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INTEGRATION OF MBR TREATMENT SYSTEM WITH NF/RO PROCESSES FOR WASTEWATER RECLAMATION AND REUSE - PILOT TESTS AT ITOB INDUSTRIAL ZONE

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Merve GÜNDOĞDU tarafından **Yüksek Lisans** tezi olarak sunulan "**Integration of MBR Treatment System with NF/RO Processes for Wastewater Reclamation and Reuse - Pilot Tests at ITOB Industrial Zone (Atık Suların Arıtımı ve Yeniden Kullanımı için MBR Arıtma Sisteminin RO ve NF Prosesleri ile Entegre Edilmesi – ITOB Organize Sanayi Bölgesi'nde Pilot Test Çalışmaları)**" başlıklı bu çalışma E.Ü. Lisansüstü Eğitim ve Öğretim Yönetmeliği ile E.Ü. Fen Bilimleri Enstitüsü Eğitim ve Öğretim Yönergesi'nin ilgili hükümleri uyarınca tarafımızdan değerlendirilerek savunmaya değer bulunmuş ve **29.07.2016** tarihinde yapılan tez savunma sınavında aday oybirliği/~~oyçokluğu~~ ile başarılı bulunmuştur.

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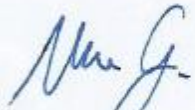

Merve Gündoğdu

ÖZET

ATIK SULARIN ARITIMI VE YENİDEN KULLANIMI İÇİN MBR ARITMA SİSTEMİNİN RO VE NF PROSESLERİ İLE ENTEGRE EDİLMESİ – ITOB ORGANİZE SANAYİ BÖLGESİ'NDE PİLOT TEST ÇALIŞMALARI

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Bu çalışma, İTOB-OSB Arıtma Tesisi'nde kurulmuş olan pilot ölçekli sprial sarım nanofiltrasyon (NF)/ters ozmos (RO) sistemi kullanılarak gerçekleştirilmiştir. İTOB-OSB'de yürütülen çalışmalarda; Membran Biyoreaktör (MBR) prosesiyle arıtılan atıksuların yeniden kullanımı için NF ve RO gibi ileri membran arıtma yöntemlerinin uygulanabilirliği araştırılmıştır. Bu amaç kapsamında ilk olarak farklı NF ve RO membranları kullanılarak membran tipinin ürün suyu geri kazanımına ve kalitesine olan etkisi araştırılmıştır. Sonrasında ise desarj edilecek konsantre su miktarının azaltılması üzerine çalışmalar yapılmıştır. Bu amaçla NF90 membranı ve farklı oranlarda MBR çıkış suyu ve konsantre su karıştırılarak hazırlanan besleme suyu karışımları kullanılmıştır. Elde edilen ürün suyun kalitesi farklı analitik yöntemler kullanılarak incelenmiş, sulama suyu ve farklı endüstrilerce yeniden kullanımı araştırılmıştır. Membran tipinin etkisinin incelendiği testlerde, NF90, NF270 ve TR60 nanofiltrasyon membranları ile elde edilen süzüntü sularının kalitesi karşılaştırıldığında, NF90 membranı ile daha yüksek kalitede su elde edildiği görülmüştür. Ayrıca, BW30 ve AG ters osmoz membranlarının süzüntü suları, su kalite standartlarıyla karşılaştırıldığında her iki membran ile yüksek kalitede su elde edildiği görülmüştür. Konsantre su miktarının azaltılmasının amaçlandığı çalışmalarda, besleme suyundaki konsantre su miktarı arttıkça birbirine benzer nitelikte süzüntü suları elde edilmiştir. Elde edilen ürün sularının kalitesi farklı alanlarda kullanım için su kalite standartlarıyla karşılaştırıldığında ise yüksek kaliteli su elde edildiği görülmüştür.

Anahtar sözcükler: Atıksu, atık suyun yeniden kullanımı, membran biyoreaktör (MBR), nanofiltasyon (NF), ters ozmos (RO)

ABSTRACT

INTEGRATION OF MBR TREATMENT SYSTEM WITH NF/RO PROCESSES FOR WASTEWATER RECLAMATION AND REUSE - PILOT TESTS AT ITOB INDUSTRIAL ZONE

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This study was performed with a mini pilot scale spiral wound nanofiltration (NF)/reverse osmosis (RO) system in İTOB-OSB wastewater treatment plant. In this study, the applicability of treatment methods such as NF and RO was investigated for reuse of wastewater treated with membrane bioreactor (MBR) process. Firstly, effect of membrane type was investigated on wastewater recovery and quality by using different type NF membranes which are NF90, NF270 and TR60 and RO membranes which are BW30 and AG membranes. The second step of studies was concentrate management tests. The aim of this study is decreasing discharged concentrate stream and at the same time to obtain good permeate quality. For this purpose, certain amount of concentrate stream was mixed with MBR effluent and obtained mixture was used as a feed stream for NF/RO membrane test system. NF90 which is nanofiltration membrane was used for these tests. Quality of permeates were compared with quality standards and search for its reusability as irrigation and process water at various industries. According to investigation, NF90 membrane showed better removal efficiencies within NF membranes for many parameters. BW30 and AG membranes had similar removal performance and similar quality product waters were obtained from these membranes. For the concentrate management tests, similar quality product waters with small difference were obtained from different feed mixtures.

Key words: Membrane bioreactor (MBR), nanofiltration (NF), reuse of waste water, reverse osmosis (RO), wastewater

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İZMİR, 2016

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1. INTRODUCTION

1.1 Water Shortage

Water which is very important for both ecosystems and humans, is a precious and increasingly scarce resource.

Although water sources covers 75% of the earth, 97% of water sources consists of seawater which is not suitable to use for drinking and industrial purposes. Approximately, 2% of water sources which is located in Poles, appears as an ice phase. According to these data, only 1% of water sources (3.10^{17} liter) is suitable for drinking purposes (Sert, 2015).

Approximately there are 40 billion people in the world and water sourses could be enough for them. Nevertheless day by day usage of water and water pollution increase. In addition to this, some areas around the world is water scarce region, disturbution of water sources are not uniform. If all these problems are thought, water scarcity is the most important problem to be solved for the life of ecosystems and humans (Güçer, 2009).

Many country face a global water crisis. There are many reasons such as population growth and increase in water demand in water scarce region; pollution of both surface and ground water; and climate that effect the hydrological cycle affecting water scarcity (Pasqualino *et al.*, 2010).

Turkey is located in the semi-arid region in the world. An average, 501 billion m^3 of water falls by rain in Turkey yearly. Surface water potential of Turkey is approximately 98 billion m^3 and 3 billion m^3 of this potential comes from neighbouring countries by rivers. Ground water potential of Turkey is approximately 12 billion m^3. In this case, currently Turkey has 110 billion m^3 of consumable surface and ground water potantial (Sert, 2015).

Country where yearly consumable water amount per people is between 8000-10000 m^3, is expressed as water rich country. In Turkey, this amount is approximately 1430 m^3 and Turkey is not a water rich company (Çetinavcı, 2009).

Yearly consumable water amount per people for other counties and average of Asia, Western Europe, Africa, South America and World are shown in Figure 1.1. Figure 1.1 shows that in Turkey, yearly consumable water amount per person below the average amount of Asia, Western Europe, Africa, South America and World.

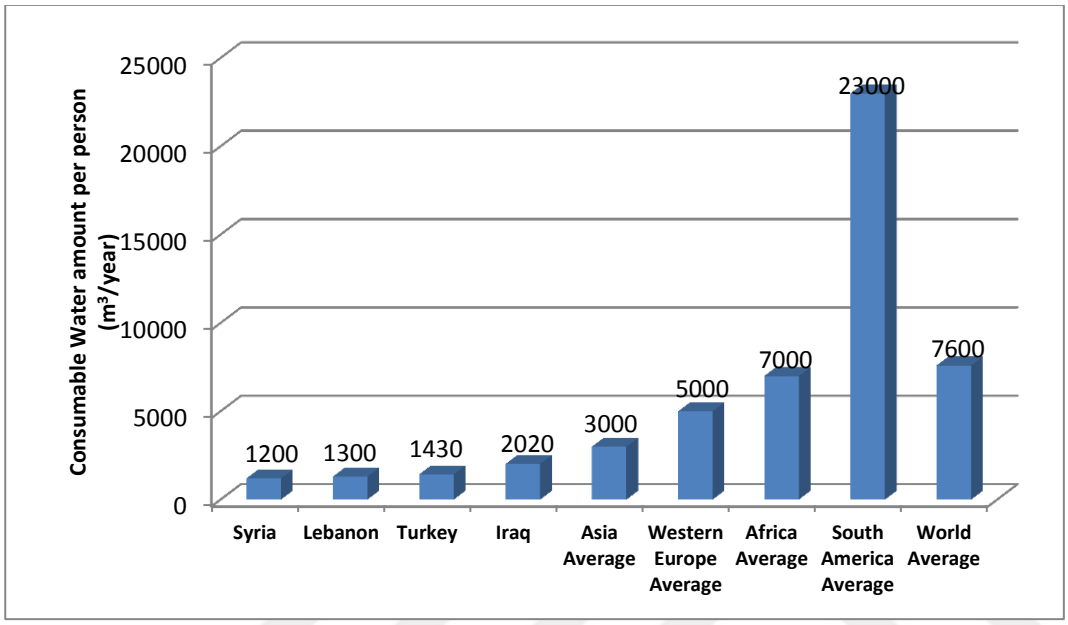


Figure 1.1 Yearly consumable water amount per person - Country/Continent Average (Çetinavcı, 2009)

According to Turkey Statistical Association (TUİK) investigation, in 2010 yearly consumable water amount per person will be 1100 m^3, and in 2050 Turkey will be face with serious water scarcity problem. To reduce this risk, serious studies should be done about water, water resources must be managed in accordance with laws (Çetinavcı., 2009).

Due to industrialization, water usage by industry increases and the result of this, discharged wastewater amount from different manufacturing sector also increases.

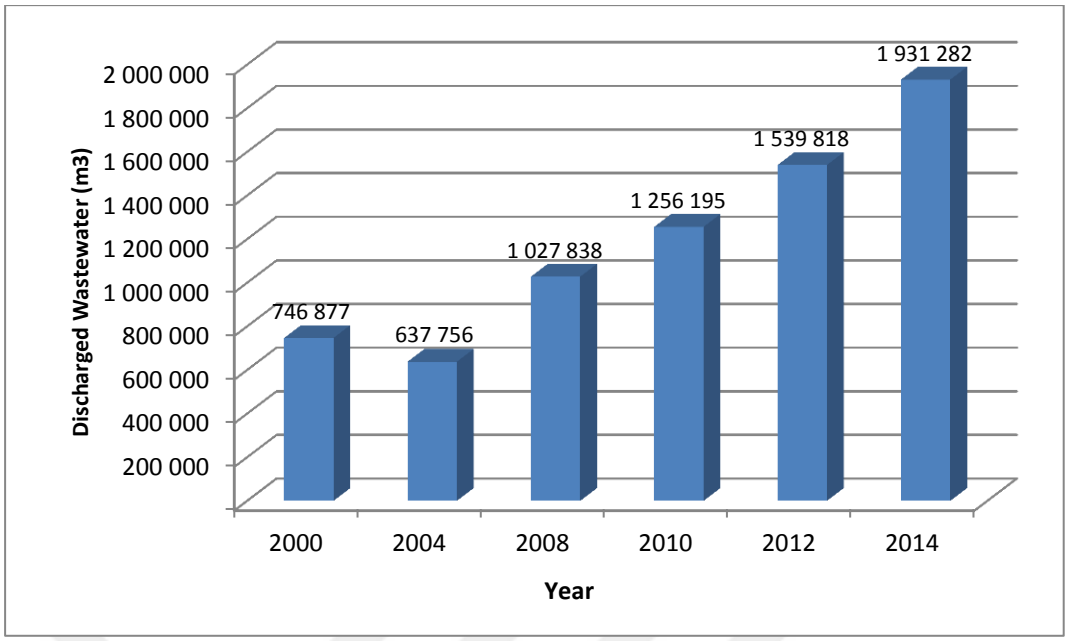


Figure 1.2 Manufacturing industry wastewater indicators, (TUIK, 2016)

According to TUİK data, between the years of 2000-2014 in Turkey, amounts of discharged wastewater from manufacturing industry are shown in Figure 1.2. These data confirm that year by year discharged wastewater tend to increasing, these data also reflect that water usage in production industry increases.

In Turkey, Water Pollution Control Regulations were amended to change and decreases the discharge limits of industrial wastewaters. Beside this, many industrial sectors in Turkey focus the minimized the waste because of ISO 14001 and IPPC Directive. For this reason reuse of wastewater with the treatment of advenced technologies became one of the most important topic in industrial sector (Sert, 2015).

1.2 Wastewater Reuse

Continuous population growth and industrialization are causing increased water demand and contamination. One way to increase water resources in water-scarce regions is to use reclaimed and desalinated water. Treated wastewater effluents have been gradually reused for an alternative water source (Lee *et al*, 2014). The reuse of wastewater that would otherwise be discharged into the environment can save the water sources and environment.

There are many benefits of water reuse (Asano *et al*., 2007). Some of them are;

- Because of the nutrient content, reuse of treated wastwater for irrigation purposes is very useful.
- It enables municipalities to generate revenue by selling their sewage.
- Wastewater reuse assists in national development.
- It provides a motivation for decreasing environmental pollution.

Reclaimed water, is reused for a variety of applications including landscaping, irrigation and recharging groundwater aquifers and the other uses are;

- Reuse for industrial application such as: cooling systems, boiler feed, process water,
- Wastewater reuse in horticulture, watering of lawns, golf courses,
- Ground water recharge for increasing ground water resources for downstream uses or for preventing saline water intrusion in coastal areas,
- Fire protection.

1.2.1 Wastewater reuse for agricultural irrigation

Water shortage is not a problem only for human and industrial activities, it also affects sustainable food production. Properly treated wastewaters which does not have the same requirements as that of drinking water can be used for irrigation (Quist-Jensen *et al.*, 2015).

The use of reclaimed water for agriculture is a most common application around the world. Many semi-arid regions, water recycling provides a major portion of the irrigation water. However water reuse programs are still faced with a number of technical, economic, social, regulatory, and institutional challenges. (Lazarova and Bahri, 2005).

Jiménez and Asano (2008) indicated that globally about 20 million hectares of agricultural land is irrigated with polluted water. Estimates of the volume of

wastewater used in different countries worldwide for irrigation are shown in Table 1.2.

Table 1.1 The twenty countries with the most volume of wastewater used for irrigation (Jiménez and Asano, 2008)

Country	Wastewater used for irrigation (m^3/d)	Country	Wastewater used for irrigation (m^3/d)
Mexico	4.493.000	Iran	422.000
Egypt	1.918.000	Chile	380.000
China	1.239.000	Jordan	225.000
Syria	1.182.000	UAE	200.000
Spain	932.000	Turkey	137.000
USA	911.000	Argentina	130.000
Israel	767.000	Tunisia	118.000
Italy	741.000	Libya	110.000
Saudi Arabia	595.000	Qatar	80.000
Kuwait	432.000	Cyprus	68.000

Data from Table 1.1 shows that Mexico is the leading country by the feature of most wastewater used in irrigation. Turkey where 137000 m^3/d wastewater use for irrigation, is the 15th country in the worldwide.

When the General Directorate of State Hydraulic Works (DSI) data are analyzed, in 2012, used 44 million m^3 of water in Turkey -from underground and surface sources- utilization of available water source by sector are given in the Figure 1.3. According to chart, 73% of the total water was consumed for agricultural irrigation, 16% of the total water was used for industrial usage.

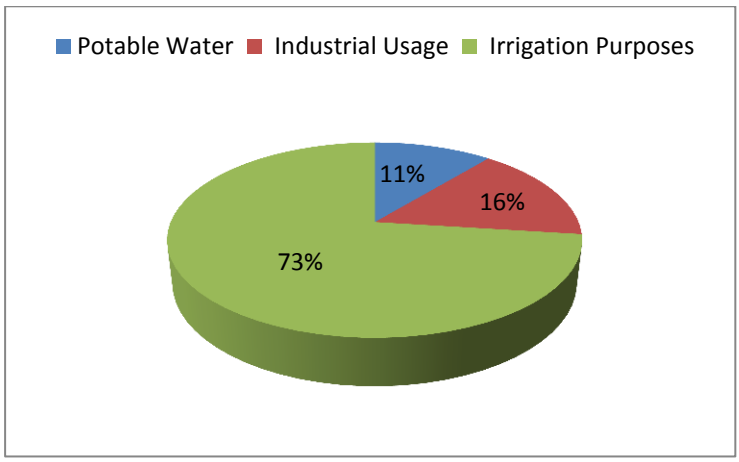


Figure 1.3 Distribution of used water in Turkey in 2012 (DSİ, 2016)

Treated wastewater that could be used for irrigation water source is important for saving water sources in Turkey.

Treated wastewaters should have some requirements to be used for irrigation purposes. For the reuse of treated wastewater in landscape irrigation, general characteristics of treated water including nutrient content, specific ion toxicity, permeability, salinity and microbiological parameters have to be compared with World Health Organization (WHO) (WHO, 1989, 2006) criteria and Food and Agriculture Organization (FAO) (FAO, 1992) and United States Environmental Protection Agency (USEPA) (USEPA, 2004) standards.

Requirements of all these World Health Organization (WHO) (WHO, 1989, 2006) criteria and Food and Agriculture Organization (FAO) (FAO, 1992) and United States Environmental Protection Agency (USEPA) (USEPA, 2004) are shown in Table 1.2.

Table 1.2 International guidelines for reuse of treated water for irrigation purposes, (Dogan *et al*, 2015)

		WHO,2006[a]			**FAO, 1992**			
		Degree of restriction on use			Degree of restriction on use			
Parameters and units		None	Slight to moferate	Severe	None	Slight to moferate	Severe	**USEPA, 2004[c]**
Conductivity (µS/cm)		< 700	700-3000	> 3000	< 700	700-3000	> 3000	-[d]
TDS (mg/L)		< 450	450-2000	> 2000	< 450	450-2000	> 2000	500-2000
SAR	0-3	EC > 0.7	EC = 0.7-0.2	EC < 0.2	EC > 0.7	EC = 0.7-0.2	EC < 0.2	
	3-6	> 1.2	0.3-1.2	< 0.3	> 1.2	0.3-1.2	< 0.3	
	6-12	> 1.9	0.5-1.9	< 0.5	> 1.9	0.5-1.9	< 0.5	-[d]
	12-20	> 2.9	1.3-2.9	< 1.3	> 2.9	1.3-2.9	< 1.3	
	20-40	> 5.0	2.9-5	< 2.9	> 5.0	2.9-5	< 2.9	
Na^+ (mg/L)	Sprinkler Irrigation	< 69	> 69	-[d]	< 69	> 69	-[d]	-[d]
	Surface Irrigation	< 69	69-207	> 207	< 69	69-207	> 207	
Chloride (mg/L)	Sprinkler Irrigation	< 106.5	> 106.5	-[d]	< 106.5	> 106.5	-[d]	-[d]
	Surface Irrigation	< 142	142-355	> 355	< 142	142-355	> 355	
Boron (mg/L)		< 0.7	0.7-3.0	> 3.0	< 0.7	0.7-3.0	> 3.0	0.75-2
Total N (mg/L)		< 5	5-30	> 30		-[d]		-[d]
Total P (mg/L)			-[d]			-[d]		-[d]
NO_3^--N (mg/L)			-[d]		< 5	5-30	>30	-[d]
NO_2^--N (mg/L)			-[d]			-[d]		-[d]
pH			6.5-8		< 7.0	7.0-8.0	>8	-[d]
Turbidity (NTU)			-[d]			0-0.2		≤ 2
SS (mg/L)		< 50	50-100	> 100	< 50	50-100	>100	<5
Ca^{2+} (mg/L)			-[d]			-[d]		-[d]
K^+ (mg/L)			-[d]			-[d]		-[d]
Mg^{2+} (mg/L)			-[d]			-[d]		-[d]
PO_4^--P (mg/L)			-[d]			-[d]		-[d]
SO_4^{2-} (mg/L)			-[d]			-[d]		-[d]
COD (mg/L)			-[d]			-[d]		-[d]
H_2S (mg/L)		< 0.5	0.5-2.0	2.0	< 0.5	0.5-2.0	2.0	-[d]
Fe (mg/L)	Drip İrrigation	< 0.1	0.1-1.5	> 1.5	< 0.1	0.1-1.5	> 1.5	-[d]
Mn (mg/L)	Drip İrrigation	< 0.1	0.1-1.5	> 1.5	< 0.1	0.1-1.5	> 1.5	-[d]
Free Chloride Residual (mg/L)		< 1	1-5	> 5	-[d]	-[d]	-[d]	-[d]
HCO_3^- (mg/L)		< 90	90-500	> 500	< 91.5	91.5-518.5	>518.5	-[d]
Fecal Coliform (CFU/100mL)			≤1000[c]			≤1000		-[f]
Total Coliform (CFU/100mL)			-[d]			-[d]		-[d]

[a] Table A1.1 Water quality for irrigation (WHO,2006);

[b] Table 8. Recommended microbiological quality guidelines for wastewateruse in agriculture, Table 9. Guidelines for interpretation of water quality for irrigation, Table 27. Water quality and clogging potential in drip irrigation systems (FAO,1992);

[c] Table 2-7 Recommended limits for constituentsin reclaimed water for irrigation, Table 4-13.. Suggested guidelines for water reuse, types of reuse, urban reuse (USEPA, 2004);

[d] there is no limit value at relevant standard (FAO, 1992; USEPA, 2004; WHO, 2006);

[e] (WHO,1989)

In Turkey, if the treated wastewater is used for irrigation purposes characteristics water should be provide the agricultural irrigation standard which is shown in Table 1.3.

Table 1.3 Republic of Turkey Ministry of Environment and Urbanisation Agricultural irrigation standard (Bunani *et al.*, 2015)

Parameters		Units	Degree of restriction on use		
			None (I. Class water)	**Slight to moderate (II. Class water)**	**Severe (III. Class water)**
Salinity					
Conductivity		µS/cm	< 700	700-3000	>3000
TDS		mg/L	< 500	500-2000	>2000
Permeability					
SAR	0-3		EC ≥ 0.7	0.7-0.2	< 0.2
	3-6		≥ 1.2	1.2-0.3	< 0.3
	6-12		≥ 1.9	1.9-0.5	< 0.5
	12-20		≥ 2.9	2.9-1.3	< 1.3
	20-40		≥ 5.0	5.0-2.9	< 2.9
Specific Ion Toxicity					
Sodium (Na)					
Surface Irrigation		SAR	< 3	3-9	> 9
Drip Irrigation		mg/L	< 70	> 70	
Chloride (Cl)					
Surface Irrigation		mg/L	< 140	140 –350	> 350
Drip Irrigation		mg/L	< 100	> 100	
Boron (B)		mg/L	< 0.7	0.7-3.0	> 3.0

Significant problems could be considered on human and environmental health according to reuse of treated wastewaters. Especially, the chemicals and microbial contaminants could be effectively removed from treated wastewater because these contaminants may cause public health problems. Hence, treatment strategies are very important. It could be simple, reasonable and acceptable and in addition to this, it will eliminate negative impacts on the environment and human health, that will ensure efficient water reuse. Produced water will be provide the national and international water quality regulations and guidelines (Dogan *et al*, 2014).

The use of membrane processes which could be microfiltration, (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO), or membrane bioreactor (MBR) for the reclamation and reuse has become a potential alternative for the reuse of reclaimed water because of their efficacies and economic viabilities (Bunani *et al*., 2013). These prosess are also important for reducing chemical usage for wastewater treatment.

1.2.2 Wasteater reuse for industrial application

Many industrial processes depend on the ready availability of reliable sources of large quantities of water. Thermoelectric power generation, pulp and paper manufacturing, textile production, food processing, chemical manufacturing processes, oil refineries, and ore extraction (mining) are some examples of water-intensive industries (Asano *et al.*, 2007).

Table 1.4 Approximate water demand of various industrial sectors. (Judd and Jefferson,2003)

Industry	Water Demand
Paper	29 m^3/t paper
Newspaper	9 m^3/t paper
Brewing	10-15 m^3/m^3 beer
Dairy	140 m^3/m^3 milk
Sugar	8 m^3/t sugar
Automotive	450 m^3/car (metal production)
Automotive	760 m^3/car (tyre production)
Dying	100 m^3/t fabric processed
Soap	2 m^3/t soap produced
Power	3 m^3/MWh (steam generation)
	60 m^3/MWh (cooling)

Table 1.4 shows the approximate fresh water demand of various industrial sectors. Freshwater demand of each industrial sector varies between 2 m^3/t for soap manufacture and 100 m^3/t for textile dyeing, with the highest absolute demand arising from power generation - around half of all freshwater demand across all industrial sectors (Judd and Jefferson, 2003).

According to Turkey Statistical Agency data, when we see the total water usage for various units of processes for different industries in 2008, big portion of quantity of water was used as cooling and prosess water (Figure 1.4).

According to water usage in different industries in Turkey, large quantity of water (785,766 m^3/year) was used in metal industry and the 90.3% of these amount (710,062 m^3/year) was used for the purpose of cooling. For the paper and textile industry, usage of water as a process water had a big portion within the used total water amount (TUIK, 2016).

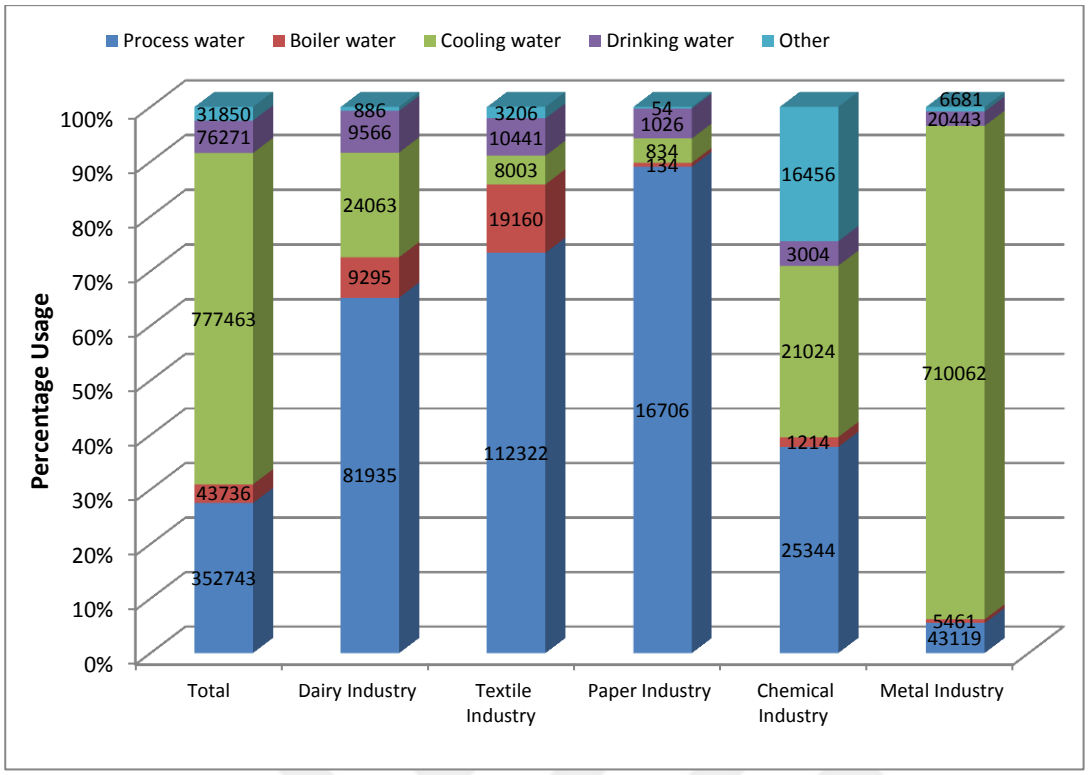


Figure 1.4 Water usage of different industries for various units of processes in 2008 (TUIK, 2016)

The reuse of wastewater has become an environmental and economically viable option for industry, due to increasingly restrictive parameters for wastewater discharge, imposition of charges both for the collection of water as well as for the discharge of effluents, and to the reduced availability and quality of water resources (Andrade *et al*., 2014).

Reclaimed water can be used successfully as a cooling water source by maintaining the appropriate operational conditions and by controlling the quality of the water. Primary considerations for cooling systems are prevention of corrosion, scaling, and biological fouling.

Reclaimed water usage can be also an economically attractive water source for boiler feedwater for the many reasons. These could be;

- it provides a reliable water supply,
- boiler feedwater generally goes through an extensive pretreatment process,
- industries are commonly located on near the large cities, where wastewater treatment plants are also located.

Reclaimed water constituents of concern in cooling tower and boiler systems are summarized in Table 1.5.

Table 1.5 Water requirements for power generation and cooling water (Judd and Jefferson, 2003)

Water Quality Parameter (all as mg/L unless otherwise stated)	**Cooling Water**	**Boiler feedwater*** (*range is based on operating presssures)
Alkalinity, mg/L as $CaCO_3$	350	40 - 350
Hardness, mg/L as $CaCO_3$	600	0.07 - 350
pH	6.9 - 9.0	7 - 10
Total dissolved solids (TDS)	500	200 - 700
Total Suspended Solids (TSS)	100	0.5 - 10
Turbidity, NTU	50	
Carbonaceus Bioehemical Oxygen Demand ($C\text{-}BOD_5$)	25	1 - 50
Chemical Oxygen Demand (COD)	75	1 - 5
Ammonia, mg/L as N	1	0.1
Phosphate, mg/L as P	4	
Aluminium	0.1	0.01 - 5
Bicarbonate	24	48 - 170
Chloride	500	Variable
Iron	0.5	0.05 - 1
Manganese	0.5	0.01 - 0.3
Silica	50	0.7 - 30
Sulphate	200	Variable

Generally, water quality requirements for boiler systems are more stringent than the requirements for cooling water. Where reclaimed water is used, advanced treatment such as RO must be employed.

The use of reclaimed water in pulp and paper ındustry is also a viable option. Water quality requirements for pulp and paper production depend on the grade of paper. Generally, lower quality water can be used for the brown grade papers such as asphalt or tar-saturated papers, linerboard, low-brightness carton board, packaging and insulating board. The white grade papers require higher water quality, and high brightness fine papers require the highest quality process water (Rommelmann *et al*., 2003). Typical water quality requirements for various papers are shown in Table 1.6.

Table 1.6 Pulp and Paper Industry Feed Water Characteristics, (Asano *et al*., 2007)

Parameters	**Brown grades**		**White grades**	
	Groundwood paper	Soda and sulfate (kraft) pulps	Kraft paper, bleached	Bleached paper
Turbidity, NTU	70	35	40	14 - 56
Color, c.u.	30	5	25	5 – 25
TDS, mg/L	250 – 1000	250 – 1000	300	75 – 650
TSS, mg/L	40	10	10	10 – 30
Alkalinity, mg/L $CaCO_3$	75 – 150	75 – 150	75	75 – 125
Hardness, mg/L $CaCO_3$	100 – 200	100 – 200	100	100
Chloride, mg/L	75	75	200	200
Fe, mg/L	0.3	0.1	0.2	0.1
Mn, mg/L	0.1	0.05	0.1	0.03
Silica, mg/L SiO_2	50	20	50	9 – 20
SO_4, mg/L	Trace	-	-	100 – 300
Temperature, ^oC	<55	27	-	15 – 27

The textile industry is the one of the industry that consumes large quantities of water for prosesses such as dyeing, rinsing, bleaching and finishing and end of these proseses large amounts of wastewater is produced. It is becoming increasingly necessary to treat wastewater essentially in view of its reuse (Ho and Sirkar, 1992). Typical water quality requirements for the textile industry are reported in Table 1.7.

Table 1.7 Typical textile ındustry feed water characteristic, (Asano *et al*, 2007)

Parameters	**Typical Textile Industry Feed Water Characteristics**
Al, mg/L	8
Color	0 - 5
Cu, mg/L	0.01 - 5
Fe, mg/L	0.1 – 0.3
Mn, mg/L	0.01 – 0.05
pH	6 - 8
SO_4, mg/L	100
TSS, mg/L	0 - 5
TDS, mg/L	100 - 200
Total Hardness, mg/L $CaCO_3$	0 - 50

Most important characteristics of water which could be used for textile processes, are to ensure that the dyes react properly and that discoloration or staining does not occur. Turbidity, color, iron, and manganese could be caused staining of fabric. Hardness is also adversely affects the process, when soaps used for cleaning processes it could be caused curd-like deposits on the textile. Hardness may cause precipitation of some dyes and increase the deformation of silk during some operations (Treweek, 1982).

Specific water quality requirements vary among industries, major water quality issues are associated with the prevention of corrosion, scaling, and biological fouling of equipment and distribution systems. Where there is potential for human contact with the reclaimed water from reclaimed water, control of pathogenic organisms is particularly important (Asano *et al*. ,2007).

Treated water is an alternative source of water, but many end users and customers are afraid to use it. These fears are based on the potential effects of contaminants on human health and the environment. Effective advanced treatment processes guaranteed that wastewater is safe for reuse (Pasqualino *et al.*, 2010).

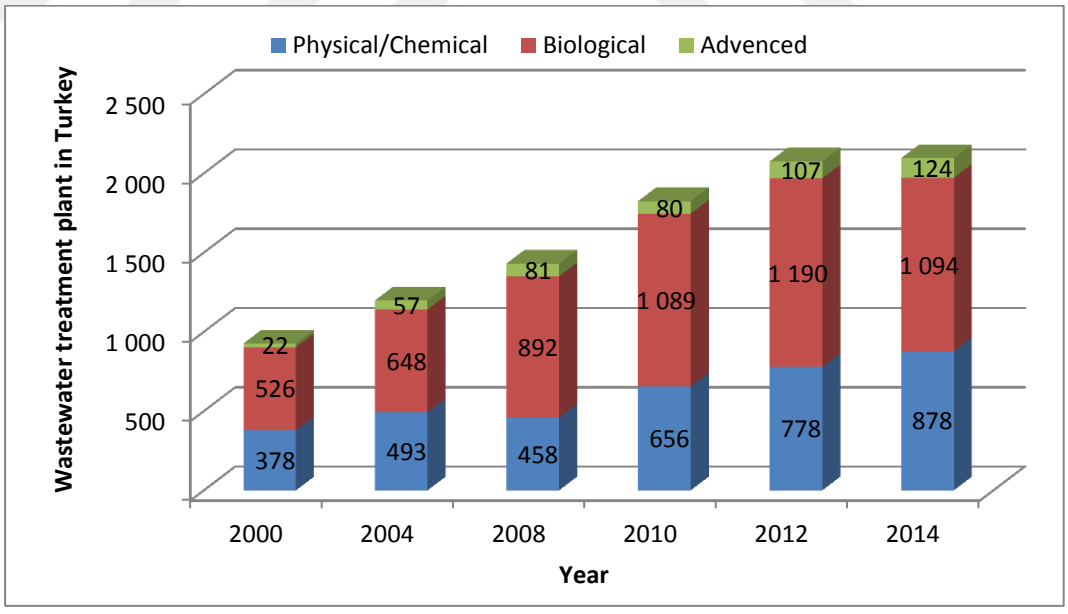


Figure 1.5 Number of treatment plants according to treatment process in Turkey in 2000-2014, (TUIK, 2016)

Figure 1.5 is presented the number of wastewater treatment plants in Turkey. It also shows the increasing the number advanced treatment plant in Turkey. The numbers of advanced treatment plants were twenty-two in 2000

whereas there were hundred-twenty-four advanced treatment plants in 2014. As we can summarize from these data, Turkey has great potential to re-use of treated wastewater for many purposes.

1.3 Membrane Bioreactor (MBR) Treatment of Wastewater

More recently, most promising technology for utilization in water reuse systems is the membrane bioreactor (MBR). MBRs combine biological treatment with an integrated membrane system to provide the increase of organics and suspended solids removal. Low-pressure membrane filtration could be the microfiltration (MF) or ultrafiltration (UF). Membranes function to replace sedimentation and depth filtration for separating the biomass in suspended growth systems from the treated water. Conventional treatment operations such as gravity sedimentation and media filtration can be eliminated. With MBR process, overall space requirements and facilities costs can be reduced. A smaller footprint allows MBR plants to be located in sites with limited area or completely enclosed in residential areas for satellite treatment applications.

A common feature of most bioreactor systems is a low-pressure membrane system (MF or UF) that is used for liquid/solids separation. The advantages of membranes over conventional clarification are:

- ancillary facilities are much smaller;
- higher quality product water can be obtained;
- increased MLSS produces a more stable sludge that is less susceptible to upsets;
- in small MBR plants, return sludge systems can be eliminated or greatly reduced;
- systems are simpler to operate (Asano *et al*, 2007).

There are two main configurations of MBR systems which are submerged or immersed and external or side-stream configurations (Sutton, 2006) (Figure 1.6).

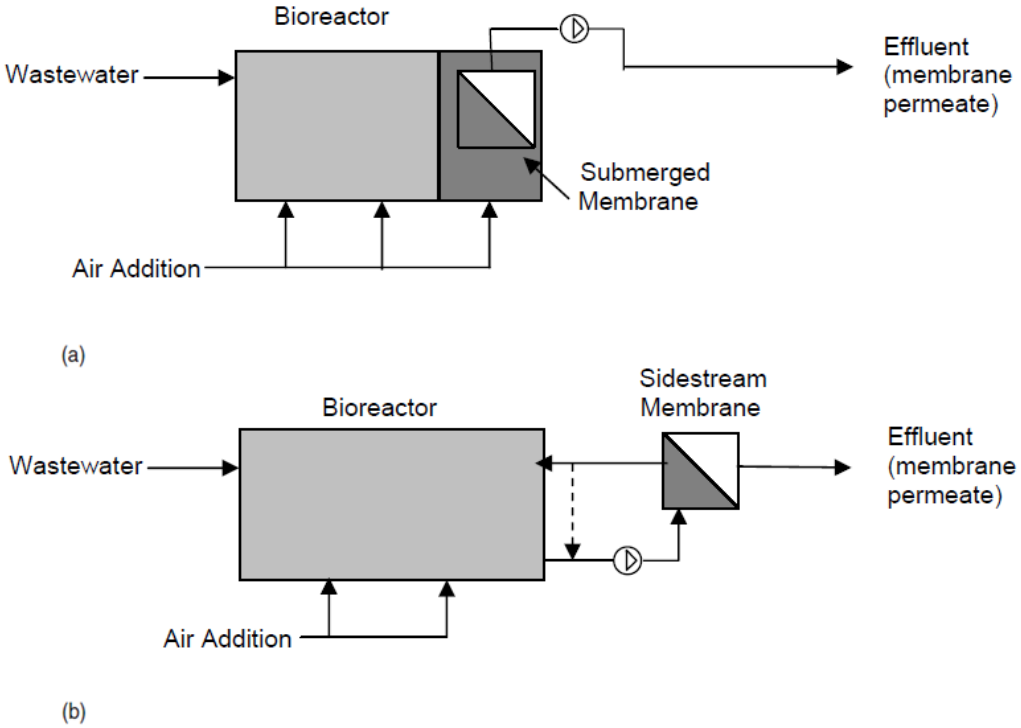


Figure 1.6 Configuration of membrane bioreactors: (a) submerged (b) external (Gürel and Büyükgüngör, 2011).

For the submerged MBR, the membrane module is submerged into the aeration tank and permeate is taken from the effluent side. The pressure across the membrane can be applied by suction through the membrane or by pressurizing the bioreactor.

According to external membrane bioreactor configuration, membrane system can be built up independently from the bioreactor. Firstly feed solution enters the bioreactor and contacts with biomass, then the mixture is pumped to the membrane filter. Permeate is removed from the membrane and retentate returned to aeration basin (Gürel and Büyükgüngör, 2011).

If we compare the the power consumption of these two configurations, it is much lower in submerged membrane modules than external modules. Submerged MBR process is called energy saving process because it is not need to use circulation pump (Gürel and Büyükgüngör, 2011).

Because most MBR installations are less than 20 year old, there are limited numbers of suppliers of the process equipments for reclaimed water. There are four principal suppliers of submerged MBRs: Zenon Environmental, a part of GE

Water and Process Technologies; Kubota Corporation; Mitsubishi Rayon Corporation; and USFilter, a subsidiary of Siemens.

The Zenon system, called Zenogem, utilizes cassettes composed of tubular hollow-fiber membrane modules that are submerged in compartmentalized cells within an activated sludge bioreactor. Each cassette has overall dimensions of 0.91 m wide by 2.13 m long, and approximately 2.44 m high (Figure 1.7).

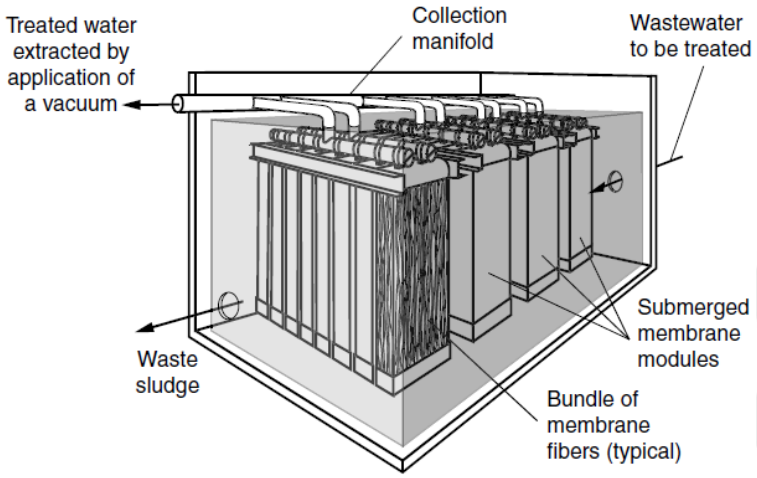


Figure 1.7 Typical Zenon submerged membrane bioreactor: schematic of placement of bundles in an activated sludge reactor (Asano et al., 2007)

The membrane unit shown in Figure 1.8 is manufactured by Kubota in Japan and marketed by Enviroquip, Inc. in the United States. The system utilizes one or more membrane panels; each panel has overall dimensions of 490 mm wide by 1000 mm high by 6 mm thick with an effective surface area of 0.8 m^2.

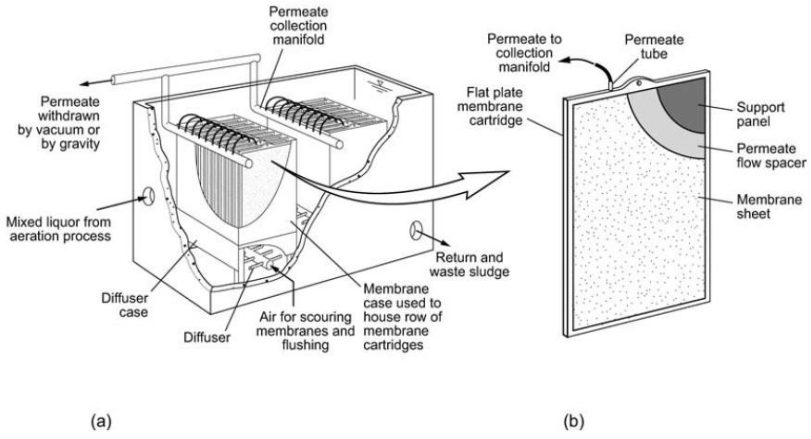


Figure 1.8 Typical Kubota submerged membrane bioreactor: (a) schematic of placement of membrane units in an activated sludge reactor and (b) view of a membrane cartridge (Asano et al., 2007).

The volume of industrial and municipal wastewater treated by MBR systems worldwide is approximately growing by 20 percent annually (Sutton, 2006). MBR systems are valuable applications especially in water scarce regions where reusable-quality effluent is desirable, space availability is limited, and/or stringent discharge standards exist. These locations could be small communities, housing developments, commercial developments, mining camps, resorts, hotels, malls, schools, and golf courses. The MBR is also applicable for industry for recycling process water to reduce cost of wastewater disposal.

There are also many studies in literature about MBR systems. Mostly, membrane performances and membrane fouling issues are evaluated with these studies (Güral and Büyükgüngör, 2011).

Rosenberger *et al.* (2002) investigated the reclamation of sewage with immersed MBR system. During experiments, MLSS concentrations was changed between 18 and 20 g/L and at the end of the study, %95 of chemical oxygen demand (COD) and %82 of total nitrogen (TN) were rejected from feed water.

Badani *et al* (2005) aimed the treatment of effluent which was obtained from textile industry processes and external membrane bioreactor was used for this aim. According to experimental results, the COD was rejected with an average value of 97% and the percent elimination of the ammonia nitrogen and color were around 70%.

1.4 Nanofiltration (NF) / Reverse Osmosis (RO) Systems for Wastewater Recovery and Reuse

Nanofiltration (NF) and reverse osmosis (RO) are capable of separating dissolved ions from the feed stream by using pressure (and sometimes a vacuum) that provide convective flow of the liquid through the membrane. NF and RO require hydrostatic pressure to overcome the osmotic pressure of the feed stream. NF and RO can remove particles of sizes less than 10^{-2} μm, which are dissolved and colloidal material such as aqueous salts, organic matter, pesticides, and herbicides.

The specious of membranes to separate small solutes from water has been known for a very long time. Milestones of NF and RO membranes are summarized in Figure 1.9.

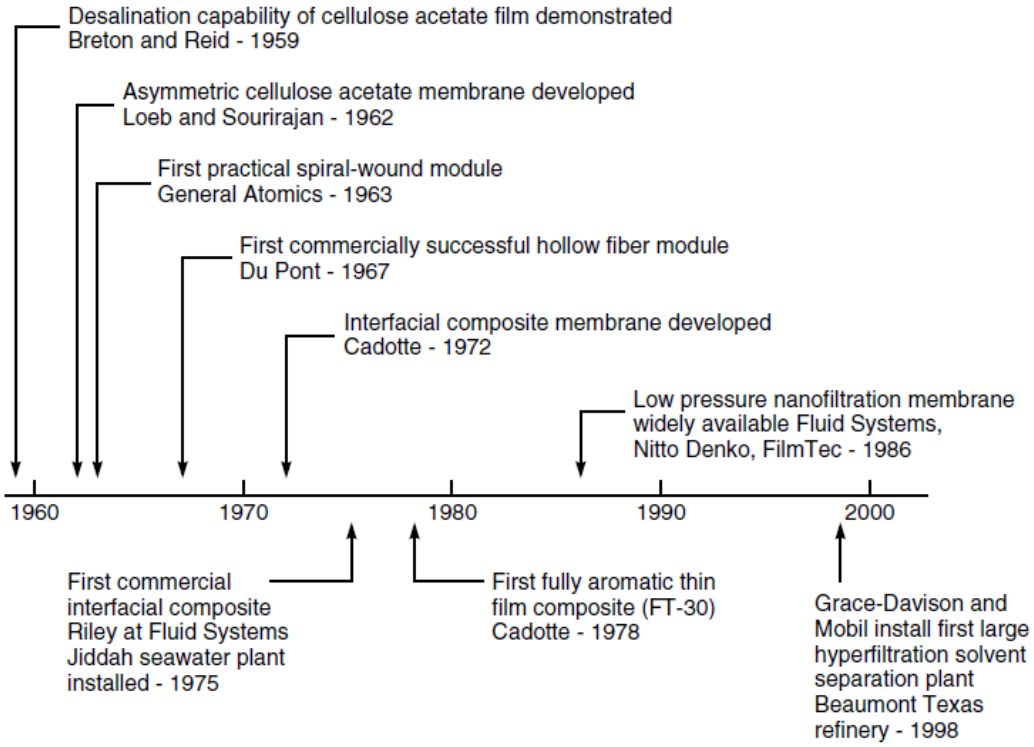


Figure 1.9 Milestones in the development of reverse osmosis (Baker, 2004)

NF is much the same as RO and the only difference is the degree of removal of monovalent ions such as sodium and chlorides. RO removes monovalent ions up to 98 to 99% range while removals with NF membranes vary between 50 and 90%, depending on the material and manufacture of the membrane. NF has the ability to reject uncharged, dissolved materials and positively charged ions according the size and shape of the molecule. It usually provide with a good rejection of small organic molecules and inorganic salts, especially multivalent ions (Asano *et al*., 2007).

RO has been used in many applications including sea and brackish water desalination and industrial process water for the removal of dissolved constituents. RO typically removes 95 to 99.5% of the total dissolved solids and 95 to 97% of dissolved organic matter (Asano *et al.*, 2013). RO membrane technology has been developed over the past 40 years to 44% share in world desalting production capacity and 80% share in the total number of desalination plants installed worldwide (Greenlee *et al*, 2009).

There are many membrane materials and membrane preparation techniques to make RO membranes. The target of seawater desalination is to reach more than 99.3% of salt rejection and produce permeate which contains less than 500 mg/L of salt. Another improvement proposal is reducing operating pressure. At the begining, to catch certain quality criteria operating pressure could be 1500 psi but now with the improvement of membrane performance, this pressure has dropped to 800–1000 psi.

Recently, the need for desalination membranes has shifted more to brackish water feeds. Brackish water salt concentrations vary between 0.2 and 0.5 wt%. For this application, membranes are typically operated at pressures in the 150–400 psi range with a target salt rejection of about 99 %. Many manufacturers tailor the properties of a single membrane material to meet the requirements of different applications. Invariably, a significant trade-off between flux and rejection is involved (Baker R. *et al.*, 2004).

Differences between two water sources (sea and brackish), including foulants, salinity, waste brine disposal options, and plant location have created significant differences in process development, implementation, and key technical problems (Greenlee *et al.*, 2009). Owing to the lower amount of total dissolved solids (TDS) in brackish waters, RO systems work better with this feed in terms of reduced pressure requirements, improved membrane lifetime and higher recovery factors (Quist-Jensen *et al.*, 2015).

Pretreatment applications are same for both types of RO and depend on the specific components of the water source. Both brackish water and seawater RO will continue to be used worldwide; new technology in energy recovery and renewable energy, as well as innovative plant design, will allow greater use of desalination for inland and rural communities, while providing more affordable water (Greenlee *et al.*, 2009).

1.4.1 Membrane modules

Before a membrane separation can be performed industrially, methods of economically and efficiently packaging large areas of membrane are required. These packages are called membrane modules. The development of the

technology to produce low-cost membrane modules was one of the breakthroughs that led to commercial membrane processes in the 1960s and 1970s (Asano *et al*., 2007).

The basic aim fo development of these modules is to provide maximum membrane area in relatively smaller volume, so that the permeate flux, the productivity of the system is maximum.

Membrane producers are frequently divisions of major chemical companies that manufacture plate-and-frame, tubular, spiral-wound, and hollow fiber membrane modules.

Plate and Frame Membrane Modules

Supporting plate of plate-frame module is the main part that is sandwiched between two flat sheet membranes. The membranes are sealed to the plate, either gaskets with locking devices, glue or directly bonded. The plate is internally porous and provides a flow channel for the permeate which is collected from a tube on the side of the plate. Ribs or grooves on the face of the plate provide a feed side flow channel. The feed channel can be a clear path with channel heights from 0.3 to 0.75 mm (Baker, 2004).

Commercial plate-frame units are usually horizontal with the membrane plates mounted vertically. They can be run with each plate in parallel plates in two or three series. A typical plate and frame module is shown in Figure 1.10 (Baker, 2004).

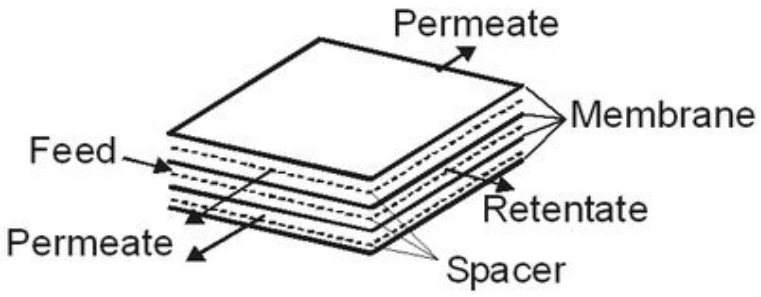


Figure 1.10 Schematic drawing illustrating the construction of a plate and frame membrane module (Baker, 2004)

The Tubular Membrane Modules

In tubular modules, the tubes consist of a porous paper or fiberglass support with the membrane formed on the inside of the tubes, as shown in Figure 1.11.

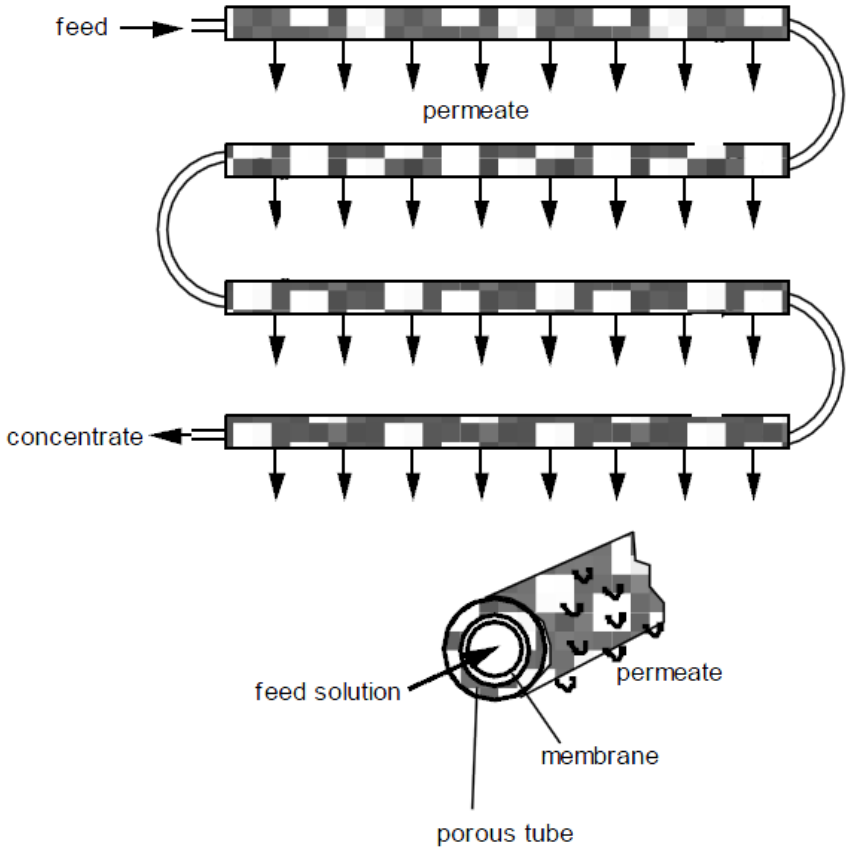


Figure 1.11 Schematic drawing illustrating the tubular membrane module (Baker, 2004)

The first tubular membranes were between 2 and 3 cm in diameter, but more recently, as many as five to seven smaller tubes, each 0.5–1.0 cm in diameter, are nested inside a single, larger tube (Baker, 2004).

Usually, 10 to 30 individual tubes are installed in a larger tube and potted at the end of the tube. The feed solution is fed in parallel through the tubular bundle while the permeate of the individual tubes is collected in the outer shell tube as indicated in the schematic drawing of Figure 1.12.

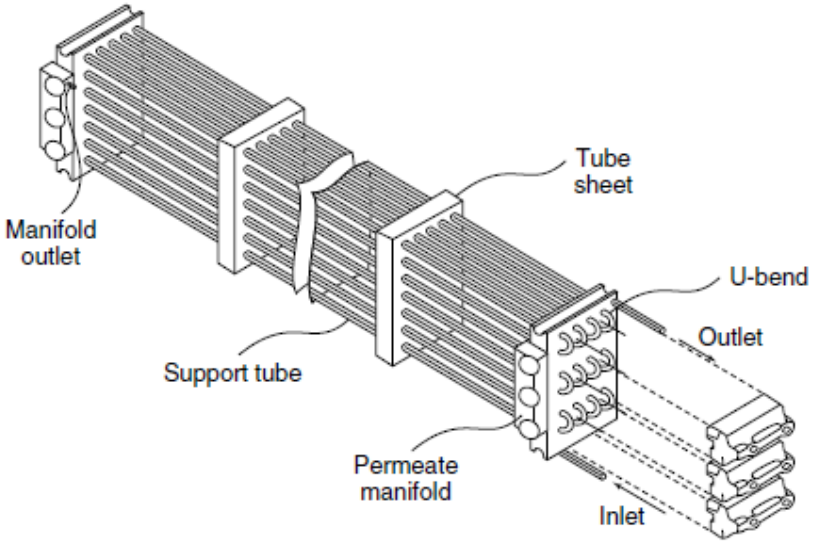


Figure 1.12 Tubular module with thirty individual tubes bundled in a shell tube (Baker, 2004)

Spiral-wound Membrane Modules

The spiral-wound module provides a relatively large membrane area per unit volume. It is a variation of the basic plate-and-frame concept and this type module is widely used in reverse osmosis, ultrafiltration, and gas separation. Its basic design is illustrated in Figure 1.13 (Baker, 2004).

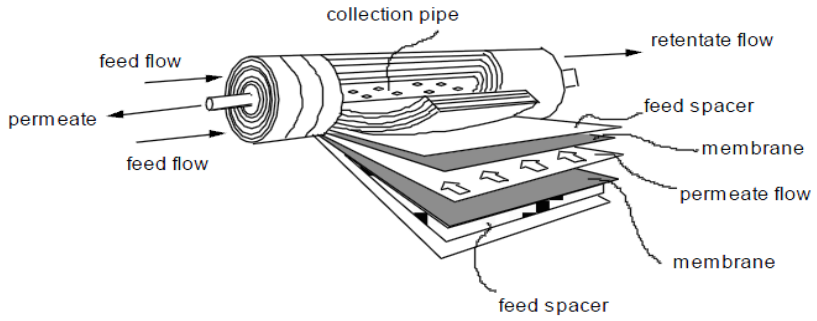


Figure 1.13 Schematic drawing of a spiral-wound membrane module (Baker, 2004)

The feed flow channel spacer, the membrane and the porous membrane support form an envelope which is rolled around a perforated central collection tube and inserted into an outer tubular pressure shell. Feed passes axially down the module across the membrane envelope. A portion of the feed permeates into the membrane envelope, where it spirals towards the center and exits through the collection tube. The filtrate is moved along the permeate channel and is collected in a perforated tube in the center of the roll (Strathmann, 2000).

The large scale production is quite cost effective and module costs per membrane area are quite low because it provides large membrane area per unit volume. The most common application of the spiral-wound module is in RO for seawater and brackish water desalination. The spiral-wound module is quite sensitive to fouling, and the feed channels can easily be blocked. So particles should be removed from the feed solution by a proper pretreatment procedure (Strathmann, 2000).

Hollow Fiber Membrane Modules

Hollow fiber membrane module, a loop or a closed bundle of fibers is contained in a pressure vessel. The system is pressurized from the shell side; permeate passes through the fiber wall and exits through the open fiber ends which is shown in Figure 1.14 (Strathmann, 2000).

Most important advantage of the hollow fiber membrane module has the highest packing density of all module types available on the market today. Its production is very cost effective and hollow fiber membrane modules can be operated at pressures in excess of 100 bars.

The main disadvantage of the hollow fiber membrane module is the difficult control of concentration polarization and membrane fouling. When operated with liquid solutions the modules do not tolerate any particles that may easily precipitated at the membrane surface. Therefore, a proper pretreatment is required when hollow fiber membranes are used for the treatment of liquid mixtures.

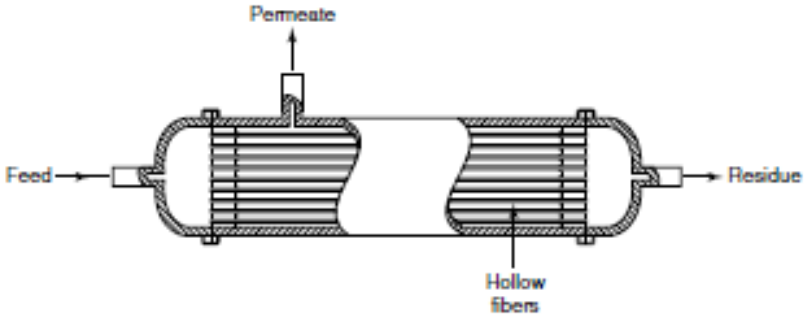


Figure 1.14 Schematic drawing illustrating the construction of a hollow fiber module (Strathmann, 2000)

The main application of the hollow fiber module is reverse osmosis desalination of sea water and in gas separation. Both application require high operating pressures and low cost membranes which have a long useful life. In reverse osmosis, of sea water an extensive pretreatment of the sea water is required (Strathmann, 2000).

1.4.2 NF and RO membrane selectivities

Membrane selectivity can be summarized according to some general guidelines as follows;

- Multivalent ions are retained better than monovalent ions. In general, the order of rejection of ions by reverse osmosis membranes is as shown below.

  For cations: $Fe^{3+} > Ni^{2+} \approx Cu^{2+} > Mg^{2+} > Ca^{2+} > Na^{+} > K^{+}$
  For anions: $PO_4^{2-} > SO_4^{2-} > HCO_3^{-} > Br^{-} > Cl^{-} > NO_3^{-} \approx F^{-}$

- Some dissolved gases: ammonia, carbon dioxide, sulfur dioxide, oxygen, chlorine and hydrogen sulfide always permeate well.
- Rejection of weak acids and bases is highly pH dependent. When the acid or base is in the ionized form the rejection will be high, but in the nonionized form rejection will be low.
- Rejection of neutral organic solutes (methanol, ethanol, acetic acid, phenol…etc) generally increases with the molecular weight of the solute. Components with molecular weights above 100 are well rejected by all RO membranes. Phenol rejection, for example, is better than ethanol rejection for RO membranes (Asano *et al*., 2007).

1.5 Integrated membrane systems in wastewater reclamation and reuse

In order to attain the environmental standards, membrane technologies provide an important solution in wastewater discharge, reuse and recovery of water and recycling valuable components from the waste stream. MBR technology obtained by the combination of the activated sludge process with MF or UF is effective tool for industrial water treatment and water reuse. If the water

use requires a higher quality, such as for indirect reusable drinking water or for industrial reuse, a tertiary treatment with NF or RO may be necessary.

The integrated membrane processes are based on combination of MBR and NF or MBR and RO processes. These processes have been commonly applied to the reclamation of wastewater after conventional biological treatments. The combination of MBR and RO processes is becoming an attractive technology for wastewater reclamation and reuse (Lozier and Fernandez, 2001; Xiao *et al*., 2014).

The combination of MBR followed by RO or NF, called MBR RO/NF integrated membrane system is one of the promising wastewater reclamation systems because it has many advantages compared with the conventional systems, such as better treated water quality, smaller footprint, lower sludge production, more convenient operation and maintenance (Herold *et al.,* 2011).

The integration of an MBR processes with RO process for the treatment of wastewater produces very high water quality. MBR–RO system for wastewater treatment produced high water quality which satisfied the drinking water requirements of the US-EPA and WHO guidelines (Altınbaş *et al.,* 1995).

Bunani *et al*. (2014a) studied treatment of MBR effluent by three different NF (CK, NF-270 and NF-90) membranes and two RO (AK-BWRO and AD-SWRO) membranes. The product water reusability in agricultural irrigation was assessed. It was concluded that product water quality by NF-90 is suitable for irrigation. Later on, in a separate work, Sert *et al*. (2015) used NF-90 membrane in pilot scale for field studies. Both results fit well with water quality standards required for agricultural irrigation.

Jin *et al*. (2013) studied with a pilot-scale MBR, NF and RO integrated system and investigated to treat coking wastewater for industrial reuse. In that study with MBR systems, the removals were 82.5% for COD, 89.6% for BOD, 99.8% for ammonium- nitrogen, 99.9% phenol and 8.9% fluoride, but the effluent did not satisfy the requirement for industrial reuse because the COD, hardness, chloride ion, and conductivity, among others, were still too high. At this point, NF and RO membranes were applied for further treatment. NF and RO systems significantly

reduced the parameters which were COD (%96.3), TN (%86.1), fluoride (%93.9), chloride ion (%95.4) and conductivity (%95.7) for industrial reuse.

Tao *et al.* (2008) investigated advantages of membrane MBR technology for reclamation of residential/domestic used water in Singapore. They made a comparison between integrated systems which were activated sludge – MF - RO (AS-MF-RO) and MBR-RO. They concluded that new MBR-RO process could produce water with drinking water standards. RO membranes in the MBR-RO process could be operated 30% higher flux than in AS-MF/UF-RO process for water reclamation and purification.

Pandey *et al* (2013), investigated water quality with different trans-membrane pressures (TMPs: 1000, 2500, and 4000 kPa) by using MBR-RO integrated membrane system. In that study, permeate from a hollow fiber membrane bio-reactor (MBR) system treating synthetic agricultural wastewater was fed into a cellulose acetate brackish water RO (BWRO30) membrane system. According to experimental results of this study, the MBR removed 97.86% of COD, and 12.63% of TP and 41.17% of TN.whereas MBR permeate feed BWRO reduced 28.24% COD, 97.90% TP, and 81.46% TN. In addition, more than 95% of TC was removed at all TMPs . In all selected TMPs, more than 96% of salinity was removed.

2. EXPERIMENTAL

2.1 Materials

2.1.1 Chemicals

The ready-prepared chemicals used in our analyses are essentially for COD, total phosphate-phosphorous, total nitrate-nitrogen, ammonium-nitrogen, nitrite-nitrogen, water hardness and silicate analysis. In sulfate and chloride analyses, the chemicals used were for mobile phase in ion chromatography analysis and pH adjustment. 0.0503 M HCl was also used for the titration analysis of HCO_3^-. The chemicals used were listed below:

- COD Test kits (LCK Hach Lange)
- Phosphate Test kits (LCK Hach Lange)
- Nitrate Test kits (LCK Hach Lange)
- Nitrite Test kits (LCK Hach Lange)
- Ammonium Test kits (LCK Hach Lange)
- Silicate Test kits (LCK Hach Lange)
- Water Hardness Test kits (LCK Hach Lange)
- Chloride Test kits (LCK Hach Lange)
- Sulphate Test kits (LCK Hach Lange)
- Vanilic Acid ($C_8H_8O_4$), > 98% (for Ion chromatography)
- N-Methyldiethanolamine ($C_5H_{13}NO_2$), 99%, d: 1.038 (for IC)
- HCl (0.0503 M)
- Ultra pure water (Milli-Q).

The measuring ranges of the kits used are summarized in Table 2.1.

Table 2.1 Measuring range of the kits

Type of kit	Measuring Range
COD Test	100-200 mg/L
	15-150 mg/L
	5-60 mg/L
Phosphate Test (as PO_4-P)	2-20 mg/L
	0.05-1.5 mg/L
Nitrite Test (as NO_2-N)	0.015-0.6 mg/L
	0.0015-0.03 mg/L
Nitrate Test (as NO_3-N)	0.23-13.5 mg/L
Total Nitrogen (TN)	20-100 mg/L
	1-16 mg/L
Ammonium Test (as NH_4-N)	2-47 mg/L
	0.015-2 mg/L
Silicate Test (as Si)	1-100 mg/L
	0.01-0.08 mg/L
Water Hardness	1-20 dH
Chloride Test	1-1000 mg/L
Sulphate Test	150-900 mg/L
	40-150 mg/L
	2-70 mg/L

2.1.2 Membranes

2.1.2.1 Membrane used in laboratory studies

In the laboratory experiments, a laboratory scale cross-flow flat sheet membrane test unit and NF200 membrane was used to investigate NF membrane rejection performance. NF200 which is nanofiltration membrane is aromatic polyamide thin-film composite membrane. Characteristic properties of membranes are given in Table 2.2.

Table 2.2 Characteristic properties of NF200 nanofiltration membrane

Designation	**Manufacturer**	**Polymer**	**Max. Temperature**	**Max. Pressure**	**pH range**	**MWCO (Da)**
NF 200	DOW FilmTec	PA TFC	45˚C	41 bar	3 - 10	~300[1]

[1]AWWA. 2011 Membrane Technology Conference. Mar 28 –31. Long Beach. CA

2.1.2.2 Membranes used in field tests

In field tests, spiral wound thin film composite NF and RO membranes were used for demineralization of MBR effluent which was taken from ITOB Organized Indutrial Zone Wastewater Treatment Plant in Tekeli-Menderes, İzmir.

Experiments were performed by using a mini pilot scale NF/RO membrane test system installed at ITOB Organized Indutrial Zone Wastewater Treatment Plant wastewater treatment plant.

Table 2.3 Characteristic properties of NF and RO membranes (Lenntech, 2016)

Membrane	**Type**	**Manufacturer**	**Polymer**	**Active Membrane Area (m^2)**	**Salt Rejection[1,2] (%)**	**Max. Temperature (^oC)**	**Max. Pressure (Bar)**	**pH Range[3]**
AG-2540T	RO	GE-Osmonics	Thin-Film - Polyamide	2.6	99.5[1]	50	31	4-11
BW30-RO	RO	Dow- Filmtech	Polyamide Thin-Film Composite	2.6	99.5[1]	50	41	2-11
NF90	NF	Dow- Filmtech	Polyamide Thin-Film Composite	2.6	>97.0[2]	45	41	2-11
NF270	NF	Dow- Filmtech	Polyamide Thin-Film Composite	2.6	>97.0[2]	45	41	2-11
TR60-2540	NF	Ropur	Cross Linked Polyamide Composite	2.6	55.0[1]	35	20	2-8

[1] NaCl salt rejection; [2] MgSO4 salt rejection ; [3] pH Range, Continuous Operation

Different NF membranes that are NF90, NF270 and TR60 and RO membranes that are BW30 and AG are employed in mini pilot scale NF/RO membrane test system. Characteristic properties and dimensions of membranes are given in Tables 2.3 and 2.4, respectivetely.

Table 2.4 Dimensions of NF and RO membranes (Sert, 2015)

Dimensions	
A	40 inch (1016 mm)
B	1.19 inch (30.2 mm)
C	0.75 inch (19 mm)
D	2.4 inch (61 mm)

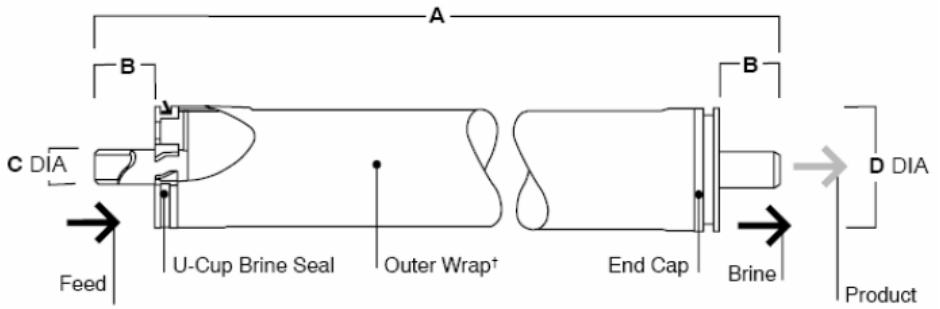


Figure 2.1 Dimensions of Spiral wound NF/RO membranes (Sert, 2015)

2.1.3 Feed water physico-chemical characteristics

2.1.3.1 Feed water characteristics for laboratory test

In the laboratory experiment, the tests were conducted by means of a cross-flow filtration system (GE Osmonics SEPA-CF-II). Feed water which is RO concentrate water, was taken from DIMES fruit juice factory in İzmir on the 5th of December 2014.

Table 2.5 Feed water (DIMES RO Concentrate) characteristics of laboratory tests

Parameters	Feed water (Average)	Parameters	Feed water (Average)
TDS (mg/L)	1666.1	**HCO_3^- (g/L)**	1.14
EC (µS/cm)	3333.1	**SO_4^{2-} (mg/L)**	195.2
pH	8.2	**Cl^- (mg/L)**	499.3
Salinity (psu)	1.9	**PO_4-P (mg/L)**	1.74
Turbidity (NTU)	0.25	**NO_3-N (mg/L)**	36.2
Na^+ (mg/L)	92.0	**NO_2-N (mg/L)**	0.03
Ca^{2+} (mg/L)	432.1	**Si (mg/L)**	34.7
K^+ (mg/L)	16.8	**COD (mg/L)**	21
Mg^{2+} (mg/L)	106.8	**Color (HAZEN)**	8.5

Salinity, conductivity, pH, turbidity, chemical oxygen demand (COD), total dissolved solids (TDS), color, concentrations of Na^+, Ca^{2+}, K^+, Mg^{2+}, HCO_3^-, SO_4^{2-}, Cl^-, PO_4-P, NO_3-N, NO_2-N and Si were measured for feed water sample during experiment. Average values for these parameters are given in Table 2.5 for feed water.

2.1.3.2 Feed water characteristics for field test

Field tests were carried out in ITOB-OSB wastewater treatment plant in Tekeli-Menderes, İzmir. In wastewater treatment plant, MBR process (where Kubota flat-sheet membranes are employed) is run. The membranes have a nominal pore size of 0.4 μm. The MBR treated wastewater used for the field test was taken from ITOB Organized Industrial Zone Wastewater Treatment Plant.

For the first field tests, effect of membrane type on water recovery and quality issues was investigated. For these tests, MBR treated wastewater and different NF and RO membranes were used. Characteristic properties of MBR treated wastewater which was used during the investigation of effect of membrane type on water recovery and quality, are given in Table 2.6.

Table 2.6 MBR treated wastewater characteristics

Parameters	**Max –Min Values**	**Parameters**	**Max –Min Values**
TDS (mg/L)	1832 – 1543	**COD (mg/L)**	11.89 – 9.44
EC (mS/cm)	3.55 – 3.01	**Hardness ($CaCO_3$ mg/L)**	523.3 – 415.8
pH	7.55 – 7.77	**SiO_2 (mg/L)**	7.2 – 6.1
Salinity (ppt)	1.87 – 1.56	**SO_4^{2-} (mg/L)**	584.5 – 555.5
TSS (mg/L)	8.1 – 6.0	**Cl^- (mg/L)**	845.5 – 689
Turbidity (NTU)	1.46 – 0.73	**Na^+ (mg/L)**	539 – 459.7
HCO_3^- (mg/L)	214.8 – 197.3	**K^+ (mg/L)**	54.9 – 43.6
NO_3-N (mg/L)	7.44 – 2.38	**Ca^{2+} (mg/L)**	154.6 - 139.4
NO_2-N (mg/L)	0.466 – 0.237	**Mg^{2+} (mg/L)**	26 – 18
PO_4-P (mg/L)	0.095 – 0.059	**TOC (mg/L)**	43.7 – 25.9
NH_4-N (mg/L)	0.716– 0.023		

For the second field tests, concentrate management tests issues were investigated. Feed waters were the mixture of MBR effluent and NF90 concentrate with the ratios of 4:1, 3:1, 2:1, 1:1, respectively, in order to decrease the amount of discharged concentrate stream from NF process. These mixtures were used as feed water for pilot scale NF/RO membrane test system. The feed water characteristics that were used for second field tests are summarized in Table 2.7.

Table 2.7 Characteristics of feed waters (mixture of MBR effluent and NF90 concentrate with different ratio)

Parameters	*MBR effluent: NF90 Conc. Ratio			
	4:1* (min- max)	**3:1* (min- max)**	**2:1* (min- max)**	**1:1* (min- max)**
TDS (mg/L)	1826-2156	1777-2240	1764-2420	1726-2890
EC(µS/cm)	3530-4150	3430-4300	3420-4640	3350-5640
Salinity (ppt)	1.85-2.20	1.80-2.28	1.79-2.47	1.75-3.05
TSS (mg/L)	3.0	3.0	3.0	3.0-3.75
Color (mg/L Pt-Co)	26-32	24-28	23-42	24-43
Turbidity (NTU)	1.14-1.78	1.31-1.61	1.15-1.27	1.24-1.65
HCO_3^- (mg/L)	257.1-303.9	280.5-358	257.1-459.7	327.3-529.9
NO_3-N (mg/L)	4.97-5.4	4.4-5.4	4.1-4.5	2.9-3.22
NO_2-N (mg/L)	0.046-0.072	0.061-0.077	0.044-0.058	0.052-0.111
PO_4-P (mg/L)	0.079-0.086	0.05-0.108	0.05-0.122	0.069-0.127
NH_4-N (mg/L)	0.266-0.293	0.260-0.280	0.224-0.286	0.178-0.386
COD (mg/L)	17.1-19.7	18-19.6	17.9-20.3	17.3-28
Hardness ($CaCO_3$ - mg/L)	441.4-512.6	420.1-509.1	402.3-534	377.4-637.2
SiO_2 (mg/L)	13.4-15.8	13.6-15.35	12.3-14.6	11.3-15.7
SO_4^{2-} (mg/L)	433-459	348-485	308-456	298-492
Cl^- (mg/L)	816-987	909-996	998-1182	927-1540
TN (mg/L)	20-34.4	20-25.2	20-31.7	20-57.2
Na^+ (mg/L)	1362.7-1649.3	1383.6-1686.3	1256-2027.8	1499.1-2016.6
K^+ (mg/L)	53.9-76.9	57.1-71.7	62.1-74.4	60.2-97.6
Ca^{2+} (mg/L)	74-84	61-69	53-96	56-79
Mg^{2+} (mg/L)	27.4-39	28.8-41.3	29.5-39.6	28.3-54.1
TOC (mg/L)	7.7-8.9	7.8-13.3	7.9-9.9	7.9-12.2

2.2 Equipments

2.2.1 GE SepaTM CF II Membrane Test System

In the laboratory experiments, a laboratory scale cross-flow flat-sheet membrane test unit (SEPA CF-II, GE), which is shown in Figure 2.2, was used.

Tests were conducted under 10 bar of operating pressure and by employing NF200 NF flat-sheet membranes for the filtration of RO concentrate wastewater during 6 hours.

Permeate and concentrate streams were send back to the feed tank to keep the feed composition constant (Figure 2.2). Feed, permeate and concentrate samples were taken for analysis, periodically. Rejection performances of membrane are given in the Result Section.

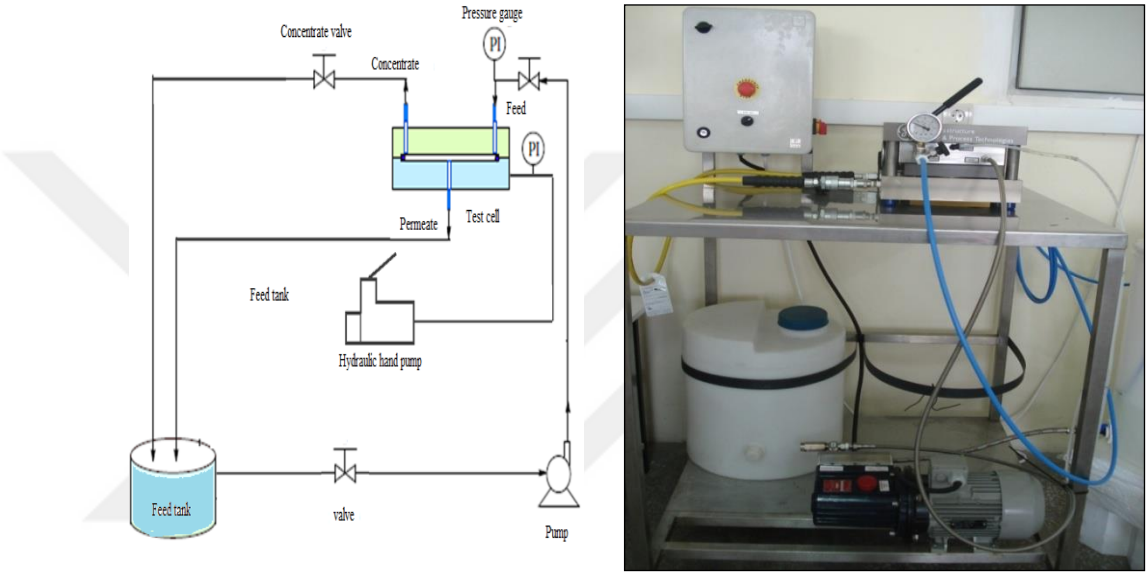


Figure 2.2 Cross-flow flat sheet test system

Sepa CF II Membrane Cell system is applicable any RO, NF, UF or MF membranes.

Flat sheet membrane unit, control panel, hydraulic hand pump, high pressure pump and feed tanks were installed on the specific manufacturing stainless steel table as seen in Figure 2.2.

GE Water & Process Technologies Sepa CF II Membrane Cell system is a capable of withstanding up to 69 bar. It provides fast and accurate performance data for any pressure driven membrane processes.

A single piece of rectangular membrane is installed in the cell body bottom (Figure 2.3) on top of the feed spacer and shim (optional). The permeate carrier is placed in the recess on the cell body top. The guideposts assure proper orientation

of the cell body halves. The cell body top fits over the guideposts of the cell body bottom.

The assembled cell body is inserted into the cell holder. Hydraulic pressure is applied through a fitting in the bottom of the cell holder. The hydraulic pressure causes the piston to extend upward and compress the cell body against the cell holder top.

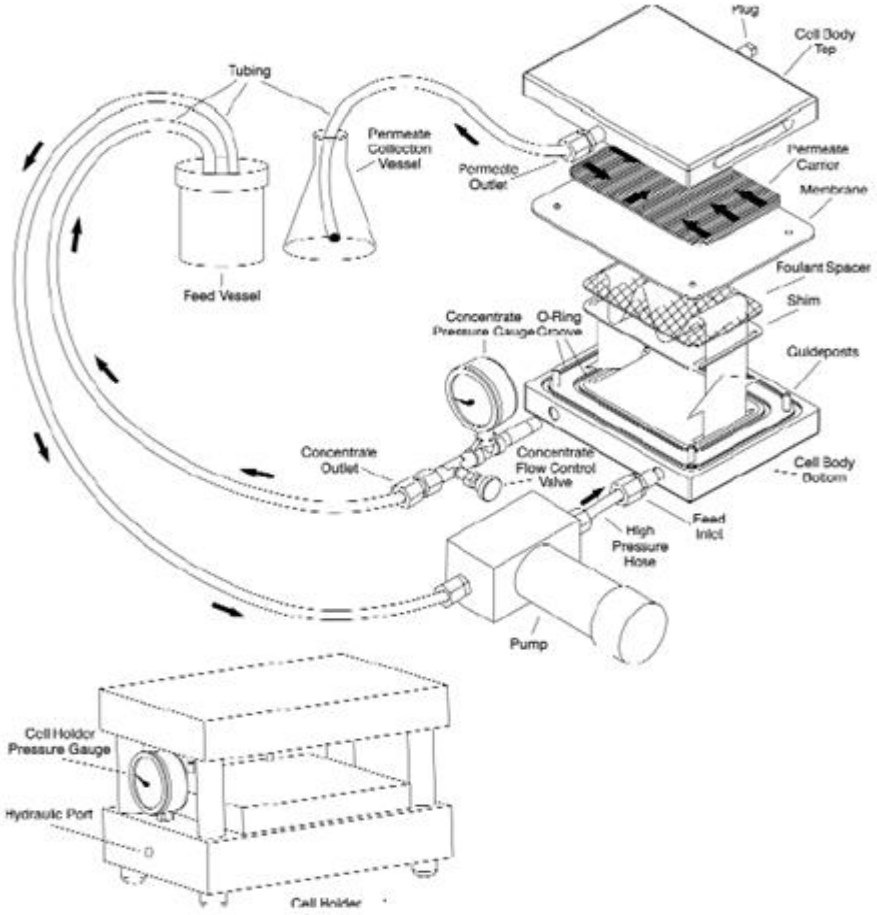


Figure 2.3 Sepa CF II Membrane Element Cell Major Components and Flow Sequence (Sert, 2015)

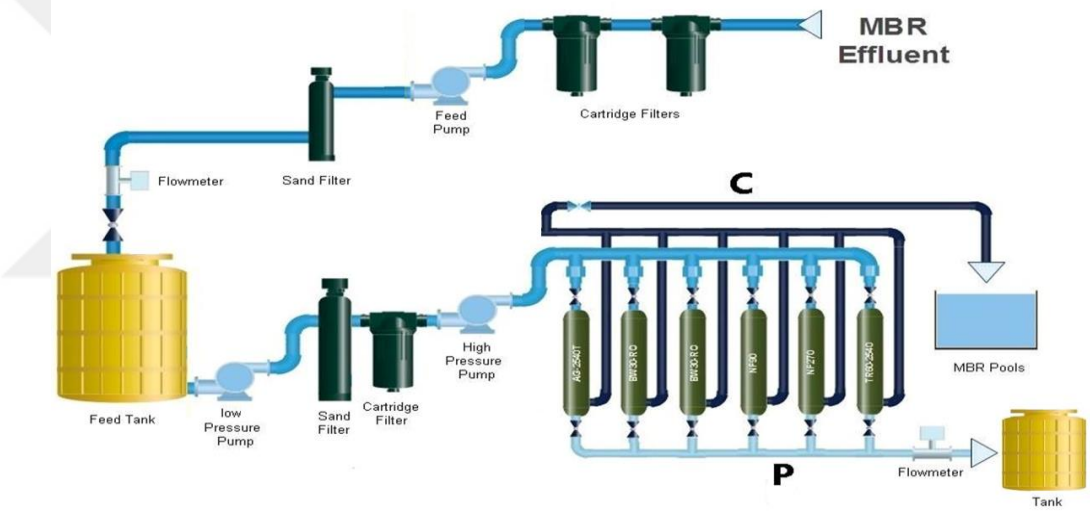
The feed stream is send from the feed tank to the feed inlet. Flow pass through a manifold into the membrane cavity. The solution tangentially flows across the membrane surface. Flow types of solution which could be laminar or turbulent, is fully controlled by user and depending on the shim, feed spacer, fluid viscosity, and fluid velocity.

Permeate flows through the permeate carrier, which is located in the cell body top. The permeate flows to the center of the cell body top, is collected in a manifold, and then flows out through the permeate outlet connection into a user-

supplied permeate collection vessel. The concentrate stream continues sweeping over the membrane and collects in the manifold. The concentrate then flows through the concentrate flow control valve into vessel or back into the feed vessel.

2.2.2 Pilot scale NF/RO test system

The field tests were performed at the wastewater treatment plant of ITOB-Organized Industrial Zone located in Menderes, Izmir where MBR process has been employed for wastewater treatment. In this study, the effluent of wastewater treated by MBR system was re-treated with NF and RO processes. For this purpose, a mini pilot scale membrane test unit having NF and RO membranes in spiral wound configurations was used. Flow diagram of mini pilot scale NF/RO system is shown in Figure 2.4.



C: Concentrate Stream **P**: Permeate Stream

Figure 2.4 Flow diagram of mini pilot scale NF/RO sytem

Mini pilot scale NF/RO system, was used under different operating pressures employing different NF and RO spiral-wound membranes for the filtration of MBR treated wastewater. MBR treated wastewater is passed through the cartridge filters and sand filter and pumped to the feed tank (500 L). Firstly, feed is filtered by the sand filter and then by cartridge filter. Next, it is passed through the membrane unit by the help of a high pressure pump.

2.2.2.1 Water storage tanks

MBR treated wastewater was stored in a feed tank after passed through cartridge and sand filters. Capacity of feed tank which is shown in Figure 2.5 is 500 L.

Figure 2.5 Feed water storage tank of a pilot scale NF/RO system

For the batch study, permeate water sent to feed water tank but there is also a permeate water storage tank in the pilot scale NF/RO system. Stored permeate water in this tank is used for back-wash of membranes. Permeate tank is shown in Figure 2.6.

Figure 2.6 Permeate water storage tank of pilot scale NF/RO sytem

2.2.2.2 Filters

In the pilot scale NF/RO system, there are three cartridge filter and two sand filter which are also shown in Figure 2.4. Two sand filter and a cartridge filter is placed before feed tank, a sand filter and a cartridge filter are placed after feed tank.

MBR treated feed water firstly pass through two cartridge filters, and then send to sand filter by the help of feed pump and finaly collected in the feed tank. These two cartridge filters which have 10 micron pore size and sand filters is shown in Figure 2.7.

Figure 2.7 Cartridge and sand filters – Before feed tank

When pilot scale NF/RO system are ready to work, feed water passes through another sand filter and cartridge filter (20 micron) which is shown in Figure 2.8.

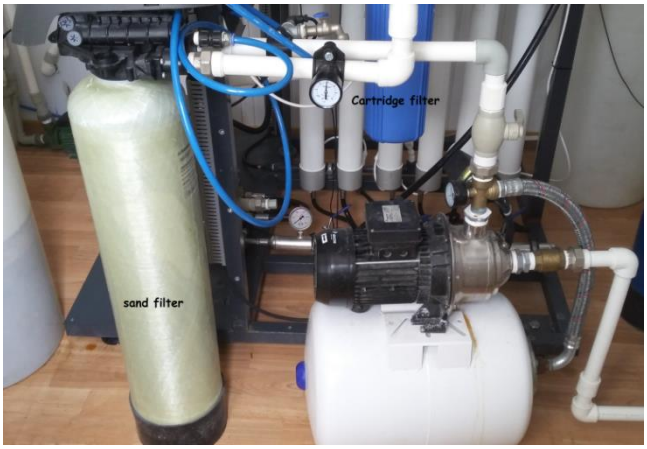


Figure 2.8 Sand and cartridge filters – After feed tank

2.2.2.3 Pumps

In the pilot scale NF/RO system, there are three pumps which are feed, low and high pressure pumps. These three pumps are shown in Figure 2.9.

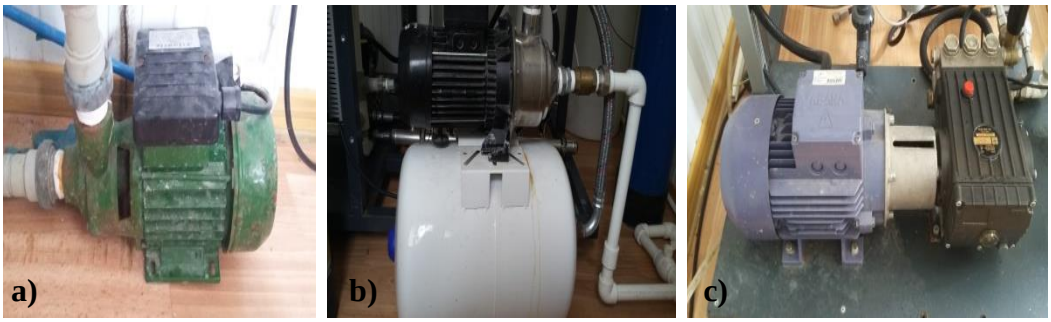


Figure 2.9 a) Feed pump **b)** Low pressure pump **c)** High pressure pump

2.2.3 Measuring Devices

2.2.3.1 pH meter & Conductometer

pH, conductivity, TDS, temperature and salinity measurements were carried out by a portable digital Hach HQ40d, which is shown in Figure 2.10.

Figure 2.10 Hach HQ40d devive and pH and conductivity probes

There are two probes connected in this device and by this way pH and other parameters which are TDS, conductivity, salinity and temperature could be measured at the same time.

2.2.3.2 Colorimeter

All COD, water hardness, phosphate-P, ammonium-N, nitrate-N, nitrite-N; silicon and color analysis were performed by using a colorimeter (Hach Lange DR3900 model) which is shown in Figure 2.11.

Figure 2.11 Hach Lange DR3900 model colorimeter

Some parameters such as COD and phosphate-P need heating. For this purpose, a thermo reactor Hach Lange LT-200 model which is shown in Figure 2.12, was used.

Figure 2.12 Hach Lange LT-200 model thermo reactor

2.2.3.3 Turbidimeter

Turbidity was measured by Micro TPI Field Portable Turbidimeter which is shown in Figure 2.13.

Figure 2.13 Micro TPI Field Portable Turbidimeter

2.2.3.4 Atomic Absorption Spectrophotometer

Na^{+}, K^{+}, Mg^{2+}, Ca^{2+} ions concentrations were determined by AA-7000 Shımadzu Atomic Absorption Spectrophotometer which is shown in Figure 2.14.

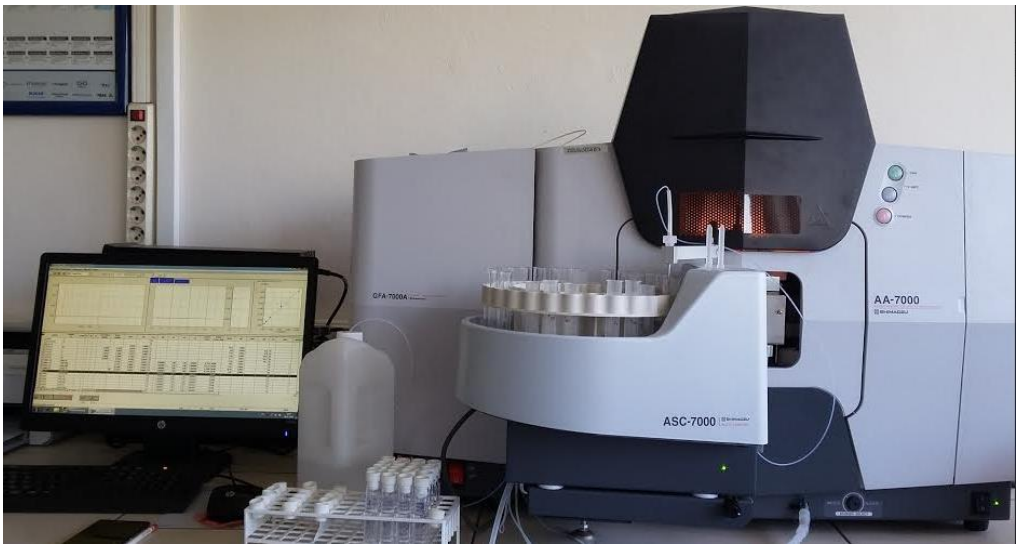


Figure 2.14 Shimadzu AA-7000 model atomic absorption spectrophotometer

2.2.3.5 Ion chromatography (IC) equipment

The analyses of sulfate and chloride were done by using a Shimadzu model ion chromatography equipment which is shown in Figure 2.15.

Figure 2.15 Shimadzu LC-10 Ai model chromatography

2.2.3.6 TOC analyzer

TOC analysis was carried out by a TOC analyzer (Shimadzu TOC-V_{CPH} Model) which is shown in Figure 2.16.

Figure 2.16 TOC analyzer (Shimadzu TOC-VCPH Model).

2.3 Calculations

2.3.1 Permeate Flux

Permeate fluxes of the each membranes were calculated by measuring the permeate volume which is collected over a certain period in terms of liter per square meter of membrane area per hour (L/m^2 h) and using the following equation;

$$J_p = \frac{F_p}{A} \tag{2.1}$$

J_p= Permeate Flux (L/m^2 h); F_p=Permeate Flowrate (L/h);

A= Effective Membrane Area (m^2)

2.3.2 Rejection

The percent removal of various parameters was calculated using the following equation;

$$R_x(\%) = 100 * (1 - \frac{X_p}{X_f}) \tag{2.2}$$

$R_x(\%)$= Percentage Rejection; X_p = X Properties in Permeate;

X_f = X Properties in Feed

2.3.3 Water Recovery

Water recovery of the system for the each working pressure and membrane are calculated by using following equation;

$$Recovery\ (\%) = \frac{Q_p}{Q_f} * 100 \qquad (2.3)$$

Q_p : flow rate of permeate; Q_f : flow rate of feed

2.3.4 Sodium Absorption Ratio (SAR)

Sodium adsorption ratio which indicated as SAR, was defined by using the following formula;

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^{2+}]+[Mg^{2+}]}{2}}} \qquad (2.4)$$

Concentrations of sodium, magnesium and calcium, in the above formula are expressed in milliequivalent per liter (meq/L) (Bunani et al., 2015).

Table 2.8 Republic of Turkey Ministry of Environment and Urbanisation Agricultural irrigation standard (Bunani *et al.*, 2015)

Parameters		Units	Degree of restriction on use		
			None (I. Class water)	Slight to moderate (II. Class water)	Severe (III. Class water)
Salinity					
Conductivity		µS/cm	< 700	700-3000	>3000
TDS		mg/L	< 500	500-2000	>2000
Permeability					
SAR	0-3		EC ≥ 0.7	0.7-0.2	< 0.2
	3-6		≥ 1.2	1.2-0.3	< 0.3
	6-12		≥ 1.9	1.9-0.5	< 0.5
	12-20		≥ 2.9	2.9-1.3	< 1.3
	20-40		≥ 5.0	5.0-2.9	< 2.9
Specific Ion Toxicity					
Sodium (Na)					
	Surface Irrigation	SAR	< 3	3-9	> 9
	Drip Irrigation	mg/L	< 70	> 70	
Chloride (Cl)					
	Surface Irrigation	mg/L	< 140	140 –350	> 350
	Drip Irrigation	mg/L	< 100	> 100	
Boron (B)		mg/L	< 0.7	0.7-3.0	> 3.0

In Table 2.8, the water chemical characterstics that regulated by Republic of Turkey Ministry of Environment and Urbanization are shown. Permeate quality that obtained after all experiments were compared with irrigation water characteristic and reuse of permeates for irrigation purposes were discussed.

A graph shown in Figure 2.17 is drawn to investigate the permeability characteristic of permeates. This graph include EC and SAR values from Table 2.8 and the region between the lines express the water characteristics of permeates.

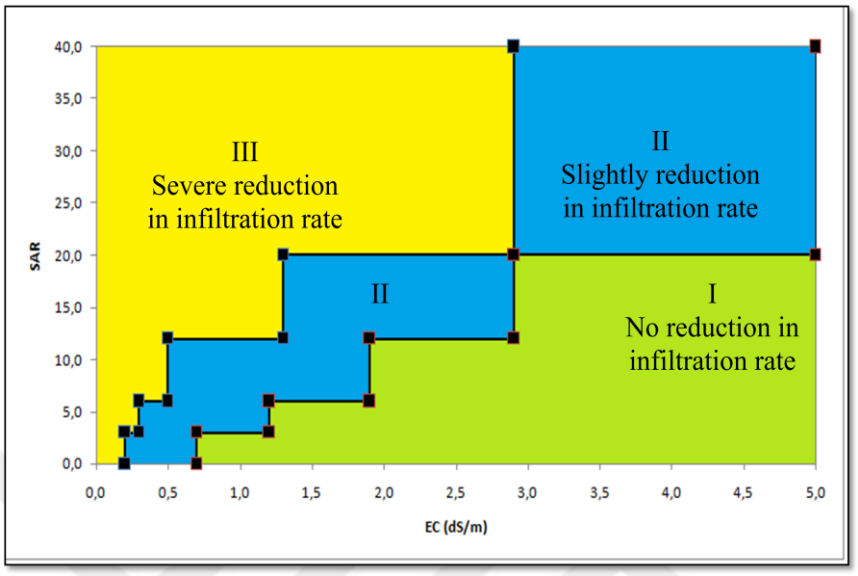


Figure 2.17 Permeability characteristics of irrigation water

3. RESULTS AND DISCUSSION

3.1 Laboratory Test

In the laboratory experiments, a lab scale cross-flow flat-sheet membrane test unit and NF200 membrane was used to investigate NF membrane rejection performance for the treatment of RO concentrate water that was taken from DIMES beverage factory in İzmir on the 5th of December 2014.

The test was conducted under an operating pressure of 10 bar by using NF200 NF membrane for 6 hours.

3.1.1 Performance of NF200 membrane for treatment of RO Concentrate

Permeate flux of NF200

The flux vs. time plot for NF200 membrane is shown in Figure 3.1.

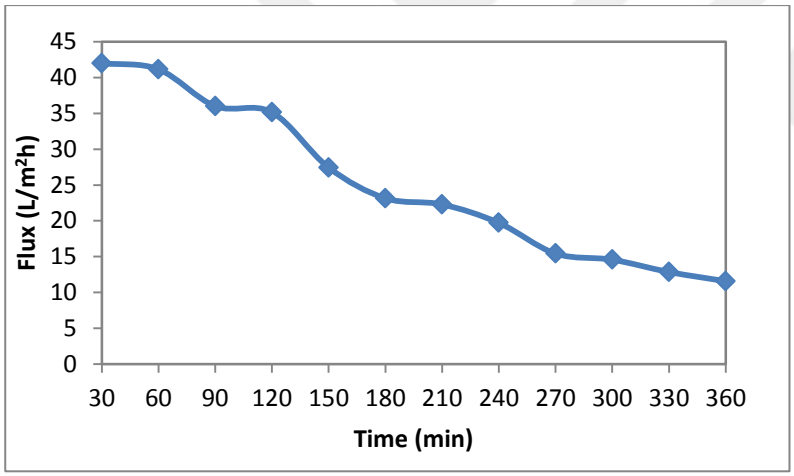


Figure 3.1 Flux vs time plot for NF200

The average flux value of NF200 membrane is 25.1 L/m^{2}h. NF200 membrane flux declined by time. The reason of such decline could be scaling or fouling on membrane surface.

Conductivity rejection of NF200

Conductivity rejection by NF200 membrane was 61.5% as average. Conductivity rejection versus time plot for the NF200 membrane is given in Figure 3.2.

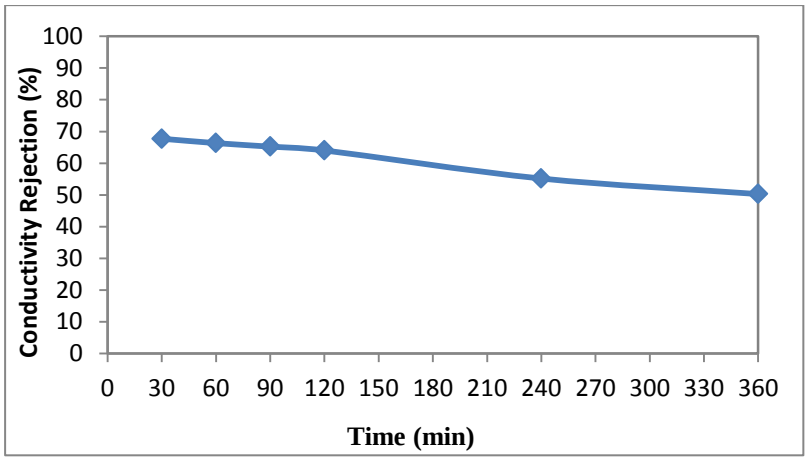


Figure 3.2 Conductivity rejection vs. time plot for NF200

TDS rejection of NF200

TDS rejection was performed by NF200 membrane with the similar average rejection as conductivity rejection. As depicted on Figure 3.3, TDS rejection vs. time plot show similar trends as well as conductivity rejection. Average TDS rejection of NF200 membrane was 61.6 %.

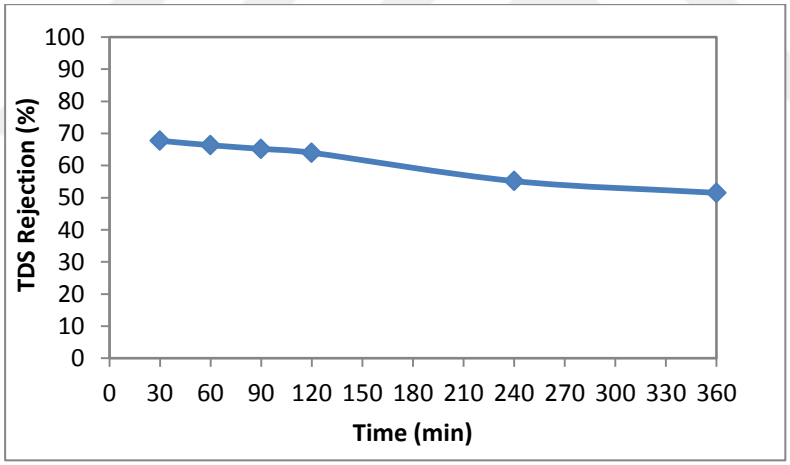


Figure 3.3 TDS rejection vs. time plot for NF200

Salinity rejection of NF200

The average salinity rejection for NF200 membrane was 60.5%. Figure 3.4 shows time versus salinity rejection plot for the NF200 membranes.

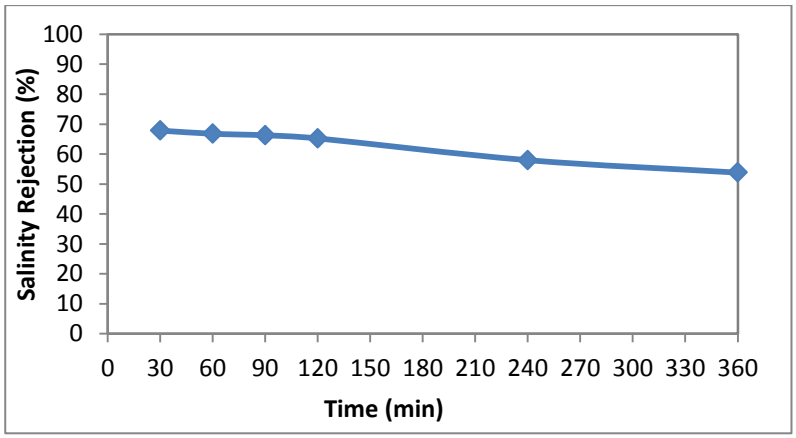


Figure 3.4 Salinity rejection vs. time plot for NF200

Color rejection of NF200

The NF200 membrane was efficient to remove color with an average rejection of 49.2% as it is shown in Figure 3.5.

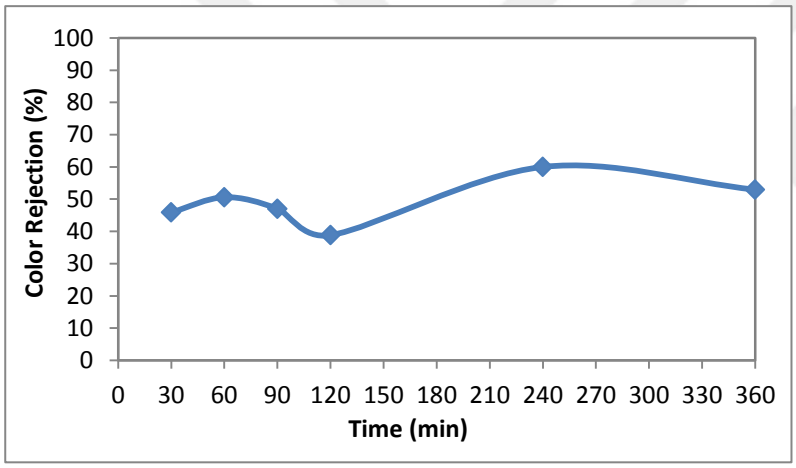


Figure 3.5 Color rejection vs. time plot for NF200

COD rejection of NF200

COD is removed by the help of NF200 membrane with an average rejection of 81.1%. COD rejection versus time plot is shown in Figure 3.6.

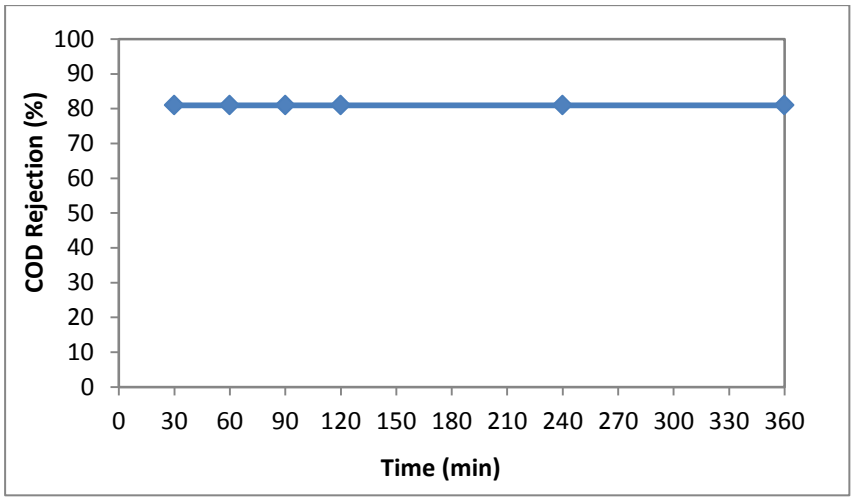


Figure 3.6 TOC rejection vs. time plots for NF200

Silicon rejection of NF200

Rejection of silicon was less effective with NF200 up to an average rejection of 27.9 %. The silicon rejection vs. time plot is shown on Figure 3.7.

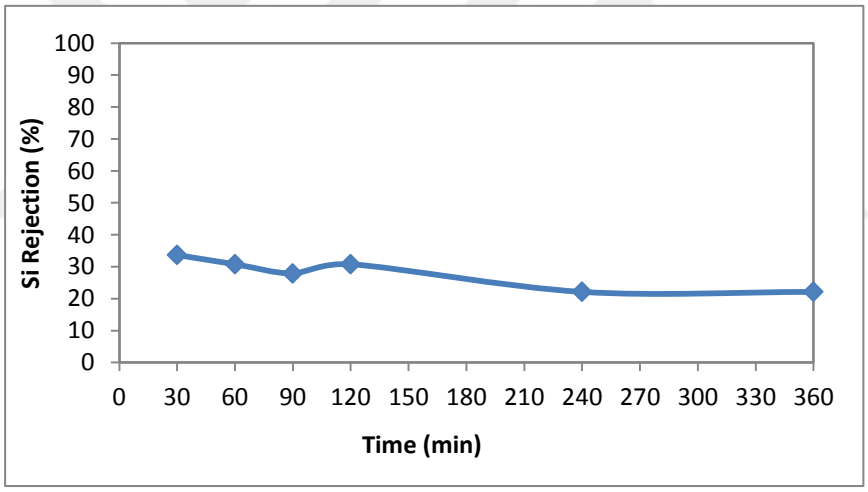


Figure 3.7 Silicon rejection vs. time plot for NF200

Turbidity rejection of NF200

Nanofiltration membranes are effective in rejection of turbidity, but when the turbidity of the feed solution is low, the rejection also becomes low. Turbidity is removed by using NF200 membrane with the average rejection of 60.5%. The turbidity rejection vs. time plot is depicted on Figure 3.8.

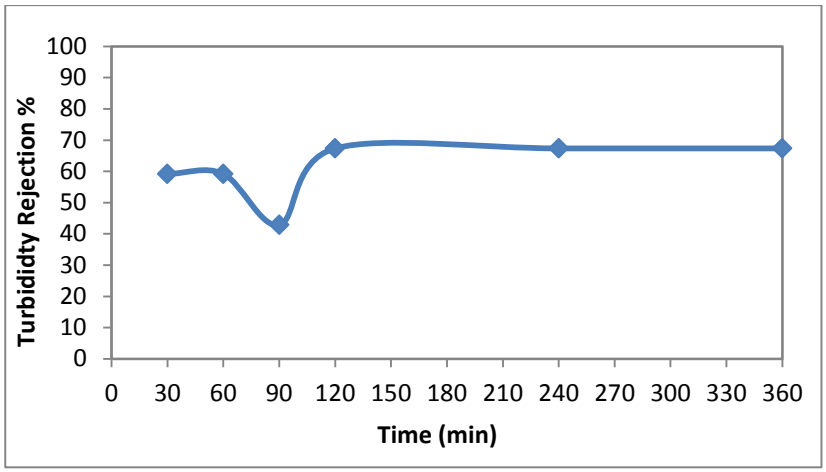


Figure 3.8 Turbidity rejection vs. time plot for NF200

Phosphate-P rejection of NF200

Average Phosphate-P removal of NF200 membrane was 79.3%. The phosphate-P vs. time plot is depicted on Figure 3.9.

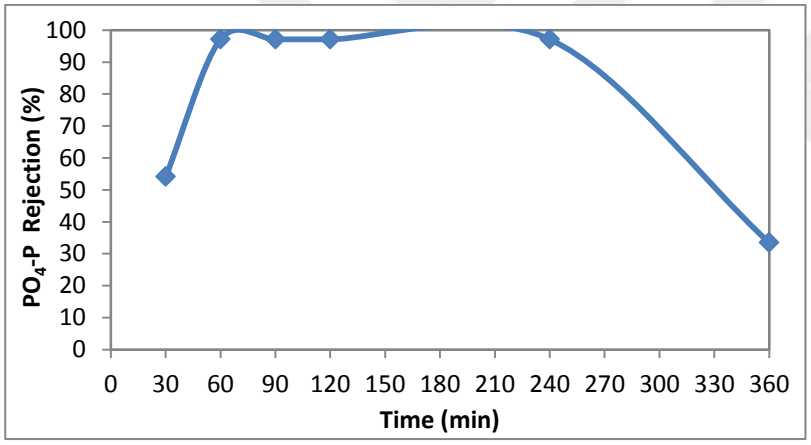


Figure 3.9 Phosphate-P rejection vs. time plot for NF200

Nitrate-N rejection of NF200

Nitrate-N is rejected by the NF200 membrane with an average rejection of 35%. Nitrate-N rejection vs. time plot for the NF200 membrane is given in Figure 3.10.

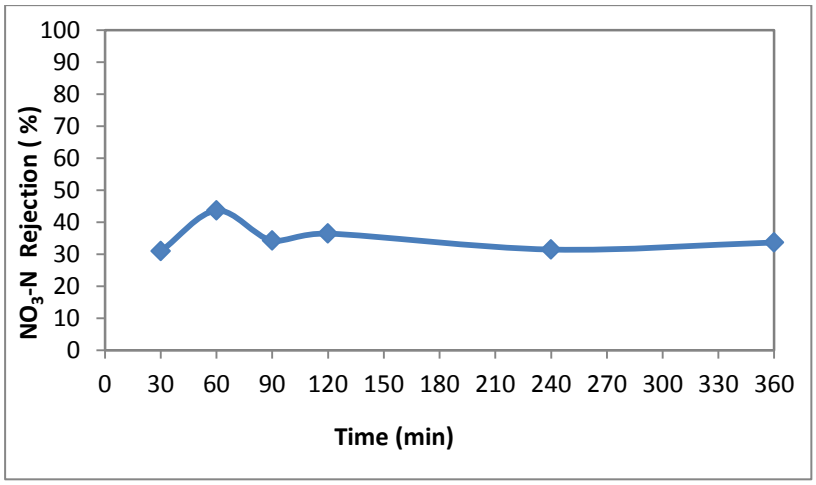


Figure 3.10 Nitrate-N rejection vs. time plot for NF200

Nitrite-N rejection of NF200

Nitrite-N is rejected by the NF200 membrane with an average rejection of 33.3%. Nitrite-N rejection vs. time plot for the NF200 membrane is given in Figure 3.11.

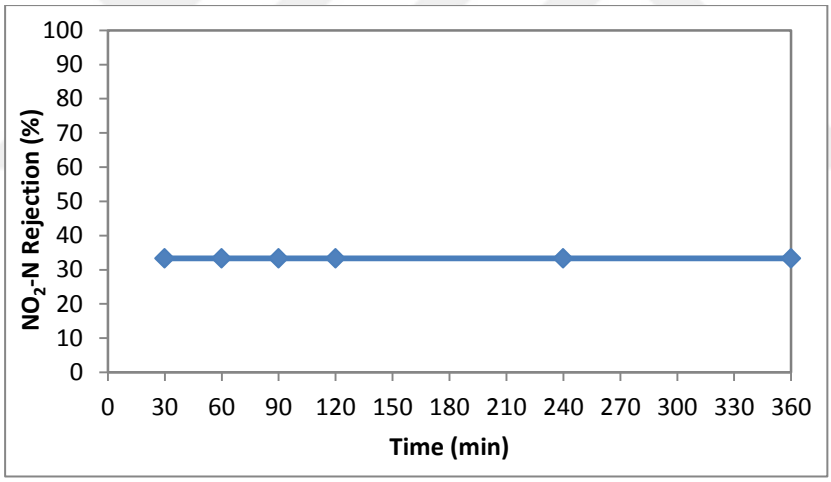


Figure 3.11 Nitrite-nitrogen rejection vs. time plot for NF200

Chloride rejection of NF200

Chloride ion is rejected by the NF200 membrane with an average rejection of 58.7%. Chloride rejection vs. time plot for the NF200 membrane is given in Figure 3.12.

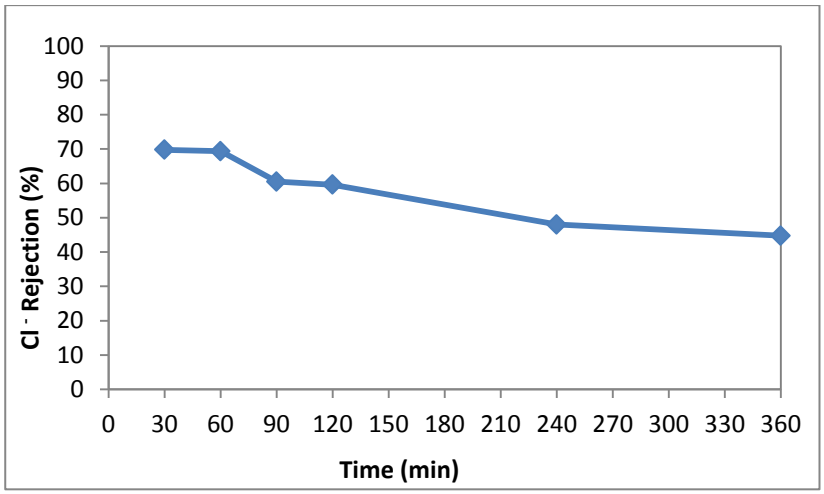


Figure 3.12 Chloride rejection vs. time plot for NF200

Bicarbonate rejection of NF200

Bicarbonate ion is rejected by the NF200 membrane with an average rejection of 71%. Bicarbonate ion rejection vs. time plot for the NF200 membrane is given in Figure 3.13.

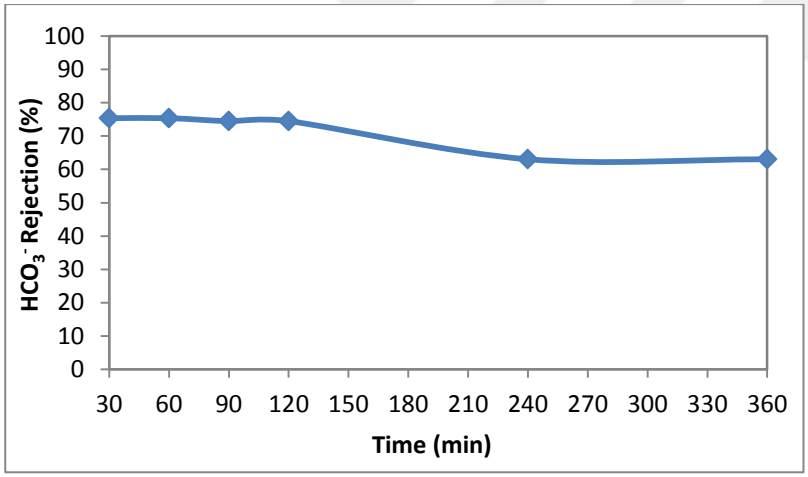


Figure 3.13 Bicarbonate rejection vs. time plot for NF200

Sulfate rejection of NF200

Sulfate is rejected by the NF200 membrane with an average rejection of 69.3%. Sulfate rejection vs. time plot for the NF200 membrane is given in Figure 3.14.

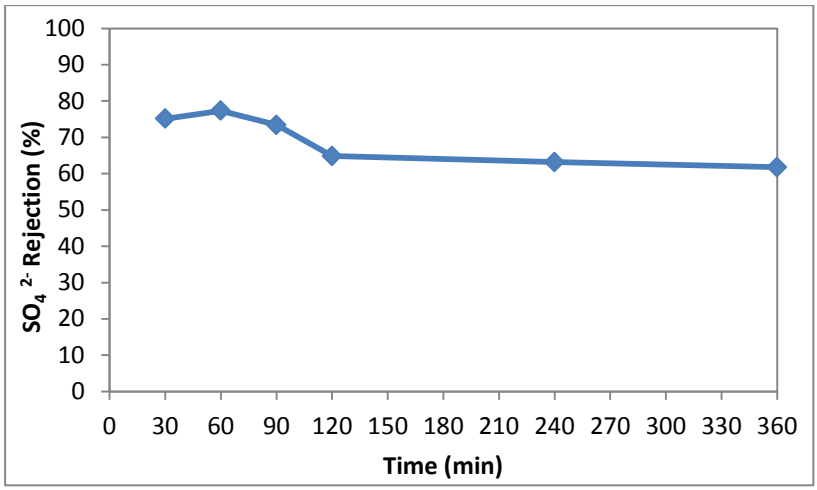


Figure 3.14 Sulfate rejection vs. time plot for NF200

Calcium rejection of NF200

Rejection of calcium was effective with NF200 up to an average rejection of 51.7%. The calcium rejection vs. time plot is shown on Figure 3.15.

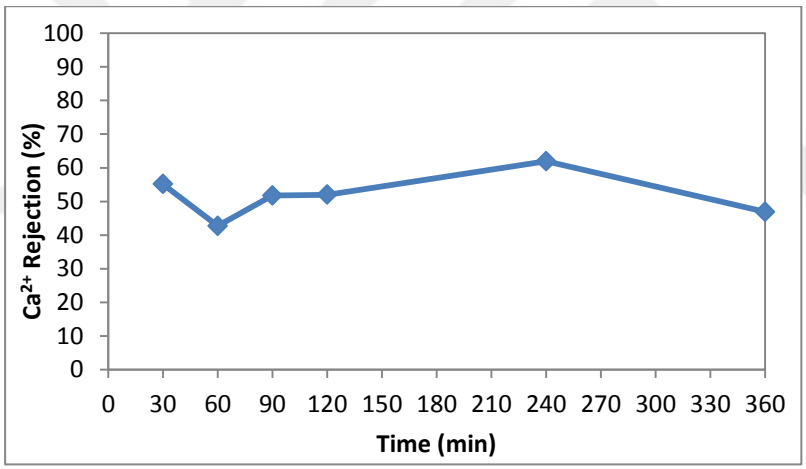


Figure 3.15 Calcium rejection vs. time plot for NF200

Magnesium rejection of NF200

Magnesium is rejected by the NF200 membrane with an average rejection of 88.4%. Magnesium rejection vs. time plot for the NF200 membrane is given in Figure 3.16.

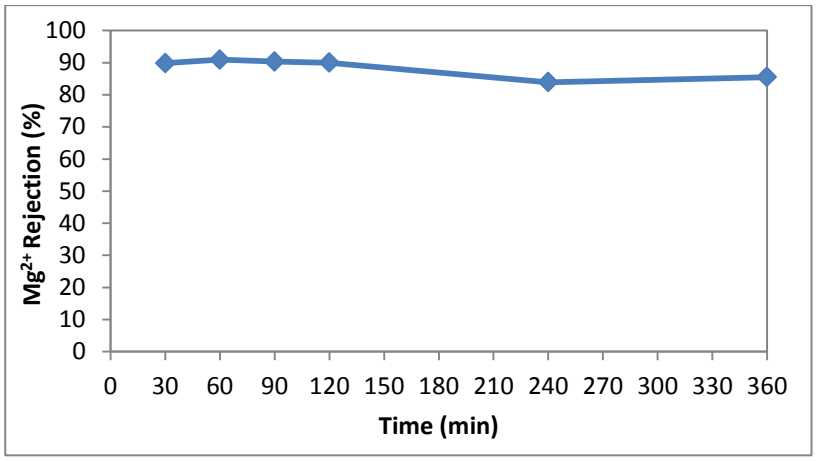


Figure 3.16 Magnesium rejection vs. time plot for NF200

Sodium rejection of NF200

Sodium is rejected by the NF200 membrane with an average rejection of 16.8%. Sodium rejection vs. time plot for the NF200 membrane is given in Figure 3.17.

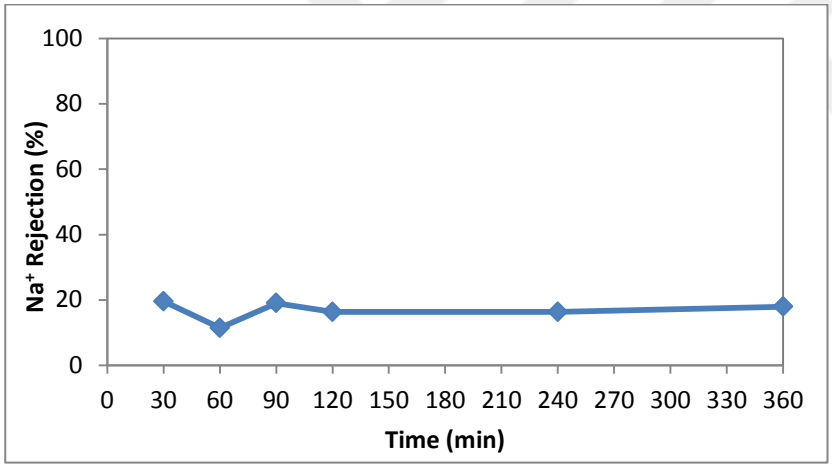


Figure 3.17 Sodium rejection vs. time plot for NF200

Potassium rejection of NF200

Potassium is rejected by the NF200 membrane with an average rejection of 42.6%. Sodium rejection vs. time plots for the NF200 membrane is given in Figure 3.18.

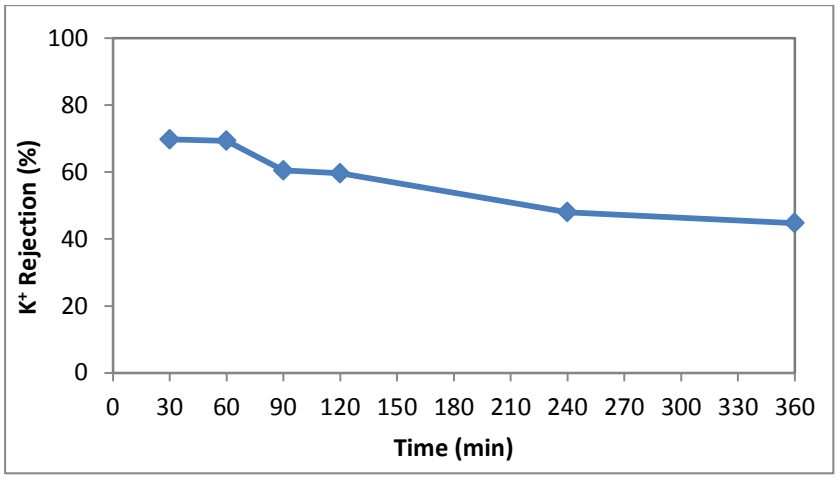


Figure 3.18 Potassium rejection vs. time plot for NF200

3.1.1.1 Quality analysis of NF treated water from DIMES RO concentrate

Product water qualities obtained by NF200 membrane, feed water characteristic and average rejection for each parameters were listed in Table 3.1. It can be seen that the NF200 membrane rejections are more than 50% for many parameters. NF200 membrane shows higher performance especially for divalent ions rejection.

Table 3.1 Experimental results for NF200 membrane at 10 bar

Parameters	Feed Characteristic (Average)	Permeate Quality (Average)	Rejection % (Average)
TDS (mg/L)	1666.1	696.5	61.65
EC (µS/cm)	3333.1	1396.3	61.46
pH	8.2	7.8	-
Salinity (psu)	1.9	0.8	62.98
Turbidity (NTU)	0.25	0.10	60.54
Na^+ (mg/L)	92.0	76.6	16.76
Ca^{2+} (mg/L)	432.1	208.6	51.73
K^+ (mg/L)	16.8	9.6	42.62
Mg^{2+} (mg/L)	106.8	12.4	88.41
HCO_3^- (g/L)	1.14	0.33	70.97
SO_4^{2-} (mg/L)	195.2	60	69.26
Cl^- (mg/L)	499.3	206.4	58.67
PO_4-P (mg/L)	1.74	0.36	79.35
NO_3-N (mg/L)	36.2	23.5	35.02
NO_2-N (mg/L)	0.03	0.02	33.33
Si (mg/L)	34.7	25	27.88
COD (mg/L)	21	< 4	> 80.95
Color (HAZEN)	8.5	4.32	49.22

3.2 Field Tests

3.2.1 Effect of membrane type on water recovery and quality

In this study, wastewater which was treated by MBR process was taken from ITOB Organized Industrial Zone Wastewater Treatment Plant which is located in Menderes, İzmir. MBR treatment process provides stable and high quality product water in the wastewater treatment plant. On the other hand, product water contains a high salinity.

Industrial wastewater which is collected from several companies (industries of beverage, plastic packaging, food, dye, oil, detergent, otomotive and so on), is treated in ITOB Organized Industrial Zone Wastewater Treatment Plant. Characteristic properties of MBR treated wastewater which was used during the investigation of effect of membrane type on water recovery and quality, is given in Table 2.7 in Experimental Section.

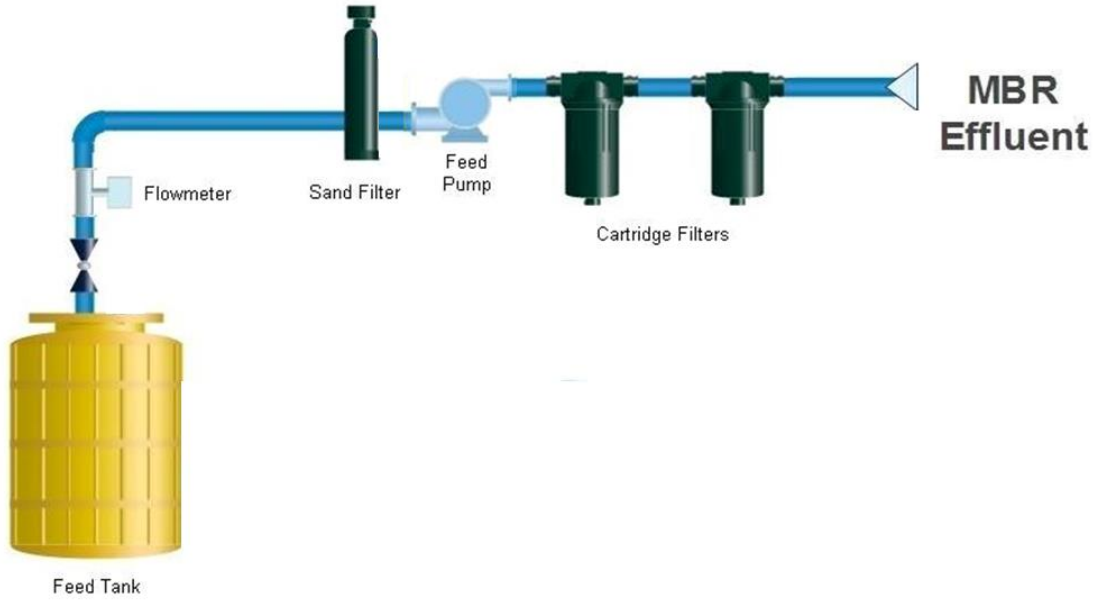


Figure 3.19 Filling feed tank with MBR treated wastewater

MBR treated wastewater is passed through the cartridge filters and sand filter and pumped to the feed tank (500 L). Filling the feed tank with MBR treatated wastewater is shown in a flow diagram on Figure 3.19.

After filling the feed tank with MBR trated wastewater, NF/RO system was started to run. Firstly, feedwater is filtered by the sand filter and then cartridge filter and next, it is passed through the spiral-wound NF/RO membrane unit by the

help a of high pressure pump. NF90, NF270 and TR60 membranes are NF membranes, AG and BW30 membranes are RO membranes. Flow diagram of study is shown in Figure 3.20.

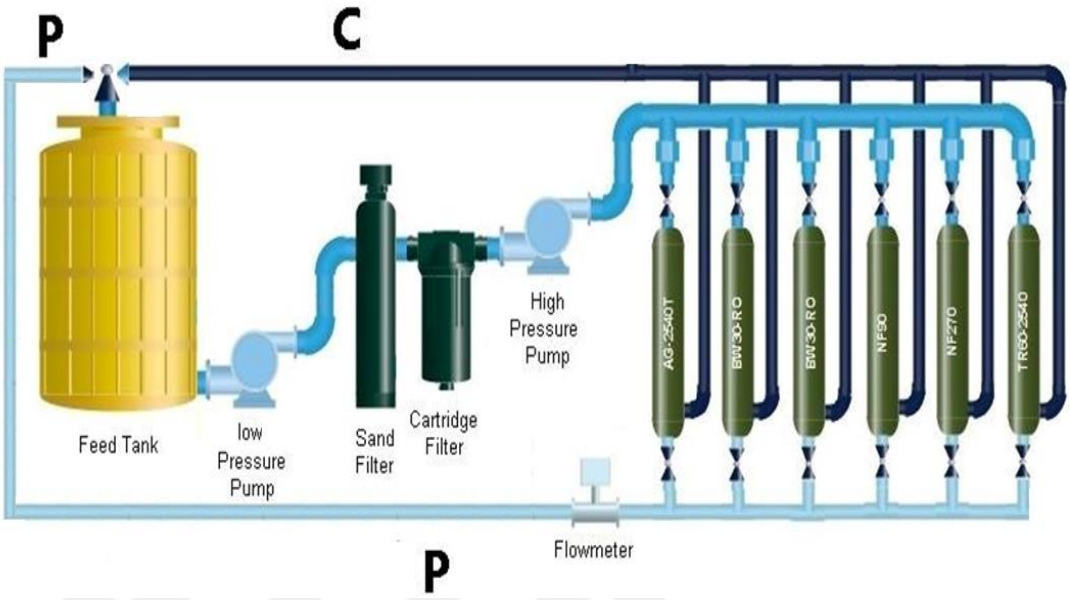


Figure 3.20 Flow diagram of mini pilot scale NF/RO system –Batch Study

Mini pilot scale NF/RO system was employed under 10 bar of operating pressure for NF spiral-wound membranes and 20 bar of operating pressure for RO spiral-wound membranes for the filtration of MBR treated wastewater during 6 hours.

During the study, batch mode of operation was used for all experiments. Both permeate and concentrate streams which are indicated as P and C in the flow diagram respectively, were recirculated back to the feed reservoir to remain feed composition steady. Feed, permeate and concentrate samples were taken for analysis, periodically.

3.2.1.1 Test with NF membranes

MBR treated industrial wastewater was re-treated by using NF membranes. For this purpose, three NF membranes which have different properties tested and their performances were also obtained as different.

Permeate Flux of NF membranes

The average permeate fluxes of NF90, NF270 and TR60 NF membranes were measured as 50.4, 64 and 54.6 L/m^{2}h, respectively, and results are shown in Figure 3.21. According to the membrane pore size; the more effective membrane was NF270 with a maximum permeate flux. Except for the NF90 membrane; two other membranes showed some decline in flux after a certain time which may be caused by fouling or scaling on membrane surface.

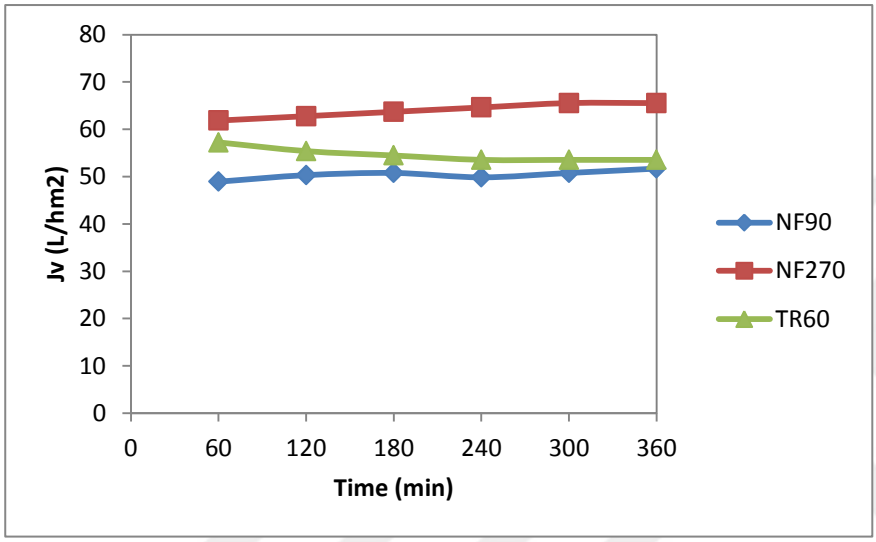


Figure 3.21 Permeate fluxes of various NF membranes vs. time plots

Conductivity rejection of NF membranes

Conductivity was rejected by the NF90 membrane with an average rejection of 96.1% while for the other membranes the average rejections were achieved 40.2% by NF270 and 18.6% by TR60. Conductivity rejection vs. time plots for the NF membranes are given in Figure 3.22. The reason of this result may be the charge effect which in addition to sieving effect with membrane pore size; played also a great role in retention of parameters that contribute in conductivity. The charge effect is due to electrostatic interactions between the ion and the membrane.

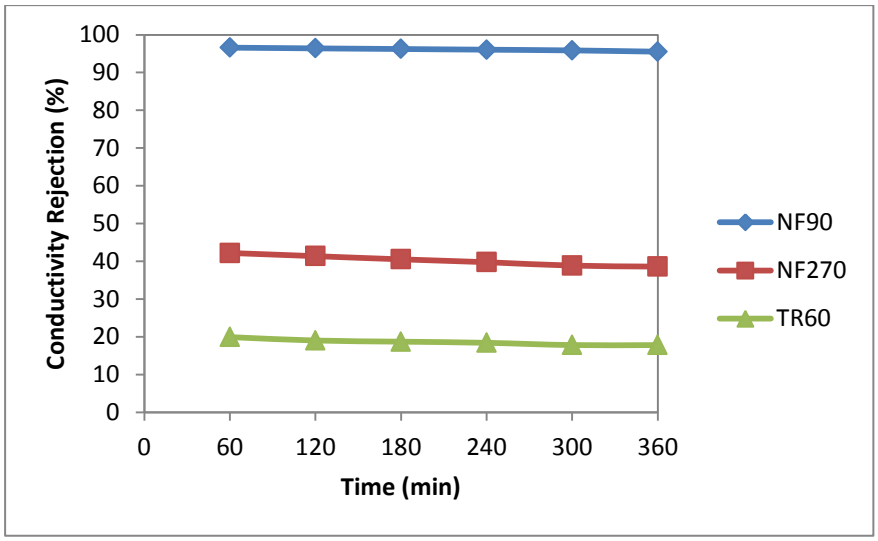


Figure 3.22 Conductivity rejections of various NF membranes vs. time plots

TDS rejection of NF membranes

Average removal efficiencies of NF90, NF270 and TR60 NF membranes were obtained about 96.5%, 41.4% and 19.4% for TDS, respectively. Best TDS removal performance was provided by NF90 membrane. TDS rejection was performed by all NF membranes with the similar average rejection rate as conductivity rejection. As depicted on Figure 3.23, TDS rejection vs. time plots show similar trends as well as conductivity rejection. Moreover, the reasons of conductivity rejection by NF membranes stand for TDS rejection as well.

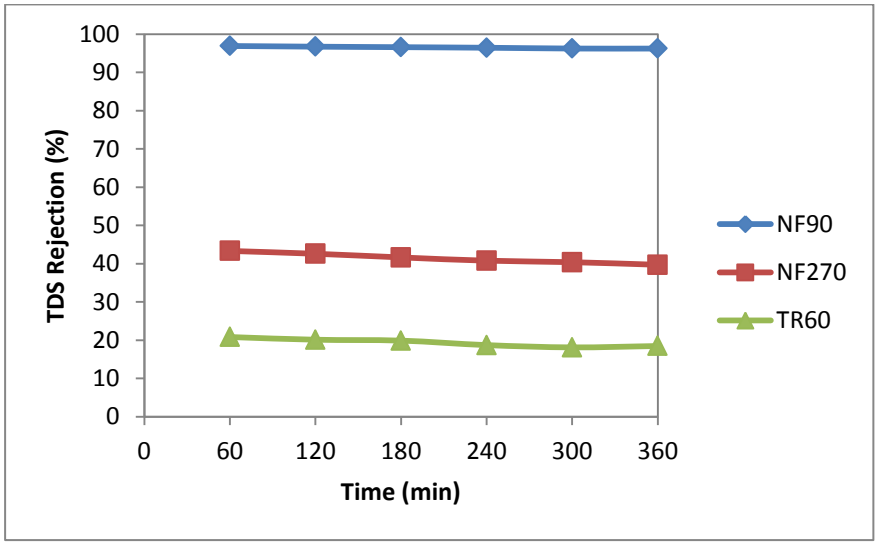


Figure 3.23 TDS rejections of various NF membranes vs. time plots

Salinity rejection of NF membranes

Salinity rejection was in the similar order with conductivity rejection given by three NF membranes. NF90 performed an average salinity rejection of 96.6% followed by NF270 membrane with an average salinity rejection of 41%. On the other hand, salinity rejection for TR60 was only 19.6%. Figure 3.24 shows salinity rejection vs. time plots for the NF membranes.

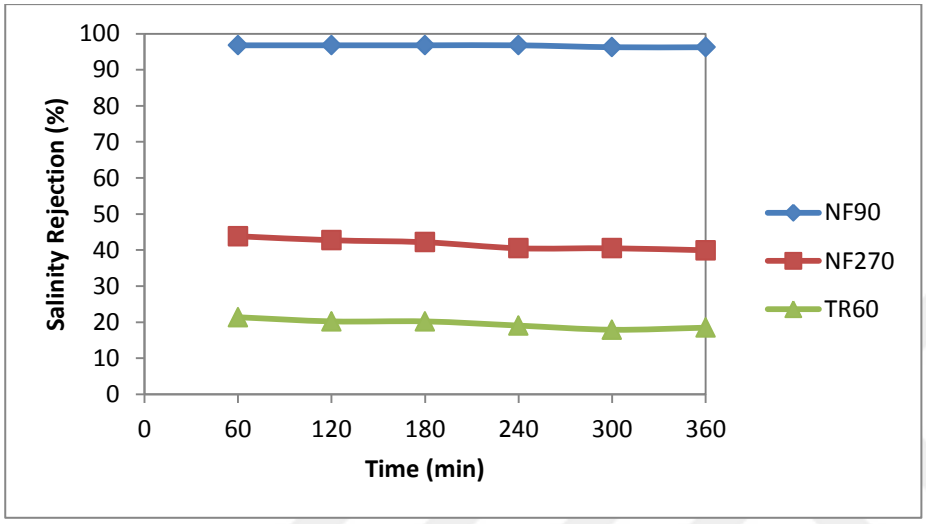


Figure 3.24 Salinity rejections of various NF membranes vs. time plots

Turbidity rejection of NF membranes

Turbidity rejection by three NF membranes from MBR treated wastewater was effective. With NF90 membrane turbidity rejection was up to 87.6% followed by TR60 with an average rejection of 68%. NF270 membrane however, showed a poor turbidity rejection with an average rejection of 52.3%. In reality, NF membranes are effective in rejection of turbidity, but when the turbidity of the feed solution is low, even the rejection becomes low. The turbidity rejection vs. time plots are shown on Figure 3.25.

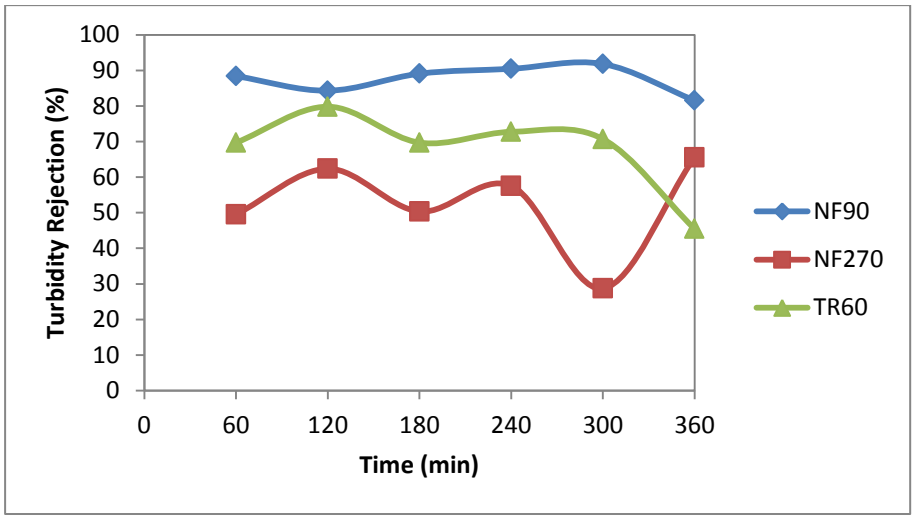


Figure 3.25 Turbidity rejections of various NF membranes vs. time plots

SiO_2 rejection of NF membranes

Rejection of silica was effective with NF90 up to an average rejection of 71.5 % while an average rejection of 18.1% and 5.7% was performed by NF270 and TR60, respectively. From these results, TR60 was found to be unable to reject silica whereas silica was successfully rejected by NF90. The silica rejection vs. time plots are shown on Figure 3.26.

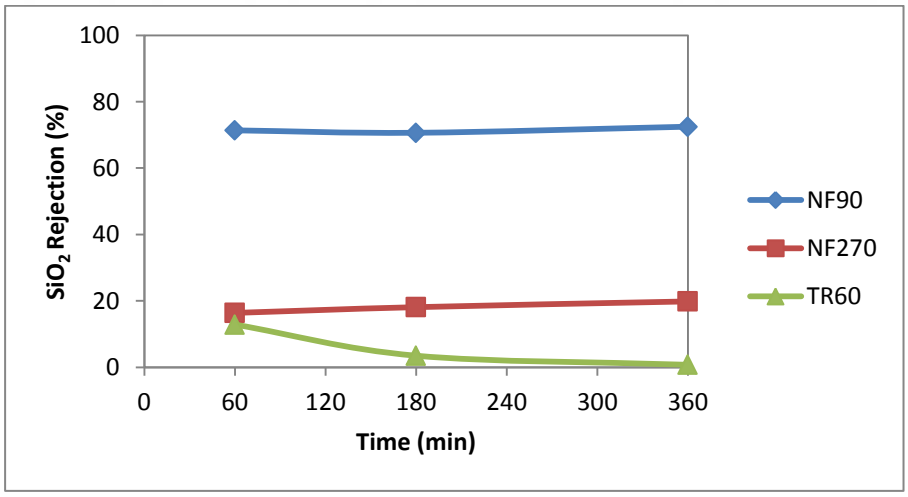


Figure 3.26 Silica rejections of various NF membranes vs. time plots

COD rejection of NF membranes

COD is rejected highly by NF90 membrane with an average rejection of 57.9% and with 38.3% by the TR60 membrane while NF270 membrane achieved

only an average rejection of 27.2%. COD rejection vs. time plots are shown in Figure 3.27.

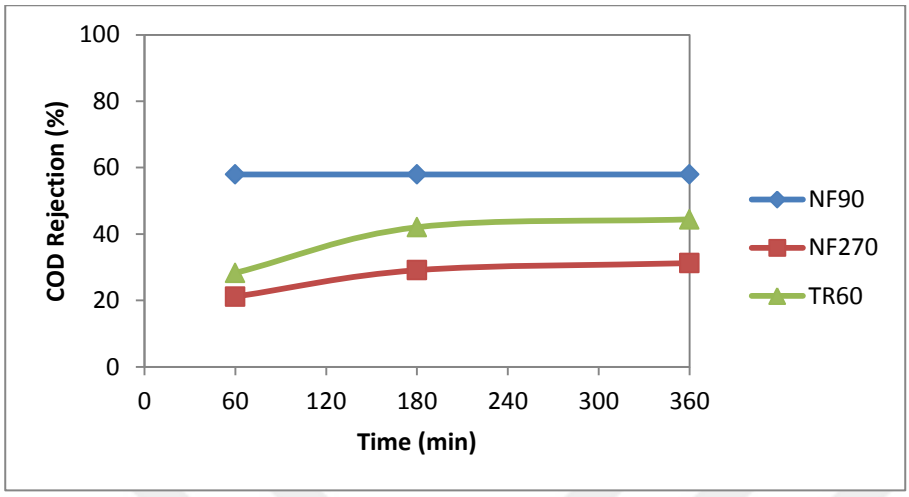


Figure 3.27 COD rejections of various NF membranes vs. time plots

Color rejection of NF membranes

All of the three NF membranes showed high rejection of color. NF membranes NF90, NF270 and TR0 were able to reject color with an average rejection of 95%, 60.8 and 83%, respectively as it is shown in Figure 3.28. It could be seen that even the TR60 membrane which shows low rejection performance for many parameters, was effective in color rejection.

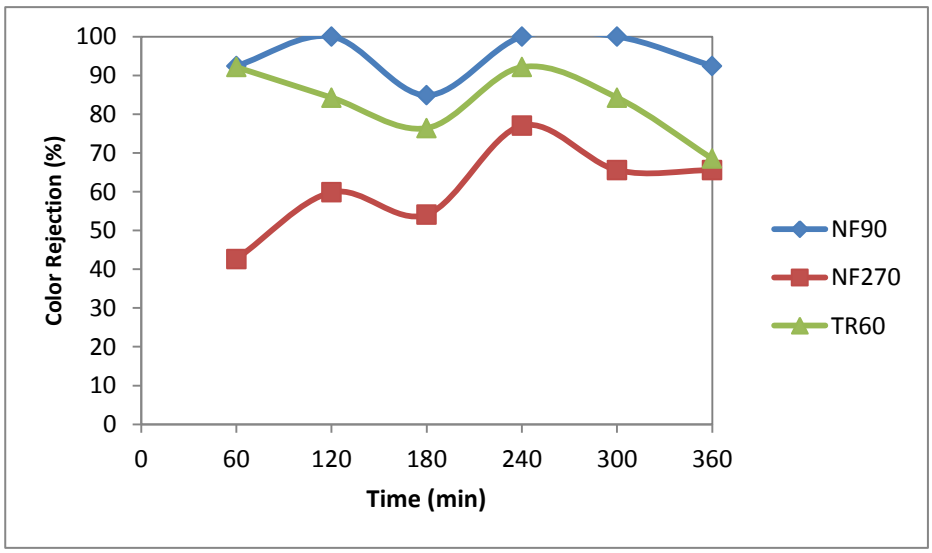


Figure 3.28 Color rejections of various NF membranes vs. time plots

TOC rejection of NF membranes

TOC is rejected highly by the NF90 and NF270 membranes with an average rejection of 98.3% and 94.8%, respectively while the TR60 membrane achieved only an average rejection of 34.3%. COD rejection vs. time plots are shown in Figure 3.29.

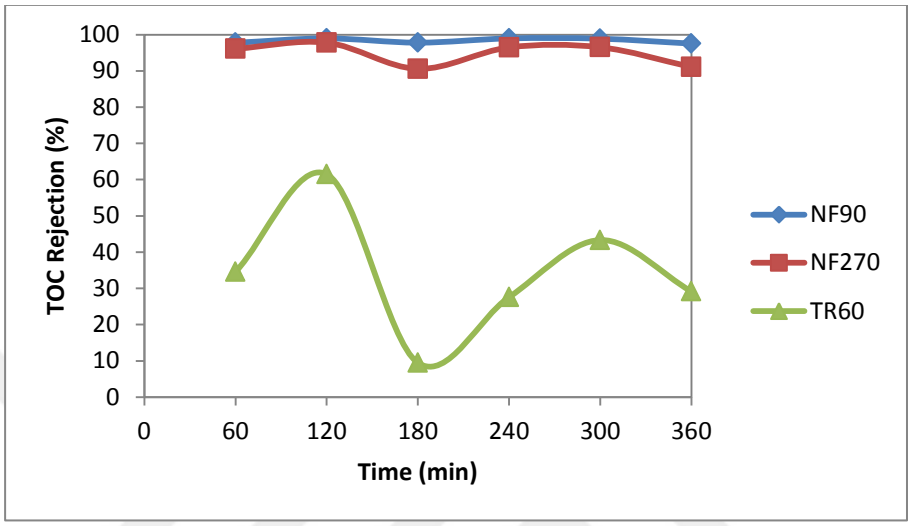


Figure 3.29 TOC rejections of various NF membranes vs. time plots

Hardness rejection of NF membranes

According to Figure 3.30, NF90 showed a good rejection with an average hardness rejection of 95.7% followed by NF270 with an average rejection of around 77%. TR60 membrane revealed an average rejection of 39.4% as shown in Figure 3.30.

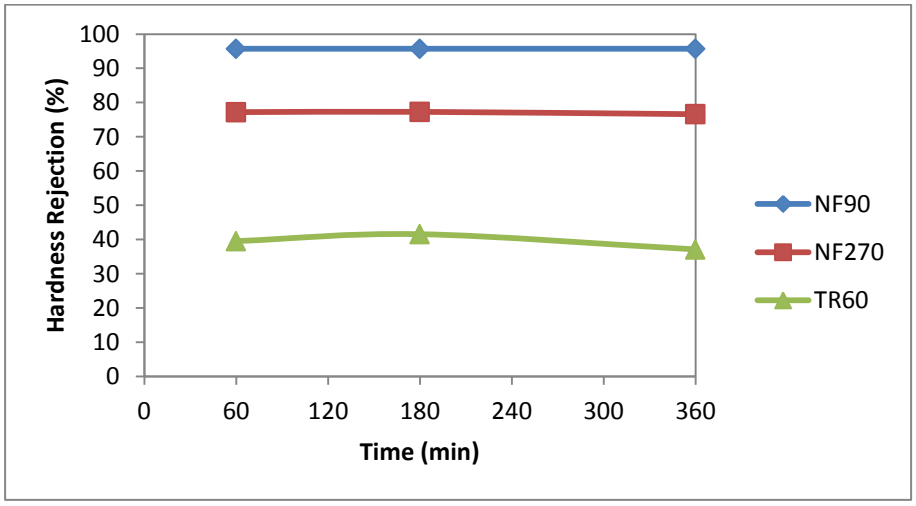


Figure 3.30 Hardness rejections of various NF membranes vs. time plots

Monovalent ion rejection of NF membranes

Na^+ rejection

NF membranes are generally known to be less effective in rejection of monovalent ions. However, NF90 membrane showed a good sodium rejection efficiency with an average rejection of 94.4%. NF270 and TR60 membranes achieved average rejections of 30% and 5.6%, respectively (Figure 3.31).

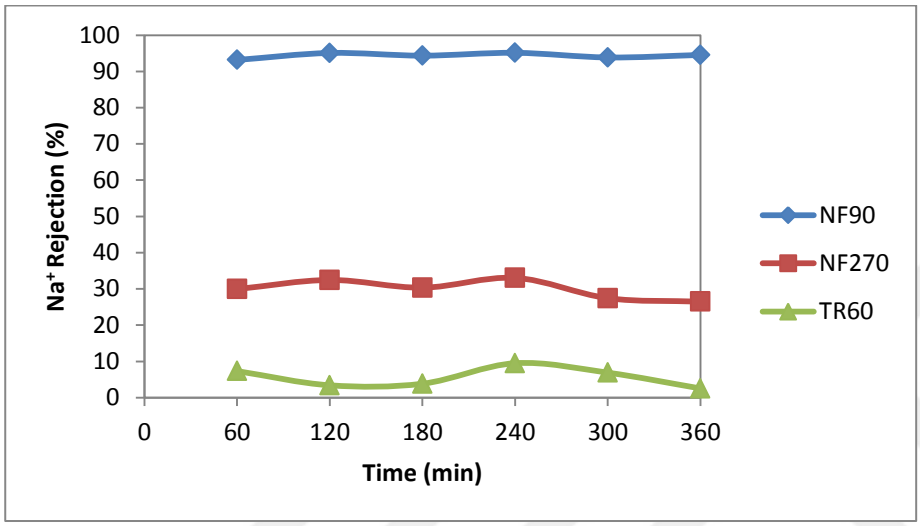


Figure 3.31 Sodium rejections of various NF membranes vs. time plots

K^+ rejection

In Figure 3.32, NF90 is seen as the best membrane in rejection of potassium with an average rejection of 97.3%. NF270 and TR60 membranes achieved average potassium rejections of 56.5% and 33.7%, respectively.

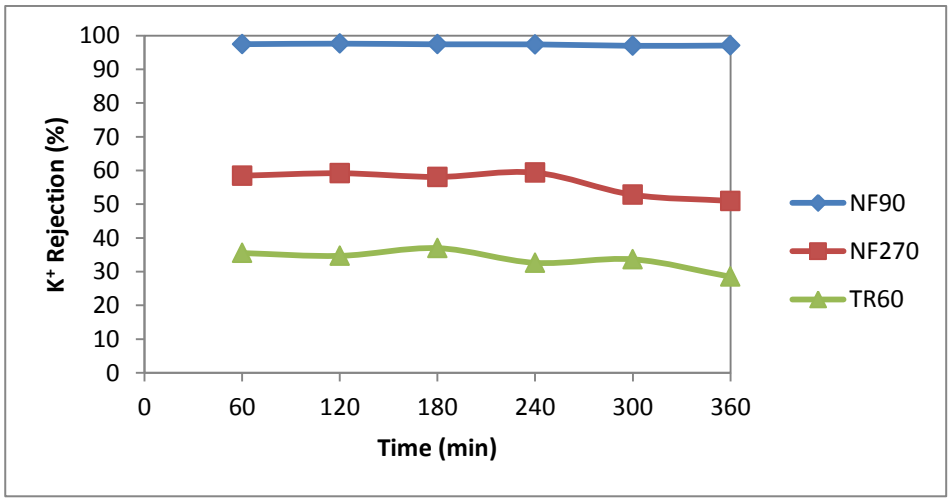


Figure 3.32 Potasium rejections of various NF membranes vs. time plots

NH_4^+- N rejection

In Figure 3.23, we can see that NF90 membrane was able to achieve an average rejection of NH_4^+-N as 95.7% and NF270 membrane achieved a 42.4% NH_4^+-N rejection. TR60 membrane is the worst membrane with an average NH_4^+-N rejection of 14.4%. Sieving effect may be the main phenomena involved in rejection of ammonium ions that has small ionic radius which favors easier transfer across the membrane.

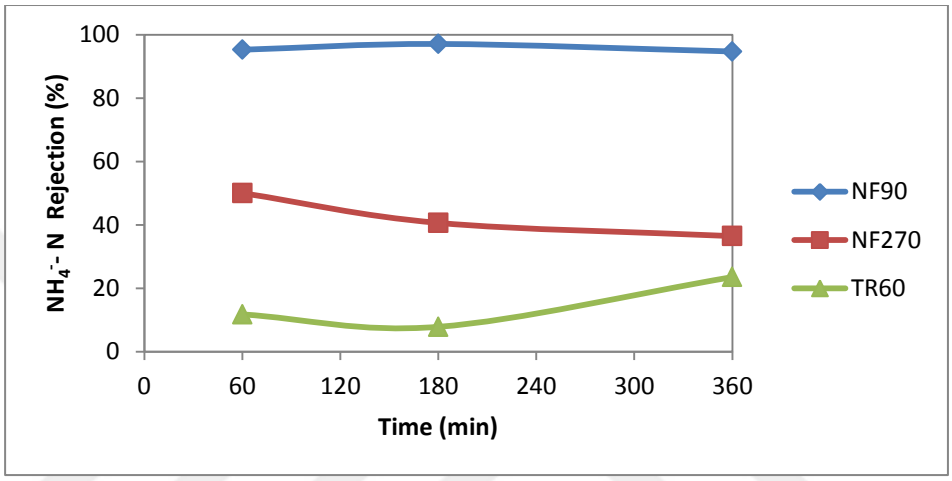


Figure 3.33 Ammonium- N rejections of various NF membranes vs. time plots

Cl^- rejection

Rejection efficiency of chloride ion was found to be sufficient for NF90 with an average rejection of 95.6%. NF270 membrane performed an average chloride rejection of 19.9%, TR60 was found to be unable to reject chloride ion which was only an average rejection of 0.8%. The low rejection for chloride by NF270 and TR60 membranes can be attributed to the small ionic radius of chloride ion (nm) and large pore size of NF membranes (Paugam *et al*, 2004). Chloride ion rejection vs. time plots for all NF membranes used are depicted on Figure 3.34.

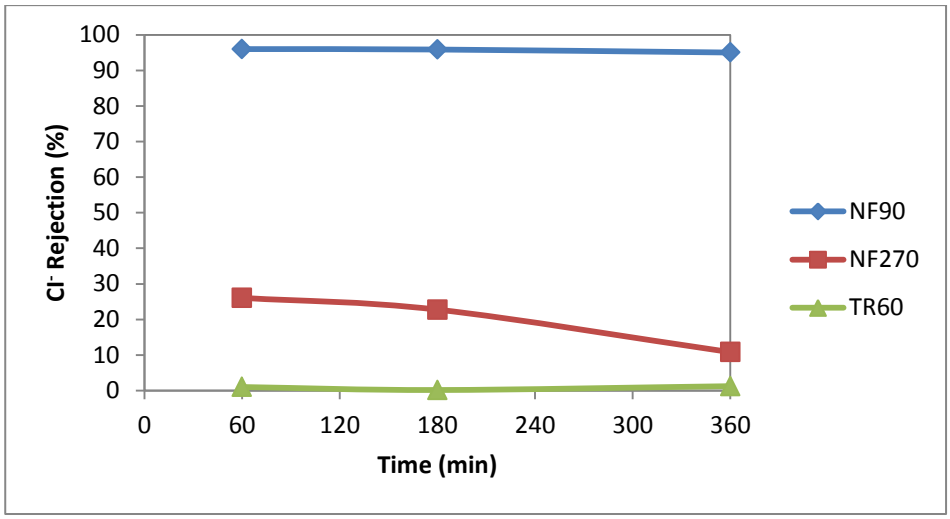


Figure 3.34 Chloride ion rejections of various NF membranes vs. time plots

NO_3^--N rejection

The rejection of nitrate was not very high. For instance, it was rejected by TR60 membrane up to an average rejection of 2.1%. NF90 and TR60 membranes achieved nitrate rejections of 62.9% and 29.7%, respectively. The low rejection for nitrate by NF membranes can be attributed to the small ionic radius of nitrate ion (0.189 nm) (Paugam et al, 2004). Therefore, the size effect governs nitrate ion to transfer across the membrane. Figure 3.35 shows nitrate rejection vs. time plots for each NF membranes.

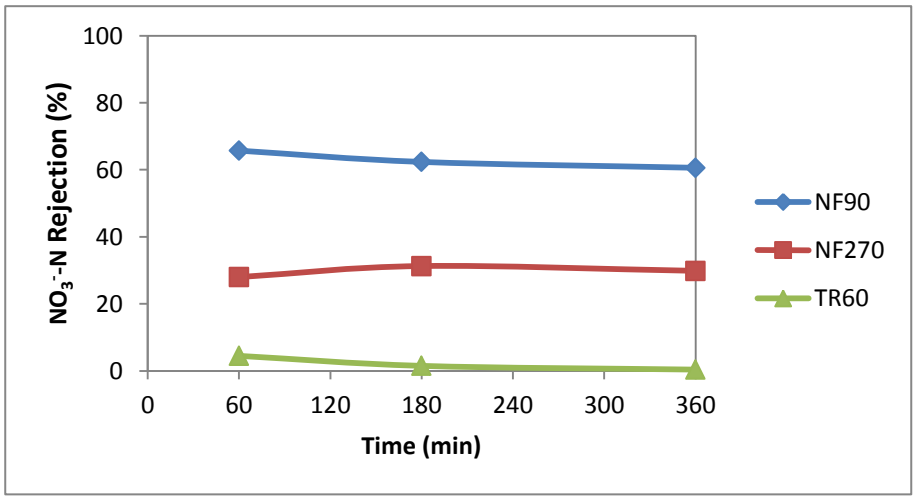


Figure 3.35 Nitrate ion rejections of various NF membranes vs. time plots

NO_2^--N rejection

Nitrite ions rejection was performed by NF90 membrane with the highest average nitrite rejection of 78.2%. The other NF membranes, NF270 and TR60 achieved average nitrite rejections of 11% and 10.7%, respectively. As it is also a monovalent ion, nitrite rejection was governed by the same phenomena as for nitrates described above. Nitrite-nitrogen rejection vs. time plots for all NF membranes used are depicted on Figure 3.36.

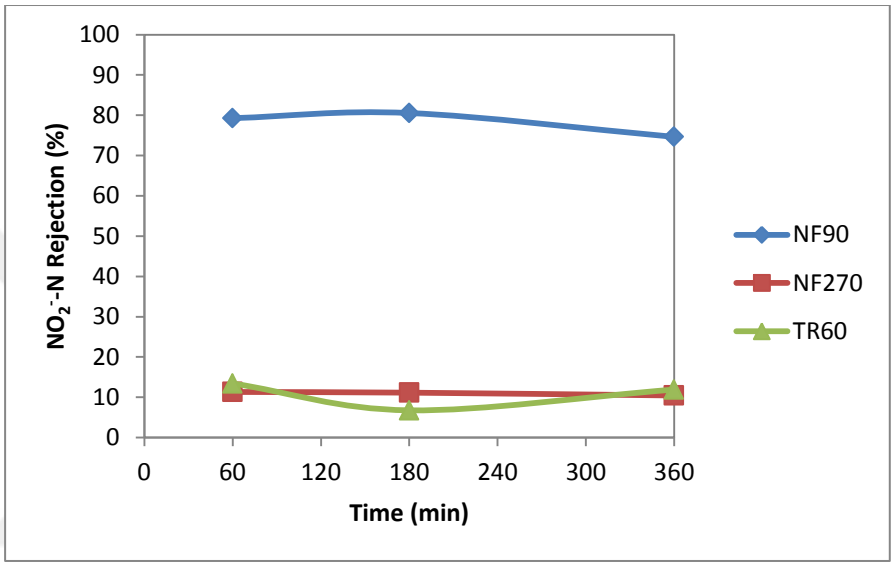


Figure 3.36 Nitrite ion rejection of various NF membranes vs. time plots

HCO_3^- rejection

Rejection of bicarbonate anions, on the contrary to other monovalent ions, was effective with NF membranes. NF90 for example achieved a better rejection with the highest average rejection of 95.7%. The NF270 and TR60 membranes were also effective for bicarbonate rejection with the average rejections of 77% and 39.4%, respectively (Figure 3.37).

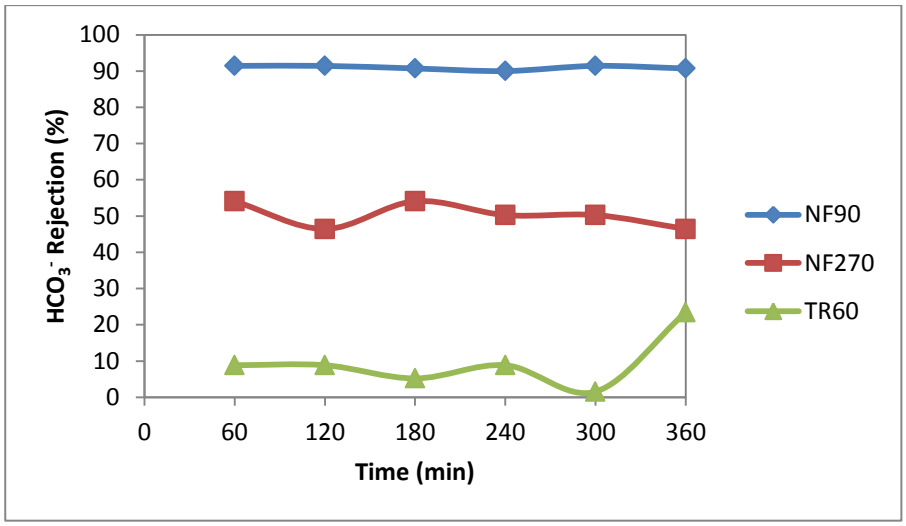


Figure 3.37 Bicarbonate ion rejections of various NF membranes vs. time plots

Multivalent ion rejection of NF membranes

Ca^{2+} rejection

Calcium rejection was highly effective by NF90 membrane with average rejections of 95.7%. The NF270 and TR60 membranes were also effective for calcium rejection with the average rejections of 73.3% and 50.2%, respectively (Figure 3.38). According to these results, sieving and charge effects might be the main effects which governed calcium rejection. NF90 with more hydrophilic character was more effective than other NF membranes.

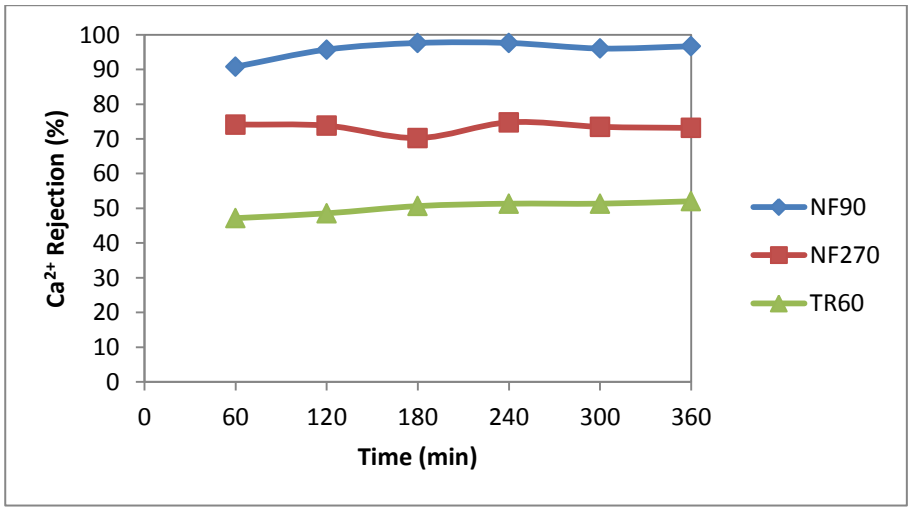


Figure 3.38 Calcium ion rejections of various NF membranes vs. time plots

Mg^{2+} rejection

Magnesium ion as it is a divalent ion was effectively rejected by all NF membranes. NF90 exhibited the highest rejection up to an average rejection of 99.9%, followed by NF270 membrane with an average rejection of 84.6% for magnesium ion. Revealed lower rejection with an average rejection of 28.1% as shown in Figure 3.39.

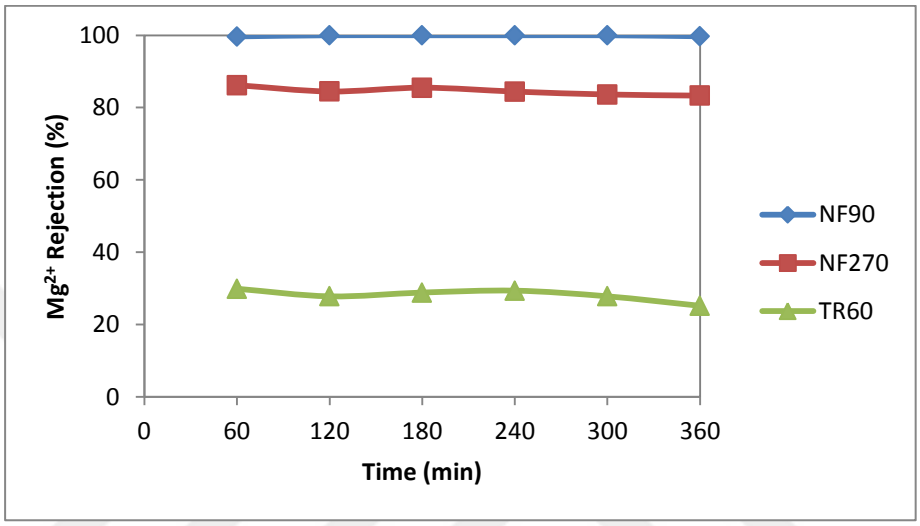


Figure 3.39 Magnesium ion rejections of various NF membranes vs. time plots

SO_4^{2-} rejection

Average rejections for sulfate ion are %93.2, 93.1% and %80.6 for NF90, NF270 and TR60 membranes, respectively (Figure 3.40). All NF membranes showed a high rejection performance regarding to sulfate rejection. This behavior is attributed to the sizes of divalent ions which generally are bigger than those of monovalent ions. The charge played also an important role in rejection of sulfate ion since an increase of anion charge leads to an increase of electrostatic interactions with charged membranes.

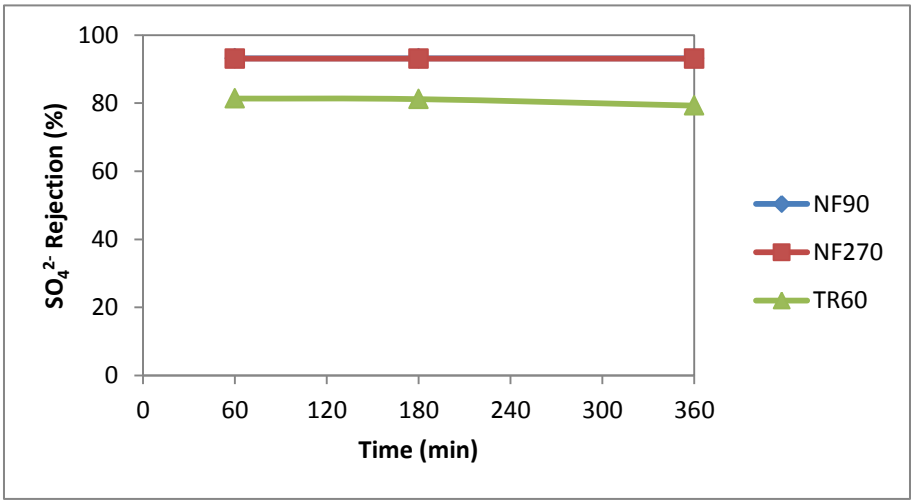


Figure 3.40 Sulfate ion rejections of various NF membranes vs. time plots

PO_4^{2-} rejection

All NF membranes tested tend to show low performance in rejection of phosphate with average rejections of 47.4%, 32.0% and 14.5% for NF90, NF270 and TR60 membranes, respectively. The rejection of phosphate ions cannot be explained only by multivalent ion size which is larger than monovalent ones but also by their charge effect. Indeed, an increase of anion charge leads to an increase of electrostatic interactions with membranes. The phosphate rejection vs. time plots have the same trends as obtained for other anions as it is depicted in Figure 3.41.

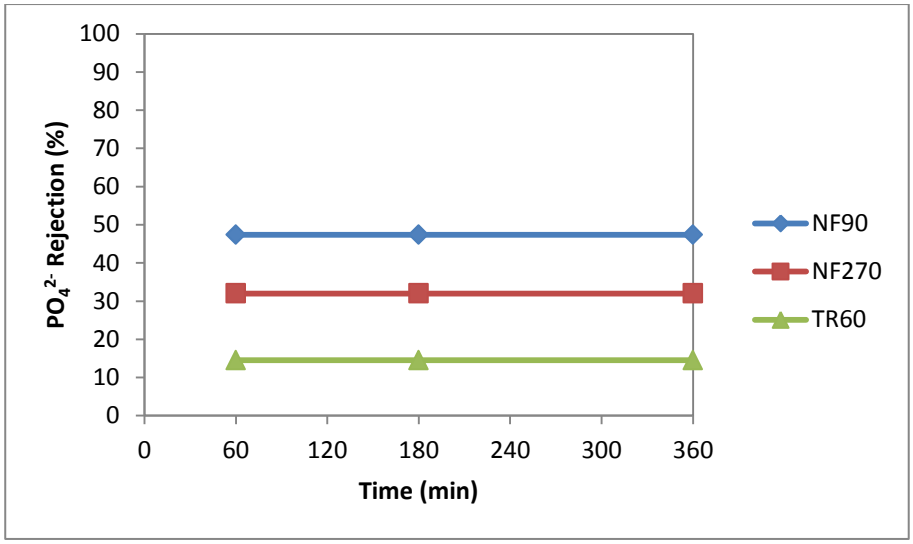


Figure 3.41 Phosphate ion rejections of various NF membranes vs. time plots

3.2.1.2 Test with RO membranes

Permeate flux of RO membranes

The performances of BW30 and AG reverse osmosis membranes in terms of permeate fluxes were depicted on Figure 3.42. As can be seen, these two membranes exhibited similar permeate fluxes at the same operating pressure which is 20 bar. Permeate fluxes of these two membranes slightly increased in the first three hours of studies. For the last three hours of studies, permeate fluxes reached steady state. The reason of slightly increases of flux could be due to the use of virgin membrane. In first three hours, pores of virgin membranes were enlarged by the applied pressure. The average permeate fluxes of BW30 and AG RO membranes were found as 65.9 and 62.7 L/m^{2}h, respectively.

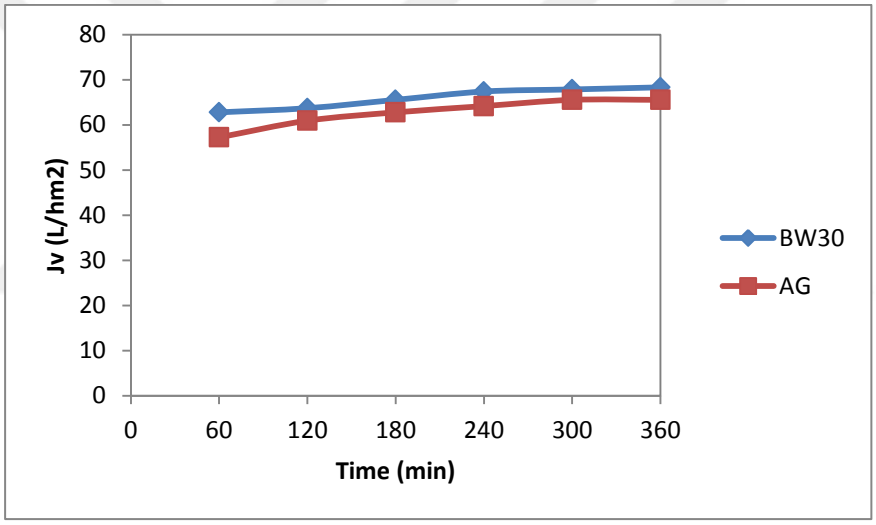


Figure 3.42 Permeate fluxes of RO membranes vs. time plots

TDS rejection of RO membranes

In Figure 3.43, TDS was highly rejected by all RO tested membranes up to an average TDS rejection of 98.1% and 97.1% by BW30 and AG, respectively.

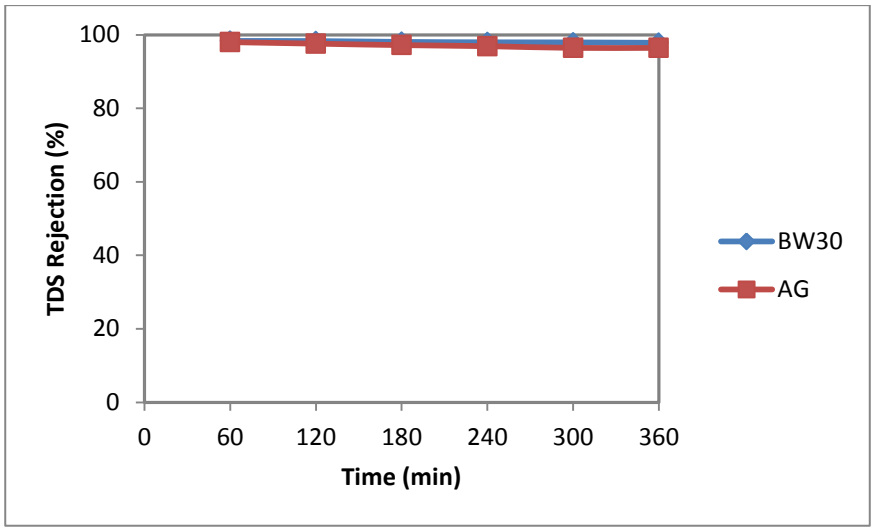


Figure 3.43 TDS rejections of RO membranes vs. time plots

Conductivity rejection of RO membranes

The results for conductivity rejections exhibited on Figure 3.44 revealed that both membranes have similar rejection performance with a small difference. The average rejections of conductivities were 95.8% and 97.6% for BW30 and AG membranes, respectively. The reason of their high rejection of conductivities is that these membranes have properties of high salt rejection as it can be seen in Tables 2.3. These membranes showed similar rejection for conductivity and TDS as well.

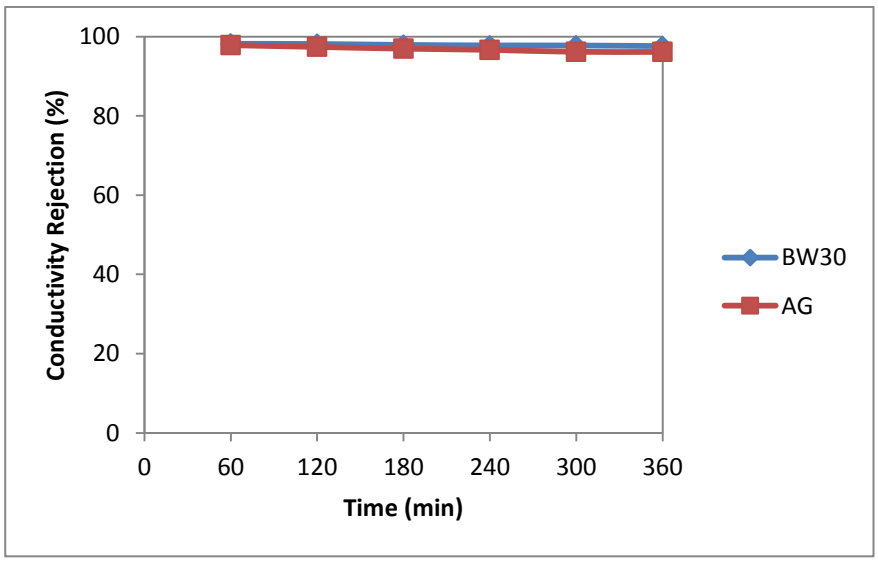


Figure 3.44 Conductivity rejections of RO membranes vs. time plots

Salinity rejection of RO membranes

The results for salinity rejections depicted on Figure 3.45 revealed that both membranes have similar rejection performance but with a small difference. Salinity was also highly rejected by both membranes with an average rejection of 98.2% for BW30 membrane and 97.2% for AG membrane.

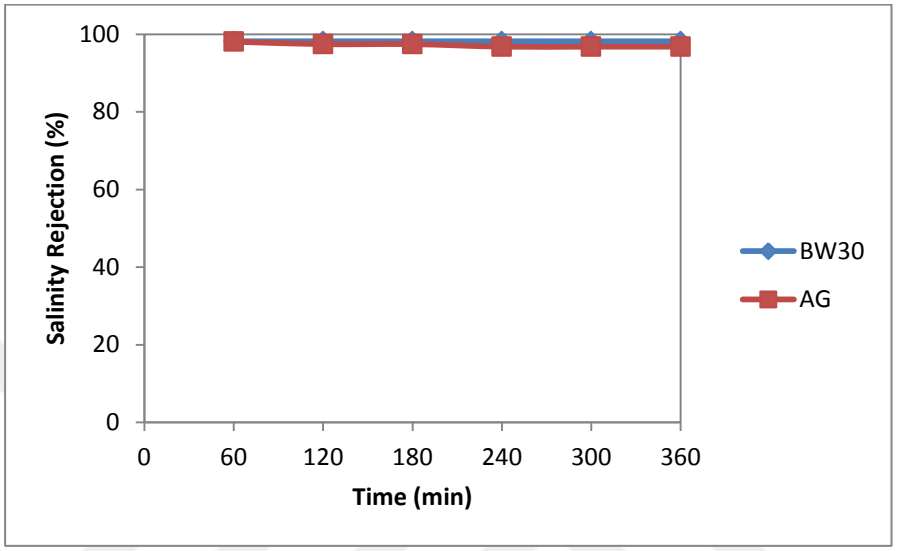


Figure 3.45 Salinity rejections of RO membranes vs. time plots

Turbidity rejection of RO membranes

Turbidity rejection by RO membranes from MBR effluent was effective with BW30 membrane by 79.7% of rejection whereas AG membrane achieved an average rejection of 74.7%. Turbidity rejection vs. time plots for RO membranes are shown in Figure 3.46.

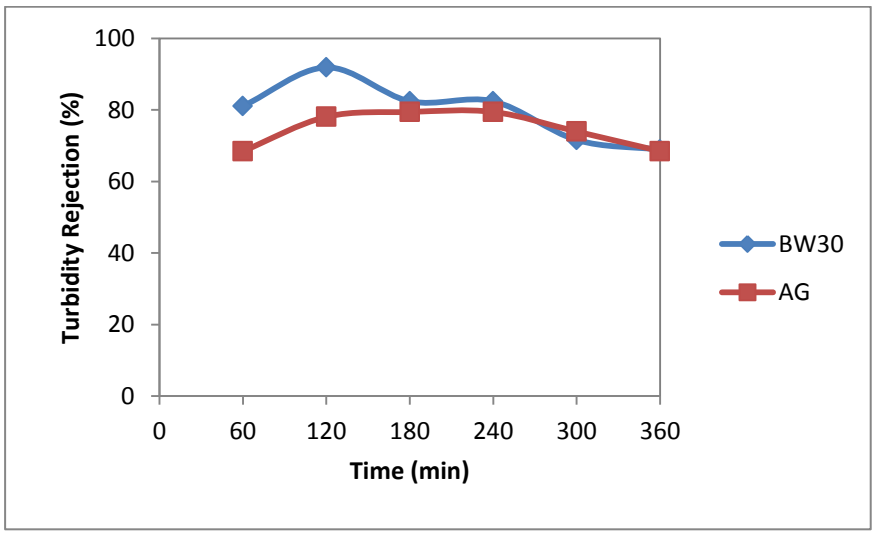


Figure 3.46 Turbidity rejections of RO membranes vs. time plots

SiO_2 rejection of RO membranes

Rejection of silica was effective with both RO membranes. These membranes performed similar average rejections (82.3% and 82.5% for silica removal by BW30 and AG membranes, respectively) as it is shown on Figure 3.47.

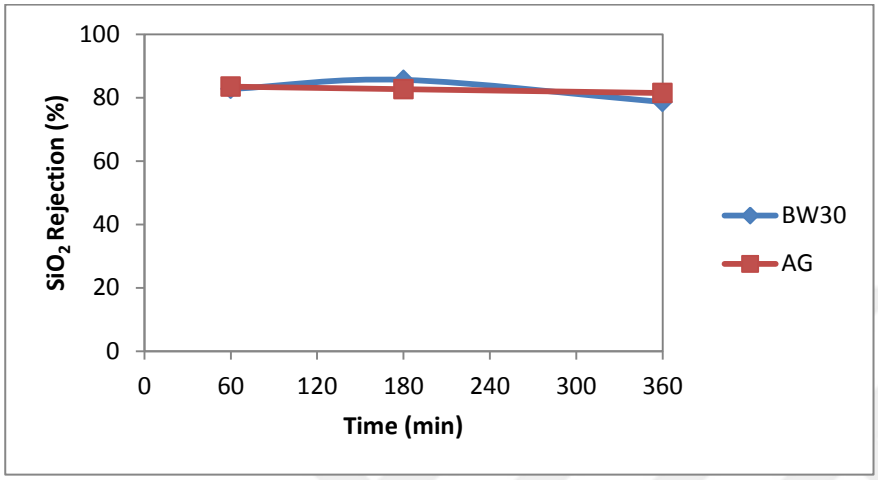


Figure 3.47 SiO_2 rejections of RO membranes vs. time plots

COD rejection of RO membranes

COD rejection of BW30 and AG membranes were similar at 20 bar with average rejections of 53% and 55.6%, respectively. COD rejection vs. time is plotted on Figure 3.48.

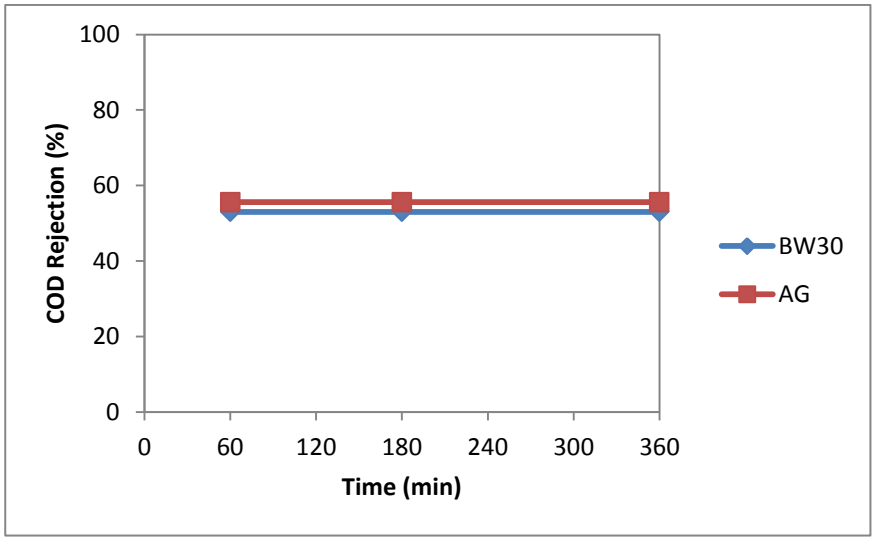


Figure 3.48 COD rejections of RO membranes vs. time plots

Color rejection of RO membranes

Investigated membranes revealed the similar rejection performance for color. BW30 membrane showed an average color rejection of 82.9% while AG membrane gave 84.2% of color rejection. Therefore, both membranes were able to reject the color highly from MBR effluent. Color rejection vs. time plots are depicted on Figure 3.49.

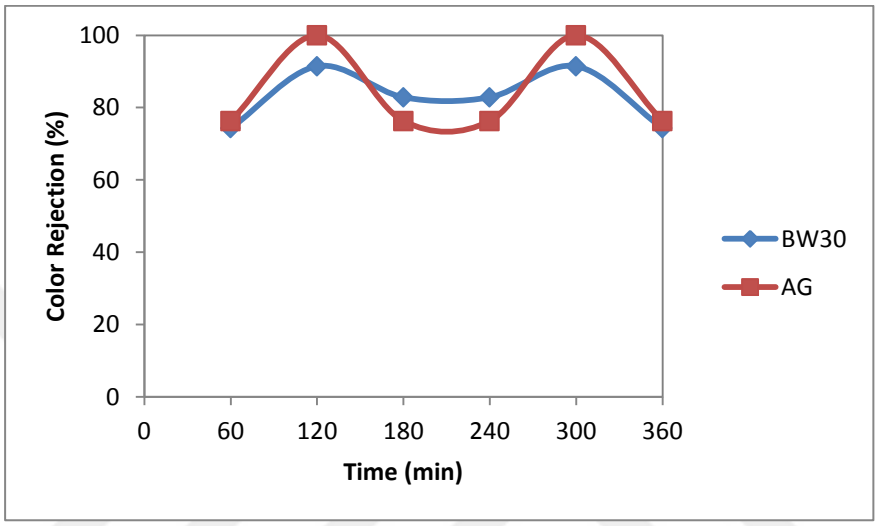


Figure 3.49 Color rejections of RO membranes vs. time plots

TOC rejection of RO membranes

As shown on Figure 3.50, TOC was also highly rejected by BW30 and AG membranes. Average rejections of 96.7% and 98.3% were achieved by BW30 and AG membranes, respectively.

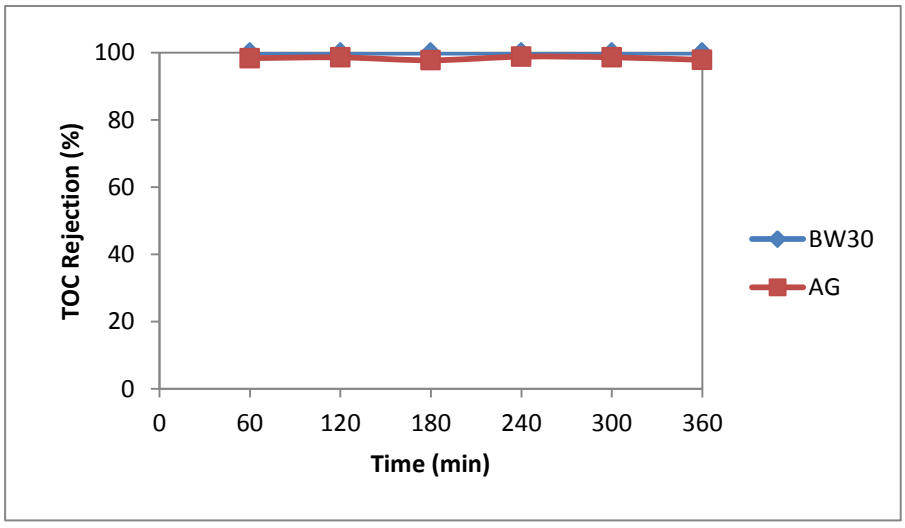


Figure 3.50 TOC rejections of RO membranes vs. time plots

Hardness rejection of RO membranes

According to Figure 3.51, both RO membranes showed a similar performance with an average hardness rejection (96.2% for BW30 and 96% for AG membrane).

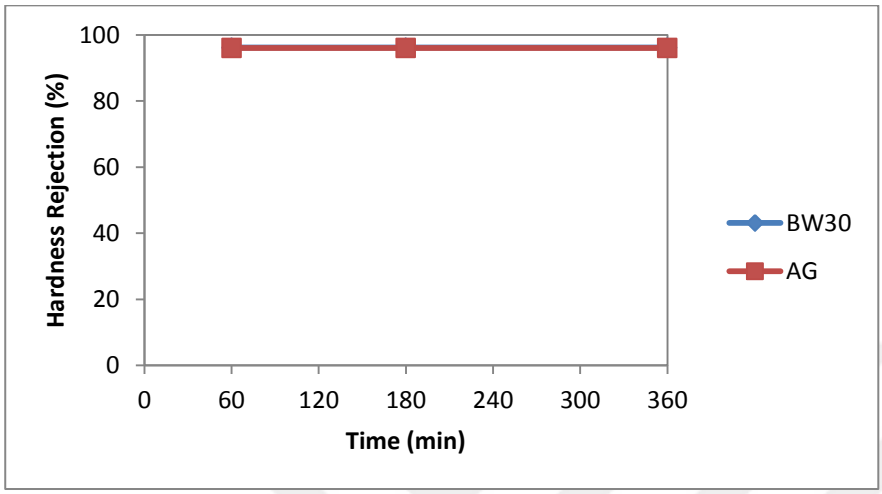


Figure 3.51 Hardness rejections of RO membranes vs. time plots

Monovalent ion rejection of RO membranes

Na^+ rejection

Although monovalent ions are generally difficult to be rejected from water by membrane process, RO membranes have been proven to be efficient in rejection of monovalent ions. In this study, sodium ions were highly rejected by BW30 membrane with an average rejection of 96.4% and an average rejection of 95.4% by AG membrane. Sodium rejection vs. time plots of RO membranes are depicted in Figure 3.52.

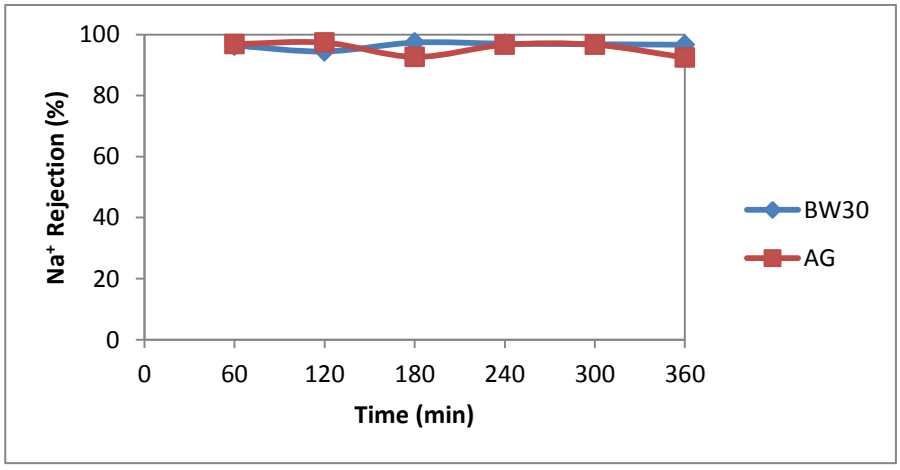


Figure 3.52 Sodium rejections of RO membranes vs. time plots

K^+ rejection

RO membranes tested in this study demonstrated similar performance in rejection of potassium ions. BW30 and AG membranes revealed a high potassium rejection by achieving average rejections of 98.3% and 97.4%, respectively. Potassium rejection vs. time plots for RO membranes are depicted in Figure 3.53.

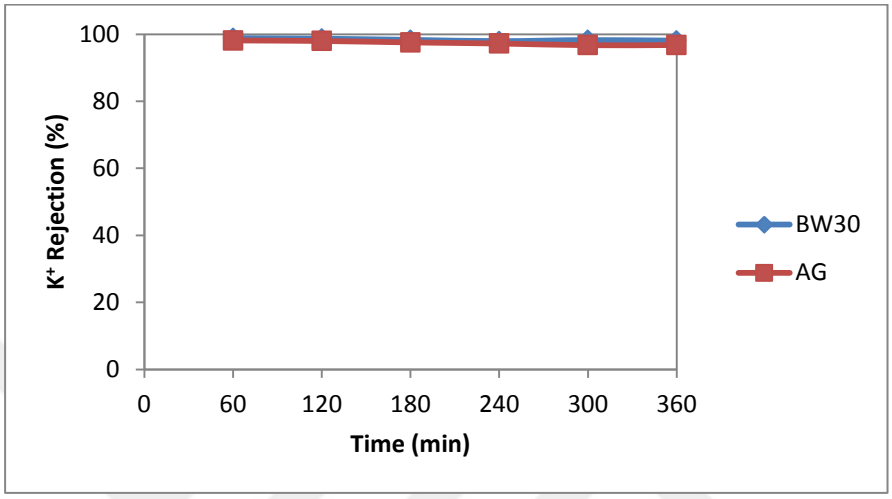


Figure 3.53 Potassium rejections of RO membranes vs. time plots

NH_4^- -N rejection

In Figure 3.54, we can see that ammonium was weakly rejected by AG membrane with an average rejection of 33.3%. BW30 membrane was able to achieve an average rejections of 51.6%. Electrostatic interactions may be the main phenomena involved in rejection of ammonium ions.

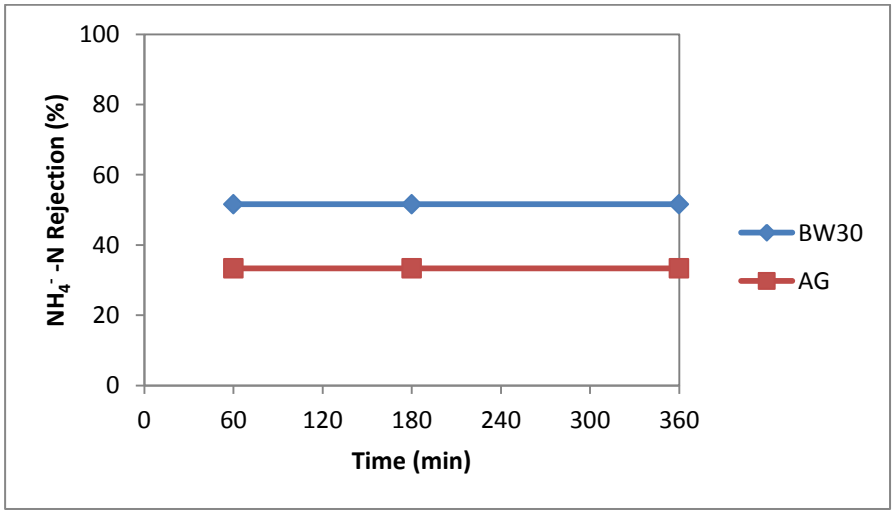


Figure 3.54 Ammonium-N rejections of RO membranes vs. time plots

Cl⁻ rejection

In Figure 3.55, it is shown that both RO membranes performed good efficiency in chloride rejection. The average rejections were achieved by BW30 membrane with 97.9%. AG membrane showed similar performance with average rejection of 96.7%.

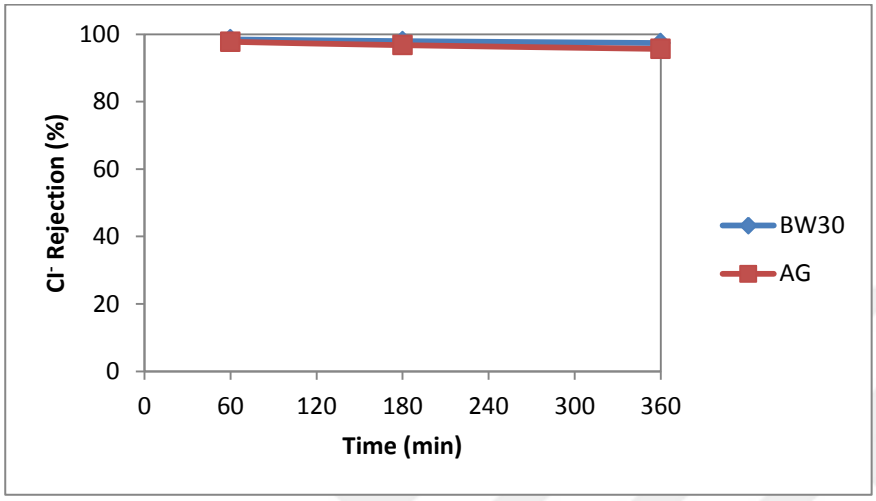


Figure 3.55 Chloride rejections of RO membranes vs. time plots

NO_3^- -N rejection

Nitrate-N rejection was effective with BW30 membrane with an average rejection of 67.9%. AG membrane achieved an average nitrate-N rejection of 66.7% (Figure 3.56).

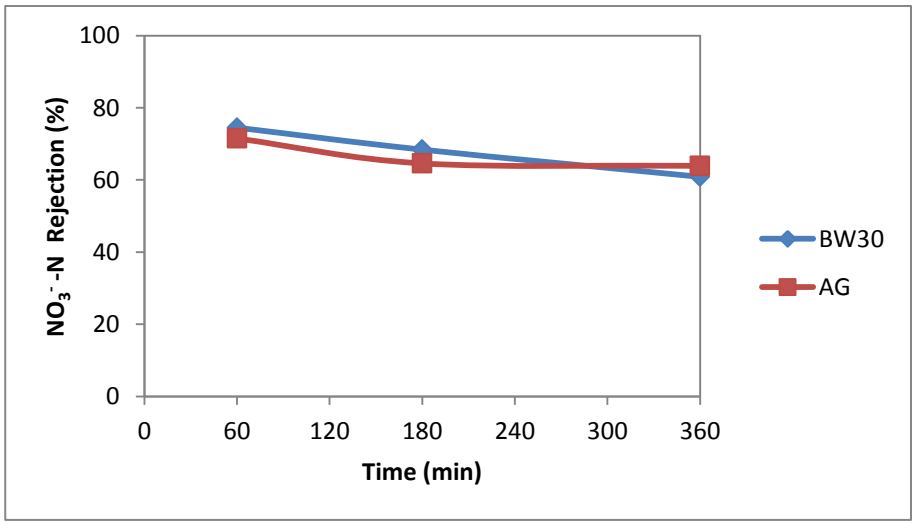


Figure 3.56 Nitrate-N rejections of RO membranes vs. time plots

NO_2^- -N rejection

According to the results depicted on Figure 3.57, nitrite-N rejection was successfully effective with average nitrite-nitrogen rejections of 96% and 93.9% for BW30 and AG membranes, respectively.

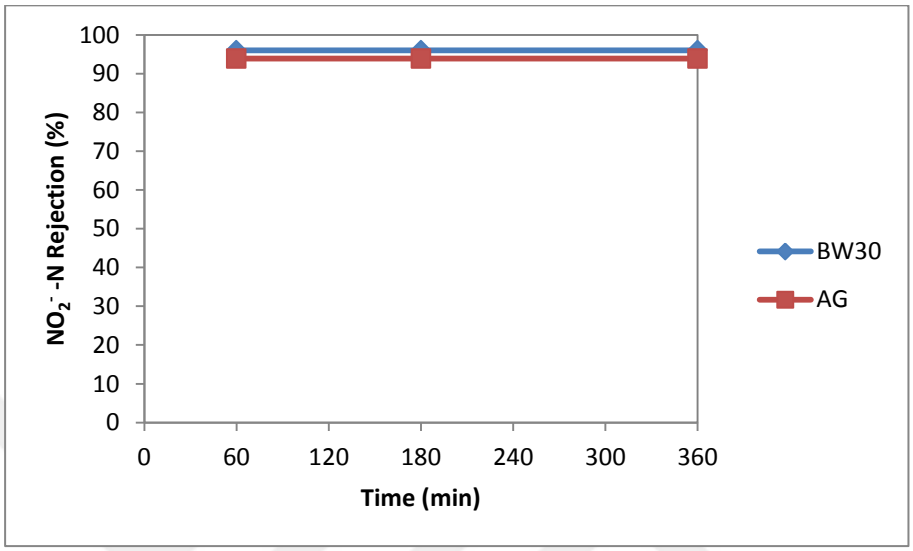


Figure 3.57 Nitrite-N rejections of RO membranes vs. time plots

HCO_3^- rejection

As demonstrated on Figure 3.58, bicarbonate rejection was high by all tested RO membranes with similar efficiencies. BW30 membrane showed average rejections of 88.7%. AG membrane revealed an average rejection of 91.5%. Thus, RO membranes were found to be good enough towards bicarbonate rejection.

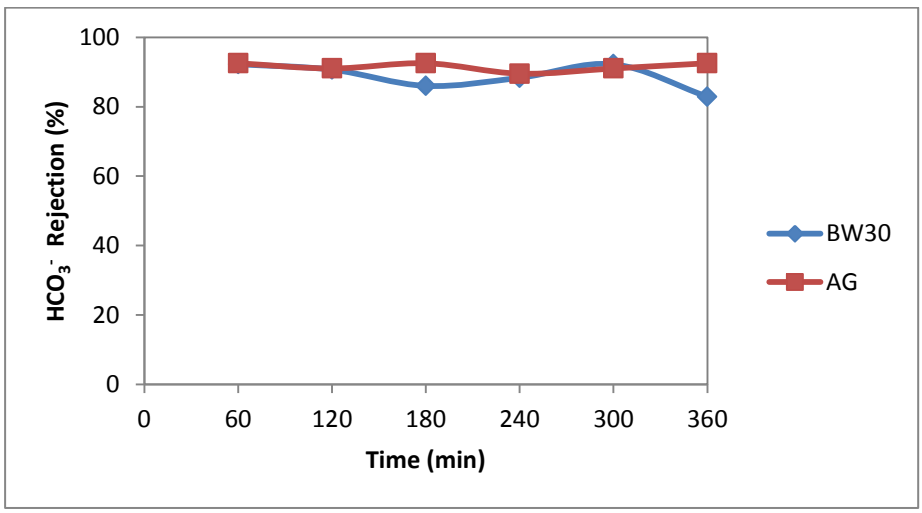


Figure 3.58 Bicarbonate rejections of RO membranes vs. time plots

Multivalent ion rejections of RO membranes

Ca^{2+} rejection

Results obtained with BW30 and AG membranes showed that calcium ion rejections of these membranes were similar with average rejections of 93.9% and 95.3%, respectively. Calcium rejection vs. time plots for RO membranes are depicted in Figure 3.59.

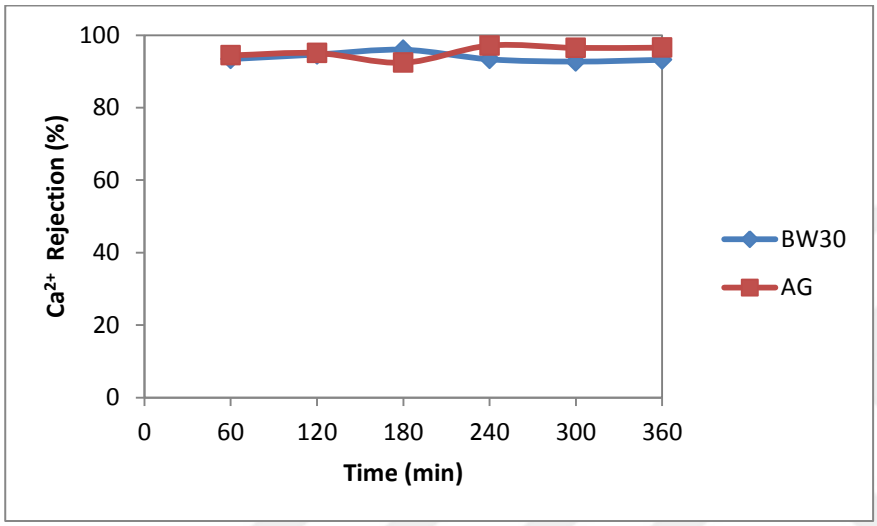


Figure 3.59 Calcium ion rejections of RO membranes vs. time plots

Mg^{2+} rejection

Figure 3.60 describes how magnesium was highly rejected with similar efficiencies by both RO membranes. If magnesium concentration in permeate for BW30 and AG membranes were analyzed, the concentrations were under the detection limit of AAS. Then, magnesium rejection of all RO membranes were assumed as around ≈100%.

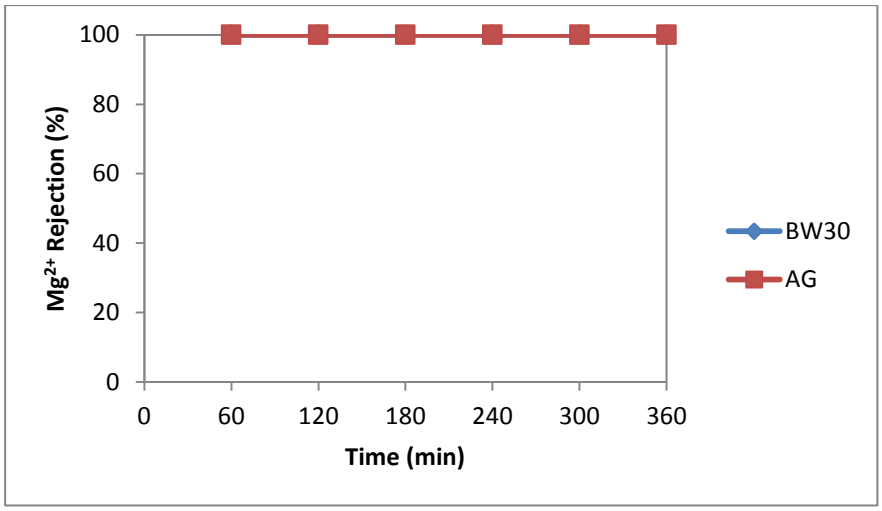


Figure 3.60 Magnesium ion rejections of RO membranes vs. time plots

SO_4^{2-} rejection

Sulfate rejection was highly performed by both RO membranes. Since sulfate is a divalent ion, it was easily rejected by RO membranes. These membranes demonstrated the similar performance with average sulfate rejections of 93% and 92.8% for BW30 and AG membranes, respectively (Figure 3.61).

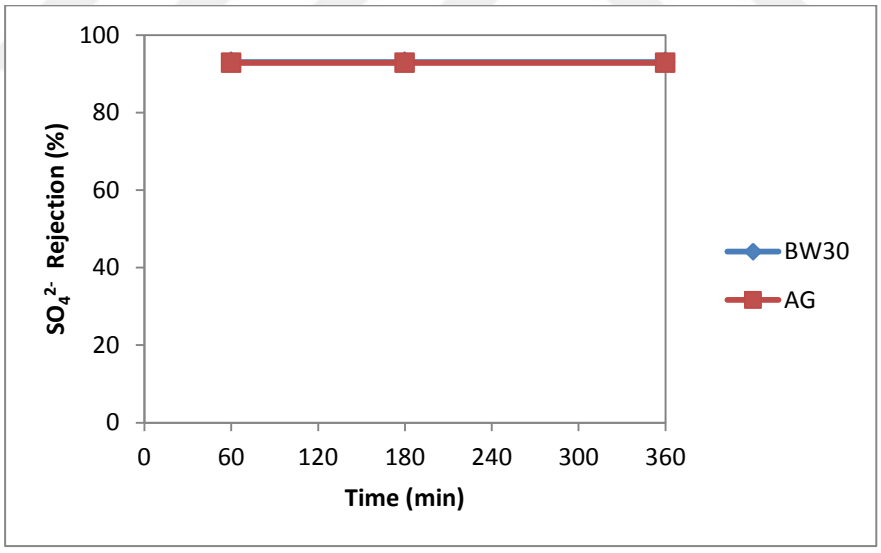


Figure 3.61 Sulfate ion rejections of RO membranes vs. time plots

PO_4^{2-} rejection

Both RO membranes tested show similar performance in rejection of phosphate with average rejections of more than 42.9% and 40.5% for BW30 and AG, respectively.

Both RO membranes tested were able to reduce phosphate under the detection limit of our colorimeter. This means that the rejections were more than percentage given above. This rejection of phosphate ions cannot be explained only by multivalent ion size which is larger than monovalent one but also by their charge effect. Indeed, an increase of anion charge leads to an increase of electrostatic interactions with membranes. The phosphate rejection vs. time plots are depicted in Figure 3.62.

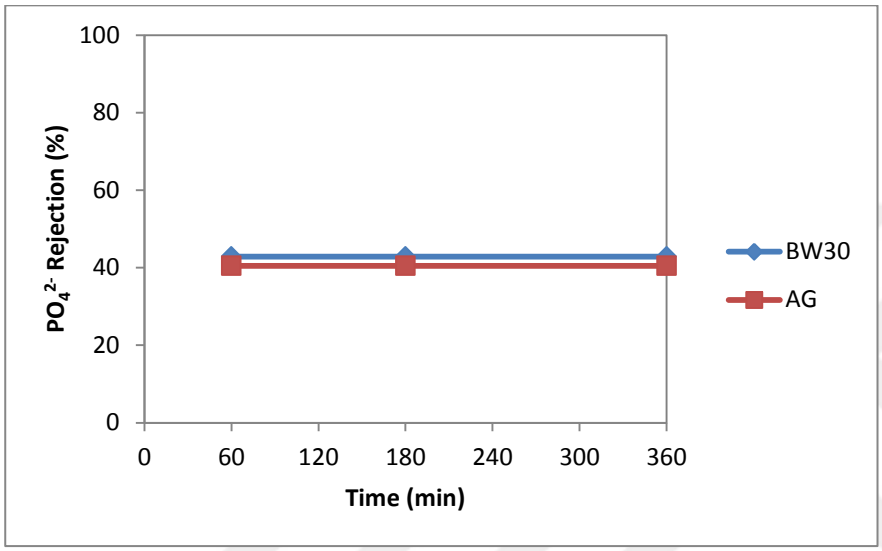


Figure 3.62 Phosphate ion rejections of RO membranes vs. time plots

3.2.1.3 Comparison of NF and RO membrane performances

During the studies quality of permeates which obtained by using NF and RO membranes was investigated with various parameters such as total dissolved solid (TDS), salinity, conductivity, pH, turbidity, chemical oxygen demand (COD), total suspended solid (TSS), color, Na^{+}, Ca^{+2}, K^{+}, Mg^{+2}, HCO_3^{-}, SO_4^{2-}, Cl^{-} PO_4-P, NH_4-N, NO_3-N, NO_2-N, total nitrogen (TN), $CaCO_3$ hardness, total organic carbon (TOC) and SiO_2 concentrations.

Quality of permeates for all membranes are listed in Table 3.2 with average values of all parameters.

Table 3.2 Permeate qualities of NF and RO membranes

Parameters	NF Membranes			RO Membranes	
	NF90	**NF270**	**TR60**	**BW30**	**AG**
TDS (mg/L)	64.0	1037	1373	31.3	44.5
Conductivity (µS/cm)	137.8	2054.3	2693.3	66.75	94.8
pH	6.23	7.23	7.67	6.41	5.97
Salinity (ppt)	0.06	1.05	1.39	0.03	0.043
TSS (mg/L)	1.83	2.5	5.67	1	1.2
Color (mg/L Pt-Co)	1.33	6.8	2.17	2	1.3
Turbidity (NTU)	0.18	0.6	0.317	0.15	0.19
HCO_3^- (mg/L)	19.4	99.7	190.5	22.2	17.4
NO_3-N (mg/L)	2.76	4.9	2.62	1.11	1.5
NO_2-N (mg/L)	0.05	0.507	0.416	<0.015	<0.015
PO_4-P (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05
NH_4-N (mg/L)	0.03	0.06	0.044	0.02	0.015
COD (mg/L)	<5	6.87	6.51	<5	<5
Hardness-$CaCO_3$ (mg/L)	<17.8	120.2	267.6	<17.8	<17.8
SiO_2 (mg/L)	1.94	5.93	6.03	1.1	1.08
SO_4^{2-} (mg/L)	<40	<40	112.3	<40	<40
Cl^- (mg/L)	36.1	677.3	823.7	15.1	22.67
TN (mg/L)	< 20	< 20	< 20	< 20	< 20
Na^+ (mg/L)	28.7	363	434	19.2	23.7
K^+ (mg/L)	1.47	24.2	32.1	0.85	1.32
Ca^{2+} (mg/L)	6.71	41.3	71.7	8.8	6.5
Mg^{2+} (mg/L)	0.03	4.01	13.7	0	0
TOC (mg/L)	0.63	1.36	25.6	1.42	0.69

Same feed water which was MBR effluent was used for all membrane performance investigation studies with batch mode. For proper comparison of each membrane, quality of MBR effluent should be same.

According to the investigation, within the NF membranes, NF270 had highest permeate flux which was 50.4 L/m^2h at 10 bar of operating pressure. During the studies, permeate flux of NF90 and NF270 membranes increased gradually. On the other hand, permate flux of TR60 membrane decreased by time. This could be the reason of membrane fouling. Fouling problem on TR60 membrane surface appeared earlier than NF90 and NF270 membranes.

At 20 bar of operating pressure, RO membranes had similar permeate flux with small difference which were 65.9 L/m^2h for BW30 and 62.7 L/m^2h for AG. During the studies permeates flux of BW30 and AG membranes increased

gradually. One of the reaon could be the use of virgin membrane. By the force of 20 bar of operating pressure, pores of virgin RO membranes could be enlarged and permeates flux increased.

With the increases of fluxes, water recovery of membranes also incresed. During the studies at 10 bar of operating pressure, obtained average recoveries of NF membranes were 50.2%, 56.0% and 51.8% for NF90, NF270 and TR60 membranes, respectively. At 20 bar of operating pressure, average percent recovery of RO membranes were 64.0% for BW30 and %62.3 AG membranes.

Among the NF membranes, NF90 membrane showed best removal efficiencies according to conductivity, salinity and total dissolved solid within NF membranes. BW30 and AG membranes had similar removal performance according to these parameters. Especially for salinity rejection, RO membranes were highly efficient.

According to cation rejection, NF90 membrane among NF membranes, BW30 and AG RO membranes showed good removal performance. Removal rates indicated that NF membranes had better removal for divalent ions than monovalent ions and RO membranes were effective for rejections of all mono and multivalent ions.

The difference in performance of the membranes observed during this work is attributed to the properties of the investigated membranes. Those properties are pore size, membrane surface charge, hydrophobic/hydrophilic characteristics and the structure or composition of the active layer of the membranes.

The water quality data obtained in this study were compared with National Irrigation Water Standards which is listed in Table 2.8. Comparion of NF and RO permates according to national irrigation water standards is given in Table 3.3.

Table 3.3 Comparison of NF and RO permeates with national irrigation water standards

		NF Membranes			RO Membranes	
Parameters		**NF90**	**NF270**	**TR60**	**BW30**	**AG**
SAR		3.04	14.4	12.3	1.8	2.6
Sodium (mg/L)		28.7	363	434	19.2	23.7
Chloride (mg/L)		36.1	677.3	823.7	15.1	22.67
TDS (mg/L)		64.0	1037	1373	31.3	44.5
EC (dS/m)		0.14	2.05	2.65	0.07	0.09
Salinity		1st class	3rd class	3 rd class	1st class	1st class
Infiltration		3 rd class	2nd class	2 nd class	3 rd class	3 rd class
Specific ion toxicity	**Na**	1st class D	2 nd class D	2 nd class D	1st class D	1st class D
	Cl	1st class Y,D	2 nd class D	2 nd class D	1st class Y,D	1st class Y,D
	B	-	-	-	-	-

(Y: Surface irrigation D: Sprinkler irrigation; -: Not determined)

NF270 and TR60 membrane permeates were satisfied 3rd class for salinity and 2nd class for other parameters. On the other hand, NF90, BW30 and AG permeates provide 1st class water for all parameters except for infiltration. Infiltration problem was caused by unbalanced removal of the Na^{+}, Ca^{2+}, and Mg^{2+} which impact on the SAR values. Mixing RO/NF permeates with MBR effluent in appropriate ranges may have suitable composition values and good permeability for agricultural irrigation.

Table 3.4 Theoretical mixture of MBR effluent and NF permeates

Membrane	**MBR effluent ratio**	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
	NF permeate ratio	**1**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**	**0**
NF90	SAR	3.0	3.7	4.4	**5.1**	5.8	6.5	7.16	7.8	8.5	9.2	9.9
	EC_w (dS/m)	0.14	0.48	0.82	**1.16**	1.50	1.84	2.19	2.53	2.87	3.21	3.55
NF270	SAR	14.4	14.0	13.6	13.1	12.7	12.3	**11.8**	11.4	11.0	10.6	10.1
	EC_w (dS/m)	2.05	2.19	2.33	2.47	2.61	2.75	**2.89**	3.02	3.16	3.30	3.44
TR60	SAR	12.3	12.0	**11.7**	11.5	11.2	10.9	10.6	10.4	10.1	9.8	9.5
	EC_w (dS/m)	2.69	2.75	**2.82**	2.88	2.94	3.00	3.06	3.12	3.19	3.25	3.31

For each NF and RO membrane permeates, theoretical mixing ratios of MBR effluent and NF/RO permeates were calculated and shown in Tables 3.4 and 3.5 and Figures 3.63 and 3.64.

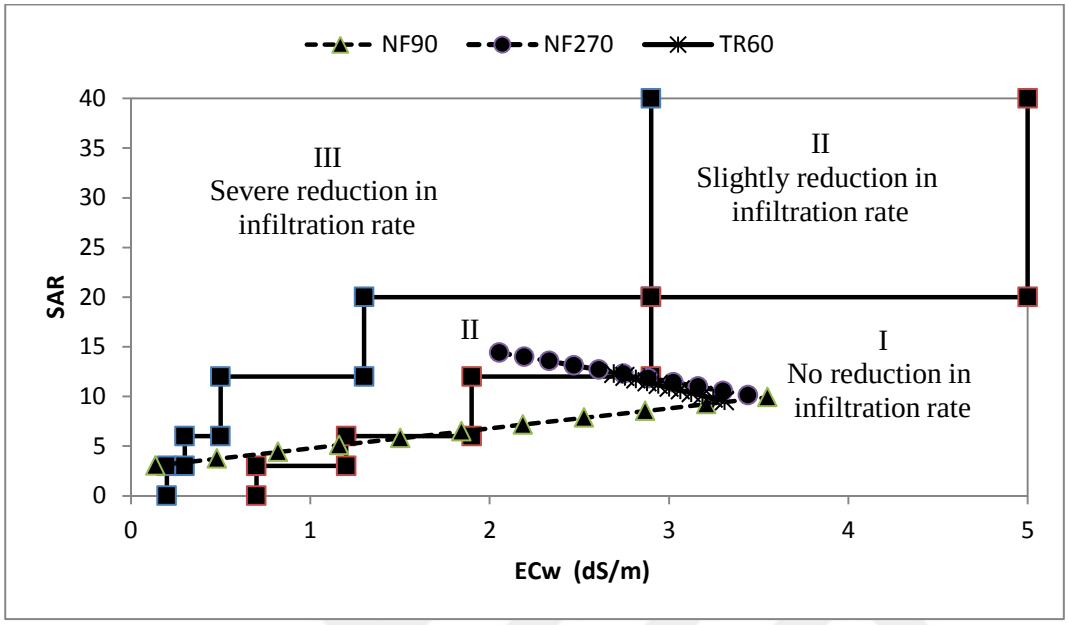


Figure 3.63 SAR and conductivity values of theoretical MBR effluent and NF permate mixtures

For the determination of optimum theoretical mixture to solve infiltration problem, salinity and specific ion toxicity were also taken into consideration. Because the mixing of MBR effluent with permeates shows adverse effect for salinity and specific ion toxicity, optimum mixing ratio should be found for irrigation.

According to all these considerations, optimum theoretical mixture of MBR effluent and permeates obtained from NF membranes were 0.2:0.8 for TR60, 0.6:0.4 for NF270 and 0.3:0.7 for NF90 membranes.

Table 3.5 Theoretical mixture of MBR effluent and RO permeates

Membrane	**MBR effluent ratio**	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
	NF permeate ratio	**1**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**	**0**
BW30	SAR	1.8	2.7	3.6	4.6	**5.5**	6.4	7.4	8.3	9.2	10.2	11.1
	EC_w (dS/m)	0.07	0.38	0.69	0.99	**1.30**	1.61	1.92	2.23	2.54	2.85	3.16
AG	SAR	2.6	3.4	4.2	5.1	**5.9**	6.7	7.6	8.4	9.2	10.1	10.9
	EC_w (dS/m)	0.09	0.39	0.68	0.97	**1.26**	1.55	1.84	2.14	2.43	2.72	3.01

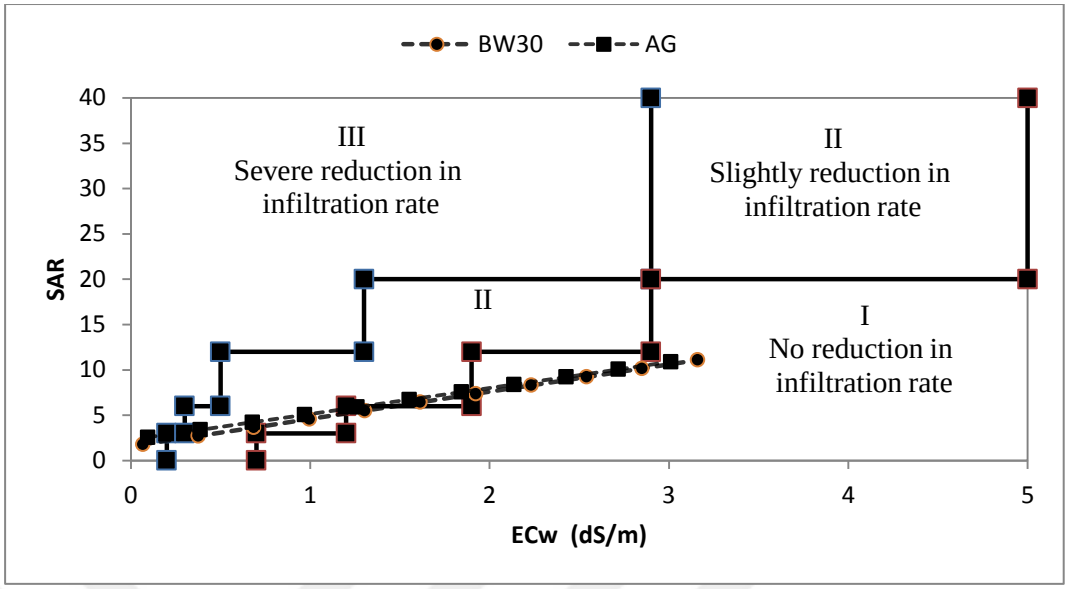


Figure 3.64 SAR and conductivity values of theoretical MBR effluent and RO permate mixtures

For RO membrane, optimum theoretical mixture of MBR effluent and permeates was 0.4:0.6 for BW30 and AG membranes.

After the determination of optimum theoretical mixtures, comparison of these mixtures with national irrigation standards is given in Table 3.6.

Table 3.6 Comparison of optimum theoretical mixtures with national irrigation water standards

		NF membranes		**RO membranes**		
Parameters		**NF90**	**NF270**	**TR60**	**BW30**	**AG**
Optimum theoretical ratio* (*MBR eff. : NF/RO perm.)		0.3:0.7	0.6:0.4	0.2:0.8	0.4:0.6	0.4:0.6
ECw (µS/cm)		1161.5	2885.7	2816.6	1304.1	1260.9
TDS (mg/L)		594.3	1476.7	1438.9	666.9	643.2
SAR		5.10	11.8	11.7	5.5	5.9
ECw (dS/m)		1.16	2.89	2.82	1.30	1.26
Na (mg/L)		172.7	456.0	439.1	227.4	222.4
CI (mg/L)		272.6	778.2	825.1	301.3	289.2
Salinity		2^{nd} class	2^{nd} class	2^{nd} class	2^{nd} class	2^{nd} class
Infiltration		1^{st} class	1^{st} class	1^{st} class	1^{st} class	1^{st} class
Specific ion toxicity	**Na**	2^{nd} class; D 3^{rd} class; Y	2^{nd} class; D 3^{rd} class; Y	2^{nd} class; D 3^{rd} class; Y	2^{nd} class; D 3^{rd} class; Y	2^{nd} class; D 3^{rd} class; Y
	CI	2^{nd} class; D,Y	2^{nd} class; D 3^{rd} class; Y	2^{nd} class; D 3^{rd} class; Y	2^{nd} class; D,Y	2^{nd} class; D,Y
	B	-	-	-	-	-

(Y: Surface irrigation D: Sprinkler irrigation; -: Not determined)

In addition to irrigation usage, quality of product water obtained NF and RO membranes was also investigated and compared with the standards of cooling and boiling feed water for industrial usage. Also, reuse of product water as process water in paper and textile industries was discussed.

Significant quantities of water are needed for power generation and cooling applications. Treated wastewater could be used as a water source for these applications. With the reuse of wastewater, natural water sources can be also protected. Water quality requirements of cooling and boiler water are based on prevention or minimisation of scaling, corrosion and fouling. Boiler water quality requirements are more stringent than those for cooling water. Because steam production required relatively higher temperature and pressure conditions. Hence it requires a higher quality feedwater (Asano *et al.*, 2007).

Obtained permeates from NF90, NF270 and TR60 NF membranes are compared to required water quality for boiler feedwater and cooling water application (Table 3.7).

Table 3.7 Comparison of NF permeates quality for using boiler feed water and cooling water (Judd and Jefferson, 2013)

Water Quality Parameter (all as mg/L unless otherwise stated)	**Permeate Quality of NF Membranes**			**Cooling Water**	**Boiler feedwater** (range is based on operating presssures)
	NF90	**NF270**	**TR60**		
Hardness, mg/L as $CaCO_3$	<17.8	120.2	267.6	600	0.07 - 350
pH	**6.23**	7.23	7.67	6.9 - 9.0	7 - 10
Total dissolved solids (TDS)	64.0	**1037**	**1373**	500	200 - 700
Total Suspended Solids (TSS)	1.83	2.5	5.67	100	0.5 - 10
Turbidity, NTU	0.18	0.6	0.317	50	
Carbonaceus Biochemical Oxygen Demand ($C\text{-}BOD_5$)	-	-	-	25	1 - 50
Chemical Oxygen Demand (COD)	<5	6.87	6.51	75	1 - 5
Ammonia, mg/L as N	0.03	0.06	0.044	1	0.1
Phosphate, mg/L as P	<0.05	<0.05	<0.05	4	
Aluminium				0.1	0.01 - 5
Bicarbonate	19.4	99.7	**190.5**	24	48 - 170
Chloride	36.1	**677.3**	**823.7**	500	Variable
Iron	-	-	-	0.5	0.05 - 1
Manganese	-	-	-	0.5	0.01 - 0.3
Silica	1.94	5.93	6.03	50	0.7 - 30
Sulphate	<40	<40	112.3	200	Variable

- **:** not measured

According to Table 3.7, NF90 permeate is suitable for cooling application according to all parameters except for pH value. In addition to this, NF90

permeate could be use as a boiler feedwater after pH adjusment. NF270 and TR60 permeates do not satisfy cooling water requirements because of the TDS, magnesium and calcium values. They are also not suitable for steam generation and do not to meet many parameters of boiler feedwater requirements.

In Table 3.8, possibility of reuse of RO permeates as a cooling and boiler water was investigated.

Table 3.8 Comparison of NF permeates qualities for using power generation and cooling water (Judd and Jefferson, 2013)

Water Quality Parameter (all as mg/L unless otherwise stated)	**Permeate Quality of RO Membranes**		**Cooling Water**	**Boiler feedwater** (range is based on operating presssures)
	BW30	**AG**		
Hardness, mg/L as $CaCO_3$	<17.8	<17.8	600	0.07 - 350
pH	**6.41**	**5.97**	6.9 - 9.0	7 - 10
Total dissolved solids (TDS)	31.3	44.5	500	200 - 700
Total Suspended Solids (TSS)	1	1.2	100	0.5 - 10
Turbidity, NTU	0.15	0.19	50	
Carbonaceus Bioehemical Oxygen Demand ($C\text{-}BOD_5$)	-	-	25	1 - 50
Chemical Oxygen Demand (COD)	<5	<5	75	1 - 5
Ammonia, mg/L as N	0.02	0.015	1	0.1
Phosphate, mg/L as P	<0.05	<0.05	4	
Aluminium			0.1	0.01 - 5
Bicarbonate	22.2	17.4	24	48 - 170
Chloride	15.1	22.67	500	Variable
Iron	-	-	0.5	0.05 - 1
Manganese	-	-	0.5	0.01 - 0.3
Silica	1.1	1.08	50	0.7 - 30
Sulphate	<40	<40	200	Variable

- **:** not measured

BW30 and NF90 permeates are suitable for cooling application according to all parameters except for pH value. In addition to this, their permeates could be use as a boiler feedwater after pH adjusment. Beside pH adjustment, operating pressure requirements should be also taken into consideration because given boiler feedwater requirements are variable according to operating pressure.

Water quality requirements for pulp and paper production depend on the grade of paper. Generally, lower quality water can be used for the brown grade papers such as asphalt or tar-saturated papers, linerboard, low-brightness carton board, packaging and insulating board. The white grade papers require higher

water quality, and high brightness fine papers require the highest quality process water (Rommelmann *et al*., 2003).

Permeates obtained from NF90, NF270 and TR60 NF membranes are compared to pulp and paper industry feed water characteristics. The results are shown in Table 3.9.

Table 3.9 Comparison of NF permeates with pulp and paper industry feed water characteristics (Asano *et al*., 2007)

Parameters	Permeate Quality of Various Membrane			Brown grades		White grades	
	NF90	NF270	TR60	Groundwood paper	Soda and sulfate (kraft) pulps	Kraft paper, bleached	Bleached paper
Turbidity, NTU	0.18	0.6	0.317	70	35	40	14 - 56
Color	1.33	6.8	2.17	30	5	25	5 – 25
TDS, mg/L	64.0	**1037**	**1373**	250 – 1000	250 – 1000	300	75 – 650
TSS, mg/L	1.83	2.5	5.67	40	10	10	10 – 30
Hardness, mg/L $CaCO_3$	<17.8	120.2	**267.6**	100 – 200	100 – 200	100	100
Chloride, mg/L	36.1	**677.3**	**823.7**	75	75	200	200
Fe, mg/L	-	-	-	0.3	0.1	0.2	0.1
Mn, mg/L	-	-	-	0.1	0.05	0.1	0.03
Silica, mg/L SiO_2	1.94	5.93	6.03	50	20	50	9 – 20
SO_4, mg/L	<40	<40	112.3	Trace	N.S	N.S	100 – 300
Temperature, ^oC	25.6	27.7	28.9	<55	27	N.S	15 – 27

- **:** not measured
N.S : not specified

According to the results obtained, permeates NF90 are suitable for all brown and white grades of paper production process. NF270 permeate was not suitable for pulp and paper feed water usage because of TDS and chloride concentration. Same for TR60 permeate, it is also not suitable for reuse in the pulp and paper industry because of TDS, chloride and hardness values.

Obtained permeates from BW30 and AG RO membranes are compared to required pulp and paper industry feed water characteristics. Comparison of permeates is depicted in Table 3.10.

The results show that permeate obtained from BW30 and AG membranes satisfied all brown and white grades feed water characteristics.

Table 3.10 Comparison of RO permeates with pulp and paper industry feed water characteristics (Asano *et al*., 2007)

Parameters	Permeate Quality of Various Membrane		Brown grades		White grades	
	BW30	AG	Groundwood paper	Soda and sulfate (kraft) pulps	Kraft paper, bleached	Bleached paper
Turbidity, NTU	0.15	0.19	70	35	40	14 - 56
Color	2	1.3	30	5	25	5 – 25
TDS, mg/L	31.3	44.5	250 – 1000	250 – 1000	300	75 – 650
TSS, mg/L	1	1.2	40	10	10	10 – 30
Hardness, mg/L $CaCO_3$	<17.8	<17.8	100 – 200	100 – 200	100	100
Chloride, mg/L	15.1	22.67	75	75	200	200
Fe, mg/L	-	-	0.3	0.1	0.2	0.1
Mn, mg/L	-	-	0.1	0.05	0.1	0.03
Silicate, mg/L SiO_2	1.1	1.08	50	20	50	9 – 20
SO_4, mg/L	<40	<40	Trace	N.S	N.S	100 – 300
Temperature, ^oC	29.6	31.1	<55	27	N.S	15 – 27

- **:** not measured
N.S : not specified

The major water quality issues for textile production are to ensure that the dyes react properly and that discoloration or staining does not occur. Turbidity, color, iron, and manganese have the potential to cause staining of fabric during production. Hardness adversely affects soaps used in various cleaning processes and can cause curd-like deposits on the textile. Usually soaps are not deposited evenly with hard water, resulting in dyeing irregularities. Hardness may cause precipitation of some dyes and increase the breakage of silk during reeling and throwing operations (Treweek, 1982). Typical water quality requirements for the textile industry are reported in Table 3.11.

Table 3.11 Comparison of permeates from various membranes with typical textile industry feed water characteristics (Asano *et al*., 2007)

Parameters	Permeate Quality of Various Membranes					Typical Textile Industry Feed Water Characteristics
	NF90	NF270	TR60	BW30	AG	
Al, mg/L	-	-	-	-	-	8
Color	1.33	**6.8**	2.17	2	1.3	0 - 5
Cu, mg/L	<0.5	<0.5	<0.5	<0.5	<0.5	0.01 - 5
Fe, mg/L	-	-	-	-	-	0.1 – 0.3
Mn, mg/L	-	-	-	-	-	0.01 – 0.05
pH	6.23	7.23	7.67	6.41	6.0	6 - 8
SO_4, mg/L	<40	<40	112.3	<40	<40	100
TSS, mg/L	1.83	2.5	**5.67**	1	1.2	0 - 5
TDS, mg/L	64.0	**1037**	**1373**	31.3	44.5	100 - 200
Total Hardness, mg/L $CaCO_3$	<17.8	**120.2**	**267.6**	<17.8	<17.8	0 - 50

- **:** not measured

Permeate obtained from NF90 is suitable for typical textile feed water usage. NF270 permeate did not meet the textile feed water requirements because of the color, TDS and total hardness values. TR60 permeate is also not suitable to use as a typical textile industry feed water because of TSS, TDS and hardness concentration.

Permeate obtained from BW30 and AG membrane satisfied the requirements of feed water for typical textile industry.

3.2.2 Concentrate management tests

The aim of this study is the reduce the amount of discharged concentrate stream. For this purpose certain amount of concentrate stream mixed with MBR effluent and obtained mixture was used as a feed stream for NF/RO membrane test system. For these tests, NF90 membrane was used as NF membrane and operating pressure was 10 bar during the concentrate management test. The flow diagram of concentrare management tests are given in Figure 3.65.

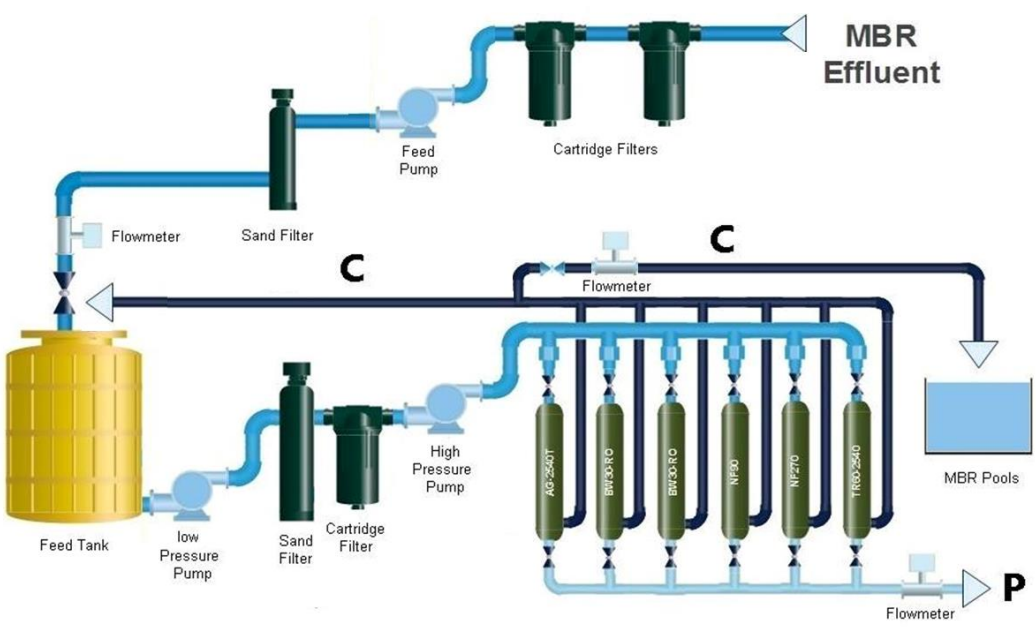


Figure 3.65 Flow diagram of mini pilot scale NF/RO system –Concentrate Management Test

MBR treated wastewater is passed through the cartridge filters and sand filter and pumped to the feed tank (500 L). After filling feed tank with MBR treated wastewater, NF/RO system was started to run. The amount of feed water used by the system was measured by concentrate and permate flowrates. The feed water amount used by system was calculated by using following equation;

Feed flowrate (L/h) : Permeate flowrate (L/h) + Concentrate flowrate (L/h) (3.1)

Feed water amount was calculated as approximately 290 L/h at 10 bar of operating pressure. By considering this feed water amount, MBR effluent and NF90 concentrate was mixed at the ratios of 4:1, 3:1, 2:1, 1:1, respectively. The obtained mixture was used as a feed water during the concentrate management tests. Recycled amounts of MBR effluent and NF90 concentrate in the feed tank with the mixing ratios of 4:1, 3:1, 2:1, 1:1 are shown in Table 3.12 and the obtained feed water mixture characteristics are summarized in Table 2.7 in the Experimental Part.

Table 3.12 Recycled amount of MBR effluent and NF90 concentrate in the feed tank for different mixing ratios

	Feed Mixture 1	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
MBR effluent to NF90 Concentrate Ratio	**4:1**	**3:1**	**2:1**	**1:1**
Recycled MBR Effluent (L/h)	219	221	202.6	143.1
Recycled NF90 Concentrate (L/h)	58.4	82	107.2	136.6

After adjusted recyled amount of MBR effluent and NF90 concentrate, first samples were taken from feed mixture, permate and concentrate streams.

During the study, continuous mode of operation was used for all experiments. Permeate was collected in the permeate tank and excess amount of concentrate stream was sent to MBR pools. Feed, permeate and concentrate samples were taken for analysis, periodically.

Permeate flux of different feed mixtures

The performances NF90 membranes in terms of permeate flux for different feed mixtures were depicted on Figure 3.66. The average permeate fluxes were found as 52.5, 49.1, 48.3 and 48.4 L/m^2h for feed mixtures 1, 2, 3 and 4, respectively. When the concentrate amount increased in the feed mixture, permeate flux slightly decreased.

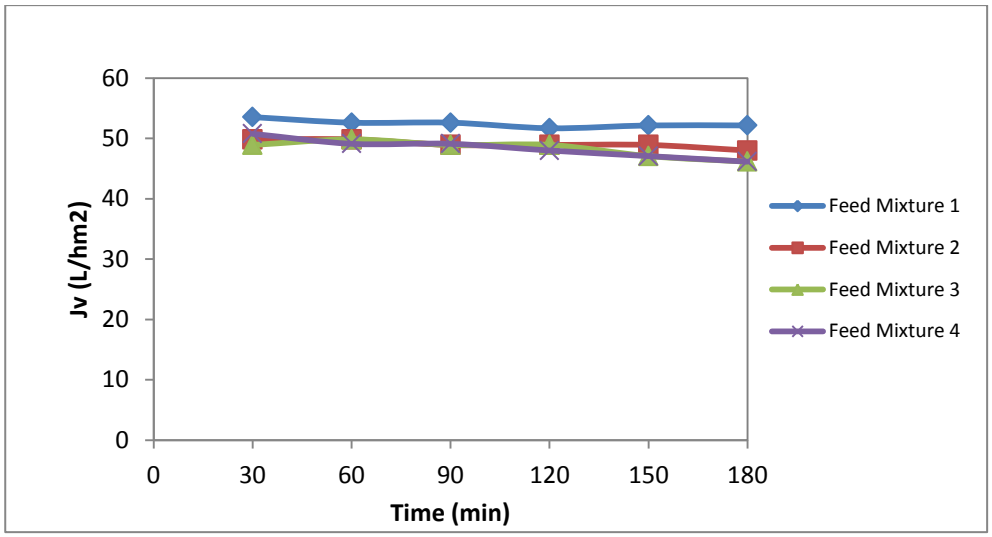


Figure 3.66 Effect of feed composition on permeate flux

TDS rejection of NF90 membranes for different feed mixtures

In Table 3.13, TDS concentration changes of each feed mixtures and obtained permeates for a certain period of time are given.

Table 3.13 TDS concentration of feed mixtures and their permeates for certain period of time.

Feed Mixtures – TDS (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	2000	1826	1777	1764
30	2133	1855	1873	1836
60	2177	1937	1944	1974
90	2196	2024	2031	2073
120	2210	2086	2126	2195
150	2230	2123	2200	2360
180	2250	2156	2240	2420
Average value:	**2171**	**2001**	**2027**	**2089**
NF90 Permates – TDS (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
30	60.0	57.5	58.4	56.2
60	64.5	61.3	61.9	64.8
90	69.0	67.2	69.3	75.6
120	72.1	71.0	74.8	84.2
150	74.0	74.0	78.3	95.0
180	76.0	77.5	84.3	107.5
Average value:	**69.3**	**68.1**	**71.2**	**80.6**

Permeates 1, 2, 3 and 4 mixtures were obtained from the feed mixtures of 1, 2, 3 and 4, respectively by using NF90 membrane and the operating pressure was 10 bar for each study.

In Figure 3.67, TDS removal of NF90 membrane for each feed mixture at 10 bar of operating pressure is shown. According to obtained results, average removals of TDS were 97.2% for feed mixture 1 and 96.6% for feed mixtures 2, 3 and 4, respectively. NF90 membrane showed similar removal performance for TDS.

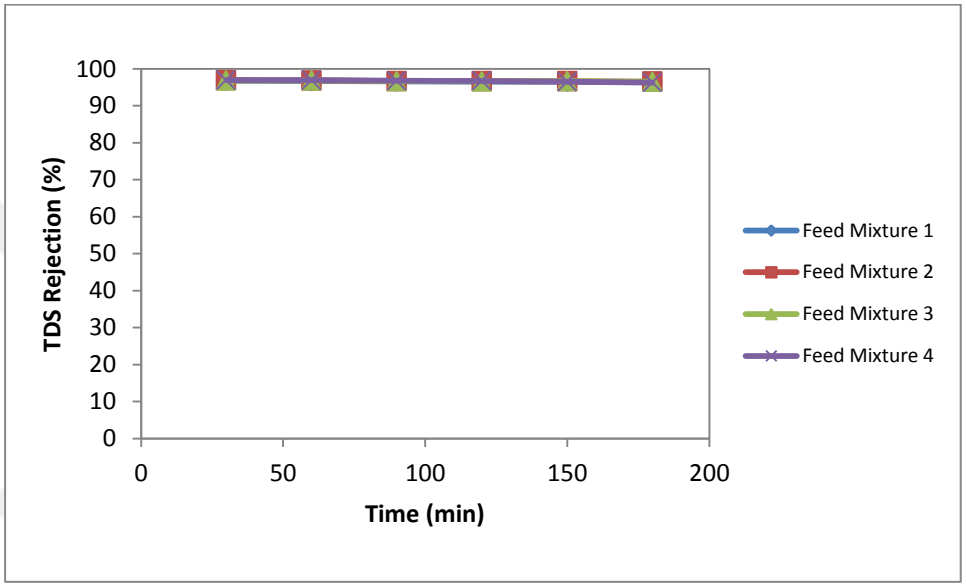


Figure 3.67 Effect of feed composition on TDS rejection

Conductivity rejection of NF90 membranes for different feed mixtures

Conductivity changes of each feed mixtures and their permeates are given for a certain period of time in Table 3.14. Permeates of the mixtures 1, 2, 3 and 4 were obtained from feed mixtures of 1, 2, 3 and 4, respectively by using NF90 membrane and operating pressure was 10 bar for each study.

Table 3.14 Conductivities of feed mixtures and their permeates for certain period of time.

Feed Mixtures – Conductivity (mS/cm)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	3530	3430	3420	3350
30	3600	3620	3550	3540
60	3750	3760	3810	4070
90	3900	3920	3990	4460
120	4020	4090	4220	4880
150	4080	4220	4510	5190
180	4150	4300	4640	5640
Average value:	**3861**	**3906**	**4020**	**4447**
NF90 Permeates – Conductivity (mS/cm)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
30	126.7	122.0	123.8	119.0
60	136.2	129.5	130.9	136.9
90	145.5	142.0	146.2	161.0
120	151.9	149.7	157.7	177.9
150	156.1	156.5	164.5	199.4
180	159.6	163.8	177.6	225.0
Average value:	146.0	143.9	150.1	169.9

The results for conductivity rejections of NF90 membrane for each feed mixtures are exhibited on Figure 3.68. NF90 membrane showed similar conductivity rejections for different feed mixtures which have different MBR effluent and NF90 concentrate proportions. The average conductivity rejections were 96.3% for feed mixture 1 and 96.4% for feed mixtures 2, 3 and 4.

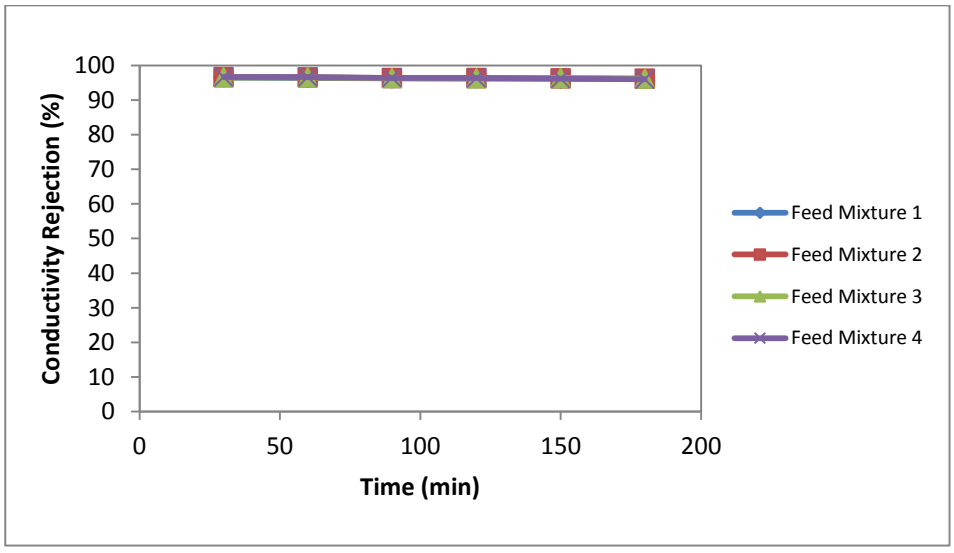


Figure 3.68 Effect of feed composition on conductivity rejection

Salinity rejection of NF90 membranes for different feed mixtures

Table 3.15 Salinities of feed mixtures and their permeates for certain period of time.

Feed Mixtures – Salinity (ppt)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	1.85	1.80	1.79	1.75
30	1.89	1.90	1.86	1.86
60	1.97	1.98	2.01	2.15
90	2.06	2.07	2.11	2.37
120	2.12	2.16	2.24	2.62
150	2.16	2.24	2.41	2.79
180	2.20	2.28	2.47	3.05
Average value:	**2.04**	**2.06**	**2.13**	**2.37**
NF90 Permates – Salinity (ppt)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
30	0.06	0.06	0.06	0.05
60	0.06	0.06	0.06	0.06
90	0.07	0.07	0.07	0.07
120	0.07	0.07	0.07	0.08
150	0.07	0.07	0.08	0.09
180	0.07	0.08	0.08	0.11
Average value:	**0.07**	**0.07**	**0.07**	**0.08**

In Table 3.15, salinity changes of each feed mixtures for a certain period of time are given. In addition to this salinity of permeates which obtained from these feed mixtures are also summarized in Table 3.15.

At the beginning of the studies (time: 0), salinity of feed mixtures were not same because MBR effluent quality changes day by day due to industrial activities changing from time to time.

Average salinity removal efficiencies of NF90 membrane were 96.8% for feed mixture of 1, 2 and 3 and 96.9% for feed mixture of 4. As depicted on Figure 3.69, salinity rejections vs. time plots showed similar trend with small difference for each feed mixtures.

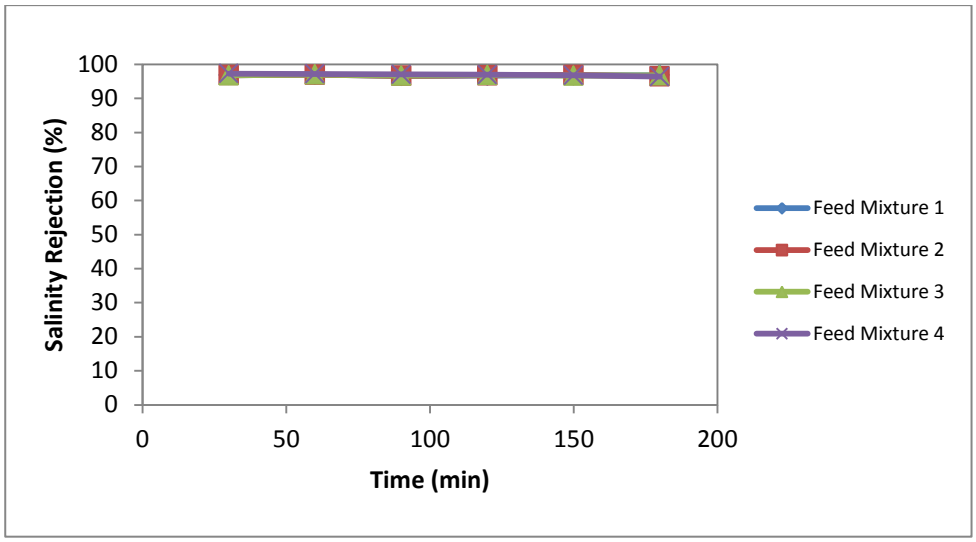


Figure 3.69 Effect of feed composition on salinity rejection

Turbidity rejection of NF90 membranes for different feed mixtures

Turbidity changes of each feed mixtures and their permeates are summarized for a certain period of time in Table 3.16.

Table 3.16 Turbidity of feed mixtures and their permeates for certain period of time.

Feed Mixtures – Turbidity (NTU)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	1.14	1.31	1.15	1.24
60	1.32	1.45	1.18	1.44
120	1.48	1.74	1.10	1.51
180	1.78	1.61	1.27	1.65
Average value:	**1.43**	**1.53**	**1.18**	**1.46**
NF90 Permates – Turbidity (NTU)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	0.20	0.18	0.16	0.11
120	0.10	0.27	0.21	0.25
180	0.10	0.28	0.15	0.27
Average value:	**0.13**	**0.24**	**0.17**	**0.21**

Turbidity rejections from different feed mixtures were effective with NF90 membrane. Average turbidity removals were %89.8, %84.9, %85.2 and %86.5 for feed mixtures 1, 2, 3 and 4, respectively. Turbidity rejections of each feed mixture vs. time plots are shown in Figure 3.70. Removals slightly decreased by the increasing concentrate amount in feed mixture.

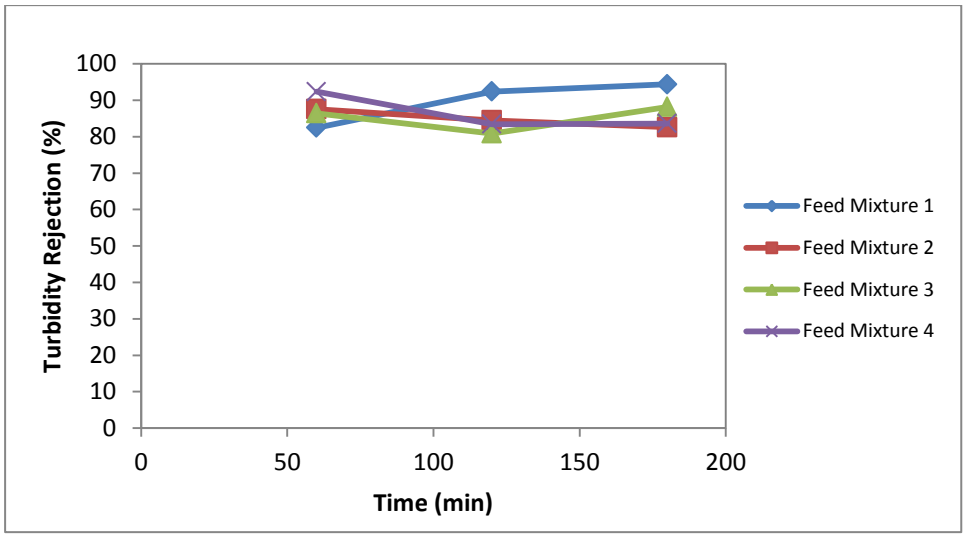


Figure 3.70 Effect of feed composition on turbidity rejection

SiO_2 rejection of NF90 membranes for different feed mixtures

SiO_2 changes of each feed mixtures and their permeates are summarized for a certain period of time in Table 3.17.

Rejection of silica was effective with for all feed mixtures. NF90 membranes performed average rejections of 57.6%, 55.1%, 58.1% and 64% for feed mixtures of 1, 2, 3 and 4, respectively. As it is seen on Figure 3.71, rejection of NF90 membrane increased with an increase in concentrate amount in the feed mixture.

Table 3.17 SiO_2 concentration of feed mixtures and their permeates for certain period of time.

Feed Mixtures – SiO_2 (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	13.43	13.60	12.28	11.30
60	14.27	14.53	13.22	12.82
120	14.42	15.35	13.57	14.12
180	15.75	15.33	14.57	15.70
Average value:	**14.47**	**14.70**	**13.41**	**13.49**
NF90 Permates – SiO_2 (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	6.23	6.89	5.65	4.92
120	6.15	6.70	5.73	5.17
180	6.45	6.68	5.95	5.20
Average value:	**6.28**	**6.76**	**5.78**	**5.10**

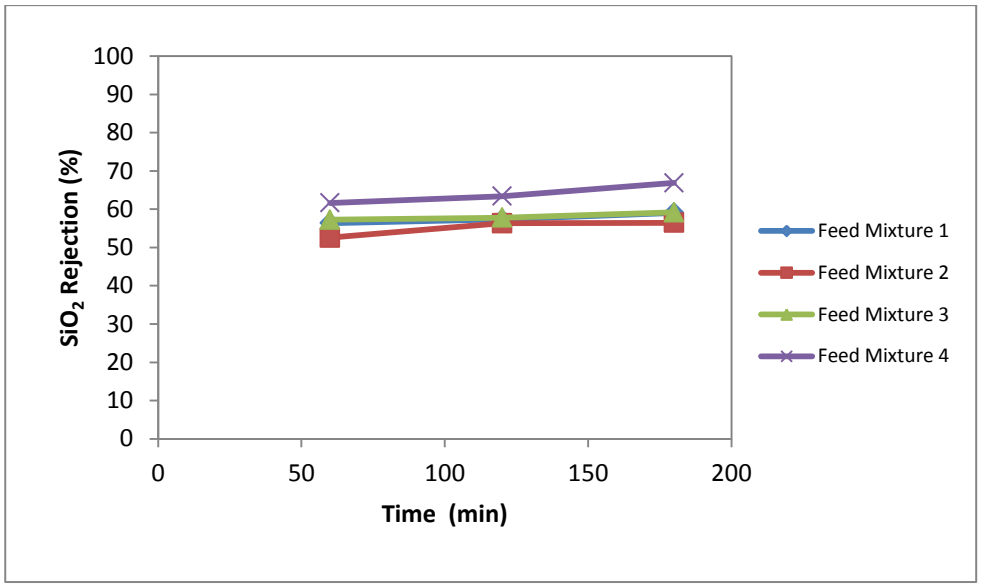


Figure 3.71 Effect of feed composition on SiO_2 rejection

COD rejection of NF90 membranes for different feed mixtures

COD values in feed mixtures and their permeates are listed for a certain period of time in Table 3.18.

Table 3.18 COD concentration of feed mixtures and their permeates for certain period of time.

Feed Mixtures – COD (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	17.10	18.00	17.90	17.30
60	16.80	18.50	17.10	17.50
120	18.30	19.90	20.70	23.70
180	19.70	19.60	20.30	28.00
Average value:	**17.98**	**19.00**	**19.00**	**21.63**
NF90 Permates – COD (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	<5	<5	<5	<5
120	<5	<5	<5	<5
180	<5	<5	<5	<5
Average value:	**<5**	**<5**	**<5**	**<5**

For each feed mixture, rejection of COD by NF90 membrane was shown in Figure 3.72. According to COD analysis, COD concentration of permeate was found smaller than 5 mg/L. Average rejections of COD were 72.5%, 74.1%, 74% ve 76.8% for feed mixtures of 1, 2, 3 and 4, respectively.

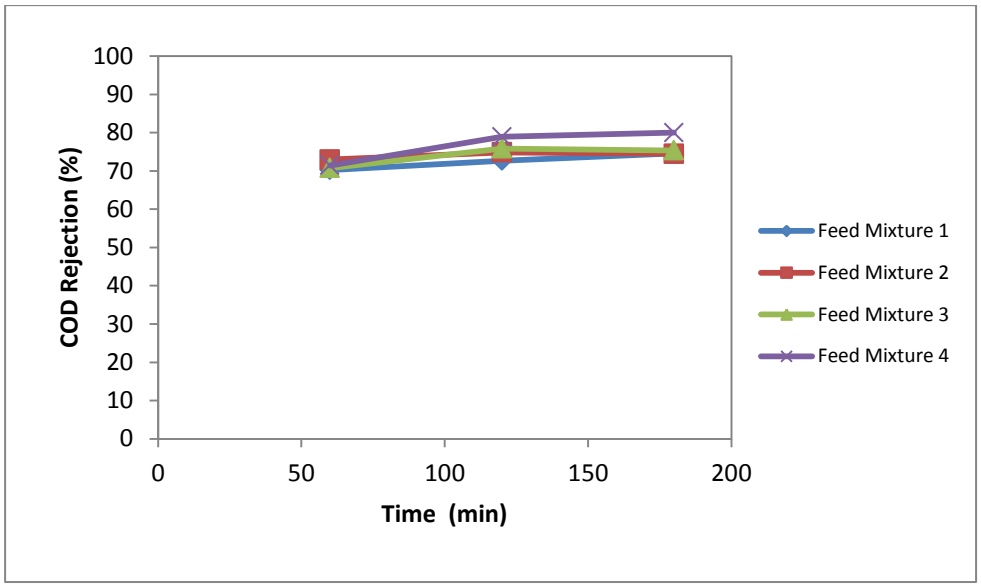


Figure 3.72 Effect of feed composition on COD rejection

Color rejection of NF90 membranes for different feed mixtures

In Table 3.19, color values of each feed mixtures for a certain period of time are given. In addition to this, color of permeates which obtained from these feed mixtures are also summarized in Table 3.19.

Table 3.19 Color of feed mixtures and their permeates for certain period of time.

Feed Mixtures – Color (mg/L Pt-Co)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	26	24	23	24
60	27	25	28	28
120	28	28	32	34
180	32	28	42	43
Average value:	**28.25**	**26.25**	**31.25**	**32.25**
NF90 Permates – Color (mg/L Pt-Co)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	UDL*	UDL	UDL	UDL
120	UDL	UDL	UDL	UDL
180	UDL	UDL	UDL	UDL
Average value:	**UDL**	**UDL**	**UDL**	**UDL**

*__UDL__: under detection limit

Color of permeate was found under detection limit. So, color rejection of NF90 membrane was approximately equal to 100% for each feed mixture. Color rejection vs. time plots are shown on Figure 3.73.

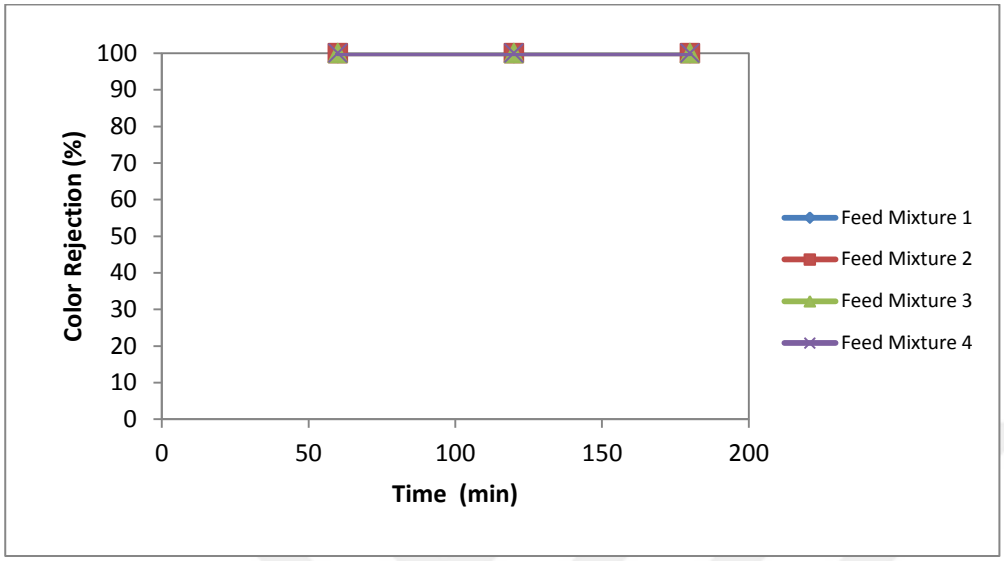


Figure 3.73 Effect of feed composition on color rejection

TOC rejection of NF90 membranes for different feed mixtures

TOC values of each feed mixtures and obtained permeates from these mixtures are listed for a certain period of time in Table 3.20.

Table 3.20 TOC of feed mixtures and their permeates for certain period of time.

Feed Mixtures – TOC (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	7.76	7.85	7.93	7.97
60	8.43	8.10	8.43	10.32
120	8.61	9.36	9.22	10.53
180	8.98	13.25	9.86	12.23
Average value:	**8.45**	**10.24**	**8.86**	**10.26**
NF90 Permates – TOC (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	1.10	0.88	0.58	0.51
120	1.09	0.67	0.63	0.50
180	0.85	0.89	0.65	0.59
Average value:	**1.01**	**0.81**	**0.62**	**0.53**

As shown on Figure 3.74, TOC rejection with NF90 membrane increased with an increase of concentrate stream portion in feed mixtures. Average rejections of 88.3%, 91.7%, 93.3% and 95.2% were obtained for feed mixtures of 1, 2, 3 and 4, respectively.

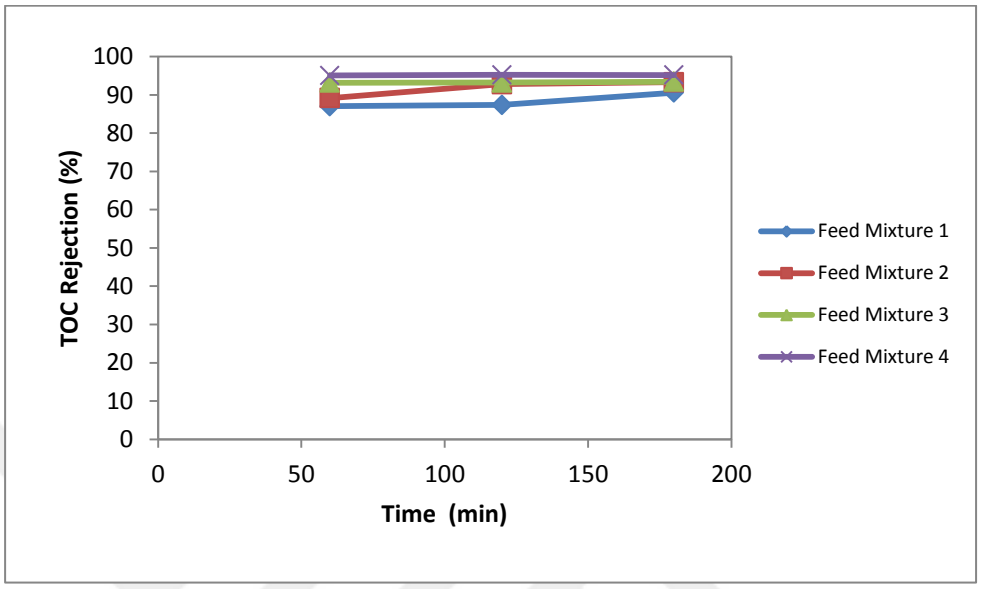


Figure 3.74 Effect of feed composition on TOC rejection

Hardness rejection of NF90 membranes for different feed mixtures

Hardness values of each feed mixtures and their permeates are summarized for a certain period of time in Table 3.21.

Table 3.21 Hardness of feed mixtures and their permeates for certain period of time.

Feed Mixtures – Hardness (mg/L $CaCO_3$)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	441.4	420.1	402.3	377.4
60	473.5	462.8	469.9	469.9
120	494.8	487.7	498.4	569.6
180	512.6	509.1	534.0	637.2
Average value:	**480.6**	**469.9**	**476.2**	**513.5**
NF90 Permates – Hardness (mg/L $CaCO_3$)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	<17.8	<17.8	<17.8	<17.8
120	<17.8	<17.8	<17.8	<17.8
180	<17.8	<17.8	<17.8	<17.8
Average value:	**<17.8**	**<17.8**	**<17.8**	**<17.8**

NF90 membrane was efficient for removal of hardness from all feed mixtures. Hardness removal of NF90 membrane for all feed mixtures were similar with small difference which were 96.4% for feed mixtures 1 and 3, 96.4% for feed mixture 2 and 96.8% for feed mixture 4. Rejection performances of NF90 membrane are indicated in Figure 3.75.

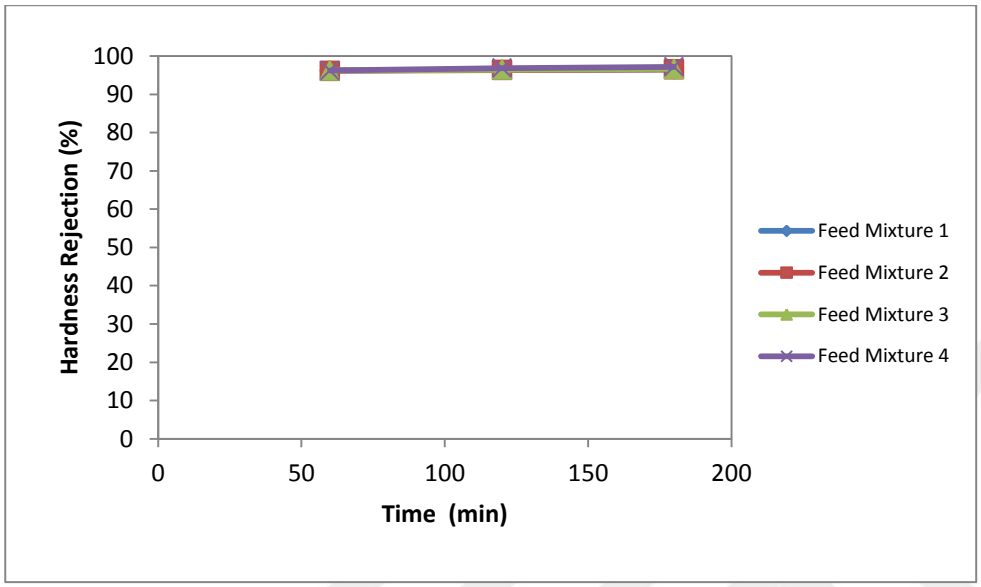


Figure 3.75 Effect of feed composition on hardness rejection

Monovalent ion rejection of NF90 membranes for different feed mixtures

Na^+ rejection

Table 3.22 Na^+ Concentration of feed mixtures and their permeates for certain period of time.

Feed Mixtures – Na^+ Concentration (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	1601	1383.6	1256	1499.1
60	1362.7	1463.7	1516.1	1670.1
120	1578.2	1528.3	2027.8	1874.5
180	1649.3	1686.3	1596.8	2016.6
Average value:	**1547.8**	**1515.5**	**1599.2**	**1765.1**
NF90 Permates – Na^+ Concentration (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	107	68.9	85.3	89
120	81.3	72.9	92.3	94.7
180	79.7	79.5	109	106.5
Average value:	**89.4**	**73.8**	**95.5**	**96.7**

Na^+ concentration changes of each feed mixtures and obtained permeates from these mixtures are listed in Table 3.22.

Although monovalent ions are generally difficult to be rejected from water by NF membranes, NF90 membrane showed a good rejection performance for monovalent ion.

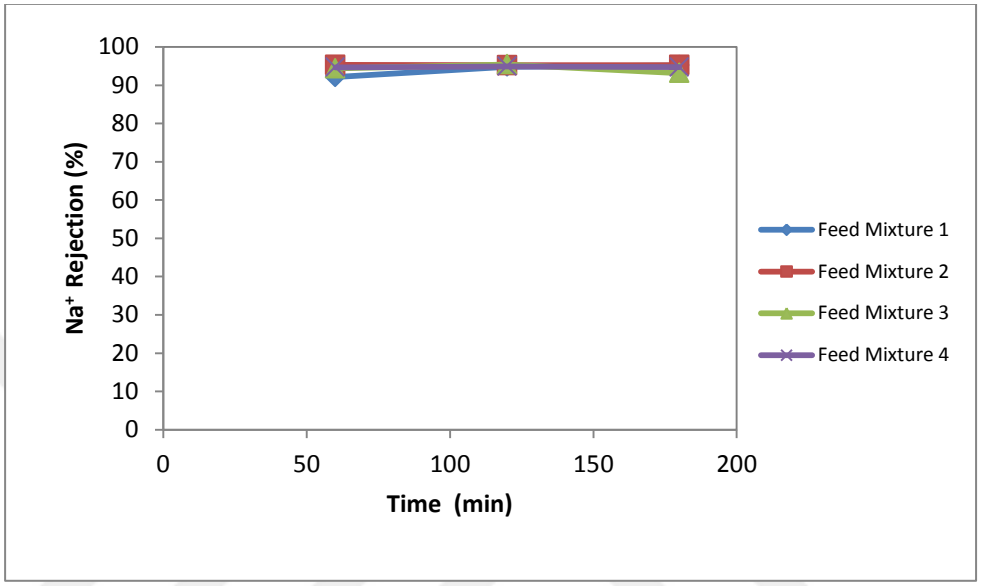


Figure 3.76 Effect of feed composition on sodium rejection

Average removals of sodium ion by NF90 membranes were 94.1%, 95.3%, 94.3% and 94.8% for feed mixtures 1, 2, 3 and 4, respectively. Sodium rejection versus time plots for NF90 membrane are depicted in Figure 3.76.

K^+ rejection

In Table 3.23, K^+ concentration changes of each feed mixtures for a certain period of time are given. In addition to this, K^+ concentration of permeates which obtained from these feed mixtures are also listed in Table 3.23.

Table 3.23 K^+ Concentration of feed mixtures and their permeates.

Feed Mixtures – K^+ Concentration (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	53.90	66.70	62.10	60.20
60	54.30	57.10	67.80	74.50
120	68.10	62.20	69.30	84.60
180	76.90	71.70	74.40	97.60
Average value:	**63.30**	**64.43**	**68.40**	**79.23**
NF90 Permates – K^+ Concentration (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	2.63	2.35	2.41	3.59
120	2.64	2.64	2.76	3.28
180	2.79	2.77	3.13	4.03
Average value:	**2.69**	**2.59**	**2.77**	**3.63**

Potassium ion rejection by NF90 membrane demonstrated similar performance for different feed mixtures. NF90 membrane revealed a high potassium rejection by achieving average rejections of 95.9% for feed mixtures 1 and 2, 96.1% for feed mixture 3 and 95.7% for feed mixture 4. Potassium removal versus time plots for different feed mixtures are depicted in Figure 3.77.

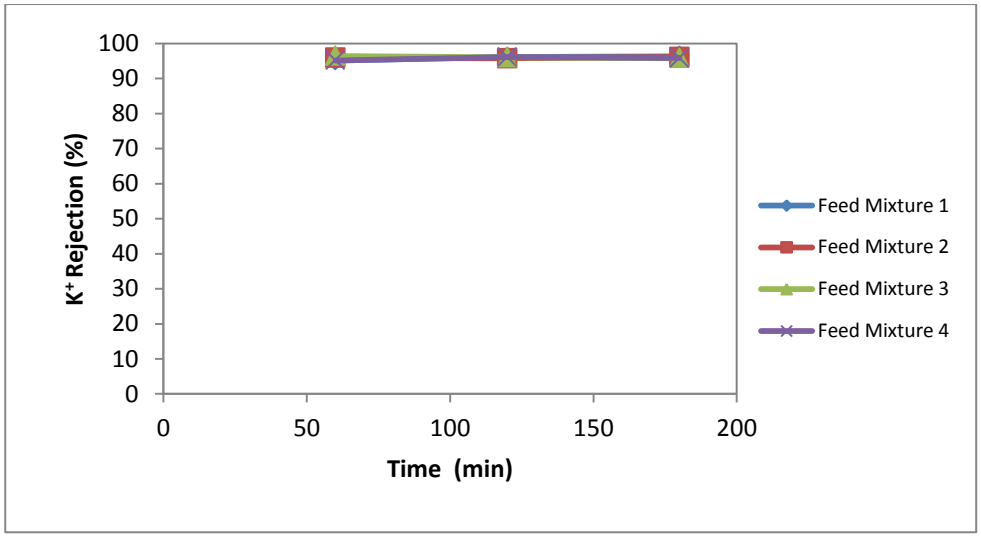


Figure 3.77 Effect of feed composition on potassium rejection

NH_4^+ -N rejection

In Table 3.24, NH_4^+ -N composition changes of each feed mixtures for a certain period of time are given. Beside this NH_4^+ -N composition of permeates which obtained from these feed mixtures are also summarized in Table 3.24.

Table 3.24 NH_4^- -N Concentration of feed mixtures and their permeates

Feed Mixtures – NH_4^+ -N Concentration (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	0.27	0.26	0.22	0.18
60	0.29	0.26	0.24	0.21
120	0.29	0.27	0.26	0.24
180	0.29	0.28	0.29	0.39
Average value:	**0.28**	**0.27**	**0.25**	**0.25**
NF90 Permates – NH_4^+ -N Concentration (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	0.015	0.019	0.018	0.015
120	0.022	0.020	0.024	0.020
180	0.022	0.021	0.024	0.048
Average value:	**0.020**	**0.020**	**0.022**	**0.028**

In Figure 3.78, we can see that ammonium was rejected effectively by NF90 for each feed mixtures. Average rejections of ammonium were 93.2%, 92.6%, 91.6% and 90.6% for feed mixtures of 1, 2, 3 and 4, respectively. As summarized from the values, when the concentrate portion increased in the feed mixtures, removal slightly decreased.

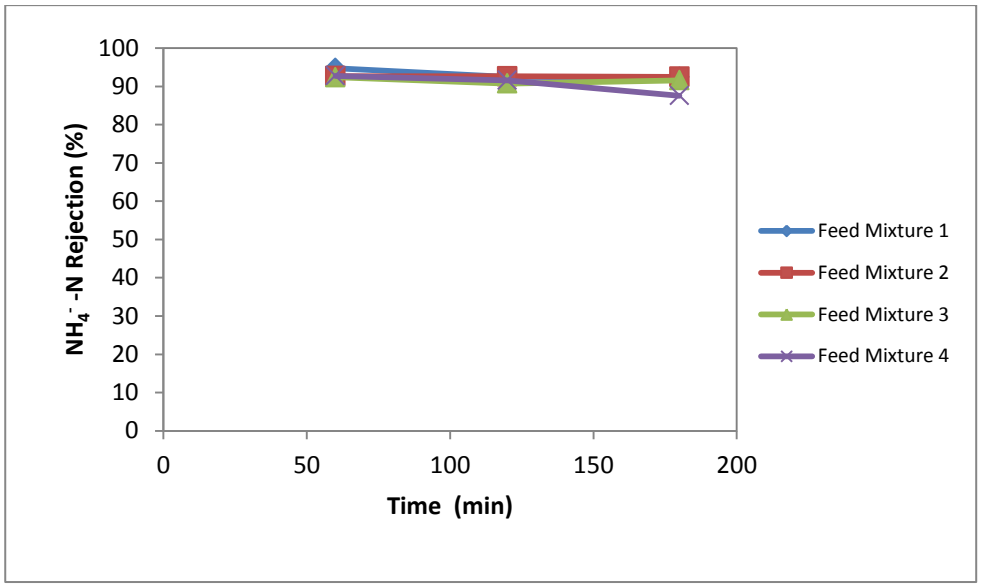


Figure 3.78 Effect of feed composition on ammonium-nitrogen rejection

Cl^- rejection of NF90 membranes for different feed mixtures

Cl^- ion concentration changes of each feed mixtures and obtained permeates from these mixtures are listed in Table 3.25.

Table 3.25 Cl^- concentration of feed mixtures and their permeates.

Feed Mixtures – Cl^- Concentration (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	816	909	998	927
60	883	932	1061	1014
120	954	962	1102	1316
180	987	996	1182	1540
Average value:	**910**	**949.8**	**1085.8**	**1199.3**
NF90 Permates – Cl^- Concentration (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	28.4	29.6	31	43.8
120	27.8	35.2	37.5	45.6
180	27.6	37.9	42.7	59.3
Average value:	**27.9**	**34.2**	**37.1**	**49.6**

In Figure 3.79, it is shown that NF90 membrane performed a good efficiency for chloride rejection for different feed mixture composition. The average rejections achieved were with 97%, 96.5%, 96.7% and 96.1% for feed mixtures of 1, 2, 3 and 4, respectively.

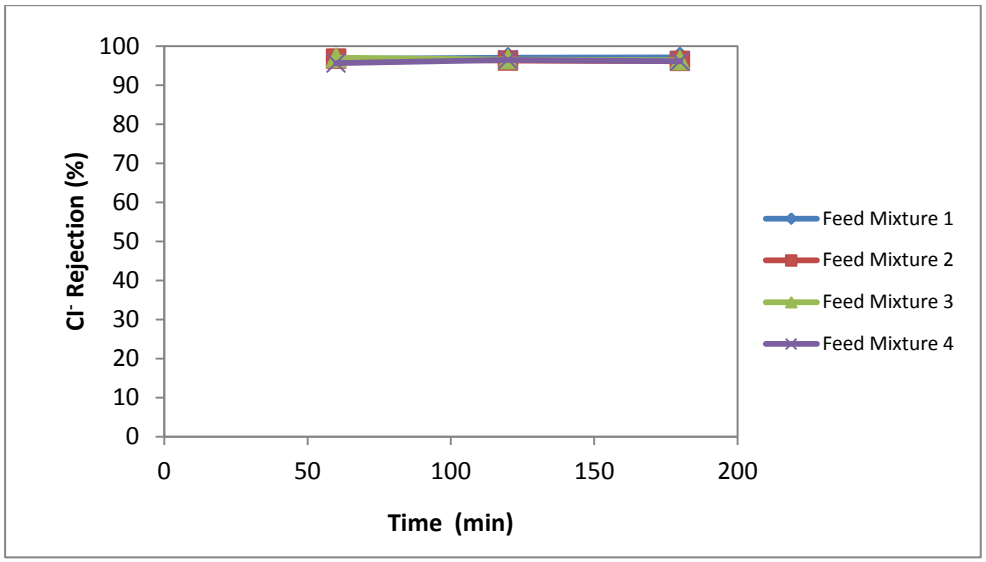


Figure 3.79 Effect of feed composition on chloride rejection

NO_3^- -N rejection

Concentrations of NO_3^--N for each feed mixtures and obtained permeates from these mixtures are summarized for a certain period of time in Table 3.26.

Table 3.26 NO_3^--N Concentration of feed mixtures and their permeates.

Feed Mixtures – NO_3^--N Concentration (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	4.97	4.40	4.13	2.85
60	5.20	4.85	4.20	2.96
120	5.37	5.20	4.25	3.14
180	5.41	5.37	4.50	3.22
Average value:	**5.24**	**4.96**	**4.27**	**3.04**
NF90 Permates – NO_3^--N Concentration (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	3.59	4.00	3.61	2.74
120	4.10	4.84	3.96	3.13
180	4.47	4.40	4.22	3.17
Average value:	**4.05**	**4.41**	**3.93**	**3.01**

Nitrate-nitrogen rejection was very low with NF90 membrane. Average rejections were %24, %14.2, %9 and %3.1 for feed mixtures of 1, 2, 3 and 4, respectively. Nitrate-nitrogen removal versus time plots for different feed mixtures are depicted in Figure 3.80.

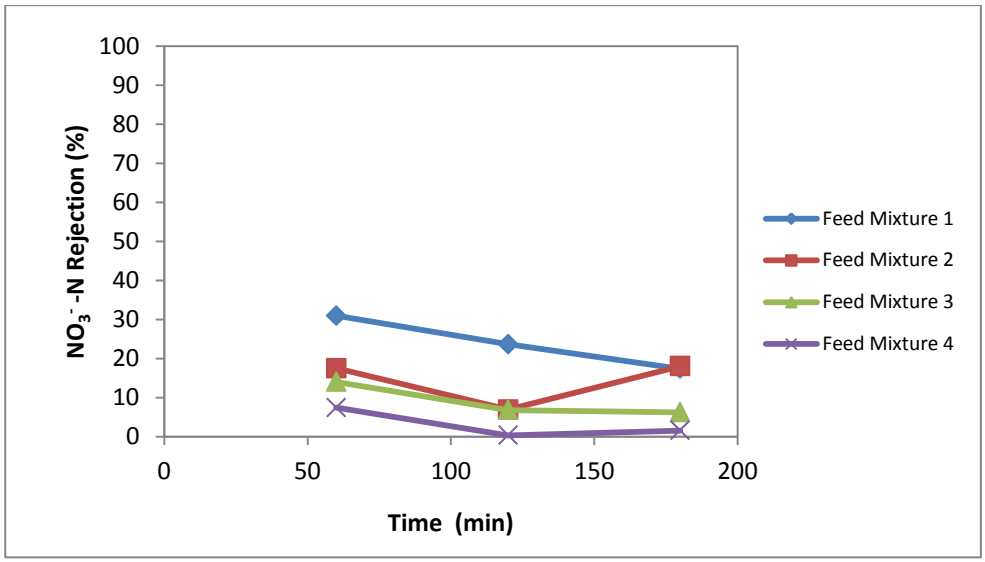


Figure 3.80 Effect of feed composition on nitrate-nitrogen rejection

NO_2^- -N rejection

NO_2^--N change of each feed mixtures and obtained permeates from these mixtures are listed for a certain period of time in Table 3.27.

Table 3.27 NO_3^- -N concentration of feed mixtures and their permeates.

Feed Mixtures – NO_2^- -N Concentration (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	0.046	0.061	0.044	0.052
60	0.054	0.069	0.051	0.054
120	0.070	0.072	0.055	0.067
180	0.072	0.077	0.058	0.111
Average value:	**0.061**	**0.070**	**0.052**	**0.071**
NF90 Permates – NO_2^- -N Concentration (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	0.019	<0.015	<0.015	0.017
120	0.017	<0.015	<0.015	0.019
180	0.016	<0.015	<0.015	0.026
Average value:	**0.017**	**<0.015**	**<0.015**	**0.021**

According to nitrite-nitrogen investigation, nitrite-nitrogen concentration of permeates which were obtained from feed mixtures of 2 and 3 were found under detection limit. So, nitrite-nitrogen rejection of NF90 membrane for feed mixtures of 2 and 3 were greater than 79.3% and 72.5%, respectively.

For feed mixtures of 1 and 4, average removal rates were 72.8% and 72.2%, respectively. Nitrite-nitrogen rejection versus time plots are shown in Figure 3.81.

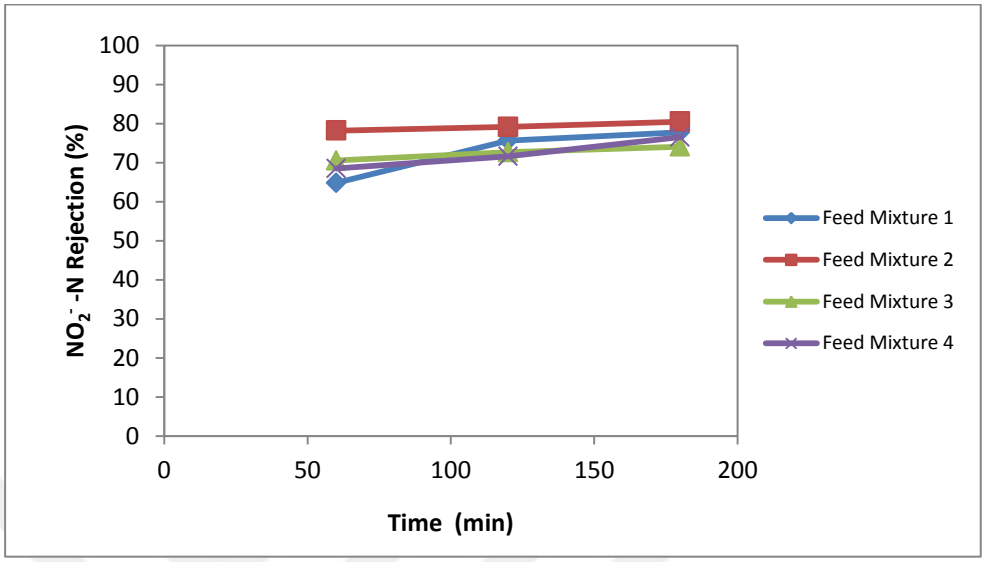


Figure 3.81 Effect of feed composition on nitrite-nitrogen rejection

HCO_3^- rejection

HCO_3^- concentration of each feed mixtures and obtained permeates from these mixtures are shown for a certain period of time in Table 3.28.

Table 3.28 HCO_3^- concentration of feed mixtures and their permeates.

Feed Mixtures – HCO_3^- Concentration (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	257.1	280.5	257.1	327.3
60	288.3	303.9	303.9	389.6
120	296.1	335	397.4	467.5
180	303.9	358	459.7	529.9
Average value:	**286.4**	**319.4**	**354.5**	**428.6**
NF90 Permates – HCO_3^- Concentration (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	15.6	17.1	15.6	24.9
120	23.3	20.3	28	26.5
180	23.3	26.5	28.1	26.5
Average value:	**20.8**	**21.3**	**23.9**	**26**

As demonstrated on Figure 3.82, bicarbonate rejections were well performed for all feed mixtures with similar efficiencies. NF90 membrane showed average rejections of 93%, 93.6%, 93.9% and 94.3% for feed mixtures of 1, 2, 3 and 4, respectively.

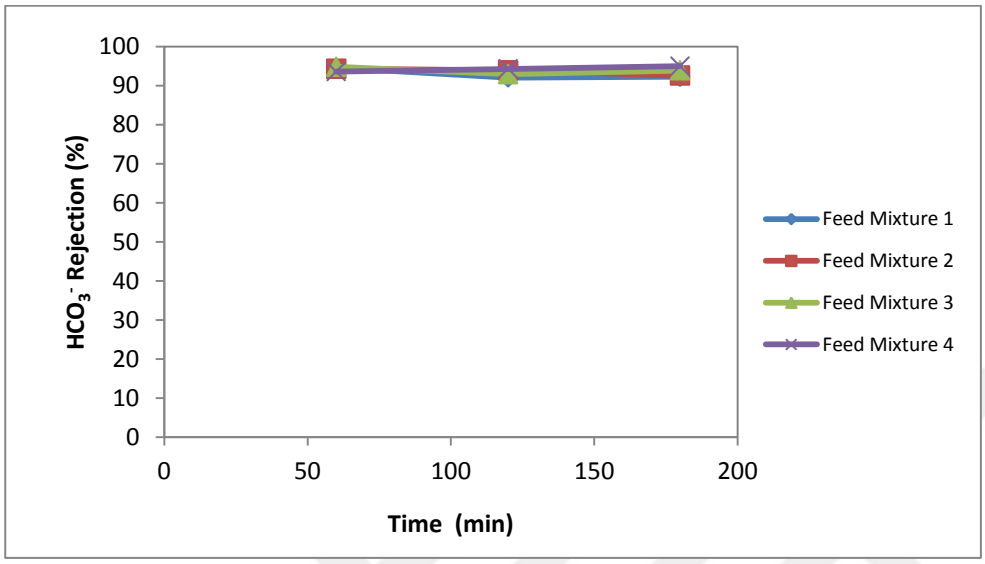


Figure 3.82 Effect of feed composition on bicarbonate rejection

Multivalent ion rejection of NF90 membranes for different feed mixtures

Ca^{2+} rejection

Table 3.29 Ca^{2+} Concentration of feed mixtures and their permeates.

Feed Mixtures – Ca^{2+} Concentration (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	74	61	53	56
60	70	58	58	62
120	83	68	74	74
180	84	69	96	79
Average value:	**77.7**	**64**	**70.3**	**67.8**
NF90 Permates – Ca^{2+} Concentration (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	2.00	3.20	9.00	4.30
120	1.60	1.90	4.00	10.70
180	4.00	1.30	7.30	6.60
Average value:	**2.53**	**2.13**	**6.77**	**7.20**

In Table 3.29, Ca^{2+} ion concentration changes for each feed mixtures in a certain period of time are given. In addition to this, Ca^{2+} ion concentration of permeates which obtained from these feed mixtures are also listed in Table 3.29.

Results obtained with NF90 membrane showed that calcium ion rejections for different feed mixtures were 96.8%, 96.6%, 90.5% and 90.1%, for feed mixtures of 1, 2, 3 and 4, respectively. Calcium rejection versus time plots for RO membranes are depicted in Figure 3.83.

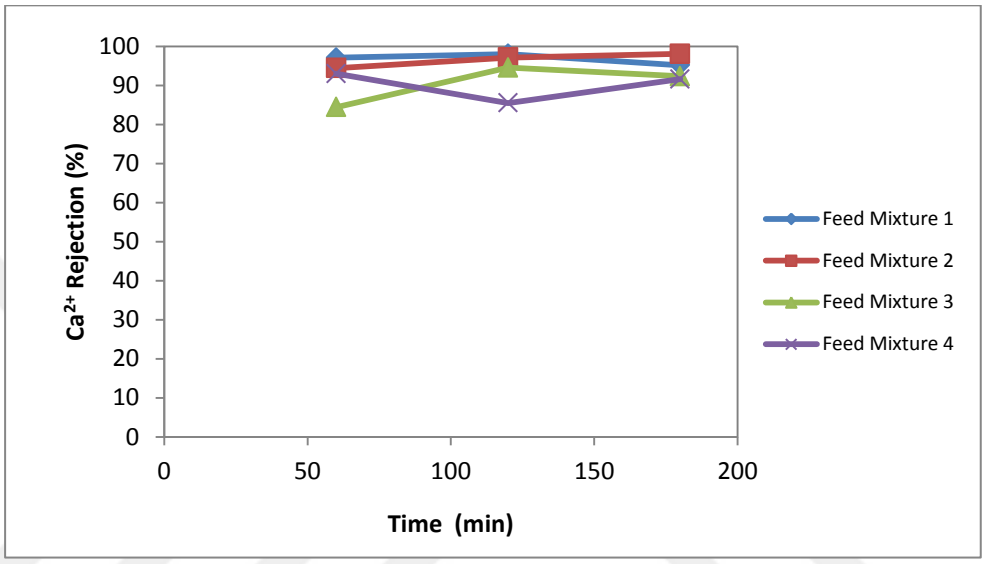


Figure 3.83 Effect of feed composition on calcium ion rejection

Mg^{2+} rejection

Table 3.30 Mg^{2+} concentration of feed mixtures and their permeates.

Feed Mixtures – Mg^{2+} Concentration (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	27.37	28.80	29.46	28.26
60	34.20	34.20	35.58	34.80
120	31.74	38.94	39.00	48.84
180	39.00	41.28	39.60	54.12
Average value:	**33.08**	**35.81**	**35.91**	**41.51**
NF90 Permates – Mg^{2+} Concentration (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	UDL*	UDL	UDL	UDL
120	UDL	UDL	UDL	UDL
180	UDL	UDL	UDL	UDL
Average value:	**UDL**	**UDL**	**UDL**	**UDL**

*__UDL__: under detection limit

Mg^{2+} ion concentration changes of each feed mixtures and obtained permeates from these mixtures are shown for a certain period of time in Table 3.30.

If magnesium concentration of permeates which obtained from different feed mixture were analyzed, concentrations were under the detection limit of AAS. Then magnesium rejections of NF90 membrane were assumed to be ≈100% for all feed mixtures.

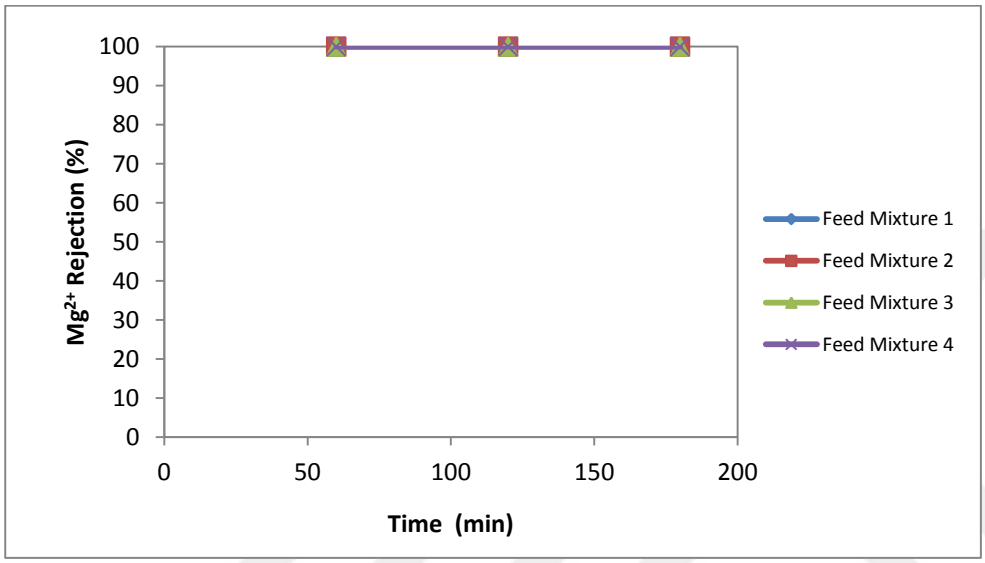


Figure 3.84 Effect of feed composition on magnesium ion rejection

SO_4^{2-} rejection

Table 3.31 SO_4^{2-} concentration of feed mixtures and their permeates.

Feed Mixtures – SO_4^{2-} Concentration (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	433	348	308	298
60	449	395	371	358
120	450	457	429	439
180	459	485	456	492
Average value:	**447.7**	**421.3**	**391.0**	**396.7**
NF90 Permates – SO_4^{2} Concentration (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	<40	<40	<40	<40
120	<40	<40	<40	<40
180	<40	<40	<40	<40
Average value:	**<40**	**<40**	**<40**	**<40**

In Table 3.31, SO_4^{2-} ion concentration changes of each feed mixtures for a certain period of time are given. In addition to this, SO_4^{2-} ion concentration of permeates which obtained from these feed mixtures are also listed in Table 3.31.

NF90 showed a good sulfate rejection performance for all feed mixtures. According to sulfate investigation, sulfate concentration of permeates which were obtained from feed mixtures were found under detection limit. So, sulfate rejection rate of NF90 membrane for feed mixtures of 1, 2, 3 and 4 were greater than 91.2%, 91%, 90.4% and 90.5%, respectively. Sulfate rejection versus time plots are shown on Figure 3.85.

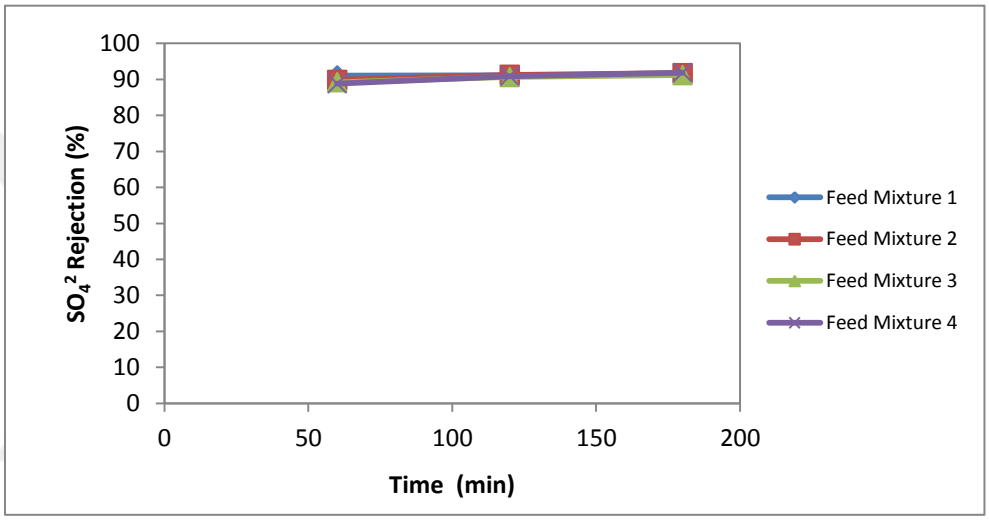


Figure 3.85 Effect of feed composition on sulfate ion rejection

PO_4^{3-}-P rejection

PO_4^{3-}-P concentration of each feed mixtures and obtained permeates from these mixtures are shown for a certain period of time in Table 3.32. Phosphate concentration of permeates which were obtained from feed mixtures were found under the detection limit.

Table 3.32 PO_4^{2-} Concentration of feed mixtures and their permeates.

Feed Mixtures – PO_4^{3-}-P Concentration (mg/L)				
Time (min)	**Feed Mixture 1**	**Feed Mixture 2**	**Feed Mixture 3**	**Feed Mixture 4**
0	0.079	0.050	0.050	0.069
60	0.082	0.099	0.111	0.080
120	0.084	0.106	0.112	0.102
180	0.086	0.108	0.122	0.127
Average value:	**0.083**	**0.091**	**0.099**	**0.095**
NF90 Permates – PO_4^{3-}-P Concentration (mg/L)				
Time (min)	**Permeate 1**	**Permeate 2**	**Permeate 3**	**Permeate 4**
60	<0.05	<0.05	<0.05	<0.05
120	<0.05	<0.05	<0.05	<0.05
180	<0.05	<0.05	<0.05	<0.05
Average value:	**<0.05**	**<0.05**	**<0.05**	**<0.05**

Because of this, phosphate rejection of NF90 membrane for feed mixtures of 1, 2, 3 and 4 were greater than 40.5%, 52%, 56.4% and 49.7%, respectively. Phosphate rejection versus time plots are shown on Figure 3.86.

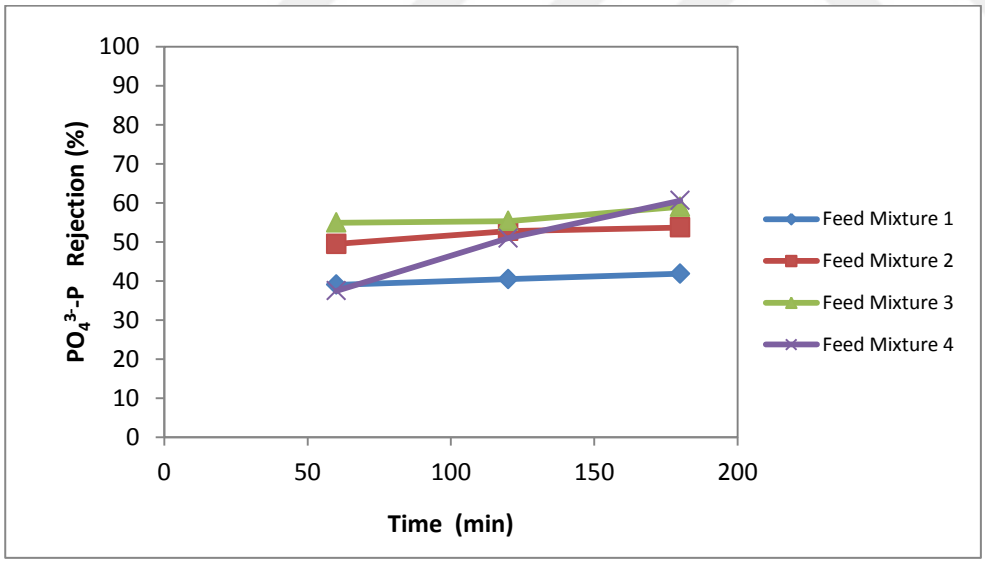


Figure 3.86 Effect of feed composition on phosphate ion rejection

3.2.2.1 Quality analysis of NF90 membrane permeates which obrained different feed mixtures

During the studies, quality of permeates which obtained from different feed mixtures by using NF90 membrane was investigated with various parameters such as total dissolved solid (TDS), salinity, conductivity, pH, turbidity, chemical

oxygen demand (COD), total suspended solid (TSS), color, Na^{+}, Ca^{+2}, K^{+}, Mg^{+2}, HCO_3^{-}, SO_4^{2-}, Cl^{-}, PO_4-P, NH_4-N, NO_3-N, NO_2-N, total nitrogen (TN), $CaCO_3$ hardness, total organic carbon (TOC) and SiO_2 concentrations.

Quality of permeates which are obtained from all feed mixtures are listed in Table 3.33 with average values of all parameters.

Table 3.33 Permeate quality of different feed mixtures

Parameters	Permeate 1	Permeate 2	Permeate 3	Permeate 4
TDS (mg/L)	69.3	68.1	71.2	80.6
EC (µS/cm)	146.0	143.9	150.1	169.9
Salinity (ppt)	0.07	0.07	0.07	0.08
TSS (mg/L)	2	2	2	1.67
Color (mg/L Pt-Co)	≈0.00	≈0.00	≈0.00	≈0.00
Turbidity (NTU)	0.13	0.24	0.17	0.21
HCO_3^{-} (mg/L)	20.75	21.30	23.90	25.97
NO_3-N (mg/L)	4.05	4.41	3.93	3.01
NO_2-N (mg/L)	0.017	0.015	0.015	0.021
PO_4-P (mg/L)	0.05	0.05	0.05	0.05
NH_4-N (mg/L)	0.020	0.020	0.022	0.028
COD (mg/L)	5.00	5.00	5.00	5.20
Hardness-$CaCO_3$ (mg/L)	<17.80	<17.80	<17.80	<17.80
SiO_2 (mg/L)	6.28	6.76	5.78	5.10
SO_4^{2-} (mg/L)	<40.00	<40.00	<40.00	<40.00
Cl^{-} (mg/L)	27.93	34.23	37.07	49.57
TN (mg/L)	<20.00	<20.00	<20.00	<20.00
Na^{+} (mg/L)	89.35	73.79	95.51	96.72
K^{+} (mg/L)	2.69	2.59	2.77	3.63
Ca^{2+} (mg/L)	2.53	2.13	6.77	7.20
Mg^{2+} (mg/L)	≈0.00	≈0.00	≈0.00	≈0.00
TOC (mg/L)	1.01	0.81	0.62	0.53

Permeates of 1, 2, 3 and 4 were obtained from feed mixtures of 1, 2, 3 and 4, respectively by using NF90 membrane. MBR effluent and NF90 concentrate

was mixed with the ratios of 4:1, 3:1, 2:1, 1:1 respectively, and obtained mixture was used as a feed water during the concentrate management tests. Recycled amount of MBR effluent and NF90 concentrate in the feed tank for the mixing ratios (4:1, 3:1, 2:1, 1:1) is shown in Table 3.12 and the obtained feed water mixture characteristics are summarized in Table 2.7 in the Experimental Part.

According to the investigation, at 10 bar of operating pressure average permeate fluxes of NF90 membrane were found as 52.5, 49.1, 48.3 and 48.4 L/m^2h for mixtures of 1, 2, 3 and 4, respectively. During the studies, permeate fluxes slightly decreased when the concentrate amount increased in feed mixture. The reason of flux decrease could be due to membrane fouling. Fouling problem on membrane surface appeared earlied when the concentration of feed mixtures increased.

NF90 membrane showed similar removal efficiency according to many parameters such as conductivity, salinity, TDS, color and total hardness. On the other hand, COD, SiO_2 and TOC ions removal increased with an increasing amount of concentrate in the feed mixture.

According to cation rejection, NF90 membrane had good removal performance for all feed mixtures. Removal rates for Na^+, K^+, Mg^{2+} ions were similar for both feed mixture but with the increases of concentrate stream amount in the feed mixture, NH_4-N and Ca^{2+} ions removal rates decreased slightly. One of the reason of this problem could be the concentration polarization.

During the studies, concentrate recoveries were 35.5%, 53.5%, 69.3% and 88.2% for feed mixtures of 1, 2, 3 and 4, respectively.

The data obtained in this study were compared with National Irrigation Water Standards which is listed in Table 2.8. Comparion of permates according to national irrigation water standard is given in Table 3.34.

Table 3.34 Comparison of NF90 permeates with national irrigation water standards

Parameters		Permeate 1	Permeate 2	Permeate 3	Permeate 4
SAR		15.4	13.9	8.3	9.9
Sodium (mg/L)		89.4	73.8	95.5	96.7
Chloride (mg/L)		27.9	34.2	37.1	49.6
TDS (mg/L)		69.3	68.1	71.2	80.6
EC (dS/m)		0.146	0.144	0.15	0.17
Salinity		1^{st} class	1^{st} class	1^{st} class	1^{st} class
Infiltration		3^{rd} class	3^{rd} class	3^{rd} class	3^{rd} class
Specific ion toxicity	**Na**	1^{st} class D 3^{rd} class, Y	1^{st} class D 3^{rd} class, Y	2^{nd} class D 3^{rd} class, Y	2^{nd} class D 3^{rd} class, Y
	Cl	1^{st} class Y,D	1^{st} class Y,D	1^{st} class Y,D	1^{st} class Y,D
	B	-	-	-	-

(Y: Surface irrigation D: Sprinkler irrigation; -: Not determined)

All permeates obeys 1^{st} class water quality for salinity and 3^{rd} class for infiltration parameter. Beside this, according to specific ion toxicity parameter all permeates were classified as 1^{st} class for chloride ion. On the other hand, according to sodium concentration, permeates 1 and 2 obey 1^{st} class and permeate 3 and 4 obey 2^{nd} class for sprinkler irrigation purposes. Infiltration problem caused by unbalanced removal of the Na^{+}, Ca^{2+}, and Mg^{2+} impact on the SAR values. Mixing permeates with MBR effluent in appropriate ranges may have suitable composition values and good permeability for agricultural irrigation.

Table 3.35 Theoretical mixture of MBR effluent and NF90 permeates

MBR effluent ratio		**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
Permeate ratio		**1**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**	**0**
Permeate 1	SAR	15.4	17.9	20.4	22.9	25.4	27.8	30.3	32.8	35.3	37.8	40.3
	EC_w (dS/m)	0.15	0.48	0.82	1.16	1.50	1.84	2.18	2.51	2.85	3.19	3.53
Permeate 2	SAR	13.9	16.2	18.4	20.7	22.9	25.2	27.4	29.7	31.9	34.2	36.4
	EC_w (dS/m)	0.14	0.47	0.80	1.13	1.46	1.79	2.12	2.44	2.77	3.10	3.43
Permeate 3	SAR	8.3	10.9	13.5	16.1	18.7	21.2	23.8	26.4	29.0	31.6	34.2
	EC_w (dS/m)	0.15	0.48	0.80	1.13	1.46	1.79	2.11	2.44	2.77	3.09	3.42
Permeate 4	SAR	9.9	13.0	16.1	19.1	22.2	25.3	28.3	31.4	34.5	37.5	40.6
	EC_w (dS/m)	0.17	0.49	0.81	1.12	1.44	1.76	2.08	2.40	2.71	3.03	3.35

For each permeates, theoretical mixing ratios of MBR effluent to NF90 permeates were calculated and shown in Table 3.35 and depicted in Figure 3.87.

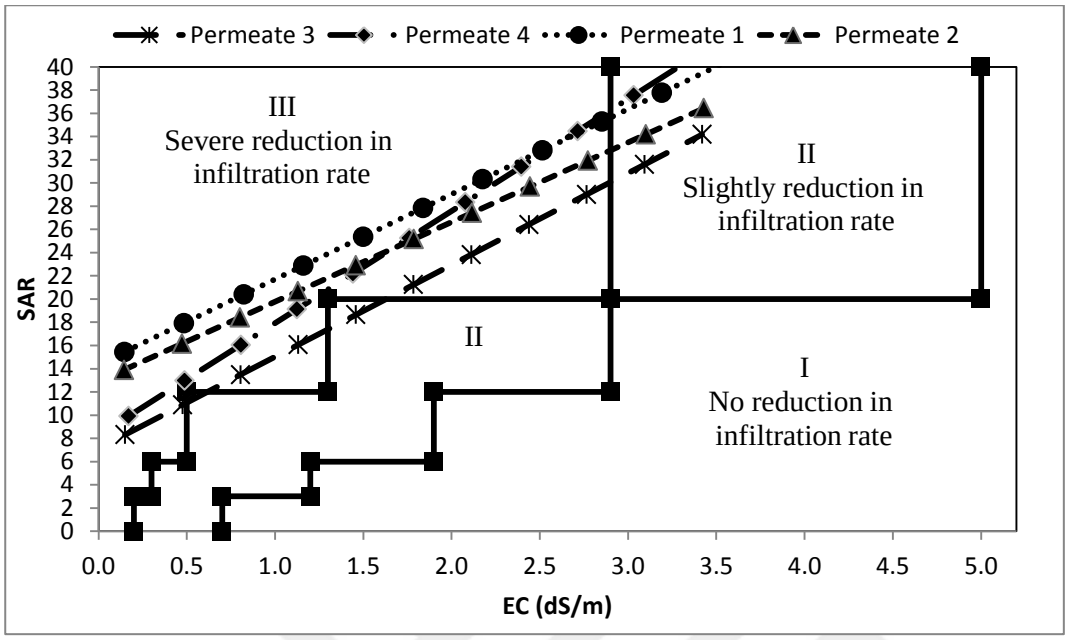


Figure 3.87 SAR and conductivity values of theoretical MBR effluent and permate mixtures

For the determination of optimum theoretical mixture in order to solve the infiltration problem, salinity and specific ion toxicity were also taken into consideration. Because the mixing of MBR effluent with permeates shows adverse effect for salinity and specific ion toxicity, so optimum mixing ratio should be found for irrigation.

As it can be seen in Figure 3.87, it was not possible to obtain 1 st class water according to infiltration parameter.

If we consider SAR calculation equation 2.4, by the increasing MBR effluent in the theoretical mixtures, low Mg^{2+} concentration and high Na^{+} concentration causes rapidly increase of SAR values which is shown in the Figure 3.87. Hence, optimum theoretical mixture of MBR effluent and permeates to increase infiltration quality to 2^{nd} class were found 0.85:0.15 for permeate 1, 2 and 4 and 0.1:0.9 for permeate 3. After the determination of optimum theoretical mixtures to increase infiltration quality, comparison of these theoretical mixtures with national irrigation standard.

After the determination of optimum theoretical mixtures to increase infiltration quality, comparison of these theoretical mixtures with national irrigation standards is given in Table 3.36.

Table 3.36 Comparison of optimum theoretical mixtures with national irrigation water standard

Parameters		Permeate 1	Permeate 2	Permeate 3	Permeate 4
Optimum theoretical ratio* (*MBR eff. : Permeates)		0.15:0.85	0.15:0.85	0.1:0.9	0.15:0.85
ECw (µS/cm)		3000.4	2937.1	477.1	2873.0
TDS (mg/L)		1562.5	1520.7	240.5	1479.2
SAR		36.5	33.1	10.9	36.0
ECw (dS/m)		30	29.4	0.47	28.7
Na (mg/L)		1374.3	1187.2	211.6	1288.7
CI (mg/L)		697.8	777.8	133.2	795.4
Salinity		2^{nd} class	2^{nd} class	2^{nd} class	2^{nd} class
Infiltration		2^{nd} class	2^{nd} class	2^{nd} class	2^{nd} class
Specific ion toxicity	**Na**	2^{nd} class; D 3^{rd} class; Y	2^{nd} class; D 3^{rd} class; Y	2^{nd} class; D 3^{rd} class; Y	2^{nd} class; D 3^{rd} class; Y
	CI	2^{nd} class; D,Y	2^{nd} class; D 3^{rd} class; Y	2^{nd} class; D 1^{st} class; Y	2^{nd} class; D,Y
	B	-	-	-	-

(Y: Surface irrigation D: Sprinkler irrigation; -: Not determined)

In addition to irrigation usage, quality of obtained permeates from different feed mixtures were also investigated and compared with the standards of cooling and boiling feed water for industrial usage. Also, reuse of product water as process water in paper and textile industries was discussed.

Obtained permeates from different feed mixtures by using NF90 membranes are compared to required water quality for power generation and cooling water application. The result is depicted in Table 3.37.

According to Table 3.37, permeates 1, 2 and 3 satisfied all parameters for using them as cooling water. But permeate 4 was not suitable to use as cooling water because of the bicarbonate hardness. There is a little difference between the required bicarbonate value and bicarbonate concentration of permeate 4.

Boiler water quality requirements are also listed and given ranges for certain parameter is depend on the operating pressure of boiler water. Higher temperature and pressure conditions require higher quality feedwater. In addition to reuse as a cooling water, permeates could be use as a boiler feedwater (Asano *et al*., 2007).

Table 3.37 Comparison of permeates quality with boiler feedwater and cooling water characteristics (Judd and Jefferson, 2013)

Water Quality Parameter (all as mg/L unless otherwise stated)	**Permeate Quality**				**Cooling Water**	**Boiler feedwater** (range is based on operating presssures)
	Permeate 1	**Permeate 2**	**Permeate 3**	**Permeate 4**		
Hardness, mg/L as $CaCO_3$	<17.8	<17.8	<17.8	<17.8	600	0.07 - 350
pH	7.22	7.35	7.14	7.08	6.9 - 9.0	7 - 10
TDS)	69.3	68.1	71.2	80.6	500	200 - 700
TSS	2.0	2.0	2.0	1.67	100	0.5 - 10
Turbidity, NTU	0.13	0.24	0.17	0.21	50	N.S
Carbonaceus Bioehemical Oxygen Demand ($C\text{-}BOD_5$)	-	-	-	-	25	1 - 50
COD	<5	<5	<5	<5	75	1 - 5
Ammonia, mg/L as N	0.020	0.020	0.022	0.028	1	0.1
Phosphate, mg/L as P	<0.05	<0.05	<0.05	<0.05	4	N.S
Aluminium	-	-	-	-	0.1	0.01 - 5
Bicarbonate	20.75	21.30	23.90	**25.97**	24	48 - 170
Chloride	27.93	34.23	37.07	49.57	500	Variable
Iron	-	-	-	-	0.5	0.05 - 1
Manganese	-	-	-	-	0.5	0.01 - 0.3
Silica	6.28	6.76	5.78	5.10	50	0.7 - 30
Sulphate	<40	<40	<40	<40	200	Variable

- **:** not measured
N.S: not specified

Also, permeates are compared to pulp and paper industry feed water characteristics and the results are shown in Table 3.38.

Table 3.38 Comparison of permeates with pulp and paper industry feed water characteristics (Asano *et al*., 2007)

Parameters	**Permeate Quality**				**Brown grades**		**White grades**	
	Permeate 1	**Permeate 2**	**Permeate 3**	**Permeate 4**	Groundwood paper	Soda and sulfate (kraft) pulps	Kraft paper, bleached	Bleached paper
Turbidity, NTU	0.13	0.24	0.17	0.21	70	35	40	14 - 56
Color	<1	<1	<1	<1	30	5	25	5 – 25
TDS, mg/L	69.3	68.1	71.2	80.6	250 – 1000	250 – 1000	300	75 – 650
TSS, mg/L	2.0	2.0	2.0	1.67	40	10	10	10 – 30
Hardness, mg/L $CaCO_3$	<17.8	<17.8	<17.8	<17.8	100 – 200	100 – 200	100	100
Cl^-, mg/L	27.93	34.23	37.07	49.57	75	75	200	200
Fe, mg/L	-	-	-	-	0.3	0.1	0.2	0.1
Mn, mg/L	-	-	-	-	0.1	0.05	0.1	0.03
SiO_2, mg/L	6.28	6.76	5.78	5.10	50	20	50	9 – 20
SO_4, mg/L	<40	<40	<40	<40	Trace	N.S	N.S	100 – 300
Temperature, ^oC	29.0	27.8	27.9	29.0	<55	27	N.S	15 – 27

- **:** not measured
N.S : not specified

Water quality requirements for pulp and paper production are varied according to grade of paper. Generally, lower quality water can be used for the brown grade papers and white grade papers require higher water quality. According to results, permeates obtained from different feed mixtures are suitable for all brown and white grades paper production process (Rommelmann *et al*., 2003).

The major water quality issues for textile production are to ensure that the dyes react properly and that discoloration or staining does not occur. Turbidity, color, iron, and manganese have the potential to cause staining of fabric during production. Hardness adversely affects soaps used in various cleaning processes and can cause curd-like deposits on the textile. Usually soaps are not deposited evenly with hard water, resulting in dyeing irregularities. Hardness may cause precipitation of some dyes and increase the breakage of silk during reeling and throwing operations (Treweek, 1982).

Table 3.39 Comparison of permeates from different feed water with typical textile industry feed water characteristics, (Asano *et al*., 2007)

Parameter	**Permeate Quality**				**Typical Textile Industry Feed Water Characteristic**
	Permeate 1	**Permeate 2**	**Permeate 3**	**Permeate 4**	
Al, mg/L	-	-	-	-	8
Color	<1	<1	<1	<1	0 - 5
Cu, mg/L	<0.5	<0.5	<0.5	<0.5	0.01 - 5
Fe, mg/L	-	-	-	-	0.1 – 0.3
Mn, mg/L	-	-	-	-	0.01 – 0.05
pH	7.22	7.35	7.14	7.08	6 - 8
SO_4, mg/L	<40	<40	<40	<40	100
TSS, mg/L	2.0	2.0	2.0	1.67	0 - 5
TDS, mg/L	69.3	68.1	71.2	80.6	100 - 200
Total Hardness, mg/L $CaCO_3$	<17.8	<17.8	<17.8	<17.8	0 - 50

- : not measured

Typical water quality requirements for the textile industry are reported in Table 3.39. According to comparison, permeates obtained from different feed mixtures by using NF90 membrane satisfied all parameters for typical textile feed water usage.

4. CONCLUSIONS

In the laboratory experiments, a cross-flow flat sheet membrane test unit and NF200 which is aromatic polyamide thin-film composite NF membrane was used to investigate NF membrane rejection performance for the treatment of RO concentrate water. In the laboratory experiment, the test was conducted by means of a cross-flow filtration system (GE Osmonics SEPA-CF-II) and RO concentrate water which was taken from DIMES beverage factory in İzmir. The test was conducted by under 10 bar of operating pressure by using NF200 flat-sheet membrane for 6 hours. Salinity, conductivity, pH, turbidity, chemical oxygen demand (COD), total dissolved solids (TDS), color, concentrations of Na^{+}, Ca^{2+}, K^{+}, Mg^{2+}, HCO_3^{-}, SO_4^{2-}, Cl^{-}, PO_4-P, NO_3-N, NO_2-N and Si were measured for feed water sample during experiment.

Average flux value of NF200 membrane was found as 25.1 L/m^2h. Flux decline was observed from time to time during the experiment. The reason of decline could be usage of high concentration of feed water which is RO concentrate water. Feed water could cause scaling or fouling on membrane surface by time.

Product water qualities obtained by NF200 membrane, feed water characteristic and average rejection for each parameters were listed in Table 3.1. It can be seen that NF200 membrane rejections are more than 50% for many parameters. NF200 membrane shows higher performance especially for divalent ions rejection.

In field test, spiral wound thin film composite NF and RO membranes were used for demineralization of MBR effluent which was taken from ITOB-OSB wastewater treatment plant in Tekeli-Menderes, Izmir where MBR process has been employed for wastewater treatment. For this purpose, a mini pilot scale membrane test unit having NF and RO membranes in spiral wound configurations was used MBR effluent of wastewater was post-treated with NF and RO processes

Different NF membranes such as NF90, NF270 and TR60 and RO membranes (BW30 and AG) are employed in mini pilot scale NF/RO membrane test system.

For the first field tests, effect of membrane type on water recovery and quality issues was investigated. For these tests, MBR treated wastewater and different NF and RO membranes were used and batch mode of operation is preferred during experiments for proper comparison of each membrane and avoid the effect of MBR effluent quality change.

Mini pilot scale NF/RO system was operated under 10 bar of operating pressure for NF membranes, while 20 bar of operating pressure was used for RO membranes for the filtration of MBR treated wastewater during 6 hours.

The average permeate fluxes of NF90, NF270 and TR60 NF membranes were found as 50.4, 64 and 54.6 L/m^2h, respectively. According to the membrane pore size, the more effective NF membrane was NF270 with a maximum permeate flux. Except for the NF90 membrane, two other NF membranes showed some decline in their fluxes after a certain time which is due to fouling or scaling on membrane surface.

The average permeate fluxes of BW30 and AG (RO) membranes were found as 65.9 and 62.7 L/m^2h, respectively. These two RO membranes exhibited similar permeate flux at the same operating pressure which is 20 bar. Permeate fluxes of these two membranes were slightly high in the first three hours of studies. For the last three hours of studies permeate fluxes reached constant value. The reason of slight increase in flux could be due to the use of virgin membrane. In the first three hours, pores of virgin membranes were enlarged by the applied pressure.

Quality of permeates obtained by NF and RO membranes was investigated measuring various parameters such as total dissolved solid (TDS), salinity, conductivity, pH, turbidity, chemical oxygen demand (COD), total suspended solid (TSS), color, Na^+, Ca^{2+}, K^+, Mg^{2+}, HCO_3^-, SO_4^{2-}, Cl^-, PO_4-P, NH_4-N, NO_3-N, NO_2-N, total nitrogen (TN), $CaCO_3$ hardness, total organic carbon (TOC) and SiO_2 concentrations.

At 10 bar of operating pressure, obtained average water recoveries of NF membranes were 50.2%, 56.0% and 51.8% for NF90, NF270 and TR60

membranes, respectively. At 20 bar of operating pressure, average water recoveries of RO membranes were 64.0% for BW30 and %62.3 AG membranes.

NF90 membrane showed the best removal efficiencies according to conductivity, salinity and total dissolved solid among NF membranes. BW30 and AG membranes had similar removal performance according to these parameters. Especially for salinity rejection, these RO membranes were highly efficient.

According to cation rejection, NF90 membrane among NF membranes, BW30 and AG RO membranes showed good removal performance. Removal percents indicated that NF membranes had better removal for divalent ions than monovalent ions. RO membranes were effective for all mono and multivalent ion rejections.

The difference in performance of the membranes observed during this work is attributed to the properties of the investigated membranes. Those properties are pore size, membrane surface charge, hydrophobic/hydrophilic characteristics and the structure or composition of the active layer of the membranes.

The data obtained in this study were compared with National Irrigation Water Standards. NF270 and TR60 membranes permeates agreed well with 3rd class for salinity and 2nd class for other parameters. On the other hand, NF90, BW30 and AG permeates provide 1st class water for all parameters except for infiltration. Infiltration problem caused by unbalanced removals of Na^{+}, Ca^{2+}, and Mg^{2+}, which impact on the SAR values. Mixing RO/NF permeates with MBR effluent in appropriate ranges may have suitable composition values and good permeability for agricultural irrigation. For the determination of optimum theoretical mixture to solve infiltration problem, salinity and specific ion toxicity values were also taken into consideration. Since the mixing MBR effluent with permeates shows adverse effect for salinity and specific ion toxicity, optimum mixing ratio should be found for utilization of treated wastewater effluents for irrigation.

Optimum theoretical mixture of MBR effluent to permeates which obtained from NF membranes were 0.2:0.8 for TR60, 0.6:0.4 for NF270 and 0.3:0.7 for NF90 membranes.

In addition to irrigation usage, qualities of product water obtained by NF and RO membranes were also investigated and compared with the standards of cooling and boiling feed waters for industrial usage. Also, reuse of product water as process water in paper and textile industries was discussed.

NF90 permeate is suitable for cooling application according to cooling water requirements except for pH value. In addition to this, NF90 permeate could be used as a boiler feedwater after pH adjusment. NF270 and TR60 permeates are not satisfied cooling water requirements because of the TDS, Mg^{2+} and Ca^{2+} values. They are also not suitable for steam generation since they do not to meet many parameters for boiler feedwater requirements.

BW30 and NF90 permeates are suitable for cooling applications according to cooling water requirements except for pH value. In addition to this, their permeates could be used as boiler feedwater after pH adjusment. In addition to pH adjustment, operating pressure requirements should be also taken into consideration because comparised boiler feed requirements are variable according to operating pressure.

Permeate obtained from NF90 is suitable for all brown and white grades paper production processes. NF270 permeate is not suitable for pulp and paper feed water usage because of TDS and chloride concentration. TR60 permeate is also not suitable for reuse in the pulp and paper industry because of TDS, chloride and hardness values. Permeate obtained by BW30 and AG membranes satisfied all brown and white grades feed water characteristics.

Finally, the obtained permeates by membranes were checked in order to use them as a typical textile industry feed water**.** The permeate obtained from NF90 are suitable for typical textile feed water usage. NF270 permeate did not meet the textile feed water requirements because of the color, TDS and total hardness values. TR60 permeate is also not suitable to use as a typical textile industry feed water because of TSS, TDS and hardness values. Permeate obtained

from BW30 and AG do not satisfy the requirements of feed water for typical textile industry.

For the second field tests, concentrate management tests issues were investigated. The aim of this study is the reduce the amount of discharged concentrate stream. For this purpose, certain amount of concentrate stream was mixed with MBR effluent and obtained mixture was used as a feed stream for NF/RO membrane test system. Feed waters were the mixture of MBR effluent to NF90 concentrate with the ratios of 4:1, 3:1, 2:1, 1:1 and obtained feed mixtures are called as feed mixtures 1, 2, 3 and 4, respectively. NF90 which is NF membrane was used and operating pressure was 10 bar during the concentrate management test. Permeates 1, 2, 3 and 4 were obtained from feed mixtures 1, 2, 3 and 4, respectively by using NF90 membrane.

During the study, continuous mode of operation was used for all experiments. Permeate was collected in the permeate tank and excess amount of concentrate stream was sent to MBR pools. Feed, permeate and concentrate samples were taken for analysis, periodically.

The average permeate fluxes were found as 52.5, 49.1, 48.3 and 48.4 L/m^2h for permeates 1, 2, 3 and 4, respectively. When the concentrate amount increases in feed mixture, permeate flux slightly decreased. The reason of flux decline could be due to membrane fouling. Fouling problem on membrane surface appeared when the concentration of feed mixtures increased.

NF90 membrane showed similar removal efficiencies according to many parameters such as conductivity, salinity, TDS, color and total hardness. On the other hand, COD, SiO_2 and TOC ions removals increased with the increases in concentrate amount in feed mixture.

According to cation rejection, NF90 membrane had good removal performance for all feed mixtures. Removals of Na^+, K^+, Mg^{2+} ions were similar for both feed mixtures but with the increases of concentrate stream amount in the feed mixture, NH_4-N and Ca^{2+} ions removals decreased slightly. One of the reason of this problem could be the concentration polarization.

During the concentrate management studies, concentrate recoveries were 35.5%, 53.5%, 69.3% and 88.2% for the feed mixtures of 1, 2, 3 and 4, respectively.

The data obtained in this study were compared with National Irrigation Water Standards. All permeates agreed well with 1st class quality for salinity and 3rd class quality for infiltration parameter. Beside this, according to specific ion toxicity parameter, all permeates were classified as 1st class for chloride ion. On the other hand, according to sodium concentration, permeates 1 and 2 obey 1st class quality and permeates 3 and 4 obey 2nd class quality for sprinkler irrigation purposes. Infiltration problem caused by unbalanced removal of the Na^{+}, Ca^{2+}, and Mg^{2+} which impact on the SAR values. Mixing permeates with MBR effluent in appropriate ranges may have suitable composition values and good permeability for agricultural irrigation.

But it was not possible to obtain 1 st class water according to infiltration parameter due to low Mg^{2+} concentration and high Na^{+} concentration in MBR effluent. If we consider SAR calculation equation 2.4, by increasing MBR effluent in the theoretical mixtures, low Mg^{2+} concentration and high Na^{+} concentration causes a rapid increase of line in Figure 3.87. Hence, optimum theoretical mixture of MBR effluent and permeates to increase infiltration quality to 2^{nd} class were found as 0.85:0.15 for permeate 1, 2 and 4 and 0.1:0.9 for permeate 3. After determination of optimum theoretical mixtures to increase infiltration quality, comparison of these theoretical mixtures should br done with national irrigation standard.

Obtained permeates from different feed mixtures by using NF90 membranes were checked whether they give water quality for power generation and cooling water application. Permeates 1, 2 and 3 agreed well with the all requirements for using them as cooling water. But permeate 4 was not suitable to use it as a cooling water because of the bicarbonate hardness. There is a little difference between the required bicarbonate value and bicorbonate concentration of permeate 4. In addition to cooling water application, permeates obey well boiler feedwater characteristics.

Permeates are also checked for pulp and paper industry feed water characteristics. Water quality requirements for pulp and paper production change according to grade of paper. Generally, lower quality water can be used for the brown grade papers but white grade papers require higher water quality. According to requirements of pulp and paper industry feed water, permeates obtained from different feed mixtures are suitable for all brown and white grades paper production process (Rommelmann *et al*., 2003).

In addition, the permeates obtained from different feed mixtures by using NF90 membrane agreed well all requirements for typical textile feed water usage.

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APPENDIX

Appendix 1: Experimental Results of ITOB MBR Treated Wastewater with NF90 Membrane with 10 Bar (Figure 3.21, 3.22, 3.23 and 3.24)

Appendix 2: Experimental Results of ITOB MBR Treated Wastewater with NF270 Membrane with 10 Bar (Figure 3.21, 3.22, 3.23 and 3.24)

Appendix 3: Experimental Results of ITOB MBR Treated Wastewater with TR60 Membrane with 10 Bar (Figure 3.21, 3.22, 3.23 and 3.24)

Appendix 4. Experimental Results of ITOB MBR Treated Wastewater with AG Membrane with 20 Bar (Figure 3.42, 3.43, 3.44 and 3.45)

Appendix 5: Experimental Results of ITOB MBR Treated Wastewater with BW30 Membrane with 20 Bar (Figure 3.42, 3.43, 3.44 and 3.45)

Appendix 6: Experimental Results of Feed Mixture 1 with NF90 Membrane with 10 Bar 142 (Figure 3.66, 3.67, 3.68 and 3.69)

Appendix 7: Experimental Results of Feed Mixture 2 with NF90 Membrane with 10 Bar (Figure 3.66, 3.67, 3.68 and 3.69)

Appendix 8: Experimental Results of Feed Mixture 3 with NF90 Membrane with 10 Bar (Figure 3.66, 3.67, 3.68 and 3.69)

Appendix 9: Experimental Results of Feed Mixture 4 with NF90 Membrane with 10 Bar (Figure 3.66, 3.67, 3.68 and 3.69)

Appendix 1 Experimental Results of ITOB MBR Treated Wastewater with NF90 Membrane with 10 Bar (Figure 3.21, 3.22, 3.23 and 3.24)

Date:06.05.2015		**Membrane: NF90**				**Bar:10 Bar**			**Feed Solution: Itob MBR Effluent**						**6 hours - Batch**		
Time	**Qc**	**Qp**	**Temperature, °C**			**Conductivity, mS/cm - µs/cm**			**TDS, mg/L**			**Salinity, ‰**			**pH**		
min	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**Conc. mS/cm**	**Feed**	**Perm.**	**Conc.**	**Feed**	**Perm.**	**Conc.**	**Feed**	**Perm.**	**Conc.**
0	134.4	-	22.5	-	-	3.55	-	-	1835	-	-	1.87	-	-	7.40	-	-
30	134.4	127.2	23.4	25.6	25.2	3.53	116.7	6.54	1820	55.1	3460	1.85	0.05	3.55	7.41	6.35	7.67
60	134.4	127.2	24.4	26.4	26.3	3.53	120.7	6.55	1820	57.1	3500	1.86	0.06	3.57	7.46	6.10	7.70
90	132.0	129.6	24.5	26.7	26.5	3.53	123.2	6.61	1819	58.3	3530	1.86	0.06	3.62	7.51	6.20	7.75
120	129.6	130.8	26.0	25.4	26.5	3.56	127.4	6.64	1835	60.2	3540	1.87	0.06	3.63	7.56	6.23	7.83
150	130.8	132.0	25.7	25.6	27.2	3.54	130.4	6.70	1828	61.1	3550	1.86	0.06	3.64	7.56	6.34	7.80
180	129.6	132.0	26.5	27.4	27.6	3.56	133.6	6.71	1836	62.7	3580	1.87	0.06	3.66	7.58	6.26	7.79
210	129.6	132.0	27.2	28.9	28.8	3.53	135.3	6.75	1821	64.2	3600	1.86	0.06	3.69	7.60	6.22	7.79
240	130.8	129.6	28.2	28.8	29.7	3.53	139.9	6.86	1819	65.3	3670	1.85	0.06	3.76	7.61	6.22	7.80
270	127.2	132.0	28.6	31.5	30.2	3.55	143.3	6.85	1824	67.8	3660	1.86	0.07	3.75	7.64	6.30	7.78
300	127.2	132.0	28.9	30.3	30.6	3.55	146.6	6.88	1838	69.2	3680	1.87	0.07	3.77	7.62	6.28	7.79
330	127.2	134.4	29.4	30.7	30.8	3.56	148.0	6.87	1839	69.6	3670	1.87	0.07	3.76	7.62	6.23	7.77
360	127.2	134.4	29.8	31.6	31.8	3.55	158.5	6.88	1839	69.3	3680	1.87	0.07	3.77	7.63	6.27	7.78

Qc: Concentrate flow rate
Qp: Permeate flow rate
Perm: Permeate
Conc: Concentrate

Appendix 2 Experimental Results of ITOB MBR Treated Wastewater with NF270 Membrane with 10 Bar (Figure 3.21, 3.22, 3.23 and 3.24)

Date:11.05.2015		**Membrane: NF270**				**Bar:10 Bar**			**Feed Solution: Itob MBR Effluent**						**6 hours - Batch**		
Time	**Qc**	**Qp**	**Temperature, °C**			**Conductivity, mS/cm - µs/cm**			**TDS, mg/L**			**Salinity, ‰**			**pH**		
min	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**min**	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**min**	**L/h**
0	134.4	-	21.5	-	-	3.42	-	-	1762	-	-	1.79	-	-	7.62	-	-
30	134.4	160.8	22.7	24.2	23.8	3.42	1981	5.07	1763	1002	2660	1.79	1.01	2.71	7.29	7.02	7.50
60	134.4	160.8	23.5	25.2	24.5	3.42	1986	5.07	1760	1003	2660	1.79	1.01	2.72	7.45	7.11	7.59
90	132	158.4	23.9	25.7	25.5	3.46	2019	5.09	1781	1016	2690	1.81	1.02	2.74	7.48	7.21	7.68
120	139.6	163.2	24.5	25.8	26.0	3.44	2015	5.10	1770	1016	2690	1.80	1.03	2.74	7.51	7.19	7.69
150	128.4	163.2	25.7	27.2	27.1	3.44	2039	5.13	1771	1028	2700	1.80	1.04	2.76	7.52	7.17	7.73
180	129.6	165.6	26.4	27.9	27.5	3.43	2044	5.13	1762	1033	2700	1.79	1.04	2.75	7.56	7.22	7.79
210	129.6	165.6	27.0	28.4	27.8	3.41	2045	5.18	1756	1032	2720	1.79	1.04	2.77	7.56	7.28	7.82
240	127.2	168	27.7	28.3	28.8	3.43	2070	5.27	1766	1048	2780	1.80	1.07	2.84	7.69	7.36	7.84
270	127.2	170.4	28.2	28.4	28.9	3.44	2094	5.19	1773	1053	2730	1.80	1.06	2.79	7.66	7.28	7.79
300	127.2	170.4	28.3	29.6	29.8	3.46	2101	5.16	1784	1055	2720	1.81	1.07	2.77	7.64	7.33	7.79
330	127.2	170.4	29.4	30.2	29.9	3.46	2084	5.16	1784	1051	2710	1.80	1.06	2.76	7.71	7.31	7.86
360	127.2	170.4	29.5	31.1	30.6	3.46	2110	5.17	1785	1067	2720	1.81	1.08	2.78	7.70	7.39	7.82

Qc: Concentrate flow rate
Qp: Permeate flow rate
Perm: Permeate
Conc: Concentrate

Appendix 3 Experimental Results of ITOB MBR Treated Wastewater with TR60 Membrane with 10 Bar (Figure 3.21, 3.22, 3.23 and 3.24)

Date:12.05.2015		**Membrane: TR60**				**Bar:10 Bar**			**Feed Solution: Itob MBR Effluent**						**6 hours - Batch**		
Time	**Qc**	**Qp**	**Temperature, °C**			**Conductivity, mS/cm - µs/cm**			**TDS, mg/L**			**Salinity, ‰**			**pH**		
min	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**min**	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**min**	**L/h**
0	134.4	-	25.1	-	-	3.32	-	-	1705	-	-	1.73	-	-	7.77	-	-
30	133.2	151.2	24.9	26.2	26.0	3.31	2640	4.10	1702	1346	2130	1.73	1.37	2.17	7.72	7.58	7.67
60	132	148.8	25.2	26.3	25.9	3.31	2650	4.09	1704	1348	2124	1.73	1.36	2.16	7.70	7.65	7.77
90	133.2	146.4	26.0	27.6	27.5	3.31	2670	3.98	1704	1363	2064	1.73	1.38	2.10	7.70	7.65	7.77
120	134.4	144	26.7	28.1	28.1	3.31	2680	3.97	1702	1360	2058	1.73	1.38	2.10	7.75	7.61	7.81
150	134.4	142.8	27.5	28.4	28.5	3.31	2650	3.96	1703	1352	2055	1.73	1.38	2.09	7.76	7.68	7.80
180	134.4	141.6	28.0	29.1	29.0	3.31	2690	3.97	1702	1364	2055	1.73	1.38	2.09	7.78	7.69	7.79
210	132	142.8	28.5	29.7	29.2	3.32	2670	3.94	1705	1359	2043	1.73	1.37	2.08	7.82	7.71	7.84
240	134.4	139.2	29.1	29.9	29.8	3.29	2700	3.92	1692	1384	2036	1.73	1.40	2.08	7.77	7.71	7.79
270	132	141.6	28.6	30.0	29.0	3.32	2690	3.95	1708	1374	2052	1.73	1.38	2.09	7.81	7.71	7.83
300	132	139.2	29.6	30.5	30.3	3.32	2720	3.96	1713	1394	2057	1.73	1.42	2.09	7.77	7.67	7.78
330	132	138	28.9	30.3	29.7	3.32	2730	3.96	1710	1385	2048	1.73	1.40	2.08	7.80	7.70	7.82
360	129.6	139.2	29.9	30.9	30.6	3.31	2720	3.94	1701	1388	2050	1.73	1.41	2.09	7.78	7.68	7.81

Qc: Concentrate flow rate
Qp: Permeate flow rate
Perm: Permeate
Conc: Concentrate

Appendix 4 Experimental Results of ITOB MBR Treated Wastewater with AG Membrane with 20 Bar (Figure 3.42, 3.43, 3.44 and 3.45)

Date: 25.05.2015		**Membrane: AG**				**Bar: 20 Bar**			**Feed Solution: Itob MBR Effluent**						**6 hours - Batch**		
Time	**Qc**	**Qp**	**Temperature, °C**			**Conductivity, mS/cm - µs/cm**			**TDS, mg/L**			**Salinity, ‰**			**pH**		
min	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**min**	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**min**	**L/h**
0	139.2	-	24.3	-	-	3.01	-	-	1541	-	-	1.56	-	-	7.61	-	-
30	138.0	148.8	25.0	26.6	26.7	3.00	63.6	5.79	1531	30.0	3060	1.56	0.03	3.16	7.39	5.77	7.61
60	117.6	148.8	25.9	27.9	27.3	3.01	65.3	5.91	1541	30.7	3140	1.56	0.03	3.21	7.48	5.93	7.71
90	105.6	158.4	26.8	28.7	28.7	3.01	72.5	6.51	1543	34.1	3450	1.56	0.03	3.53	7.57	5.90	7.81
120	93.6	158.4	27.1	29.4	29.1	3.00	78.7	6.82	1537	37.1	3640	1.56	0.04	3.73	7.56	6.00	7.85
150	93.6	160.8	28.0	30.6	30.2	3.00	88.9	7.40	1536	41.6	3970	1.56	0.04	4.07	7.48	5.96	7.89
180	88.8	163.2	28.6	31.6	30.9	3.00	91.9	7.54	1537	43.3	4060	1.56	0.04	4.18	7.65	5.95	7.89
210	88.8	165.6	30.5	32.5	32.1	3.00	98.0	7.86	1534	46.2	4220	1.56	0.04	4.32	7.64	5.99	7.88
240	76.8	166.8	30.5	32.0	32.1	3.00	101.0	8.01	1535	47.7	4320	1.56	0.05	4.43	7.72	5.83	7.90
270	76.8	170.4	30.6	32.3	32.5	3.00	113.2	8.69	1536	53.5	4690	1.56	0.05	4.82	7.70	5.97	7.84
300	75.6	170.4	30.7	33.3	32.8	3.01	115.8	8.82	1543	54.9	4780	1.56	0.05	4.92	7.72	6.04	7.93
330	75.6	168.0	30.9	33.2	33.2	3.00	118.2	8.90	1540	55.4	4820	1.56	0.05	4.96	7.70	6.06	7.86
360	75.6	170.4	32.6	35.1	33.8	3.03	116.3	8.78	1553	54.8	4760	1.56	0.05	4.90	7.68	6.02	7.88

Qc: Concentrate flow rate
Qp: Permeate flow rate
Perm: Permeate
Conc: Concentrate

Appendix 5 Experimental Results of ITOB MBR Treated Wastewater with BW30 Membrane with 20 Bar (Figure 3.42, 3.43, 3.44 and 3.45)

Date: 20.05.2015		**Membrane: BW30**				**Bar: 20 Bar**			**Feed Solution: Itob MBR Effluent**						**6 hours - Batch**		
Time	**Qc**	**Qp**	**Temperature, °C**			**Conductivity, mS/cm - µs/cm**			**TDS, mg/L**			**Salinity, ‰**			**pH**		
min	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**min**	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**min**	**L/h**
0		-	23.1	-	-	3.15	-	-	1618	-	-	1.64	-	-	7.95	-	-
30	134.4	158.4	23.8	24.2	25.6	3.16	46.0	6.44	1623	21.52	3430	1.65	0.02	3.51	7.76	6.04	7.55
60	127.2	163.2	24.9	27.3	26.8	3.14	57.3	6.79	1611	27.0	3620	1.64	0.03	3.71	7.72	6.24	7.75
90	115.2	165.6	26.1	27.7	27.2	3.16	56.2	7.25	1619	26.4	3880	1.65	0.02	3.97	7.66	6.55	7.88
120	110.4	165.6	26.7	28.8	28.7	3.14	59.2	7.45	1613	27.7	4000	1.64	0.03	4.10	7.72	6.63	7.90
150	98.4	172.8	26.6	28.2	29.5	3.16	60.9	7.87	1624	28.6	4260	1.65	0.03	4.37	7.72	6.73	7.92
180	98.4	170.4	27.6	29.9	29.4	3.15	66.6	7.93	1620	31.3	4290	1.64	0.03	4.40	7.71	6.37	7.94
210	98.4	172.8	28.4	29.9	29.8	3.15	65.1	8.12	1615	30.4	4380	1.64	0.03	4.49	7.77	6.42	7.95
240	97.2	175.2	28.2	29.6	29.2	3.16	70.4	8.33	1624	33.0	4500	1.65	0.03	4.63	7.78	6.38	7.99
270	93.6	175.2	29.8	31.9	31.5	3.17	72.3	8.36	1629	34.1	4490	1.65	0.03	4.62	7.75	6.07	7.90
300	91.2	176.4	30.0	32.0	31.6	3.17	71.1	8.42	1626	33.5	4550	1.65	0.03	4.70	7.78	6.49	7.95
330	93.6	177.6	30.7	32.4	32.4	3.17	72.0	8.33	1629	33.6	4500	1.65	0.03	4.62	7.85	6.56	7.95
360	91.2	177.6	31.4	32.8	32.7	3.18	75.9	8.65	1631	35.4	4680	1.65	0.03	4.80	7.87	6.47	7.99

Qc: Concentrate flow rate
Qp: Permeate flow rate
Perm: Permeate
Conc: Concentrate

Appendix 6 Experimental Results of Feed Mixture 1 with NF90 Membrane with 10 Bar (Figure 3.66, 3.67, 3.68 and 3.69)

Date: 22-06-2015			**Membrane: NF90**				**Bar: 10**			**Feed Solution: Feed Mixture 1**						**3 hours**		
Time	**Q_f[a]**	**Q_c[a]**	**Q_p**	**Temperature, °C**			**Conductivity, mS/cm - µs/cm**			**TDS, mg/L**			**Salinity, ‰**			**pH**		
min	**L/h**	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**Conc. mS/cm**	**Feed**	**Perm.**	**Conc.**	**Feed**	**Perm.**	**Conc.**	**Feed**	**Perm.**	**Conc.**
0	-	-	-	27.2	-	-	3.53	-	-	1826	-	-	1.85	-	-	7.48	-	-
30	223.2	60	139.2	27.5	28.5	28.6	3.60	126.7	6.37	1855	60.0	3400	1.89	0.06	3.48	7.50	6.80	7.44
60	218.4	60	136.8	28.0	28.8	28.4	3.75	136.2	6.56	1937	64.5	3490	1.97	0.06	3.58	7.57	7.06	7.56
90	220.8	57.6	136.8	27.8	28.8	28.8	3.90	145.5	6.83	2024	69.0	3650	2.06	0.07	3.74	7.61	7.26	7.67
120	223.4	58.8	134.4	28.4	29.0	29.1	4.02	151.9	6.98	2086	72.1	3720	2.12	0.07	3.82	7.76	7.46	7.73
150	223.2	55.2	135.6	28.3	29.9	29.3	4.08	156.1	7.12	2123	74.0	3820	2.16	0.07	3.91	7.72	7.32	7.80
180	223.2	58.8	135.6	28.8	29.3	29.5	4.15	159.6	7.23	2156	76.0	3870	2.20	0.07	3.96	7.76	7.44	7.80

[a] :Recyled amount

Qc: Concentrate flow rate
Qp: Permeate flow rate
Perm: Permeate
Conc: Concentrate

Appendix 7 Experimental Results of Feed Mixture 2 with NF90 Membrane with 10 Bar (Figure 3.66, 3.67, 3.68 and 3.69)

Date: 23-06-2015			**Membrane: NF90**				**Bar: 10**			**Feed Solution: Feed Mixture 2**						**3 hours**		
Time	**Q_f[a]**	**Q_c[a]**	**Q_p**	**Temperature, °C**			**Conductivity, mS/cm - µs/cm**			**TDS, mg/L**			**Salinity, ‰**			**pH**		
min	**L/h**	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**Conc. mS/cm**	**Feed**	**Perm.**	**Conc.**	**Feed**	**Perm.**	**Conc.**	**Feed**	**Perm.**	**Conc.**
0	-	-	-	26.2	-	-	3.43	-	-	1777	-	-	1.80	-	-	7.86	-	-
30	222	81	129.6	26.7	27.3	27.7	3.62	122.0	6.26	1873	57.5	3320	1.90	0.06	3.40	7.66	7.21	7.75
60	225	82.5	129.6	27.1	27.8	28.0	3.76	129.5	6.41	1944	61.3	3410	1.98	0.06	3.49	7.63	7.27	7.78
90	219	81	127.2	26.8	27.8	27.5	3.92	142.0	6.73	2031	67.2	3590	2.07	0.07	3.69	7.60	7.37	7.83
120	222	82.5	127.2	27.3	27.9	27.9	4.09	149.7	6.98	2126	71.0	3730	2.16	0.07	3.82	7.67	7.55	7.86
150	219	82.5	127.2	27.1	27.9	27.5	4.22	156.5	7.14	2200	74.0	3820	2.24	0.07	3.92	7.84	7.58	7.95
180	219	82.5	124.8	27.7	28.7	27.8	4.30	163.8	7.32	2240	77.5	3920	2.28	0.08	4.02	7.81	7.32	7.99

[a] :Recyled amount

Qc: Concentrate flow rate
Qp: Permeate flow rate
Perm: Permeate
Conc: Concentrate

Appendix 8 Experimental Results of Feed Mixture 3 with NF90 Membrane with 10 Bar (Figure 3.66, 3.67, 3.68 and 3.69)

Date: 24-06-2015			**Membrane: NF90**				**Bar: 10**			**Feed Solution: Feed Mixture 3**						**3 hours**		
Time	**Q_f[a]**	**Q_c[a]**	**Q_p**	**Temperature, °C**			**Conductivity, mS/cm - µs/cm**			**TDS, mg/L**			**Salinity, ‰**			**pH**		
min	**L/h**	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**Conc. mS/cm**	**Feed**	**Perm.**	**Conc.**	**Feed**	**Perm.**	**Conc.**	**Feed**	**Perm.**	**Conc.**
0	-	-	-	26.2	-	-	3.42	-	-	1764	-	-	1.79	-	-	7.85	-	-
30	204	108	127.2	26.6	27.4	27.7	3.55	123.8	6.22	1836	58.4	3310	1.86	0.06	3.39	7.77	7.06	7.83
60	201.6	108	129.6	26.5	27.0	27.2	3.81	130.9	6.46	1974	61.9	3440	2.01	0.06	3.51	7.83	7.18	7.88
90	204	105.6	127.2	27.0	27.5	28.1	3.99	146.2	6.91	2073	69.3	3700	2.11	0.07	3.80	7.83	7.12	7.93
120	204	108	127.2	27.6	28.2	28.1	4.22	157.7	7.25	2195	74.8	3880	2.24	0.07	3.98	7.67	7.22	7.93
150	200.4	105.6	122.4	27.6	27.9	28.1	4.51	164.5	7.47	2360	78.3	4010	2.41	0.08	4.12	7.93	7.14	7.97
180	201.6	108	120	28.3	29.6	28.9	4.64	177.6	7.76	2420	84.3	4170	2.47	0.08	4.28	7.92	7.10	7.97

[a] :Recyled amount

Qc: Concentrate flow rate
Qp: Permeate flow rate
Perm: Permeate
Conc: Concentrate

Appendix 9 Experimental Results of Feed Mixture 4 with NF90 Membrane with 10 Bar (Figure 3.66, 3.67, 3.68 and 3.69)

Date: 25-06-2015			**Membrane: NF90**				**Bar: 10**			**Feed Solution: Feed Mixture 4**						**3 hours**		
Time	**Q_f[a]**	**Q_c[a]**	**Q_p**	**Temperature, °C**			**Conductivity, mS/cm - µs/cm**			**TDS, mg/L**			**Salinity, ‰**			**pH**		
min	**L/h**	**L/h**	**L/h**	**Feed**	**Perm.**	**Conc.**	**Feed mS/cm**	**Perm. µs/cm**	**Conc. mS/cm**	**Feed**	**Perm.**	**Conc.**	**Feed**	**Perm.**	**Conc.**	**Feed**	**Perm.**	**Conc.**
0	-	-	-	26.5	-	-	3.35	-	-	1726	-	-	1.75	-	-	7.77	-	-
30	146.4	139.2	132	27.0	28.0	28.1	3.54	119.0	6.20	1827	56.2	3290	1.86	0.05	3.37	7.72	7.25	7.83
60	145.2	136.8	127.7	27.7	28.3	28.3	4.07	136.9	6.93	2113	64.8	3700	2.15	0.06	3.80	7.77	6.91	7.86
90	144	136.8	127.7	28.0	28.4	28.8	4.46	161.0	7.39	2330	75.6	3960	2.37	0.07	4.07	7.78	7.06	7.90
120	141.6	134.4	124.8	27.9	28.8	27.9	4.88	177.9	8.18	2560	84.2	4410	2.62	0.08	4.54	7.88	7.16	7.93
150	139.2	135.6	122.4	28.5	29.6	29.3	5.19	199.4	8.78	2730	95	4750	2.79	0.09	4.90	7.85	6.98	7.96
180	141.6	136.8	120	29.2	29.9	29.5	5.64	225	9.34	2890	107.5	5080	3.05	0.11	5.22	7.90	6.91	7.96

[a] :Recyled amount

Qc: Concentrate flow rate
Qp: Permeate flow rate
Perm: Permeate
Conc: Concentrate