximum Pressure Drop	15 psig (1.0 bar)
pH Range, Continuous Operation	2-11
Maximum Feed Silt Density Index	SDI 5
Free Chlorine Tolerance	<0.1 ppm
Active Area	29 ft^2 (2.8 m^2)
Maximum Feed Flow Rate	6 gpm (1.4 m^3/h)
Permeate Flow Rate[b]	700 gpd (2.6 m^3/d)
Stabilized Salt Rejection	99.4 %

2.2 Equipments

2.2.1 Reverse Osmosis Equipment

Desalination tests were performed using reverse osmosis (RO) system which was located in İzmir-Urla region.The RO system at Urla was shown in Figure 2.1.

Figure 2. 1 Reverse osmosis system at Urla, İZMİR

2.2.1.1 Desalination by Reverse Osmosis (RO)

Desalination tests were carried out with two membranes at different pressures (55, 60, 62 bar) and temperatures (10- 27°C).

First the feed tank was filled with seawater. Before RO tests, chlorination was performed to control biological fouling of the membranes and after that, residual chlorine was eliminated by addition of sodium metabisulphite in order to protect the membranes from oxidation. Free chlorine residual must be lower than 0.1 mg/L. After chlorination, raw seawater in the feed tank was transferred by low pressure pump to sand filter and cartridge filter, respectively. Colloidal fouling was partially controlled by filtering seawater through and cartridge filters. A proper antiscalant (PC100) and addition of HCl (in order to adjust pH) also helped the membranes be protected from scaling. Physically and chemically pretreated seawater was transferred to RO membranes via a high pressure pump in order to be desalinated. Two parallel mounted reverse osmosis membranes were used in the system. Membranes used (spiral wound FilmTecTM SW30-2540 and high rejection membrane XUS SW30XHR-2540) are produced commercially by Dow Chem.Co. Block diagram of the RO process was shown in Fig 2.2.

RO tests were performed for both short and long term periods. Experimental time for the short term studies were 90 minutes for both membranes and permeate samples were taken at for every 15 minutes. Long term studies were performed with experimental periods ranging from 12 to 24 hours and permeate samples were taken from the system at each hour. For each run of experiments, samples from permeate and concentrate streams were taken at different periods and some parameters such as TDS, conductivity, pH, flow rate, temperature and salinity have been measured during the operation. All feed, permeate and concentrate samples were stored in clean plastic bottles.

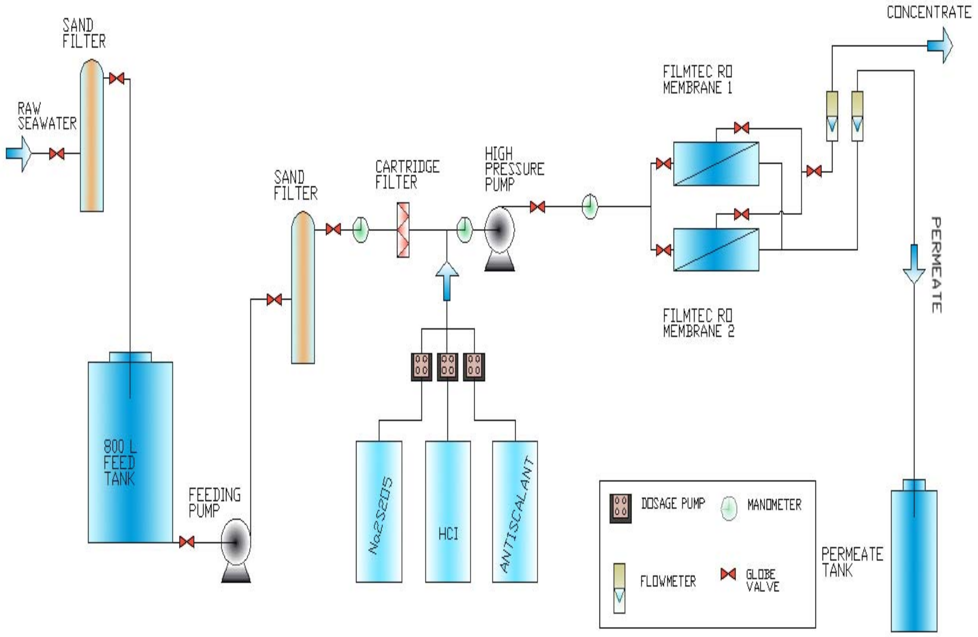

Figure 2. 2 Blok diagram of the RO process

2.2.2 Instrumental Analyses Equipments

Quality of product water obtained was determined by electrical conductivity (EC), pH, total dissolved solid (TDS) and salinity, cations (Na$^+$, K$^+$, Mg^{2+}, Ca^{2+}), anions (Cl$^-$, SO$_4^{2-}$,), CO$_3^{2-}$ HCO$_3^-$ and turbidity.

Electrical conductivity (EC), total dissolved solid (TDS) and salinity were measured by a digital conductivity meter (WTW LF-330/SET) and pH was measured by a portable pH meter (Metrohm 691 Model).

The analysis of Cl$^-$ and SO$_4^{2-}$ ions were determined by Shimadzu model ion chromatography equipment (model LC 10 A*i*). Na$^+$, K$^+$, Mg^{2+}, Ca^{2+} ion concentrations were measured by Varian 10 Plus Model Atomic Absorption Spectrophotometer. CO$_3^{2-}$ and HCO$_3^-$ concentrations were determined by titration method. Turbidity measurement was performed by Micro TPI Field Portable Turbidimeter.

2.2.2.1 Anion Analysis (Cl^-, SO_4^{2-}) by Ion Chromotography

The analyses of chloride and sulfate were carried out using a Shimadzu model ion chromatography equipment (Fig 2.3.) which has an LC 10Ai liquid delivery pump, a CDD 6A conductivity detector, a CTA 10A oven and a CBM 10A system controller.

Figure 2. 3 Shimadzu LC-10 Ai model Chromography

MCI GEL column was used (4. 6 mm I.D. x 150 mm) in our analysis. MCI GEL columns are packed with MCI GEL packing materials (hydrophilic polymer) which are spherical packings with a narrow particle size distribution. This column provides excellent separation and short analysis time. Functional group of these columns is NR_3^+ and mobil phase is 3.0 mM Vanillic Acid, 2.8 mM N-Methyldiethanolamine (pH: 6.2) supplied at a flow rate of 1.2 mL/min.

The injection port of an ion chromatography commonly consists of an injection valve and the sample loop. The sample was injected into the loop via the injection valve.

Filtration of the eluents before operation works to remove small particulates that may contaminate the pump check valves and cause erratic flow rates. Therefore, all natural samples must be pre-filtered through 0.25 μm membrane filters before use.

The standards solutions were analyzed by ion chromatography and calibration curves which show the concentration against the area. The concentrations of unknown samples were calculated from the calibration curve obtained. For ion chromatographic analysis feed seawater samples were diluted 1000 times and permeate samples were diluted 20 times.

2.2.2.2 Cation (Na^+, K^+, Mg^{2+}, Ca^{2+}) analysis by AAS

Na^+, K^+, Mg^{2+}, Ca^{2+} ions concentrations were determined by Varian 10 Plus Model Atomic Absorption Spectrophotometer (Fig 2.4.).

The standards solutions were analyzed and a calibration curve which shows the concentration against the amount of radiation absorbed was obtained. Concentrations of unknown samples were calculated from the calibration curve obtained. Feed seawater samples were diluted 50 times and permeate samples were measured directly.

Figure 2. 4 Varian 10 Plus Atomic Absorption Spectrophotometer

2.2.2.3 <u>Carbonate and bicarbonate analysis by titration</u>

CO_3^{2-} and HCO_3^- concentrations of feed and permeate samples were determined by titration method. HCl was used as a titrant. Before titration 0.01 N HCl was adjusted with Na_2CO_3 using two different indicators (methyl orange and phenolphthalein). The concentration of HCl was found as 0.1011 N.

After adjusting HCl, 100.0 mL of sample (feed, permeate) measured by pipette was taken into a 250 mL volumetric flask. A 0.1 mL phenolphthalein was added and the solution was titrated with standard hydrochloric acid solution until the disappearance of the pink color. The volume up to this point was defined as V_1. After that, methyl orange indicator was added and the same solution was titrated with adjusted hydrochloric acid solution until the color turned into onion red. This volume was called V_2.

To calculate amount of carbonate, we used the following equation:

$CO_3^{2-} + H^+ \rightarrow HCO_3^-$

$V_{CO_3^{2-}} = 2V_1$

$m_{CO_3^{2-}} = V_{CO_3^{2-}}$ (mL) * M_{HCl} (mol/L)*60(g/mol)* 10 = … mg CO_3^{2-} / L

To calculate the amount of bicarbonate, we used the following equation:

$HCO_3^- + H^+ \rightarrow H_2O + CO_2$

$V_{HCO_3^-} = (V_2 - V_1)$

$m_{HCO_3^-} = V_{HCO_3^-}$ (mL) * M_{HCl} (mol/L)*61(g/mol)* 10 = mg HCO_3^- / L

MW (CO_3^{2-}) = 60 g/mol MW (HCO_3^-) = 61g/mol 10 = Dilution factor

2.2.2.4 Turbidity analysis by Turbidimeter

Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness. Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.

Turbidity analyses of feed and permeate samples were performed by Micro TPI Field portable turbidimeter (Fig 2.5). The turbidity is reported as Nephelometric Turbidity Units (NTU).

Before measurement, the instrument should be calibrated. Therefore, cuvettes used for instrument calibration or sample measurement should be indexed. Each calibration standard (0.0.2, 10, 1000 NTU) is supplied with indexing ring and each instrument has a reference point for indexing the calibration standard. To index calibration standard, the lowest turbidity reading was observed and located the cuvette position with the lowest turbidity reading and indexing ring was installed on the standard. For calibration procedures, calibration function of the instrument was selected and 0.02 NTU standard was inserted into the sample well and the indexing ring with the arrow on the instrument was aligned. After the reading has stabilized, it should be calibrated on this point. The same process was applied to other standards. When calibration was finished, the instrument automatically adjusted to the normal operating mode from calibration mode.

After calibration, clean and dry sample cuvette was rinsed with sample several times. After rinsed the cuvette, we read the lowest turbidity by pressing and holding down the ↵ button while rotating, for index the cuvette. Once cuvette was indexed, turbidity of feed and permeate samples were measured. For each experiment, this process was applied five times and average results were reported. Turbidity results have been observed for each sample.

Figure 2. 5 Micro TPI Field Portable Turbidimeter

2 RESULTS AND DISCUSSION

For RO tests, two types of membranes which are FilmTec SW30-2540 RO membrane and high rejection membrane FilmTec XUS SW30XHR-2540, were used.

RO tests were performed for both short and long term periods. In the experiments (Tests 1-28), seawater pH was 8.1-8.2 at which HCl dosing has been performed. For Tests 3, 4, 8, 12, 15, 18, and 21, feed seawater pH was not adjusted by HCl and natural seawater pH was employed. Feed flow rate was 250-270 L/h and permeate flow rate was between 40-70 L/h.

Long term studies were made using the experimental periods ranging from 12 to 24 hours at natural seawater pH and at 55 and 60 bar of pressure.

At the same pressure, effect of temperature on quality of product water was investigated. When the feed temperature was kept the constant, the applied pressure was changed.

3.1 Short–term Tests

Short-term tests were performed for 90 minutes of operation time for two types of membranes.

3.1.1 Tests with FilmTec SW30-2540 RO membrane

3.1.1.1 Effect of Feed Seawater Temperature on Chemical Composition of Permeate

The effect of feed temperature on chemical composition of permeate was investigated at a constant pressure (55 bar) and using FilmTec SW30-2540 RO membrane. Temperature affects the permeate quantity and quality. TDS (total dissolved solid), conductivity, salinity and ion concentrations were higher in the permeate collected at high temperature due to the increase in ionic mobility with increasing temperature.

Rejection percentages of ions were calculated using concentrations in feed and permeate. From the experimental data, we derived relation between temperature and rejection of species in seawater. The results for cations were given in Figures 3.1-3.4 as a function of time.

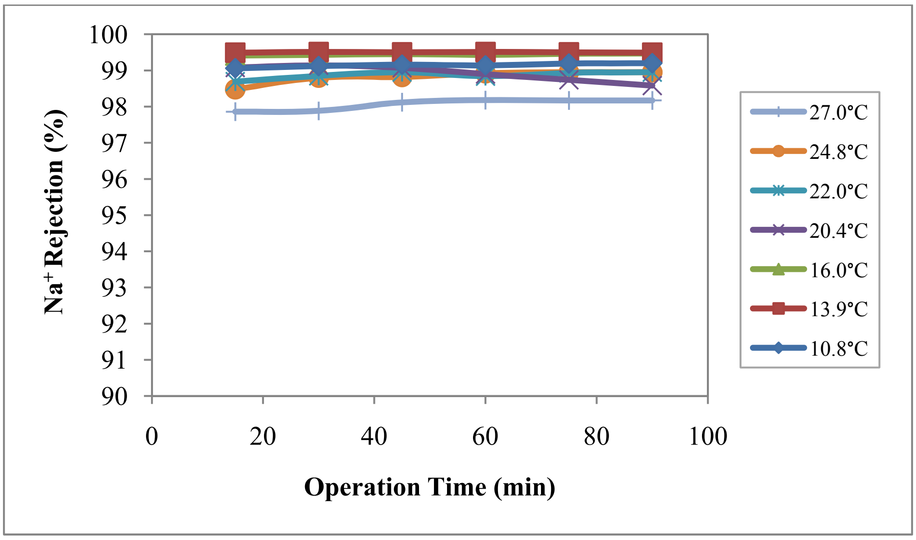

Figure 3. 1 Effect of temperature on Na$^+$ rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

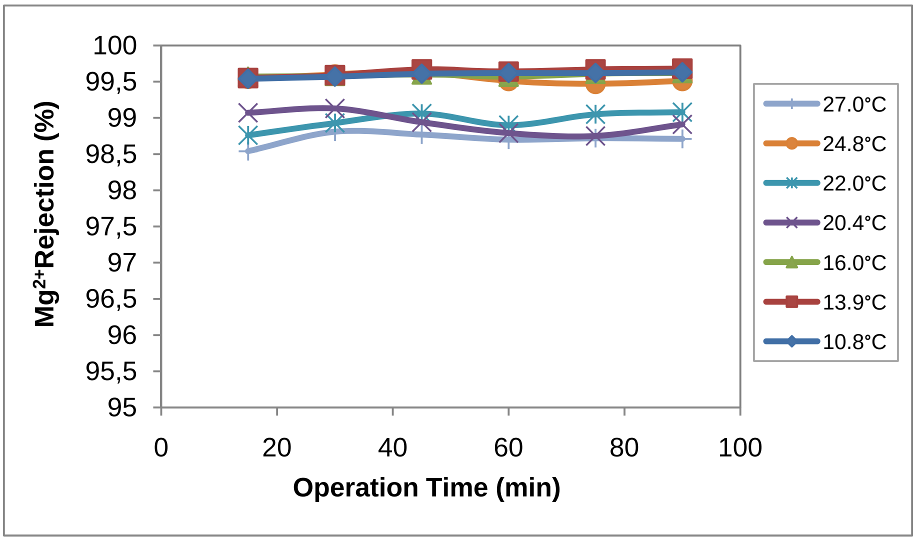

Figure 3. 2 Effect of temperature on Mg^{2+} rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

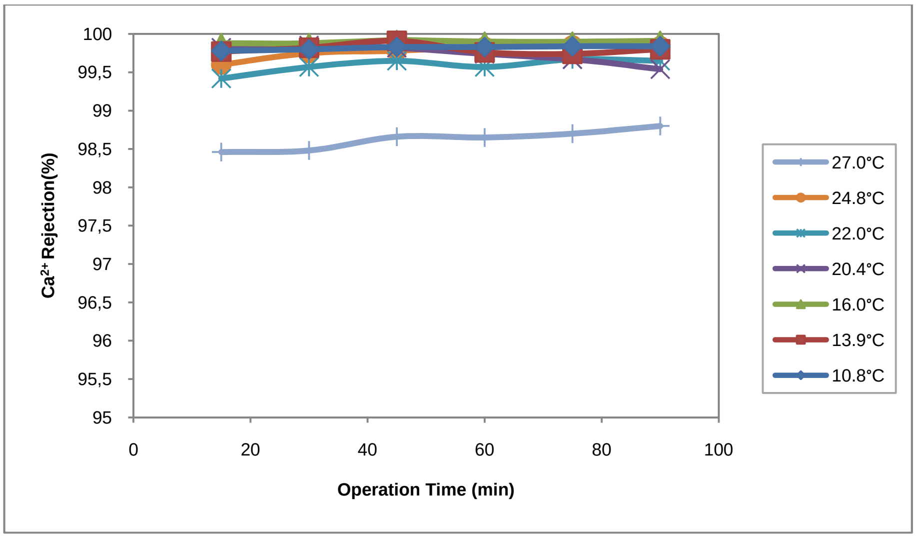

Figure 3. 3 Effect of temperature on Ca^{2+} rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

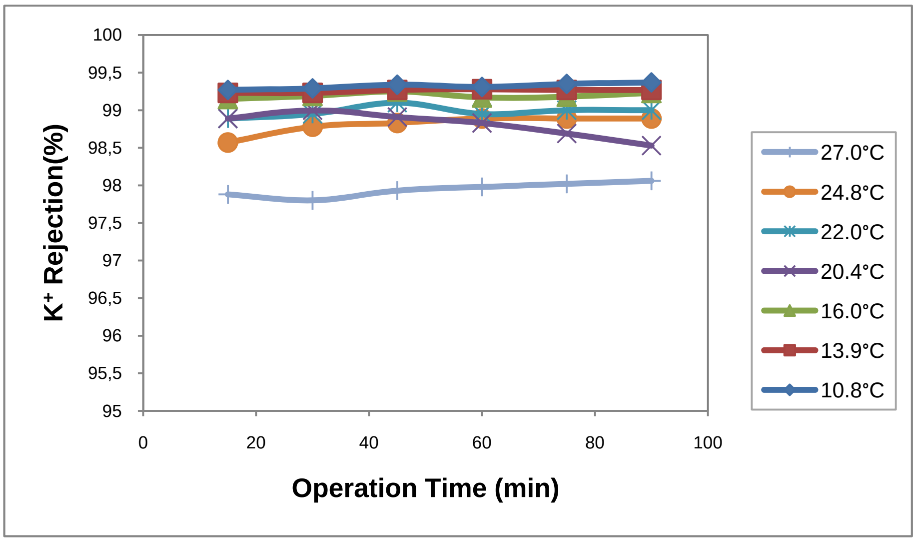

Figure 3. 4 Effect of temperature on K^{+} rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

The percent of cation rejections decreased when the feed temperature increased since ion diffusion through membrane increased by the increase in temperature. This decrease by temperature may be explained such that bonds within the membrane matrix are more relaxed and diffusion rate becomes faster at higher temperatures. The cation concentrations of feed seawater were given in Table 2.2 in Experimental part. According to the results, cation rejections were obtained about 97.9-99.5 % for Na^{+}, 98.5-99.9 % for Ca^{2+}, 98.5- 99.7 % for Mg^{2+}, 97.8-99.4 % for K^{+} using FilmTec SW30-2540 RO membrane. As seen from the rejection percentages, divalent ions were rejected largely than monovalent ions because of the greater charge (electrostatic rejection was greater with divalent cations).

Anion rejections from seawater as a function of temperature were given Figures 3.5. and 3.6.

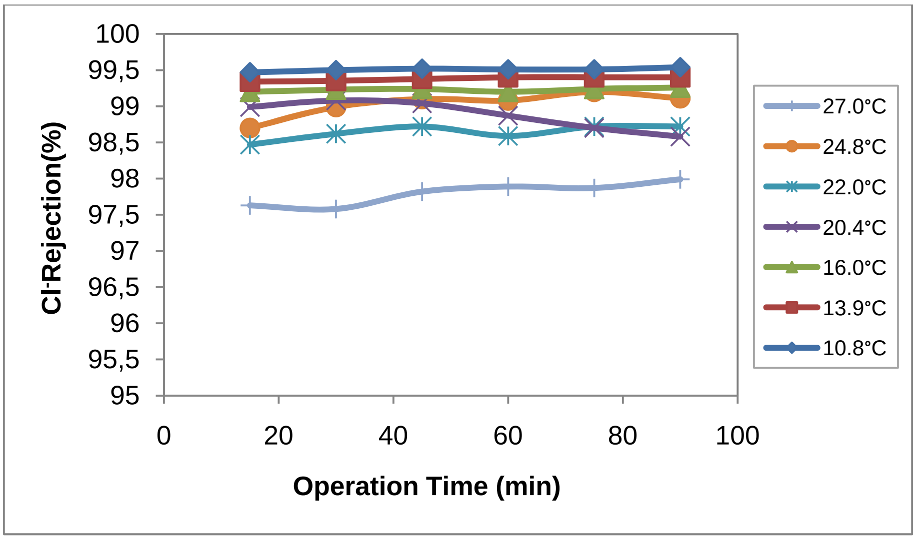

Figure 3. 5 Effect of temperature on Cl^- rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

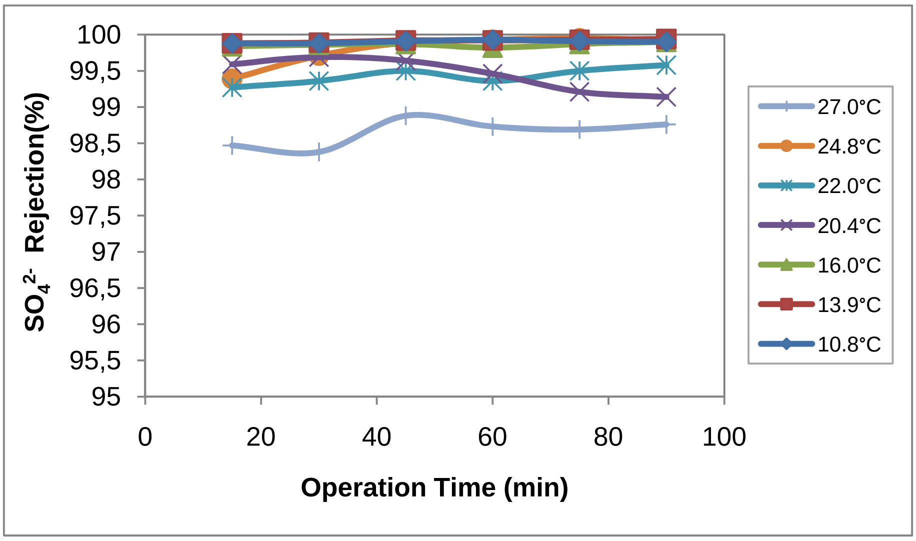

Figure 3. 6 Effect of temperature on SO_4^{2-} rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

While the chloride rejection was 97.63-99.40% for SWRO membrane, rejection was 98.38-99.97 % for sulfate.

Natural seawater pH range is 7.5-8.3. The seawater has higher bicarbonate concentration (123-180 mg/L) than carbonate concentration (0 mg/L).

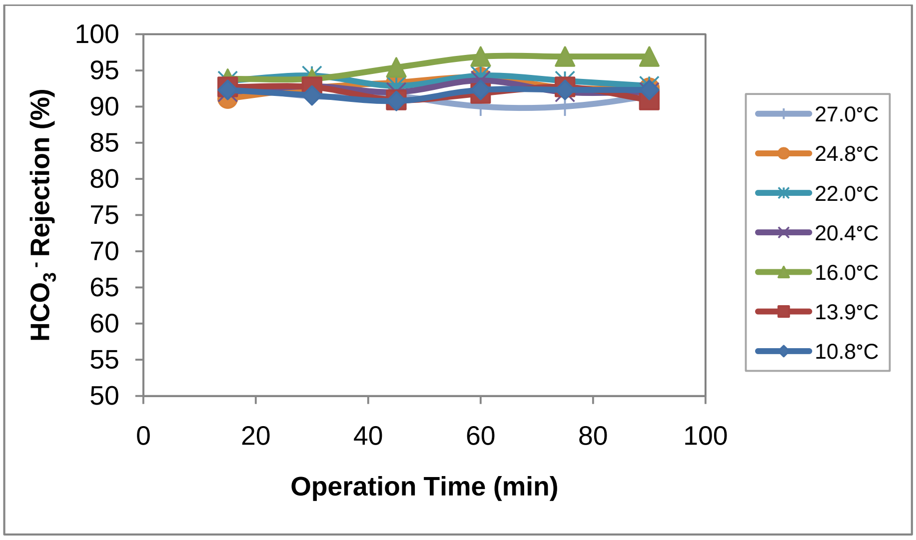

Figure 3. 7 Effect of temperature on HCO_3^- rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

RO tests were performed between pH 8.1-8.4. According to titration results, carbonate ions were removed from seawater with 100% of rejection by RO. Rejection percents for bicarbonate were about 90-96.92 % for SWRO membrane. Temperature did not affect bicarbonate rejection.

Figure 3.8 shows the turbidity of permeate vs time plots as a function of temperature.

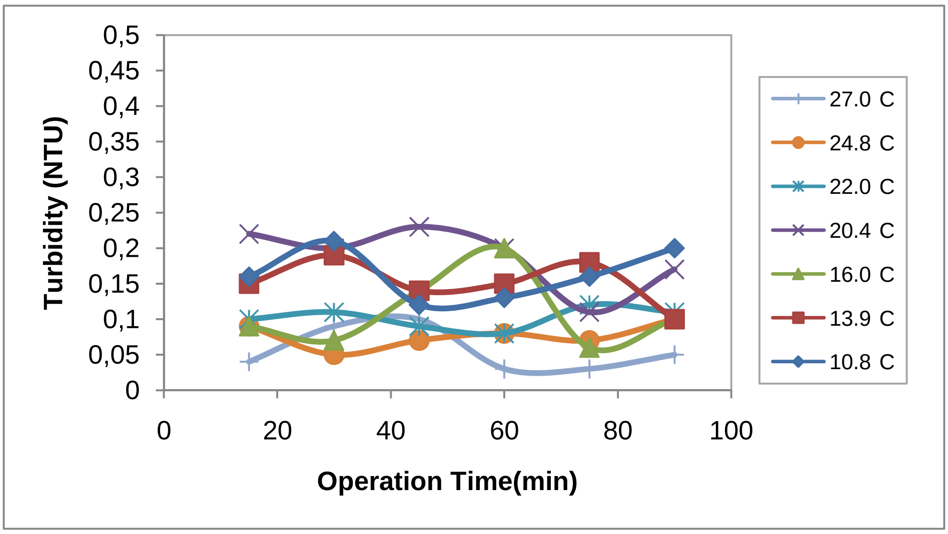

Figure 3. 8 Effect of temperature on turbidity (Tests 5, 6, 10, 16, 19, 20 and 22)

The turbidity level of seawater was reduced from 0.25-0.60 NTU to 0.03-0.21 NTU (in permeate) during SWRO membrane operations.

3.1.1.2 Effect of applied pressure on chemical composition of permeate

Applied pressure also affects the permeate quantity and quality. Pressure is a driving force for a reverse osmosis process and it is one of the most important parameters that have to be investigated basically. The membranes that were used in Urla were durable to max. 62 bar pressure. Therefore, effect of applied pressure on rejection of cations (Na^+, Ca^{2+}, Mg^{2+}, K^+), anions (Cl^- and SO_4^{2-}, CO_3^{2-}, HCO_3^-) and turbidity was investigated for the pressures of 55, 60 and 62 bar. This investigation was performed at a constant feed seawater temperature of 16°C for SWRO membrane.

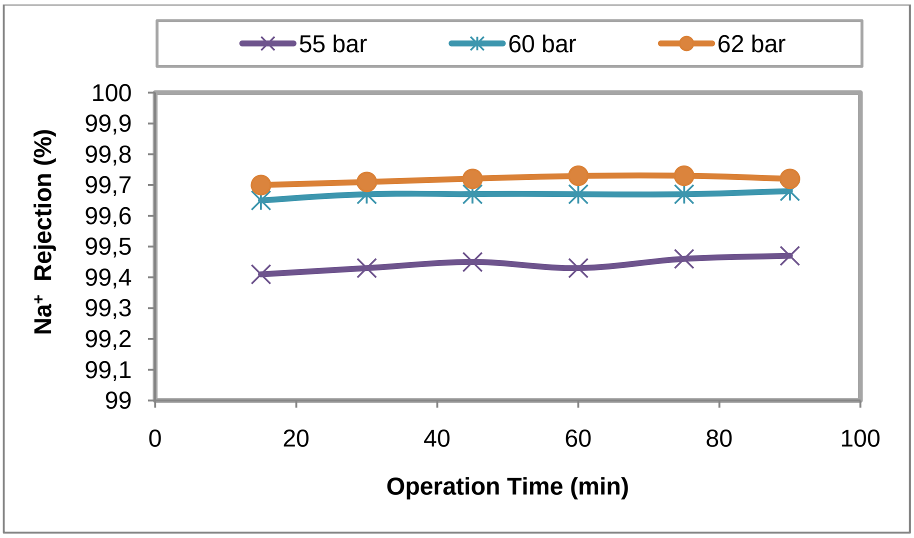

Figure 3. 9 Effect of pressure on Na^+ rejection (Tests 5, 13 and 14)

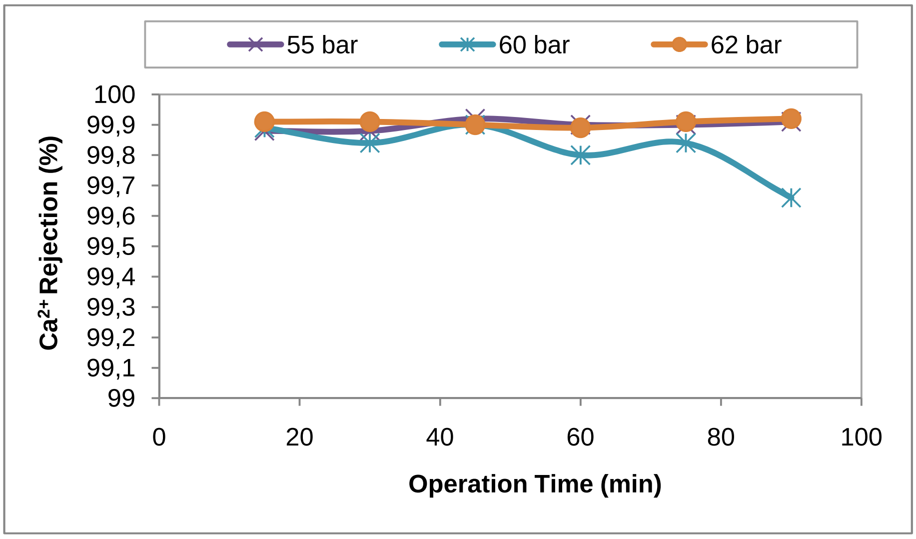

Figure 3. 10 Effect of pressure on Ca^{2+} rejection (Tests 5, 13 and 14)

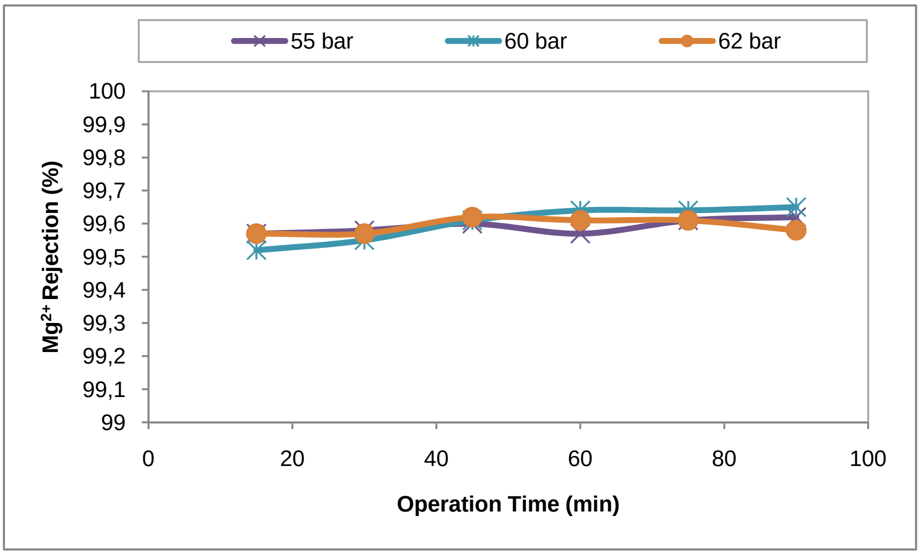

Figure 3. 11 Effect of pressure on Mg^{2+} rejection (Tests 5, 13 and 14)

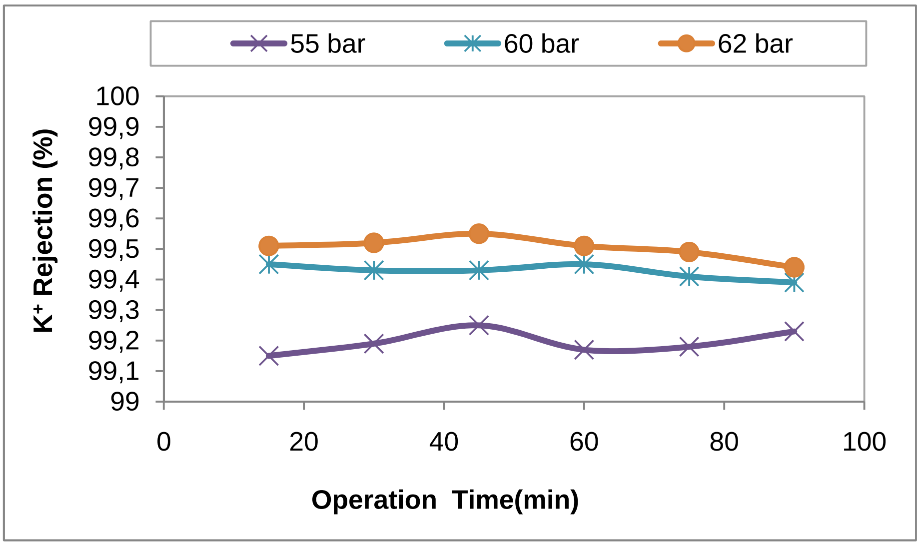

Figure 3.12 Effect of pressure on K^+ Rejection (Tests 5, 13 and 14)

At the end of the experiments, ion rejections were 99.46-99.68 % for Na^+, 99.66-99.92 % for Ca^{2+}, 99.57-99.64 % for Mg^{2+} and 99.15-99.55 % for K^+. When the membrane operating pressure was 62 bar, rejections of K^+, Na^+ in permeate increased, rejections of Ca^{2+} and Mg^{2+} did not change with applied pressure significantly.

The effect of applied pressure for Cl^- rejection was given as a function of operation time in Figure 3.13 for chloride. SO_4^{2-} concentrations in the permeate were below the limit of detection.

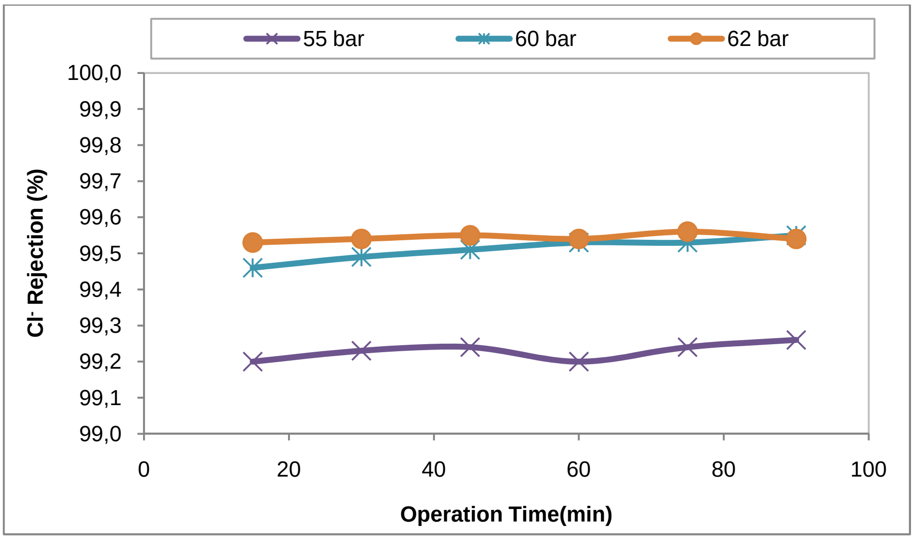

Figure 3. 13 Effect of pressure on Cl^- rejection (Tests 5, 13 and 14)

The carbonate ions were completely removed from seawater with 100% rejection. However, the rejection of bicarbonate was about 90-94.26%, which is slightly lower than carbonate ions. Figure 3.14 shows the changes in bicarbonate rejection vs. time as a function of pressure. Maximum rejections of HCO_3^- ions were 93.33 % 93.60 % and 94.26 % for 55, 60 and 62 bar, respectively.

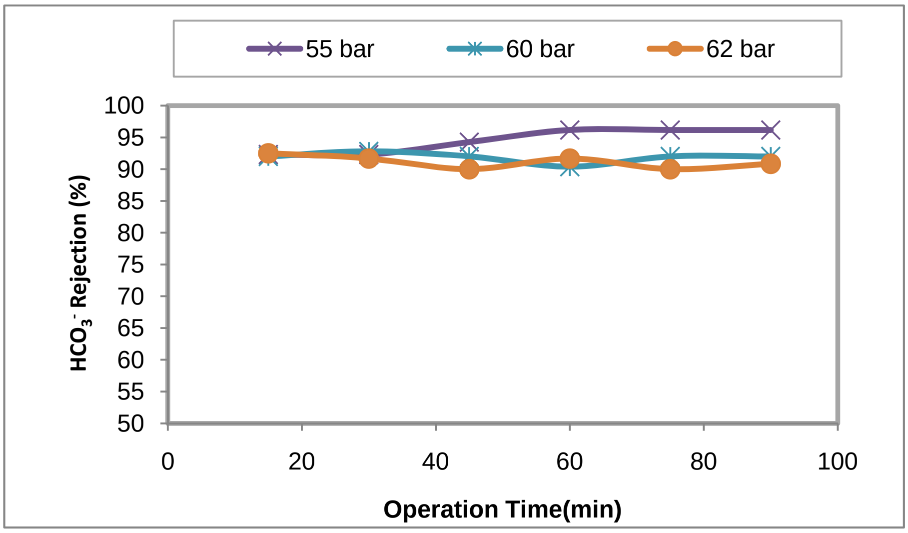

Figure 3. 14 Effect of pressure on HCO_3^- rejection (Tests 5, 13 and 14)

Figure 3.15 shows that the turbidity of permeate decreased to 0.17 NTU at 62 bar, to 0.15 NTU at 60 bar and to 0.06 at 55 bar, while the respective turbidity values of feed seawater were 0.47, 0.46 and 0.27, respectively.

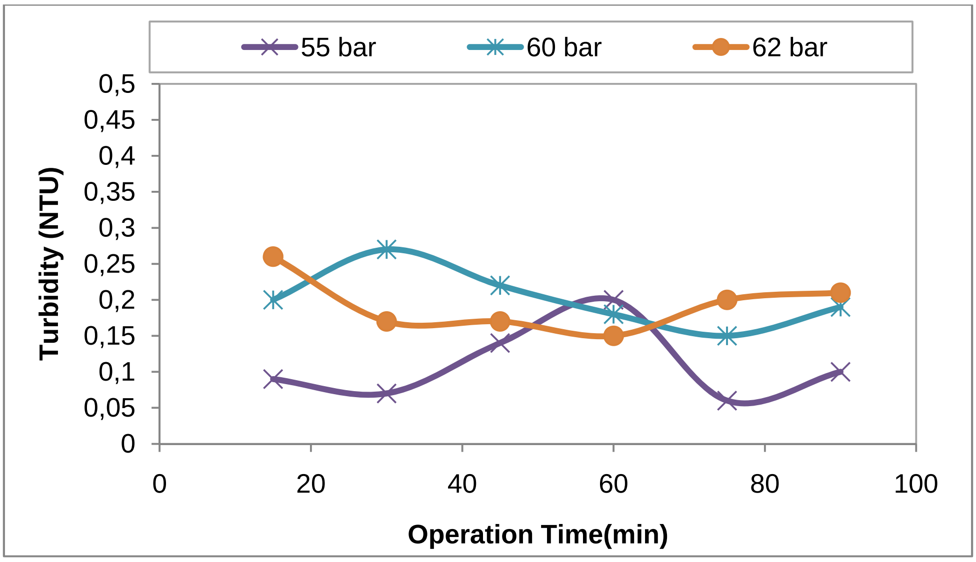

Figure 3. 15 Effect of pressure on permeate turbidity (Tests 5, 13 and 14)

3.1.2 Tests with high rejection membrane Filmtech XUS SW30 XHR 2540 membrane

3.1.2.1 Effect of Feed Seawater Temperature on Chemical Composition of Permeate

The effect of feed seawater temperature on chemical composition of permeate was investigated for high rejection membrane FilmTec XUS SW30XHR-2540 membrane at a constant pressure (55 bar).

Figures 3.16-3.19 show the rejections of Na^+, Ca^{2+}, Mg^{2+}, K^+ ions with respect to feed seawater temperature for high rejection XUS SW30XHR-2540 membrane.

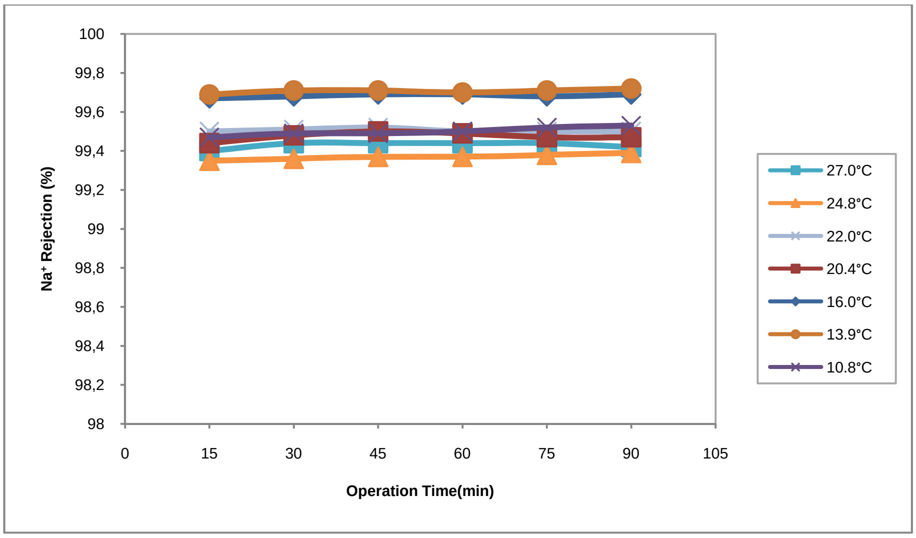

Figure 3. 16 Effect of temperature on Na^+ rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

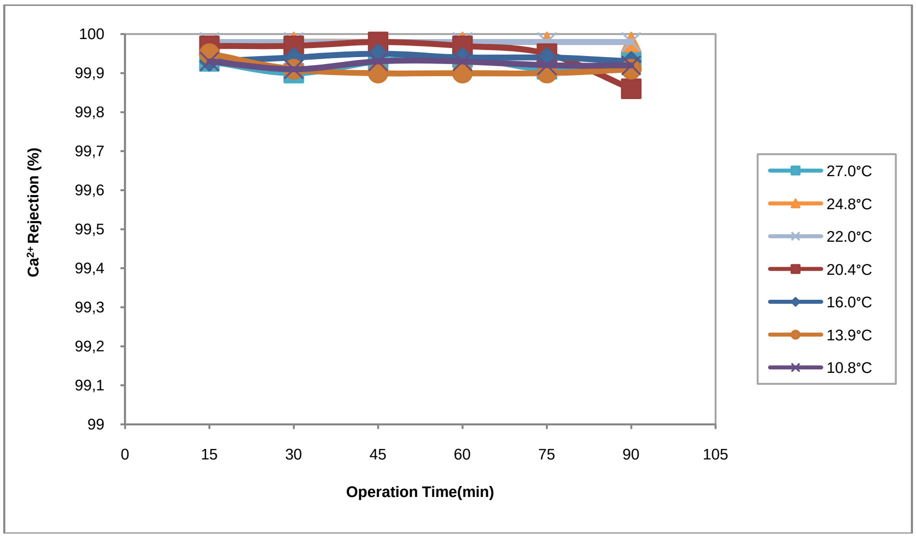

Figure 3. 17 Effect of temperature on Ca^{2+} rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

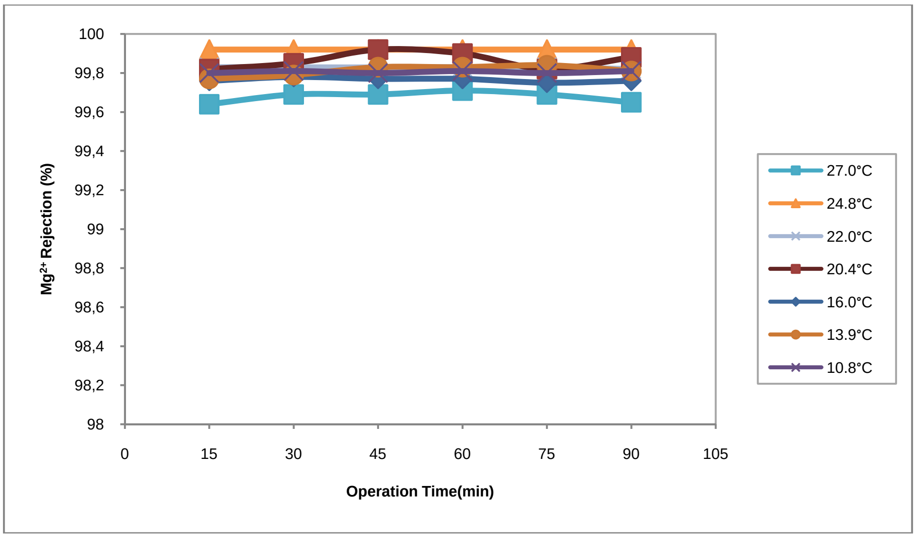

Figure 3. 18 Effect of temperature on Mg^{2+} rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

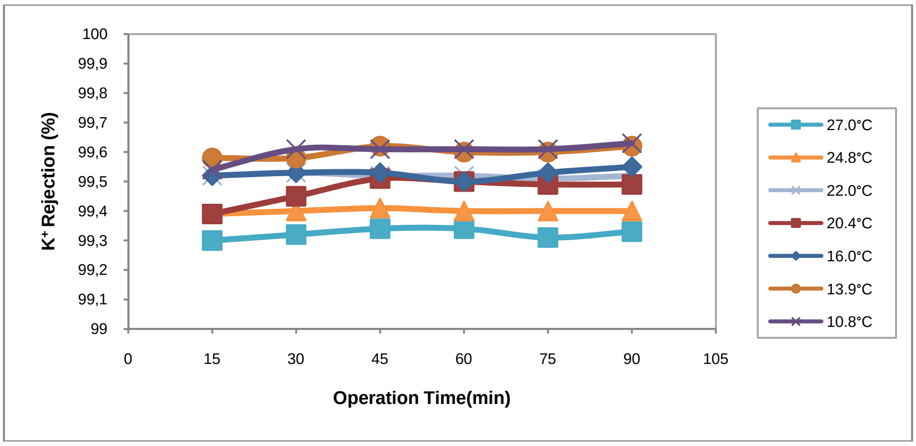

Figure 3. 19 Effect of temperature on K^+ rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

According to the results, ion rejections were obtained about 99.35-99.76 % for Na^+, 99.90-99.98 % for Ca^{2+}, 99.64- 99.84 % for Mg^{2+}, 99.30-99.71 % for K^+ using high rejection membrane FilmTec XUS SW30 XHR-2540 at 10.8-27.0 ºC. As temperature increased, Mg^{2+} and K^+ removal decreased. Highest K^+ rejecton removal value (99.63 %) was achieved for the lowest feed seawater temperature (10.8°C). The highest rejection value for Mg^{2+} ions was 99.84 % at the feed temperature of 13.9°C. For rejection of Ca^{2+} and Na^+, rejection values for some points are overlapping. Figures 3.20 and 3.21 show the variation of Cl^- and SO_4^{2-} ions with respect to feed seawater temperature, respectively.

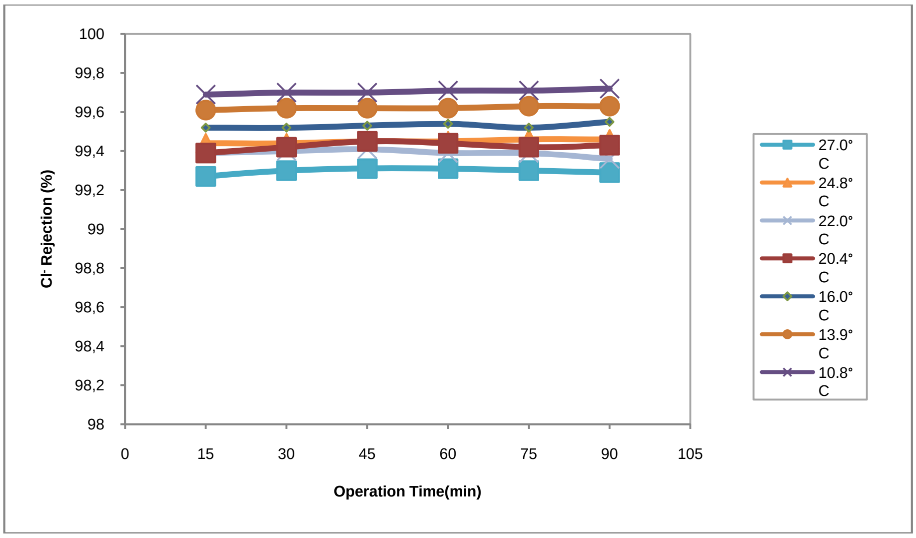

Figure 3. 20 Effect of temperature on Cl- rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

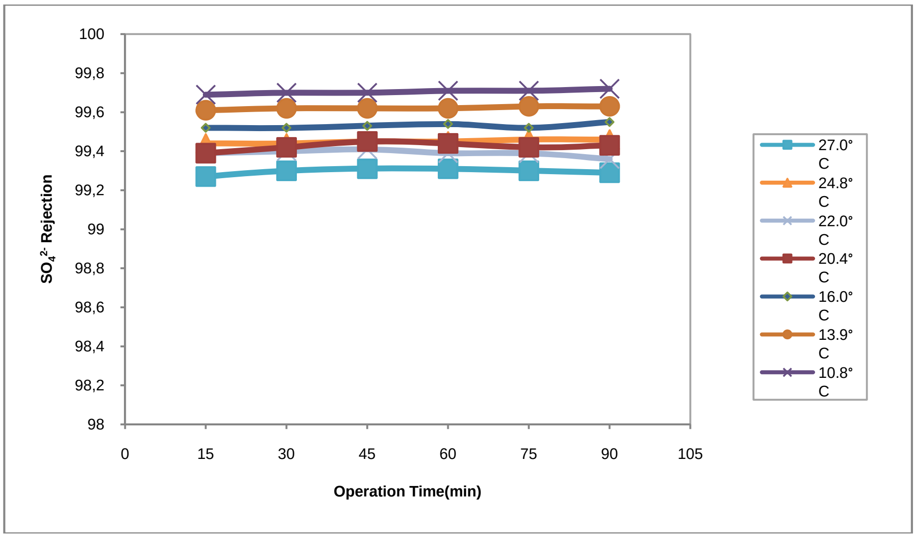

Figure 3. 21 Effect of temperature on SO_4^{2-} rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

At the temperature of 10.8ºC, both of Cl^- and SO_4^{2-} rejections were the highest, while Cl^- rejection was 99.72% and SO_4^{2-} rejection was 99.99%. As the temperature increased, rejections decreased.

Rejection values for HCO_3^- ions were given in Figure 3.22 for high rejection membrane FilmTec XUS SW30 XHR-2540. CO_3^{2-} was removed with 100% of rejection.

As seen in Figure 3.22, some points overlapped. For HCO_3^- removal, feed seawater temperature did not affect the rejection, greatly.

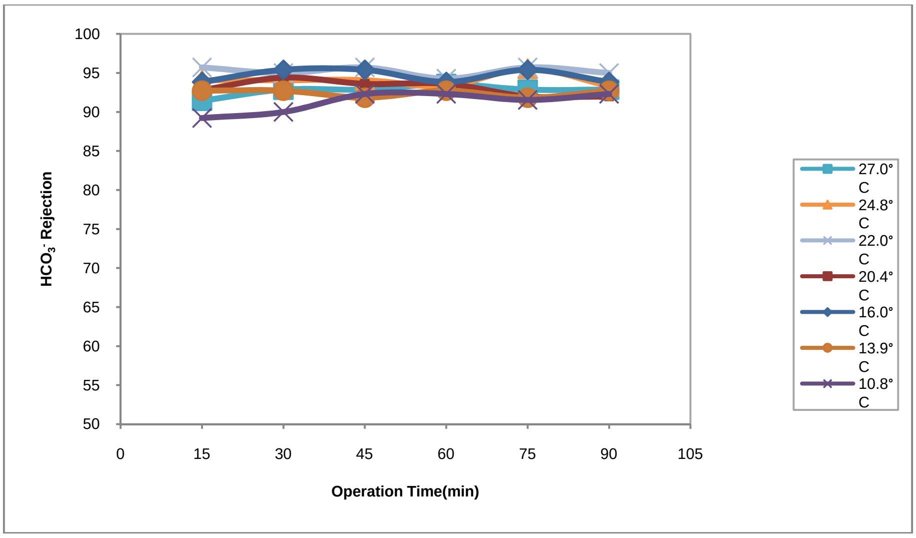

Figure 3. 22 Effect of temperature on HCO_3^- rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

Figure 3.23 shows the change of turbidity by feed seawater temperature.

The turbidity level of seawater was reduced from 0.27-0.60 NTU to 0.01-0.10 NTU for high rejection membrane operations. Feed seawater temperature did not affect the rejection of turbidity, greatly.

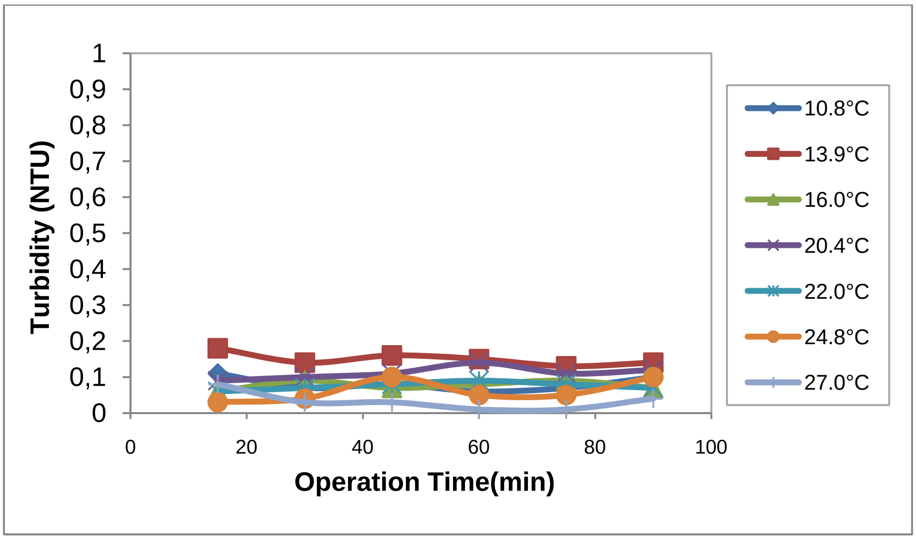

Figure 3. 23 Effect of temperature on turbidity (Tests 5, 6, 10, 16, 19, 20 and 22)

3.1.2.2 Effect of applied pressure on chemical composition of permeate

Effect of applied pressure on chemical composition of permeate was also investigated for high rejection membrane FilmTec XUS SW30 XHR-2540.

Membrane operating pressures tested were 55, 60 and 62 bar. When effect of pressure was studied, the temperature was around 16°C. Figures 3.24-3.27 showed the effect of applied pressure on rejections of cations.

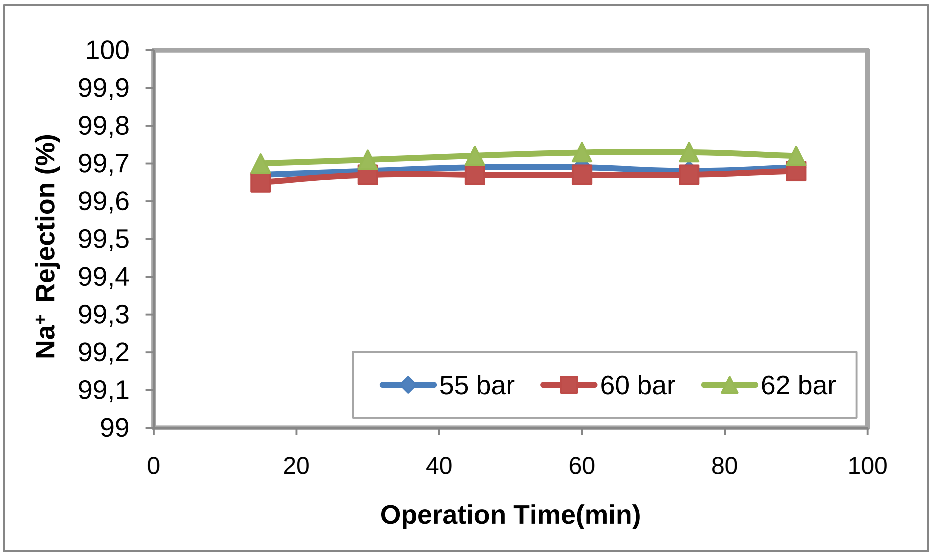

Figure 3. 24 Effect of pressure on Na^+ rejection (Tests 5, 13 and 14)

When the applied pressure was 62 bar, Na^+ rejection was enhanced and highest rejection value (99.73 % as average value) was achieved for the highest applied pressure. Average values were calculated as 99.68 and 99.67% for the pressures of 55 and 60 bar, respectively.

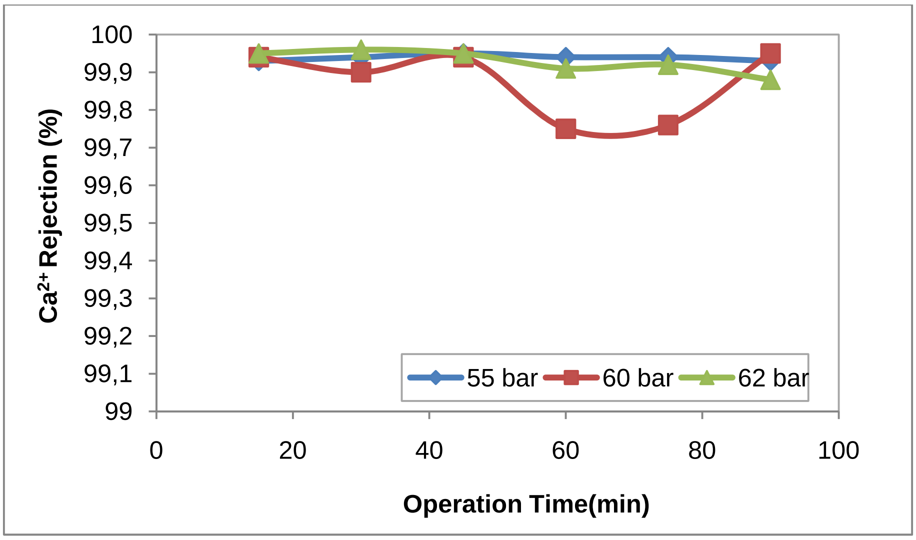

Figure 3. 25 Effect of pressure on Ca^{2+} rejection (Tests 5, 13 and 14)

For Ca^{2+} rejection, pressure values of 55 and 62 bar were closer to each other, Ca^{2+} rejection values for some points overlapped. At pressure 60 bar, some scattered data were obtained.

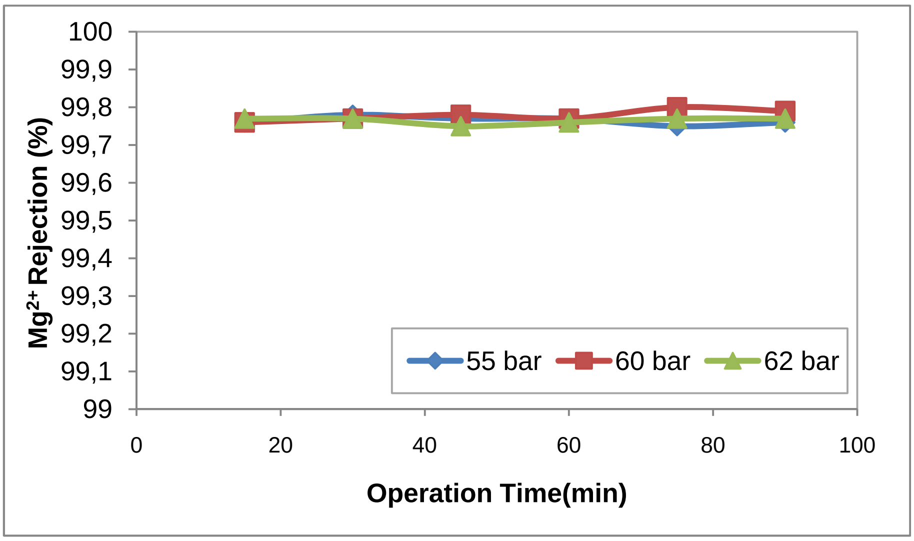

Figure 3. 26 Effect of pressure on Mg^{2+} rejection (Tests 5, 13 and 14)

Figure 3.26 shows the variations of Mg^{2+} rejection by the applied pressure. As seen in Figure 3.26, applied pressure did not affect the Mg^{2+} rejection. Rejection values were closer to each other, 99.77, 99.78 and 99.77% for the pressures of 55, 60 and 62, respectively.

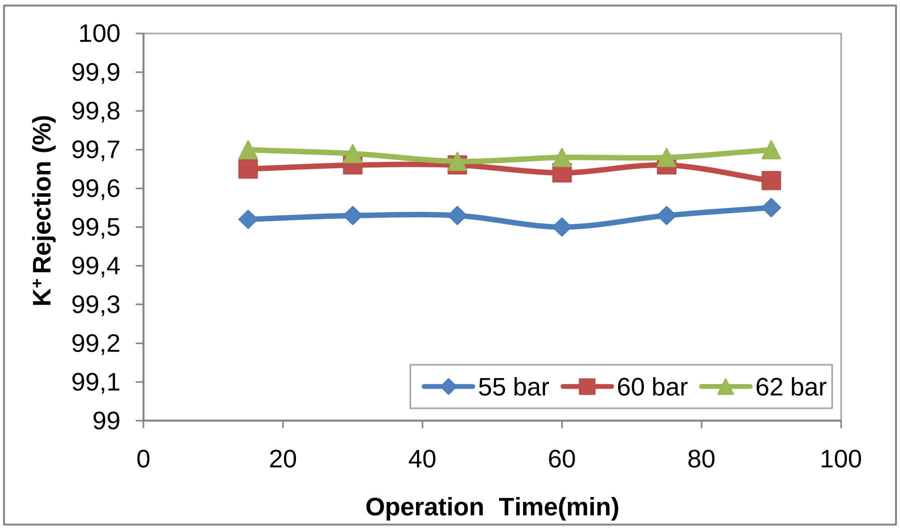

Figure 3. 27 Effect of pressure on K^+ Rejection (Tests 5, 13 and 14)

K^+ rejection increased with increasing applied pressures and their average values were recorded as 99.53, 99.65 and 99.69% for the pressures of 55, 60 and 62 bar, respectively (Figure 3.27)

In Figure 3.28, variations of Cl^- rejection as a function of applied pressure was shown. Permeate SO_4^{2-} values were below the limit of detection.

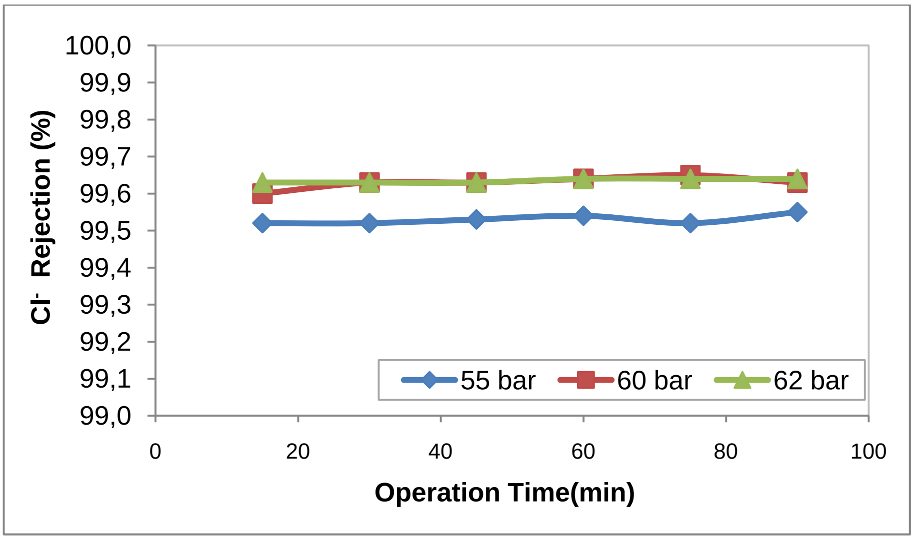

Figure 3. 28 Effect of pressure on Cl^- rejection (Tests 5, 13 and 14)

Average Cl^- rejection was nearly the same as 99.63 and 99.64% at applied pressures of 60 and 62 bar, respectively. As applied pressure decreased, rejection also decreased. At a pressure of 55 bar, average Cl^- rejection was 99.53%.

The carbonate ions were completely removed from seawater with 100% rejection. HCO_3^- rejection as a function of the applied pressure was shown in Figure 3.29.

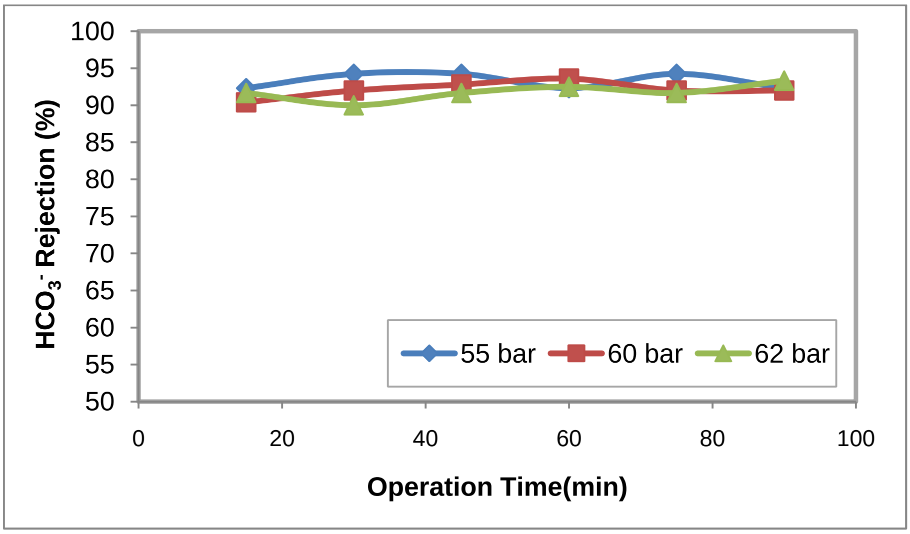

Figure 3. 29 Effect of pressure on HCO_3^- rejection (Tests 5, 13 and 14)

HCO_3^- rejection values were 91.81, 92.13 and 94.63% for pressures of 55, 60 and 62 bar, respectively.

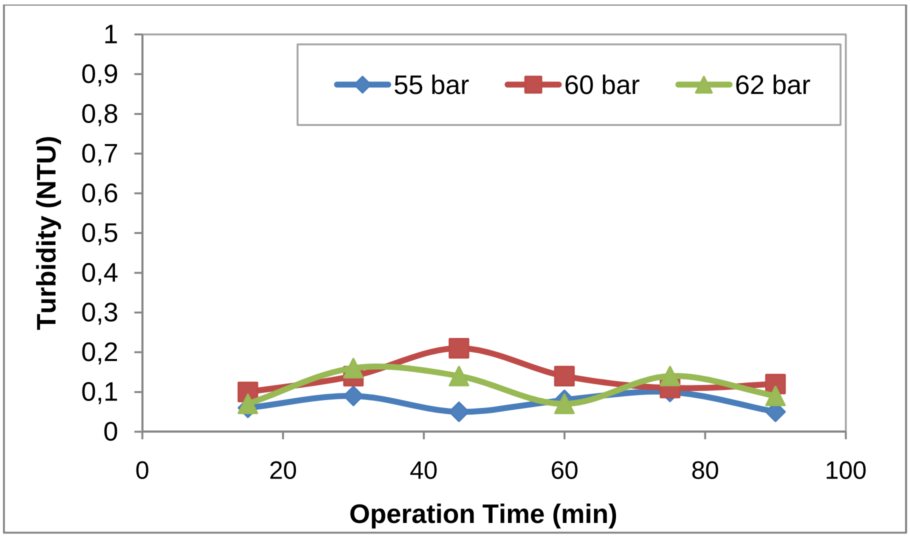

Figure 3. 30 Effect of pressure on turbidity of permeate (Tests 5, 13 and 14)

As shown in Figure 3.30, the turbidity of permeate was 0.07 NTU at 55 bar, 0.14 NTU at 60 bar and 0.10 at 62 bar, respective feed seawater turbidity values were 0.27, 0.46 and 0.47, respectively.

3.1.3 Comparative study with FilmTec SW30-2540 and FilmTec XUS SW30XHR-2540 RO membranes

Reverse osmosis tests at Urla Bay were performed both membrane SW30-2540 (conventional membrane) and high rejection membrane XUS SW30XHR-2540. In this study, two types of membranes were compared to see the difference between the performances of two different membranes.

3.1.3.1 Effect of feed seawater temperature

In Figure 3.31, the relations between Na^+ rejection and feed seawater temperature were given for both membranes.

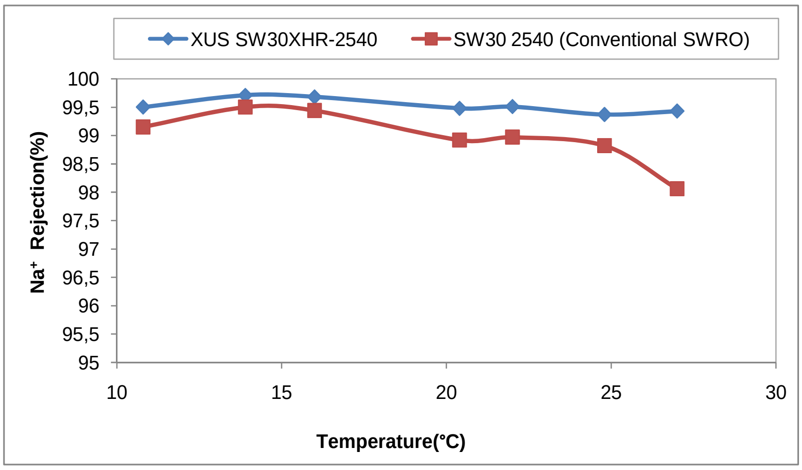

Figure 3. 31 Effect of feed water temperature on Na^+ rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

It was observed that Na^+ rejection decreased with increasing temperature for both membranes. It should also be noted that Na^+ rejection for XUS SW30XHR-2540 membrane was higher than the SW30-2540 membrane at corresponding temperature values.

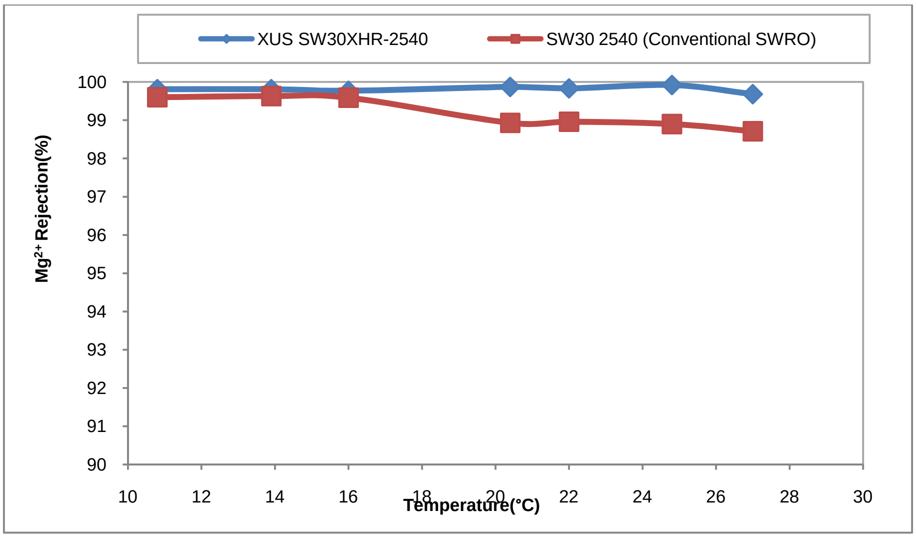

Figure 3. 32 Effect of temperature on Mg^{2+} rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

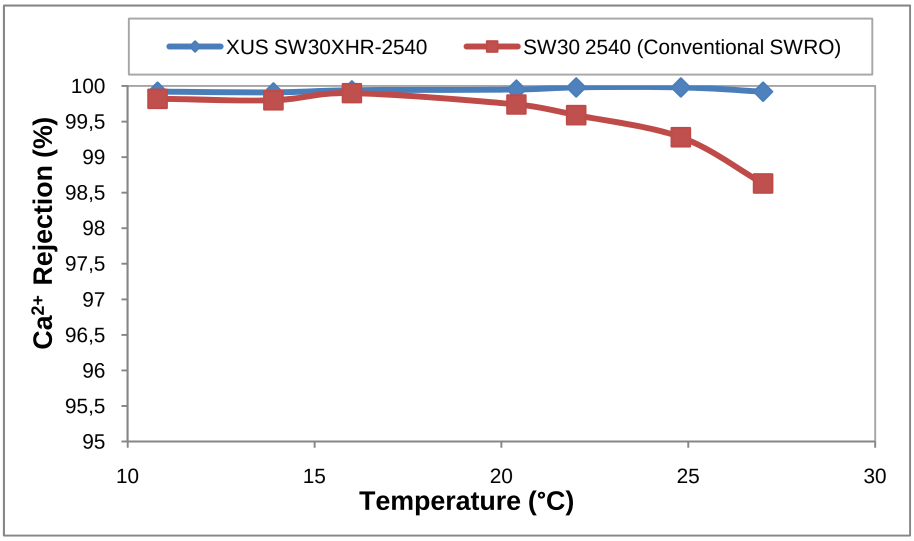

Figure 3. 33 Effect of temperature on Ca^{2+} rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

In Figures 3.32 and 3.33, it was seen that as the temperature increased, Mg^{2+} and Ca^{2+} rejection values dereased for SW30 2540 membranes. When XUS SW30XHR-2540 membrane was operated, rejections of both Mg^{2+} and Ca^{2+} were not influenced by temperature.

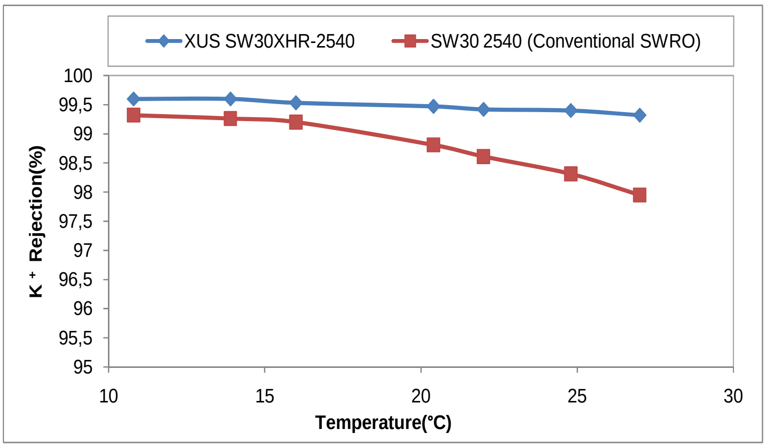

Figure 3. 34 Effect of temperature on K^+ rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

When the results compared for both two types of membranes, XUS SW30XHR-2540 membrane performance for rejections of cations were higher than the SW30-2540 membrane. As seen in Figure 3.34, as temperature increased, rejection of K^+ decreased. At the lowest temperature, 10.8°C, an average highest K^+ rejection was measured as 99.60%, when the high rejection XUS SW30XHR-2540 membrane was operated. For SW30-2540 membrane, average highest rejection was 99.32% at 10.8°C.

The comparison between two types of membranes was given in Figure 3.35 for Cl^- and in Figure 3.36 for SO_4^{2-} rejection. As seen in Figure 3.35, higher values of Cl^- rejection were observed at lower temperatures. In addition, high rejection membrane XUS SW30XHR-2540 has a better performance to reject Cl^- than the SW30-2540 RO membrane. At the lowest temperature, 10.8°C, an average Cl^- rejection was 99.71% for XUS SW30XHR-2540 membrane and 99.51% for SW30-2540 RO membrane.

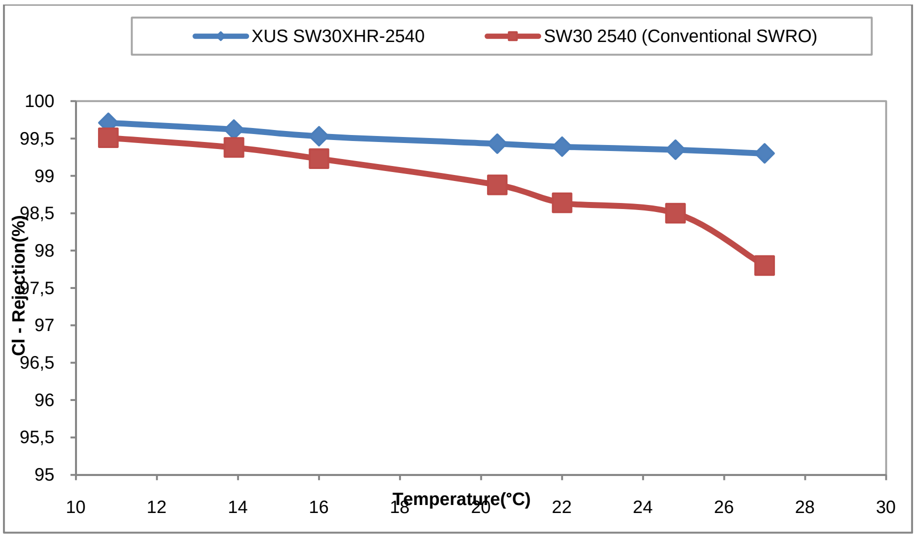

Figure 3. 35 Effect of temperature on Cl^- rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

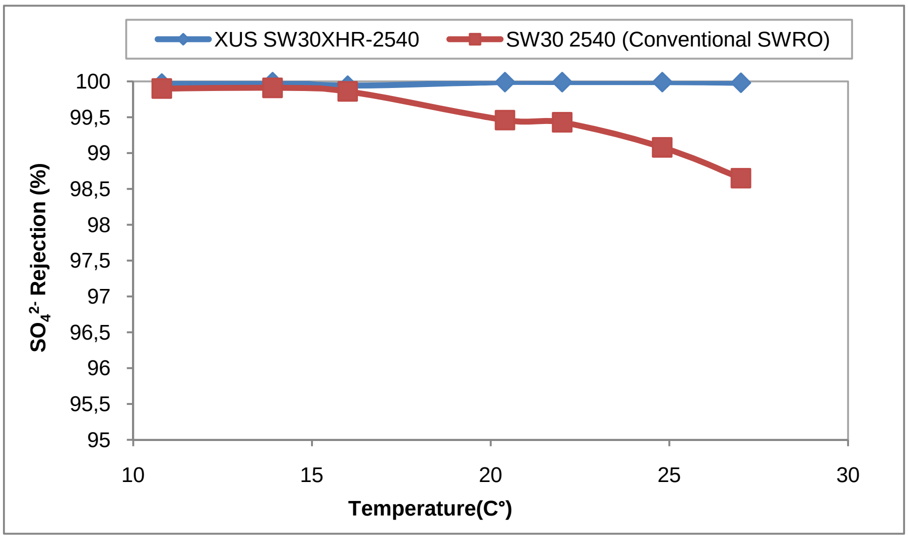

Figure 3. 36 Effect of temperature on SO_4^{2-} rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

In Figure 3.36, SO_4^{2-} rejection decreased as temperature increased for SW30-2540 RO membrane. For XUS SW30XHR-2540 membrane, temperature did not affect the rejection of SO_4^{2-}.

The carbonate ions were completely removed from seawater with 100% of rejection with both membranes. Bicarbonate ions rejection was shown in Figure 3.37 for both two types of membranes.

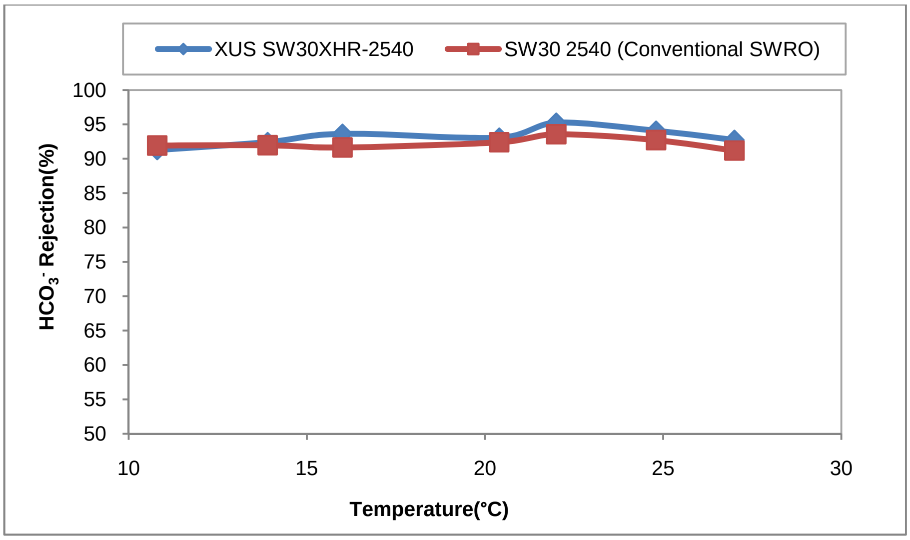

Figure 3. 37 Effect of temperature on HCO_3^- rejection (Tests 5, 6, 10, 16, 19, 20 and 22)

Figure 3.37 shows that temperature had no influence on bicarbonate rejection. For both membranes, as seen in Figure 3.37, as the temperature of feed seawater increased, the rejection of bicarbonate was almost not affected.

Figure 3.38 shows the effect of temperature on turbidity for both types of membranes. In Figure 3.38, for high rejection membrane XUS SW30XHR-2540, permeate turbidity values were 0.08, 0.15, 0.08, 0.11, 0.08, 0.06 and 0.03 at temperatures 10.8, 13.9, 16.0, 20.4, 22, 24.8 and 27 ^{o}C, respectively. At the same temperatures, for SW30-2540 RO membrane, turbidity values were as 0.16, 0.15, 0.11, 0.19, 0.10, 0.08 and 0.06 while feed seawater turbidity values were 0.30, 0.54, 0.60, 0.42, 0.35, 0.27 and 0.35, respectively.

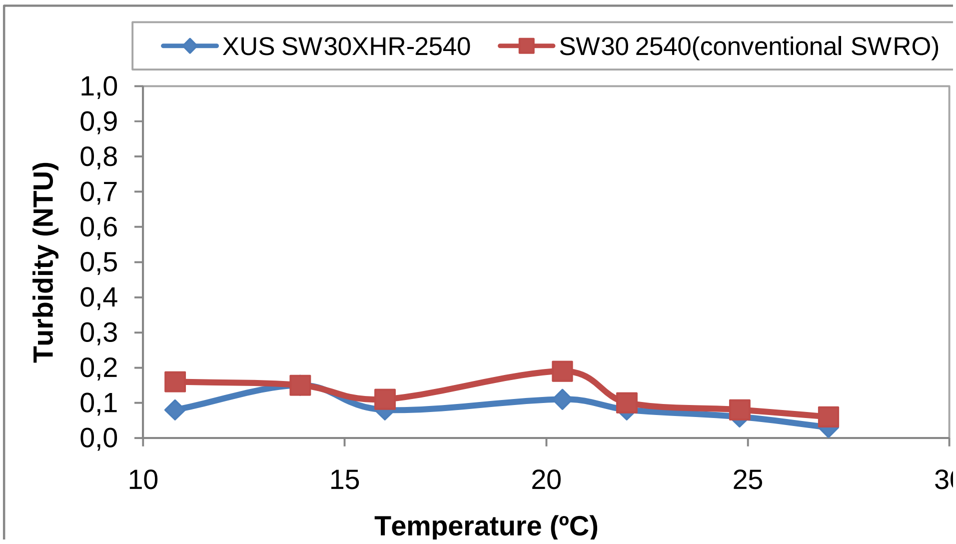

Figure 3. 38 Effect of temperature on turbidity (Tests 5, 6, 10, 16, 19, 20 and 22)

3.1.3.2 Effect of applied pressure on chemical composition of permeate

The effect of applied pressure was also investigated to compare both of the membranes performances.

For pressures of 55, 60 and 62 bar, both two types of membranes were investigated and compared for their performances. In Figure 3.39, as the applied pressure increased, Na^+ rejection increased for both membranes. But Na^+ rejection of high rejection (XUS SW30XHR-2540) membrane was higher than conventional membrane (SW30-2540). At the highest pressure of 62 bar, while average rejection of Na^+ was 99.72% for high rejection membrane, the highest average rejection was 99.66% for SW30-2540 RO membrane.

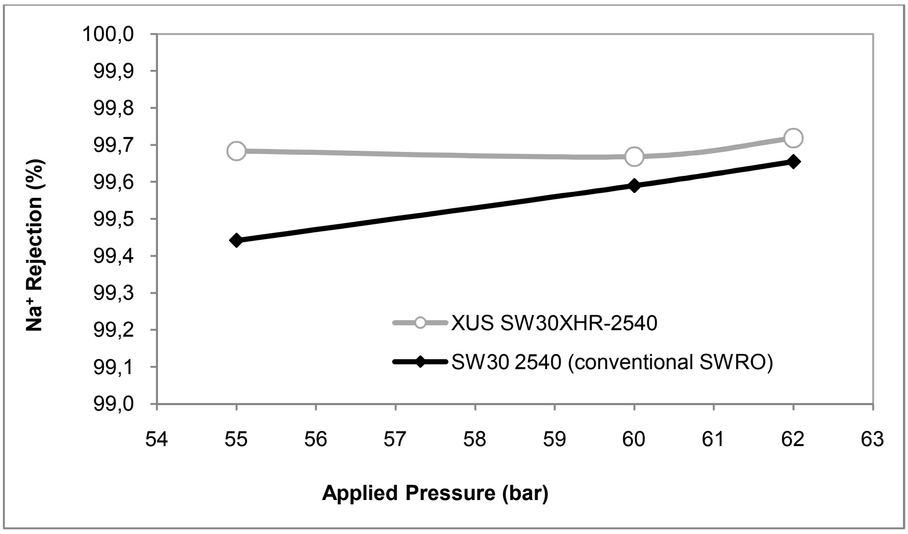

Figure 3. 39 Effect of pressure on Na^+ rejection (Tests 5, 13 and 14).

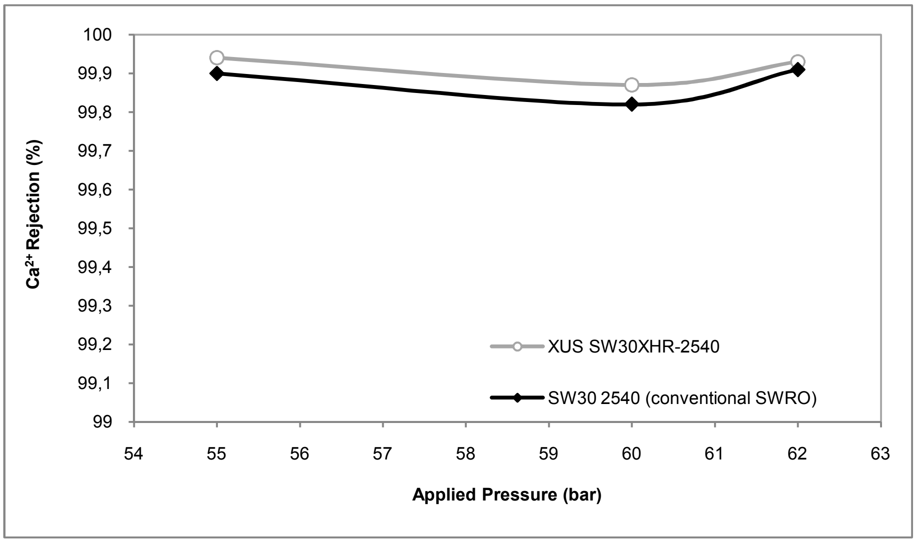

Figure 3. 40 Effect of pressure on Ca^{2+} rejection (Tests 5, 13 and 14).

Ca^{2+} rejections were 99.94, 99.87 and 99.93% at pressures of 55, 60 and 62 bar, respectively, for high rejection membrane and 99.90, 99.82 and 99.91% at corresponding pressures for SW30 2540 membrane.

Figure 3.41 shows variation of Mg^{2+} rejection by applied pressure for both types of membranes. For high rejection membrane, rejections were 99.77, 99.78 and 99.77% at pressures of 55, 60 and 62 bar, respectively. If the results were compared with both types of membranes, high rejection membrane XUS SW30XHR-2540 had higher rejection trend than SW30-2540 RO membrane.

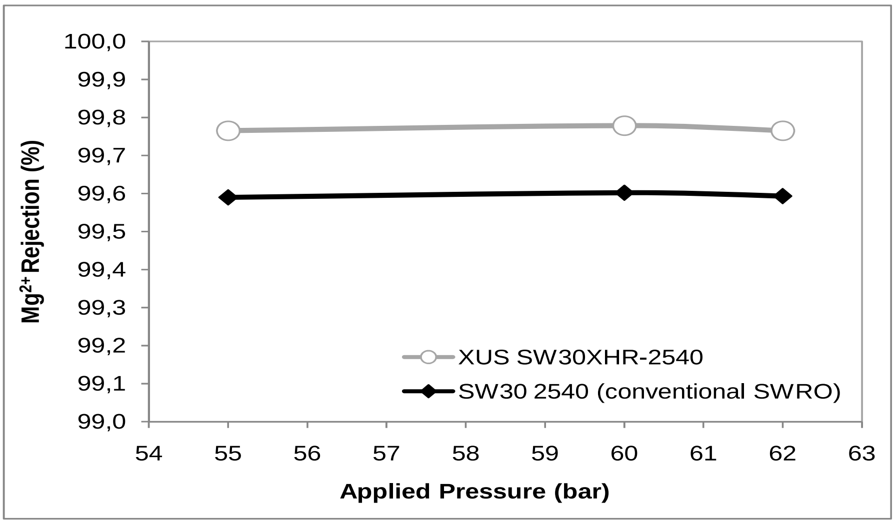

Figure 3. 41 Effect of pressure on Mg^{2+} rejection (Tests 5, 13 and 14).

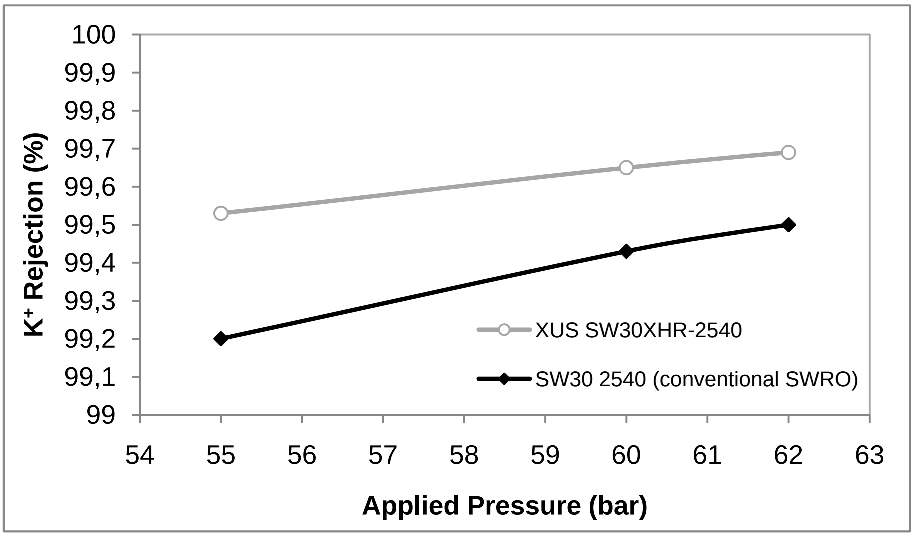

Figure 3.42 Effect of pressure on K^+ rejection (Tests 5, 13 and 14).

As shown in Figure 3.42, K^+ rejection using high rejection membrane was higher than that of SW30-2540 RO membrane. K^+ rejection was highest at pressure of 62 bar for both of membranes, 99.69 and 99.50%, respectively.

As seen in Figure 3.43, if the pressure increased, the rejection of Cl^- also increased. For high rejection membrane XUS SW30XHR-2540 the rejections for Cl^- ions were 99.53, 99.63 and 99.64% at pressures of 55, 60 and 62 bar, respectively. For conventional membrane, the corresponding rejections were 99.23, 99.51 and 99.54%, respectively.

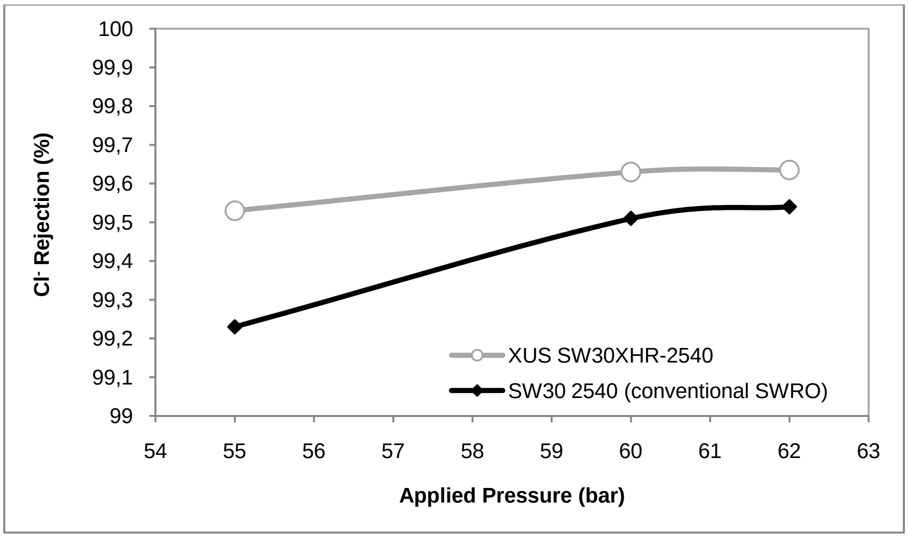

Figure 3. 43 Effect of pressure on Cl^- rejection (Tests 5, 13 and 14).

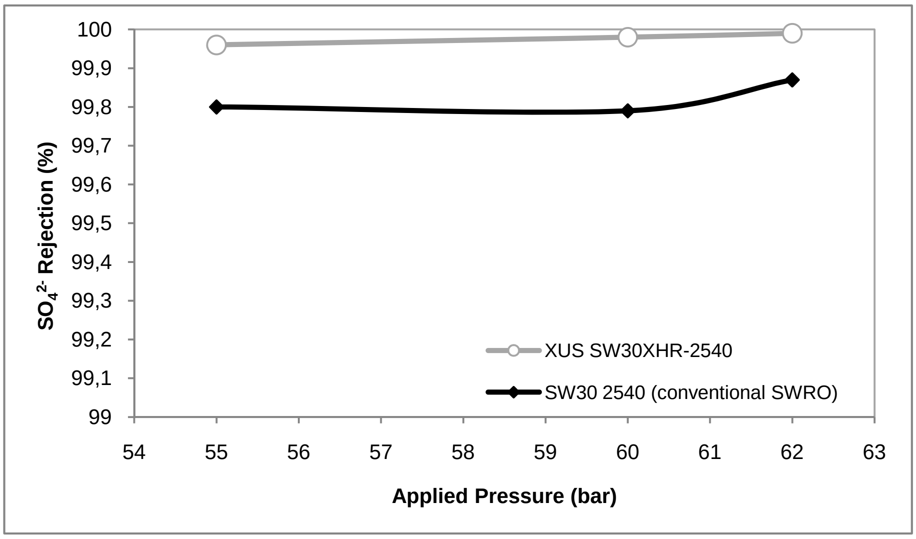

Figure 3. 44 Effect of pressure on SO_4^{2-} rejection (Tests 5, 13 and 14).

Sulphate rejection has increasing trend with increasing pressures for SW30 2540 membrane but rejection values were closer to each other for both types of membranes. The rejections obtained at 55, 60 and 62 bars were 99.96, 99.98 and 99.99% for high rejection XUS SW30XHR-2540 membrane, respectively and 99.80, 99.79 and 99.87% for SW30-2540 membrane.

The carbonate ions were completely rejected from seawater with 100% rejection for both membranes at each pressure. In Figure 3.45, bicarbonate rejections were shown. As pressure increased from 55 to 60 bar, bicarbonate rejection did not change so significantly for both membranes. At 62 bar, bicarbonate rejection increased for both membranes.

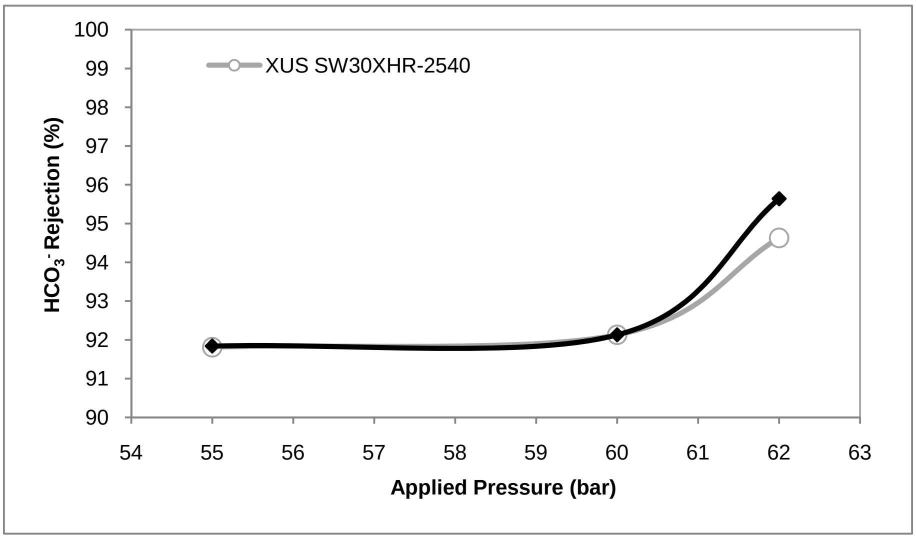

Figure 3. 45 Effect of pressure on HCO_3^- rejection (Tests 5, 13 and 14).

The turbidities of permeate were 0.09, 0.14 and 0.11 NTU at 55, 60 and 62 bar respectively for high rejection XUS SW30XHR-2540 membrane. Feed seawater turbidities were 0.27, 0.46 and 0.47 NTU, respectively at 55, 60 and 62 bar of pressure for high rejection XUS SW30XHR-2540 membrane. For SW30-2540 membrane, turbidities were 0.11, 0.22 and 0.21 NTU at pressures of 55, 60 and 62 bar, respectively (Figure 3.46).

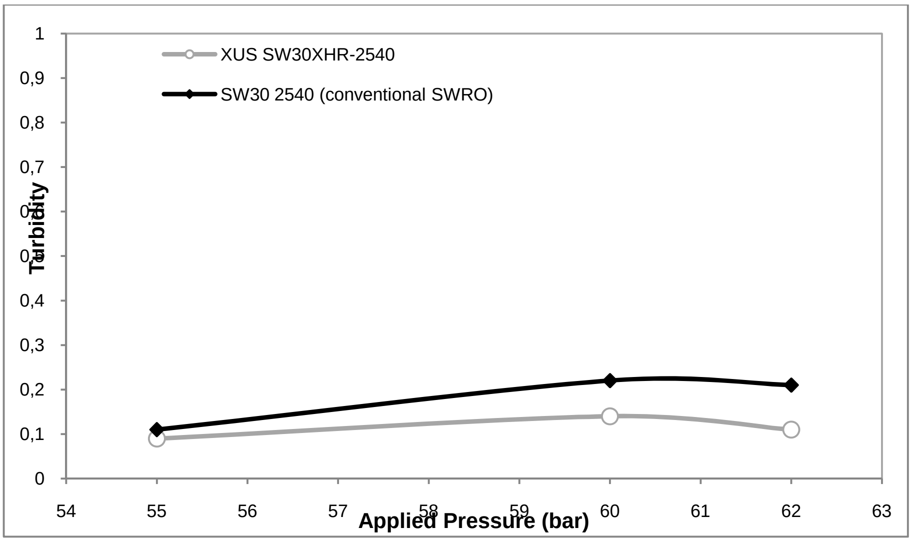

Figure 3. 46 Effect of pressure on permeate turbidity (Tests 5, 13 and 14).

3.2. Long-term Studies

Long-term operational data were collected for both types of membranes, high rejection XUS SW0XHR-2540 membrane and SW30-2540 membrane, for different experimental time (12 and 24 h). Permeate samples were collected from the system at each hour during the first 6 h and at each two hours during the remaining 6 or 18 h. Experiments were performed at natural pH (8.3-8.4) and at 55 and 60 bar. Feed flow rate was 275-292 L/h while permeate flow rate between 52-67 L/h. Table 3.1 shows the characteristics of feed seawater and Table 3.2 ion concentrations of feed seawater for long-term experiments.

Table 3. 1 Characteristics of the feed seawater

Test Number	Seawater Temp. (°C)	Operation Time (hour)	Applied pressure (bar)	EC (mS/cm)	TDS (mg/L)	Flow rate (L/h)	pH	Salinity (‰)
25	29.1	12	60	57.8	39634	292.2	8.3	38.8
26	28.6	24	55	58.1	39839	276.0	8.4	38.9
27	26.6	24	55	58.4	39838	276.6	8.4	39.0
28	26.9	12	60	58.3	39839	280.2	8.4	39.0

Table 3. 2 Ion concentrations of feed seawater

Test Number	Na^+ (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	K^+ (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)	CO_3^{2-} (mg/L)	Turbidity (NTU)
25	14650	557	1214	781	26505	3379	123.34	0	0.17
26	14400	541	1173	750	26495	3253	148.01	0	0.13
27	16650	640	807	503	25286	3616	160.34	0	0.22
28	14850	575	1442	779	25312	3476	160.34	0	0.21

At this part, two types of membranes were compared with their performances at 60 bar for 12 h and at 55 bar for 24 h.

3.3.1 Comparison two membranes at 60 bar for 12 h

RO tests were performed at 60 bar for 12 h. In order to compare the performance of two membranes for the long term of operation in terms of cations, anions, carbonate, bicarbonate and turbidity rejection, Figures 3.47-3.53 were plotted.

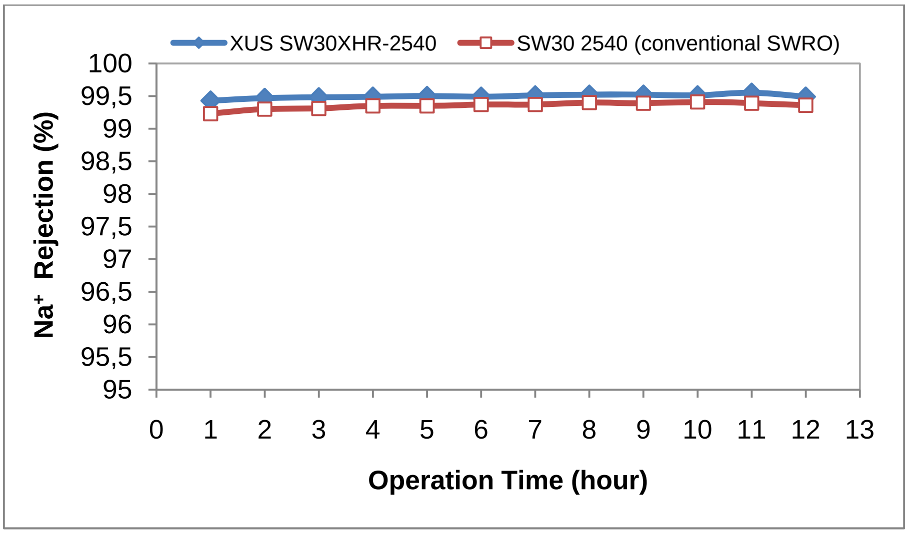

Figure 3. 47 Variation in permeate Na^+ rejection of the membranes for long term operation (Tests 25(XUS SW30XHR-2540) and 28 (SW30 2540 conventional membrane)).

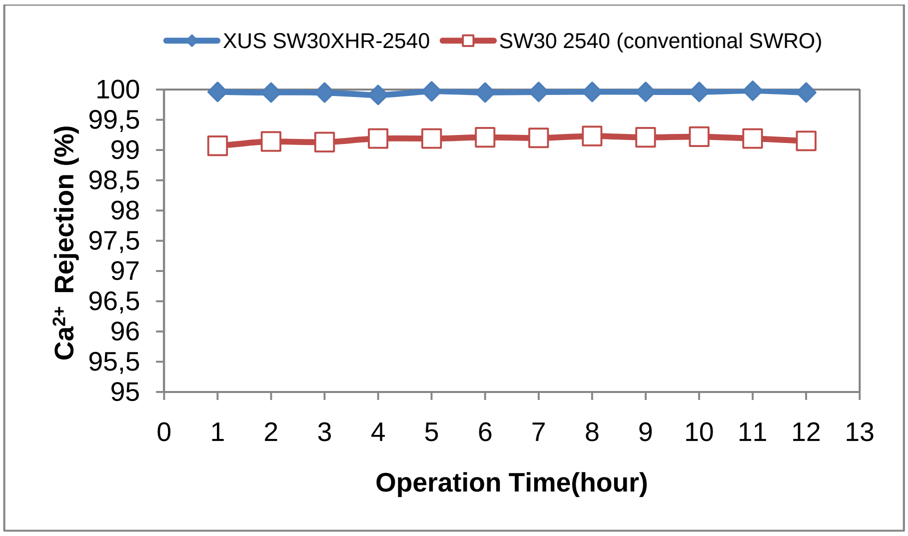

Figure 3. 48 Variation in permeate Ca^{2+} rejection of the membranes for long term operation (Tests 25(XUS SW30XHR-2540) and 28 (SW30 2540 conventional membrane)).

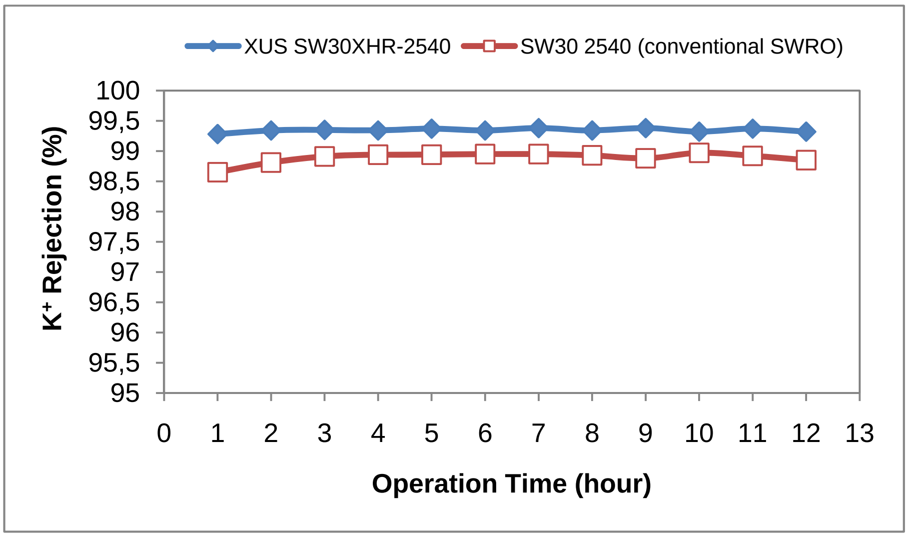

Figure 3.49 Variation in permeate K^+ rejection of the membranes for long term operation (Tests 25(XUS SW30XHR-2540) and 28 (SW30 2540 conventional membrane)).

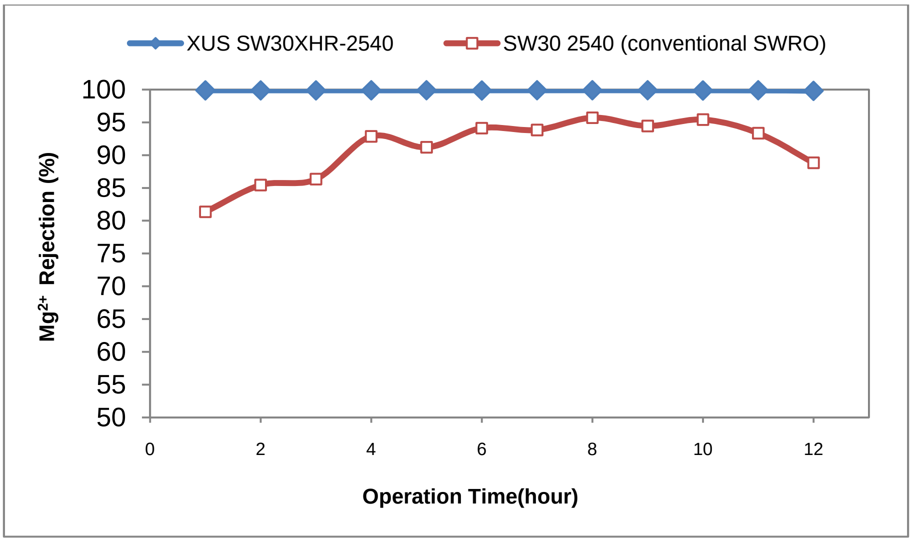

Figure 3.50 Variation in permeate Mg^{2+} rejection of the membranes for long term operation (Tests 25(XUS SW30XHR-2540) and 28 (SW30 2540 conventional membrane)).

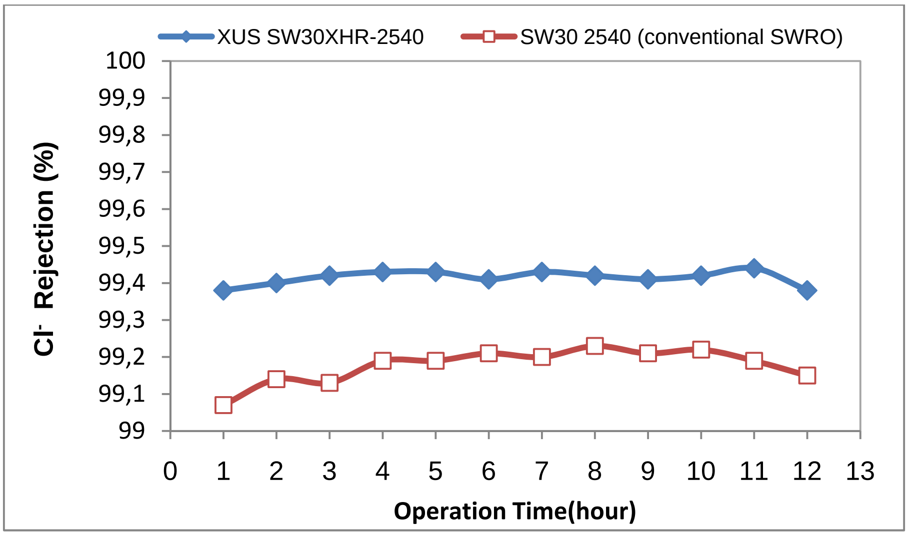

Figure 3.51 Variation in permeate Cl^- rejection of the membranes for long term operation (Tests 25(XUS SW30XHR-2540) and 28 (SW30 2540 conventional membrane)).

As seen in Figures 3.47-3.51, high rejection membrane performance was higher that of conventional membrane during 12 h.

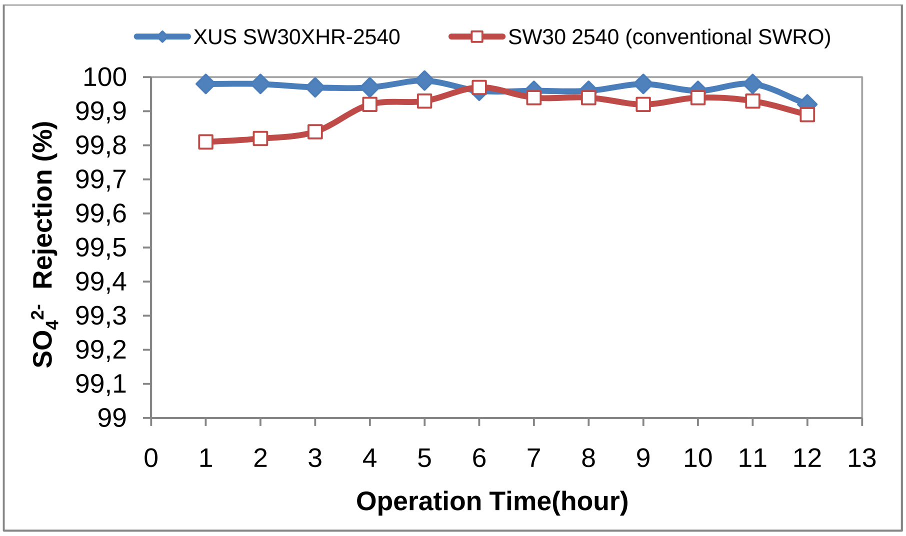

Figure 3.52 Variation in permeate SO_4^{2-} rejection of the membranes for long term operation (Tests 25(XUS SW30XHR-2540) and 28 (SW30 2540 conventional membrane)).

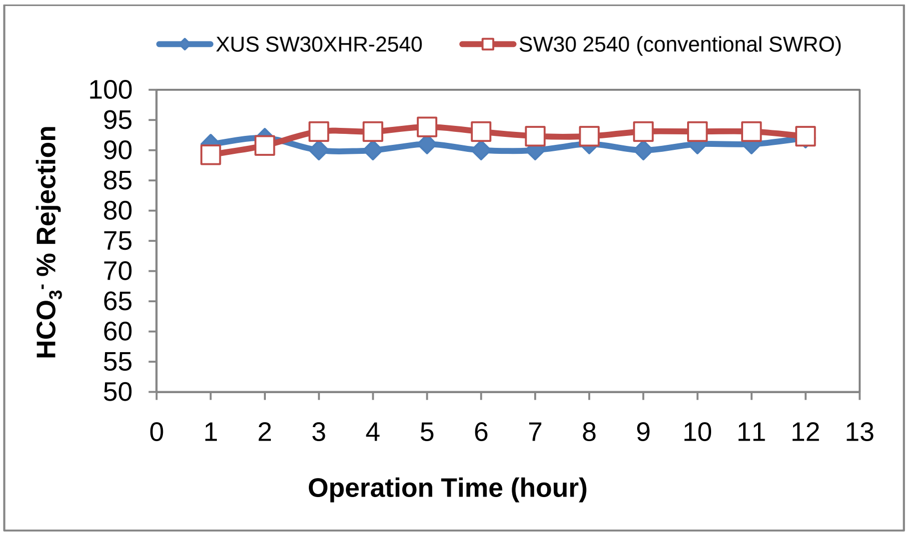

Figure 3.53 Variation in permeate HCO_3^- rejection of the membranes for long term operation (Tests 25(XUS SW30XHR-2540) and 28 (SW30 2540 conventional membrane)).

In Figure 3.52, some points were overlapping but high rejection membrane performance was higher. As seen in Figure 3.53, bicarbonate rejection using conventional membrane was better.

3.3.2 Comparison of two membranes at 55 bar for 24 h

Studies at 55 bar were performed for 24 h. As seen in Figures 3.54-3.60, for both types of membranes, results showed that, when studies were performed, rejection stayed nearly constant in the long term tests.

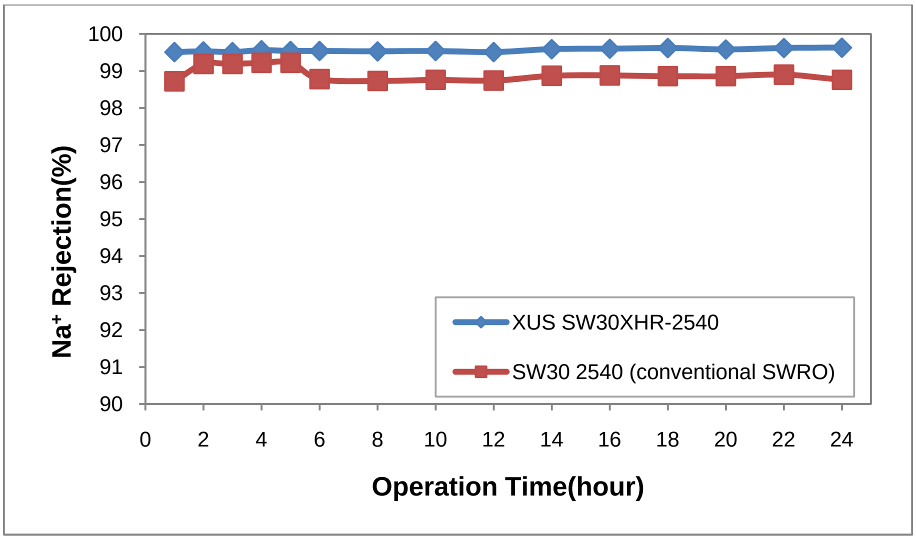

Figure 3.54 Variation in permeate Na^+ rejection of the membranes for long term operation (Tests 26 (XUS SW30XHR-2540) and 27 (SW30 2540 conventional membrane)).

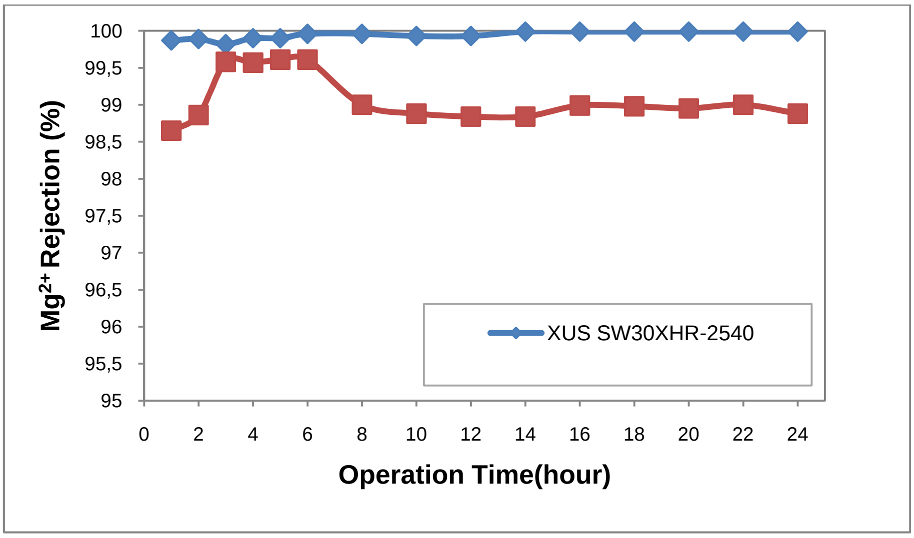

Figure 3.55 Variation in permeate Mg^{2+} rejection of the membranes for long term operation (Tests 26 (XUS SW30XHR-2540) and 27 (SW30 2540 conventional membrane)).

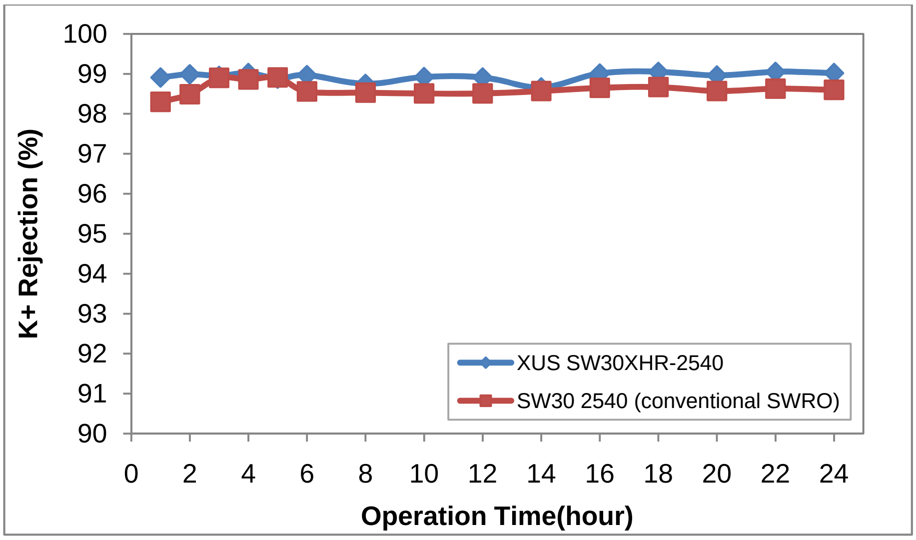

Figure 3.56 Variation in permeate K^+ rejection of the membranes for long term operation (Tests 26 (XUS SW30XHR-2540) and 27 (SW30 2540 conventional membrane)).

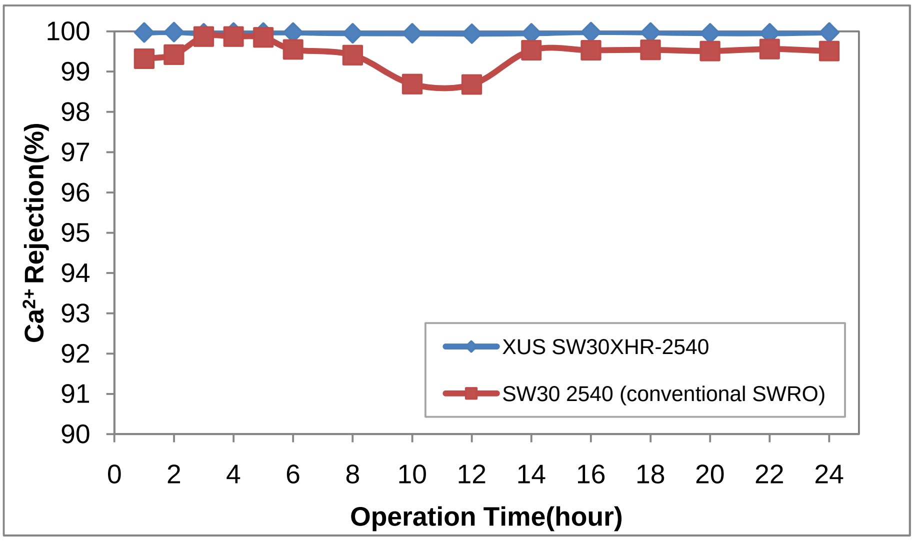

Figure 3.57 Variation in permeate Ca^{2+} rejection of the membranes for long term operation (Tests 26 (XUS SW30XHR-2540) and 27 (SW30 2540 conventional membrane)).

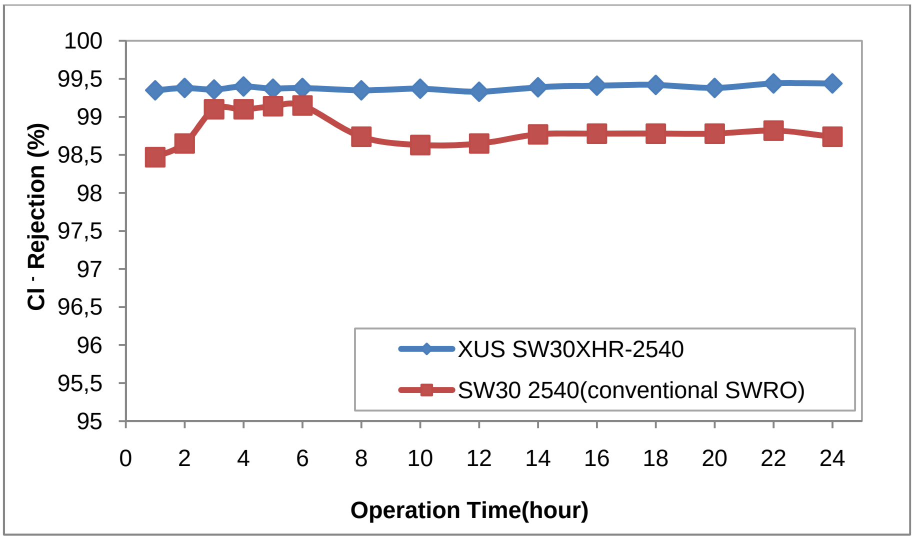

Figure 3.58 Variation in permeate Cl^- rejection of the membranes for long term operation (Tests 26 (XUS SW30XHR-2540) and 27 (SW30 2540 conventional membrane)).

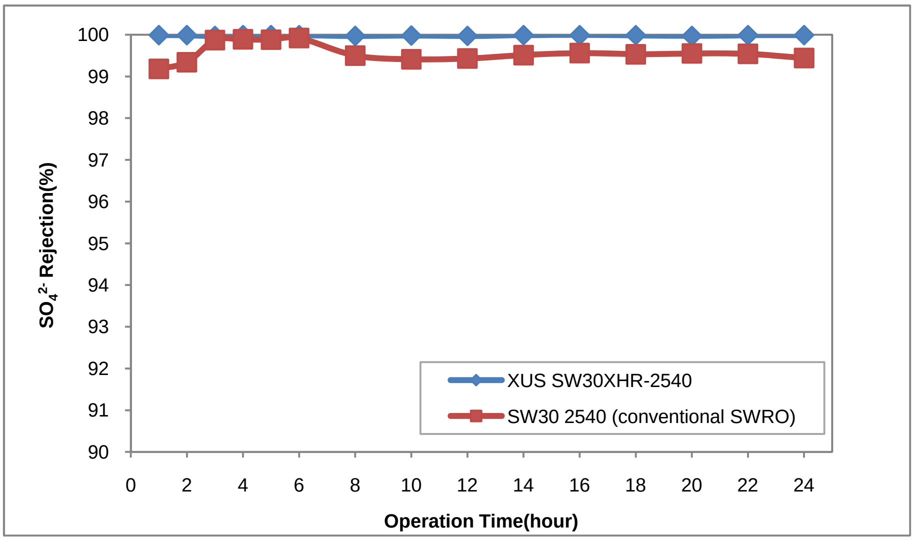

Figure 3. 59 Variation in permeate SO_4^{2-} rejection of the membranes for long term operation (Tests 26 (XUS SW30XHR-2540) and 27 (SW30 2540 conventional membrane)).

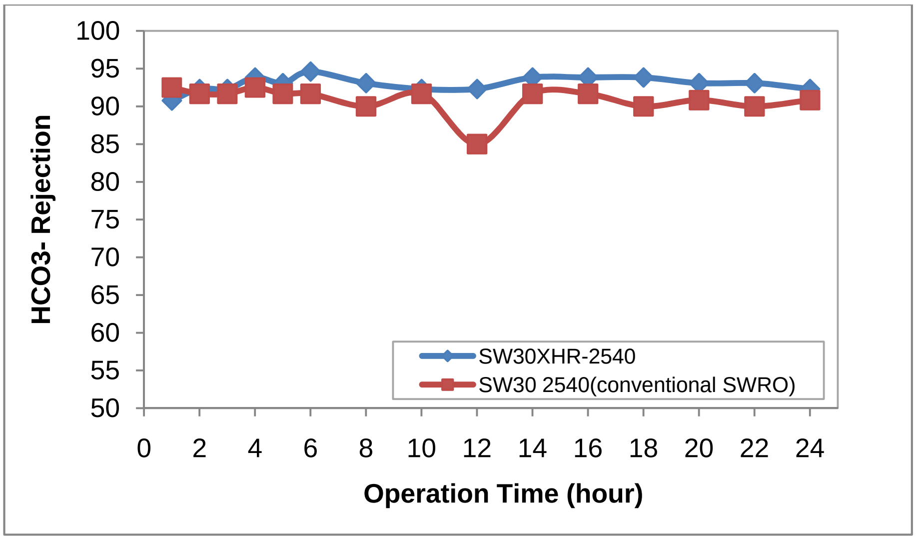

Figure 3. 60 Variation in permeate HCO_3^- rejection of the membranes for long term operation (Tests 26 (XUS SW30XHR-2540) and 27 (SW30 2540 conventional membrane)).

3.4 Reverse osmosis performance for both membranes during one year of operation

RO performance of both types of membranes was investigated during one year of operation. For that, data were collected from November 2008 until November 2009 (Tests 3, 6, 9, 10, 12, 15, 16, 18, 19, 20, 22 and 23).

Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, HCO_3^- and SO_4^{2-} concentrations of product water were investigated for both types of membranes. All data in the graphs were calculated by taking average of data series. Tests which were performed at 55 bar were used. Table 3.3 and 3.4 show the data collected during one-year of operation for both membranes.

Table 3. 3 Results for one-year operation for high rejection XUS SW30XHR-2540 membrane

Month / Parameters	Nov	Dec.	Jan.	Feb.	Mar	Apr.	May	June	July	Aug	Sept	Nov
Temp.(°C)	17.7	10.8	13.5	13.9	13.2	15.8	20.4	25.6	27	24.8	22.0	18.1
pH	7.0	7.1	7.1	7.0	7.4	7.4	7.2	7.7	7.5	7.4	7.4	7.2
Conductivity (µS/cm)	0.353	0.318	0.332	0.344	0.360	0.381	0.460	0.533	0.598	0.543	0.470	0.390
TDS	177	159	139	172	180	191	230	266	299	234	236	196
Na^+ (mg/L)	33.67	53.93	55.00	39.10	50.55	53.43	64.13	57.18	70.68	81.84	72.50	61.67
K^+ (mg/L)	2.84	3.09	2.84	3.00	2.95	2.40	3.14	3.97	4.80	5.00	5.48	4.65
Mg^{2+}(mg/L)	1.41	1.96	2.77	2.60	3.00	3.87	1.44	3.70	4.58	1.25	1.78	1.94
Ca^{2+}(mg/L)	0.32	0.40	0.56	0.96	0.55	0.46	0.44	0.34	0.37	0.18	0.15	0.14
Cl^-(mg/L)	111.36	100.10	103.30	105.25	108.94	113.36	143.07	160.34	186.25	151.00	144.72	114.87
SO_4^{2-}(mg/L)	2.88	1.33	0.70	0.51	0.52	B.L.D.*	0.28	0.63	0.73	B.L.D.	B.L.D.	B.L.D.
HCO_3^- (mg/L)	23.12	13.97	12.33	10.28	13.15	10.48	10.68	12.33	12.54	9.87	8.22	9.04
Turbidity (NTU)	0.11	0.10	0.18	0.12	0.16	0.10	0.15	0.05	0.03	0.06	0.04	0.07

*:below limit of detection

Table 3. 4 Results for one-year operation for SW30-2540 conventional membrane

Month / Parameters	Nov	Dec.	Jan.	Feb.	Mar	Apr.	May	June	July	Aug	Sept	Nov
Temp.(°C)	17.7	10.8	13.5	13.9	13.2	15.8	20.4	25.6	27	24.8	22.5	18.1
pH	8.1	7.4	7.9	7.4	7.6	7.9	7.4	8.3	8.0	7.9	7.5	7.2
Conductivity (µS/cm)	0.550	0.527	0.559	0.567	0.468	0.580	0.926	2.02	1.89	1.97	1.14	0.78
TDS	276	264	280	283	234	290	463	1009	947	473	575	394
Na^+ (mg/L)	55.67	92.50	101.60	66.40	62.98	80.51	131.73	234.18	240.65	153.33	166.50	116.17
K^+ (mg/L)	5.66	5.25	5.10	5.60	4.45	4.23	7.06	14.72	14.60	9.90	11.80	9.00
Mg^{2+}(mg/L)	2.75	4.00	4.90	5.00	6.71	9.56	14.45	37.00	20.10	7.20	10.80	7.50
Ca^{2+}(mg/L)	0.50	0.92	1.15	1.21	0.87	1.08	2.28	7.41	6.60	2.02	3.03	1.45
Cl^-(mg/L)	173.88	168.50	172.30	172.90	137.44	171.34	279.95	610.18	583.80	266.67	322.23	218.17
SO_4^{2-} (mg/L)	4.44	4.00	3.66	3.17	3.79	4.98	16.76	47.88	14.80	7.47	15.83	5.08
HCO_3^- (mg/L)	26.19	12.95	13.36	10.90	14.40	12.33	11.70	14.80	15.20	12.13	11.10	10.28
Turbidity (NTU)	0.14	0.16	0.18	0.13	0.16	0.08	0.16	0.04	0.06	0.09	0.11	0.08

Figures 3.61-3.67 show variations of permeate Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, SO_4^{2-} and HCO_3^- rejections (respectively) during one year of operation period for two types of membranes, high rejection XUS SW30XHR-2540 membrane and SW30-2540 membrane.

As seen in Figures 3.61-3.66, when temperature increased, rejection performance decreased for SW30-2540 membrane. Temperature change did not affect the rejection performance for high rejection XUS SW30XHR-2540 membrane. In summer season (especially June and July), rejection of all species was lower for SW30-2540 membrane. For all of the species, rejection values of high rejection membrane were higher than those of SW30-2540 membrane during one-year study.

For SW30-2540 membrane, the highest Na^+ rejection was 99.50% at 13.9ºC and lowest rejection (98.06%) was obtained at 27.0ºC.

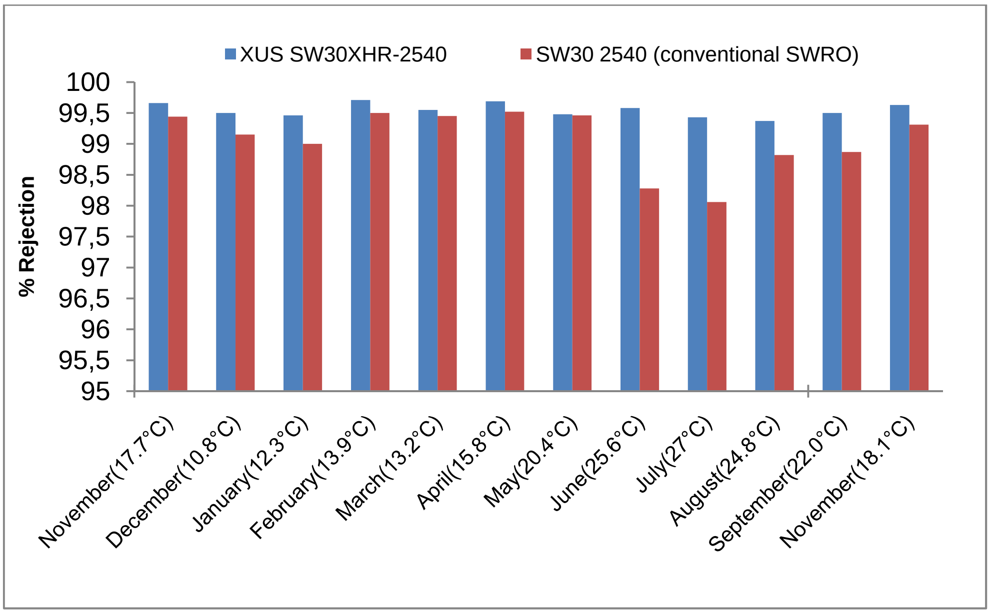

Figure 3.61 Variations in Na^+ rejections of permeate during one year of operation (Tests 3, 6, 9, 10, 12, 15, 16, 18, 19, 20, 22 and 23)

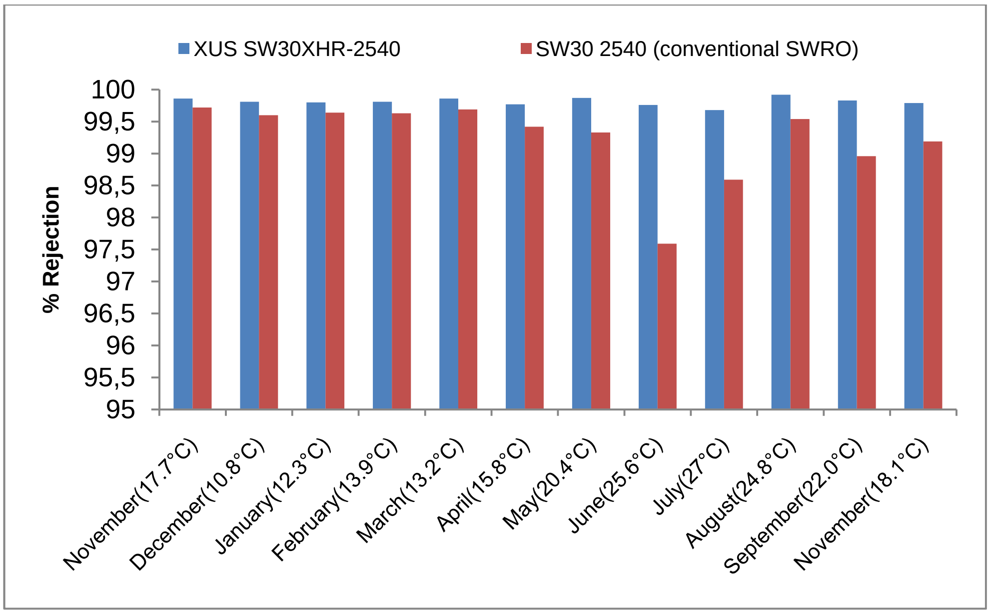

Figure 3.62 Variations in Mg^{2+} rejections of permeate during one year of operation (Tests 3, 6, 9, 10, 12, 15, 16, 18, 19, 20, 22 and 23)

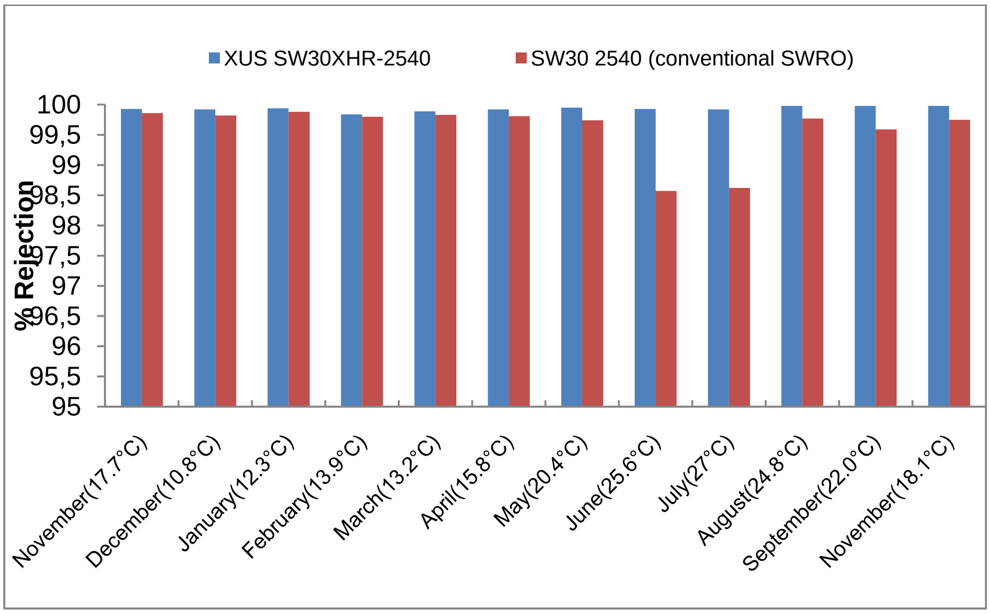

Figure 3.63 Variations in Ca^{2+} rejection of permeate during one year of operation (Tests 3, 6, 9, 10, 12, 15, 16, 18, 19, 20, 22 and 23)

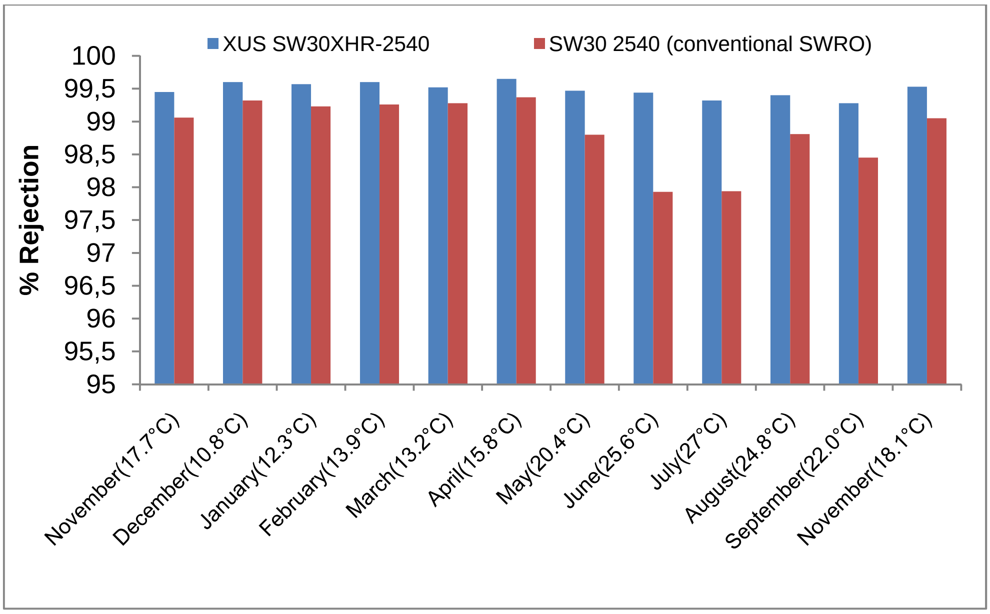

Figure 3.64 Variations in K^+ rejections of permeate during one year of operation (Tests 3, 6, 9, 10, 12, 15, 16, 18, 19, 20, 22 and 23)

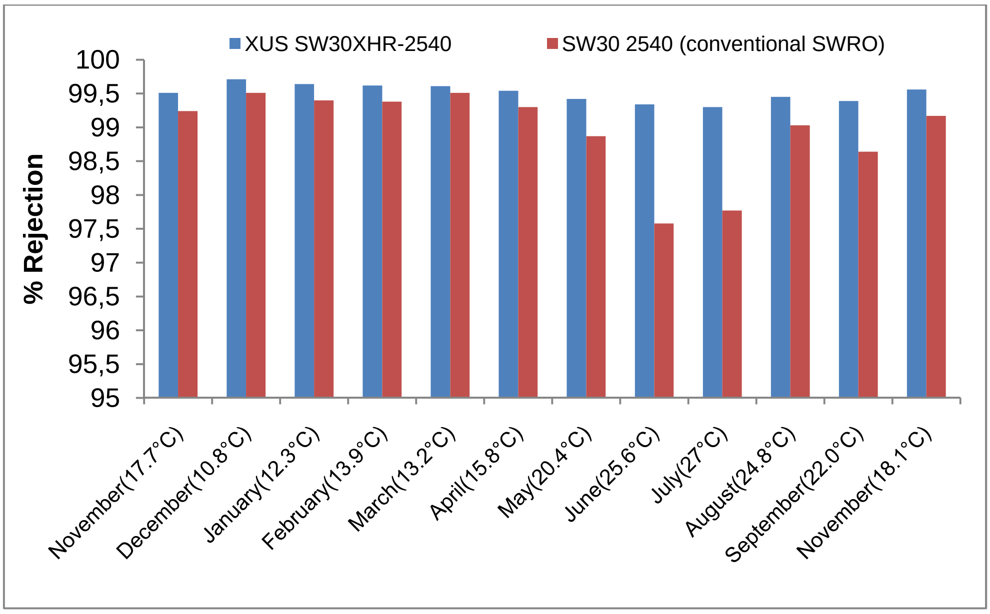

Figure 3.65 Variations in Cl^- rejections of permeate during one year of operation (Tests 3, 6, 9, 10, 12, 15, 16, 18, 19, 20, 22 and 23)

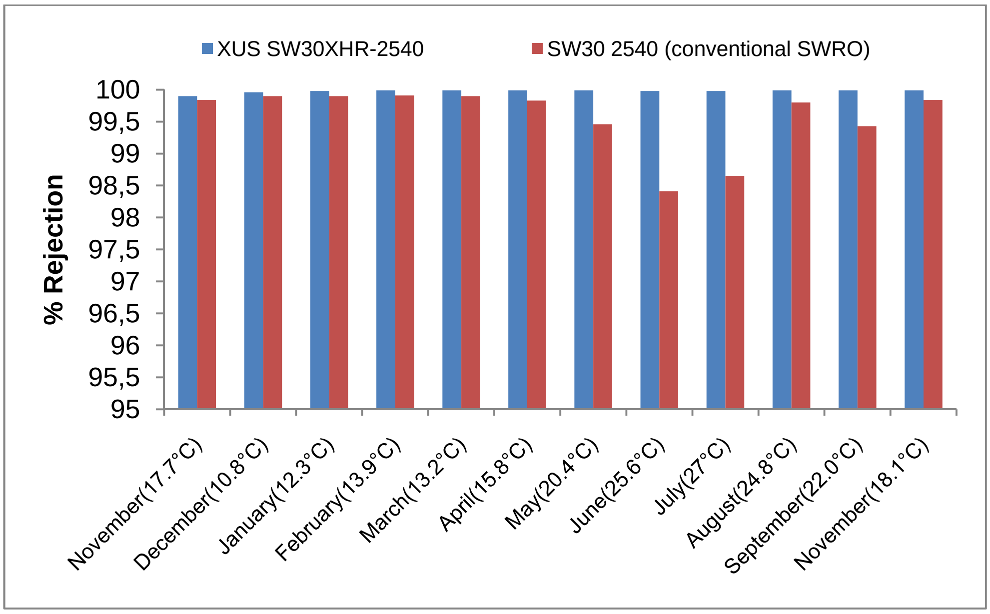

Figure 3.66 Variations in SO_4^{2-} rejections of permeate during one year of operation (Tests 3, 6, 9, 10, 12, 15, 16, 18, 19, 20, 22 and 23)

For the months June and July when the seawater temperature was highest, Mg^{2+}, Ca^{2+}, K^{+}, Cl^{-} and SO_4^{2-} rejections were lower than at other months for SW30-2540 membrane.

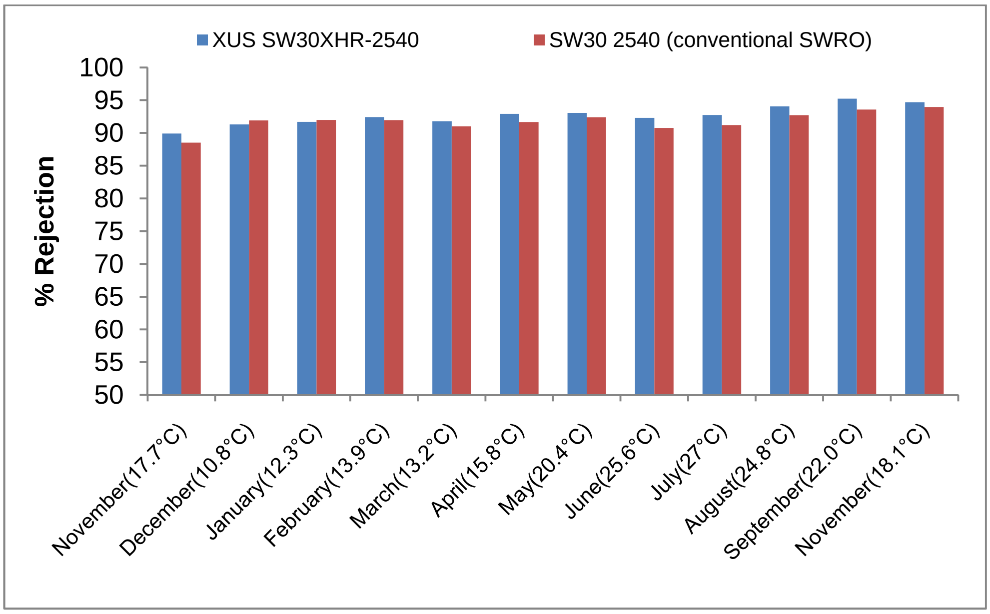

Figure 3.67 Variations in HCO_3^- rejections of permeate during one year of operation (Tests 3, 6, 9, 10, 12, 15, 16, 18, 19, 20, 22 and 23)

From Figure 3.67, it can be seen that temperature did not affect the HCO_3^- rejection and also difference of HCO_3^- rejections for both membranes was small. But in December and January, HCO_3^- rejection of SW30-2540 membrane was higher than that of high rejection XUS SW30XHR-2540 membrane.

3.5 Evaluation of product water from RO plant as drinking and/or irrigation water

Quality of product water which was obtained by using reverse osmosis system, was compared for both types of membranes. The permeate quality was also compared with irrigation and drinking water quality standards to see whether the product water is suitable to drink and/or to use it for irrigation. In Table 3.4, a comparison for ion concentrations of Urla permeate obtained by using two different membranes with water quality standards (WHO, TSE, irrigation water standards) were given.

It was seen that all characteristics of product water such as TDS, conductivity, pH, Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^- and turbidity, were below the limit of water standards values. So we can consider that Urla permeate water is suitable to use as irrigation and drinking water in terms of the water characteristics measured.

In order to use permeate obtained by using reverse osmosis method, as irrigation or/and drinking water, some other characteristics such as microbiological properties and some other chemical characteristics (trace elements etc) should be also checked.

Table 3. 3 Comparison of product water quality with water quality standards

Parameters	WHO Drinking water	TSE 266 Drinking Water	Irrigation Water	XUS SW30XHR-2540 (13.2^{o}C, 55 bar)	SW30 2540 (conventional SWRO) (13.2^{o}C, 55 bar)
TDS	1000	1500	1st Class	180	234
Conductivity (µS/cm)	500-800	2500	1st Class	360	468
pH	6.5-8.8	6.5-9.2	1st Class	7.1	7.6
Cl^- (mg/L)	250	600	1st Class	108.94	137.44
Na^+ (mg/L)	200	175	1st Class	50.55	62.98
Mg^{2+} (mg/L)	30	50	1st Class	3.00	6.70
Ca^{2+} (mg/L)	75	200	1st Class	0.55	0.87
K^+ (mg/L)	N.G.	12	No guideline	2.95	4.45
SO_4^{2-} (mg/L)	250	250	1st Class	0.52	3.80
HCO_3^- (mg/L)	No guideline	No guideline	No guideline	12.33	14.40
Turbidity (NTU)	< 0.5	< 1	No guideline	0.16	0.16

4 CONCLUSIONS

Water is he most important life source. Because of the water scarcity in the world, alternative water resources such as seawater, has become popular. Desalination of seawater has been used to protect fresh water in consumption. Quality of fresh water which is obtained from desalination of seawater by reverse osmosis (RO) method, should be suitable for people consumption.

In this study, the quality of product water obtained from RO method was analysed using various analytical methods. The suitability of product water as irrigation and/or drinking water was investigated and was compared with well-established water quality criteria (WHO, EPA, TSE and irrigation water criteria). The product water was found suitable in terms of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, Cl^{-} and turbidity of water.

The effect of applied pressure and temperature was investigated for two types of membranes, SW30 2540 and high rejection XUS SW30XHR-2540. While applied pressure had positive effect on product water quality, temperature increase affected the rejections of species from feed seawater negatively. When temperature was increased, rejection decreased for both two types of membranes. Rejections obtained by using high rejection membrane XUS SW30XHR-2540 was higher than that of SW30-2540 membrane.

Long term performances of RO membranes were also investigated for 12 and 24 h of operation periods. High rejection XUS SW30XHR-2540 membrane exhibited better performance than conventional SW30-2540 membrane during long-term of operation.

During one-year of RO operation tests, the obtained results showed that the rejections of species were lower in summer season (June and July) because of the increase in temperature.

When RO permeate results were compared with water quality standards, it can be concluded that concentrations of various species in product waters produced using both membranes were below the limit of water standards values. Urla permeate water was suitable to use as irrigation and drinking water in terms of investigated characteristics. To be able to use permeate water as irrigation or drinking water, some other characteristics such as microbiological and the other chemical parameters should be also checked.

CHAPTER TWO

SEPARATION OF ENDOCRINE DISRUPTORS (DİMETYL PHTHALATES, DİETYL PHTHALATES AND BİS PHENOL A) FROM WATER BY MOLECULARLY IMPRINTED POLYMERS

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CHAPTER TWO

1.INTRODUCTION

1.1 Pthalates

Phthalates or phthalate esters, are esters of phthalic acid. Phthalic esters (PEs) are a group of chemicals widely used as additive in the manufacturing of plastics. They are listed as priority pollutants in many countries due to their suspected mutagenicity and endocrine disrupting effects. Since PEs are not chemically bound to the host plastics, they are inevitably leached from the products and released to the environment ultimately. They have been detected in surface water, wastewater, sewage sludge and sediment, as well as landfill leachate (Liang, 2007).

Phthalate esters are used in virtually every major product category including construction, automotive, household products, package and medicine products. They represent a large family of chemicals, which are widely used as plastisizers primarily in the production of polyvinyl chloride (PVC) resins. The short-chained esters (dimethyl and diethyl phthalate esters) are typically used in cellulose ester-based plastics, such as cellulose acetate or butyrate, respectively. As these products become waste and are exposed to photochemical, thermal and microbial degradation, the phthalate esters are leached out by water thus turning into ubiquitous water pollutant. Some of the phthalate esters, especially the long chained esters, have been recognized as cancer suspect agents and are, therefore, considered as priority pollutant. In addition, phthalate esters are found to accumulate in the environment and to be toxic to a variety of aquatic organisms, which are at the base natural food chain in both marine and fresh water environments. Numerous studies have demonstrated the biodegradability of severalphthalate esters from soil, synthetic or real waste waters by activated sludge treatment, by biodegradation from natural sources of microorganisms or by pure bacteria cultures and strains isolated from these habitats (Muneer, 2001).

A wide spectrum of use has been found for the phthalic acid esters (PAEs) and the largest market for these esters is as plasticizing agents for poly(vinyl chloride) products. The plasticizers are not irreversibly bound in the polymer matrix, and with certain use or disposal conditions, can migrate from the plastic to the external environment. PAEs have been ubiquitous environmental pollutant because of their widespread manufacture, use, and disposal, as well as their high concentration in plastics and their ability to migrate from the plastics. Dibutyl phthalate (DBP) is a PAE that is used as a plasticizer in elastomers such as polyvinyl, as a textile lubricating agent, as a resin solvent, and in safety glass, printing inks, paper coatings, and adhesives DBP is also used in cosmetics as a perfume solvent and fixative, as a suspension agent for solids in aerosols, as a lubricant for aerosol valves, as an antifoamer, as a skin emollient, and as a plasticizer in nailpolish, fingernail elongators, and hair spray (Ema et al., 2000).

The major field of application for phthalates is the usage as general-purpose plasticizers in polymers, primarily in PVC. Typical products containing phthalates are floorings, roofings, wall coverings, cables, sealants, coatings, paints, clothing, packaging materials, toys, lacquers and adhesives (Wittassek et al., 2007).

Because of their large and widespread use, phthalates are taken up by the general population from various sources. Since exposure to phthalates may be harmful to human health several authorities such as the European Food Safety Authority (EFSA) or the US Environmental Protection Agency (US EPA) have deduced exposure limit values for some phthalates. For purposes of health prevention, it is necessary to determine the human phthalate doses taken up by humans and if necessary to reduce exposure. An assessment of the internal phthalate exposure is generally possible by measuring the amount of specific metabolites excreted via urine. With the knowledge of human metabolism and elimination properties of the metabolites measured as a precondition, daily phthalate intakes are deducible from urinary metabolite levels (Wittassek et al., 2007).

Phthalates are important class of chemicals manufactured for use, primarily, as plasticisers in polyvinyl resin, cellulosic and polyurethane polymers for manufacturing building materials, home furnishings, transportation, clothing, and for packaging of food and medical products. Dimethyl phthalate (DMP) is typically used in cellulose-ester based plastics, such as cellulose acetate and butyrate, which are esters of 1,2-benzenedicarboxylic acid sharing a common structure made up of a benzene ring with two side chains. Phthalates with lower molecular weight are toxic to aquatic organisms (e.g.DMP, DEP and DBP). They are also used as additives in paints, adhesives, cardboard, lubricants and fragrances. Phthalates have also been observed to have disrupting properties on the endocrine system (Pirsaheb et al., 2009).

Phthalates are the group of multifunctional chemicals used in consumer and personal care products, plastics, and medical devices. Laboratory studies show that some phthalates are reproductive and developmental toxicants. Recently, human studies have shown measurable levels of several phthalates in most of the U.S. general population. Despite their widespread use and the consistent toxicologic data on phthalates, information is limited on sources and pathways of human exposure to phthalates (Hauser et al., 2004).

1.1.1 Dimetyl Pthalate (DMP)

Dimethyl phthalate (DMP), one of the phthalate ester isomers, has two carboxyl groups at the ortho-position on the aromatic ring (Figure 1.1). DMP has been listed as ‘‘priority pollutant’’ by the U.S. EPA (Fang et al., 2009).

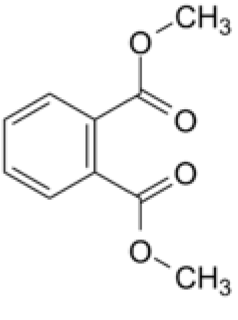

Figure 1.1 :Structure of Dimetyl Pthalate

DMP is an ingredient in some hair care products, including aerosol fixatives. The reported maximum concentration of use of DMP in cosmetics is 2% in aerosol hair sprays (Api, 2001). Phthalate acid esters (PAEs) are a large class of chemicals widely used in the plastics manufacturing industries as plasticizers. It has been used in the production of PVC for over half a century and in other industrial products relying on softness and flexibility such as home furniture, daily used containers and children's toys (Gu et al., 2009).

DMP is of low to moderate toxicity, but when accidentally ingested in large amounts it may cause gastrointestinal irritation, central nervous system depression with coma, and hypotension. It is an irritant to the eyes and the mucous membranes. It is not irritant to the skin and is not absorbed (Claytonet al., 1981).

Dimethyl phthalate (DMP) was also assayed for its toxicity, but no carcinogenic activity in male and female rats has been demonstrated in the relevant investigations. However, uncertainty of its effects on the male and female mice tested has not been resolved in terms of carcinogenic activity. Large uptake of DMP instigated central nervous depression and noticeable kidney damage (Gu et al., 2009).

1.1.2 Diethyl Pthalates

Diethyl phthalate is a colourless liquid with a slight aromatic odour and low volatility. It is soluble in water (1000 mg/litre at 25 °C). Diethyl phthalate is used as a plasticizer in a wide variety of consumer products, including plastic packaging films, cosmetic formulations, and toiletries, as well as in medical treatment tubing. As a result of its use, human exposure to diethyl phthalate is expected to be significant (Api, 2001).

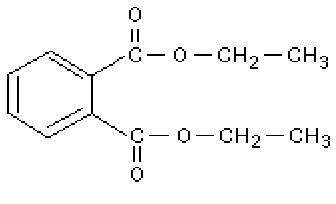

Figure 1.2:Structure of Diethyl Pthalate

Currently, there is a scientific and public concern about potential human health risks from exposure to phthalates and diesters of phthalic acid. Diethyl phthalate (DEP) was found in 71% of personal care products; it was also found in 57% of the perfumes and 25% of the deodorants surveyed. In a limited study, DEP was found in different medical devices, including dialysis tubing and intestinal tubing. In a recent study, urinary concentrations of monoethyl phthalate (MEP), a metabolite of DEP, were found to be high in both males and females, indicating high usage of DEP in various personal care products. DEP is also known to be transported through the placenta, making it potentially a health risk to future generations. So far, no studies have reported the effect of DEP on the histology of adrenal and thyroid glands, but increase in weights of both these organs have been reported in an earlier study (Pereira et al., 2007).

Diethyl phthalate is used as a plasticizer for cellulose ester plastic films and sheets (photographic, blister packaging, and tape applications) and moulded and extruded articles (consumer articles such as toothbrushes, automotive components, tool handles, and toys). There is a wide variety of consumer products that contain diethyl phthalate or are covered with diethyl phthalate-containing plastic packaging. Diethyl phthalate was reported as an ingredient in 67 cosmetic formulations, including bath preparations (oils, tablets, and salts), eye shadow, toilet waters, perfumes and other fragrance preparations, hair sprays, wave sets, nail polish and enamel removers, nail extenders, bath soaps, detergents, aftershave lotions, and skin care preparations. More specifically, diethyl phthalate is used in nail polish as a solvent for nitrocellulose and cellulose acetate, in perfumes as a fixative and solvent, in toilet preparations as an alcohol denaturant, and in fingernail elongators as a plasticizer. In addition, diethyl phthalate is used as a component in insecticide sprays and mosquito repellents, as a camphor substitute, as a plasticizer in solid rocket propellants, as a wetting agent, as a dye application agent, as an ingredient in aspirin coatings, as a diluent in polysulfide dental impression materials, and in adhesives, plasticizers, and surface lubricants used in food and pharmaceutical packaging. In a limited study, the concentrations of diethyl phthalate in different medical devices, including dialysis tubing, were generally low (<1% of total volatiles), with the exception of a sample of intestinal tubing, in which the concentration of diethyl phthalate reached <20% of total volatiles. Polyvinyl chloride (PVC) tubing may still be used for dialysis patients (Wahl et al., 1999).

In a recent study, daily exposure of DEP to population of mothers of male infants showing reduced AGD was found to be 6.64 µg/kg/day which was much lower as compared to the current USEPA levels found i.e. 800 µg/kg/day of DEP. (Pereira et al., 2007).

US EPA (1993) reviewe an unpublished study in which groups of 15 male and 15 female rats were administered 0, 0.5, 2.5, or 5.0% diethyl phthalate (corresponding to approximately 0, 250, 1250, or 2500 mg/kg body weight per day, respectively) in the diet for 2 years. Decreased body weight gain without depression of food intake was detected in the high-dose groups (males and females) only throughout the study. No other effects related to diethyl phthalate exposure were observed in the following examinations: haematology, blood sugar and nitrogen, urinalysis, and gross pathological observation or histopathology. Due to the small study size, the study is inadequate for the evaluation of carcinogenicity (EPA, 1993).

1.2 Bis Phenol A

Bis Phenol A [BPA;2,2-bis(4-hydroxyphenyl)propane] is made by combining acetone and phenol and is widely used as a material for the production of epoxy resins, phenol resins, polycarbonates, polyacrylates, polyesters, and lacquer coatings on food cans. BPA is known as one of endocrine disruptors and has an acute toxicity to aquatic organisms in the range of 1–10 µg/ml for freshwater and marine species (Kang et al., 2005). BPA can contaminate aquatic environment owing to its release from industrial waste water. It has been evidenced that BPA cannot be completely eliminated by conventional treatment in drinking water supplies and in some case, can conduct to by-products with higher endocrine disrupting action (Torres et al., 2007).

Most (99.9%) domestically produced BPA is used by the manufacturers as an intermediate in the production of polycarbonate and epoxy resins, flame retardants, and other specialty products. Final products include adhesives, protective coatings, powder paints, automotive lenses, protective window glazing, building materials, compact disks, optical lenses, thermal paper, paper coatings, as a developer in dyes, and for encapsulation of electrical and electronic parts. BPA may be inadvertently released as fugitive dust from closed systems during processing, handling, and transportation (Staples et al., 2000).

Human exposure to bisphenol A eventually released from these materials is of increasing concern due to its endocrine disrupting potential. In fact, BPA was one of the first chemicals discovered to mimic estrogens. In 1936, bisphenol A was found to stimulate growth of the rodent uterus, an indication of estrogenic action. The estrogenic effect of bisphenol A has been shown both in in vitro and in vivo experiments (Rodriguez-Mozaz et al., 2005).

2.EXPERIMENTAL

2.1 Materials

2.1.1 Molecularly imprinted polymers

For removal of dietyl phthalates, dimetyl phthalates and Bis Phenol A from water, molecularly imprinted polymer sorbents were used. Polymers were obtained by the bulk polymerization. To remove Bis Phenol A from water, polymer with Bis phenol A template was used. For removal of Dimetyl Pthalate (DMP) and Dietyl Pthalate (DEP) polymer was imprinted with Dibutyl Pthalate (DBP) template. To check whether this polymer was suitable for removal of Dimetyl Pthalate and Dietyl Pthalate, sorption studies were performed.

Preparation of molecularly imprinted polymer (MIP)

Procedure:

1. Inhibitors from monomers styrene (S) and divinylbenzene (DVB) were removed and monomers were extracted with 10 % solution of NaOH, washed with water.

2. Preparation of reaction mixtures: in glass tubes were mixing the right amount of monomers in which the initiator of polymerization (AIBN:Azoisobutyronitrile) was dissolved, the ratio of monomers S:DVB 3:7 wt.:wt., the amount of AIBN = 1 %wt. in the relation to monomers mixture. The solvent was added in the same volume as volume of monomers, ratio solvent:monomers = 50:50 v:v, in the case of resin without of templates the reaction mixtures were treated by nitrogen gas for removing of oxygen from reaction mixture, oxygen is an inhibitor of polymerization. In the case of polymer with imprints the right amount of Dibutyl phthalate was added. The amount of templates in the beggining mixture was 5 %wt. in the relation to monomers amount.To prepare polymer for removal of BPA, 1 mL of ethanol (96%) in the case of resin without imprint – was added to reaction mixture, in the case of resin with imprints 1 mL in which BPA was solved (7 %wt). BPA

in relation to monomers amount). After this the reaction mixture was treated by nitrogen gas too, for oxygen removing.

3. In the next step the tubes which were covered by metallic paper, were put to the dryer and the polymerization was beginning in the temperature range of 60-70 ^{0}C for 48 h.

4. After polymerization the tubes were broken, the polymers were grinded and the extraction with methanol, in the Soxhlet aparature was beggining, for 24 h- for removing of non-polymerized monomers, solvents and removing the substance which was given the imprint.

5. After extraction polymers were dried, the ground into the smaller particcles and sieved.

2.1.2 Chemicals

For sorption isotherm studies, model solutions were prepared. Dimetyl phthalates (DMP) (%99+, SAFC) and dietyl phthalates (DEP) (%99, SAFC) solutions were pretreated with ethanol (%96, POCH).

For removal of Bis Phenol A (%99+, Aldrich), 0.4 mmol/L BPA model solution was prepared. It was also pretreated with ethanol (%96, POCH).

2.2 Methods

2.2.1 Sorption experiments using polymers with imprint and without imprint

For sorption isotherms, 0.02 g polymer sorbents without imprint and with imprint were used. Sorbents were shaken in solutions containing 2.5-90.0 mg/L DMP and 1.0-50.0 mg/L DEP in pure water at 22±2 °C for 48 h.

After 48 h, samples were filtrated and concentrations of DMP and DEP were determined by spectrophotometer (JASCO V-530 UV-VIS). According to their concentrations, sorption capacities of polymer were calculated. Sorption capacity was calculated as follows:

$$S = [(C_o - C) / m] \times V \qquad (1)$$

where C_o and C are the initial and final DMP and DEP concentrations (mg/L) in the solution respectively, m the amount of the adsorbent used (g) and V the volume of the aqueous phase (L).

Figure 2.1: Spectrophotometer: JASCO V-530 UV/VIS Spectrophotometer.

2.2.2 Sorption-submerged membrane filtration hybrid method

For removing of Bis Phenol A (BPA), sorption-submerged membrane filtration hybrid system was used. This study is focused on the application of the ion exchange membrane filtration hybrid process, which comprises sorption of BPA using moleculary imprinted or without imprint polymers and membrane separation of the BPA loaded sorbent, for BPA removal from synthetic BPA solution (0.4 mmol/L).

As shown in Figures 2.2 and 2.3, the BPA containing model solution was passed through the membrane module along with polymers with imprint and without imprint of a certain amount. BPA was sorbed by sorbents. Then, the treated water was forced to penetrate into the fibre by keeping the vacuum inside. Concentrations of BPA in permeate were determined by time while feeding the fresh suspension of sorbents to the membrane module and removing saturated resin from the module. In order to protect the system against accumulation of resin on the membrane surface, the sorbent was withdrawn from the system at the same rate of feed mixture entering into the membrane module. Permeate samples were collected from the module at time intervals of 30, 60, 90, 120, 150 and 180 minutes and the BPA concentrations were determined by spectrophotometer (JASCO V-530 UV-VIS) at 276 nm wavelength.

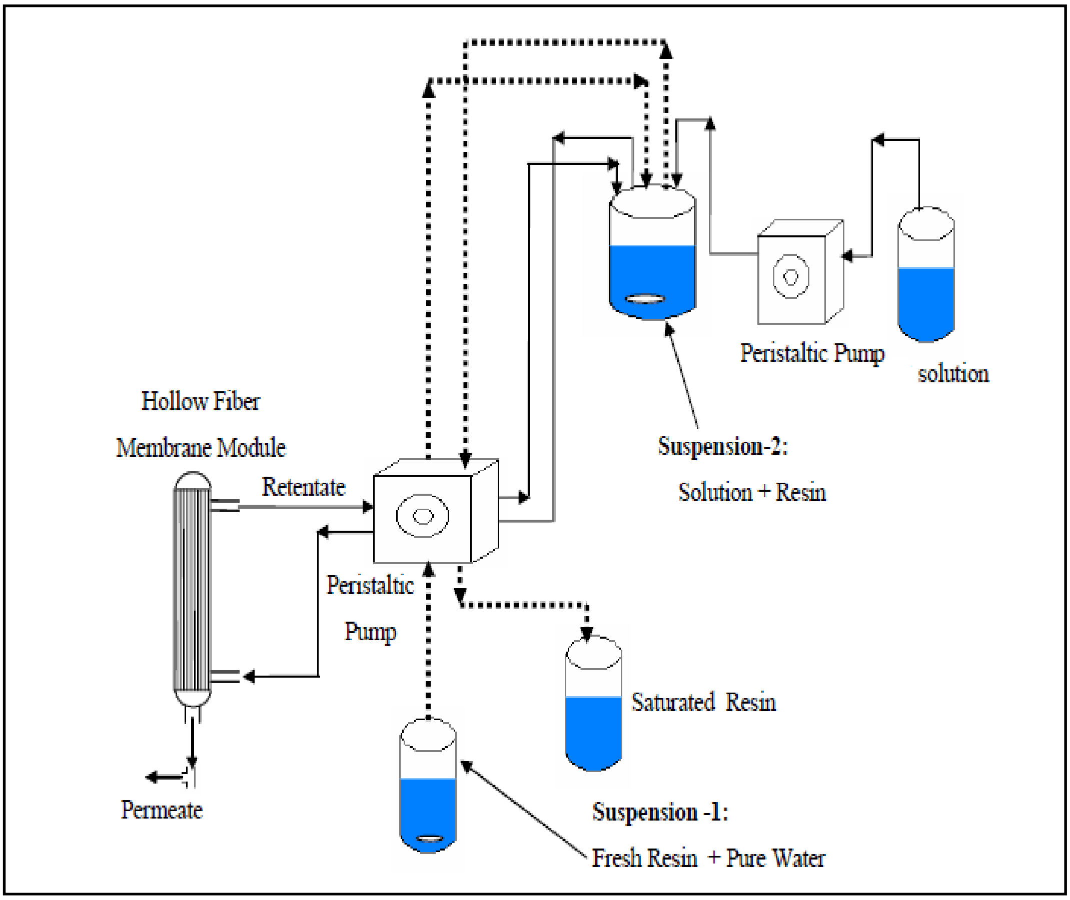

Figure 2.2: Experimental set-up of sorption-submerged membrane filtration hybrid system

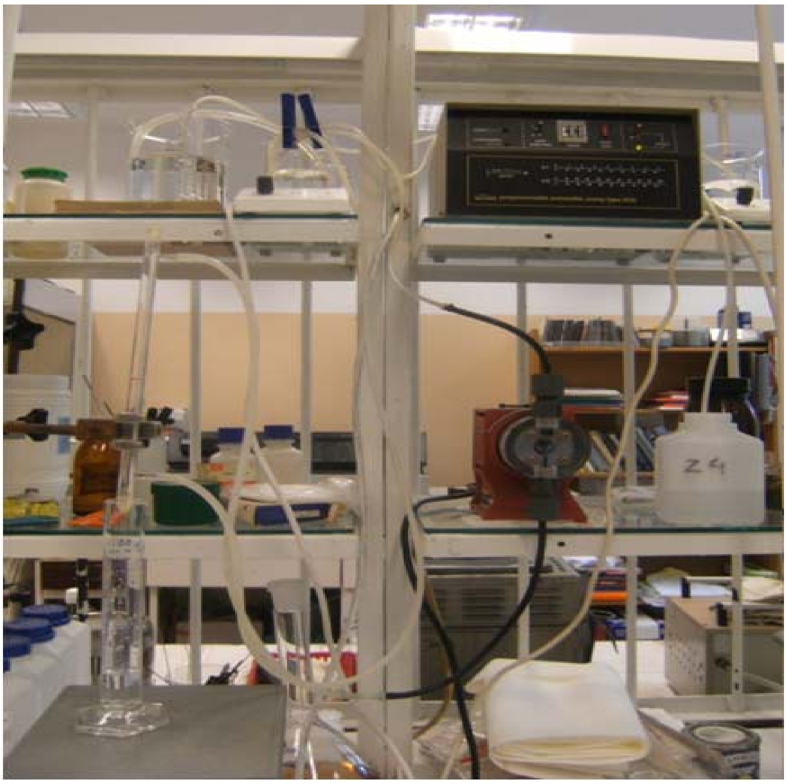

Figure2.3:A photo of experimental set-up of sorption-submerged membrane filtration hybrid system

2.2.3 Analytical Methods

2.2.3.1 Dimetyl Pthalate (DMP) Analysis

DMP was measured by using a Spectrophotometer (JASCO V-530 UV-VIS). The measurements were performed at 243.0 nm. The concentrations of the standard solutions and their absorbances were given in Table 2.1 and the calibration curve of DMP analysis was shown in Figure 2.4.

Table 2.1:The concentrations of the standard solutions and their absorbances.

DMP concentration (mg/L)	Absorbance (at 243 nm)
4.85	0.1105
9.70	0.2448
19.40	0.4861
29.10	0.7321
38.80	0.9284
48.50	1.1942
58.20	1.4258
67.90	1.6479

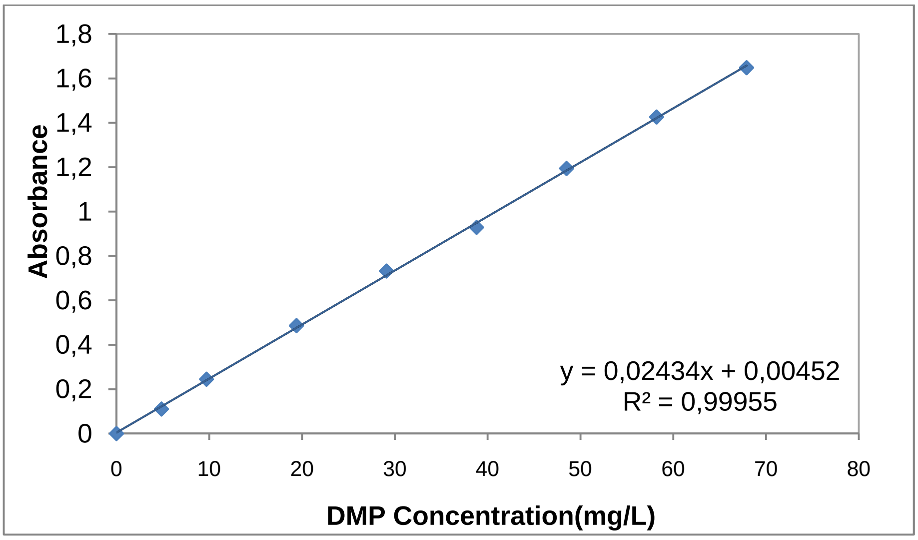

Figure 2.4: The calibration curve of DMP

2.2.3.2 Dietyl Pthalate (DEP) Analysis

DEP analysis of tests were measured by using Spectrophotometer (JASCO V-530 UV-VIS). The measurements were performed at 229.0 nm. The concentrations of the standard solutions and their absorbances were given in Table 2.2 and the calibration curve of DMP analysis was shown in Figure 2.5.

Table 2.2: The concentrations of the standard solutions and their absorbances

DEP concentration (mg/L)	Absorbance (at 229 nm)
5.31	0.1978
10.62	0.3747
21.24	0.7874
31.86	1.1654
42.48	1.5308
53.10	1.9373
63.72	2.2833

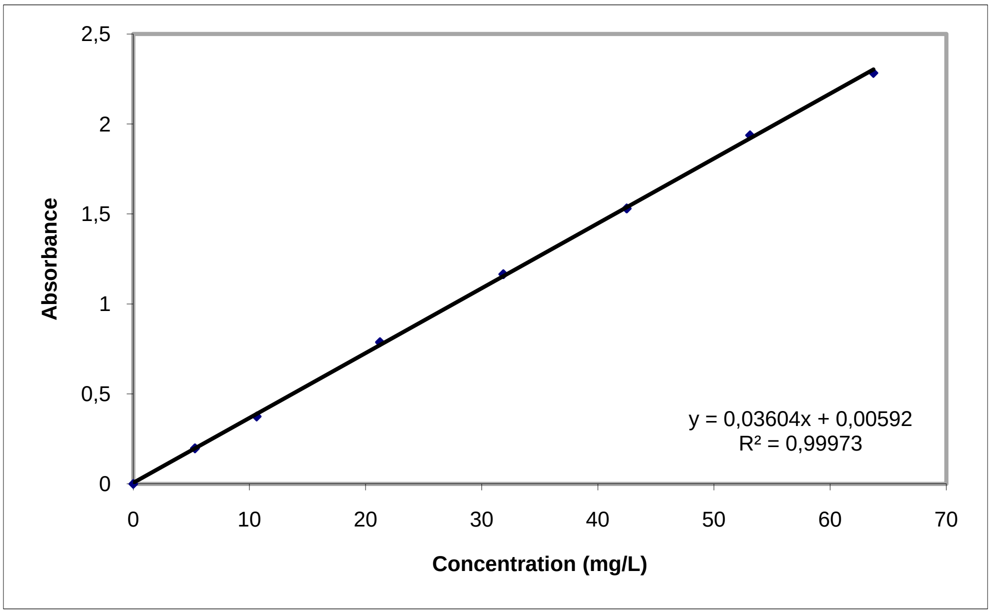

Figure 2.5: The calibration curve of DEP

2.2.3.3 Bis Phenol A (BPA) Analysis

Bis phenol A analysis of tests were determined by using Spectrophotometer (JASCO V-530 UV-VIS). The measurements were performed at 276.0 nm. The concentrations of the standard solutions and their absorbances were given in Table 2.3 and the calibration curve was shown in Figure 2.6.

Table 2.3: The concentrations of the standard solutions and their absorbances

Bis phenol A concentration (mg/L)	**Absorbance(at 276 nm)**
0.005	0.0172
0.0125	0.0393
0.025	0.0762
0.033	0.1155
0.05	0.153
0.0625	0.2308
0.08	0.2804
0.1	0.3323
0.12	0.3939
0.14	0.4717
0.15	0.4637
0.175	0.5393
0.2	0.6315
0.25	0.7911
0.3	0.9721
0.4	1.359
0.5	1.682
1	3.2

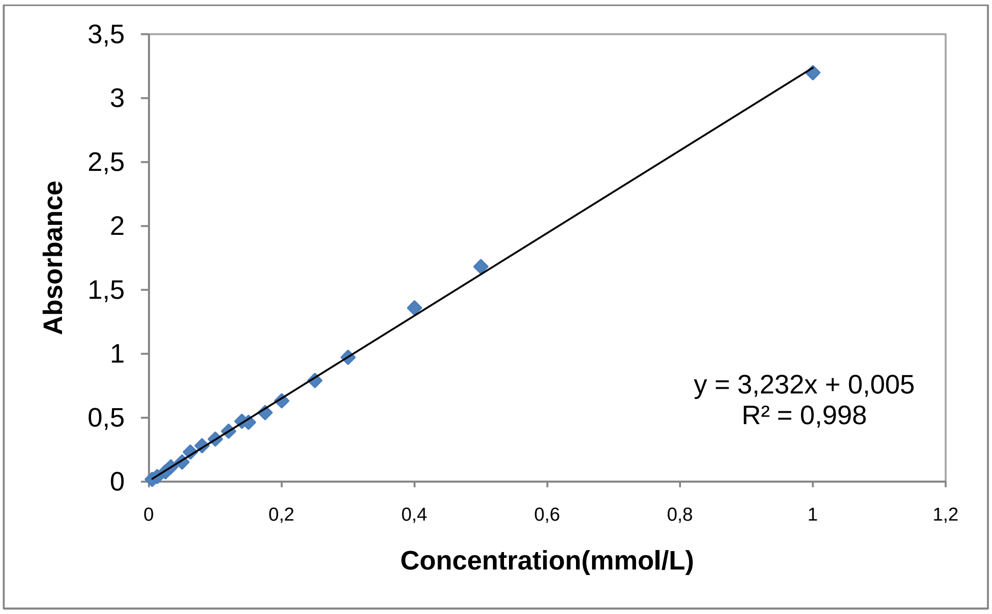

Figure 2.6: The calibration curve of BPA

3. RESULTS AND DISCUSSION

3.1 Sorption Isoterms for DMP

3.1.1 Sorption experiments using polymer without imprint

In order to remove DMP from water, sorption studies were performed. Polymers without imprint (0.02 g/L) and different volume of DMP solutions were used. In Table 3.1, it was shown that concentration of solutions before and after sorption and also sorption capacity.

Table 3.1: Results of sorption studies for DMP

C_i(mg/L)	C_e(mg/L)	Sorption(mg/g)
2.5	1.1193	0
5	1.7490	7.8230
7	1.8971	12.8252
10	1.4033	21.5765
15	3.1687	30.9045
20	5.3789	39.1344
25	10.9753	45.6379
30	13.8990	54.5516
40	21.0988	59.8198
50	31.2551	65.3070
60	36.9835	65.7443

C_i:initial concetration C_e:eventual concentration

Figure 3.1 shows that sorption isoterm of DMP. As seeen from Table 3.1 and Figure 3.1, the sorption performance of polymer without imprint was reasonably high for DMP removal.

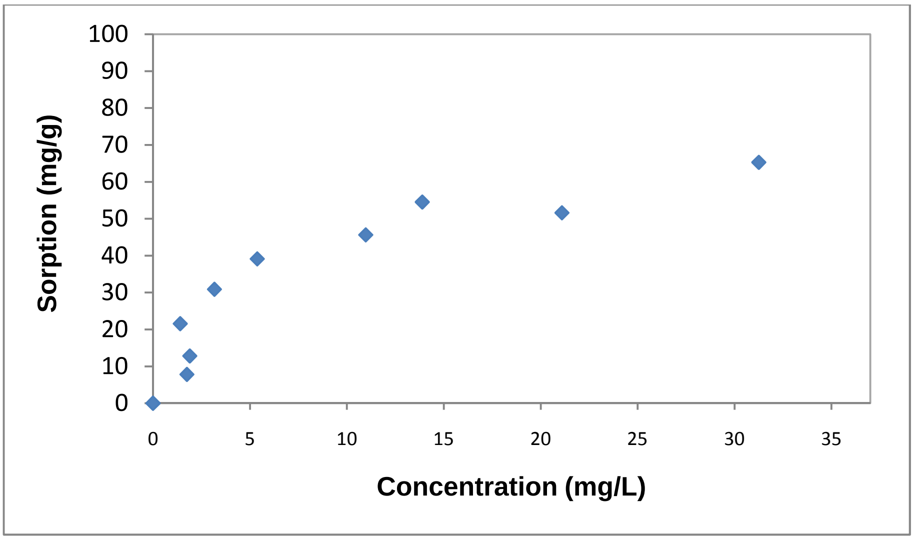

Figure 3.1: Sorption isoterm of DMP using polymer without imprint

3.1.2 Sorption experiments using polymer with imprint

Molecularly imprinted polymers obtained by bulk polimerization were tested for removal of Dimetyl Pthalate. Sorption experiments were performed for 48 h with continious shaking. Their inital and final concentrations and sorption values were shown in Table 3.2 and sorption isoterms were given in Figure 3.2.

Table 3.2 : Results of sorption studies for DMP removal using polymer with imprint

C_i(mg/L)	C_e (mg/L)	Sorption(mg/g)
2.5	0	0
5	0	0
7	3.5062	8.8766
10	5.2551	13.3464
15	8.3169	18.4738
20	9.5226	25.3845
25	17.9095	27.9117
30	25.8519	25.9033
40	34.9095	26.8367
50	47.5679	25.4689
60	50.4342	33.3135
70	62.2305	48.5067
90	71.2387	50.5236

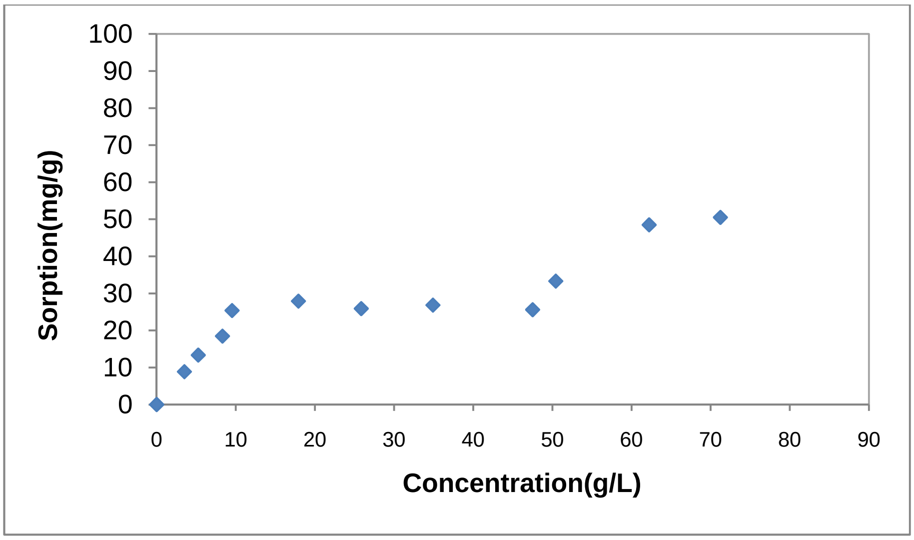

Figure 3.2: Sorption isoterm of DMP using polymer with imprint

3.1.3 Comparison of polymers with imprint and without imprint

Figure 3.3 shows the comparison of polymers with imprint and without imprint for DMP. As seen in Figure 3.3, sorption capacities of polymer without imprint has showed better affinity for DMP. It can be explained that this polymer was imprinted with DBP template and DBP is bigger molecule than DMP. So, Sorption capacity of DMP with this polymer was lower than polymer without imprint.

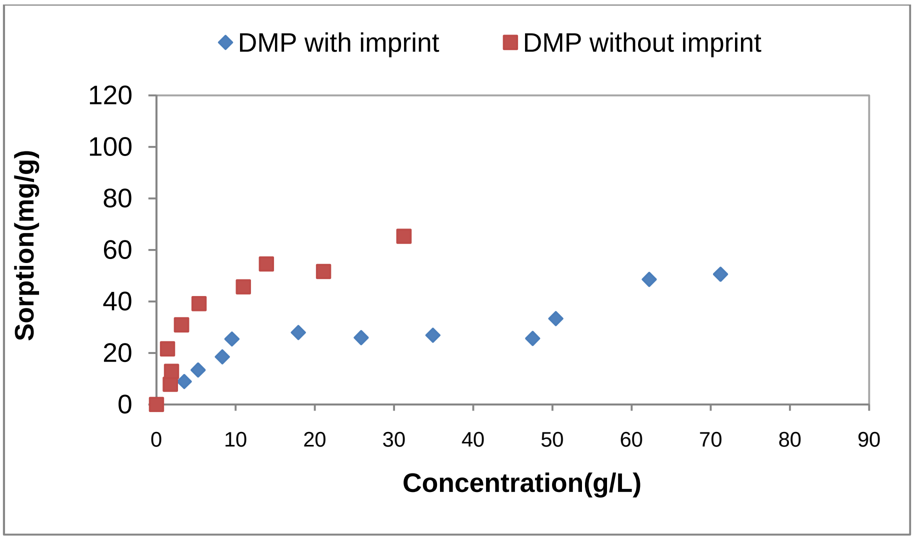

Figure 3.3:Comparison of Sorption isoterms for polymers with imprint and without imprint

3.2 Sorption Isoterms for DEP

3.2.1 Sorption experiments using polymer without imprint

For removal of DEP, sorption studies were performed by using polymer without imprint of 0.02 g/L and solutions containing different DEP concentrations (1.0, 2.5, 5.0, 10.0, 20.0, 30.0, 40.0 an 50.0 mg/L). Table 3.3 shows the results for DEP sorption studies.

Table 3.3 : Results of sorption studies for DEP removal using polymer without imprint

C_i(mg/L)	C_e (mg/L)	Sorption (mg/g)
1	0.1826	2.2001
2.5	0.2436	5.5843
5	0.1964	11.5086
10	0.5849	20.9923
20	1.2092	46.0295
30	3.5039	68.7044
40	6.5644	86.8726
50	11.3979	106.8298

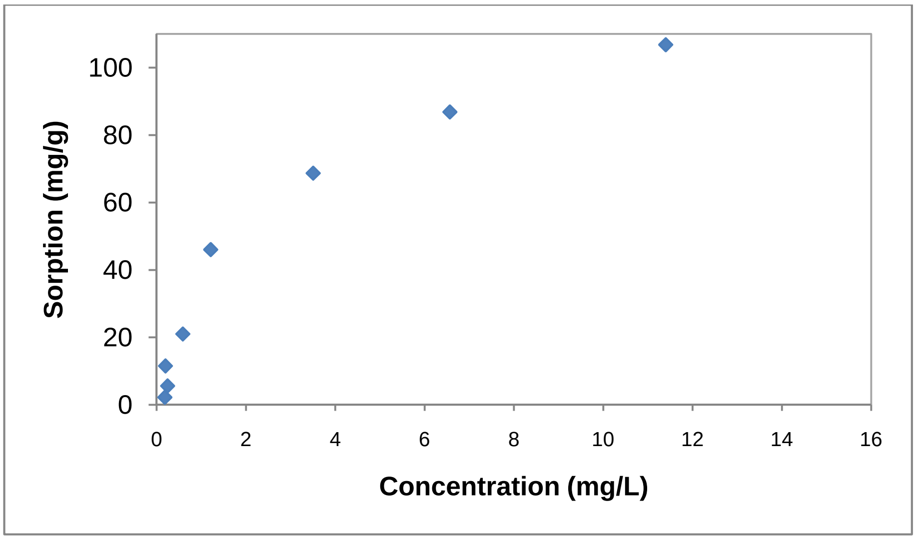

Figure 3.4: Sorption isoterm of DEP using polymer without imprint

In Figure 3.4, sorption isotherm is given graphically by plotting the amount of adsorbed DEP per 0.02 g of polymer without imprint against equilibrium concentration of DEP.

3.2.2 Sorption experiments using polymer with imprint

For sorption studies using polmer with imprint, initial and eventual DEP concentrations and sorption capacity of these experiments were given in Table 3.4.

Table 3.4 : Results of sorption studies for DEP removal using polymer with imprint

C_i(mg/L)	**C_e (mg/L)**	**Sorption (mg/g)**
1	0.218	2.11
2.5	0.385	5.24
5	2.291	6.58
10	3.829	14.84
20	5.194	35.12
30	6.745	52.57
40	12.008	72.91
50	16.648	93.29

Figure 3.5 shows sorption isoterm for DEP by using polymer with imprint. As seen in Table 3.4 and Figure 3.5, when DEP initial concentration increased, removal of DEP also increased.

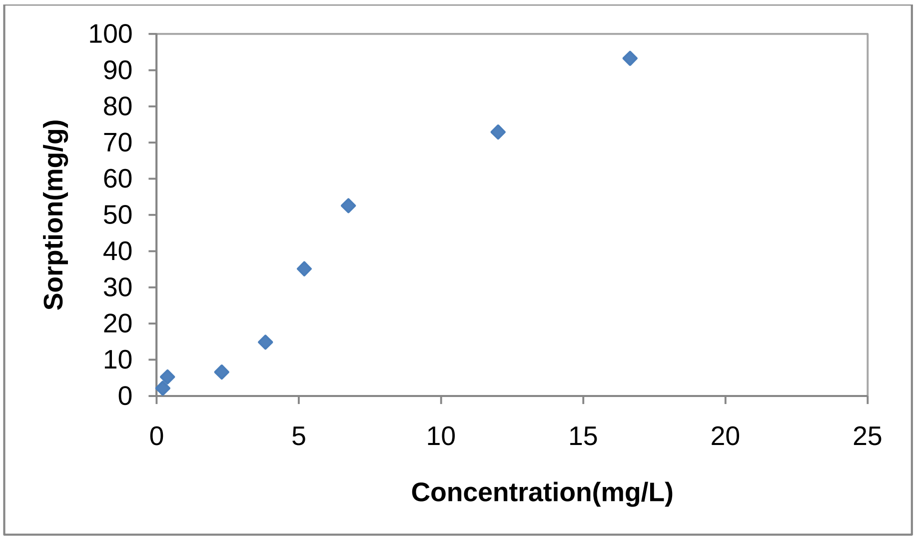

Figure 3.5: Sorption isoterm of DEP using polymer with imprint

3.2.3 Comparison of polymers with imprint and without imprint

Figure 3.6 shows the comparison of polymers with imprint and without imprint for DEP. As seen in Figure 3.6, sorption capacities of polymer without imprint has showed better affinity for DEP.

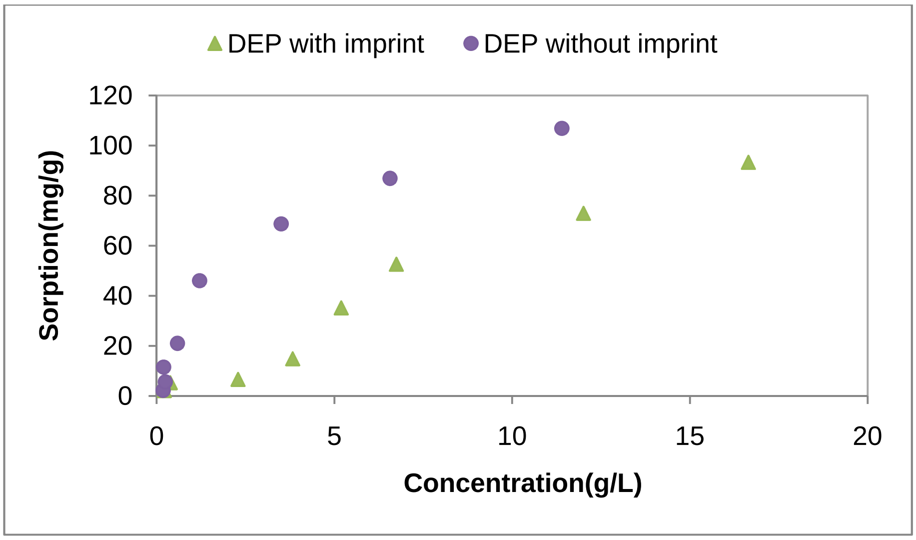

Figure 3.6:Comparison of sorption isoterms for polymers with imprint and without imprint

2.2 Removal of bis phenol A (BPA) using sorption-submerged membrane filtration hybrid system

The submerged membrane filtration hybrid system was used for Bis Phenol A removal from water by using polymers with and without imprint. The BPA selective resin with and without imprint with different concentration of resin (X g/L) were used for the tests. The submerged membrane filtration hybrid system was employed using different pump speed, 0. 1 and 0.3.

Table 3.5: Tests for removal of Bis phenol A

Polymeric Resin	Pump speed	Test Number	X (g/L)
Without imprint	0.1	1	0.2
		2	0.4
		3	0.8
		4	1
		5	2
	0.3	6	0.2
		7	0.4
		8	0.8
		9	1
With imprint	0.1	10	0.2
		11	0.4
		12	0.8
		13	1
		14	2
	0.3	15	0.2
		16	1

3.3.1 Effect of resin amount on Bis phenol A removal

3.3.1.1 Effect of resin amount on Bis phenol A removal for pump speed 0.1

In Figures 3.7 and 3.8, ratio of BPA concentration of permeate to initial BPA concentration were given for different amount of BPA selective resin without imprint and with imprint, respectively.

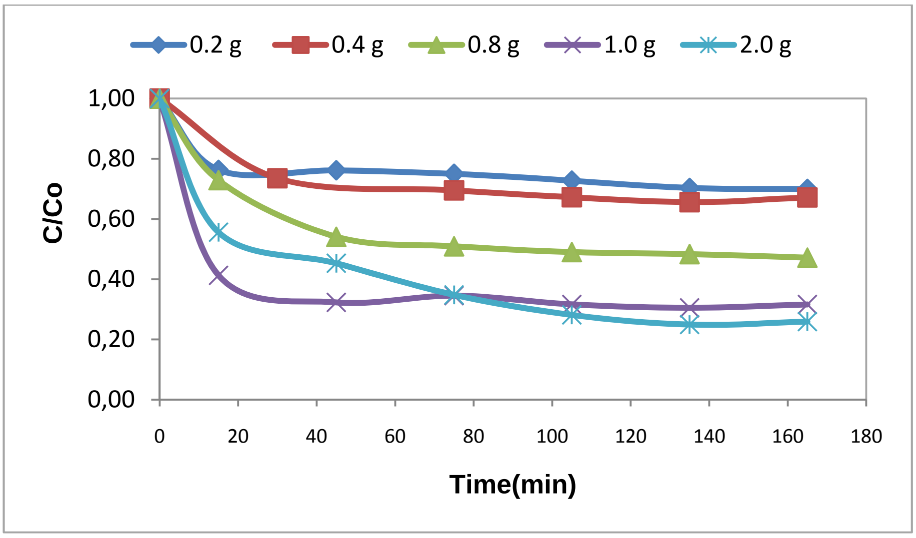

Figure 3.7:Effect of resin amount on BPA removal by using resin without imprint (Tests 1, 2, 3, 4 and 5)

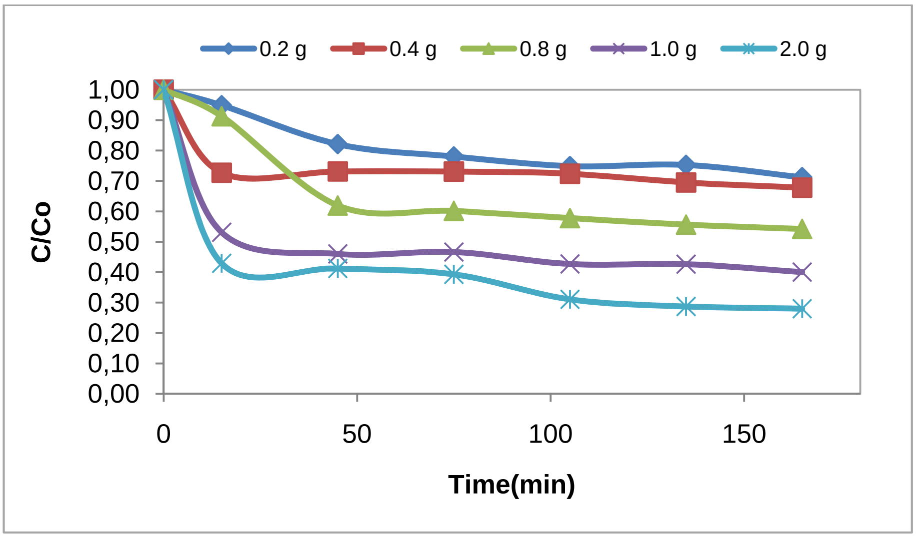

Figure 3.8:Effect of resin amount on BPA removal by using resin with imprint (Tests 10, 11, 12, 13 and 14)

As seen in Figure 3.7 and 3.8, It was determined that as the resin amount increased, BPA concentration of permeate was increased.

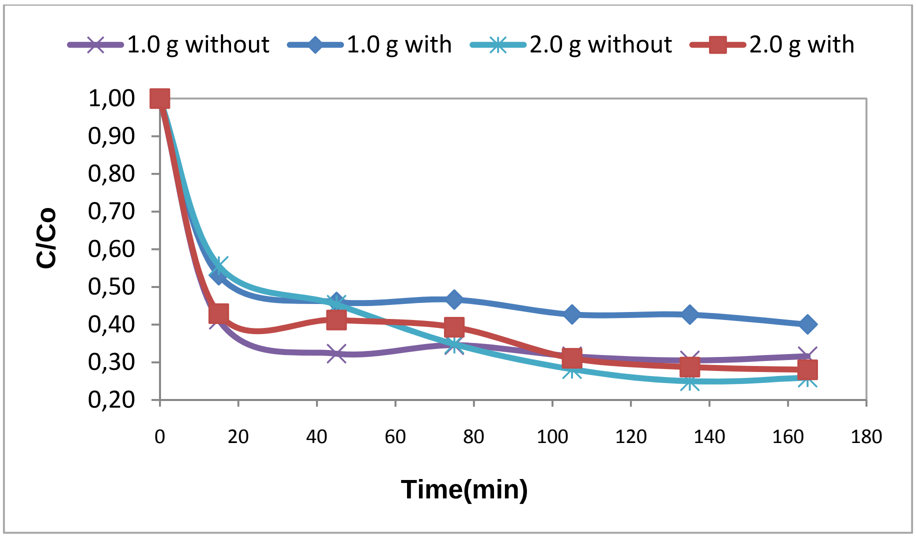

Figure 3.9:Comparison of resins with imprint and without imprint for BPA removal (Tests 4, 5, 13 and 14)

Figure 3.9 shows the comparison of resins with imprint and without imprint for resin amount of 1 and 2 g/L. It was seen in Figure 3.9 that when amount of 2 g/L resin without imprint was used, removal of BPA increased especially after 115 minutes.

3.3.1.2 <u>Effect of resin concentration on Bis phenol A removal for pump speed 0.3</u>

In Figures 3.10 and 3.11, ratio of BPA concentration of permeate (C) to initial BPA concentration (C_o) were given for various amount of BPA selective resins without imprint and with imprint, respectively. In Figures 3.10 and 3.11, when resin amount increased, ratio of BPA concentration of permeate to initial BPA concentration decrased.

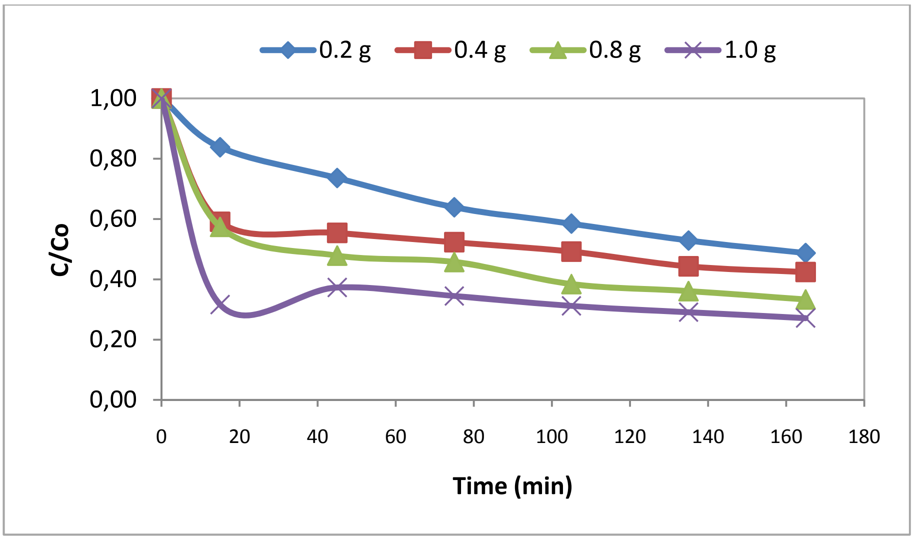

Figure 3.10: Effect of resin amount on BPA removal by using resin without imprint (Tests 6, 7, 8 and 9)

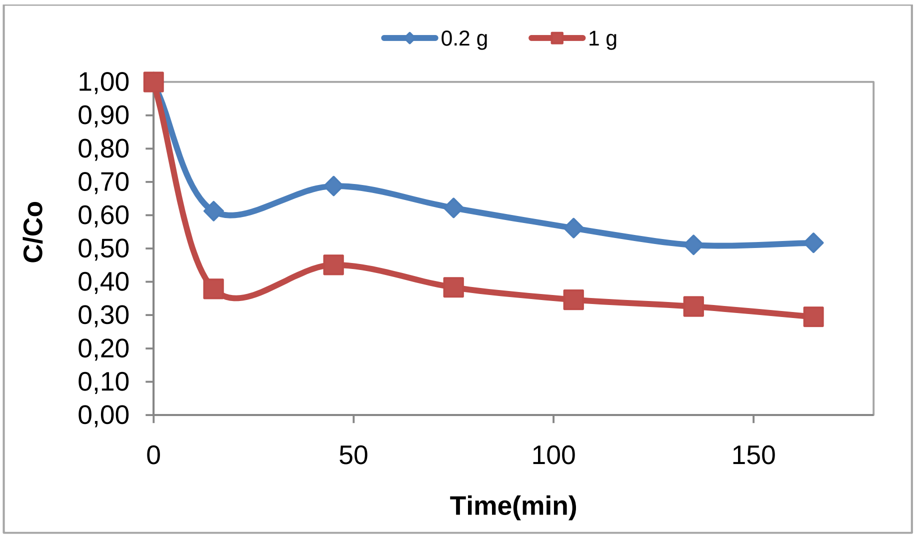

Figure 3.11: Effect of resin amount on BPA removal by using resin with imprint (Tests 15 and 16)

Figure 3.12 shows the comparison of resins with and without imprint for resin amount of 1 g/L. As seen in Figure 3.12, removal percentage of BPA increased by using resin without imprint especially after 45 minutes.

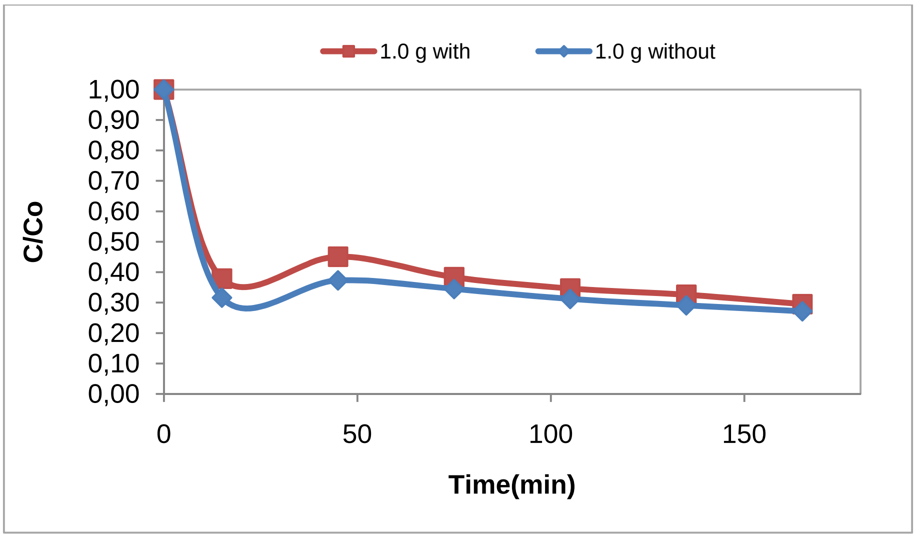

Figure 3.12:Comparison of resins with imprint and without imprint for BPA removal (Tests 9 and 16)

3.3.2 Effect of pump speed on Bis phenol A removal

Tests were performed for removal of BPA in submerged membrane filtration hybrid system at various pump speed, 0.1 and 0.3. To compare their removal performance, Figure 3.13 was drawn for resin amount of 1 g/L. As seen in Figure 3.13, when pump speed was 0.3 and resin without imprint was used, removal of BPA increased.

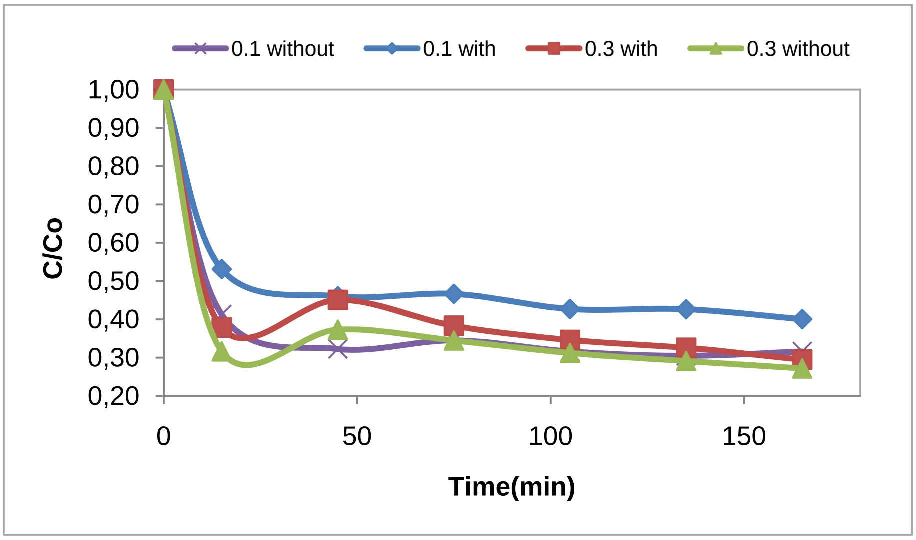

Figure 3.13: Comparison of pump speed for 1 g/L resin amount (Tests 4, 9, 13 and 16)

3 CONCLUSION

Phthalic esters (DMP and DEP) are groups of chemicals widely used as additive in the manufacturing of plastics. They are listed as priority pollutants in many countries due to their suspected mutagenicity and endocrine disrupting effects, BPA is known as one of endocrine disruptors and has an acute toxicity to aquatic organisms. These chemicals have to be removed from water for human health.

For removal of DMP and DEP from water sorption studies were performed and BPA was removed from water by using sorption-submerged membrane filtration hybrid system.

Sorption studies showed that when resin without imprint were used, removal percentage of DMP and DEP increased.

For removal of BPA by using sorption-submerged membrane filtration hybrid system, when resin amount was increased and pump speed was 0.3, ratio of BPA concentration of permeate to initial BPA concentration decreased.

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APPENDIX

Short–term Tests:

Tests with FilmTec SW30-2540 RO membrane

Table A.1 Results for effect of temperature on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Parameters	Operation Time (min)	15	30	45	60	75	90
Mg^{2+} [mg/L]	**Permeate**	2.33	2.13	2.22	2.21	2.43	2.29
	Rejection, %	99.76	99.78	99.77	99.77	99.75	99.76
Na^+ [mg/L]	**Permeate**	60.9	59.0	57.5	57.2	58.4	55.8
	Rejection, %	99.67	99.68	99.69	99.69	99.68	99.69
Ca^{2+} [mg/L]	**Permeate**	0.35	0.29	0.25	0.28	0.30	0.35
	Rejection, %	99.93	99.94	99.95	99.94	99.94	99.93
K^+ [mg/L]	**Permeate**	3.47	3.39	3.40	3.56	3.38	3.26
	Rejection, %	99.52	99.53	99.53	99.50	99.53	99.55
Cl^- [mg/L]	**Permeate**	184.05	176.53	174.42	182.80	175.16	171.25
	Rejection, %	99.20	99.23	99.24	99.20	99.24	99.26
SO_4^{2-} [mg/L]	**Permeate**	5.12	3.93	4.00	5.66	4.05	3.23
	Rejection, %	99.84	99.86	99.87	99.82	99.87	99.90
HCO_3^- [mg/L]	**Permeate**	12.33	12.33	9.20	6.16	6.16	6.16
	Rejection, %	92.31	92.31	94.26	96.16	96.16	96.16
Turbidity	**Permeate**	0.04	0.06	0.10	0.09	0.07	0.06

(Test 5; 16°C, adjusted-acid (HCl) addition, 55 bar)

Table A.2 Results for effect of temperature on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Parameters \ **Operation Time (min)**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	4.62	4.26	3.85	3.77	3.81	3.64
	Rejection, %	99.54	99.57	99.61	99.62	99.62	99.63
Na^+ [mg/L]	**Permeate**	101.9	95.0	90.7	92.9	88.1	86.4
	Rejection, %	99.06	99.12	99.16	99.14	99.19	99.20
Ca^{2+} [mg/L]	**Permeate**	1.12	1.00	0.85	0.89	0.83	0.84
	Rejection, %	99.78	99.80	99.83	99.83	99.84	99.84
K^+ [mg/L]	**Permeate**	5.64	5.48	5.12	5.33	5.06	4.86
	Rejection, %	99.27	99.29	99.34	99.31	99.35	99.37
Cl^- [mg/L]	**Permeate**	179.70	171.08	164.18	169.08	167.96	158.77
	Rejection, %	99.47	99.50	99.52	99.51	99.51	99.54
SO_4^{2-} [mg/L]	**Permeate**	4.78	4.75	3.58	3.00	3.53	4.26
	Rejection, %	99.88	99.88	99.91	99.93	99.91	99.90
HCO_3^- [mg/L]	**Permeate**	12.33	13.57	14.80	12.33	12.33	12.33
	Rejection, %	92.31	91.54	90.77	92.31	92.31	92.31
Turbidity	**Permeate**	0.21	0.12	0.13	0.16	0.20	0.16

(Test 6; 10.8°C, adjusted-acid (HCl) addition, 55 bar)

Table A.3 Results for effect of temperature on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	6.07	5.60	4.55	4.89	4.47	4.39
	Rejection, %	99.55	99.59	99.67	99.64	99.67	99.68
Na^+ [mg/L]	**Permeate**	68.0	64.6	66.1	65.3	66.0	68.4
	Rejection, %	99.49	99.51	99.50	99.51	99.50	99.49
Ca^{2+} [mg/L]	**Permeate**	1.41	1.07	0.56	1.43	1.60	1.20
	Rejection, %	99.77	99.82	99.91	99.76	99.74	99.80
K^+ [mg/L]	**Permeate**	5.79	5.82	5.51	5.41	5.51	5.51
	Rejection, %	99.23	99.23	99.27	99.28	99.27	99.27
Cl^- [mg/L]	**Permeate**	183.76	179.71	173.07	166.32	168.3	166.29
	Rejection, %	99.34	99.35	99.38	99.40	99.40	99.40
SO_4^{2-} [mg/L]	**Permeate**	4.30	3.98	2.84	3.07	2.56	2.26
	Rejection, %	99.88	99.89	99.92	99.92	99.93	99.94
HCO_3^- [mg/L]	**Permeate**	9.87	9.87	12.33	11.10	9.87	12.33
	Rejection, %	92.72	92.72	90.91	91.82	92.72	90.91
Turbidity	**Permeate**	0.15	0.19	0.14	0.15	0.18	010

Test 10; 13.9°C, adjusted-acid (HCl) addition, 55 bar

Table A.4 Results for effect of temperature on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Parameters \ **Operation Time (min)**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	9.98	9.35	11.36	12.97	13.41	11.66
	Rejection, %	99.07	99.13	98.94	98.79	98.75	98.91
Na^+ [mg/L]	**Permeate**	112.5	104.6	113.1	134.1	152.9	173.2
	Rejection, %	99.08	99.14	99.07	98.90	98.74	98.58
Ca^{2+} [mg/L]	**Permeate**	1.60	1.32	1.58	2.29	2.88	4.03
	Rejection, %	99.82	99.85	99.82	99.74	99.67	99.54
K^+ [mg/L]	**Permeate**	6.59	5.90	6.46	6.93	7.77	8.73
	Rejection, %	98.89	99.00	98.91	98.83	98.69	98.53
Cl^- [mg/L]	**Permeate**	252.35	228.67	238.21	281.74	324.5	354.24
	Rejection, %	98.99	99.08	99.04	98.87	98.70	98.58
SO_4^{2-} [mg/L]	**Permeate**	12.58	9.48	11.15	16.68	24.29	26.39
	Rejection, %	99.59	99.69	99.64	99.46	99.21	99.14
HCO_3^- [mg/L]	**Permeate**	12.33	11.10	12.33	9.87	12.33	12.33
	Rejection, %	92.00	92.80	92.00	93.60	92.00	92.00
Turbidity	**Permeate**	0.22	0.20	0.23	0.20	0.11	0.17

Test 16; 20.4°C, adjusted-acid (HCl) addition, 55 bar

Table A.5 Results for effect of temperature on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Parameters \ **Operation Time (min)**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	20.76	16.96	17.56	18.55	18.29	18.42
	Rejection, %	98.54	98.81	98.77	98.70	98.72	98.71
Na^+ [mg/L]	**Permeate**	265.8	263.6	233.5	225.7	227.5	227.8
	Rejection, %	97.86	97.88	98.12	98.18	98.17	98.17
Ca^{2+} [mg/L]	**Permeate**	7.38	7.28	6.45	6.47	6.25	5.78
	Rejection, %	98.46	98.48	98.66	98.65	98.70	98.80
K^+ [mg/L]	**Permeate**	15.04	15.67	14.73	14.33	14.07	13.76
	Rejection, %	97.88	97.80	97.93	97.98	98.02	98.06
Cl^- [mg/L]	**Permeate**	627.46	642.58	576.76	558.32	563.79	533.92
	Rejection, %	97.63	97.58	97.82	97.89	97.87	97.99
SO_4^{2-} [mg/L]	**Permeate**	46.58	49.1	33.93	38.58	39.64	37.55
	Rejection, %	98.47	98.38	98.88	98.73	98.69	98.76
HCO_3^- [mg/L]	**Permeate**	12.33	14.80	14.80	17.27	17.27	14.80
	Rejection, %	92.86	91.43	91.43	90.00	90.00	91.43
Turbidity	**Permeate**	0.04	0.09	0.10	0.03	0.03	0.05

Test 19; 27.0°C, adjusted-acid (HCl) addition, 55 bar

Table A.6 Results for effect of temperature on Na^{+}, Mg^{2+}, Ca^{2+}, K^{+}, SO$_4^{2-}$, Cl^{-}, HCO$_3^{-}$ and turbidity rejection (Figures 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	7.21	6.33	5.83	7.72	8.33	7.77
	Rejection, %	99.54	99.60	99.63	99.51	99.47	99.51
Na^{+} [mg/L]	**Permeate**	197	156	153	141	137	136
	Rejection, %	98.48	98.80	98.82	98.92	98.95	98.95
Ca^{2+} [mg/L]	**Permeate**	3.59	2.21	1.99	1.52	1.38	1.42
	Rejection, %	99.60	99.75	99.78	99.83	99.85	99.84
K^{+} [mg/L]	**Permeate**	11.91	10.16	9.75	9.2	9.19	9.19
	Rejection, %	98.57	98.78	98.83	98.89	98.89	98.89
Cl^{-} [mg/L]	**Permeate**	358.29	277.77	246.30	252.09	218.47	244.69
	Rejection, %	98.70	98.99	99.10	99.08	99.20	99.11
SO$_4^{2-}$ [mg/L]	**Permeate**	22.47	10.69	3.93	2.54	2.03	3.13
	Rejection, %	99.39	99.71	99.89	99.93	99.95	99.92
HCO$_3^{-}$ [mg/L]	**Permeate**	14.80	12.33	11.10	9.87	12.33	12.33
	Rejection, %	91.11	92.59	93.33	94.07	92.59	92.59
Turbidity	**Permeate**	0.09	0.05	0.07	0.08	0.07	0.10

Test 20; 24.8°C, adjusted-acid (HCl) addition, 55 bar

Table A.7 Results for effect of temperature on Na^{+}, Mg^{2+}, Ca^{2+}, K^{+}, SO$_4^{2-}$, Cl^{-}, HCO$_3^{-}$ and turbidity rejection (Figures 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	12.92	11.2	9.76	11.44	9.94	9.56
	Rejection, %	98.76	98.93	99.06	98.90	99.05	99.08
Na^{+} [mg/L]	**Permeate**	192	169	155	171	157	155
	Rejection, %	98.69	98.85	98.95	98.84	98.93	98.95
Ca^{2+} [mg/L]	**Permeate**	4.26	3.16	2.58	3.19	2.43	2.56
	Rejection, %	99.42	99.57	99.65	99.57	99.67	99.65
K^{+} [mg/L]	**Permeate**	12.68	11.98	11.27	12.05	11.38	11.4
	Rejection, %	98.34	98.43	98.52	98.42	98.51	98.50
Cl^{-} [mg/L]	**Permeate**	361.83	326.36	302.98	334.91	303.66	303.64
	Rejection, %	98.47	98.62	98.72	98.59	98.72	98.72
SO$_4^{2-}$ [mg/L]	**Permeate**	20.16	17.73	13.83	17.80	13.79	11.65
	Rejection, %	99.27	99.36	99.50	99.36	99.50	99.58
HCO$_3^{-}$ [mg/L]	**Permeate**	11.1	9.87	12.33	9.87	11.1	12.33
	Rejection, %	93.57	94.28	92.86	94.28	93.57	92.86
Turbidity	**Permeate**	0.10	0.11	0.09	0.08	0.12	0.11

Test 22; 22.0°C, adjusted-acid (HCl) addition, 55 bar

Table A.8 Results for effect of applied pressure on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.9, 3.10, 3.11, 3.12, 3.13, 3.14, 3.15, 3.39, 3.40, 3.41, 3.42, 3.43, 3.44, 3.45 and 3.46)

Parameters	**Operation Time (min)**	**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	4.12	4.00	3.79	4.05	3.72	3.63
	Rejection, %	99.57	99.58	99.60	99.57	99.61	99.62
Na^+ [mg/L]	**Permeate**	108.0	103.5	100.2	104.4	99.5	97.0
	Rejection, %	99.41	99.43	99.45	99.43	99.46	99.47
Ca^{2+} [mg/L]	**Permeate**	0.58	0.60	0.39	0.49	0.52	0.42
	Rejection, %	99.88	99.88	99.92	99.90	99.90	99.91
K^+ [mg/L]	**Permeate**	6.12	5.80	5.41	5.93	5.87	5.51
	Rejection, %	99.15	99.19	99.25	99.17	99.18	99.23
Cl^- [mg/L]	**Permeate**	184.05	176.53	174.42	182.80	175.16	171.25
	Rejection, %	99.20	99.23	99.24	99.20	99.24	99.26
SO_4^{2-} [mg/L]	**Permeate**	5.12	3.93	4.00	5.66	4.05	3.23
	Rejection, %	99.84	99.86	99.87	99.82	99.87	99.90
HCO_3^- [mg/L]	**Permeate**	12.33	12.33	9.20	6.16	6.16	6.16
	Rejection, %	92.31	92.31	94.26	96.16	96.16	96.16
Turbidity	**Permeate**	0.04	0.06	0.10	0.09	0.07	0.06

Test 5; 16°C, adjusted-acid (HCl) addition, 60 bar

Table A.9 Results for effect of applied pressure on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.9, 3.10, 3.11, 3.12, 3.13, 3.14, 3.15, 3.39, 3.40, 3.41, 3.42, 3.43, 3.44, 3.45 and 3.46)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	7.14	6.65	5.70	5.35	5.32	5.23
	Rejection, %	99.52	99.55	99.61	99.64	99.64	99.65
Na^+ [mg/L]	**Permeate**	65.4	61.0	58.6	58.0	57.3	58.3
	Rejection, %	99.55	99.58	99.60	99.60	99.61	99.60
Ca^{2+} [mg/L]	**Permeate**	0.58	0.81	0.48	1.02	0.79	1.71
	Rejection, %	99.89	99.84	99.90	99.80	99.84	99.66
K^+ [mg/L]	**Permeate**	3.85	3.96	4.01	3.84	4.10	4.28
	Rejection, %	99.45	99.43	99.43	99.45	99.41	99.39
Cl^- [mg/L]	**Permeate**	144.53	136.66	131.58	125.62	126.27	121.19
	Rejection, %	99.46	99.49	99.51	99.53	99.53	99.55
SO_4^{2-} [mg/L]	**Permeate**	2.47	1.63	1.49	0.94	0.63	0.41
	Rejection, %	99.93	99.95	99.96	99.97	99.98	99.99
HCO_3^- [mg/L]	**Permeate**	12.33	11.10	12.33	14.80	12.33	12.33
	Rejection, %	92.00	92.80	92.00	90.40	92.00	92.00
Turbidity	**Permeate**	0.20	0.27	0.22	0.18	0.15	0.19

Test 13; 16°C, adjusted-acid (HCl) addition, 60 bar

Table A.10 Results for effect of applied pressure on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.9, 3.10, 3.11, 3.12, 3.13, 3.14, 3.15, 3.39, 3.40, 3.41, 3.42, 3.43, 3.44, 3.45 and 3.46)

Parameters	**Operation Time (min)**	**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	5.90	5.86	5.11	5.34	5.30	5.68
	Rejection, %	99.57	99.57	99.62	99.61	99.61	99.58
Na^+ [mg/L]	**Permeate**	56.1	55.5	54.7	54.5	55.4	58.1
	Rejection, %	99.65	99.66	99.66	99.66	99.66	99.64
Ca^{2+} [mg/L]	**Permeate**	0.50	0.47	0.55	0.61	0.48	0.44
	Rejection, %	99.91	99.91	99.90	99.89	99.91	99.92
K^+ [mg/L]	**Permeate**	3.02	2.96	2.80	3.02	3.14	3.45
	Rejection, %	99.51	99.52	99.55	99.51	99.49	99.44
Cl^- [mg/L]	**Permeate**	126.16	123.83	122.24	124.17	119.6	124.24
	Rejection, %	99.53	99.54	99.55	99.54	99.56	99.54
SO_4^{2-} [mg/L]	**Permeate**	0.84	0.65	0.75	0.46	0.4	0.91
	Rejection, %	99.98	99.98	99.98	99.99	99.99	99.97
HCO_3^- [mg/L]	**Permeate**	11.10	12.33	14.80	12.33	14.80	13.56
	Rejection, %	92.50	91.67	90.00	91.67	90.00	90.84
Turbidity	**Permeate**	0.26	0.17	0.17	0.15	0.20	0.21

Test 14; 16°C, adjusted-acid (HCl) addition, 62 bar

Tests with high rejection membrane Filmtech XUS SW30 XHR 2540 membrane

Table A.11 Results for effect of temperature on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.16, 3.17, 3.18, 3.19, 3.20, 3.21, 3.22, 3.23 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Parameters	**Operation Time (min)**	**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	2.33	2.13	2.22	2.21	2.43	2.29
	Rejection, %	99.76	99.78	99.77	99.77	99.75	99.76
Na^+ [mg/L]	**Permeate**	60.9	59.0	57.5	57.2	58.4	55.8
	Rejection, %	99.67	99.68	99.69	99.69	99.68	99.69
Ca^{2+} [mg/L]	**Permeate**	0.35	0.29	0.25	0.28	0.30	0.35
	Rejection, %	99.93	99.94	99.95	99.94	99.94	99.93
K^+ [mg/L]	**Permeate**	3.47	3.39	3.40	3.56	3.38	3.26
	Rejection, %	99.52	99.53	99.53	99.50	99.53	99.55
Cl^- [mg/L]	**Permeate**	110.20	109.32	108.13	106.56	109.70	104.48
	Rejection, %	99.52	99.52	99.53	99.54	99.52	99.55
SO_4^{2-} [mg/L]	**Permeate**	1.17	1.86	2.01	1.90	1.83	1.32
	Rejection, %	99.96	99.94	99.93	99.94	99.94	99.95
HCO_3^- [mg/L]	**Permeate**	12.33	9.2	9.2	12.33	9.2	12.33
	Rejection, %	92.31	94.26	94.26	92.31	94.26	92.31
Turbidity	**Permeate**	0.04	0.06	0.10	0.09	0.07	0.06

Test 5; 16.0°C, adjusted-acid (HCl) addition, 55 bar

Table A.12 Results for effect of temperature on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.16, 3.17, 3.18, 3.19, 3.20, 3.21, 3.22, 3.23, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Parameters	**Operation Time (min)**	**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	2.00	1.91	1.99	1.93	2.00	1.94
	Rejection, %	99.80	99.81	99.80	99.81	99.80	99.81
Na^+ [mg/L]	**Permeate**	57.3	55.6	54.9	53.7	51.5	50.6
	Rejection, %	99.47	99.49	99.49	99.50	99.52	99.53
Ca^{2+} [mg/L]	**Permeate**	0.35	0.44	0.38	0.37	0.42	0.42
	Rejection, %	99.93	99.91	99.93	99.93	99.92	99.92
K^+ [mg/L]	**Permeate**	3.59	3.01	2.99	3.05	3.02	2.88
	Rejection, %	99.54	99.61	99.61	99.61	99.61	99.63
Cl^- [mg/L]	**Permeate**	104.25	102.39	101.16	99.72	97.49	95.46
	Rejection, %	99.69	99.70	99.70	99.71	99.71	99.72
SO_4^{2-} [mg/L]	**Permeate**	1.61	1.43	1.42	1.62	1.15	0.78
	Rejection, %	99.96	99.96	99.96	99.96	99.97	99.98
HCO_3^- [mg/L]	**Permeate**	17.27	16.03	12.33	12.33	13.57	12.33
	Rejection, %	89.23	90.00	92.31	92.31	91.54	92.31
Turbidity	**Permeate**	0.06	0.05	0.08	0.04	0.07	0.06

Test 6; 10.8°C, adjusted-acid (HCl) addition, 55 bar

Table A.13 Results for effect of temperature on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.16, 3.17, 3.18, 3.19, 3.20, 3.21, 3.22, 3.23, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Parameters	**Operation Time (min)**	**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	3.12	2.89	2.33	2.34	2.21	2.63
	Rejection, %	99.77	99.79	99.83	99.83	99.84	99.81
Na^+ [mg/L]	**Permeate**	40.5	38.8	38.9	40.3	38.4	37.7
	Rejection, %	99.69	99.71	99.71	99.70	99.71	99.72
Ca^{2+} [mg/L]	**Permeate**	0.28	0.56	0.62	0.61	0.60	0.54
	Rejection, %	99.95	99.91	99.90	99.90	99.90	99.91
K^+ [mg/L]	**Permeate**	3.15	3.17	2.89	3.02	3.01	2.83
	Rejection, %	99.58	99.58	99.62	99.60	99.60	99.62
Cl^- [mg/L]	**Permeate**	107.14	106.93	106.3	105.52	102.94	102.7
	Rejection, %	99.61	99.62	99.62	99.62	99.63	99.63
SO_4^{2-} [mg/L]	**Permeate**	0.89	0.29	0.5	0.67	0.46	0.28
	Rejection, %	99.98	99.99	99.99	99.98	99.99	99.99
HCO_3^- [mg/L]	**Permeate**	9.87	9.87	11.10	9.87	11.10	9.87
	Rejection, %	92.72	92.72	91.82	92.72	91.82	92.72
Turbidity	**Permeate**	0.08	0.10	0.11	0.12	0.07	0.06

Test 10; 13.9 °C, adjusted-acid (HCl) addition, 55 bar

Table A.14 Results for effect of temperature on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.16, 3.17, 3.18, 3.19, 3.20, 3.21, 3.22, 3.23, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Parameters	**Operation Time (min)**	**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	1.94	1.62	0.83	1.06	1.93	1.28
	Rejection, %	99.82	99.85	99.92	99.90	99.82	99.88
Na^+ [mg/L]	**Permeate**	68.6	63.7	61.3	62.6	64.6	64
	Rejection, %	99.44	99.48	99.50	99.49	99.47	99.47
Ca^{2+} [mg/L]	**Permeate**	0.28	0.27	0.19	0.25	0.41	1.27
	Rejection, %	99.97	99.97	99.98	99.97	99.95	99.86
K^+ [mg/L]	**Permeate**	3.62	3.29	2.93	2.98	3.01	3.01
	Rejection, %	99.39	99.45	99.51	99.50	99.49	99.49
Cl^- [mg/L]	**Permeate**	152.2	144.81	137.47	139.52	143.83	140.59
	Rejection, %	99.39	99.42	99.45	99.44	99.42	99.43
SO_4^{2-} [mg/L]	**Permeate**	0.77	0.26	b.l.d.	b.l.d.	0.23	0.43
	Rejection, %	99.98	99.99	-	-	99.99	99.99
HCO_3^- [mg/L]	**Permeate**	11.10	8.63	9.87	9.87	12.33	12.33
	Rejection, %	92.80	94.40	93.60	93.60	92.00	92.00
Turbidity	**Permeate**	0.09	0.15	0.21	0.24	0.11	0.12

Test 16; 20.4°C, adjusted-acid (HCl) addition, 55 bar

Table A.15 Results for effect of temperature on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.16, 3.17, 3.18, 3.19, 3.20, 3.21, 3.22, 3.23, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Parameters	**Operation Time (min)**	**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	5.09	4.41	4.43	4.13	4.45	4.98
	Rejection, %	99.64	99.69	99.69	99.71	99.69	99.65
Na^+ [mg/L]	**Permeate**	74.6	69	69.2	69.3	70.1	71.9
	Rejection, %	99.40	99.44	99.44	99.44	99.44	99.42
Ca^{2+} [mg/L]	**Permeate**	0.34	0.50	0.32	0.27	0.45	0.34
	Rejection, %	99.93	99.90	99.93	99.94	99.91	99.93
K^+ [mg/L]	**Permeate**	4.99	4.83	4.70	4.65	4.89	4.79
	Rejection, %	99.30	99.32	99.34	99.34	99.31	99.33
Cl^- [mg/L]	**Permeate**	194.38	186.05	181.94	181.91	184.74	188.49
	Rejection, %	99.27	99.30	99.31	99.31	99.30	99.29
SO_4^{2-} [mg/L]	**Permeate**	1.12	0.47	0.53	0.29	0.96	1.03
	Rejection, %	99.96	99.98	99.98	99.99	99.97	99.97
HCO_3^- [mg/L]	**Permeate**	14.80	12.33	12.33	11.10	12.33	12.33
	Rejection, %	91.43	92.86	92.86	93.57	92.86	92.86
Turbidity	**Permeate**	0.08	0.03	003	0.01	0.01	0.04

Test 19; 27.0°C, adjusted-acid (HCl) addition, 55 bar

Table A.16 Results for effect of temperature on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.16, 3.17, 3.18, 3.19, 3.20, 3.21, 3.22, 3.23, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Parameters \ **Operation Time (min)**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	1.31	1.22	1.21	1.24	1.25	1.27
	Rejection, %	99.92	99.92	99.92	99.92	99.92	99.92
Na^+ [mg/L]	**Permeate**	85	83	82	82	80	79
	Rejection, %	99.35	99.36	99.37	99.37	99.38	99.39
Ca^{2+} [mg/L]	**Permeate**	0.23	0.19	0.17	0.17	0.20	0.14
	Rejection, %	99.97	99.98	99.98	99.98	99.98	99.98
K^+ [mg/L]	**Permeate**	5.09	5.01	4.93	4.96	5.01	5.01
	Rejection, %	99.39	99.40	99.41	99.40	99.40	99.40
Cl^- [mg/L]	**Permeate**	154.84	153.40	151.34	149.80	148.63	148.00
	Rejection, %	99.44	99.44	99.45	99.45	99.46	99.46
SO_4^{2-} [mg/L]	**Permeate**	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.
	Rejection, %	-	-	-	-	-	-
HCO_3^- [mg/L]	**Permeate**	9.87	9.87	9.87	11.10	7.40	11.10
	Rejection, %	94.07	94.07	94.07	93.33	95.55	93.33
Turbidity	**Permeate**	0.03	0.04	0.10	0.05	0.05	0.10

Test 20; 24.8°C, adjusted-acid (HCl) addition, 55 bar

Table A.17 Results for effect of temperature on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.16, 3.17, 3.18, 3.19, 3.20, 3.21, 3.22, 3.23, 3.31, 3.32, 3.33, 3.34, 3.35, 3.36, 3.37 and 3.38)

Operation Time (min) / **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	1.75	1.74	1.78	1.76	1.8	1.83
	Rejection, %	99.83	99.83	99.83	99.83	99.83	99.82
Na^+ [mg/L]	**Permeate**	73	72	71	73	73	73
	Rejection, %	99.50	99.51	99.52	99.50	99.50	99.50
Ca^{2+} [mg/L]	**Permeate**	0.15	0.16	0.15	0.14	0.16	0.12
	Rejection, %	99.98	99.98	99.98	99.98	99.98	99.98
K^+ [mg/L]	**Permeate**	5.49	5.38	5.45	5.51	5.55	5.48
	Rejection, %	99.28	99.29	99.28	99.28	99.27	99.28
Cl^- [mg/L]	**Permeate**	144.15	141.27	140.85	144.94	145.27	151.82
	Rejection, %	99.39	99.40	99.41	99.39	99.39	99.36
SO_4^{2-} [mg/L]	**Permeate**	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.
	Rejection, %	-	-	-	-	-	-
HCO_3^- [mg/L]	**Permeate**	7.40	8.63	7.40	9.87	7.40	8.63
	Rejection, %	95.71	95.00	95.71	94.28	95.71	95.00
Turbidity	**Permeate**	0.06	0.07	0.08	0.09	0.8	0.07

Test 22; 22.0°C, adjusted-acid (HCl) addition, 55 bar

Table A.18 Results for effect of applied pressure on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.24, 3.25, 3.26, 3.27, 3.28, 3.29, 3.30, 3.39, 3.40, 3.41, 3.42, 3.43, 3.44, 3.45, 3.46)

Parameters / **Operation Time (min)**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	2.33	2.13	2.22	2.21	2.43	2.29
	Rejection, %	99.76	99.78	99.77	99.77	99.75	99.76
Na^+ [mg/L]	**Permeate**	60.9	59.0	57.5	57.2	58.4	55.8
	Rejection, %	99.67	99.68	99.69	99.69	99.68	99.69
Ca^{2+} [mg/L]	**Permeate**	0.35	0.29	0.25	0.28	0.30	0.35
	Rejection, %	99.93	99.94	99.95	99.94	99.94	99.93
K^+ [mg/L]	**Permeate**	3.47	3.39	3.40	3.56	3.38	3.26
	Rejection, %	99.52	99.53	99.53	99.50	99.53	99.55
Cl^- [mg/L]	**Permeate**	110.20	109.32	108.13	106.56	109.70	104.48
	Rejection, %	99.52	99.52	99.53	99.54	99.52	99.55
SO_4^{2-} [mg/L]	**Permeate**	1.17	1.86	2.01	1.90	1.83	1.32
	Rejection, %	99.96	99.94	99.93	99.94	99.94	99.95
HCO_3^- [mg/L]	**Permeate**	12.33	9.2	9.2	12.33	9.2	12.33
	Rejection, %	92.31	94.26	94.26	92.31	94.26	92.31
Turbidity	**Permeate**	0.06	0.09	0.05	0.08	0.10	0.05

Test 5; 16°C, adjusted-acid (HCl) addition, 55 bar

Table A.19 Results for effect of applied pressure on Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^-, HCO_3^- and turbidity rejection (Figures 3.24, 3.25, 3.26, 3.27, 3.28, 3.29, 3.30, 3.39, 3.40, 3.41, 3.42, 3.43, 3.44, 3.45, 3.46)

Parameters	**Operation Time (min)**	**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	3.52	3.33	3.29	3.37	3.01	3.15
	Rejection, %	99.76	99.77	99.78	99.77	99.80	99.79
Na^+ [mg/L]	**Permeate**	50.8	48.3	48.4	47.4	48.0	46.1
	Rejection, %	99.65	99.67	99.67	99.67	99.67	99.68
Ca^{2+} [mg/L]	**Permeate**	0.30	0.49	0.28	1.26	1.21	0.21
	Rejection, %	99.94	99.90	99.94	99.75	99.76	99.95
K^+ [mg/L]	**Permeate**	2.44	2.39	2.41	2.52	2.39	2.68
	Rejection, %	99.65	99.66	99.66	99.64	99.66	99.62
Cl^- [mg/L]	**Permeate**	106.08	99.52	100.38	96.4	94.83	97.79
	Rejection, %	99.60	99.63	99.63	99.64	99.65	99.63
SO_4^{2-} [mg/L]	**Permeate**	B.L.D	0.92	B.L.D	B.L.D	B.L.D	B.L.D
	Rejection, %	-	-	-	-	-	-
HCO_3^- [mg/L]	**Permeate**	14.80	12.33	11.10	9.87	12.33	12.33
	Rejection, %	90.40	92.00	92.80	93.60	92.00	92.00
Turbidity	**Permeate**	0.10	0.14	0.21	0.14	0.11	0.12

Test 13; 16°C, adjusted-acid (HCl) addition, 60 bar

Table A.20 Results for effect of applied pressure on Na$^+$, Mg^{2+}, Ca^{2+}, K$^+$, SO$_4^{2-}$, Cl$^-$, HCO$_3^-$ and turbidity rejection (Figures 3.24, 3.25, 3.26, 3.27, 3.28, 3.29, 3.30, 3.39, 3.40, 3.41, 3.42, 3.43, 3.44, 3.45, 3.46)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	3.11	3.17	3.39	3.22	3.12	3.06
	Rejection, %	99.77	99.77	99.75	99.76	99.77	99.77
Na$^+$ [mg/L]	**Permeate**	47.9	46.1	45.4	44.1	44.1	44.7
	Rejection, %	99.70	99.71	99.72	99.73	99.73	99.72
Ca^{2+} [mg/L]	**Permeate**	0.25	0.23	0.29	0.49	0.41	0.67
	Rejection, %	99.95	99.96	99.95	99.91	99.92	99.88
K$^+$ [mg/L]	**Permeate**	1.87	1.94	2.02	1.96	1.95	1.83
	Rejection, %	99.70	99.69	99.67	99.68	99.68	99.70
Cl$^-$ [mg/L]	**Permeate**	99.44	99.09	99.18	97.98	96.76	96.45
	Rejection, %	99.63	99.63	99.63	99.64	99.64	99.64
SO$_4^{2-}$ [mg/L]	**Permeate**	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.
	Rejection, %	-	-	-	-	-	-
HCO$_3^-$ [mg/L]	**Permeate**	12.33	14.80	12.33	11.10	12.33	9.87
	Rejection, %	91.67	90.00	91.67	92.50	91.67	93.33
Turbidity	**Permeate**	0.07	0.16	0.14	0.07	0.14	0.09

Test 14; 16°C, adjusted-acid (HCl) addition, 62 bar

Long-term Studies

A.21 Variations in permeate Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of the membranes for long term operation (Figures 3.47, 3.48, 3.49, 3.50, 3.51, 3.52 and 3.53)

Test 25; 29.1°C, 12h, 60 bar, high rejection XUS SW30XHR-2540 membrane

Parameters	**Operation Time (h)**	**1**	**2**	**3**	**4**	**5**	**6**
Mg^{2+} [mg/L]	**Permeate**	1.55	1.45	1.41	1.36	1.21	1.67
	Rejection, %	99.87	99.88	99.88	99.89	99.90	99.86
Na^+ [mg/L]	**Permeate**	83	78	76	74	73	75
	Rejection, %	99.43	99.47	99.48	99.49	99.50	99.49
Ca^{2+} [mg/L]	**Permeate**	0.22	0.27	0.30	0.49	0.19	0.30
	Rejection, %	99.96	99.95	99.95	99.91	99.97	99.95
K^+ [mg/L]	**Permeate**	5.65	5.18	5.08	5.13	4.92	5.13
	Rejection, %	99.28	99.34	99.35	99.34	99.37	99.34
Cl^- [mg/L]	**Permeate**	165.55	158.56	154.72	150.74	151.41	156.33
	Rejection, %	99.38	99.40	99.42	99.43	99.43	99.41
SO_4^{2-} [mg/L]	**Permeate**	0.79	0.82	0.85	1.01	0.43	1.21
	Rejection, %	99.98	99.98	99.97	99.97	99.99	99.96
HCO_3^- [mg/L]	**Permeate**	11.10	9.87	12.33	12.33	11.10	12.33
	Rejection, %	91.00	92.00	90.00	90.00	91.00	90.00
Turbidity	**Permeate**	0.03	0.04	0.05	0.05	0.03	0.12

Operation Time (h) **Parameters**		**7**	**8**	**9**	**10**	**11**	**12**
Mg^{2+} [mg/L]	**Permeate**	1.23	1.18	1.20	1.74	1.26	2.44
	Rejection, %	99.90	99.90	99.90	99.86	99.90	99.80
Na^{+} [mg/L]	**Permeate**	72	71	70	72	66	75
	Rejection, %	99.51	99.52	99.52	99.51	99.55	99.49
Ca^{2+} [mg/L]	**Permeate**	0.25	0.25	0.20	0.22	0.11	0.30
	Rejection, %	99.96	99.96	99.96	99.96	99.98	99.95
K^{+} [mg/L]	**Permeate**	4.83	5.12	4.83	5.29	4.88	5.33
	Rejection, %	99.38	99.34	99.38	99.32	99.37	99.32
Cl^{-} [mg/L]	**Permeate**	150.11	152.78	155.39	154.55	147.31	164.5
	Rejection, %	99.43	99.42	99.41	99.42	99.44	99.38
SO_4^{2-} [mg/L]	**Permeate**	1.50	1.46	0.64	1.39	0.62	2.68
	Rejection, %	99.96	99.96	99.98	99.96	99.98	99.92
HCO_3^{-} [mg/L]	**Permeate**	12.33	11.10	12.33	11.10	11.10	9.87
	Rejection, %	90.00	91.00	90.00	91.00	91.00	92.00
Turbidity	**Permeate**	0.05	0.11	0.05	0.04	0.03	0.07

A.22 Variations in permeate Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of the membranes for long term operation (Figures 3.47, 3.48, 3.49, 3.50, 3.51, 3.52 and 3.53)

Test 28; 26.9°C, 12h, 60 bar, SW30-2540 membrane

Operation Time (h) **Parameters**		**1**	**2**	**3**	**4**	**5**	**6**
Mg^{2+} [mg/L]	**Permeate**	2.69	2.1	1.97	1.03	1.27	0.85
	Rejection, %	81.35	85.44	86.34	92.86	91.19	94.11
Na^+ [mg/L]	**Permeate**	114	104	102	96	97	93
	Rejection, %	99.23	99.30	99.31	99.35	99.35	99.37
Ca^{2+} [mg/L]	**Permeate**	1.2	1.1	0.8	0.5	0.5	0.5
	Rejection, %	99.79	99.81	99.86	99.91	99.91	99.91
K^+ [mg/L]	**Permeate**	10.5	9.3	8.47	8.28	8.29	8.17
	Rejection, %	98.65	98.81	98.91	98.94	98.94	98.95
Cl^- [mg/L]	**Permeate**	234.15	217.83	219.60	203.91	204.70	200.72
	Rejection, %	99.07	99.14	99.13	99.19	99.19	99.21
SO_4^{2-} [mg/L]	**Permeate**	6.64	6.41	5.50	2.69	2.53	1.02
	Rejection, %	99.81	99.82	99.84	99.92	99.93	99.97
HCO_3^- [mg/L]	**Permeate**	17.27	14.80	11.10	11.10	9.87	11.10
	Rejection, %	89.23	90.77	93.08	93.08	93.84	93.08
Turbidity	**Permeate**	0.09	0.10	0.08	0.07	0.09	0.11

Operation Time (h) **Parameters**		**7**	**8**	**9**	**10**	**11**	**12**
Mg^{2+} [mg/L]	**Permeate**	0.89	0.62	0.8	0.66	0.96	1.61
	Rejection, %	93.83	95.70	94.45	95.42	93.34	88.83
Na^+ [mg/L]	**Permeate**	93	89	90	88	90	95
	Rejection, %	99.37	99.40	99.39	99.41	99.39	99.36
Ca^{2+} [mg/L]	**Permeate**	0.50	0.40	0.50	0.50	0.50	0.90
	Rejection, %	99.91	99.93	99.91	99.91	99.91	99.84
K^+ [mg/L]	**Permeate**	8.15	8.33	8.71	8.04	8.44	9.00
	Rejection, %	98.95	98.93	98.88	98.97	98.92	98.85
Cl^- [mg/L]	**Permeate**	201.39	195.68	198.70	197.82	204.30	214.90
	Rejection, %	99.20	99.23	99.21	99.22	99.19	99.15
SO_4^{2-} [mg/L]	**Permeate**	1.95	1.90	2.73	1.91	2.48	3.85
	Rejection, %	99.94	99.94	99.92	99.94	99.93	99.89
HCO_3^- [mg/L]	**Permeate**	12.33	12.33	11.10	11.10	11.10	12.33
	Rejection, %	92.31	92.31	93.08	93.08	93.08	92.31
Turbidity	**Permeate**	0.11	0.11	0.09	0.08	0.07	0.08

A.23 Variations in permeate Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of the membranes for long term operation (Figures 3.54, 3.55, 3.56, 3.57, 3.58, 3.59 and 3.60)

Test 26; 28.6°C, 24 h, 55 bar, SW30-2540 membrane

Operation Time (h) **Parameters**		**1**	**2**	**3**	**4**	**5**	**6**
Mg^{2+} [mg/L]	**Permeate**	15.81	13.34	4.93	5.07	4.58	4.59
	Rejection, %	98.65	98.86	99.58	99.57	99.61	99.61
Na^+ [mg/L]	**Permeate**	185	117	117	113	113	176
	Rejection, %	98.72	99.19	99.19	99.22	99.22	98.78
Ca^{2+} [mg/L]	**Permeate**	3.67	3.12	0.71	0.69	0.8	2.41
	Rejection, %	99.32	99.42	99.87	99.87	99.85	99.55
K^+ [mg/L]	**Permeate**	12.72	11.31	8.26	8.57	8.2	10.79
	Rejection, %	98.30	98.49	98.90	98.86	98.91	98.56
Cl^- [mg/L]	**Permeate**	405.79	358.18	237.85	237.62	227.86	225.38
	Rejection, %	98.47	98.65	99.10	99.10	99.14	99.15
SO_4^{2-} [mg/L]	**Permeate**	26.72	21.6	4.26	3.58	3.81	2.7
	Rejection, %	99.18	99.34	99.87	99.89	99.88	99.92
HCO_3^- [mg/L]	**Permeate**	11.10	12.33	12.33	11.10	12.33	12.33
	Rejection, %	92.50	91.67	91.67	92.50	91.67	91.67
Turbidity	**Permeate**	0.05	0.04	0.03	0.03	0.05	0.03

Operation Time (h) **Parameters**		**8**	**10**	**12**	**14**	**16**	**18**
Mg^{2+} [mg/L]	**Permeate**	11.78	13.11	13.63	13.64	11.8	12
	Rejection, %	99.00	98.88	98.84	98.84	98.99	98.98
Na^+ [mg/L]	**Permeate**	183	179	181	163	162	164
	Rejection, %	98.73	98.76	98.74	98.87	98.88	98.86
Ca^{2+} [mg/L]	**Permeate**	3.18	7.06	7.12	2.53	2.56	2.49
	Rejection, %	99.41	98.69	98.68	99.53	99.53	99.54
K^+ [mg/L]	**Permeate**	11.05	11.19	11.19	10.75	10.14	10
	Rejection, %	98.53	98.51	98.51	98.57	98.65	98.67
Cl^- [mg/L]	**Permeate**	334	363.88	357.14	325.98	324.41	322.19
	Rejection, %	98.74	98.63	98.65	98.77	98.78	98.78
SO_4^{2-} [mg/L]	**Permeate**	16.1	19.18	18.54	15.94	14.2	15.34
	Rejection, %	99.50	99.41	99.43	99.51	99.56	99.53
HCO_3^- [mg/L]	**Permeate**	14.80	12.33	22.20	12.33	12.33	14.80
	Rejection, %	90.00	91.67	85.00	91.67	91.67	90.00
Turbidity	**Permeate**	0.05	0.06	0.12	0.09	0.02	0.06

Operation Time (h) Parameters		20	22	24
Mg^{2+} [mg/L]	**Permeate**	12.32	11.69	13.11
	Rejection, %	98.95	99.00	98.88
Na^{+} [mg/L]	**Permeate**	164	159	179
	Rejection, %	98.86	98.90	98.76
Ca^{2+} [mg/L]	**Permeate**	2.63	2.4	2.65
	Rejection, %	99.51	99.56	99.51
K^{+} [mg/L]	**Permeate**	10.74	10.28	10.5
	Rejection, %	98.57	98.63	98.60
Cl^{-} [mg/L]	**Permeate**	323.02	312	334.5
	Rejection, %	98.78	98.82	98.74
SO$_4^{2-}$ [mg/L]	**Permeate**	14.73	15.1	18.34
	Rejection, %	99.55	99.54	99.44
HCO$_3^{-}$ [mg/L]	**Permeate**	13.57	14.80	13.57
	Rejection, %	90.83	90.00	90.83
Turbidity	**Permeate**	0.06	0.05	0.04

A.24 Variations in permeate Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of the membranes for long term operation (Figures 3.54, 3.55, 3.56, 3.57, 3.58, 3.59 and 3.60)

Test 27; 26.6°C, 24 h, 55 bar, high rejection XUS SW30XHR-2540 membrane

Operation Time (h) **Parameters**		**1**	**2**	**3**	**4**	**5**	**6**
Mg^{2+} [mg/L]	**Permeate**	1.05	0.89	1.45	0.79	0.78	0.3
	Rejection, %	99.87	99.89	99.82	99.90	99.90	99.96
Na^+ [mg/L]	**Permeate**	81	78	81	74	76	76
	Rejection, %	99.51	99.53	99.51	99.56	99.54	99.54
Ca^{2+} [mg/L]	**Permeate**	0.2	0.1	0.3	0.2	0.2	0.2
	Rejection, %	99.97	99.98	99.95	99.97	99.97	99.97
K^+ [mg/L]	**Permeate**	5.46	5.1	5.3	4.94	5.62	5.18
	Rejection, %	98.91	98.99	98.95	99.02	98.88	98.97
Cl^- [mg/L]	**Permeate**	165.55	156.8	161.67	152.23	158.3	156.27
	Rejection, %	99.35	99.38	99.36	99.40	99.37	99.38
SO_4^{2-} [mg/L]	**Permeate**	b.l.d.	b.l.d.	1.09	b.l.d.	b.l.d.	b.l.d.
	Rejection, %	-	-	99.97	-	-	-
HCO_3^- [mg/L]	**Permeate**	14.8	12.33	12.33	9.87	11.10	8.63
	Rejection, %	90.77	92.31	92.31	93.84	93.08	94.62
Turbidity	**Permeate**	0.09	0.07	0.08	0.07	0.08	0.05

Operation Time (h) **Parameters**		**8**	**10**	**12**	**14**	**16**	**18**
Mg^{2+} [mg/L]	**Permeate**	0.3	0.53	0.53	b.l.d.	b.l.d.	b.l.d.
	Rejection, %	99.96	99.93	99.93	-	-	-
Na^+ [mg/L]	**Permeate**	78	76	81	69	66	64
	Rejection, %	99.53	99.54	99.51	99.59	99.60	99.62
Ca^{2+} [mg/L]	**Permeate**	0.3	0.3	0.4	0.3	0.1	0.2
	Rejection, %	99.95	99.95	99.94	99.95	99.98	99.97
K^+ [mg/L]	**Permeate**	6.28	5.41	5.47	6.74	4.96	4.76
	Rejection, %	98.75	98.92	98.91	98.66	99.01	99.05
Cl^- [mg/L]	**Permeate**	164.06	159.8	170.19	153.98	148.85	146.29
	Rejection, %	99.35	99.37	99.33	99.39	99.41	99.42
SO_4^{2-} [mg/L]	**Permeate**	1.12	0.77	1.23	b.l.d.	b.l.d.	b.l.d.
	Rejection, %	99.97	99.98	99.97	-	-	-
HCO_3^- [mg/L]	**Permeate**	11.10	12.33	12.33	9.87	9.87	9.87
	Rejection, %	93.08	92.31	92.31	93.84	93.84	93.84
Turbidity	**Permeate**	0.09	0.10	0.10	0.09	0.10	0.09

Parameters \ **Operation Time (h)**		**20**	**22**	**24**
Mg^{2+} [mg/L]	**Permeate**	b.l.d.	b.l.d.	b.l.d.
	Rejection, %	-	-	-
Na^{+} [mg/L]	**Permeate**	70	63	62
	Rejection, %	99.58	99.62	99.63
Ca^{2+} [mg/L]	**Permeate**	0.3	0.3	0.2
	Rejection, %	99.95	99.95	99.97
K^{+} [mg/L]	**Permeate**	5.21	4.79	4.94
	Rejection, %	98.96	99.05	99.02
Cl^{-} [mg/L]	**Permeate**	156.76	142.62	142.53
	Rejection, %	99.38	99.44	99.44
SO_4^{2-} [mg/L]	**Permeate**	0.91	b.l.d.	b.l.d.
	Rejection, %	99.97	-	-
HCO_3^{-} [mg/L]	**Permeate**	11.10	11.10	12.33
	Rejection, %	93.08	93.08	92.31
Turbidity	**Permeate**	0.07	0.09	0.08

Reverse Osmosis performance for both membranes during one year of operation

A.25 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Parameters \ Operation Time (min)		15	30	45	60	75	90
Mg^{2+} [mg/L]	**Permeate**	3.11	2.93	2.85	2.62	2.50	2.48
	Rejection, %	99.68	99.70	99.71	99.73	99.74	99.75
Na^+ [mg/L]	**Permeate**	64.2	58.6	55.3	53.0	52.7	50.2
	Rejection, %	99.35	99.41	99.44	99.46	99.47	99.49
Ca^{2+} [mg/L]	**Permeate**	0.58	0.52	0.52	0.47	0.45	0.46
	Rejection, %	99.87	99.88	99.88	99.89	99.90	99.90
K^+ [mg/L]	**Permeate**	5.19	4.80	4.80	4.72	4.73	4.90
	Rejection, %	99.00	99.08	99.08	99.10	99.09	99.06
Cl^- [mg/L]	**Permeate**	184.93	178.16	173.53	170.08	171.91	164.69
	Rejection, %	99.19	99.22	99.24	99.26	99.25	99.28
SO_4^{2-} [mg/L]	**Permeate**	5.08	5.64	4.74	4.12	4.00	3.07
	Rejection, %	99.82	99.80	99.83	99.85	99.85	99.89
HCO_3^- [mg/L]	**Permeate**	18.50	24.64	24.64	30.83	27.72	30.83
	Rejection, %	89.76	86.36	86.36	82.94	84.66	82.94
Turbidity	**Permeate**	0.10	0.08	0.13	0.17	0.22	0.16

Test 3; 17.7°C, 55 bar, SW30-2540 membrane, November 2008.

A.26 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

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Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	1.68	1.59	1.39	1.31	1.35	1.16
	Rejection, %	99.83	99.84	99.86	99.87	99.87	99.88
Na^+ [mg/L]	**Permeate**	42.1	38.8	34.9	31.8	28.6	25.8
	Rejection, %	99.57	99.61	99.65	99.68	99.71	99.74
Ca^{2+} [mg/L]	**Permeate**	0.3	0.41	0.29	0.24	0.42	0.25
	Rejection, %	99.93	99.91	99.94	99.95	99.91	99.94
K^+ [mg/L]	**Permeate**	2.98	2.79	2.88	2.85	2.76	2.81
	Rejection, %	99.43	99.46	99.45	99.45	99.47	99.46
Cl^- [mg/L]	**Permeate**	116.04	118.67	108.19	110.65	110.20	104.44
	Rejection, %	99.49	99.48	99.53	99.52	99.52	99.54
SO_4^{2-} [mg/L]	**Permeate**	3.33	3.01	2.58	3.02	2.81	2.57
	Rejection, %	99.88	99.89	99.90	99.89	99.90	99.91
HCO_3^- [mg/L]	**Permeate**	15.41	21.58	21.58	21.58	18.5	18.5
	Rejection, %	91.47	88.06	88.06	88.06	89.76	89.76
Turbidity	**Permeate**	0.13	0.08	0.13	0.09	0.15	0.09

Test 3; 17.7°C, 55 bar, high rejection XUS SW30XHR-2540 membrane, November 2008

A.27 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	4.62	4.26	3.85	3.77	3.81	3.64
	Rejection, %	99.54	99.57	99.61	99.62	99.62	99.63
Na^+ [mg/L]	**Permeate**	101.9	95.0	90.7	92.9	88.1	86.4
	Rejection, %	99.06	99.12	99.16	99.14	99.19	99.20
Ca^{2+} [mg/L]	**Permeate**	1.12	1.00	0.85	0.89	0.83	0.84
	Rejection, %	99.78	99.80	99.83	99.83	99.84	99.84
K^+ [mg/L]	**Permeate**	5.64	5.48	5.12	5.33	5.06	4.86
	Rejection, %	99.27	99.29	99.34	99.31	99.35	99.37
Cl^- [mg/L]	**Permeate**	179.70	171.08	164.18	169.08	167.96	158.77
	Rejection, %	99.47	99.50	99.52	99.51	99.51	99.54
SO_4^{2-} [mg/L]	**Permeate**	4.78	4.75	3.58	3.00	3.53	4.26
	Rejection, %	99.88	99.88	99.91	99.93	99.91	99.90
HCO_3^- [mg/L]	**Permeate**	12.33	13.57	14.80	12.33	12.33	12.33
	Rejection, %	92.31	91.54	90.77	92.31	92.31	92.31
Turbidity	**Permeate**	0.21	0.12	0.13	0.16	0.20	0.16

Test 6; 10.8°C, 55 bar, SW30-2540 membrane, December 2008

A.28 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	2.00	1.91	1.99	1.93	2.00	1.94
	Rejection, %	99.80	99.81	99.80	99.81	99.80	99.81
Na^+ [mg/L]	**Permeate**	57.3	55.6	54.9	53.7	51.5	50.6
	Rejection, %	99.47	99.49	99.49	99.50	99.52	99.53
Ca^{2+} [mg/L]	**Permeate**	0.35	0.44	0.38	0.37	0.42	0.42
	Rejection, %	99.93	99.91	99.93	99.93	99.92	99.92
K^+ [mg/L]	**Permeate**	3.59	3.01	2.99	3.05	3.02	2.88
	Rejection, %	99.54	99.61	99.61	99.61	99.61	99.63
Cl^- [mg/L]	**Permeate**	104.25	102.39	101.16	99.72	97.49	95.46
	Rejection, %	99.69	99.70	99.70	99.71	99.71	99.72
SO_4^{2-} [mg/L]	**Permeate**	1.61	1.43	1.42	1.62	1.15	0.78
	Rejection, %	99.96	99.96	99.96	99.96	99.97	99.98
HCO_3^- [mg/L]	**Permeate**	17.27	16.03	12.33	12.33	13.57	12.33
	Rejection, %	89.23	90.00	92.31	92.31	91.54	92.31
Turbidity	**Permeate**	0.06	0.05	0.08	0.04	0.07	0.06

Test 6; 10.8°C, 55 bar, high rejection XUS SW30XHR-2540 membrane, December 2008

A.29 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Parameters	**Operation Time (min)**	**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	5.52	4.94	4.83	4.71	4.70	4.65
	Rejection, %	99.59	99.63	99.64	99.65	99.65	99.66
Na^+ [mg/L]	**Permeate**	109.7	101.2	100.5	99.9	99.6	98.6
	Rejection, %	98.92	99.01	99.01	99.02	99.02	99.03
Ca^{2+} [mg/L]	**Permeate**	1.34	1.54	1.10	0.97	0.95	0.98
	Rejection, %	99.86	99.84	99.89	99.90	99.90	99.90
K^+ [mg/L]	**Permeate**	5.52	5.27	4.82	4.96	5.00	5.01
	Rejection, %	99.16	99.20	99.27	99.25	99.24	99.24
Cl^- [mg/L]	**Permeate**	184.91	176.68	171.26	169.74	166.09	165.09
	Rejection, %	99.36	99.38	99.40	99.41	99.42	99.42
SO_4^{2-} [mg/L]	**Permeate**	4.71	3.77	3.44	3.51	3.15	3.39
	Rejection, %	99.87	99.90	99.90	99.90	99.91	99.91
HCO_3^- [mg/L]	**Permeate**	12.33	12.33	14.80	14.80	12.33	13.57
	Rejection, %	91.67	91.67	90.00	90.00	91.67	90.83
Turbidity	**Permeate**	0.04	0.06	0.08	0.11	0.07	0.06

Test 8; 12.3°C, 55 bar, SW30-2540 membrane, January 2009

A.30 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Parameters	**Operation Time (min)**	**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	2.74	2.87	2.79	2.83	2.69	2.70
	Rejection, %	99.80	99.79	99.79	99.79	99.80	99.80
Na^+ [mg/L]	**Permeate**	55.9	56.4	55.0	55.2	54.4	53.0
	Rejection, %	99.45	99.45	99.46	99.46	99.47	99.48
Ca^{2+} [mg/L]	**Permeate**	0.57	0.61	0.58	0.47	0.69	0.48
	Rejection, %	99.94	99.94	99.94	99.95	99.93	99.95
K^+ [mg/L]	**Permeate**	3.01	3.03	2.92	2.95	2.80	2.30
	Rejection, %	99.54	99.54	99.56	99.55	99.57	99.65
Cl^- [mg/L]	**Permeate**	106.05	105.06	103.24	103.19	100.91	101.37
	Rejection, %	99.63	99.63	99.64	99.64	99.65	99.65
SO_4^{2-} [mg/L]	**Permeate**	0.74	0.78	0.59	1.05	0.54	0.54
	Rejection, %	99.98	99.98	99.98	99.97	99.99	99.99
HCO_3^- [mg/L]	**Permeate**	11.10	11.10	12.33	13.57	12.33	13.57
	Rejection, %	92.50	92.50	91.67	90.83	91.67	90.83
Turbidity	**Permeate**	0.08	0.06	0.11	0.09	0.07	0.05

Test 8; 12.3°C, 55 bar, high rejection XUS SW30XHR-2540 membrane, January 2009

A.31 Variations in Na^{+}, Mg^{2+}, Ca^{2+}, K^{+}, SO$_4^{2-}$, Cl^{-} and HCO$_3^{-}$ rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	6.07	5.60	4.55	4.89	4.47	4.39
	Rejection, %	99.55	99.59	99.67	99.64	99.67	99.68
Na^{+} [mg/L]	**Permeate**	68.0	64.6	66.1	65.3	66.0	68.4
	Rejection, %	99.49	99.51	99.50	99.51	99.50	99.49
Ca^{2+} [mg/L]	**Permeate**	1.41	1.07	0.56	1.43	1.60	1.20
	Rejection, %	99.77	99.82	99.91	99.76	99.74	99.80
K^{+} [mg/L]	**Permeate**	5.79	5.82	5.51	5.41	5.51	5.51
	Rejection, %	99.23	99.23	99.27	99.28	99.27	99.27
Cl^{-} [mg/L]	**Permeate**	183.76	179.71	173.07	166.32	168.3	166.29
	Rejection, %	99.34	99.35	99.38	99.40	99.40	99.40
SO$_4^{2-}$ [mg/L]	**Permeate**	4.30	3.98	2.84	3.07	2.56	2.26
	Rejection, %	99.88	99.89	99.92	99.92	99.93	99.94
HCO$_3^{-}$ [mg/L]	**Permeate**	9.87	9.87	12.33	11.10	9.87	12.33
	Rejection, %	92.72	92.72	90.91	91.82	92.72	90.91
Turbidity	**Permeate**	0.15	0.19	0.14	0.15	0.18	010

Test 10; 13.9°C, 55 bar, SW30-2540 membrane, February 2009

A.32 Variations in Na^{+}, Mg^{2+}, Ca^{2+}, K^{+}, SO$_4^{2-}$, Cl^{-} and HCO$_3^{-}$ rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	3.12	2.89	2.33	2.34	2.21	2.63
	Rejection, %	99.77	99.79	99.83	99.83	99.84	99.81
Na^{+} [mg/L]	**Permeate**	40.5	38.8	38.9	40.3	38.4	37.7
	Rejection, %	99.69	99.71	99.71	99.70	99.71	99.72
Ca^{2+} [mg/L]	**Permeate**	0.28	0.56	0.62	0.61	0.60	0.54
	Rejection, %	99.95	99.91	99.90	99.90	99.90	99.91
K^{+} [mg/L]	**Permeate**	3.15	3.17	2.89	3.02	3.01	2.83
	Rejection, %	99.58	99.58	99.62	99.60	99.60	99.62
Cl^{-} [mg/L]	**Permeate**	107.14	106.93	106.3	105.52	102.94	102.7
	Rejection, %	99.61	99.62	99.62	99.62	99.63	99.63
SO$_4^{2-}$ [mg/L]	**Permeate**	0.89	0.29	0.5	0.67	0.46	0.28
	Rejection, %	99.98	99.99	99.99	99.98	99.99	99.99
HCO$_3^{-}$ [mg/L]	**Permeate**	9.87	9.87	11.10	9.87	11.10	9.87
	Rejection, %	92.72	92.72	91.82	92.72	91.82	92.72
Turbidity	**Permeate**	0.08	0.10	0.11	0.12	0.07	0.06

Test 10; 13.9°C, 55 bar, high rejection XUS SW30XHR-2540 membrane, February 2009

A.33 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Parameters	Operation Time (min)	15	30	45	60	75	90
Mg^{2+} [mg/L]	Permeate	3.47	2.93	2.74	3.2	2.72	2.9
	Rejection, %	99.68	99.73	99.75	99.71	99.75	99.73
Na^+ [mg/L]	Permeate	53.7	50.7	50.0	49.5	49.3	50.1
	Rejection, %	99.53	99.55	99.56	99.56	99.57	99.56
Ca^{2+} [mg/L]	Permeate	1.41	0.31	0.34	0.47	0.42	0.36
	Rejection, %	99.73	99.94	99.93	99.91	99.92	99.93
K^+ [mg/L]	Permeate	3.28	3.01	2.98	2.87	2.84	2.73
	Rejection, %	99.47	99.51	99.52	99.54	99.54	99.56
Cl^- [mg/L]	Permeate	148.58	140.72	139.06	134.54	133.61	128.12
	Rejection, %	99.47	99.50	99.51	99.52	99.53	99.55
SO_4^{2-} [mg/L]	Permeate	4.65	4.12	4.26	3.73	3.24	2.74
	Rejection, %	99.87	99.89	99.88	99.90	99.91	99.92
HCO_3^- [mg/L]	Permeate	14.80	14.80	17.27	14.80	12.33	12.33
	Rejection, %	90.77	90.77	89.23	90.77	92.31	92.31
Turbidity	Permeate	0.06	0.06	0.05	0.09	0.07	0.08

Test 12; 13.2°C, 55 bar, SW30-2540 membrane, March 2009

A.34 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Parameters	Operation Time (min)	15	30	45	60	75	90
Mg^{2+} [mg/L]	Permeate	7.58	7.31	6.65	6.51	6.22	5.99
	Rejection, %	99.30	99.33	99.39	99.40	99.43	99.45
Na^+ [mg/L]	Permeate	68.2	63.5	65.0	62.1	59.8	59.3
	Rejection, %	99.40	99.44	99.43	99.45	99.47	99.48
Ca^{2+} [mg/L]	Permeate	0.94	1.29	1.05	0.79	0.60	0.56
	Rejection, %	99.82	99.75	99.80	99.85	99.88	99.89
K^+ [mg/L]	Permeate	4.88	4.54	4.60	4.23	4.31	4.19
	Rejection, %	99.21	99.27	99.26	99.32	99.30	99.32
Cl^- [mg/L]	Permeate	114.1	110.32	109.95	107.28	106	106.01
	Rejection, %	99.60	99.61	99.61	99.62	99.62	99.62
SO_4^{2-} [mg/L]	Permeate	1.31	0.36	0.52	0.45	0.24	0.27
	Rejection, %	99.96	99.99	99.99	99.99	99.99	99.99
HCO_3^- [mg/L]	Permeate	12.33	12.33	14.80	12.33	14.80	12.33
	Rejection, %	92.31	92.31	90.77	92.31	90.77	92.31
Turbidity	Permeate	0.04	0.06	0.10	0.09	0.07	0.06

Test 12; 13.2°C, 55 bar, high rejection XUS SW30XHR-2540 membrane, March 2009

A.35 Variations in Na^{+}, Mg^{2+}, Ca^{2+}, K^{+}, SO$_4^{2-}$, Cl^{-} and HCO$_3^{-}$ rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	3.77	3.89	3.7	3.92	4.14	3.78
	Rejection, %	99.70	99.69	99.70	99.69	99.67	99.70
Na^{+} [mg/L]	**Permeate**	55.2	55.3	53.2	52.7	51.4	52.8
	Rejection, %	99.68	99.68	99.69	99.69	99.70	99.69
Ca^{2+} [mg/L]	**Permeate**	0.52	0.26	0.94	0.21	0.21	0.62
	Rejection, %	99.91	99.95	99.83	99.96	99.96	99.89
K^{+} [mg/L]	**Permeate**	2.66	2.48	2.44	2.35	2.28	2.18
	Rejection, %	99.61	99.63	99.64	99.65	99.66	99.68
Cl^{-} [mg/L]	**Permeate**	162.36	160.58	167.49	194.15	183	160.5
	Rejection, %	99.34	99.35	99.32	99.21	99.26	99.35
SO$_4^{2-}$ [mg/L]	**Permeate**	4.09	3.53	3.87	7.76	6.56	4.09
	Rejection, %	99.86	99.88	99.87	99.74	99.78	99.86
HCO$_3^{-}$ [mg/L]	**Permeate**	12.33	12.33	9.20	6.16	6.16	6.16
	Rejection, %	92.31	92.31	94.26	96.16	96.16	96.16
Turbidity	**Permeate**	0.04	0.06	0.10	0.09	0.07	0.06

Test 15; 15.8°C, 55 bar, SW30-2540 membrane, April 2009

A.36 Variations in Na^{+}, Mg^{2+}, Ca^{2+}, K^{+}, SO$_4^{2-}$, Cl^{-} and HCO$_3^{-}$ rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	9.18	8.53	8.76	11.49	10.42	8.98
	Rejection, %	99.27	99.32	99.30	99.08	99.17	99.28
Na^{+} [mg/L]	**Permeate**	4.12	4.12	4.00	4.75	4.40	4.02
	Rejection, %	99.39	99.39	99.41	99.30	99.35	99.41
Ca^{2+} [mg/L]	**Permeate**	0.35	0.29	0.25	0.28	0.30	0.35
	Rejection, %	99.93	99.94	99.95	99.94	99.94	99.93
K^{+} [mg/L]	**Permeate**	3.47	3.39	3.40	3.56	3.38	3.26
	Rejection, %	99.52	99.53	99.53	99.50	99.53	99.55
Cl^{-} [mg/L]	**Permeate**	116.23	114.33	113.99	111	112.77	112.88
	Rejection, %	99.53	99.54	99.54	99.55	99.54	99.54
SO$_4^{2-}$ [mg/L]	**Permeate**	B.L.D.	B.L.D.	B.L.D.	B.L.D.	B.L.D.	B.L.D.
	Rejection, %	-	-	-	-	-	-
HCO$_3^{-}$ [mg/L]	**Permeate**	12.33	12.33	9.20	6.16	6.16	6.16
	Rejection, %	92.31	92.31	94.26	96.16	96.16	96.16
Turbidity	**Permeate**	0.04	0.06	0.10	0.09	0.07	0.06

Test 15; 15.8°C, 55 bar, high rejection XUS SW30XHR-2540 membrane, April 2009.

A.37 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	9.98	9.35	11.36	12.97	13.41	11.66
	Rejection, %	99.07	99.13	98.94	98.79	98.75	98.91
Na^+ [mg/L]	**Permeate**	112.5	104.6	113.1	134.1	152.9	173.2
	Rejection, %	99.08	99.14	99.07	98.90	98.74	98.58
Ca^{2+} [mg/L]	**Permeate**	1.60	1.32	1.58	2.29	2.88	4.03
	Rejection, %	99.82	99.85	99.82	99.74	99.67	99.54
K^+ [mg/L]	**Permeate**	6.59	5.90	6.46	6.93	7.77	8.73
	Rejection, %	98.89	99.00	98.91	98.83	98.69	98.53
Cl^- [mg/L]	**Permeate**	252.35	228.67	238.21	281.74	324.5	354.24
	Rejection, %	98.99	99.08	99.04	98.87	98.70	98.58
SO_4^{2-} [mg/L]	**Permeate**	12.58	9.48	11.15	16.68	24.29	26.39
	Rejection, %	99.59	99.69	99.64	99.46	99.21	99.14
HCO_3^- [mg/L]	**Permeate**	12.33	11.10	12.33	9.87	12.33	12.33
	Rejection, %	92.00	92.80	92.00	93.60	92.00	92.00
Turbidity	**Permeate**	0.22	0.20	0.23	0.20	0.11	0.17

Test 16; 20.4°C, 55 bar, SW30-2540 membrane, May 2009.

A.38 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	1.94	1.62	0.83	1.06	1.93	1.28
	Rejection, %	99.82	99.85	99.92	99.90	99.82	99.88
Na^+ [mg/L]	**Permeate**	68.6	63.7	61.3	62.6	64.6	64
	Rejection, %	99.44	99.48	99.50	99.49	99.47	99.47
Ca^{2+} [mg/L]	**Permeate**	0.28	0.27	0.19	0.25	0.41	1.27
	Rejection, %	99.97	99.97	99.98	99.97	99.95	99.86
K^+ [mg/L]	**Permeate**	3.62	3.29	2.93	2.98	3.01	3.01
	Rejection, %	99.39	99.45	99.51	99.50	99.49	99.49
Cl^- [mg/L]	**Permeate**	152.2	144.81	137.47	139.52	143.83	140.59
	Rejection, %	99.39	99.42	99.45	99.44	99.42	99.43
SO_4^{2-} [mg/L]	**Permeate**	0.77	0.26	b.l.d.	b.l.d.	0.23	0.43
	Rejection, %	99.98	99.99	-	-	99.99	99.99
HCO_3^- [mg/L]	**Permeate**	11.10	8.63	9.87	9.87	12.33	12.33
	Rejection, %	92.80	94.40	93.60	93.60	92.00	92.00
Turbidity	**Permeate**	0.09	0.15	0.21	0.24	0.11	0.12

Test 16; 20.4°C, 55 bar, high rejection XUS SW30XHR-2540 membrane, May 2009.

A.39 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	2.33	2.13	2.22	2.21	2.43	2.29
	Rejection, %	99.76	99.78	99.77	99.77	99.75	99.76
Na^+ [mg/L]	**Permeate**	60.9	59.0	57.5	57.2	58.4	55.8
	Rejection, %	99.67	99.68	99.69	99.69	99.68	99.69
Ca^{2+} [mg/L]	**Permeate**	0.35	0.29	0.25	0.28	0.30	0.35
	Rejection, %	99.93	99.94	99.95	99.94	99.94	99.93
K^+ [mg/L]	**Permeate**	3.47	3.39	3.40	3.56	3.38	3.26
	Rejection, %	99.52	99.53	99.53	99.50	99.53	99.55
Cl^- [mg/L]	**Permeate**	184.05	176.53	174.42	182.80	175.16	171.25
	Rejection, %	99.20	99.23	99.24	99.20	99.24	99.26
SO_4^{2-} [mg/L]	**Permeate**	5.12	3.93	4.00	5.66	4.05	3.23
	Rejection, %	99.84	99.86	99.87	99.82	99.87	99.90
HCO_3^- [mg/L]	**Permeate**	12.33	12.33	9.20	6.16	6.16	6.16
	Rejection, %	92.31	92.31	94.26	96.16	96.16	96.16
Turbidity	**Permeate**	0.04	0.06	0.10	0.09	0.07	0.06

Test 18; 25.6°C, 55 bar, SW30-2540 membrane, June 2009.

A.40 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	2.33	2.13	2.22	2.21	2.43	2.29
	Rejection, %	99.76	99.78	99.77	99.77	99.75	99.76
Na^+ [mg/L]	**Permeate**	60.9	59.0	57.5	57.2	58.4	55.8
	Rejection, %	99.67	99.68	99.69	99.69	99.68	99.69
Ca^{2+} [mg/L]	**Permeate**	0.35	0.29	0.25	0.28	0.30	0.35
	Rejection, %	99.93	99.94	99.95	99.94	99.94	99.93
K^+ [mg/L]	**Permeate**	3.47	3.39	3.40	3.56	3.38	3.26
	Rejection, %	99.52	99.53	99.53	99.50	99.53	99.55
Cl^- [mg/L]	**Permeate**	184.05	176.53	174.42	182.80	175.16	171.25
	Rejection, %	99.20	99.23	99.24	99.20	99.24	99.26
SO_4^{2-} [mg/L]	**Permeate**	5.12	3.93	4.00	5.66	4.05	3.23
	Rejection, %	99.84	99.86	99.87	99.82	99.87	99.90
HCO_3^- [mg/L]	**Permeate**	12.33	12.33	9.20	6.16	6.16	6.16
	Rejection, %	92.31	92.31	94.26	96.16	96.16	96.16
Turbidity	**Permeate**	0.04	0.06	0.10	0.09	0.07	0.06

Test 18; 25.6°C, 55 bar, high rejection XUS SW30XHR-2540 membrane, June 2009.

A.41 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	20.76	16.96	17.56	18.55	18.29	18.42
	Rejection, %	98.54	98.81	98.77	98.70	98.72	98.71
Na^+ [mg/L]	**Permeate**	265.8	263.6	233.5	225.7	227.5	227.8
	Rejection, %	97.86	97.88	98.12	98.18	98.17	98.17
Ca^{2+} [mg/L]	**Permeate**	7.38	7.28	6.45	6.47	6.25	5.78
	Rejection, %	98.46	98.48	98.66	98.65	98.70	98.80
K^+ [mg/L]	**Permeate**	15.04	15.67	14.73	14.33	14.07	13.76
	Rejection, %	97.88	97.80	97.93	97.98	98.02	98.06
Cl^- [mg/L]	**Permeate**	627.46	642.58	576.76	558.32	563.79	533.92
	Rejection, %	97.63	97.58	97.82	97.89	97.87	97.99
SO_4^{2-} [mg/L]	**Permeate**	46.58	49.1	33.93	38.58	39.64	37.55
	Rejection, %	98.47	98.38	98.88	98.73	98.69	98.76
HCO_3^- [mg/L]	**Permeate**	12.33	14.80	14.80	17.27	17.27	14.80
	Rejection, %	92.86	91.43	91.43	90.00	90.00	91.43
Turbidity	**Permeate**	0.04	0.09	0.10	0.03	0.03	0.05

Test 19; 27.0°C, 55 bar, SW30-2540 membrane, July 2009.

A.42 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	5.09	4.41	4.43	4.13	4.45	4.98
	Rejection, %	99.64	99.69	99.69	99.71	99.69	99.65
Na^+ [mg/L]	**Permeate**	74.6	69	69.2	69.3	70.1	71.9
	Rejection, %	99.40	99.44	99.44	99.44	99.44	99.42
Ca^{2+} [mg/L]	**Permeate**	0.34	0.50	0.32	0.27	0.45	0.34
	Rejection, %	99.93	99.90	99.93	99.94	99.91	99.93
K^+ [mg/L]	**Permeate**	4.99	4.83	4.70	4.65	4.89	4.79
	Rejection, %	99.30	99.32	99.34	99.34	99.31	99.33
Cl^- [mg/L]	**Permeate**	194.38	186.05	181.94	181.91	184.74	188.49
	Rejection, %	99.27	99.30	99.31	99.31	99.30	99.29
SO_4^{2-} [mg/L]	**Permeate**	1.12	0.47	0.53	0.29	0.96	1.03
	Rejection, %	99.96	99.98	99.98	99.99	99.97	99.97
HCO_3^- [mg/L]	**Permeate**	14.80	12.33	12.33	11.10	12.33	12.33
	Rejection, %	91.43	92.86	92.86	93.57	92.86	92.86
Turbidity	**Permeate**	0.08	0.03	003	0.01	0.01	0.04

Test 19; 27.0°C, 55 bar, high rejection XUS SW30XHR-2540 membrane, July 2009.

A.43 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	7.21	6.33	5.83	7.72	8.33	7.77
	Rejection, %	99.54	99.60	99.63	99.51	99.47	99.51
Na^+ [mg/L]	**Permeate**	197	156	153	141	137	136
	Rejection, %	98.48	98.80	98.82	98.92	98.95	98.95
Ca^{2+} [mg/L]	**Permeate**	3.59	2.21	1.99	1.52	1.38	1.42
	Rejection, %	99.60	99.75	99.78	99.83	99.85	99.84
K^+ [mg/L]	**Permeate**	11.91	10.16	9.75	9.2	9.19	9.19
	Rejection, %	98.57	98.78	98.83	98.89	98.89	98.89
Cl^- [mg/L]	**Permeate**	358.29	277.77	246.30	252.09	218.47	244.69
	Rejection, %	98.70	98.99	99.10	99.08	99.20	99.11
SO_4^{2-} [mg/L]	**Permeate**	22.47	10.69	3.93	2.54	2.03	3.13
	Rejection, %	99.39	99.71	99.89	99.93	99.95	99.92
HCO_3^- [mg/L]	**Permeate**	14.80	12.33	11.10	9.87	12.33	12.33
	Rejection, %	91.11	92.59	93.33	94.07	92.59	92.59
Turbidity	**Permeate**	0.09	0.05	0.07	0.08	0.07	0.10

Test 20; 24.8°C, 55 bar, SW30-2540 membrane, August 2009

A.44 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	1.31	1.22	1.21	1.24	1.25	1.27
	Rejection, %	99.92	99.92	99.92	99.92	99.92	99.92
Na^+ [mg/L]	**Permeate**	85	83	82	82	80	79
	Rejection, %	99.35	99.36	99.37	99.37	99.38	99.39
Ca^{2+} [mg/L]	**Permeate**	0.23	0.19	0.17	0.17	0.20	0.14
	Rejection, %	99.97	99.98	99.98	99.98	99.98	99.98
K^+ [mg/L]	**Permeate**	5.09	5.01	4.93	4.96	5.01	5.01
	Rejection, %	99.39	99.40	99.41	99.40	99.40	99.40
Cl^- [mg/L]	**Permeate**	154.84	153.40	151.34	149.80	148.63	148.00
	Rejection, %	99.44	99.44	99.45	99.45	99.46	99.46
SO_4^{2-} [mg/L]	**Permeate**	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.
	Rejection, %	-	-	-	-	-	-
HCO_3^- [mg/L]	**Permeate**	9.87	9.87	9.87	11.10	7.40	11.10
	Rejection, %	94.07	94.07	94.07	93.33	95.55	93.33
Turbidity	**Permeate**	0.03	0.04	0.10	0.05	0.05	0.10

Test 20; 24.8°C, 55 bar, high rejection XUS SW30XHR-2540 membrane, August 2009.

A.45 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Parameters	**Operation Time (min)**	**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+}	**Permeate**	12.92	11.2	9.76	11.44	9.94	9.56
[mg/L]	**Rejection, %**	98.76	98.93	99.06	98.90	99.05	99.08
Na^+	**Permeate**	192	169	155	171	157	155
[mg/L]	**Rejection, %**	98.69	98.85	98.95	98.84	98.93	98.95
Ca^{2+}	**Permeate**	4.26	3.16	2.58	3.19	2.43	2.56
[mg/L]	**Rejection, %**	99.42	99.57	99.65	99.57	99.67	99.65
K^+	**Permeate**	12.68	11.98	11.27	12.05	11.38	11.4
[mg/L]	**Rejection, %**	98.34	98.43	98.52	98.42	98.51	98.50
Cl^-	**Permeate**	361.83	326.36	302.98	334.91	303.66	303.64
[mg/L]	**Rejection, %**	98.47	98.62	98.72	98.59	98.72	98.72
SO_4^{2-}	**Permeate**	20.16	17.73	13.83	17.80	13.79	11.65
[mg/L]	**Rejection, %**	99.27	99.36	99.50	99.36	99.50	99.58
HCO_3^-	**Permeate**	11.1	9.87	12.33	9.87	11.1	12.33
[mg/L]	**Rejection, %**	93.57	94.28	92.86	94.28	93.57	92.86
Turbidity	**Permeate**	0.10	0.11	0.09	0.08	0.12	0.11

Test 22; 22.0°C, 55 bar, SW30-2540 membrane, September 2009.

A.46 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Parameters	**Operation Time (min)**	**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+}	**Permeate**	1.75	1.74	1.78	1.76	1.8	1.83
[mg/L]	**Rejection, %**	99.83	99.83	99.83	99.83	99.83	99.82
Na^+	**Permeate**	73	72	71	73	73	73
[mg/L]	**Rejection, %**	99.50	99.51	99.52	99.50	99.50	99.50
Ca^{2+}	**Permeate**	0.15	0.16	0.15	0.14	0.16	0.12
[mg/L]	**Rejection, %**	99.98	99.98	99.98	99.98	99.98	99.98
K^+	**Permeate**	5.49	5.38	5.45	5.51	5.55	5.48
[mg/L]	**Rejection, %**	99.28	99.29	99.28	99.28	99.27	99.28
Cl^-	**Permeate**	144.15	141.27	140.85	144.94	145.27	151.82
[mg/L]	**Rejection, %**	99.39	99.40	99.41	99.39	99.39	99.36
SO_4^{2-}	**Permeate**	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.	b.l.d.
[mg/L]	**Rejection, %**	-	-	-	-	-	-
HCO_3^-	**Permeate**	7.40	8.63	7.40	9.87	7.40	8.63
[mg/L]	**Rejection, %**	95.71	95.00	95.71	94.28	95.71	95.00
Turbidity	**Permeate**	0.06	0.07	0.08	0.09	0.8	0.07

Test 22; 22.0°C, 55 bar, high rejection XUS SW30XHR-2540 membrane, September 2009

A.47 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) / **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	2.33	2.13	2.22	2.21	2.43	2.29
	Rejection, %	99.76	99.78	99.77	99.77	99.75	99.76
Na^+ [mg/L]	**Permeate**	60.9	59.0	57.5	57.2	58.4	55.8
	Rejection, %	99.67	99.68	99.69	99.69	99.68	99.69
Ca^{2+} [mg/L]	**Permeate**	0.35	0.29	0.25	0.28	0.30	0.35
	Rejection, %	99.93	99.94	99.95	99.94	99.94	99.93
K^+ [mg/L]	**Permeate**	3.47	3.39	3.40	3.56	3.38	3.26
	Rejection, %	99.52	99.53	99.53	99.50	99.53	99.55
Cl^- [mg/L]	**Permeate**	184.05	176.53	174.42	182.80	175.16	171.25
	Rejection, %	99.20	99.23	99.24	99.20	99.24	99.26
SO_4^{2-} [mg/L]	**Permeate**	5.12	3.93	4.00	5.66	4.05	3.23
	Rejection, %	99.84	99.86	99.87	99.82	99.87	99.90
HCO_3^- [mg/L]	**Permeate**	12.33	12.33	9.20	6.16	6.16	6.16
	Rejection, %	92.31	92.31	94.26	96.16	96.16	96.16
Turbidity	**Permeate**	0.04	0.06	0.10	0.09	0.07	0.06

Test 23; 18.1°C, 55 bar, SW30-2540 membrane, November 2009.

A.48 Variations in Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, Cl^- and HCO_3^- rejections of permeate during one year of operation (Figures 3.61, 3.62, 3.63, 3.64, 3.65, 3.66 and 3.67)

Operation Time (min) / **Parameters**		**15**	**30**	**45**	**60**	**75**	**90**
Mg^{2+} [mg/L]	**Permeate**	2.33	2.13	2.22	2.21	2.43	2.29
	Rejection, %	99.76	99.78	99.77	99.77	99.75	99.76
Na^+ [mg/L]	**Permeate**	60.9	59.0	57.5	57.2	58.4	55.8
	Rejection, %	99.67	99.68	99.69	99.69	99.68	99.69
Ca^{2+} [mg/L]	**Permeate**	0.35	0.29	0.25	0.28	0.30	0.35
	Rejection, %	99.93	99.94	99.95	99.94	99.94	99.93
K^+ [mg/L]	**Permeate**	3.47	3.39	3.40	3.56	3.38	3.26
	Rejection, %	99.52	99.53	99.53	99.50	99.53	99.55
Cl^- [mg/L]	**Permeate**	184.05	176.53	174.42	182.80	175.16	171.25
	Rejection, %	99.20	99.23	99.24	99.20	99.24	99.26
SO_4^{2-} [mg/L]	**Permeate**	5.12	3.93	4.00	5.66	4.05	3.23
	Rejection, %	99.84	99.86	99.87	99.82	99.87	99.90
HCO_3^- [mg/L]	**Permeate**	12.33	12.33	9.20	6.16	6.16	6.16
	Rejection, %	92.31	92.31	94.26	96.16	96.16	96.16
Turbidity	**Permeate**	0.04	0.06	0.10	0.09	0.07	0.06

Test 23; 18.1°C, 55 bar, high rejection XUS SW30XHR-2540 membrane, November 2009.

APPENDIX

(FOR CHAPTER TWO)

Removal of bis phenol A (BPA) using sorption-submerged membrane filtration hybrid system

A.49 Results for Test 1, 0.2 g/L resin without imprint, 0.1 pump speed (Figure 3.7)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0.3423	0.7631	0.5	0.73
60	0.3417	0.7618	0.5	0.80
90	0.3364	0.7501	0.5	0.83
120	0.3263	0.7274	0.5	0.80
150	0.3154	0.7032	0.5	0.83
180	0.3139	0.6998	0.5	0.77

A.50 Results for Test 2, 0.4 g/L resin without imprint, 0.1 pump speed (Figure 3.7)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0.3298	0.7352	0.5	0.93
60	0.3118	0.6952	0.5	0.83
90	0.3016	0.6725	0.5	0.87
120	0.2942	0.6560	0.5	0.83
150	0.3012	0.6716	0.5	0.83
180	0.3298	0.7352	0.5	0.80

A.51 Results for Test 3, 0.8 g/L resin without imprint, 0.1 pump speed(Figure 3.7)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0.3793	0.9128	0.5	0.77
60	0.2573	0.6191	0.5	0.83
90	0.2499	0.6015	0.5	0.83
120	0.2400	0.5777	0.5	0.83
150	0.2312	0.5563	0.5	0.83
180	0.2253	0.5421	0.5	0.87

A.52 Results for Test 4, 1.0 g/L resin without imprint, 0.1 pump speed (Figures 3.7, 3.9 and 3.13)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0.1757	0.4286	0.5	0.47
60	0.1388	0.3386	0.5	0.33
90	0.1480	0.3611	0.5	0.30
120	0.1361	0.3320	0.5	0.30
150	0.1250	0.3050	0.5	0.27
180	0.1296	0.3162	0.5	0.30

A.53 Results for Test 5, 2.0 g/L resin without imprint, 0.1 pump speed (Figures 3.7 and 3.9)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0.2344	0.5718	0.5	0.43
60	0.2231	0.5442	0.5	0.43
90	0.1491	0.3639	0.5	0.43
120	0.1218	0.2973	0.5	0.60
150	0.1087	0.2651	0.5	0.60
180	0.1063	0.2592	0.5	0.60

A.54 Results for Test 6, 0.2 g/L resin without imprint, 0.3 pump speed (Figure 3.10)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0,3483	0,8383	1.5	0.57
60	0,3059	0,7362	1.5	0.77
90	0,2656	0,6392	1.5	0.83
120	0,2430	0,5849	1.5	0.80
150	0,2198	0,5289	1.5	0.80
180	0,2025	0,4873	1.5	0.77

A.55 Results for Test 7, 0.4 g/L resin without imprint, 0.3 pump speed (Figure 3.10)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0,2455	0,5909	1.5	0.50
60	0,2303	0,5541	1.5	0.50
90	0,2174	0,5232	1.5	0.60
120	0,2045	0,4920	1.5	0.67
150	0,1841	0,4431	1.5	0.60
180	0,1763	0,4243	1.5	0.63

A.56 Results for Test 8, 0.8 g/L resin without imprint, 0.3 pump speed (Figure 3.10)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	$J_{saturated}/J_{per.}$	**J (ml/min)**
30	0.2385	0.5739	1.5	0.83
60	0.1989	0.4788	1.5	0.87
90	0.1901	0.4576	1.5	0.80
120	0.1597	0.3842	1.5	0.83
150	0.1500	0.3610	1.5	0.77
180	0.1385	0.3332	1.5	0.73

A.57 Results for Test 9, 1.0 g/L resin without imprint, 0.3 pump speed (Figures 310, 3.12 and 3.13)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	$J_{saturated}/J_{per.}$	**J (ml/min)**
30	0.1249	0.3165	1.5	0.80
60	0.1472	0.3731	1.5	0.93
90	0.1361	0.3448	1.5	1.00
120	0.1231	0.3120	1.5	1.03
150	0.1149	0.2911	1.5	1.00
180	0.1072	0.2716	1.5	1.00

A.58 Results for Test 10, 0.2 g/L resin with imprint, 0.1 pump speed (Figure 3.8)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0.3943	0.9488	0.5	0.80
60	0.3412	0.8210	0.5	0.87
90	0.3244	0.7806	0.5	0.87
120	0.3112	0.7488	0.5	0.83
150	0.3129	0.7529	0.5	0.80
180	0.2960	0.7123	0.5	0.83

A.59 Results for Test 11, 0.4 g/L resin with imprint, 0.1 pump speed (Figure 3.8)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0.2495	0.6004	0.5	0.73
60	0.3039	0.7313	0.5	0.77
90	0.3037	0.7310	0.5	0.80
120	0.3007	0.7236	0.5	0.83
150	0.2888	0.6950	0.5	0.73
180	0.2817	0.6779	0.5	0.77

A.60 Results for Test 12, 0.8 g/L resin with imprint, 0.1 pump speed (Figure 3.8)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0.3793	0.9128	0.5	0.73
60	0.2573	0.6191	0.5	0.73
90	0.2499	0.6015	0.5	0.73
120	0.2400	0.5777	0.5	0.73
150	0.2312	0.5563	0.5	0.73
180	0.2253	0.5421	0.5	0.73

A.61 Results for Test 13, 1.0 g/L resin with imprint, 0.1 pump speed (Figure 3.8, 3.9 and 3.13)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0.2350	0.5734	0.5	0.80
60	0.2059	0.5025	0.5	0.77
90	0.2085	0.5087	0.5	0.80
120	0.1924	0.4693	0.5	0.77
150	0.1921	0.4687	0.5	0.80
180	0.1815	0.4427	0.5	0.77

A.62 Results for Test 14, 2.0 g/L resin with imprint, 0.1 pump speed (Figures 3.8 and 3.9)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0.1932	0.4714	0.5	0.70
60	0.1863	0.4546	0.5	0.67
90	0.1784	0.4353	0.5	0.67
120	0.1447	0.3530	0.5	0.67
150	0.1351	0.3297	0.5	0.70
180	0.1321	0.3223	0.5	0.67

A.63 Results for Test 15, 0.2 g/L resin with imprint, 0.3 pump speed (Figures3.8 and 3.11)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0.2545	0.6124	1.5	0.77
60	0.2857	0.6875	1.5	0.77
90	0.2584	0.6219	1.5	0.80
120	0.2333	0.5614	1.5	0.80
150	0.2123	0.5108	1.5	0.7
180	0.2149	0.5171	1.5	0.73

A.64 Results for Test 16, 1.0 g/L resin with imprint, 0.3 pump speed (Figures 3.11, 3.12 and 3.13)

Time (min)	**Cp (mmol/L)**	**Cp/Co**	**$J_{saturated}/J_{per.}$**	**J (ml/min)**
30	0.1494	0.3786	1.5	0.73
60	0.1779	0.4507	1.5	1.10
90	0.1513	0.3834	1.5	0.97
120	0.1367	0.3462	1.5	1.03
150	0.1286	0.3258	1.5	0.97
180	0.1164	0.2949	1.5	1.00

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Presentations in National Conferences

1. E.Güler, E.Yavuz, S. Solak, G.Sert, M.Arda, M.Yüksel, Ü.Yüksel, V.Gündoğdu, N.Kabay, Deniz Suyundan Kullanım Suyu Üretiminde Ters Ozmos Yöntemi-Doğal Deniz Suyu Ortamında Ters Ozmos Membranlarının Performans Karşılaştırması, *Membran Teknolojileri ve*

Uygulamaları Sempozyumu, 2-3, Kasım, 2009, İstanbul (Poster presentation).

2. E.Yavuz, S. Solak, G.Sert, Ş.G.Öner, M.Arda, Ü.Yüksel, M.Yüksel, V.Gündoğdu, N.Kabay, A Comparative Study for Long Term Desalination Tests at urla bay –Effect of Membrane Type on Product Water Quality, *Eastern Mediterranean Chemical Engineering Conference (EMCC-6)*, March 7-12, 2010 (Poster presentation).

3. E.Yavuz, O.Arar, K.Volkan Ozdokur, A.Onaç, S.Solak, M.Arda, U.Yüksel, N.Kabay, M.Yüksel, Desalination Performance of a Small Scale SWRO System for Geothermal Water-Effect of Applied Pressure, *The 4th International student Conference on Advanced Science and Technology (ICAST)*, May 25-26, 2010 (poster presentation).

4. S.Solak, E.Yavuz, G.Sert, M.Arda, Ü.Yüksel, V.Gündoğdu, M.Yüksel, N.Kabay, Ters Ozmos Sistemiyle Deniz Suyundan Üretilen Tatlı Suyun Kullanım Suyu Standartlarına Uygunluğunun İncelenmesi, 24. Ulusal Kimya Kongresi, 29 Haziran-2 Temmuz 2010 (poster presantation).

National Projects Involved

1. Project No: 2009 FEN 042, Scientific Research Project of Ege University, Quality Analysis of Water Produced from Seawater by Reverse Osmosis Method- Studying the Effect of Membrane Type on Water Quality.

Work Experience

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