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أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان: دراسة مقارنه بين أداء النانو فلتر والتناضح العكسي في تحليه مياه شديدة الملوحه

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The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification

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Comparative study between the performance of NF and RO membranes in desalination of saline water

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **ضياء أنور فهمي أبوعاصي** لنيل درجة الماجستير في **كلية *الهندسة*** قسم **الهندسة المدنية – البنى التحتية** وموضوعها:

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comparative study between the performance of NF & RO membranes in Desalination of saline water

وبعد المناقشة التي تمت اليوم السبت 18 ذو القعدة 1435هـ، الموافق 2014/09/13م الساعة الحادية عشرة صباحاً، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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والله ولي التوفيق ،،،

مساعد نائب الرئيس للبحث العلمي وللدراسات العليا

أ.د. فؤاد علي العاجز

ABSTRACT

Gaza Strip suffers from scarcity of drinking water sources, Where groundwater is the main source of drinking water, as a result of the substantial increase in the number of population in the Gaza Strip led to the disruption of equilibrium. So that a consumption rate of groundwater much bigger than the supply, which led to the poor quality of the water and lack of compatibility with the WHO standards for drinking water quality, both in the physical and chemical properties. So several desalination plants set up, all of these stations used Reverse Osmosis (RO) membranes, which need large quantities of pressure which means the consumption of large amounts of energy, while the limited sources of energy had to be a search for techniques less energy-consuming.

This research aims to work a comparative study between (RO) membranes and Nanofiltration (NF) in terms of the ability to remove TDS and NO_3, as well as the amount of water produced at each pressure, in the same conditions and energy consumption compared in each of these cases.

A small desalination unit was installed and used to compare two different types of membrane NF90-4040 Nanofiltration and TM-710 Reverses Osmosis membrane, where both types have been tested in the same conditions and using different types of water.

Three types of water were used (aqueous solution, real brackish water and seawater) were examined the effectiveness of each membrane by measuring the flux rate and rejection rate of TDS and NO_3, the concentration of TDS in aqueous solution ranging from (4500 to 17000) ppm and the concentration of nitrates from (0 to 150) ppm, under different operating pressures ranging from (6 to 24) bar.

The results show that the productivity of NF membranes were more than that using RO membrane. Results also showed the possibility of using NF membranes to product drinkable water agreed with WHO guideline when the feed water TDS concentration less than 9,281 ppm. Also NF membranes can be used as pretreatment when the feed water TDS concentration more than 9,281 ppm also it can be used as pretreatment for desalinating sea water .

The results indicate that the efficiency of nitrate rejection affected overall concentration of feed water TDS concentration, as well as the nitrate rejection rate using NF membrane could be up to 95% while nitrate rejection rate using RO membrane may reach greater than 98 %, according to feed water TDS concentration and the pressure used.

Results indicated clearly that the use of NF membranes can provide a rate of 25 to 60% of energy compared with the use of RO membranes, according to feed water TDS concentration.

Finally we can say that the NF90 membrane effective for TDS and nitrate removal at high permeate flux and low applied pressure, also it can be say that the use of NF membranes, as pretreatment in a sea water and with feed water TDS concentration more than 9,281 ppm or main treatment with water of TDS concentration less than 9,281 ppm we can say that it is a better economic choice of RO membrane technology Gaza

الملخص

يعاني قطاع غزة من شح في مصادر مياه الشرب، حيث تعتبر المياه الجوفية المصدر الاساسي لمياه الشرب، ونتيجة للزيادة الكبيرة في عدد السكان في قطاع غزة حيث ادى ذلك الى اختلال الاتزان بحيث اصبح معدل استهلاك المياه الجوفية اكبر بكثير من الامداد المائي الداخل لها، الامر الذي ادى الى سوء جودة هذه المياه وعدم توافقها مع معايير منظمة الصحة العالمية لجودة مياه الشرب سواء في الخواص الفيزيائية او الكيميائية، لذلك تم انشاء العديد من محطات تحلية المياه الجوفية حيث استخدمت جميع هذه المحطات اغشية التناطح العكسي (RO) والتي تحتاج الى كميات كبيرة من الضغط الامر الذي يعني استهلاك كميات كبيرة من الطاقة، في حين ان مصادر الطاقة محدودة ايضا كان لابد من البحث عن تقنيات اقل استهلاكا للطاقة.

يهدف هذا البحث الى عمل دراسة مقارنة بين اغشية (RO) واغشية النانو فلتر(NF) من حيث القدرة على ازالة الاملاح الذائبة والنترات وكذلك كمية المياه المنتجة عند كل ضغط وفي نفس الظروف ومقارنة استهلاك الطاقة في كل حالة من تلك الحالات.

من اجل ذلك تم تركيب وحدة تحلية صغيرة حيث تم استخدام نوعين مختلفين من الاغشية غشاء نانو فلتر NF90-4040 واخر غشاء تناطح عكسي TM-710 حيث تم اختبار كلا النوعين في نفس الظروف وباستخدام انواع مختلفة من المياه.

تم استخدام ثلاثة انواع من المياه (محلول مائى ـ مياه ابار ـ ماء بحر) وتم فحص فعالية كل غشاء من خلال قياس معدل التدفق الانتاجية وقدرة الغشاء على ازالة الا ملاح الذائبة والنترات حيث تراوح تركيز الاملاح في المحلول من٤٥٠٠ حتى ١٧٠٠٠ملجرام/لتر وتركيز النترات من الصفر حتى ١٥٠ملجرام /لتر وتحت ضغوط مختلفة من ٦حتى ٢٤بار.

اشارت النتائج الى ان انتاجية اغشية النانو اكثر من انتاجية RO عند نفس الضغط ، كما اشارت النتائج الى امكانية استخدام اغشية النانو حيث لديها القدرة على انتاج ماء يتوافق مع القيم الارشادية لمنظمة الصحة العالمية لجودة المياه وذلك عندما تكون الاملاح الذائبة في المياه المحلاة اقل من ٩٢٨١ ملجرام/لتر كما يمكن استخدام اغشية NF كمرحلة معالجة اولية بحيث تمكن من تقليل الطاقة المستخدمة وكذلك تقليل من احتمالية تسديد الاغشية عندما تكون الاملاح في المياه المحلاة عالية مثل مياه البحر او المياه التى يزيد تركيز الاملاح الذائبة فيها عن ٩٢٨١ ملجرام /لتر.

كما اشارت النتائج الى ان كفاءه ازالة النترات تتأثر بشكل عام بتركيز الاملاح الذائبة ،وكذلك بأن ازاله النترات باستخدام NF قد يصل الى نسبة ٩٥% بينما نسبة ازاله النترات باستخدام RO قد تصل اكبر من ٩٨% وذلك وفقاً لنوعية المياه المراد تحليلها والضغط المستخدم.

اشارت النتائج بشكل واضح الى ان استخدام اغشية NF يمكن يوفر ما نسبته 25 الى 60 %من الطاقة وذلك بالمقارنة مع استخدام اغشية ROوذلك وفقا لنوعية المياه المراد تحليلها.

في النهاية يمكن القول ان الغشاء NF90 تقنيته فعالة للتخلص من الاملاح الذائبة وكذلك النترات ويمكن ان تعطى معدل تدفق "انتاجية" عالية باستخدام ضغط منخفض كما يمكن القول ان استخدام اغشية النانو سواء كمرحلة اولى في المعالجة في حالة مياه البحر و المياه التي يزيد تركيز الاملاح فيها عن ٩٢٨١ ملجرام/لتر او كمرحلة معالجة اساسية في حالة المياه التي يقل فيها تركيز الاملاح الذائبة عن ٩٢٨١ ملجرام /لتر يمكن القول انها خيار اقتصادي افضل من تقنية التناطح العكسي المستخدم في غزة.

DEDICATION

This research is dedicated to:

My Father and Mother for their love, pray, and continuous sacrifices…

TO my wife and my son Anwar and my daughter Raneem

And all of my brothers and sisters

TO ALL OF MY FRIENDS AND COLLEAGUES…

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LIST OF ABBREVIATIONS

BAT	Best Available Technologies
BW	Brackish water
BWRO	Brackish water Reverse Osmoses
CA	Cellulose Acetate
CMWU	Coastal Municipalities Water Utility
EC	Electrical Conductivity
ED	Electrodialysis
EDR	Electro-dialysis reversal
EPA	Environment Protection Agency
EPA	Environmental Protection Agency
FO	Forward Osmosis
FW	Fresh Water
HTD	High-temperature distillation system
IEC	Israel Electric Corporation
IX	Ion Exchange
LTD	Low-temperature distillation system
MAC	Maximum Acceptable Concentration
MASWDP	Middle Area Sea Water Desalination Plant
MCL	Maximum Concentration Level
MCM	Million Cubic Meters
MD	Membrane distillation
MED	Multiple effect distillation
MED|MEE	multiple-effect distillation| multiple-effect evaporator
MENA	Middle East and North Africa
MF	Microfiltration
MOA	Ministry of Agriculture
MOH	Ministry of Health
MSF	Multistage Flash Distillation
NF	Nanofiltration
NO_3	Nitrate
NOM	Neutral Organic Martial
PA	Polyamide Acetate
PWA	Palestinian Water Authority
PWA	Palestinian Water Authority
RO	Reverse Osmoses
SWM	Spiral wound modules
TDS	Total Dissolved Solids

TFC	Thin film composite
UF	Ultrafiltration
UNDP	United Nations Developing Program
VC	Vapor compression system
GPP	Gaza Power Plant
WHO	World Health Organization
OLR	Organic Loading Rate
HRT	Hydraulic Retention Time
SRT	Sludge Retention Time
CFV	Cross Flow Velocity

LIST OF UNITES

µm	Micro meter
Km	Kilometre
Km^2	Square Kilometre
L/c/d	Litter per capita per day
$L/m^2.hr$	Litter per square meter per hour
$L/m^2.hr.bar$	Litter per square meter per hour per bar
$L/(m^2.hr.bar)$	Litter per square meter per hour per bar
m^2	Square meter
m^3	Cubic meter
m^3/d	Cubic meter per day
m^3/hr	Cubic Meter per hour
m^3/y	Cubic meter per year
MCM	Million Cubic Meter
psi	Pounds per square inch
Ppm	Part per million
KWh	Kilo Watt per hour
µs	Micro Siemens

CHAPTER 1 : Introduction

1.1 Background

Water is a limited finite resource, vital for the very existence of life on earth and a necessity for economic and social development and for environmental sustainability, is becoming a scarce commodity. This is caused by the population growth, the change of lifestyle, water pollution.

The Gaza Strip is a narrow area lying along the southwestern portion of the Palestinian coastal plains, its area is about 365 km2. The length is about 45 km on the western Mediterranean coast and the width varies from 7 km to 12 km.

In the Gaza Strip area in Palestine, there is a large gap between water resources and demand, and the groundwater aquifer is deteriorated because of pollution, increasing demands and the Israeli control of Palestinian water resources.

Since Gaza is very small with the highest population density in the world, urgent action should be taken to meet the increasing demand for water. Such as seawater desalination as an alternative source of water supply(Baalousha, 2006)

Desalination process represent the appropriate solution for this crisis which is the process of removing dissolved solids from brackish water and seawater to produce potable water. The amount of salt in water is usually described by the concentration of total dissolved solids (TDS) in the water. TDS refers to the sum of all minerals, metals, cations and anions dissolved in water. Water that contains significant amounts of dissolved salts is called saline water, and is expressed as the amount of TDS in water in ppm.(DACH, 2008)

Seawater is characterized by having high degree of hardness, varying turbidity and bacterial contents and high TDS(Hilal. et al., 2005) and has a salt concentration in the order of 35000 ppm. More than seventy elements are dissolved in seawater, but only two elements (Chloride and Sodium) make up greater than 85% by weight of all the dissolved water.

Brackish water contains less TDS than seawater but more than freshwater. The TDS concentrations in brackish water can range between1000 ppm to15000 ppm

Nanofiltration membrane is a type of pressure driven membrane that has properties in between those of ultrafiltration (UF) and reverse osmosis (RO) membranes, NF membranes have the advantages of providing a high water flux at low operating pressure and maintaining a high salt and organic matter rejection The NF process benefits from ease of operation, reliability and comparatively low energy consumption as well as high efficiency of pollutant removal (Hilal. et al., 2005).

In the Gaza Strip there is no desalination plant using nanotechnology. The aim of this research to compare between the using of RO technology and NF for desalination of sea and brackish water by removing TDS and NO_3.

1.2 Problem Statement

During the last few decades, groundwater quality has been deteriorated to a limit that the municipal tap water became brackish and unsuitable for human drinking consumption in most parts of the strip, as shown in Table (1-1).

Due to excessive usage of nitrate fertilizer in agriculture and discharging of wastewater from treatment plants, and leakage of wastewater form cesspools, nitrate level in the groundwater has increased (Mogheir and Albahnasawi, 2014).

Table (1-1): Potability of groundwater in the Gaza Strip (PWA, 2013)

Dissolved substances	Acceptable concentration (ppm) WHO Guidelines	Gaza concentration (ppm)
Total dissolved solid	500	381-20026
Sodium (Na^+)	20	41-5900
Chloride (Cl^-)	250	57-11431
Calcium (Ca^{+2})	36	8-99
Sulfate (So_4^{-2})	250	3-1542
Magnesium (Mg^{+2})	30	1.62-99
Nitrate (NO_3)	45	2.9-496

Contamination of this water will cause many effect on health, babies below the age of six months who drink water containing nitrate in excess of the max-contamination level (MCL) could become seriously ill and, if untreated, may die.

Due to the sharp shortage of water and the bad quality of groundwater, desalination plants were set up in the Gaza Strip area in Palestine. Currently, there are six reverse osmosis desalination plants in the Gaza Strip owned and operated by the Palestinian Water Authority (PWA) and different municipalities. In addition, there are many small desalination units owned and operated by private investors for commercial purposes (Baalousha, 2006).

Desalination plants began to be established in Gaza strip using RO technique to correspond with Environmental Protection Agency EPA standard level as shown in table (1-2). The shortage of energy source become a big constrain facing desalination plants of which these plants are operating at limited operational hours, The need to find more choices to develop water sector in Gaza Strip become an essential priority(Mogheir and Albahnasawi, 2014).

There are no resources of renewable energy in Gaza strip that will need for operation of these plant is another problem. Nanofiltration technology can wangle from the contamination with low operation pressure, high flux, high retention of multivalent anion salt.

Table (1-2) secondary standard for drinking water, based on EPA

Contaminant	Level	Contaminant effects
Aluminum	0.05-0.2 ppm	Water discoloration
Chloride	250 ppm	Taste, Pipe corrosion
Color	15 color units	Aesthetic
Copper	1 ppm	Taste, porcelain staining
Corrosivity	Noncorrosive	Pipe leaching of lead
Fluoride	2ppm	Dental fluorosis
Foaming agents	0.5 ppm	Aesthetic
Iron	0.3 ppm	Taste, laundry staining
Manganese	0.05 ppm	Taste, laundry staining
Odor	3 threshold odor	Aesthetic
PH	6.5-8.5	Corrosive
Silver	0.1 ppm	Skin discoloration
Sulfate	250 ppm	Taste, laxative
Total Dissolved solid	500 ppm	Taste, corrosively, detergent

1.3 Goals

The main goal of this study is to a comparison between the performance of NF and RO membrane in the flux, recovery rate, TDS and nitrate rejection rate and energy consumption using brackish and saline water.

1.4 Objectives

The objectives of this research are:

- Determine the technical and energetic limits in which Nanofiltration (NF) operation can replace advantageously RO operation in the desalinaton of brackish water and saline water feeds.
- a comparison between the performance of NF and RO membrane in the flux, recovery rate, TDS and nitrate rejection rate and energy consumption
- Determine the economical limits in which Nanofiltration (NF) operation could replace advantageously RO operation in the treatment of brackish water and see water feeds .

1.5 Methodology

It is intended to achieve the objectives of the study by the following steps:

1.5.1 Literature review

Revision of accessible references as books, studies and researches relative to the topic of this research which may include: Nanofiltration, Reverse Osmoses, Nitrate removal, Desalination, Membrane ..etc.

1.5.2 Data collection

Data gathering from relevant authorities such as Palestinian water authority, Coastal municipalities water utility, Ministries and others that includes details and time series data about different parameters (TDS, PH, NO_3) for municipal wells in Gaza strip.

1.5.3 Sample collection and preparing

Water samples was collected from different municipal wells distributed the TDS concentration in this sample will be mildly brackish, moderately brackish, saline and sea water. The number of samples that collected were six sample. Another solution was prepared in laboratory. The TDS concentrated in solution was 4500, 11500 and 17,000 ppm. The nitrate concentrate was zero, 80 and 150 ppm.

1.5.4 Water Sample Analysis

After collecting the samples, major chemical analysis will performed for these samples such as (Ph, TDS, NO_3) and then operate the unit at different operating pressure (6-8-10-12-14-16-18-20-22-24) bar using different two type of membrane (TM-710 and NF90-4040) the total number of tests were 220 test as shown in table (1-3).

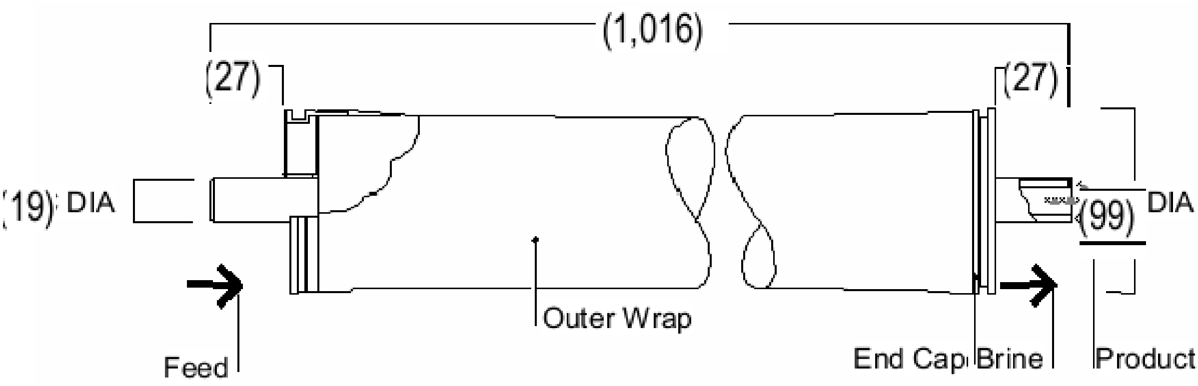
Table (1-3): Total number of tests.

Samples	Number of samples	Number of test (#sample*operating Pressure* type of membrane)
Sample from well and sea water	6	6*10*2=120
Solution sample	5	5*10*2=100
Total	11	220

1.6 RO and NF Experiment

System Component :

the system consist of (House membrane, Nanofiltration Membrane, Reverses Osmosis Membrane, Flow meter, Pump, Electricity control panel, Pipes), figure (1-1) illustrated the configuration of NF90-4040 membrane



Figure(1-1) : NF90-4040 Membrane Unit (mm)

1.7 Expected Results

1. Testing the efficiency of NF in desalination of sea water and brackish water.
2. Comparison between using of NF and RO in the desalination of sea and brackish water.
3. Relation between Nitrate rejection rate and pressure.
4. Relation between TDS rejection rate and pressure.
5. Relation between Nitrate rejection rate and TDS concentration in feed water (PH and Pressure fixed).
6. Relation between flux rate and pressure.
7. Relation between Nitrate rejection rate and Nitrate concentration in feed water.
8. Relation between TDS rejection rate and TDS concentration in feed water.

1.8 Thesis Outline

The thesis is composed of the following six chapters that cover the subject as illustrated

1. Chapter One (Introduction): Includes a general background about scare water problem in Gaza Strip and polluted with NO_3. Follows by statement of the problem, objectives, methodology used in order to achieve the objectives and thesis outline.
2. Chapter Two (Literature Review): Covers a general literature review about desalination technology, membrane classification, performance evaluation and technology of removing TDS and NO_3.
3. Chapter Three (Water situation and Study Area): Describes the study area with respect to its location, population, water quality and quantity and rainfall, geology, desalination experience and electricity catastrophe.
4. Chapter Four (Material and Methods): Discusses the Material and Methods of study including Experimental description, Experimental apparatus, Measurement and analytical method and Experimental Procedure.
5. Chapter Five (Results and Discussion): Presents the result of the use of NF&RO membrane and the factor effecting on flux and rejection of TDS and NO3 and comparison between these results.
6. Chapter Six (Conclusions and Recommendations): Presents the main conclusions and recommendations of study.

CHAPTER 2 : Literature Review

Desalination refer to the removal of salts and minerals from water, Salt water is desalinated to produce fresh water suitable for human consumption or irrigation using different technology and different types of membrane technology, this chapter will cover the desalination technology, membrane classification, comparison between NF and RO membrane and finally the performance evaluation for each membrane technology.

2.1 Desalination Technology

Desalination of water is the process that separates seawater into fresh water with low concentration of salts and impurities, and concentrated brine water. Fresh water desalinated from the process has a good quality for drinking and suitable for irrigation. This process requires a type of energy for separation with different technologies. Desalination is a widespread technology used in the world especially in the Middle East countries .

The water desalination processes require significant quantities of energy to achieve the salt separation and to get fresh water. The amount and type of the energy required differs according to the used technique (Ahmed et al., 2002).

Many different desalination technologies exist to separate dissolved salts from water. Water desalination can be accomplished by different techniques that can be classified into two categories: thermal and membrane processes. The thermal processes can be subdivided into the following processes:(i) Multistage flash evaporation, (ii) Multiple effect distillation and (iii) Vapor compression. The membrane processes are subdivided into: (i) Reverse osmosis (ii) Electrodialysis and (iii) Nanofiltration (DACH, 2008).

The choice of technology used for water desalination depends on a number of site specific factors, including source water quality, the intended use of the water produced, plant size, capital costs, energy costs and the potential for energy reuse (Al-Subaie et al. 2007)

2.1.1 Thermal Technology

Thermal technologies are based on the concept of using evaporation and distillation processes. Modern thermal-based technologies are mostly developed as dual-purpose power and water desalination systems, table (2-1) illustrated advantages and disadvantages of thermal distillation (Younos and Tulou, 2005).

Thermal desalination technologies include low-temperature distillation system (LTD), high-temperature distillation system (HTD), vapor compression system (VC), simple distillation, fractional distillation, steam distillation, vacuum distillation, short path distillation, freezing distillation system, solar distillation system, nuclear distillation system, multi -stage flash distillation

(MSF) and multiple-effect distillation| multiple-effect evaporator (MED|MEE) (Assessment MASWDP, 2011).

1- Low-Temperature Distillation System (LTD): uses the natural effects of gravity and atmospheric pressure to create a vacuum in which water can evaporate and condense at lower temperature than normal for distillation (Assessment MASWDP, 2011).

2- Vapor Compression System (VC): processes rely on reduced pressure operation to drive evaporation. The heat for the evaporation is supplied by the compression of the vapor, either with a mechanical compressor or a steam ejector Vapor compression processes are particularly useful for small to medium installations (E. Miller, 2003).

3- Vacuum distillation: it is a special method of separating compounds at pressure lower than the standard atmospheric pressure. So, the compounds boil below their normal boiling temperature(House and Road, 2011).

4- Short Path Distillation : in this technique, the separated compounds are condensed immediately without traveling the condenser. The condenser is configured in a vertical manner between the heating flask and the collecting flask. Similar to vacuum type, the pressure is maintained below the atmospheric pressure. Short path distillation is used for the separation of organic compounds with high molecular weight (Assessment MASWDP, 2011).

5- Freezing Distillation System : when seawater freezes, the ice crystals that are produced form pure water in solid form. The salt is separated and trapped between the ice crystals. The main problem lies in separating the ice crystals from the salt. This is usually done by washing off the salt with fresh water. The ice is then melted and becomes fresh liquid water. High costs and engineering problems have prevented the commercial use of freezing as a desalting method (Ismail, 2003). .

6- Solar Distillation System: A pond of saltwater with a clear cover takes improvement of solar heat. The saltwater evaporates and condenses on the cover. The brine stays in the pool and condensation forms potable water(Younos and Tulou, 2005).

7- Multi-Stage Flash (MSF) :It is a distillation (thermal) process that involves evaporation and condensation of water. The evaporation and condensation steps are coupled in MSF. So, the hidden heat of evaporation is recovered for reuse by preheating the incoming water. To maximize water recovery, each stage of an MSF unit operates at a successively lower pressure. A key design feature of MSF systems is bulk liquid boiling (E. Miller, 2003).Until the early 1990's, multistage flash distillation was the most commonly employed method of seawater desalination. In the MSF process, a stream of heated seawaterflows through the bottom of the vessel containing up to 40 chambers or stages, each operating at a slightly lower pressure than the previous one (Public Health and the Environment WHO, 2007).

8- Electro Deionization(EDI): it is a combination of ion exchange and electro dialysis. Electric charge is applied to plates outside of membranes with resin beads between them. Saltwater passes between membranes. Saltwater ions take place of ions on resin then are pulled out through membranes in front of electrically charged plates. Water passes through resin and is free from ions, thus producing purified water Can produce ultra-pure water (Younos and Tulou, 2005).

9- Membrane Distillation(MD): A temperature difference occurs on opposing sides of the membrane. Differences in vapor pressure drive the system and only vapor passes through the membrane. Salt is not vaporized so it cannot pass through pores Requires high amounts of energy /not fully developed (Assessment MASWDP, 2011).

Table (2-1): General advantages and disadvantages of Thermal Distillation

(Assessment MASWDP, 2011).

Advantages	Disadvantages
Has low energy, material and equipment costs.	Disposal of the output brine is a problem in many regions.
Low temperature distillation plants have efficient energy and effective cost.	It requires large amounts of land and direct sunlight.
doesn't require adding chemicals for pretreatment.	High level of technical knowledge is required to design and operate distillation n plants.
The technology can be combined with other processes, such as using heat energy from power generation plant.	

2. 1.2 Membrane Technology

The membranes are made of long chain high molecular weight organic polymers, which have an affinity for water. This hydrophilic characteristic allows water molecules to readily diffuse, or permeate through the membrane structure, while restricting the passage of other substances

Membrane technologies include electro-dialysis reversal (EDR), forward osmosis (FO),membrane distillation (MD), carbon nano-tubes, micro filtration (MF), ultra filtration (UF), nanofiltration (NF) and reverse osmosis (RO) as illustrated in Figure (2-1) (Assesment MASWDP, 2011).

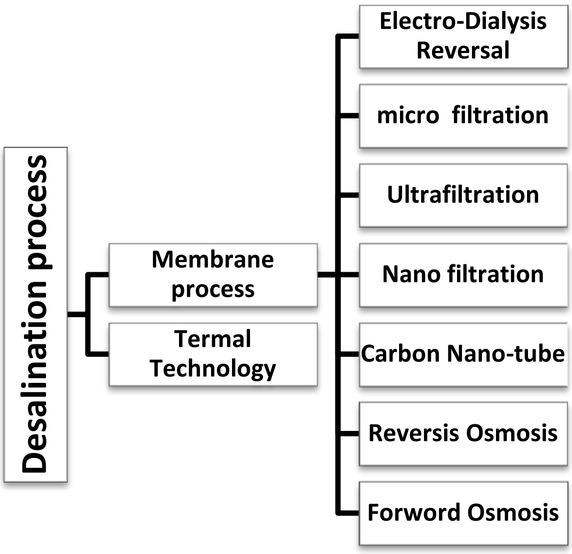


Figure (2-1): Membrane Desalination Techniques

2.2 Membranes classification

Membrane filtration can be a very efficient and economical way of separating components that are suspended or dissolved in a liquid. The membrane is a physical barrier that allows certain compounds to pass through, depending on their physical and/or chemical properties. Membranes commonly consist of a porous support layer with a thin dense layer on top that forms the actual membrane (munir, 2006).

Membranes can be classified according to: membrane material, membrane shape and module designs, nominal size of membrane, and membrane structure, as described in the following section.

2.2.1 Membrane based on using technology

In general, membrane treatment processes use either pressure-driven or electrical-driven technologies. Pressure-driven membrane technologies include reverse osmosis (RO), nanofiltration (NF), ultrafiltration, and microfiltration. Electrical-driven membrane technologies that are effective with salt removal include Electrodialysis (ED) and electrodialysis reversal (EDR) (Younos and Tulou, 2005).

2.2.2 Types of membranes materials

Membranes are made from a wide variety of materials such as polymeric materials that include cellulose, acetate, and nylon, and non-polymeric materials such as ceramics, metals and composites. Synthetic membranes are the most widely used membranes in the desalination process and their use is growing at a rate of 5-10% annually (Younos and E. Tulou, 2005).

Membranes can be classified based on membrane material into organic, inorganic and hybrids of organic -inorganic materials.

2.2.2.1 Organic membranes

Polymeric membranes account for biggest proportion of installed membranes currently in use. Several different polymers are used to suit the molecular weight cut off required, or achieve the desired resistance to fouling or performance when contacted with a specific process fluid (Suen. et al., 2003).

Organic membranes are commonly made of natural or synthetic polymer. The common materials include; cellulose acetate, polysulfone, aromatic polyamides, polyacrylonitrile (Ulbricht, 2006).

2.2.2.2 Inorganic membranes

Membranes can also be prepared from inorganic materials such as ceramics, metals and glass. Two main classes of membranes can be distinguished :dense (they are made of metals, hybrid organic–inorganic or mixed conductive oxides) and porous (ceramic) membranes. Inorganic membranes compete with organic membranes for specific applications in drastic conditions. Inorganic materials such as ceramic are only selected in specific instances were pH, temperature, or cleaning chemistry prohibit the use of polymers (Koch membrane system, 2012)

2.2.2.3 Hybrid membranes

Organic-inorganic hybrid materials offer specific advantages for the preparation of artificial membranes exhibiting high selectivity and flux, as well as a good thermal and chemical resistance (Suen. et al., 2003).

2.2.3 Membrane based on Physical configurations and module designs

Physical configurations include hollow fiber, spiral wound, cartridge, and tubular(American Membrane Technology Association AMTM, 2007).

Plate-and-frame and tubular membrane module are two of the earliest module design that based on simple filtration technology. Both systems are still available until today, but due to their relatively high cost and inefficiency, they have been mainly substituted by hollow fiber and spiral wound membrane (Lau Kok Keong, 2007).

Membranes are manufactured as flat sheets, hollow fibers, tubular and spiral modules. The principal advantages and disadvantages of different modules are given in Table (2-2).

Table (2-2): Principal advantages and disadvantages of different modules

(shon. et al.,2010)

Shape of module	Tubular	Hollow fiber	Flat sheet	Spiral
Packing density (m^2/m^3)	Low 10 - 300	High9000 - 30000	Low 100 - 400	High 300 - 1000
Hydraulic diameter(mm)	5 - 15	0.1 - 1	1 - 5	0.8 -1.2
Membrane material	Inorganic Organic	Organic	Organic inorganic	Organic
Replacement of membranes	Tube	Module	Sheet	Cartridge
Risk of clogging	Low	High	Average	High
Cost	High	High	High	Low
Maintenance	Easy	Difficult	Easy	Difficult
Dead volume	High	Low	Low	Low

Membrane can be classified based on Physical configurations and module designs into tubular module, hollow fiber, spiral wound and flat sheet as described below:

2.2.3.1 Tubular module

In this type the membrane is cast on the inside of a support tube as shown in figure (2-2), a number of tubes are then placed in pressure vessel ,the feed water is pumped through the feed tube and the product water is collected on through the skin of the membrane .the concentrate continues to flow through the feed tube .this type is used for water with high suspended solids content since it is the easiest to clean. The main problem for this is that the attachment of the membrane to the supporting layer is very weak .Tubular membranes have a diameter of about 5 to 15 mm. The tubes are encased in reinforced fibreglass or enclosed inside a rigid PVC or stainless steel shell (Dach, 2008)

Figures(2-2): Tubular membrane module (Schafer et al., 2007)

2.2.3.2 Hollow Fiber

In hollow fiber modules hundreds to thousands of hollow fibers are bundled together to form a module ,the entire assembly is inserted into a pressure vessel .the feed water can be applied to the inside of the fiber (inside out flow), or the outside of the fiber (outside-in flow). Figures (2-3) show the configuration of hollow fiber membrane.

Hollow fibers that can be operated in the outside-in or inside-out direction of flow(AMTM, 2007).

Hollow fiber membranes are small tubular membranes with a diameter of below 2mm. Hollow fiber membranes are self-supporting membranes. The selective barrier is sufficiently strong to resist filtration pressures. Because of this, the flow through these membranes can be either inside out or outside in (Maurel, 1993).

There are two basic configurations for hollow-fiber membrane module. The first is the closed-end design. In this module, a loop of fiber or a closed bundle is contained in a pressure vessel. The system is pressurized from the shell side and permeate passes through the fiber wall and exits via the open fiber ends. This design allows large fiber membrane areas to be contained in an economical system. Since the fiber wall supports a considerable hydrostatics pressure, these fibers usually have a small diameter, around 100µID and ~200µm OD (Lau Kok Keong, 2007).

The second basic design for hollow fiber module is more common. In this case, the fibers are laid out parallel to each other in bundles and the open ends are then cast into two resin blocks which are bonded into shrouds to form a cartridge. I order to minimize the pressure drops in the inside of the fibers, the fibers often have larger diameters than fine fibers used in closed loop system. Membrane in these on figurations are available for reverse osmosis, ultrafiltration and microfiltration applications such as seawater desalination, water clarification, fruit clarification, eletrophoretic paint recovery, oil waste water treatment and etc (Scott et al., 1996).

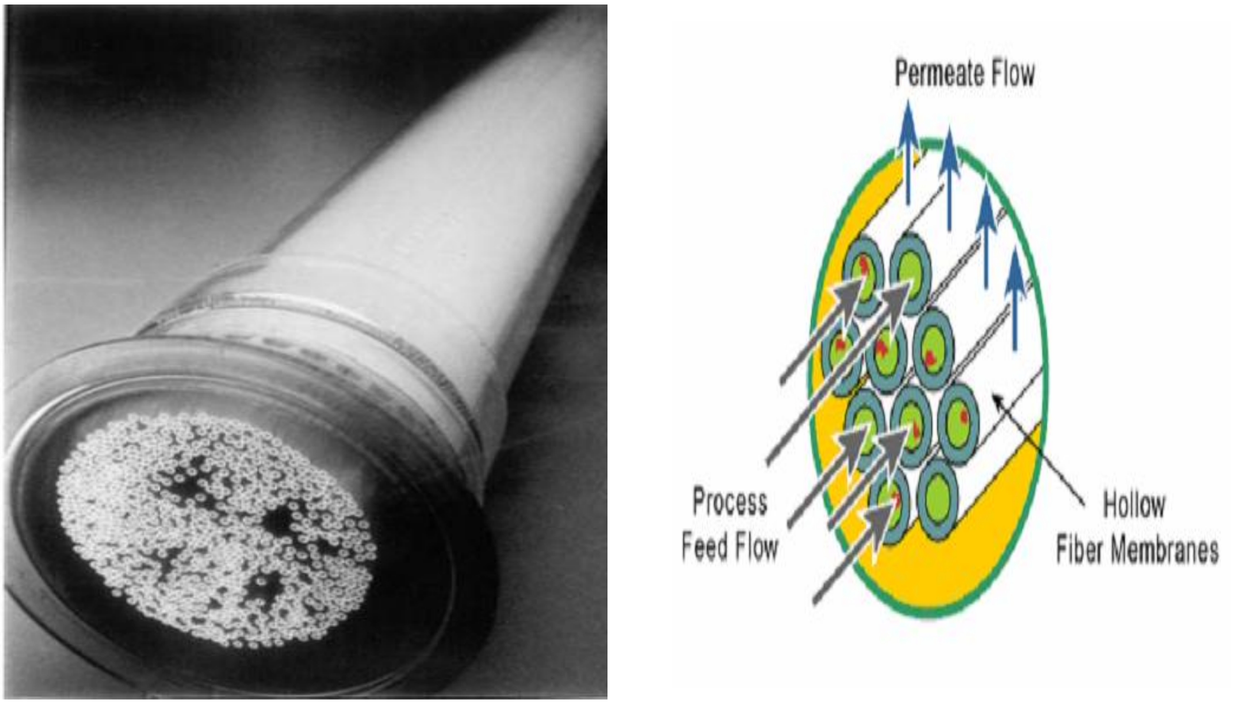
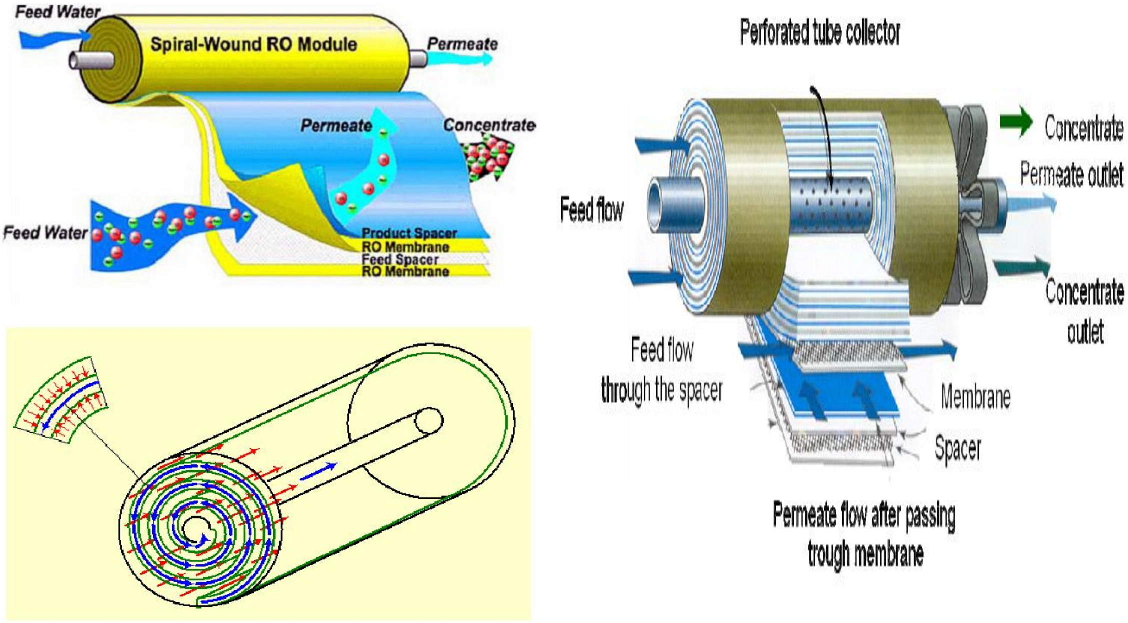


Figure (2-3) Hollow Fiber Membrane (Lau Kok Keong, 2007)**.**

2.2.3.3 Spiral Wound Modules

In hollow the spiral-Wound membrane, a flexible permeate spacer is placed between two flat membrane sheets, the membranes are sealed on three sides ,the fourth open side is attached to a perforated pipe. a flexible feed spacer is added and the flat sheets are rolled into tight circular configuration.A spiral wound module contains from one to more than 30 membranes leafs, depending on the element diameter and element type. Each leaf is made of two membrane sheets glued together back-to-back with a permeate spacer in between them (Lau Kok Keong, 2007)

The term spiral is derived from the fact that the flow in the rolled up arrangement of membranes and support sheets follows a spiral Flow pattern. The feed water can be applied to the inside of the fiber (inside out flow), or the outside of the fiber (outside-in flow). The construction of a spiral wound membrane element is schematically shown in Figure (2-4).



Figures(2-4):Construction of Spiral Wound element (UOP, 2009).

2.2.3.4 Flat sheet module

The simplest device for packing flat sheet membranes is a plate-and-frame module. Plate-and frame modules can be constructed in different sizes and shapes ranging from lab-scale devices that hold single, small-size membrane coupons to full-scale systems that hold more than 1700 membranes. Two of the main limitations of plate-and-frame elements for membrane applications are lack of adequate membrane support and low packing density. Lack of adequate membrane support limits operation to low hydraulic pressure and/or operation at similar pressures on both sides of the membrane (requiring relatively high process control). Low packing density leads to a larger system footprint, higher capital costs, and higher operating costs (labor for membrane replacement). Other limitations of the plate-and-frame configuration include problems with internal and external sealing, difficulty in monitoring membrane integrity, and a limited range of operating conditions (e.g., flow velocities and pressures) (Dach, 2008). Table (2-3) shows Advantages and disadvantages for each module.

Table (2-3): Advantages and disadvantages for different module (shon. et al., 2002).

Design module	Advantages	Disadvantages
Flat sheet	• Wide choice of membrane • Can be dissembled and cleaned • Low energy requirement	• High cost • Replacing membrane is time consuming • Can have seal problem
Hollow Fiber	• Very compact system • Low liquid hold-up • Low capital cost • Back flushable	• Can be fouled with particulates • Not suitable for viscous systems • Limited range of products
Spiral Wound	• Low hold-up • Compact system • Wide range of materials • Wide range of size • Low capital cost	• Can have dead spots • Cannot be back flushed
Tubular	• Can tolerate feeds with high suspended solid • Can work with viscous and Non-Newtonian fluides • Easy to clean mechanically	• High energy requirement • High capital cost • Disassembly long • High hold-up

2.2.4 Nominal size of membranes

Membrane separations can be divided into four categories: microfiltration(MF) ,ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). Each of these processes relies on pressure and size exclusion to filter the water. Separation is based on the pore size with microfiltration having the “loosest” pores and reverse osmosis having the “tightest” pores. As the pore size becomes smaller, the membrane becomes tighter. As a result, higher pressure is needed to force the water through it (Radcliff and Zarnadze, 2004).

Membrane can be classified based on the membrane pore to Microfiltration(MF), Ultrafiltration (UF), Nanofiltration (NF) and Reverse osmosis (RO) as described below (Mogheir and Albahnasawi, 2014).

1- Microfiltration (MF) is characterized by a membrane pore size between 0.05 and 2 µm and operating pressures below 2 bar. MF is primarily used to separate particles and bacteria from other smaller solutes .
2- Ultrafiltration (UF) is characterized by a membrane pore size between 2 nm and 0.05 µm and operating pressures between 1 and 10 bar. UF is used to separate colloids like proteins from small molecules like sugars and salts.

Ultrafiltration membranes can be used both to purify material passing through the filter and also to collect material retained by the filter. Materials significantly smaller than the pore size rating pass through the filter and can separated from high molecular weight contaminants. Materials larger than the pore size rating are retained by the filter and can be concentrated or separated from low molecular weight contaminants. Ultrafiltration is typically used to separate proteins from buffer components for buffer exchange, desalting, or concentration. Ultrafilters are also ideal for removal or exchange of sugars, non-aqueous solvents, the separation of free from protein bound ligands, the removal of materials of low molecular weight, or the rapid change of ionic and/or pH environment (munir, 2006).

3- Nanofiltration (NF) is characterized by a membrane pore size between 0.5 and 2 nm and operating pressures between 5 and 40 bar. NF is used to achieve a separation between sugars, other organic molecules and multivalent salts on one hand and monovalent salts and water on the other.

4- Reverse osmosis (RO) or hyper filtration. RO membranes are considered not to have pores. Transport of the solvent is accomplished through the free volume between the segments of the polymer of which the membrane is constituted. The operating pressures in RO are generally between 10 and 100 bar and this technique is mainly used to remove water (Albahnasawi, 2013). The importance of these membrane processes can be judged from the membrane area installed in the various industrial sector (Timmer, Johannes M.K. 2001).

Figure (2-5) illustrated the MF, UF, NF and RO membrane process characteristics.

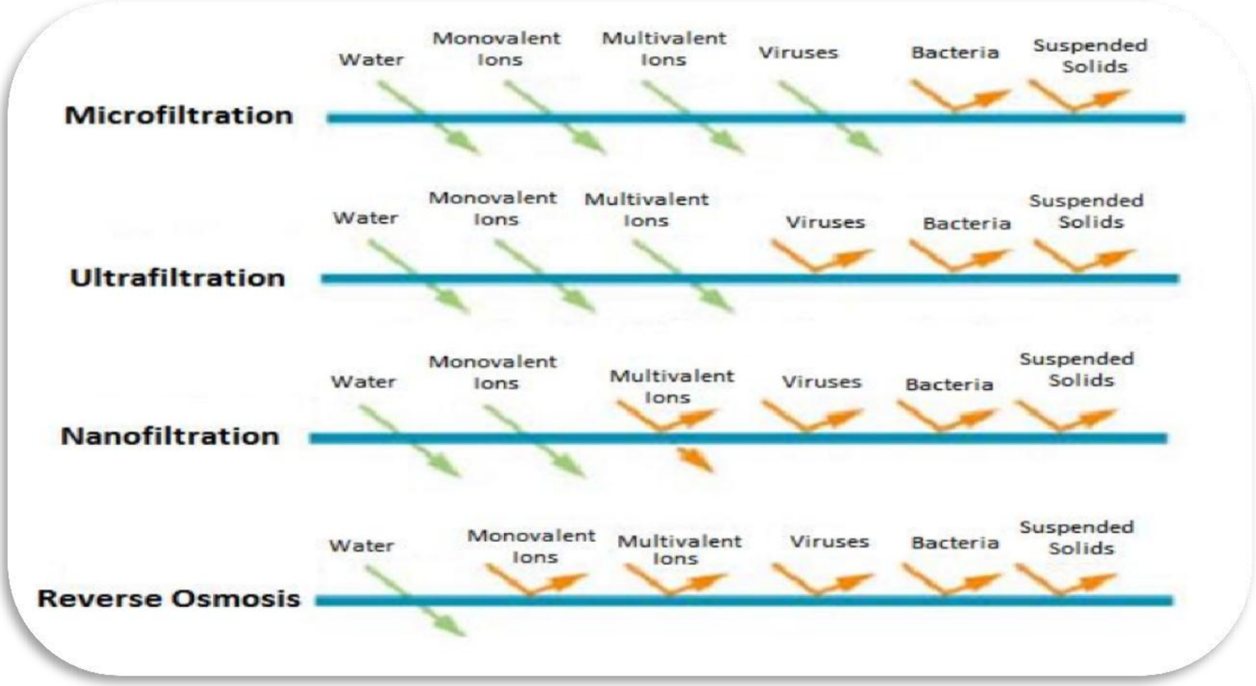


Figure (2-5): MF, UF, NF and RO membrane process characteristics (Koch membrane system, 2012).

2.2.5 Membrane structure

The classification occurs according to the homogeneity of the pore structure along the membrane cross section into symmetric, asymmetric and composite membranes (Dach, 2008).

2.2.5.1 Symmetric membranes

Symmetric membranes have a homogenous pore diameter and/or pore cross section across the thickness of the membrane.Symmetric membranes are used today mainly in dialysis, electrodialysis and microfiltration (Strathmann, 2000).

2.2.5.2 Asymmetric membranes

An asymmetric membrane comprises a very thin (0.1-1.0 micron) skin layer on a highly porous (100-200 microns) thick substructure. The thin skin acts as the selective membrane. Its separation characteristics are determined by the nature of membrane material or pore size, and the mass transport rate is determined mainly by the skin thickness. Porous sub-layer acts as a support for the thin, fragile skin and has little effect on the separation characteristics (Maurel, 1993; Matsuyama. et al., 2000) In asymmetric membranes structural as well as transport properties vary over the membrane cross-section. Most of the membranes used today in pressure driven separation processes are composed of rather sophisticated asymmetric structures in which the two basic properties required of any membrane, i.e. high mass transport rates for certain components and good mechanical strength, are separated(Strathmann, 2000).

2.2.5.3 Thin film composite membranes (TFC)

This preparation mode leads to significant advantages of the composite membrane compared to asymmetric membranes: (i) it improves the permeation rate which is inversely proportional to the thickness of the barrier layer and thus composite membranes shows a much higher permeation rate then asymmetric, (ii) increases the rejection rate of the membranes and (iii) minimizes the pressure drop across the membrane (Ulbricht, 2006).The materials used for the support layer and the skin layer can be different and optimized for the best combination of high water flux and low solute permeability. The TFC membrane structure is especially suitable for reverse osmosis and Nanofiltration which require high flux on one hand and high salt rejection rate on the other(Dach, 2008).

2.3 NF versus RO membrane

The term 'nanofiltration' signifies that particles of Nano metric dimensions are separated through the NF membranes. NF membranes have low molecular weight cut-offs (200 - 1000 Da) and smaller pore size (∼1 nm). Therefore, the separation of components with these molecular weights from higher molecular weight components can be accomplished (Timmer, Johannes M.K. 2001).They also have a surface electrostatic charge which gives them great selectivity towards ions or charged molecules. More specifically, NF membrane can be used to remove small neutral organic molecules while surface electrostatic properties allowed monovalent ions to be reasonably well transmitted with multivalent ions mostly retained (Bowen and Welfoot, 2002).

Following our lab work results, we may conclude that Nanofiltration membranes for desalting water are potentially suitable for brackish desalination in Gaza Strip due to: reasonable salt rejection, (up to 51%) for NF1 membrane at relatively low operating pressure of 12 bar attributing to energy consumption reduction as well as cost effective compared to the current used technology of RO membranes(Mogheir. et. al., 2013).

The rejection characteristic of a specific NF membrane is often quantified by the MWCO. Usually, the MWCO is defined as the MW of a solute that was rejected at 90 percent (Van der Bruggen. et al., 1999); although, this definition is not explicit and it can vary between 60 and 90 percent depending upon protocols used by various manufacturers. Variations in solute characteristics, solute concentration, solvent characteristics, as well as flow conditions such as dead-end versus cross-flow filtration, make comparison of results from different manufacturers difficult (Cleveland. et al., 2002).

NF offers several advantages, such as low operation pressure, high flux, high retention of multivalent anion salt and organic molecular above 300, relatively low investment, low operation and maintenance cost. By the second half of the eighties, nanofiltration had become established, and the first applications were reported table (2-4) shows the advantages and disadvantages of the NF system (Conlon and McClellan, 1989; Eriksson, 1988)

A nanofiltration (NF) membrane works similar to reverse osmosis except that with NF, less pressure is needed (70 and 140 psi) because of larger membrane pore size (0.05 µm to 0.005 µm). Nanofiltration can remove some total dissolved solids, but is often used to partially soften water and is successful at removing solids, as well as dissolved organic carbon. For low TDS brackish waters, NF may be used as a standalone treatment for removing salts (Younos and Tulou, 2005).

Nanofiltration (NF) membranes have lower rejection of monovalent ions when compared to RO membranes specifically designed for nitrate (MWH, 2005; Bellona. et al., 2008).

Table(2-4): The advantages and disadvantages of the NF system (Assessment MASWDP, 2011)

Advantages	Disadvantages
• has a higher flux rate • Operates at a lower pump pressure than RO • Requires fewer membrane elements than RO • Doesn't require chemicals to remove hardness ions. • Lower energy costs. • Lower discharge and less wastewater than reverse osmosis. • Reduction of total dissolved solids (TDS) content of slightly brackish water. • Reduction of pesticides and organic chemicals. • Reduction of heavy metals. • Reductions of nitrates and sulfates. • Reduction color, tannins, and turbidity، Hard water softening. • Being chemical-free (i.e., does not use salts or chemicals. • Water pH after nanofiltration is typically	• The NF membrane rejection degree is less for monovalent ions, such as Cl^-, Na^+ than that for the divalent ions such as SO_4^{-2} and Ca^{+2}

Reverse osmosis (RO) is a physical process that uses the osmosis phenomenon, the separation phenomenon in RO is usually based on solution diffusion . NF takes in to account effect of diffusion and sieving effect, with an addition effect of charge, which is due to the surface characteristics of NF(Hussain. et al., 2009)

RO membrane is a pressure-driven membrane separation process in which feed water passes through a semipermeable membrane due to a pressure difference at the opposite sides of the membrane (Symons. et al., 2001; Darbi. et al., 2003; MWH, 2005). For a pressure driven membrane process, the concentrated solution containing substances that do not pass through the membrane is called the reject water or concentrate. (Symons. et al., 2001). The main application of RO is desalination of seawater and brackish water, and the first commercial RO desalination plant was built in Goalinga, California in 1965 (MWH, 2005). However, RO membranes can be used for the removal of natural organic matter (NOM), microorganisms, inorganic contaminants such as arsenic, nitrate, nitrite, selenium, barium, and fluoride, and for softening (Shoeleh, 2013).

2.3.1 Mechanism of removing and structure.

A comparison between NF and RO membrane structure and the mechanism of removal will discussed in these part.

2.3.1.1 NF Membrane Structure and Mechanism of Removal

The transport inside the NF membrane is due to diffusion, convection and Electro migration. Since, the NF membrane carries negative charge at the surface, positive charged ions will be attracted and negative charge will be repelled due to Donnan effect. The dielectric exclusion occurs due to difference in dielectric constant in NF pore, membrane material and solvent which also repels ions from the system. The NF membrane is prepared with the interfacial polymerization of sulphonic acid and acetyl chloride which contributes negative charge at the surface. The preparation is proprietary in nature. The ions selectivity in NF is dependent on the pressure; the ions are transferred by two mechanisms convection and diffusion while only diffusion is involved in RO (DACH, 2008).

Convection. They are carried by the solvent stream as a function of the transfer coefficient. The larger ions are more retained (physical parameters).

Solution–diffusion: is the movement of molecules from higher to lower concentration, that is down their concentration gradient. Until equilibrium achieved and they are distributed equally (chemical parameters).

The convection transfer mechanisms are modified by altering the physical parameters (pressure, recovery rate), without altering diffusion, which is influenced only by the chemical parameters (concentration, pH). Convection is low at low pressure and in contrast, the physical parameters predominate at high pressure, and the larger ions are better retained. Nevertheless, chemical selectivity is always much more important than physical selectivity for separating ions. This means that selectivity is always higher at low pressure (Lhassani. et al 2001).

NF is a suitable method for the removal of a wide range of pollutants from groundwater or surface water ,in view of drinking water production. The major application is softening, but NF is usually applied for the combined removal of natural organic material NOM, micro pollutants, viruses and bacteria, nitrates and arsenic, or for partial desalination. Industrial full-scale installations have proven the reliability of NF in these areas(Bruggen and Carlo, 2003).

2.3.1.2 RO Membrane Structure and Mechanism of Removal

The first RO membranes were made from cellulose acetate (CA) at the University of California in 1949 for desalination of seawater. CA membranes are more hydrophilic than and polyamide (PA) membranes, and therefore less vulnerable to fouling. Also, CA membranes can tolerate up to 1 ppm of chlorine, while PA membranes deteriorate at any concentration of free chlorine (Shoeleh, 2013).

2.3.2 Fouling and cleaning

Fouling is the common name for all types of blocking of the membrane surface Fouling of nanofiltration (NF) membranes is typically caused by inorganic and organic materials present in water that adhere to the surface and pores of the membrane and results in deterioration of performance (reduced membrane flux) with a consequent increase in costs of energy and membrane replacement ,Inorganic fouling due to scale formation of sparingly soluble inorganic salts occurs whenever the ionic salt concentration stream exceeds the equilibrium solubility Scale formation takes place by homogenous or heterogeneous crystallization mechanisms. Biofilm formation also becomes an issue when its thickness and surface coverage reduces permeability (Al-Amoudia and Lovitt, 2007).

2.3.2.1 Types of membrane fouling

The main difference between the types of fouling (colloidal fouling, organic fouling, scaling and bio fouling) is the nature of the particles that cause the fouling. The difference between types of fouling is made because each type of foulant has an effect on membrane performance and also has its own type of counter measures (feed pre-treatment (before) and cleaning (afterwards), In addition, fouling can be divided into reversible and irreversible fouling based on the attachment strength of particles to the membrane surface. Reversible fouling can be removed by means of strong shear force or backwashing. Formation of a strong matrix of fouling layer with the solute during continuous filtration process will result in reversible fouling being transformed into irreversible fouling layer. Irreversible fouling is normally caused by strong attachment of particles, which is impossible to be removed by physical cleaning method (Franken, 2009)

Fouling is categorized into Colloidal, Organic, Scaling or precipitation and Biological (Yiantsios. et al., 2007).

1- Colloidal fouling

Colloidal particles are ubiquitous in natural waters. Colloids cover a wide size range, from a few nanometers to a few micrometers. Examples of aquatic colloids are clay minerals, microorganisms, biological debris (plant and animal), colloidal silica, aluminium, iron and manganese oxides, polysaccharides (gums, slime, plankton, fibrils), organic colloids and suspended matter, and calcium carbonate precipitates, The surface charge of aquatic colloids reflects their surface properties and the chemical composition of natural waters, During membrane fouling, colloids accumulate on the membrane surface or within the membrane pores and adversely affect both the quantity (permeate flux) and quality (solute concentration) of the product water (Yiantsios. et al., 2007).

2- Organic fouling

The term organic fouling is applied for those substances that are dissolved in the feed solution and that tend to stick to the surface of the membrane. The main difference between colloidal fouling and organic fouling are particles and the latter are dissolved. One has to bear in mind that both types of foulant can lead to the same type of gel layer and often a “mixed” layer is formed. The fouling mechanisms in both organic and colloidal are: cake formation or pore constriction or pore blockage (Yiantsios. et al., 2007).

3- Scaling

Scaling or precipitation fouling involves crystallization of solid salts, oxides and hydroxides from solutions. Through changes in temperature, or water removal (as in reverse osmosis), the concentration of salts may exceed the saturation, leading to a precipitation of salt crystals. Precipitation fouling is not only a problem in reverse osmosis, but is also a very common problem in boilers and heat exchangers operating with hard water and often results in lime scale(Al-Amoudia and Lovitt, 2007).

4- Bio fouling

Bio fouling is a special class of organic fouling and is the result of complex interactions between the membrane material, dissolved substances, fluid flow parameters and microorganisms. A biofilm is defined as a structured community of microorganisms encapsulated within a self-developed polymeric matrix and adherent to a living or inert surface. Biofilms are also often characterized by surface attachment, structural heterogeneity, genetic diversity, complex community interactions, and an extracellular matrix of polymeric substances (Franken,2009).

2.3.2.2 Factor Affecting Membrane Fouling

The nature and extent of membrane fouling are strongly influenced by operating conditions, and biomass characteristics. There are explained below (Sombatsompop, 2007)

1- Operating Conditions

1- Organic Loading Rate (OLR) and Hydraulic Retention Time (HRT):

Increasing flux rate increases the probability of particles contacting (fouling) the membrane surface. Several studies have investigated the effects of organic loading rate and hydraulic retention time on membrane fouling (Yamamoto. et al., 1991; Harada. et al., 1994; Seo. et al.,1997; Rosenberger. et al., 2002).

2- Sludge Retention Time (SRT)

Sludge retention time (SRT) or sludge age is directly linked to the sludge production of excess sludge, and significantly affects biological performance by changing sludge compositions (Bouhabia. et al., 2001). A long SRT and a short

HRT would predictably increase the biomass concentration that may facilitate the biodegradation of refractory pollutants. On the other hands, this may have some negative effects, such as high sludge viscosity which leads to excessive fouling.

3- Cross Flow Velocity (CFV)

The CFV is mainly influenced by a number of factors, such asaeration rate, reactor structure and fluid viscosity (Liu et al.,2003). The CFV, which was created by aeration, not only provided oxygen to the biomass, but also maintained the solids in suspension, scoured the membrane surface and removed fouling. The CFV affected the mass transport of particles away from the membrane surface, and thus the resultant cake layer thickness, by increasing the shear and shear-induced diffusion. In order to reduce deposition of suspended solids at the membrane surface, a high cross flow velocity should be supplied by a circulation pump. (Sombatsompop, 2007)

4- Aeration

Increases in aeration rate and cross flow velocity (CFV) suppress fouling and increase permeate flux although most studies on permeate flux are based on side-stream operation. Studies carried out with submerged MBR or with ideal feed solution suggest that an increase in air flow rate at the membrane surface can limit the fouling.

2- Biomass Characteristics

1- Extracellular Polymeric Substances (EPS :Protein and Carbohydrate)
2- Biomass Concentration (MLSS)
3- Particle/Floc Size Remedy

2.3.2.3 Types of Cleaning

Cleaning can be defined as “a process where material is relieved of a substance, which is not an integral part of the material” (Al-Amoudia and Lovitt, 2007) there are two Types of cleaning physical and chemical.

1- Physical cleaning

Physical cleaning methods include for example: hydrodynamic forward or reverse flushing, permeate back pressure, air spurge and automatic sponge ball cleaning. These methods depend on a mechanical treatment to dislodge and remove foulants from the membrane surface. Application of these methods usually results in a more complex control and design of equipment. The physio-chemical cleaning methods use mechanical cleaning methods with the addition of chemical agents to enhance cleaning effectiveness (Al-Amoudia and Lovitt, 2007).

2- Chemical cleaning

There are several factors that can affect the chemical cleaning process which include temperature, pH, concentration of the cleaning chemicals ,contact time between the chemical solution and the membrane and the operation conditions such as cross-flow velocity and pressure. The role of temperature and pH in cleaning are membrane dependent. These factors play very important role in flux recovery (Al-Amoudia and Lovitt, 2007).

Cleaning mainly involves the dissolution of the material from the membrane surface and several factors could affect the chemical cleaning process. These are: temperature, pH, concentration of the cleaning chemicals, contact time between the chemical solution and the membrane and operation conditions such as cross-flow velocity and pressure (Mohammadi. et al., 2003).

2.3.3 Flow modes

There are two types of flow modes: Dead-end or direct filtration and cross flow filtration.

2.3.3.1 Dead-end" Direct" Filtration

The most basic form of filtration is dead-end filtration. The complete feed flow is forced through the membrane and the filtered matter is accumulated on the surface of the membrane. The dead-end filtration is a batch process as accumulated matter on the filter decreases the filtration capacity, due to clogging. A next process step to remove the accumulated matter is required. Dead-end filtration can be a very useful technique for concentrating compounds (Munir, 2006).

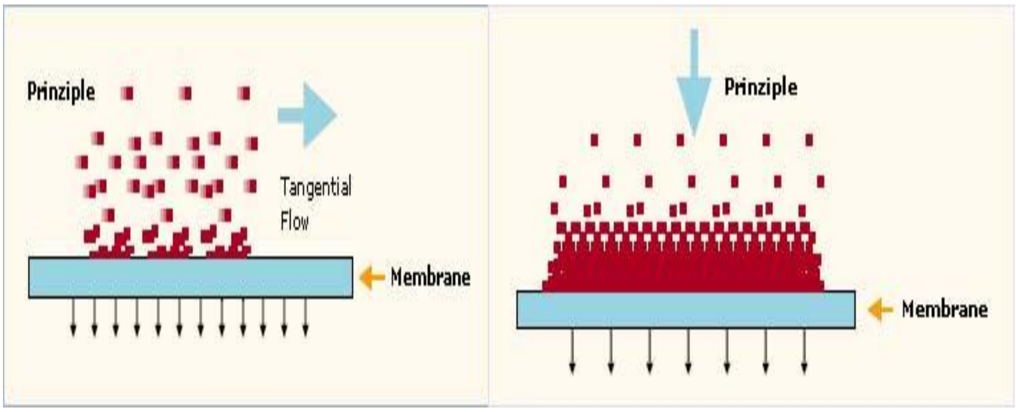
When using a dead-end filtration technique, all the fluid passes through the membrane and all particles larger than the pore sizes of the membrane are stopped at its surface. Particle size prevents contaminants from entering and passing through the membrane. This means that the trapped particles start to build up a "filter cake" on the surface of the membrane which reduces the efficiency of the filtration process until the filter cake is washed away in back flushing (Assessment MASWDP, 2011).

A disadvantage of the stirred cells that it doesn‘t simulated large scale modules, particularly in term of the boundary layer mass transfer coefficient. The stirred cell would tend to achieve lower retention and experience more fouling than large scale SWM modules (Schafer. et al., 2008).

2.3.3.2 Cross-Flow Filtration

With cross-flow filtration a constant turbulent flow along the membrane surface prevents the accumulation of matter on the membrane surface. The membranes used in this process are commonly tubes with a membrane layer on the inside wall of the tube. The feed flow through the membrane tube has an elevated pressure as driving force for the filtration process and a high flow speed to create turbulent conditions. The process is referred to as "cross-flow", because the feed flow and filtration flow direction have a 90 degrees angle. Cross-flow filtration is an excellent way to filter liquids with a high concentration of filterable matter (Munir, 2006).

In cross flow filtration, the fluid feed stream runs tangential to the membrane, establishing a pressure differential across the membrane. This causes some of the particles to pass through the membrane. Remaining particles continue to flow across the membrane, "cleaning it". In contrast to the dead-end filtration technique, the use of a tangential flow will prevent thicker particles from building up a "filter cake" as shown in Figure (2-6).



A B

Figure (2-6) : A- cross flow Filtration B- Dead-end Filtration (Koch membrane system, 2012)

2.3.4 Parameter affecting on Membrane Performance

Various physical and chemical parameters that affect the crystallization process within a membrane system and include temperature, pH, flow velocity, permeation rate, types of pretreatment, salt concentration and concentration polarization, membrane type, materials and metal ions (Kasper, 1993).

Many factors like water pressure and temperature, membrane selection, and proper maintenance influence performance (Habboub, 2007).

Many authors have studied the influence of operating conditions on NF membranes performance The most important operating parameters affecting the performance of NF membranes are similar to those for most cross flow filtration processes such as pressure, temperature, cross flow velocity, recovery rate, PH degree, and salinity (Dach, 2008):

1- Salinity "concentration of ions on feed water": the effective pore radius of a charged pore will increase as the ionic strength of the surrounding liquid increases. Therefore, the rejection of monovalent ions will decrease as their concentration in the feed solution increases. The rejection of divalent ions will be affected to a lower extent. The shield effect of membrane charge also increases as the ionic strength of feed solution increases (Dach, 2008). Increasing the concentration of sodium Cations of the solution involves the formation of a screen which gradually neutralizes the negative charge of the membrane. As the total charge of the membrane decreases, the retention of the anions decreases since the electrostatic effect of the membrane becomes weaker (Childress et al. 2000)This means that the effect of membrane charge is completely eliminated when the salt concentration is high enough (Scheap and Vandecasteele, 2001). In real water, the percentage of nitrate removal was influenced by TDS value in general, but to be more specific, it was found that the concentration of sulphat has a great effect on nitrate removal, as the sulphat concentration increased the nitrate removal decreased (Mogheir and Albahnasawi, 2014).

2- Pressure: Pressure difference is the driving force responsible for a NF process. The effective driving pressure is the supplied hydraulic pressure less the osmotic pressure applied on the membrane by the solutes. Increases of operating pressure increase the flux and recovery rate (Albahnasawi, 2013). The performance of a membrane in a pressure driven separation process is determined by its filtration rate (Strathmann, 2000).

3- Temperature: Increasing the process temperature increases the NF membrane flux due to viscosity reduction. Additionally, increasing temperature increases mean pore radii and the molecular weight cut off suggesting changes in the structure and morphology of the polymer matrix comprising the membrane barrier layer. The rejection of NF membranes is not dependent significantly on the process temperature (Dach, 2008).

4- Cross flow velocity: Increasing the cross flow velocity in an NF membrane process increases the average flux due to efficient removal of fouling layer from the membrane surface. However, the mechanical strength of the membrane, and construction of the element and system hardware will determine the maximum cross flow velocity that can be applied. Running a NF membrane at too high cross flow velocity may cause premature failure of membranes and modules. Increasing cross flow velocity also increase the pressure drop(Dach, 2013).

5- Recovery rate :many authors have reported that an increase of feed water recovery leads to a decrease in rejection (Bannoud, 2001; Lhassani. et al. 2001; Abouzaid. et al., 2003). Recovery rate is a major parameter for evaluating membrane effectiveness. Recovery is defined as the volume of freshwater produced as a percentage of the volume of feed water processed. Typical recovery rates for RO systems can be 30 percent to 80 percent depending on the quality of feed water, pressure applied, and other factors. Reverse osmosis membranes that operate at low pressures but maintain high recovery rates have been developed.(Younos and Tulou, 2005)

6- pH: pH affects performance of NF membranes in more than one way. The charged sites on the NF membrane surface (i.e. carboxylic group, sulfonic group) are negatively charged at neutral pH or higher, but lose their charge at acidic pH. It is well known that most NF and RO membranes have lower rejection at low pH, or after acid rinse. It should be noted, however, that since different membrane manufacturers use different chemistries to produce their thin film composite layer, the pH dependency of a membrane should be determined for each membrane type. In addition to the effect of pH on the membrane itself, pH can be responsible for changes in the feed solution, causing changes in membrane performance. Two examples are change of solubility of ions at different pH regimes, causing different rejection rate; and change in the dissociation state of ions at different pH ranges (Teixeira. et al., 2005; Bellona. et al., 2004).

7- Properties of membrane: the performance of membrane can be evaluated by the properties of membrane such as pore size or sieving effect and other addition effect such as the effect of surface charge. The performance of a composite membrane is not only determined by the properties of the selective barrier layer, but it is also significantly affected by properties of the microporous support (Strathmann, 2000).

2.4 Performance evaluation

Early RO plants were developed for the treatment of brackish water and the membranes were not suitable for seawater desalination. Since the early days, the membranes have been improved in terms of salt rejection, productivity, resistance to higher pressure as well as higher temperature. They are presently used for seawater desalination (SWRO) (Al-Subaie. et al., 2007)

The main performance indicators of a pilot scale desalination system are productivity in the form of flux and recovery, desalination efficiency in the form of retention with regards to total dissolved solids, individual elements, and energy requirements in the form of specific energy consumption(DACH 2008).

2.4.1 Water productivity and recovery rate

Permeate flux is an important parameter in design and economic feasibility analysis of membrane separation processes. When the level of solute rejection is met, the permeate flux becomes a fundamental factor in optimization of the process. The higher the permeate flux, the lower the filtration area necessary for a certain amount of solution to be processed. Each membrane has a specific permeability for a given values of temperature and feed water salinity.

Recovery also can be called productivity. According to mass balance, the feed flow equal to the sum of concentrate flow and permeate flow. Recovery can be calculated using equation (2-1).

$$\gamma = \frac{Qp}{Qf} \times 100\% = \frac{Qp}{Qp + Qc} \times 100\% \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (2-1)$$

Where :

γ: $Recovery$ rate

Q_p :permeated flow m3/h

$Q_{f:}$ feed flow m^3/h

2.4.2 Water quality and rejection rate

The second indicator of a pilot scale desalination system is the water quality or rejection rate which should correspond with WHO guideline .

Rejection rate represent the ability of membrane to reject salts and impurities from feed water. This is one of the most important characteristics of membrane; that‘s depended on the feed water characteristics, membrane characteristics and applied pressure. The ability of membrane to reject TDS & NO_3 was measured using equation (2-2).

$$R = \frac{1 - Cp}{Cf} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (2-2)$$

Where;

R: rejection rate %

C_p: salt concentration in permeate (ppm).

C_f: salt concentration in feed water (ppm).

2.4.3 Specific Energy Consumption

The Specific Energy Consumption (SEC) is what ultimately determines the cost of the system as energy requirements (Schäfer. et al., 2007).

Energy requirement increase linearly with increasing permeate flow which is a result of increasing pressure. The electricity consumed for membrane filtration is proportional to trans membrane pressure (Dach, 2008)

SEC is proportional to the trans-membrane pressure. It is calculated using equation (2-3)

$$\mathrm{E} = \frac{\Delta \mathrm{P}}{\eta . \mathrm{r}} . \frac{100}{36} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (2-3)$$

Where :

ΔP: the trans membrane pressure in bar.

η : the global pumping system efficiency.

r: the conversion rate.

2.5 Nitrate removal

Nitrates are very soluble, therefore, they have a high potential to migrate to groundwater sources. When these ground waters are purposed for potable drinking water sources, the presence of nitrates can pose serious health risks, especially for infants and pregnant women. Nitrate is a chemical compound of one part nitrogen and three parts oxygen that is designated the symbol “NO_3” It is the most common form of nitrogen found in water. Other forms of nitrogen include nitrite (one part nitrogen and two parts oxygen – NO_2) (Albahnasawi, 2013). Due to excessive usage of nitrate fertilizer in agriculture and discharging of wastewater from treatment plants, and leakage of wastewater form cesspools, nitrate level in the groundwater has increased (Mogheir and Albahnasawi, 2014). Nitrates have no detectable color, taste or smell at the concentrations involved in drinking water supplies, and can occur both naturally and from man-made sources. Because they do not evaporate, nitrates/nitrites are likely to remain in water until consumed by plants or other organisms. Nitrate contamination originates mainly from agricultural operations including farm runoff and fertilizer usage, septic system failure and improper discharge of industrial and food processing waste and wastewater. The primary inorganic nitrates which may contaminate drinking water are potassium nitrate and ammonium nitrate both of which are widely used as fertilizers.

2.5.1 Health Concern

Several health problems may be caused by excess nitrate in water sources, The removal of nitrate is essential for water contaminated with nitrate before being utilized since a large amount of nitrate in drinking water often causes a disease called methemoglobinemia and other health disorders such as hypertension, increased infant mortality , goiter , stomach cancer , thyroid disorder, cytogenetic defects and birth defects (Choi and Kim, 2007)

Elevated nitrate in water resources could lead to serious problem including eutrophication, and potential hazards for human and animal health (Mogheir and Albahnasawi, 2014).

Moreover, the fact that nitrate rejection decreased when increasing nitrate feed concentration with single salt solutions showed that the charge effect plays an important role in the rejection mechanism, This conclusion is in agreement with the results obtained when treating groundwater, for which the electro-static interactions are decreased due to the high concentration of the solution, and the rejection is mainly the result of size effect ,therefore nitrate rejection strongly decrease sand salt rejection is higher because of the high divalent ion content of the groundwater. (Moros. et al., 2005)

Nitrate is converted to nitrite through microbial reduction. The reaction between nitrite and secondary or tertiary amine in acidic mediums such as the human stomach can result in the formation of N-nitroso compounds (NOC), which are known to be carcinogenic, teratogenic, and mutagenic (Pontius, 1993; Mikuska and Vecera, 2003; van Grinsven, 2006).NOC (nitroso compounds carcinogenic) might cause cancers such as stomach and bladder cancer. However, studies that investigated relations between drinking water nitrate contamination and cancer risks have resulted in contradictory conclusions (Ward. et al., 2005; van Grinsven, 2006; Chiu. et al., 2007).

2.5.2 Treatment Technologies

At high nitrate concentrations, water must be treated to meet regulated concentrations. But, it is almost impossible to remove nitrate by conventional drinking water treatment methods such as coagulation and filtration due to its high stability and solubility, as well as its low potential for Co precipitation or adsorption in water. Therefore, other technologies including biological denitrification, ion exchange (IX), reverse osmosis (RO), Electrodialysis (ED), and chemical denitrification have been studied or applied to remove nitrate from drinking water. Physical and chemical processes such as reverse osmosis, ion exchange, electrodialysis and chemical denitrification have been developed for nitrate removal from water (Albahnasawi, 2013). Although these techniques are effective in removing nitrate from contaminated water, they are very expensive for pilot scale operation with a limited potential application (Choi and Kim, 2007).

WHO has suggested biological denitrification and IX as nitrate removal methods (WHO, 1992), While IX, RO, and ED are approved by Environmental Protection Agency (EPA) as Best Available Technologies (BAT) for removing nitrate (USEPA, 2004). Each of these technologies has its own strengths and drawbacks and their feasibility is weighted against factors such as cost, water quality improvement, Rejection rate , Recovery rate ,residuals handling, and post-treatment requirements.

CHAPTER 3 : Water situation and study area

Gaza strip is located in the south-western part of Palestine that is located on the southeastern cost of the Mediterranean Sea at the Middle East, where it forms a long and narrow rectangular area of about 365 km^2.The Gaza Strip is a highly populated, small area in which the groundwater is the main water source. During the last few decades, groundwater quality has been deteriorated to a limit that the municipal tap water became brackish and unsuitable for human drinking consumption in most parts of the Strip (Al-Khatib and A. Arafat, 2009; Habboub, 2007; Shomar. et al 2008; Aish, 2010).

3.1 Water Resources and Water usage in the Gaza strip

Groundwater is one of the most precious natural resources in the Gaza Strip as it is the only source of drinking water for the majority of the population. The groundwater aquifer of Gaza is extremely susceptible to surface-derived contamination because of the high permeability of sands and gravels that compose the soil profile of Gaza (Mogheir and Albahnasawi, 2014; Shomar. et al., 2005).

3.1.1 Water resource in the Gaza strip

In the Gaza strip, the main source of water is groundwater, the main source of groundwater comes from the coastal aquifer (shallow aquifer), which consists mainly of sandstone, sand and gravel. The aquifer is highly permeable with transmissivity of about 1000 m2/day and an average porosity of 25%. The depth to water ranges between 70 m in the highly elevated area in the east and 5 m in the low land area. The total annual recharge of the aquifer is estimated at 48.2 Mcm. A deficit with an average of 70 Mcm/yr is observed in the water balance due to over pumping. Therefore, the aquifer is replenished from brackish or seawater, which results in a deterioration of quality. The main source of drinking water is (Shumbulo and Ahmed, 2007; Al-Khatib. et al., 2003).

1- 205 Domestic water wells produce 70 Mcm/yr.
2- More than 4000 agricultural water wells produce 90 Mcm/yr.
3- Water is purchased from an Israeli company “Mekkorot” (48 Mcm/yr),
4- Six BWRO plants.
5- The Middle Area SWRO plant produces 0.2 Mcm/yr.

3.1.1 Water usage in the Gaza strip

The population growth and socio-economic development control water demand for the different uses. In year 2005, it was estimated that approximately 150 Mcm/yr of water was pumped from about 4100 wells. Of which, about 90 Mcm/yr of water was used for irrigation and 60 Mcm/yr were pumped for domestic and industrial from 100 municipal wells (PWA, 2006).

The domestic and industrial (D&I) demand presents quantity of water at water supply source that should be delivered to the domestic and industrial customers. It is clear that in the case of the Gaza Strip, the total D&I water needs will reach to about 182 Mcm by 2020 assuming an overall efficiency of 20%. If the demand for irrigation is calculated on the basis of the food requirements of the growing population, it appears that it will increase from the present usage of about 90 Mcm/yr to 185 Mcm/yr by 2020. However, this figure is not a realistic projection for the Gaza Strip, because neither the water nor the land to support an increase in agricultural activity exists. Therefore, the estimated future demands for agriculture are based on the actual water amounts of today. Generally, the overall water demand in Gaza Strip is estimated to increase to about 260 Mcm/yr in 2020. This includes D&I demand at water supply source and agricultural demand (Metcalf and Eddy, 2000).

3.2 Ground water quality in the Gaza strip

Gaza strip has a big water problem in terms of water quantity and water quality. Due to over-abstraction of groundwater from the Gaza aquifer and to seawaterintrusion, most of the water pumped from water wells is characterized by high salinity and does not meet the WHO standards. The main quality problem is the increase in salinity and nitrate content. The nitrate concentration reaches more than 200 ppm in the northern part of the Gaza Strip and salinity reaches more than 1.600 ppm in the middle and southern parts of the Strip. In addition to seawater intrusion in the case of Gaza, this deterioration in the water quality could be related to the unregulated disposal of various forms of waste, including domestic industrial solid waste as well as liquid and agricultural waste "fertilisers and pesticides" (Shumbulo and Ahmed, 2007). More than 90% of the population of the Gaza Strip depends on desalinated water for drinking purposes. About 90% of the groundwater is unacceptable for drinking as a result of contamination by nitrate and chloride (Al-Agha and Mortaja, 2005). Several studies in Gaza reported high nitrate (NO_3^-) levels in groundwater as one of the major concerns among the public and governmental decision makers (Abu Maila. Et al., 2004; Shomar, 2006). Recent observations revealed a high positive correlation between the concentrations of NO_3^- (N80 ppm) in groundwater of the Gaza Strip and the occurrence of methemoglobinemia in babies younger than six months of age. Among 640 babies tested in Gaza, 50% showed signs of methemoglobinemia in their blood samples (Shomar. et al., 2008).

The groundwater quality changes in both horizontal and vertical directions. The fresh groundwater is not distributed evenly throughout the whole of the Strip. Salinity of the groundwater increases over time due to seawater intrusion and mobilization of incident deep brackish water caused by over abstraction of the groundwater. In most parts of the Gaza Strip, the chloride and nitrate content of domestic water exceeds the WHO guidelines .Freshwater availability in Gaza strip indicates that eight out of 14 countries have an annual per capita supply of less than 500 m^3 of renewable water resources. In addition, seven of these countries have less than 200 m3 per capita per year, placing them among the world's 15 poorest countries in terms of water resources availability (ESCWA, 2009).

Table (3-1) shows the water quality in the different governorates of the Gaza Strip according to the concentration of NO_3, TDS and Cl respectively. Nitrate concentration ranges from 4 ppm to 496 ppm, total dissolved solids ranges from 381 ppm to 20000 ppm and chloride concentration ranges from 84 ppm to 11289 ppm. Therefore, the most serious water problems in the Gaza Strip are the shortage and contamination of the groundwater. One of the major options for solving the water problems is the utilization of desalination technology for both sea and brackish.

Table (3-1): Water quality in the Gaza governorates regarding NO_3, TDS and Cl^- concentrations (PWA chemical test, 2013)

Water Quality	NO_3 (ppm)		TDS (ppm)		CL^- (ppm)	
	Range	Mean	Range	Mean	Range	Mean
North Gaza	37-254	111.5	452-5003	2334	85-2592	982.9
Gaza	4-253	115	600-20000	2343	724- 11289	965
Middle Gaza	16.7-496	124	753-10695	2662	206-5325	1116
Khan Younis	49.3-357	116	381- 9300	2367	84-4473	981
Rafah	9.5-289.9	114.8	198-3472	2315	9.5-289.9	967

3.3Desalination experience in Gaza strip

Due to the sharp shortage of water and the bad quality of groundwater, desalination plants were set up in the Gaza Strip area in Palestine. Six large brackish water desalination plants (BWDPs) and one seawater desalination plant are operating and providing drinking water along with small private plants they are operated by Coastal Municipal Water Utilities (CMWU). The desalinated water produced from these plants represents nearly 4% of the total water consumption by the population, with more than 90% of this population depending on desalinated water for drinking purposes (Al-Agha & Mortaja, 2005). All these plants are reverse osmosis plants and their operational conditions are similar in terms of production, recovery rate, and energy consumption. The quality of the plants feed was found not to comply with WHO and Palestinian Standards in most cases, unlike the permeate from all plants. (Mogheir. et al., 2013).

Mogheir. et al.,(2013) studied a Large-scale brackish water desalination plants in Gaza Strip and Al-Khatib. et al.,(2003) study the strategy of water desalination in Gaza strip as following:

- The desalination story in Gaza began with the first established reverse osmosis (RO) brackish desalination plant in 1991 in Deir El-Balah in the central Gaza Strip (Mogheir. et al., 2013). The plant was built with a capacity of 45 m^3/h by a subsidiary of the Israeli Mekorot water company, Since then, many small- and large-scale desalination plants have been built and operated to provide potable water for the population of Gaza Strip(Mogheir. et al., 2013 and Abuhabib. et al., 2012).
- In 1991Deir El-Balah desalination plant constructed with capacity of 60m3/h and cost 650,000$, its production 420 m3/day and recovery rate 75%, its energy consumption 120 Kwh.
- In 1997 Khanyounis desalination plant constructed with capacity of 55m3/h and cost 500,000$, its production 440 m3/day and recovery rate 70%, its energy consumption 60 Kwh.
- In 1998 Khanyounis desalination plant constructed with capacity of 80 m3/h and cost 250,000$, its production 640 m3/day and recovery rate 70%, its energy consumption 60 Kwh.
- In 2009 Al-Bureij desalination plant constructed with capacity of 60 m3/h, its production 480 m3/day and recovery rate 83 %, its energy consumption 60 Kwh.
- In 2010 Bani Suhaila-Khanyounis desalination plant constructed with capacity of 50 m3/h, its production 400 m3/day and recovery rate 75 %, its energy consumption 60 Kwh.
- In 2010 Rafah desalination plant constructed with capacity of 60 m3/h, its production 480 m3/day and recovery rate 80 %, its energy consumption 60 Kwh, as shown in Table (3-2).

Table (3-2): Operational parameters of the large BWDPs in Gaza Strip
(Mogheir. et al., 2013).

Plant name	**Location and construction date**	**Cost (USD$)**	**Capacity (m^3/h)**	**Production (m^3/day)**	**Recovery rate (%)**	**Energy consumption (kwh)**	**$/$m^3$**
Al-Balad	Deir El-Balah (1991)	650,000	60	420	75	120	0.72
Al-Sharqia	Khanyounis (1997)	500,000	55	440	70	60	0.31
Al-Saada	Khanyounis (1998)	250,000	80	640	70	60	0.34
Al-Bureij	Al-Bureij (2009)		60	480	83	60	0.28
Al-Nuwairi	Bani Suhaila-Khanyounis (2010)		50	400	75	60	0.34
Al-Salam	Rafah (2010)		60	480	80	60	0.27

3.3.1 Private plants in the Gaza strip

Small desalination plants in the Gaza strip are owned privately, which try to maintain adequate amounts of fresh water for the population. The vast majority of these plants were established since 1998. The companies used the RO desalination system to produce desalinated water. They distribute this water by tankers. The small private desalination plants have a production capacity of about 20 m^3/day to 120 m^3/day, and brine water rejection ranges from 30 m^3/day to 240 m^3/day depending on the inlet. Brine from these commercial desalination plants is disposed of in the sewer system, irrigation and Wadi Gaza. There are more than 80 small RO private plants and distribution stations are operating and provide potable water for the population of the Gaza Strip at reasonable cost. However, only 37 of these plants are subjected to PWA licensing and regular monitoring (Mogheir. et al., 2013).

3.3.2 RO Household Units

The RO homes units system has started in the Gaza strip at 1996. Since people awareness of Gaza's water problems has increased, more families are using this system, it's also has been adopted by other users such as government centers, society service centers, schools, hospitals. Capacity range of RO homes units about (120-240 litter/day) and the average cost is about $250 (Assessment of MASWDP, 2013).

3.4 Electricity catastrophe in the Gaza strip

It is known that the Gaza strip has a high population growth rate, where it has a high electricity demand. Since the Gaza strip's energy resources are controlled by Israel, which employed policies to restrict the electrical production capacity of the Palestinian territories On May 1994, the Palestinian authority received its responsibilities, and despite many obstacles, work has begun to set up new generation electricity in 1999. the plant started operation on June 2002, and the commercial operation began in April, 2004.The station did not operate with full capacity because the fuel required for operation was not always available. The Gaza Strip is supplied with electricity from main sources (Assessment of MASWDP, 2013):

- The Israel Electric Corporation IEC provides 120 MW to north and central Gaza (about 60% of the electrical supply to Gaza)
- The Gaza Power Plant GPP provides 65 MW to the southern area (but relies on fuel supplied by Israeli firms).
- Egypt provides 17 MW to Rafah area. However, the total 202 MW consumed does not meet the increased demand which amount in 2007 at 240 MW

During the month of January 2012, the electricity power supply in the Gaza Strip remained unreliable, including the supply to water and wastewater facilities connected via grid lines. Power cuts of around eight hours per day continued throughout the Gaza Strip. With the drop in seasonal temperatures, a reduction in the demand for water was registered (WASH report, 2012).

CHAPTER 4 : Materials and Methods

4.1 Experimental Description

The objective of this study is to test the use of Nanofiltration cross flow for removal of nitrate and TDS from sea and brackish water and compare with reverses osmosis.

Across flow a pilot scale desalination system especially designed for research purpose is to be used for the experimental works in this research. The schematic representation of this unit is illustrated as shown in Figure (4-1).

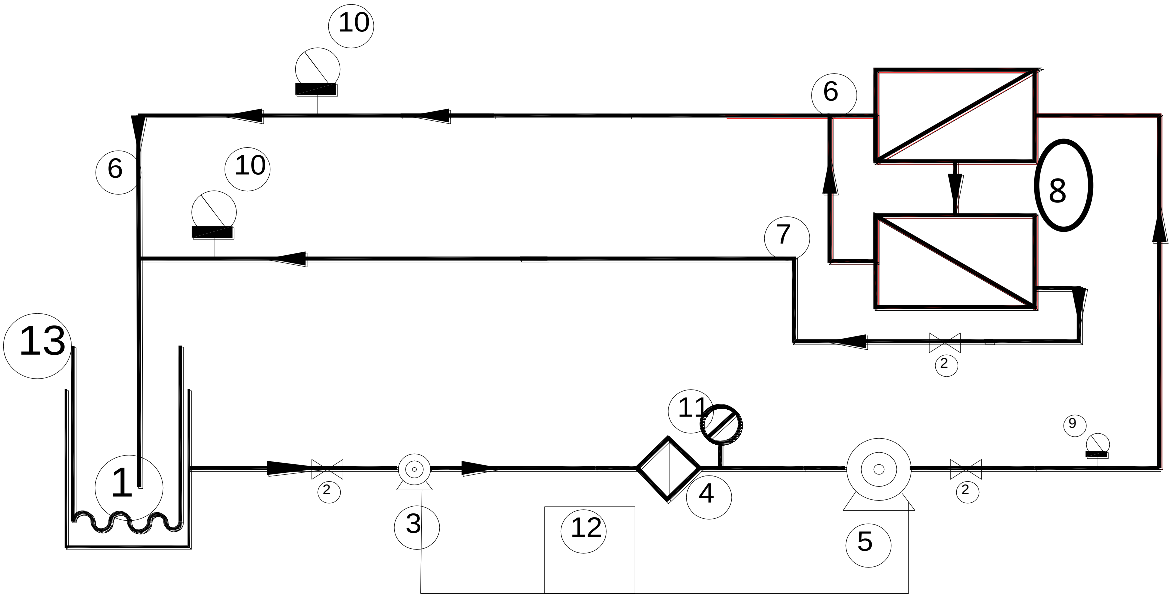


Figure (4-1): Schematic representation of pilot desalination unit

The unit in figure (4-1) consist of: 1- Tank. 2- Valve. 3- Low pressure pump. 4- Cartridge filter. 5- High pressure pump. 6- Permeated water. 7- Concentrated water "brine". 8- Membranes. 9- Pressure gauge. 10- Flow meter. 11- Heat measurement. 12- Electricity panel. 13- Cooling coil.

4.2 Materials

There are some other materials used in the experiments such as membranes, chemical, deionized water and real water sample.

4.2.1 Membrane

Two types of membrane were used in the experiments, two membrane of FILMTEC™ NF90-4040 Nanofiltration, and another two membranes of TM710 Reverses Osmosis, as shown in Figure (4-2).

Figure (4-2): a- NF90-4040 membrane, b- TM710 membrane

4.2.2 Chemicals

The chemical used to prepare aqueous solutions are sodium chloride NaCL and sodium nitrate NANO3 with purity 99 % which used to prepare (17000, 11500, 4500) ppm NaCL solution and (150, 80, 0) ppm nitrate solutions. Table (4-1) shows the aqueous solutions properties.

Table (4-1): The aqueous solutions properties.

Solution	TDS as NaCl (ppm)	Nitrate (as NO_3)
Solute 1	17000	150
Solute 2	11500	150
Solute 3	4500	150
Solute 4	17000	0
Solute 7	17000	80

4.2.3 Deionized Water preparation

The deionized water was used to prepare solution and it was prepared in abed Salam yaseen companyin Gaza city.

4.2.4 Real water sample

Real water samples were collected from five different wells and the sea water. The sample collected were based on the concentration of TDS that arranged as mildly brackish, moderately brackish , saline and seawater.

The selection of wells was based on PWA chemical tests results in 2013. Table (4-2) shows PWA chemical testing. Table (4-3) shows the chemical analysis of selected wells which were performed in the Public health Lab in January 2014.

Table (4-2): *PWA* chemical tests results of selected wells.

Well name	الصبرة-٣	الشيخ رضوان-٨	Amenam	(R/338)الرمال ٣	الشيخ رضوان- ٥
Well ID	R/308	E/154		R/115	R/162D
EC (μΩ/cm)	3060	14600	Private well	29800	32300
TDS	1897	9052		18476	20026
PH	7.35	6.95		7.74	6.9
Calcium Ca(ppm)	108	616		558	744
Magnesium Mg (mg/L)	84	420		626	760
Sodium Na (ppm)	430	2100		5600	5700
Potassium K (ppm)	9.1	7		140	145
Floride F (ppm)	1.3	0.71			1.1
Chloride Cl (ppm)	483	4757		10272	11289
Nitrate NO3 (ppm NO3)	220.5	32.3		113.1	109.1
Nitrite NO2 (ppm)	0	0			0
Ammonia NH3(ppm)	0	0.2			0
Sulphate SO4 (ppm)	181	476		1521	1542
Alkalinity	430	183		225	204
Hardness	615	3270		3972	4992

Table (4-3): Chemical analysis of selected wells.

Well name	EC (μΩ/cm)	TDS (ppm)	Nitrate (ppm) NO_3	Chloride Cl (ppm)	PH	Classification
Sabra 3	2781	1724	211	504	7.34	mildly brackish
Redwan 8	10910	6764	72.2	3528	7.77	moderately brackish
Amen Am	14969	9281	113	4914	7.14	
Remal 3	26600	16492	99	9191	7.25	saline
Redwan 5	32200	19964	105	11418	6.91	
Sea	56000	34720	5	21584	7.87	seawater

4.3 Experimental Apparatus

The experimental apparatus was composed of (membrane, pumps and facilities). Figure (4-3) show the Experimental apparatus.

4.3.1 Membrane

Two types of membrane were used nanofiltration NF90-4040 and reverses osmosis TM710 membrane as following.

4.3.1.1 NF 90-4040 membrane

The FILMTEC NF90 membrane elements provides high productivity performance and removing a high percentage of salts, nitrate, iron and organic compounds such as pesticides, herbicides and THM precursors. The low net driving pressure of the NF90 membrane allows the removal of these compounds at low operating pressures. Table (4-4) shows the Specifications of NF90-4040 membrane comparing with RO TM-710 membrane.

Table (4-4): The Specifications of NF90-4040and TM710 (FILMTEC™ Membranes **).**

Specifications	NF90-4040 membrane	RO TM-710 membrane
Membrane Type	Polyamide Thin-Film Composite	Cross Linked Fully Aromatic Polyamide Composite.
Active area (m^2)	7.6	8
Permeated flow rate (m^3/d)	7.6	9.1
Stabilized salt rejection %	>97.0	99.7
Applied Pressure	70 psi (4.8 bar)	225 psi (15.5 bar)
Feed Water Concentration	2,000 ppm NaCl	2,000 ppm NaCl
Maximum Operating Temperature	113°F (45°C)	77 ˚F (25 ˚C)
Maximum Operating Pressure	600 psi (41 bar)	600 psi (41 bar)
Maximum Feed Flow Rate	16 gpm (3.6 m^3/hr)	-

4.3.1.2 TM 710 membrane

It is based on a pressure-driven process, the driving force resulting from the difference of the electrochemical potential on both sides of the membrane. Operating pressures can reach up to 41 bars. Reverse Osmosis (RO) elements designed to produce high quality water and reduce capital and operation cost. Table (4-3) shows the specifications of NF90-4040 membrane comparing with RO TM-710 membrane.

4.3.2 Pump

Two types of pump were used to generate the pressure required. High pressure pump (hpp) and low pressure pump (lpp), frequency control pressure were used to control the pressure generated from these pump.

4.3.2.1 High pressure pump

VS 2-22 (3HP) high pressure pump was used to generate the pressure needed the operating condition of the pump is: temperature of liquid from 0°C to 110°C (max), ambient temperature max to 40°CMax, working pressure 25 bar.

4.3.2.2 Low pressure pump

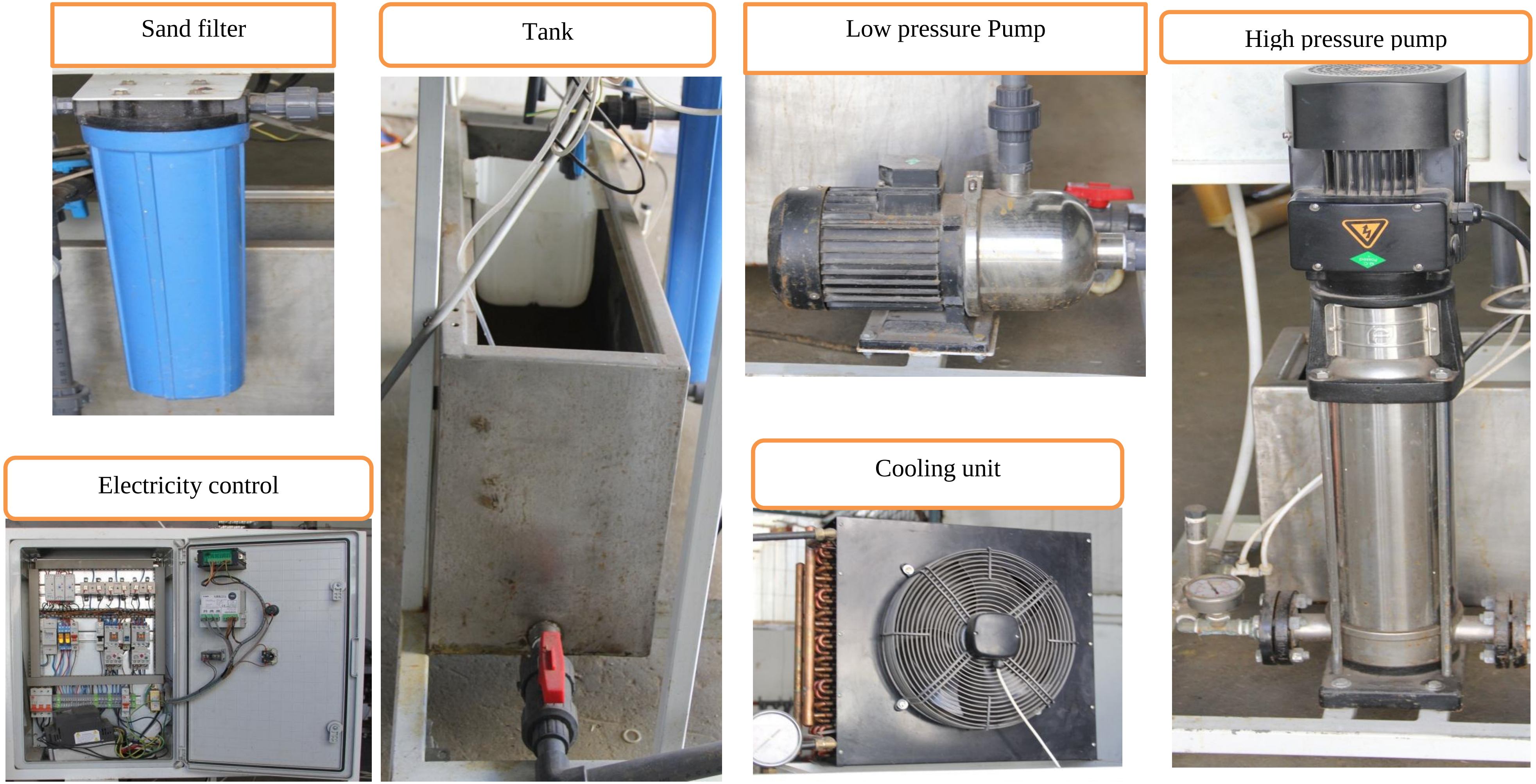
Dap Low pressure Centrifugal pump, JETINOX 102 M (1HP) was used to generate low pressure.

4.3.3 Facilities

The facilities used in the experiment consist of: Cartage filter, tank, pipes, Cooling coil, heat measurement, flow meter, pressure gauge, frequency control pressure and house membrane, the description and function of the facilities illustrated in table (4-5), Figure (4-3b) shows D. abo asee thesis team, Gaza, Palestine.

Table (4-5): Facilities description and function.

Experimental facilities	Description and function
Cartage filter	A 5µm cartage filters was used to avoid the carryover of large debris into the membrane system.
Tank	Noristic feed tank with capacity 120 litter was used in the desalination unite.
Pipes	PVC pipes were used to connect the part of desalination unite, the maximum operating pressure was 30 bar.
Cooling coil	A cooling coil was installed inside the feed tank for circulating cold water to maintain constant feed temperature within the range of 16-18 °C.
Heat measurement	The heat measurement was used to measure the temperature of feed water.
Flow meter	The flow meter was used to measure the Flow rate of the concentrated and product water.
Pressure Gauge	The pressure Gauge was used to measure the operating pressure.
Frequency Control Pressure	The Frequency Control Pressure was used to control with operating pressure.
House membrane	Membranes are usually housed in house membrane, the maximum operating pressure of the house membrane was 30 bar.



Sand filter

Tank

Low pressure Pump

High pressure pump

Electricity control

Cooling unit

Figure (4-3a) The Experimental apparatus.

Figure (4-3b): D. abo asee technical team, Gaza, Palestine, April 2014

4.4 Measurements and analytical method

The chemical analysis were performed for samples includes: TDS, NO3, CL- and pH. The chemical analysis performed for samples which collected from the wells after and befor exposed to operating pressure.

4.4.1 TDS Measurement

Concentration of TDS was determined by Conductivity meter (Microprocessor conductivity meter Sension7. TDS concentration can be calculated using equation (4-1).

TDC ppm=E.C micro S/cm *0.62 …………………… (4-1)

4.4.2 Nitrate Measurement

Standard method 4500-NO3 nitrogen (nitrate) was used in nitrate measurement. Nitrate concentration was determined by UV-VIS Spectrophotometer. The instrument was turned on and warmed up for 15- 20 min before starting any sample measurement and adjusted at 220 nm, then the sample is measured after that the concentration of unknown sample is determined compared with Standard Curve.

4.4.3 Ph measurement

PH is a logarithmic notation used to measure hydrogen activity (i.e., whether a solution is acid or basic). PH can be calculated using equation (4-2).

Ph = - log [H+] …………………… (4-2)

4.4.4 Flux and Recovery Rate

Flux represents the volume of liquid passing through specific area of membrane at certain operating pressure during a period of time. It can be calculated using equations (4-3a,b).

Flux rate (l/m2.hr) = V/A.t …………………… (4-2a)

Flux rate (l/m2.hr)= Flow rate (lph)/A …………………… (4-2b)

Where:

V: volume of water permeated at the time (t).

A: surface area of membrane (7.6 m^2 NF and 8 m^2 RO).

t: time of filtration (hr).

Recovery rate represent the ratio between the product water to the feed water. It can be calculated using equation (2-1).

4.4.5 Rejection Rate

Rejection rate is the percent removal of the solute from water, The ability of membrane to reject TDS, CL and NO_3 was measured using equation (2-2).

4.4.6 Hydraulic Permeability

Hydraulic Permeability is obtained from the slope of the plot of flux versus the increasing trans membrane pressure (ΔP) and the intercept on x-axis of the plot gives the critical pressure Pc when the transmembrane pressure is equal to the osmotic pressure(DACH, 2008), and its unit $L/(m^2.hr.bar)$.

4.4.7 Specific Energy Consumption

The Specific Energy Consumption (SEC) is what ultimately determines the cost of the system as energy requirements (Schäfer. et al., 2007). The main performance indicator of desalination system in this research is energy requirements in the form of specific energy consumption and its unit (kwh/m^3).

The SEG proportional to the transmembrane pressure. SEC can be calculated using equation (2-3).

4.5 Experimental Procedure

In this research the experimental procedure was as follows:

1- The pilot scale of desalination system was fixed as shown in figure (4-1).

2- The chemical analysis were made on the samples of water shown in Table (4-2) which collected from the wells, and then the solution shown in Table (4-1) were prepared.

3- Nanofiltration NF90-4040 membrane gathered in the house membrane, and one water sample with volume 100 litter was used .

4- The temperature maintained to 16 to18°C and adjustment.

5- The pressure controlled on 24 bar, then turn on the unit 10 minutes.

6- After 10 min the following data recorded:

- Produced flow water.
- Concentrated flow water.
- Electricity consumption.

7- TDS & NO_3& CL concentration were measured. Recovery rate, Flux rate and Rejection rate for (TDS, NO_3, CL) were Calculated.

8- Step5 was repeated using pressure (6, 8, 10, 12, 14, 16, 18, 20, 22 and 24) bar with repeated step7 for each pressure.

9- Reverses Osmosis TM-710 membrane replaced NF90-4040 membrane and steps (4, 5, 6, 7, 8) were repeated .

10- The membrane was flushed with deionized water and then use another water sample and step from 3 to 9 were repeated.

11- In the filtration tests, both the permeate and the concentrated were returned to the feed tank in order to keep a constant concentration and volume.

CHAPTER 5 : Result and discussion

This chapter shows the comparison of the performance between NF and RO membrane in terms of hydraulic permeability, flux rate, specific energy and salt/ion rejection. The experiment measurements described in previous chapter were used to study the comparison performance between NF and RO membrane in nitrate and TDS rejection at deferent operating pressures using different feed water nitrate and TDS concentrations. The results of aqueous solution and real water samples of groundwater wells and sea water are discussed.

5.1 Comparison between membrane performances in desalinating aqueous solution

In this section, the performance of NF90-4040 for TDS and nitrate removal from brackish and solute water was evaluated and compared with Reverses Osmosis TM710, five samples of the solute were prepared as illustrated in Table(4-1). TDS concentration of the samples varies in the rage of TDS (4500 - 17000) ppm and NO_3 (0-150) ppm.

Many factors influence the flux rate and the rejection rate such as the operating pressure and the ionic concentration. Consequently, these two factors were carefully studied.

5.1.1 Flux and Recovery Rate Comparison

The first factor that can measure the effectiveness of membrane is the quantity of produced water represented in flux and recovery rate. Flux of the investigated membranes with water was measured under different operation pressures, feed water TDS, and nitrate concentration.

5.1.1.1 Effect of Operating Pressure on Flux and Recovery

Figures (5-1a,b) illustrate the effect of the pressures on the flux using NF and RO membrane respectively, as shown in figure (5-1a) using NF membrane the maximum flux was 94.47 L/m^2.hr at pressure 24 bar when feed water TDS concentration4500 ppm and feed water nitrate concentration 150 ppm, while the minimum flux was 7.89 L/m^2.hr at pressure 6 bar using the same solution. Figure (5-12) shows the result using RO membrane it can be noticed that the maximum flux was 48.75 L/m^2.hr at pressure 24 bar when feed water TDS concentration4500 ppm and feed water nitrate concentration 150 ppm, while the minimum flux was 3.75 L/m^2.hr at pressure 6 bar using the same solution. The NF90 membrane exhibits higher permeate flux values compared to the RO membranes, The NF membrane has more opened pores compared to the RO membranes (Mänttäri. Et al., 2004).

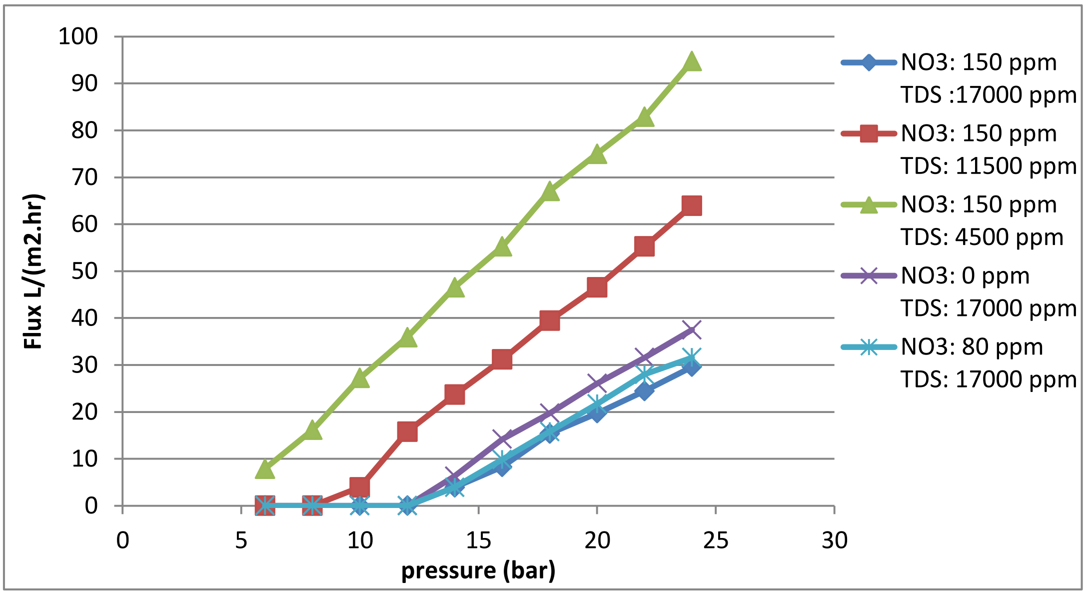


Figure (5-1a): Effect of operating pressures on flux for solute using NF membrane.

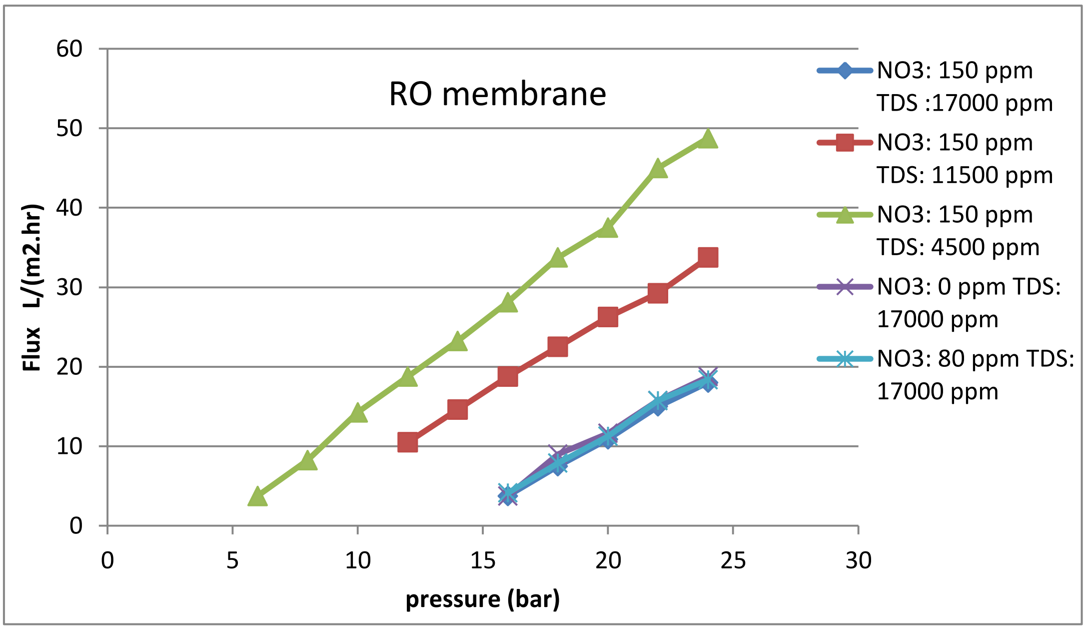


Figure (5-1b): Effect of operating pressures on flux for solute using RO membrane.

Figures (5-2a,b) illustrate the effect of pressure on recovery rate using five solution samples. Figure (5-2a) shows that using NF membrane the maximum recovery rate was 68.4% at pressure 6 bar, while the minimum recovery rate was 25.5% at pressure 24 bar using solution with feed water TDS concentration 4500 ppm and feed water nitrate concentration 150 ppm. Figure (5-2b) shows that using RO membrane the maximum recovery rate was 52% at pressure 24 bar, while the minimum recovery rate was 14.26% at pressure 6 bar using the same solution.

Figures (5-1a,b) Figures (5-2a,b) shows that the flux and recovery rate are directly proportional to the pressure using both NF and RO membranes. It can be noticed that the flux rate and recovery rate using NF membrane was more than that using RO membrane at the same pressure as illustrated in the Figures (5-1a,b). For example: using solute with TDS=4500 ppm and NO_3=150 ppm the flux rate at pressure 24 bar using NF membrane was 94.74 L/m^2.hr, while the flux decreases using RO membrane at the same pressure and solute to 48.75 L/m^2.hr.

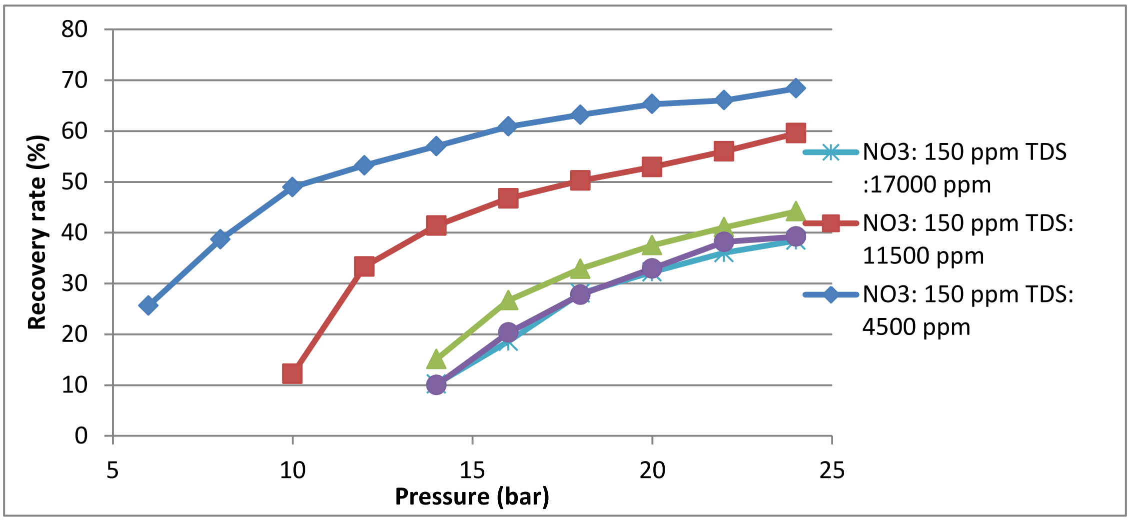


Figure (5-2a): Effect of operating pressures on recovery rate for solution using NF membrane.

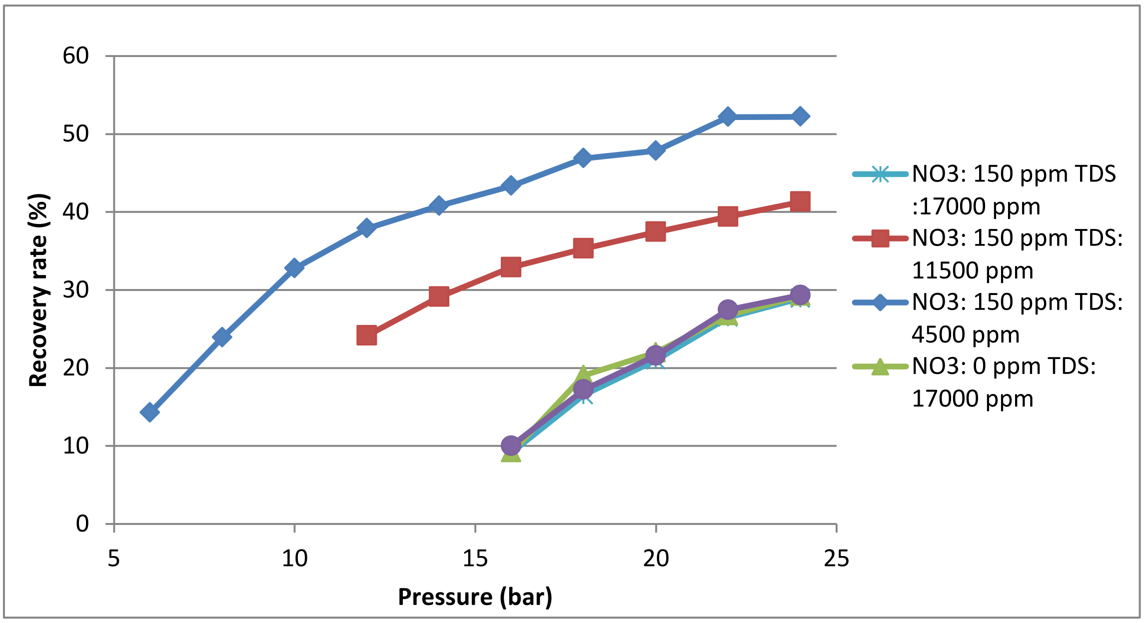


Figure (5-2b): Effect of operating pressures on recovery rate for solution using RO membrane.

5.1.1.2 Effect of feed water TDS Concentration on hydraulic permeability

Figure (5-3) shows the effect of feed water TDS concentration on hydraulic permeability with constant nitrate NO3=150 ppm. Figure (5-3) shows that increasing the feed water TDS concentration leads to decreasing the hydraulic permeability. It can be noticed that the hydraulic permeability using NF membrane was more than that in RO membrane. Its mean that the possibility of fouling in NF membrane less that in RO membrane.

For example when the feed water TDS concentration was 11,5000 ppm the hydraulic permeability using NF membrane was 4.13 L/(m2.hr.bar), while it decreases to 1.9 L/(m2.hr.bar) using RO membrane.

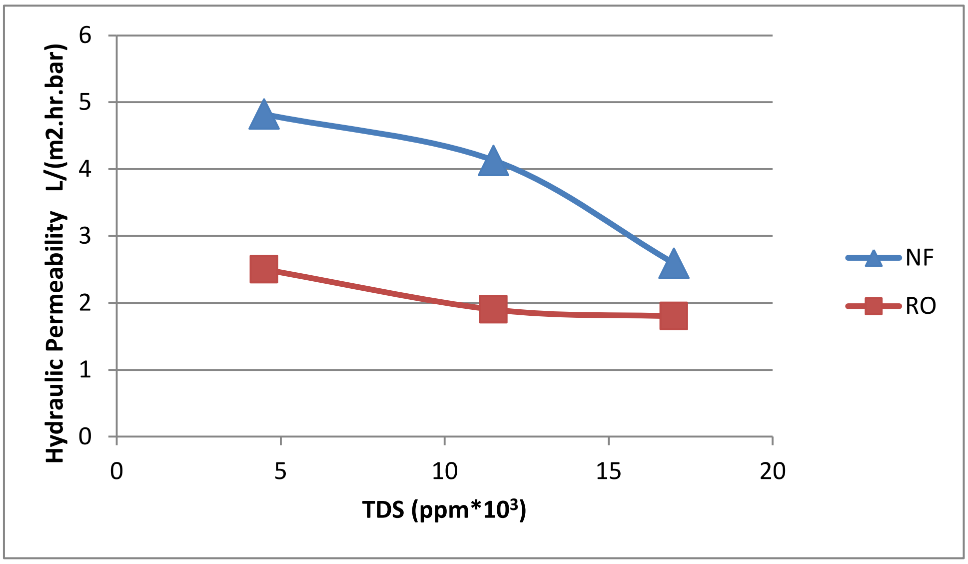


Figure (5- 3): Effect of feed water TDS Concentration on hydraulic permeability.

5.1.1.3 Effect of feed water NO_3 Concentration on hydraulic permeability

Figure (5-4) shows the effect of feed water nitrate concentration on hydraulic permeability using constant total dissolved solid TDS=17,000 ppm. Figure (5-4) illustrate that increasing feed water nitrate concentration leads to decreasing the hydraulic permeability, also feed water nitrate concentration using RO membrane not affected significantly on the hydraulic permeability. While the reduction using NF membrane are more significant. For example, using RO membrane when feed water nitrate concentration was zero with TDS=17,000 ppm, the hydraulic permeability was 1.8 L/(m2.hr.bar). The hydraulic permeability was 1.75 L/(m2.hr.bar) when the feed water nitrate concentration increases to 150 ppm. While using NF membrane hydraulic permeability was 3.1 L/(m2.hr.bar) when the feed water nitrate concentration was zero, and the hydraulic permeability decreases to 2.6 L/(m2.hr.bar) when the feed water nitrate concentration increases to 150 ppm.

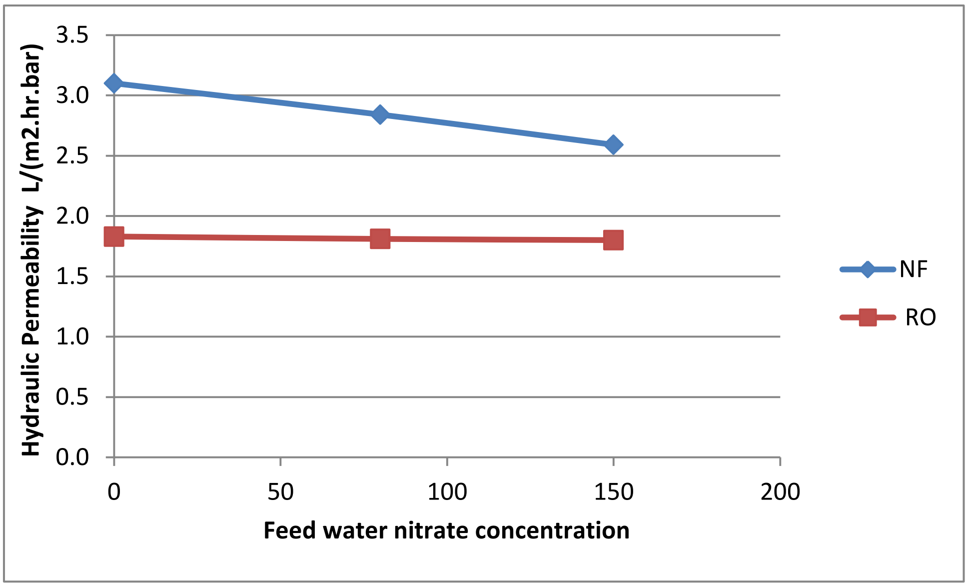


Figure (5- 4): Effect of feed water NO_3 Concentration on hydraulic permeability.

5.1.2 Rejection Rate of Ionic Components

The second factor for measuring the effectiveness of membrane is the quality of product water that is represented by the rejection of Ionic components such as TDS and NO_3. This section will discuss this factor. To investigate this factor, the NaCl concentration was varied from (4,500 to17,000) ppm and nitrate was varied from (0-150) ppm, then the desalination unite was operated at different pressures.

5.1.2.1 Effect of Operating Pressure on TDS and NO_3 Rejection

The rejection using the investigated NF and RO membranes of TDS and NO_3 rejection was plotted against the operating pressure as shown in Figures (5-5a,b) and figures (5-6a,b), respectively. It can be noticed that the rejection of TDS increases with the increases of the operating pressure. The rejection rates of TDS and NO_3 using NF membrane was lower than that using RO membrane, because the NF membrane has more opened pores compared to RO membrane, also it can be noticed that the effect of pressure on TDS rejection disappears at pressure 14 bar using NF membrane, while these effect disappears at pressure 18 bar using RO membrane. Using solution with TDS concentration 4500 ppm, it can be noticed that the difference between TDS rejection was 6% using NF membrane. since it was 98% when the pressure was 24 bar and it decreases to 92% when the pressure decrease to 6 bar. While the difference between TDS rejection was 1% using RO membrane. since it was 99.5% when the pressure was 24 bar and it decreases to 98.5% when the pressure decrease to 6 bar

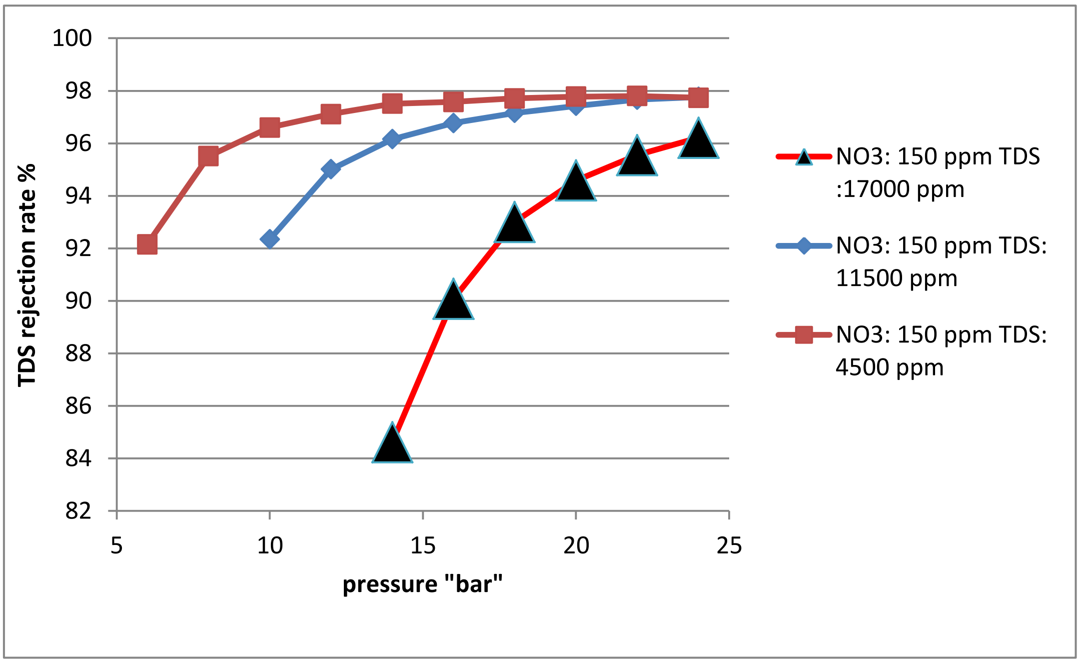


Figure (5-5a): Effect of Operating Pressure on TDS Rejection using NF membrane.

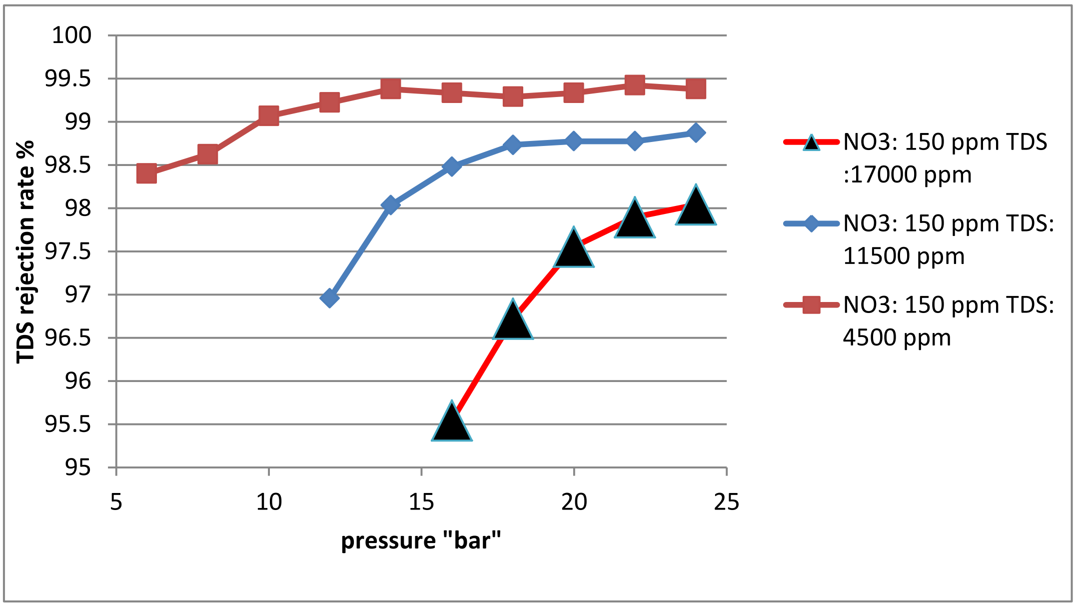


Figure (5-5b): Effect of Operating Pressure on TDS Rejection using RO membrane.

Figure (5-6a) shows the effect of operating pressure on nitrate rejection using NF membrane, it can be noticed that the increasing of operation pressure increasing the nitrate rejection. Also it can be noticed that the TDS concentration effected on the nitrate rejection, for example at pressure 18 bar the nitrate rejection was 28% when feed water TDS concentration 17,000 ppm and nitrate concentration 150 ppm while it increase to 90% when feed water TDS concentration decreases to 4500. Also it can be noticed that using feed water TDS concentration 4500 ppm the maximum nitrate rejection rate was 93% at pressure 20 bar, while the minimum nitrate rejection was 80% at pressure 6 bar.

Figure (5-6b) shows the effect of operating pressure on nitrate rejection using RO membrane, it can be noticed that the increasing of operation pressure increasing the nitrate rejection. Also it can be noticed that the TDS concentration effected on the nitrate rejection, for example at pressure 20 bar the nitrate rejection was 91.5% when feed water TDS concentration 17,000 ppm and nitrate concentration 150 ppm, while it increase to 98% when feed water TDS concentration decreases to 4500. Also it can be noticed that using feed water TDS concentration 4500 ppm the maximum nitrate rejection rate was 98.6% at pressure 22 bar, while the minimum nitrate rejection was 95.3% at pressure 6 bar.

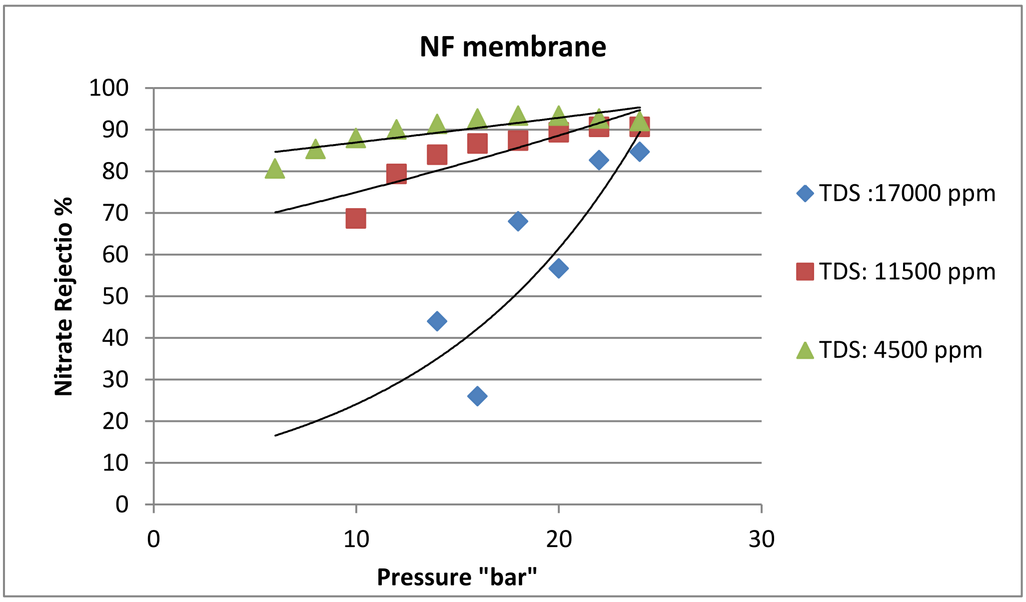


Figure (5-6a): Effect of Operating Pressure on NO_3 Rejection using NF membrane.

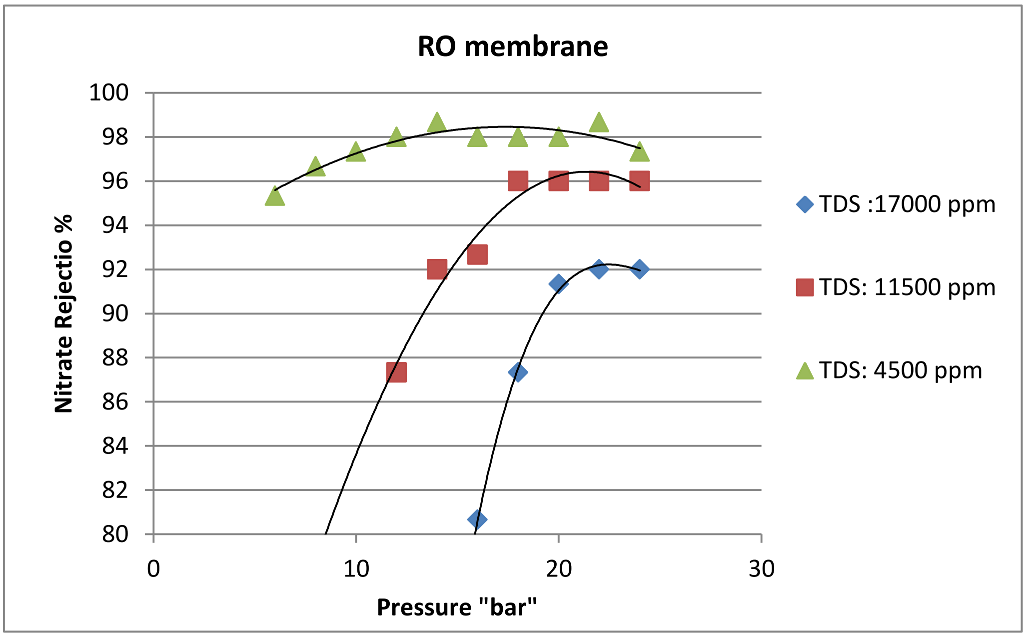


Figure (5-6b): Effect of Operating Pressure on NO_3 Rejection using RO membrane.

5.1.2.2 Effect of Feed water TDS Concentration on TDS and NO_3 Rejection

Figures (5-7a,b) illustrates the effect of feed water TDS Concentration on TDS and NO_3 rejection. As shown in the figures (5-7a,b) increasing of feed water TDS concentration leads to decreasing the TDS and NO_3 rejection in both NF and RO membrane.

The effective pore radius of a charged pore will increase as the ionic strength of the surrounding liquid increases. Therefore, the rejection of monovalent ions will decrease as their concentration in the feed solution increases. The rejection of divalent ions will be affected to a lower extent. The shield effect of membrane charge also increases as the ionic strength of feed solution increases (Dach, 2008).

In this case higher rejection at lower feed concentration and lower rejection at higher feed concentration was observed (Peters. et al. 1998). Increasing the concentration of sodium cations of the solution involves the formation of a screen which gradually neutralizes the negative charge of the membrane. As the total charge of the membrane decreases, the retention of the anions decreases since the electrostatic effect of the membrane becomes weaker (Childress. et al., 2000). This means that the effect of membrane charge is completely eliminated when the salt concentration is high enough (Scheap and Vandecasteele, 2001). Also it can be noticed that the rejection rate of TDS and NO_3 using RO membrane was higher that using NF membrane.

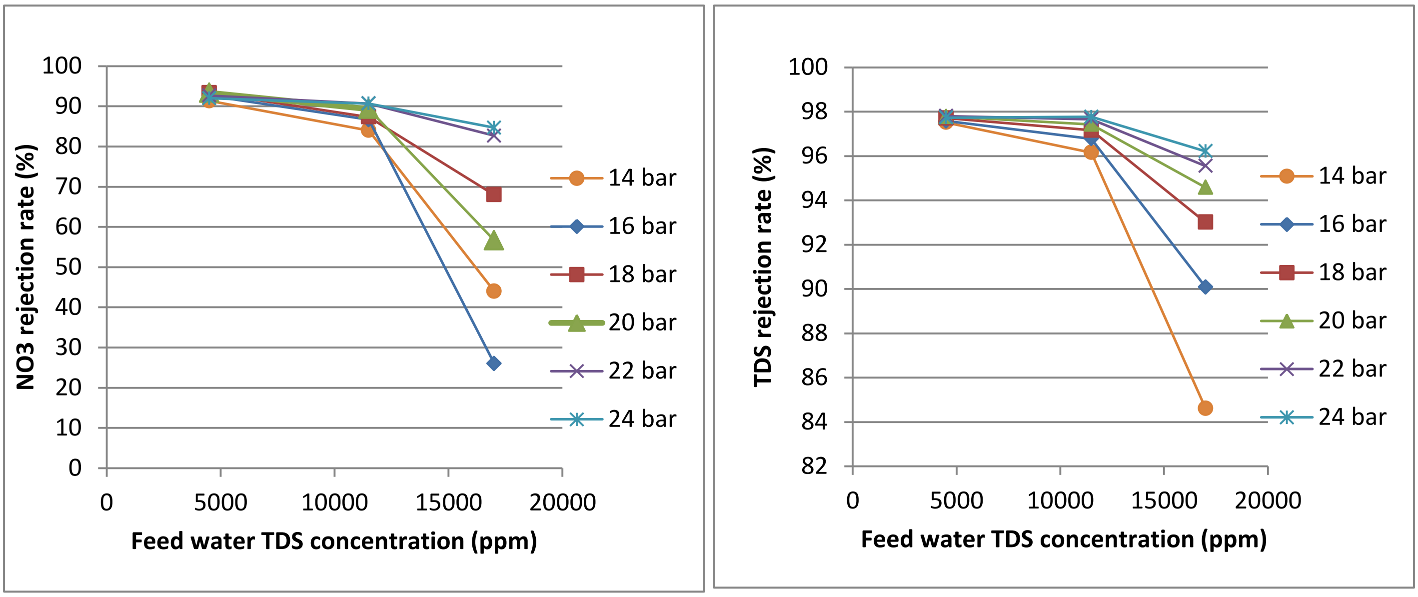


Figure (5-7a): Effect of Feed water TDS Concentration on TDS and NO_3 Rejection using NF membrane

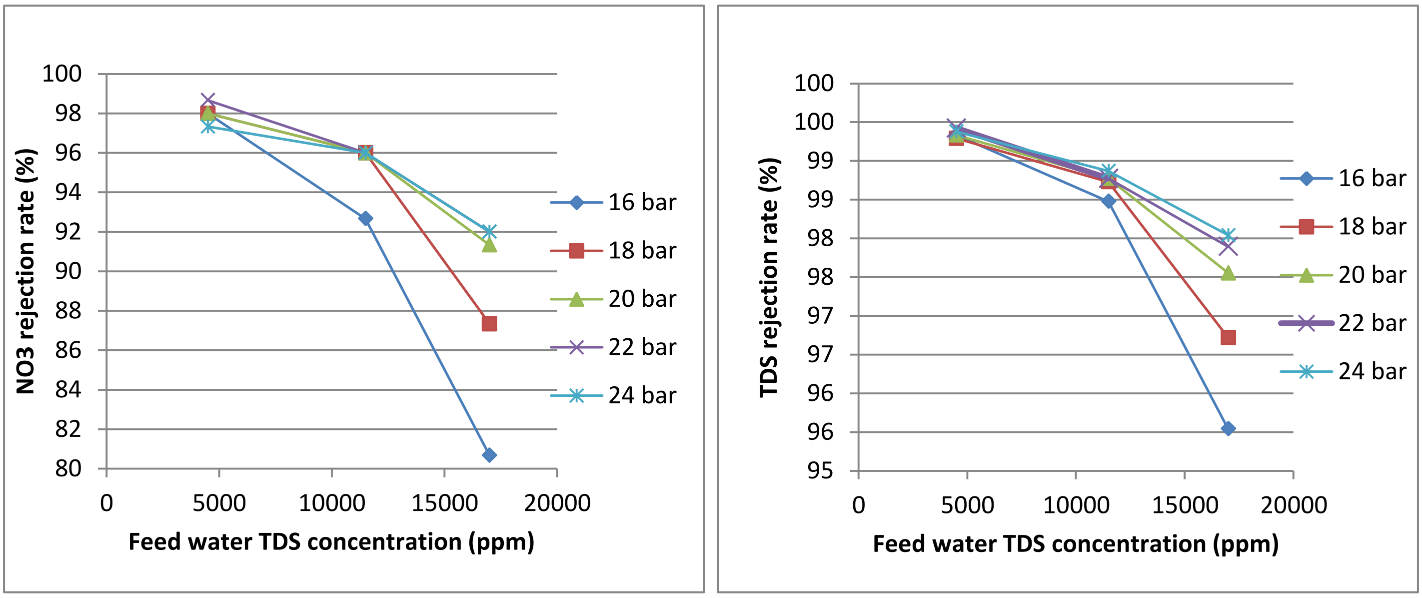


Figure (5-7b): Effect of Feed water TDS Concentration on TDS and NO_3 Rejection using RO membrane

5.2 Comparison between Membrane Performances in real brackish and sea Water

In this section, the performance of NF90-4040 for TDS and nitrate removal using real brackish and sea water were evaluated and compared with RO TM710 membrane.

Five samples were collected from different wells distributed in Gaza City, TDS concentration of these samples varies TDS in the rage of (1724 to 19964) ppm and nitrate from (99 to 211) ppm.

Another sample was collected from the sea, with TDS concentration 34720 ppm and nitrate concentration 10 ppm.

The main performance indicators of a pilot scale desalination system are productivity in the form of flux or hydraulic permeability and recovery rate, desalination efficiency in the form of retention with regards to total dissolved solids, individual elements, and energy requirements in the form of specific energy consumption (Dach H, 2008).

5.2.1 Flux and Recovery Rate Comparison

Flux and recovery rate of the investigated membranes with water was measured under different operation pressures.

Experimental data for the permeated flux and recovery rate using real water sample as a function of the operating pressure and ionic concentration and energy consumption were obtained.

5.2.1.1 Effect of Operating Pressure on flux and Recovery

Figures (5-8a,b) illustrate the effect of the pressures on the flux and recovery rate using six random samples selected from water wells (Sabra 3, Redwan 8, Amen Am, Remal 3, Redwan 5 and Sea water). The TDS concentration in these samples ranges between (1724-34720) ppm and the nitrate concentration in these sample ranges between (10-211) ppm.

As noticed in Figures (5-8a,b) the flux and recovery rate is directly proportional to the pressure as in the case of the aqueous solution observed in section 5.1. The maximum flux and recovery rate observed at 24 bar in Sabre3 well, and minimum flux at 16 bar in Redwan5 well.

It was observed that Sabre3 well sample contains the lowest TDS concentration its 1724 ppm, and Redwan5 well sample contains highest TDS concentration (19964 ppm). Therefore, the TDS concentration has influenced the flux rate as discussed in section 5.2.1.2

Table (5-1) shows the flux of water sample at different pressure for all the six samples. The maximum flux was 102.63 L/m2.hr with recovery rate 68.1% using

NF90-4040 NF membrane obtained at Sabra3 well using pressure 24 bar. The maximum flux using TM710 RO membrane was 54.38 L/m^2.hr with recovery rate 53.7% using the same well sample at the same pressure.

The minimum flux was 1.97 L/m^2.hr using NF90-4040 NF membrane with recovery rate 5.1 %, obtained at Redwan5 well using pressure 16 bar. The minimum flux using TM710 RO membrane was 1.88 L/m2.hr at pressure 18 bar with recovery rate 4.5% using the same well sample.

Table (5-1) and Table (5-2) show that the flux using NF membrane was higher than the flux using RO membrane at the same pressure. For example: at pressure 24 bar, the result of testing Sabra3 sample using NF membrane indicated that the flux rate was 102.63 L/m2.hr, while using RO membrane at pressure 24bar the flux rate was 54.38 L/m2.hr. Although the result of testing Sabra3 sample using NF membrane indicated that the flux rate was 60 L/m^2.hr, while using RO membrane the flux rate was 30 L/m2.hr.

Figures (5-8a,b) show the line slope indicated that the value of the hydraulic permeability in NF were higher than hydraulic permeability in RO at the same pressure. For example, the hydraulic permeability using NF membrane at pressure 24 bar was 4.8 L/(m^2.hr.bar), while it was 2.7 L/(m^2.hr.bar) using RO membrane using the same sample .

In Remal3 well sample the flux through the NF membranes starts under 14 bar, while using RO membrane the permeate flux is obtained by applying a pressure higher than 16 bar.

The NF90 membrane exhibits higher permeate flux values compared to the RO membranes. The NF membrane has more opened pores compared to the RO membranes. the permeability of a membrane is also related to a thickness of selective layer (Mänttäri. Et al., 2004) and surface roughness of the membrane (Hiros. et al., 1996; Gao and chen, 1998).

For each tested concentrations, the results show that the volumetric permeate flux increases linearly with the pressure. The results show that at fixed salinity, the contents of all parametrs decreases with the applied pressure for each membrane. These results can be attributed essentially to the increase in the solvent flow. (Elazhar. et al., 2013).

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Table (5-1): Real water flux at deferent pressures using NF membrane

TDS	Pressure/ well name	Pressure										Hydraulic Permeability L/(m^2.hr.bar)
		6	8	10	12	14	16	18	20	22	24	
		Flux L/(m^2.hr)										
TDS 1724	Sabra 3	15.79	26.05	39.47	51.32	63.16	75.00	78.95	87.63	94.74	102.63	4.80
TDS 6764	Redwan 8	5.92	11.84	19.74	25.66	33.55	39.47	46.58	53.29	60.00	67.11	3.40
TDS 9281	Amen Am			7.89	9.87	17.76	24.47	31.58	38.68	45.39	53.29	3.36
TDS 16492	Remal 3					2.37	4.74	9.87	15.79	20.13	26.84	2.50
TDS 19964	Redwan 5					1.97	4.34	8.29	13.82	17.76	21.71	2.06
TDS 34720	Sea									4.74	11.45	2.26

Table (5-2): Real water flux at deferent pressures using RO membrane

TDS	Pressure/ well name	Pressure										Hydraulic Permeability L/(m^2.hr.bar)
		6	8	10	12	14	16	18	20	22	24	
		Flux L/(m^2.hr)										
TDS 1724	Sabra 3	4.50	12.75	18.00	24.38	30.00	35.63	41.25	44.25	49.13	54.38	2.70
TDS 6764	Redwan 8			4.50	10.13	13.13	18.75	22.50	26.25	30.00	33.75	2.07
TDS 9281	Amen Am				3.75	9.38	12.00	17.06	21.75	23.25	29.25	2.04
TDS 16492	Remal 3						1.88	4.13	7.50	11.25	13.88	1.55
TDS 19964	Redwan 5							1.88	5.63	7.50	11.25	1.50

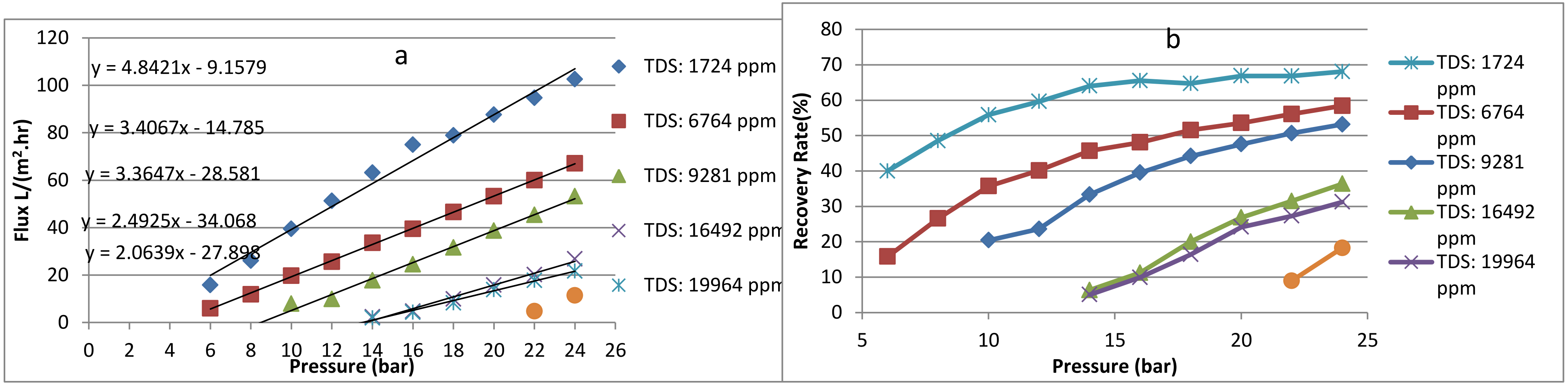


Figure (5- 8a): Effect of operating pressures on(a-flux, b- recovery rate) for Real water samples using NF membrane.

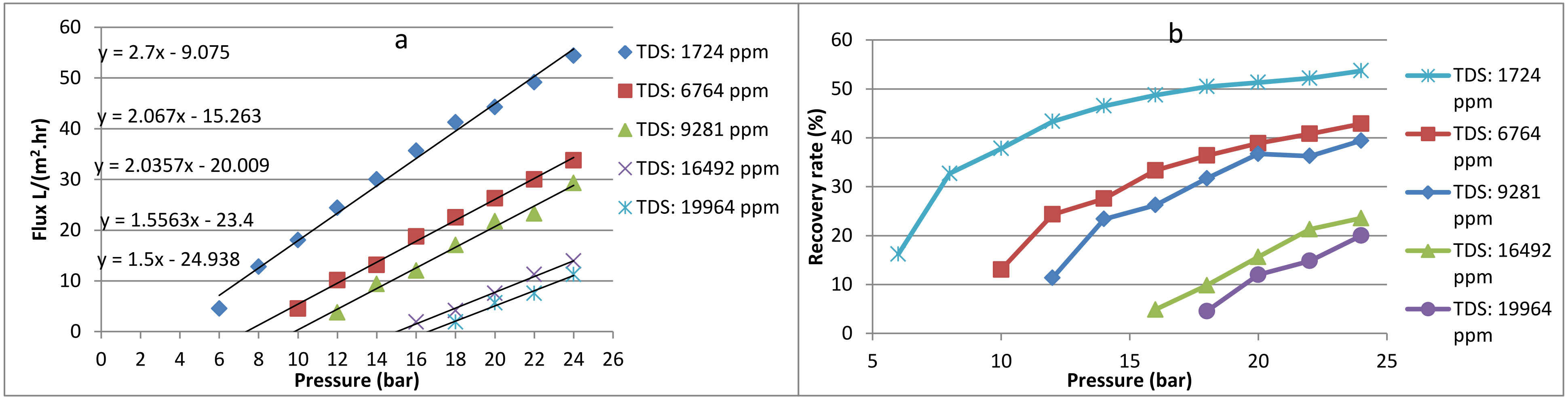


Figure (5- 8b): Effect of operating pressures on (a-flux, b- recovery rate) for Real water samples using RO membrane.

5.2.1.2 Effect of feed water TDS Concentration on Hydraulic Permeability and Flux

Figure (5-9) illustrates the effect of feed water TDS concentration on hydraulic permeability, it can be noticed that increasing the feed water TDS leads to decreasing the hydraulic permeability.

In NF membrane, the maximum hydraulic permeability at Sabra3 well where it contains a minimum TDS concentration(1724 ppm), was 4.8 L/(m^2.hr.bar). The maximum hydraulic permeability using RO membrane was 2.7 L/(m^2.hr.bar) at the same well sample.

The minimum hydraulic permeability using NF membrane at Redwan5 well where the maximum TDS concentration (19964 ppm), was 2.06 L/(m^2.hr.bar). The minimum hydraulic permeability using RO membrane was 1.5 L/(m^2.hr.bar) at the same well sample.

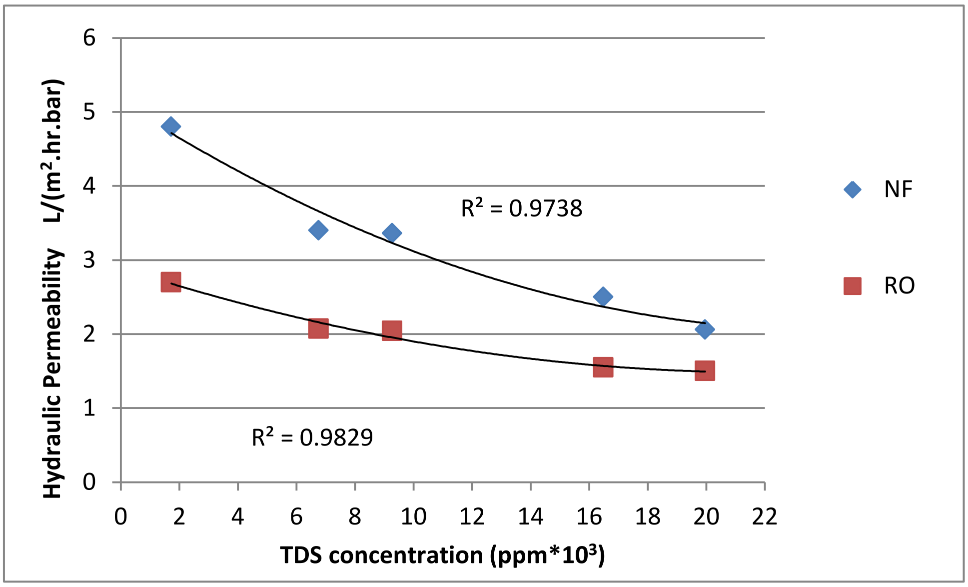
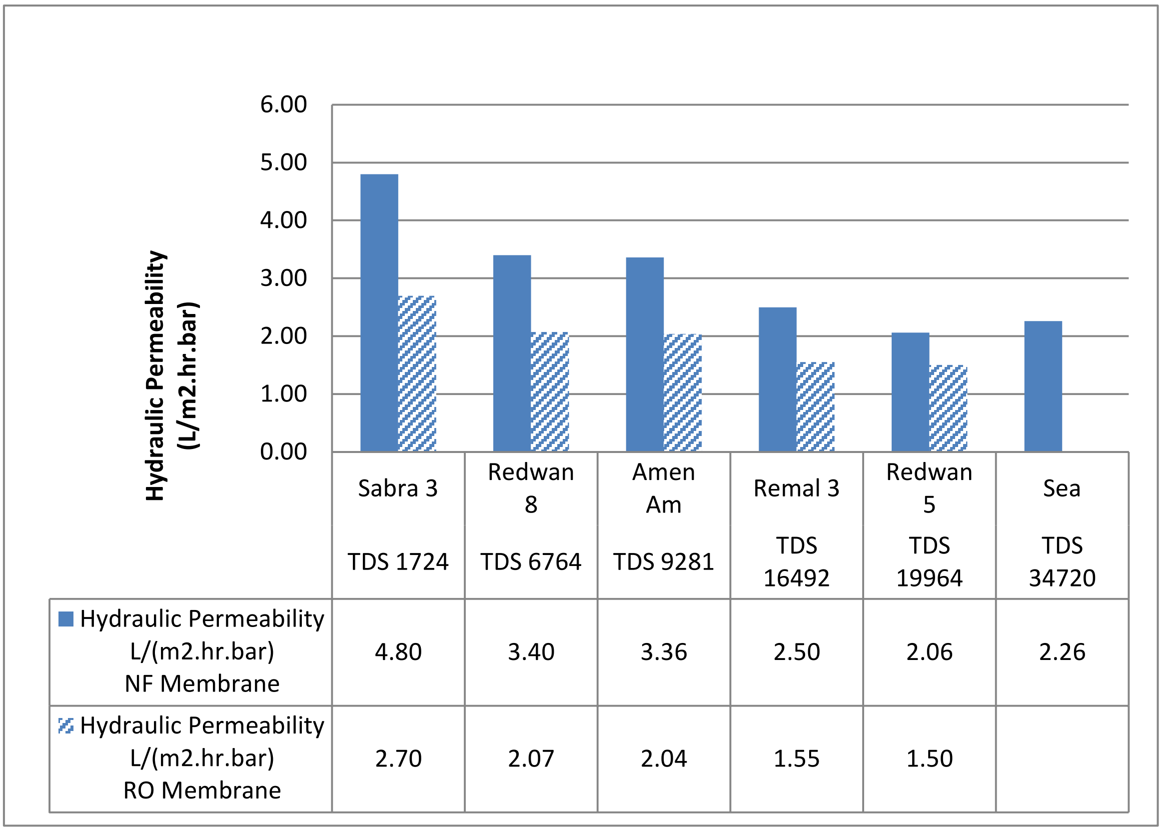


Figure (5-9) The effect of feed water TDS concentration on Hydraulic Permeability.



	Sabra 3 TDS 1724	Redwan 8 TDS 6764	Amen Am TDS 9281	Remal 3 TDS 16492	Redwan 5 TDS 19964	Sea TDS 34720
■ Hydraulic Permeability L/(m2.hr.bar) NF Membrane	4.80	3.40	3.36	2.50	2.06	2.26
▨ Hydraulic Permeability L/(m2.hr.bar) RO Membrane	2.70	2.07	2.04	1.55	1.50	

Figure (5-10) Hydraulic Permeability at different TDS.

Figure (5-10) shows the effect of TDS on Hydraulic Permeability. As noticed increasing feed water TDS concentration decreasing the hydraulic permeability. Also it can be noticed that the Hydraulic Permeability using NF membrane was more than using RO.

Figures (5-11a,b) show the relation between feed water TDS concentration and flux rate. The result show that while the TDS concentration increases the flux rate decreases, Also it can be noticed that the permeate flux using NF membrane was higher than using RO membrane at the same operating pressure and feed water TDS concentration.

Figure (5-11a) shows that using NF membrane at feed water TDS concentration up to 6764 ppm, the result of testing shows that the membrane started to product water at pressure 6 bar, and started to produced water at 10 bar when feed water TDS concentration 9281 ppm, and started to produced water at 14 bar when feed water TDS concentration higher than 16492 ppm.

Figure (5-11b) shows that using RO membrane at feed water TDS concentration up to 1724 ppm, the result of testing shows that the membrane started to product water at pressure 6 bar, and started to produced water at 10 bar when feed water TDS concentration 6764 ppm, and started to produced water at 12 bar when feed water TDS concentration 9281 ppm.

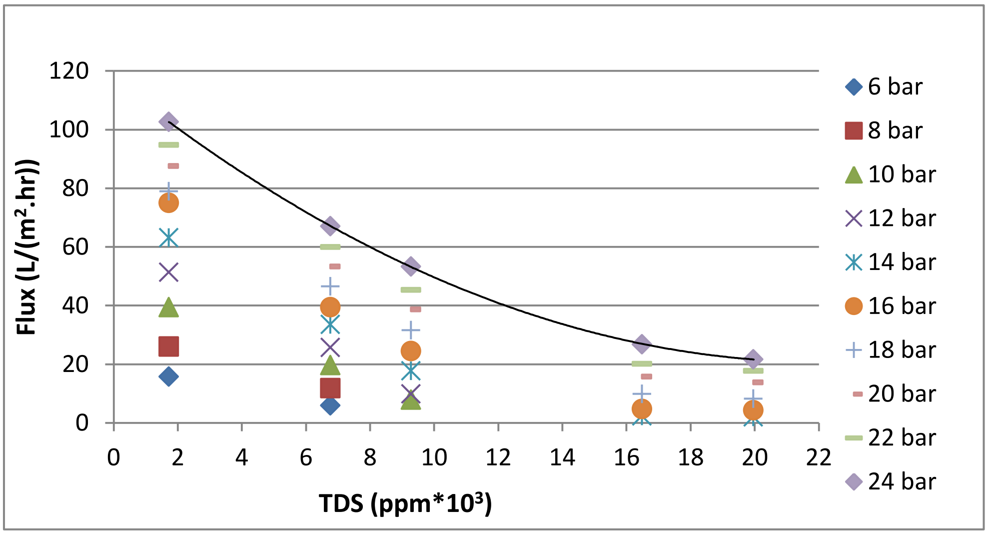


Figure (5-11a): Effect of feed water TDS concentration on flux using NF membrane.

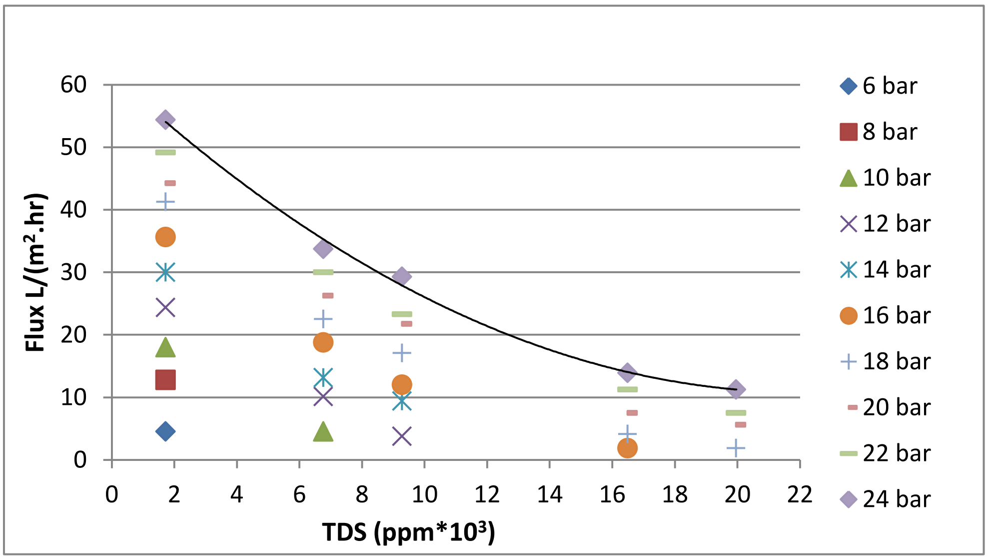


Figure (5-11b): Effect of feed water TDS concentration on flux using RO membrane.

5.2.2 Rejection Rate of TDS Component

The performance characteristics of NF and RO membranes were evaluated using TDS rejection for different operating conditions and the characteristics of the investigated membranes were compared.

5.2.2.1 Effect of Operating Pressure on TDS Removal

The rejection of TDS for the investigated membranes were plotted against the operating pressure using NF and RO membrane as shown in Fig(5-12a,b). It can be noticed that the rejection rate of TDS increases with increases of operating pressure in both NF and RO membrane, also it can be noticed that the rejection rate of TDS using NF membrane lower that using RO membrane, because the NF membrane having more open pores, So NF membrane allow solute to pass through the size more than RO membrane.

Increasing operating pressure will increase the ion rejection efficiency. This is because the water flux increases linearly with the increase of operating pressure. Ion permeation is only a function of feed concentration and is independent of the operating pressure (Ahmed. et al., 2004; Li. et al., 2008)

In NF the salt rejection increases gradually with the applied pressure. This can be explained by considering salt transport through the membrane as a result of diffusion and convection, which are respectively due to a concentration and a pressure gradient across the membrane at a low trans membrane pressure (TMP), diffusion contributes substantially to the salt transport resulting in a lower retention. With increasing TMP, the salt transport by diffusion becomes relatively less important, so that salt retention is higher (Schaep. et al., 1999;Van Gestel. et al., 2002).

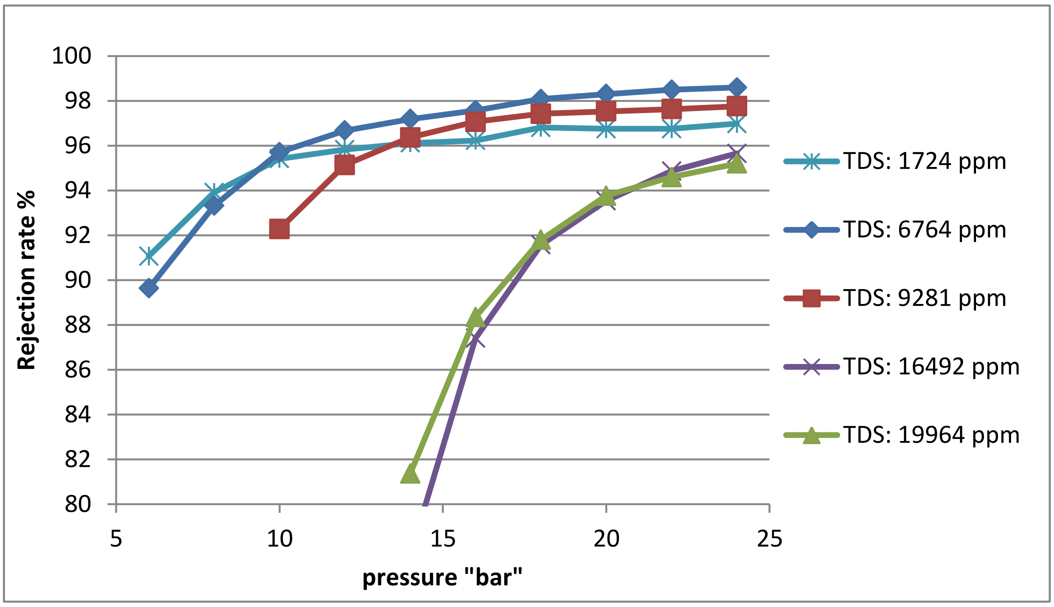


Figure (5-12a): Effect of operating pressure on TDS rejection using NF membrane.

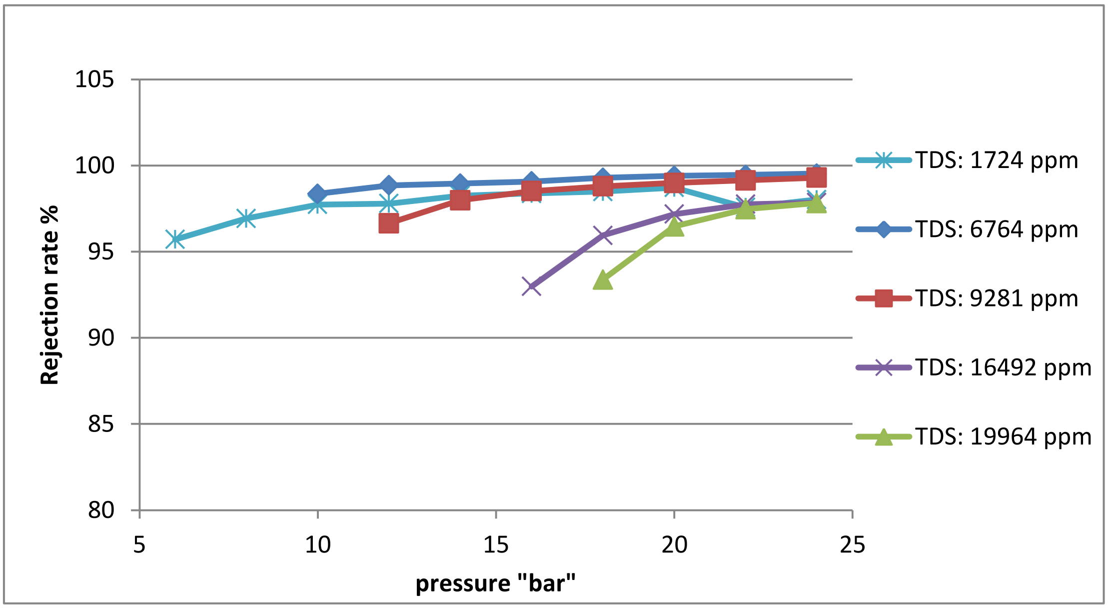


Figure (5-12b): Effect of operating pressure on TDS rejection using RO membrane.

Figures (5-13a,b) show the permeated TDS concentration at different pressure using NF and RO membrane respectively. The figures show that water samples which met with WHO guideline TDS concentration. Figure (5-13a) shows Permeated TDS concentration at different pressure using NF membrane. It can be noticed that at pressure more than 12 bar the result of testing samples using NF membrane indicate that water produced agreed with WHO guidelines in TDS concentration when feed water TDS concentration less than 9281. Using feed water TDS concentration more than 9281 ppm the water produced not agreed with WHO guideline using NF membrane. Figure (5-13b) shows Permeated TDS concentration at different pressure using RO membrane. It can be noticed that at pressure more than 24 bar the result of testing samples using RO membrane indicate that water produced agreed with WHO guidelines.

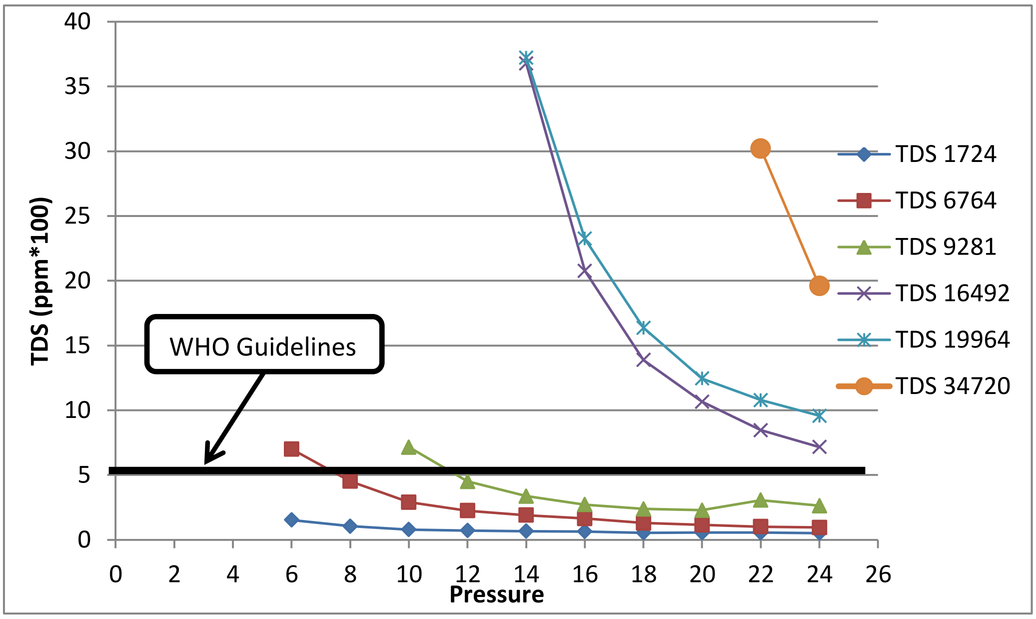


Figure (5-13a): TDS concentration in Permeated water at different pressure using NF membrane.

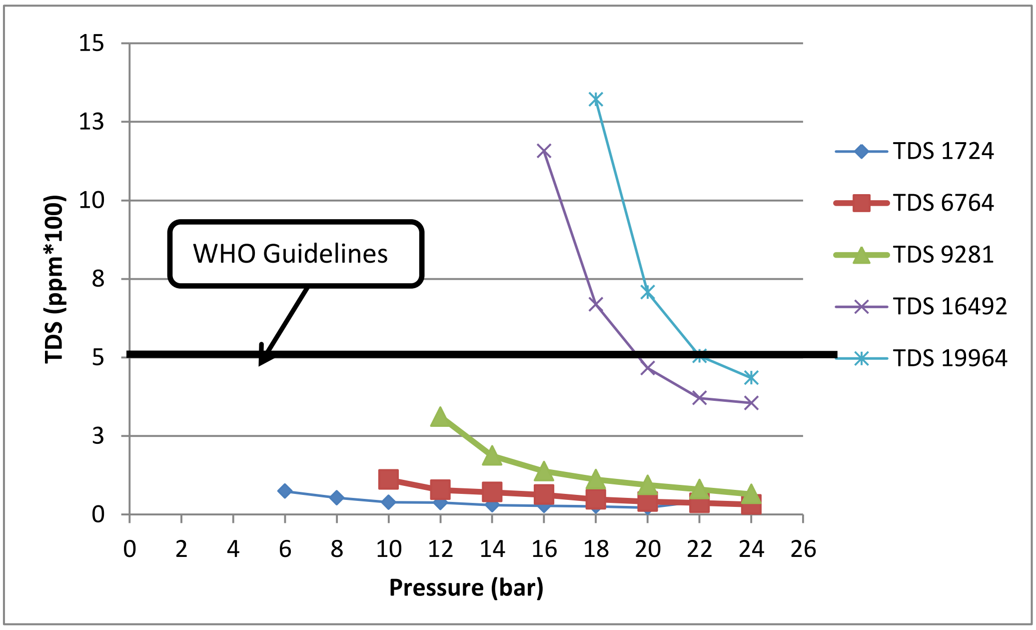


Figure (5-13b): TDS concentration in Permeated water at different pressure using RO membrane.

5.2.2.2 Effect of Feed water TDS Concentration on TDS rejection rate

Table (5-3) and Table (5-4) show the effect of feed water TDS concentration on the rejection rate of TDS at different pressure and using different real sample water using two different type of membrane NF and RO membrane.

As observed, the salt concentration increases leads to the rejection decreases moderately brackish ,saline and sea water desalinating.

In this case higher rejection at lower feed concentration and lower rejection at higher feed concentration was observed, characteristic of charged membranes (Peters et al. 1998).Increasing the concentration of sodium Cations of the solution involves the formation of a screen which gradually neutralizes the negative charge of the membrane. As the total charge of the membrane decreases, the retention of the anions decreases since the electrostatic effect of the membrane becomes weaker (Childress et al. 2000)This means that the effect of membrane charge is completely eliminated when the salt concentration is high enough (Scheap and Vandecasteele, 2001).

Table (5-3): Effect of feed water TDS concentration on the rejection rate of TDS using NF membrane

REJECTION RATE OF TDS %											
TDS	well name /Pressure	6	8	10	12	14	16	18	20	22	24
1724	Sabra 3	91.07	93.91	95.42	95.82	96.11	96.23	96.81	96.75	96.75	96.98
6764	Redwan 8	89.64	93.32	95.71	96.67	97.19	97.58	98.08	98.30	98.49	98.60
9281	Amen Am			92.29	95.14	96.37	97.07	97.42	97.53	97.63	97.76
16492	Remal 3					77.70	87.41	91.58	93.54	94.86	95.65
19964	Redwan 5					81.36	88.35	91.80	93.76	94.60	95.20
34720	Sea									8.96	18.24

Table (5-4): Effect of feed water TDS concentration on the rejection rate of TDS using RO membrane

REJECTION RATE OF TDS %											
TDS	Well name /Pressure	6	8	10	12	14	16	18	20	22	24
1724	Sabra 3	95	96.93	97.74	97.80	98.26	98.38	98.49	98.72	97.56	98.03
6764	Redwan 8			98.36	98.85	98.95	99.07	99.29	99.39	99.45	99.53
9281	Amen Am				96.65	97.99	98.51	98.79	98.99	99.14	99.30
16492	Remal 3						92.98	95.94	97.17	97.75	97.85
19964	Redwan 5							93.38	96.46	97.47	97.82
34720	Sea										

5.2.3 Rejection Rate of NO_3 Component

The performance characteristics of NF and RO membranes were evaluated using NO_3 rejection for different operating conditions and the characteristics of the investigated membranes were compared.

5.2.3.1 Effect of operating Pressure on NO_3 rejection rate

FigureS (5-14a,b) illustrated the effective of pressure on NO_3 rejection using NF and RO membranes. It can be noticed that the increasing of pressure is directly proportional to the nitrate rejection .

For example, at pressure 10 bar the result of testing Sabra3 well sample using NF membrane indicated that the nitrate rejection 91.5%, While it reach to 93.4% with increasing pressure to 24 bar, but for other well the operating pressure was not the main influencing factor, TDS concentration plays an important role.

Also, it can be noticed that the efficiency of RO membrane in nitrate rejection was more that using NF membrane, For example: at pressure 24 bar the result of testing Sabra3 well sample using NF membrane indicate that the nitrate rejection was 93.4%, while it was 98% using RO membrane and using the same sample and operating condition.

Figures (5-15a,b) show nitrate concentration in permeated water at different pressure using NF and RO membrane respectively comparing with WHO guidelines. It can be noticed that the efficiency of nitrate rejection decreases with increases of feed water TDS concentration. For example at feed water TDS concentration 1724ppm the result of testing Sabra3 well sample indicate that permeated nitrate concentration 35ppm,where the feed water nitrate concentration was 211ppm, which mean NF membrane can be used for rejection of nitrate at low feed water TDS concentration.

Also it can be noticed that the nitrate concentration in permeated water using RO membrane agreed with WHO guideline regardless feed water TDS concentration as shown in Figure (5-15b), that mean the RO membrane rejected the NO_3 with height efficiency. While the nitrate concentration in permeated water using NF membrane was agreed with WHO guideline but with high pressure with high feed water TDS concentration as shown in Figure (5-15a).

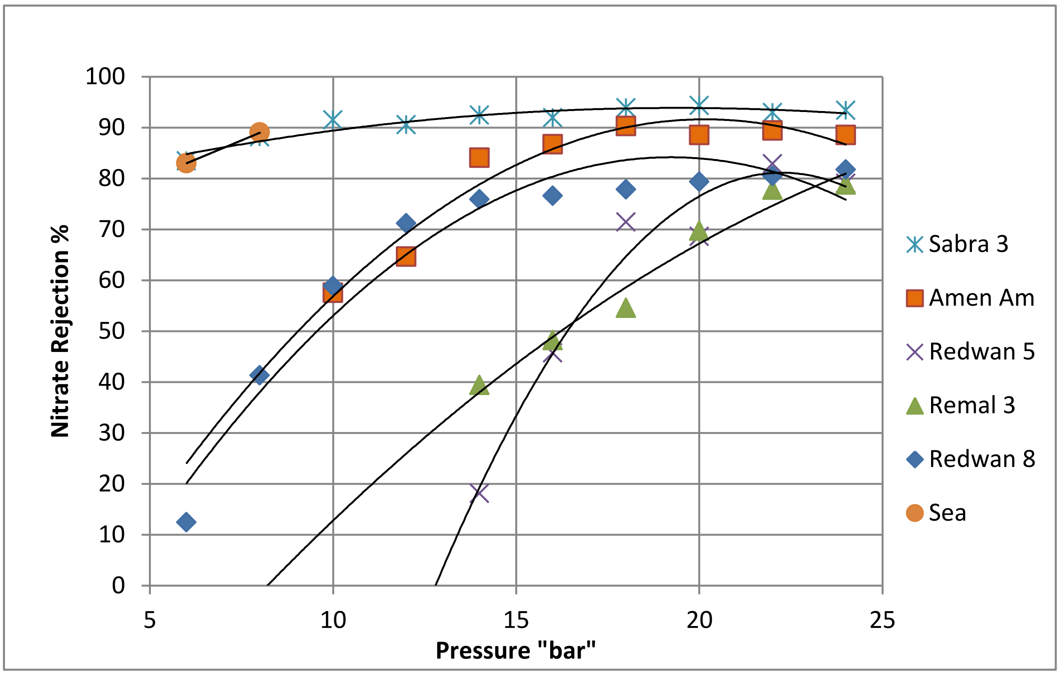


Figure (5-14a): Effect of pressure on nitrate rejection using NF membrane.

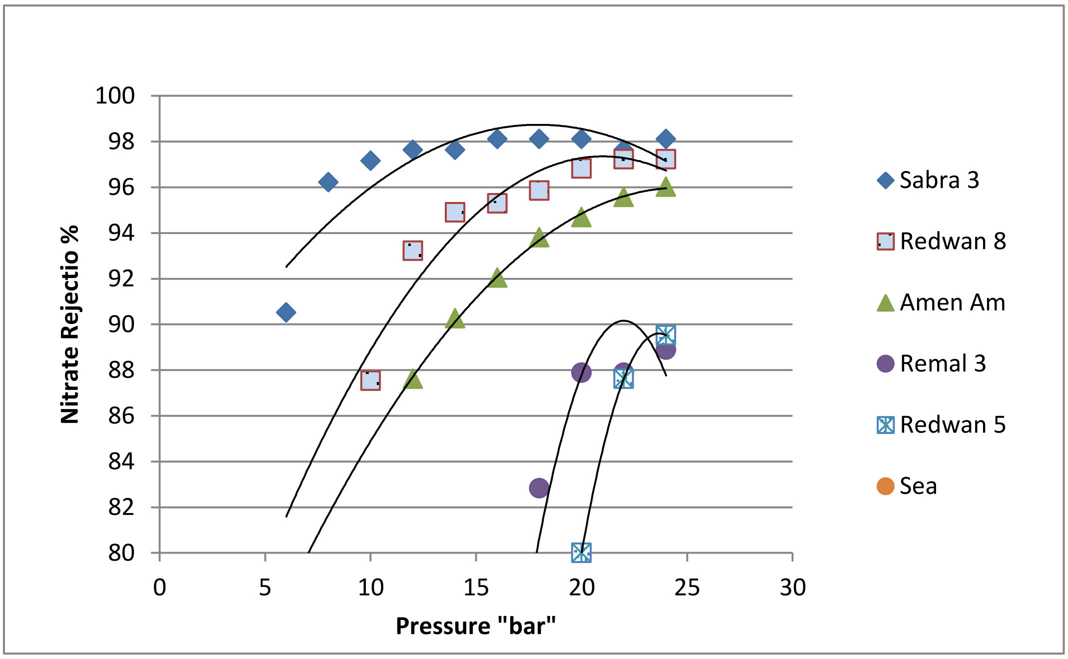


Figure (5-14b): Effect of pressure on nitrate rejection using RO membrane.

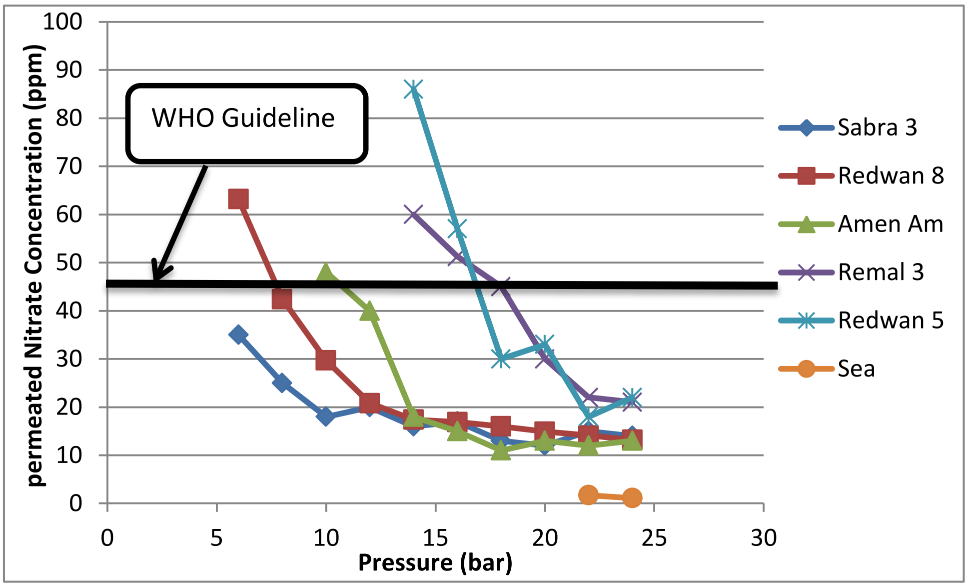


Figure (5-15a): Permeated Nitrate concentration at different pressure using NF membrane.

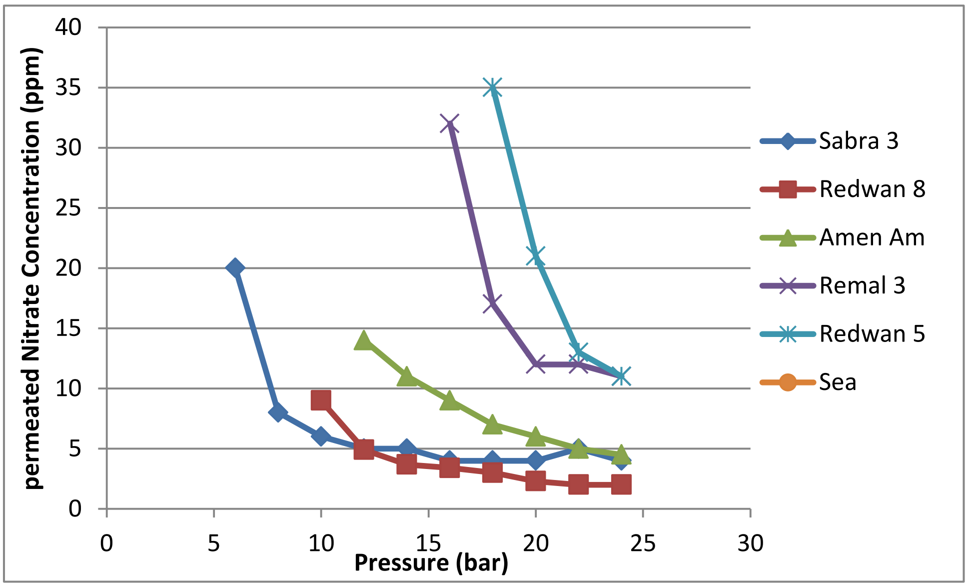


Figure (5-15b): Permeated Nitrate concentration at different pressure using RO membrane.

5.2.3.2 Effect of feed water TDS concentration on nitrate removal

Figure (5-16a,b) illustrated the effective of feed water TDS concentration on nitrate rejection using NF and RO membrane respectively. It can be noticed that increasing of TDS decreasing nitrate rejection. For example, at pressure 20 bar with feed water TDS concentration 1724 ppm the result of testing Sabra3 well sample using RO membrane indicate that the nitrate rejection 98.1%, while it was 80% at feed water TDS concentration 19964ppm using Redwan5 well sample using the same membrane and operating conditions.

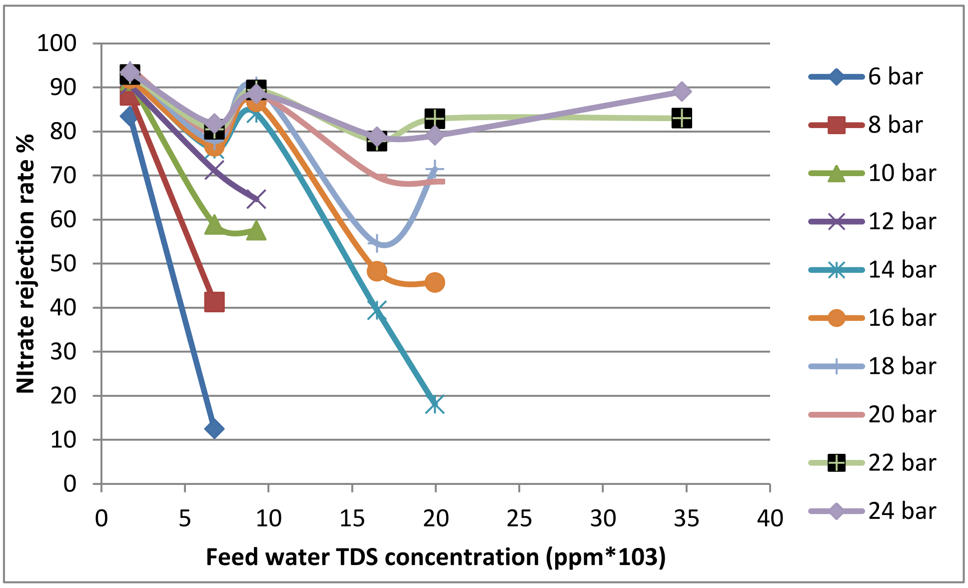


Figure (5-16a): Effect of feed water TDS concentration on Nitrate rejection using NF membrane.

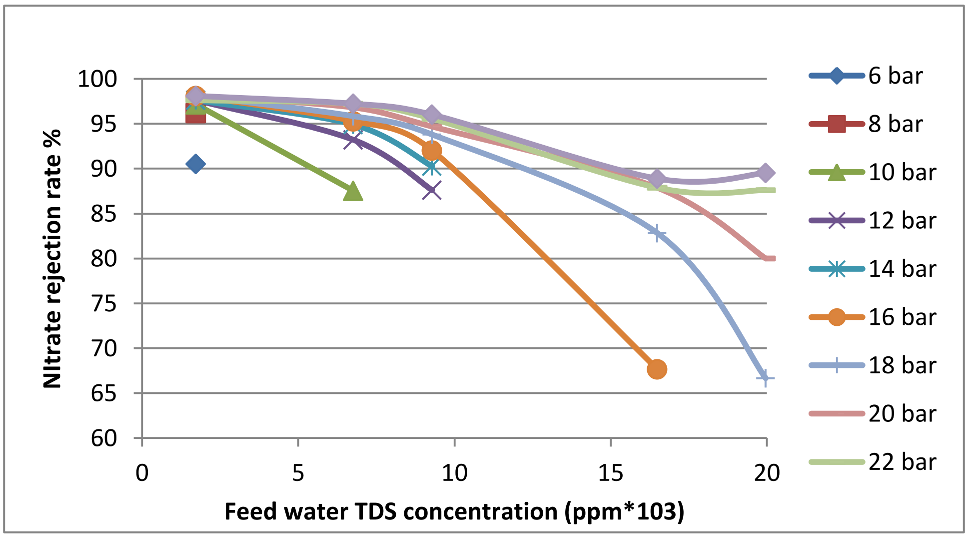


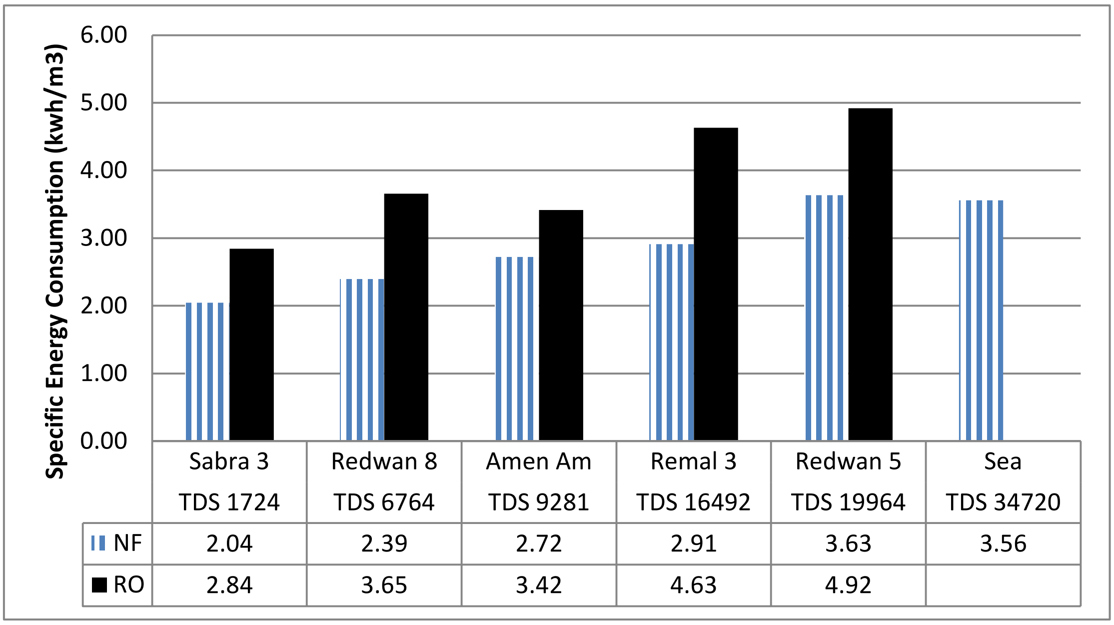
Figure (5-16a): Effect of feed water TDS concentration on Nitrate rejection using RO membrane.

5.2.4 Specific Energy Consumption Comparison

Figure (5-17) shows the comparison of Specific Energy Consumption using NF and RO membrane using different sample well. It can be noticed that the energy needed for desalinating water using RO membrane was more than that using NF membrane. This is due to low operating pressure used in NF membrane. For example, The energy consumption by NF membrane required to produce one fresh cubic meter from redwan8 well was 2.72KWh, while it was 3.65KWh using RO membrane for the same well sample. It means 1 KWh can be reduced in producing one cubic meter that means reduction of 30% of energy in this case.

Another example, that the result of testing Remal3 using NF membrane indicates that the specific energy consumption was 2.91 KWh/m^3, while it was 4.63 KWh/m^3 using RO membrane. This means 1.72 KWh/m^3 can be reduced. That means reduction of 60% of operating energy cost.

The properties of NF90 membranes are close to RO membranes (Elazhar. Et. Al., 2013).



	Sabra 3 TDS 1724	Redwan 8 TDS 6764	Amen Am TDS 9281	Remal 3 TDS 16492	Redwan 5 TDS 19964	Sea TDS 34720
▥ NF	2.04	2.39	2.72	2.91	3.63	3.56
■ RO	2.84	3.65	3.42	4.63	4.92	

Figure (5-17): Specific Energy Consumption comparison.

5.3 Comparison between Real water and Aqueous Solutions

5.3.1 Effect of pressure on the flux using pure water

Figure (5-18) shows the effect of pressure on the flux using pure water. It can be noticed that increasing of pressure leads to increase the flux, for example using NF membrane the flux at pressure 6 bar was 25.6 L/m^2.hr and the flux increasing to 63 L/m^2.hr when the pressure increasing to 12 bar. Also the flux using NF membrane was more that using RO membrane. For example, using NF membrane at pressure 24 bar the flux was 129 L/m^2.hr, while flux was 62 L/m^2.hr using RO membrane.

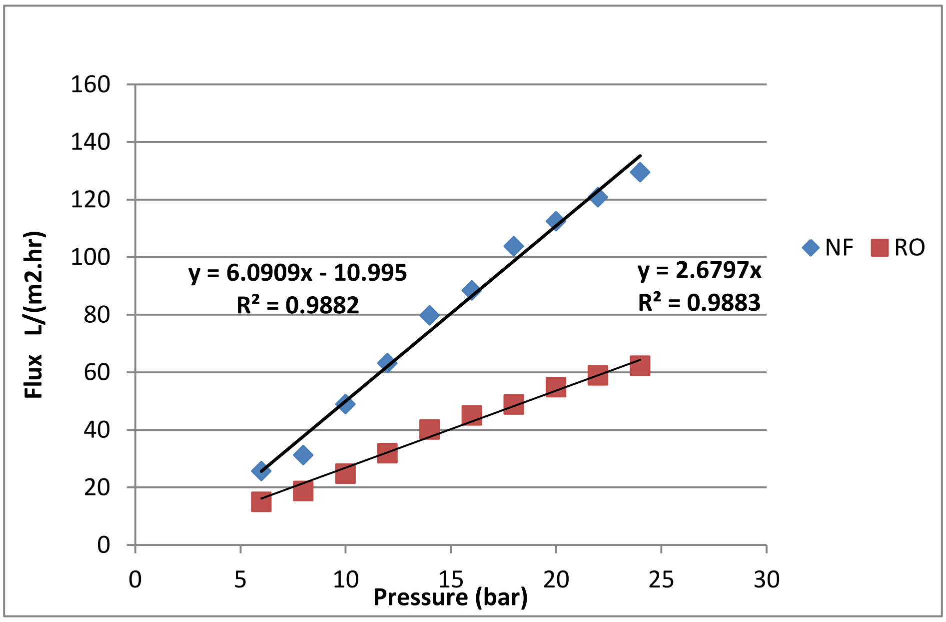


Figure (5-18): Effect of pressure on the flux using pure water.

5.3.2 Comparison between real water and solution using the effect of pressure on the flux

Figure (5-19a) shows the Comparison between real water and solution using NF membrane. It can be noticed that increases of pressure leads to increase of flux, also it can be noticed that The performance of NF membrane varied in terms of flux rate. Consequently, the pure water flux rate was higher than the real water flux rate. For example at pressure 16 using NF membrane the flux was 63 L/m^2.hr in solution, while the flux decrease to 39.5 L/m^2.hr using real water (feed water TDS concentration 6764 ppm and nitrate concentration 72.2 ppm). As the water contains more salts or other substances, the flux rate decreases. Also complexity of water character play a good role in membrane behavior and that is why the NaCl solution flux rate is higher than real water flux rate. The maximum flux rate for aqueous solution was obtained at 24 bar (94.7 L/m2.hr) for pure water and minimum flux rate was obtained at 6 bar (23.68 L/m2.hr). The maximum flux rate for real water was obtained at 24 bar (67.2 L/m^2.hr) for Redwan8 well and minimum flux rate was obtained at 6 bar (5.92 L/m^2.hr) for Redwan8 well.

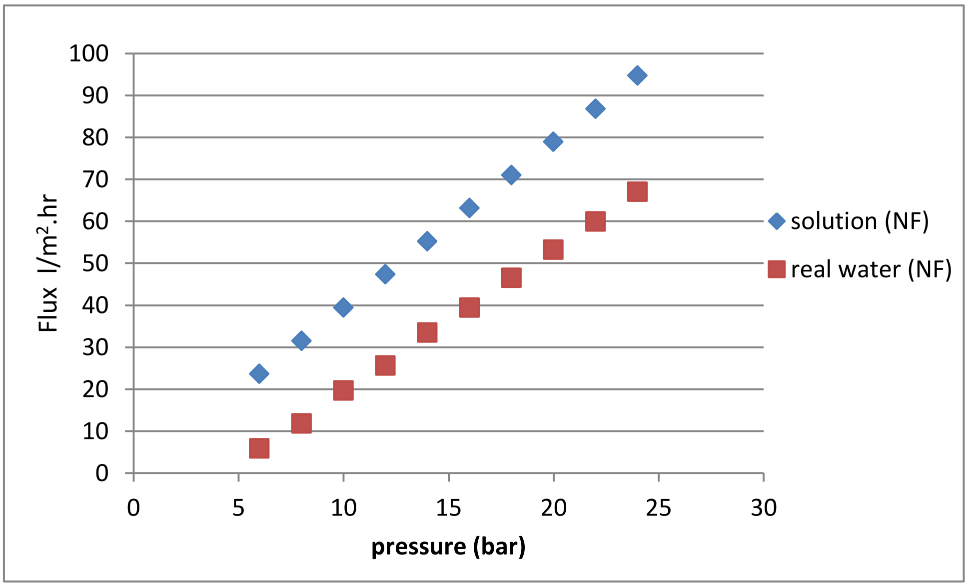


Figure (5-19a): Comparison between real water and solution using NF membrane.

Figure (5-19b) shows the Comparison between real water and solution using RO membrane. It can be noticed that increases of pressure leads to increase of flux, also it can be noticed that The performance of RO membrane varied in terms of flux rate. Consequently, the pure water flux rate was higher than the real water flux rate. For example at pressure 16 using RO membrane the flux was 29.7 L/m^2.hr in solution, while the flux decrease to 18.8 L/m^2.hr using real water (feed water TDS concentration 6764 ppm and nitrate concentration 72.2 ppm). As the water contains more salts or other substances, the flux rate decreases. Also complexity of water character play a good role in membrane behavior and that is why the NaCl solution flux rate is higher than real water flux rate. The maximum flux rate for aqueous solution was obtained at 24 bar (44.6 L/m2.hr) for pure water and minimum flux rate was obtained at 6 bar (6.6 L/m2.hr). The maximum flux rate for real water was obtained at 24 bar (33.6 L/m^2.hr) for Redwan8 well and minimum flux rate was obtained at 6 bar (4.5 L/m^2.hr) for Redwan8 well.

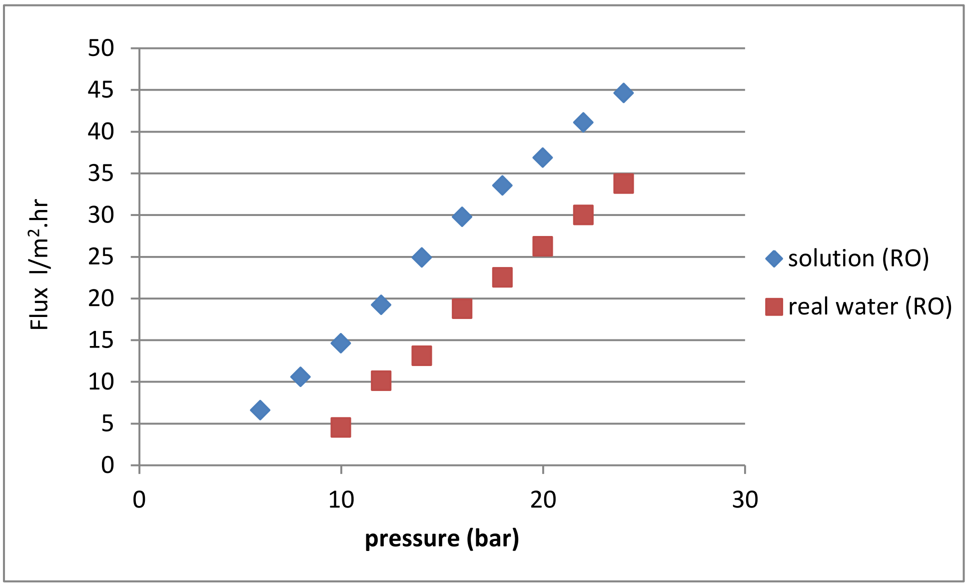


Figure (5-18b): Comparison between real water and solution using RO membrane.

CHAPTER 6 : Conclusion and Recommendation

6.1 Conclusion

In this research, a comparison between two types of membrane NF90-4040 and RO TM-710 membranes in removal of nitrate and TDS was studied. The pressures applied in these experiments were in the range of 6 to 24 bar and well sample TDS in the range of 1,724 to 19964 ppm and nitrate in the range of 72 to 211 ppm. The efficiency of tow type of membranes NF and RO membrane has been evaluated with model solutions, a groundwater and sea water, the followings are the main conclusion of this research:

- The permeate fluxes for all membranes (RO, NF) increases with pressure increases
- NF membrane have higher flux and recovery rate than RO membrane using different operating pressure and different well sample.
- NF membrane have high flux rate reach to 102.63 L/m^2.hr, while RO membrane have relatively low flux rate reach to 54.38 L/m^2.hr.
- Hydraulic permeability using NF membrane was more than that using RO membrane.
- Increasing of feed water nitrate concentration decreasing the hydraulic permeability.
- RO membrane have higher rejection percentage than NF using different operating pressure and different well sample.
- The rejections of the investigated salts for all membranes (RO, NF) increases with pressure increases.
- The permeate fluxes for all membranes (RO, NF) decrease with the decrease of feed water TDS concentration.
- The efficiency of nitrate rejection affected overall concentration of feed water TDS concentration, as well as the nitrate rejection rate using NF membrane could be up to 95% while nitrate rejection rate using RO membrane may reach greater than 98% , according to concentration of TDS on feed water and the pressure used.
- Nanofiltration membrane can be used as a standalone treatment for removing salts to produce drinkable water when feed water TDS concentration lower than 9281ppm, also it can be used as first stage when feed water TDS concentration more than 9281ppm.
- RO membrane can be used in water desalination when feed water TDS concentration up to 19964 using high operating pressure more than 24 bar.
- NF membrane showed good result for nitrate removal in aqueous solution, which varied between 26% and 84.67% depending on operating pressure and initial nitrate concentration, while RO membrane varied between 80% and 92% depending on operating pressure and initial nitrate concentration.

- NF membrane showed good results for nitrate removal in real water, which varied between 12.47% and 93.3%, while RO membrane nitrate rejection varied between 67.68% and 98.1%.
- NF90 was observed to be an effective method to nitrate removal of Gaza Strip at higher permeate flux and lower applied pressure especially in region where low TDS and high nitrate concentration.
- The energy needed for desalinating water using RO membrane were more than that using NF membrane. That means reduction of 25 to 60% of energy in desalinating water using NF membrane. This is due to lower operating pressure needed for NF membrane.
- Using NF membrane the power needed to reach to pressure needed was more that needed using RO membrane.

6.2 Recommendation

- Desalination unit using more than two membrane (6 or 8) membrane should be test to get more accuracy real results.
- The testing presented in Part II of Chapter 5, demonstrated performance efficiency of the NF90 and RO membranes for real water sample, but did not provide any indication of membrane lifetime under real operating conditions. It is recommended. Therefore, that long-term membrane testing under variable flow conditions should be conducted to establish membranes performances over time.
- Fouling is an unavoidable phenomenon in most of the membrane filtration process. It is known that it strongly influence not only the production of drinking water but also removal efficiency of the membranes. Numerous dedicated investigations have been devoted to study the fouling effects on performances of RO membranes.
- It would be advantageous to use NF membrane for producing drinkable water as feed water TDS concentration less than 9281 ppm, and use as pretreatment when feed water TDS concentration more that.
- Recovery rate, system arrangement, cleaning frequency, and module design. The pilot study did not examine all these variables, it has been demonstrated that some of these variables might have certain effects on the overall removal efficiency. So its recommended to study these variables.
- Effects of parameters such as Temperature and pH of the solution on NF removal efficiency is recommended to be studied.

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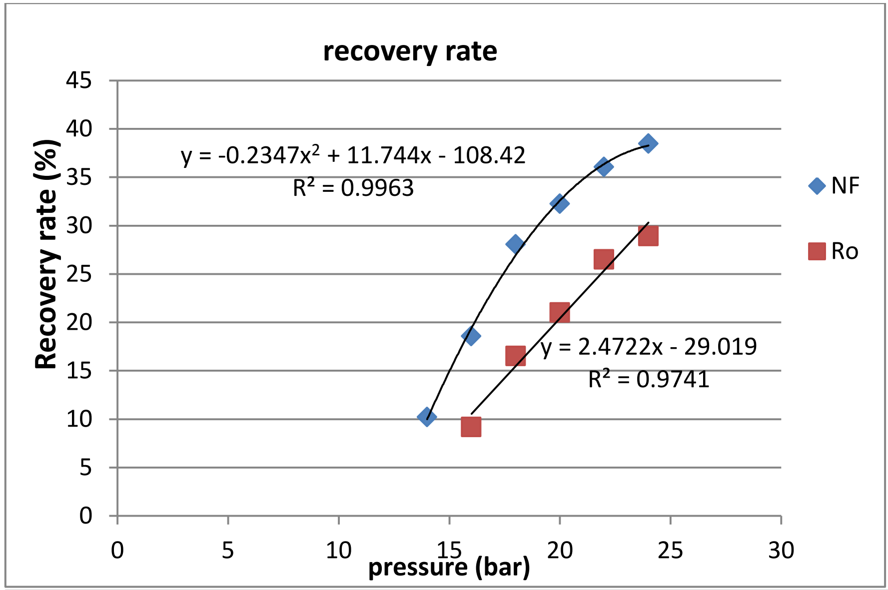
Appendix

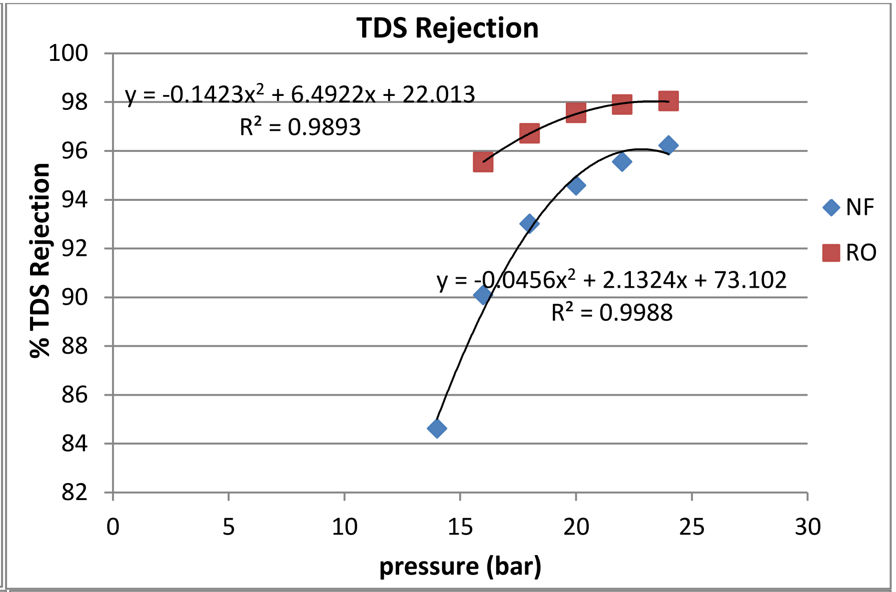
APPENDIX (1)

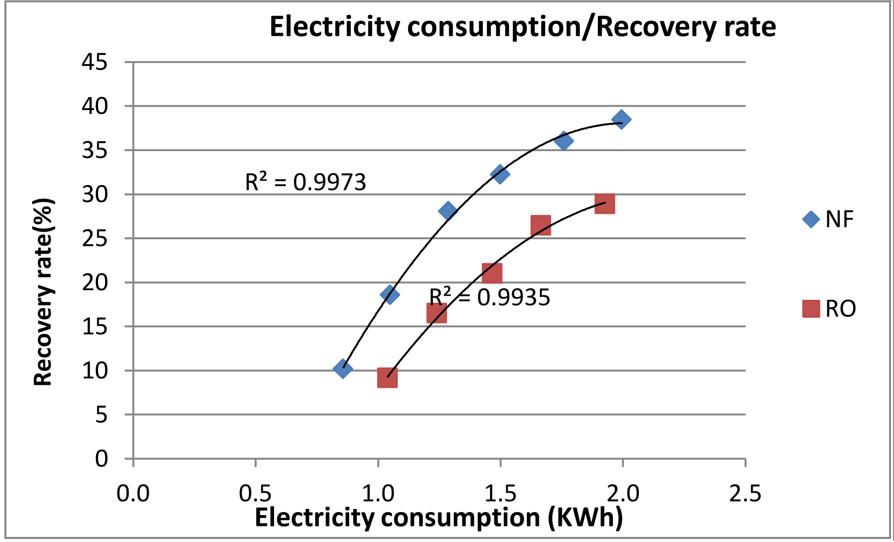
Aqueous solution result

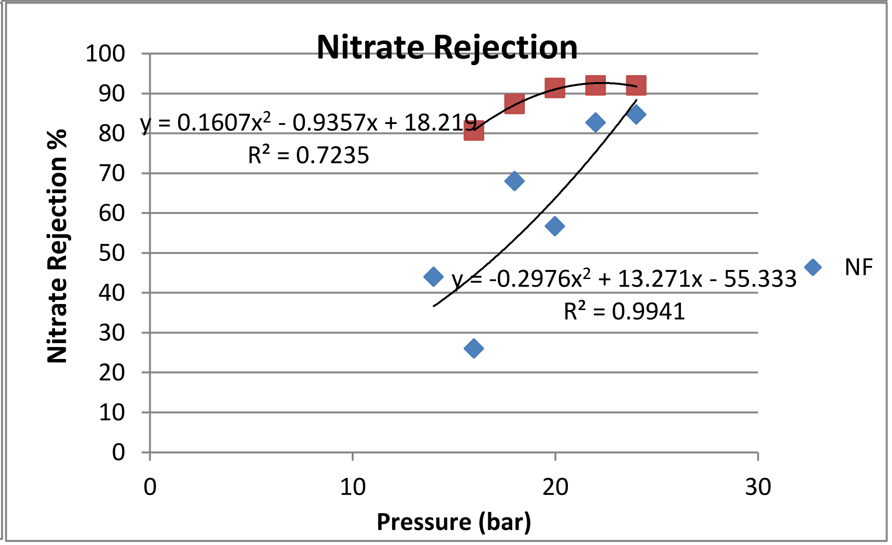
well Name	**solution 1**	**Time**	**10 min**	**Membrane**		**NF**	**Temperature**		**16 C**	**Date**	**15/02/2014**	
TDS	**17000**	**NO3**	**150**	**Chloride**		**9898**	**PH**		**7.6**	**membrane area**	**15.2**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate(TDS)	Rejection rate(NO3)	Rejection rate(cl)	Flux L/(m2.hr)
14	**1**	**8.8**	**0.86**	**2616**	**84**	**1314**	**6.49**	**10.20**	**84.61**	**44.00**	**86.72**	**3.95**
16	**2.1**	**9.2**	**1.05**	**1686**	**111**	**880**	**6.81**	**18.58**	**90.08**	**26.00**	**91.11**	**8.29**
18	**3.9**	**10**	**1.29**	**1189**	**48**	**618**	**6.21**	**28.06**	**93.01**	**68.00**	**93.76**	**15.39**
20	**5**	**10.5**	**1.50**	**921**	**65**	**476**	**6.81**	**32.26**	**94.58**	**56.67**	**95.19**	**19.74**
22	**6.2**	**11**	**1.76**	**756**	**26**	**391**	**6.21**	**36.05**	**95.55**	**82.67**	**96.05**	**24.47**
24	**7.5**	**12**	**2.00**	**644**	**23**	**334**	**6.2**	**38.46**	**96.21**	**84.67**	**96.63**	**29.61**

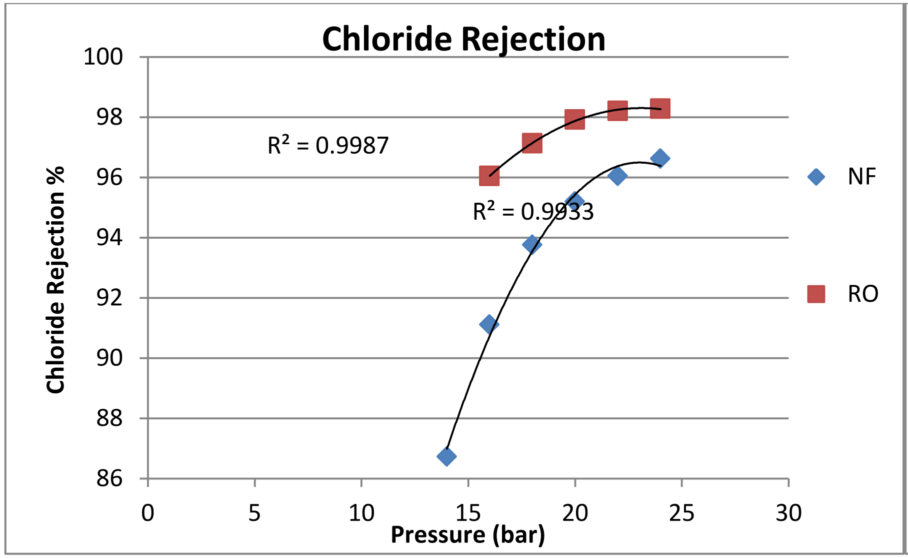
well Name	**solution 1**	**Time**	**10 min**	**Membrane**		**RO**	**Temperature**		**16 C**	**Date**	**15/02/2014**	
TDS	**17000**	**NO3**	**150**	**Chloride**		**9898**	**PH**		**7.6**	**membrane area**	**16**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
16	**1**	**9.9**	**1.04**	**758**	**29**	**391**	**6.06**	**9.17**	**95.54**	**80.67**	**96.05**	**3.75**
18	**2**	**10.1**	**1.24**	**558**	**19**	**284**	**4.41**	**16.53**	**96.72**	**87.33**	**97.13**	**7.50**
20	**2.9**	**10.9**	**1.47**	**416**	**13**	**206**	**5.86**	**21.01**	**97.55**	**91.33**	**97.92**	**10.88**
22	**4**	**11.1**	**1.67**	**358**	**12**	**178**	**6.28**	**26.49**	**97.89**	**92.00**	**98.20**	**15.00**
24	**4.8**	**11.8**	**1.93**	**333**	**12**	**170**	**5.63**	**28.92**	**98.04**	**92.00**	**98.28**	**18.00**

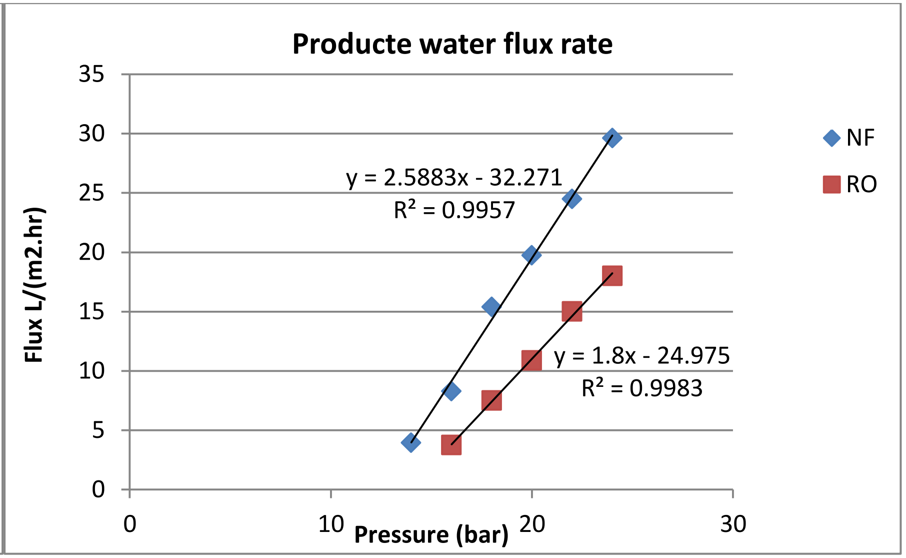

recovery rate
Recovery rate (%)
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
pressure (bar)
y = -0.2347x² + 11.744x - 108.42
R² = 0.9963
y = 2.4722x - 29.019
R² = 0.9741
◆ NF
■ Ro

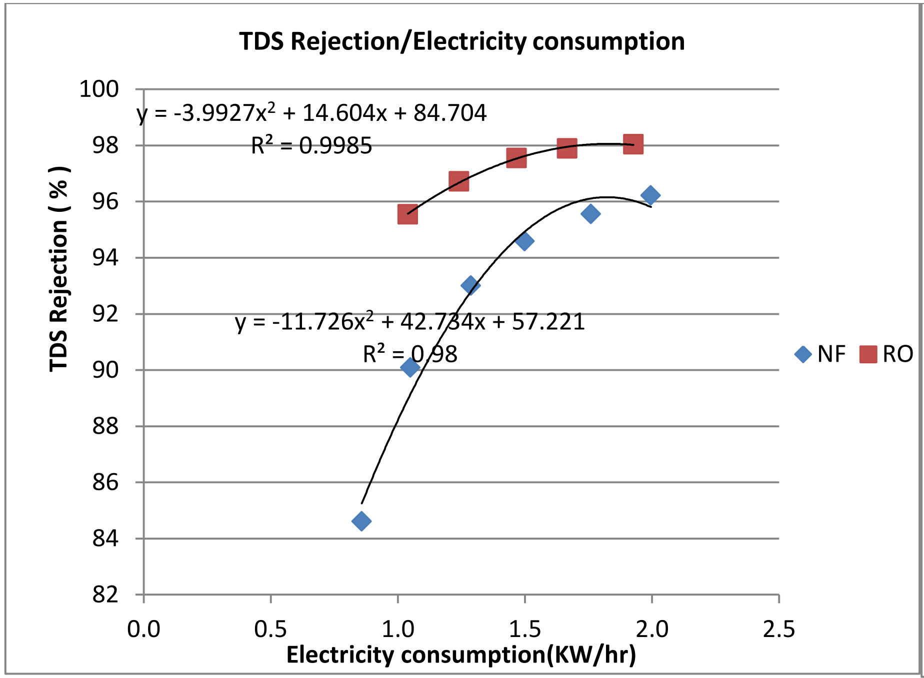

TDS Rejection
% TDS Rejection
100
98
96
94
92
90
88
86
84
82
0
5
10
15
20
25
30
pressure (bar)
y = -0.1423x² + 6.4922x + 22.013
R² = 0.9893
y = -0.0456x² + 2.1324x + 73.102
R² = 0.9988
◆ NF
■ RO

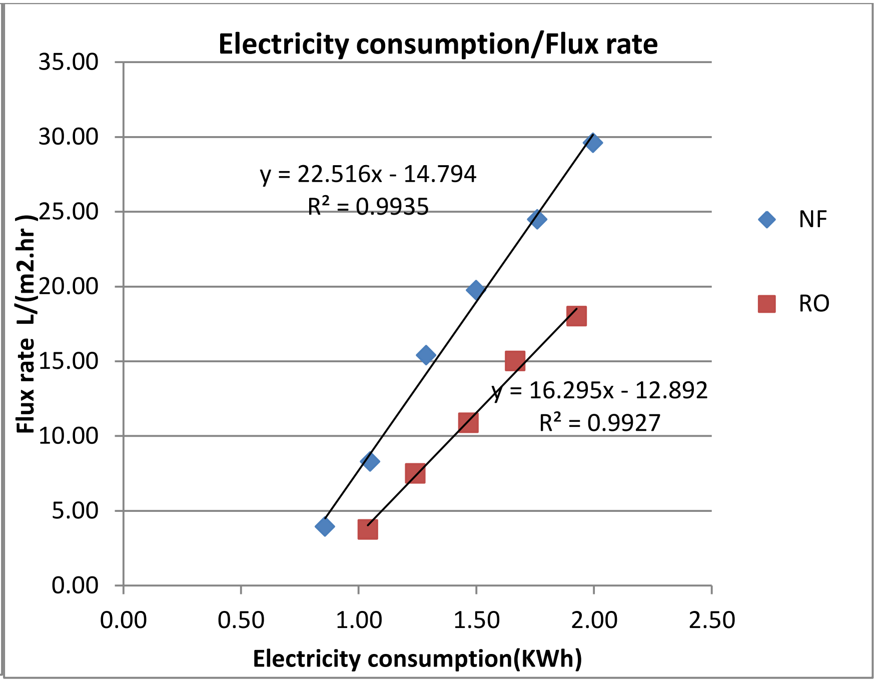

Electricity consumption/Recovery rate
Recovery rate(%)
45
40
35
30
25
20
15
10
5
0
0.0
0.5
1.0
1.5
2.0
2.5
Electricity consumption (KWh)
R² = 0.9973
R² = 0.9935
◆ NF
■ RO

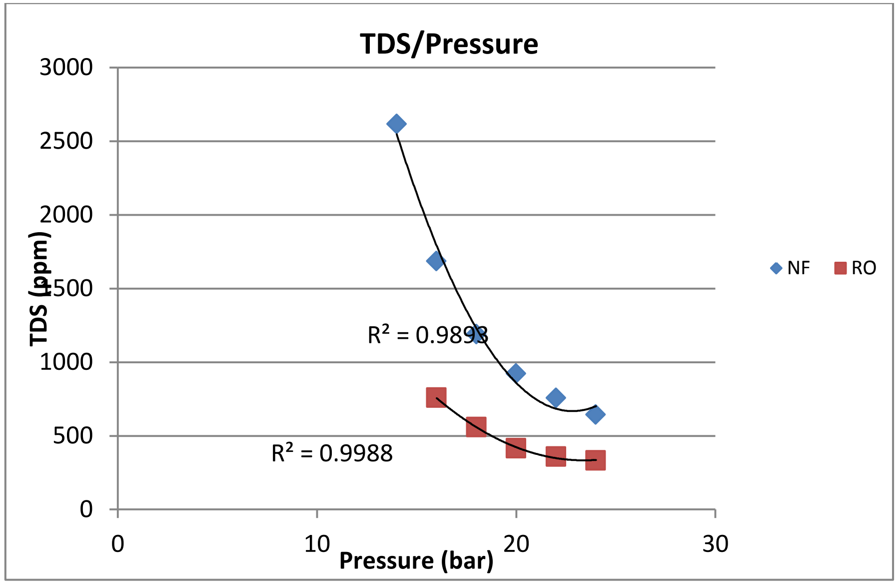

Nitrate Rejection
Nitrate Rejection %
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
Pressure (bar)
y = 0.1607x² - 0.9357x + 18.219
R² = 0.7235
y = -0.2976x² + 13.271x - 55.333
R² = 0.9941
◆ NF

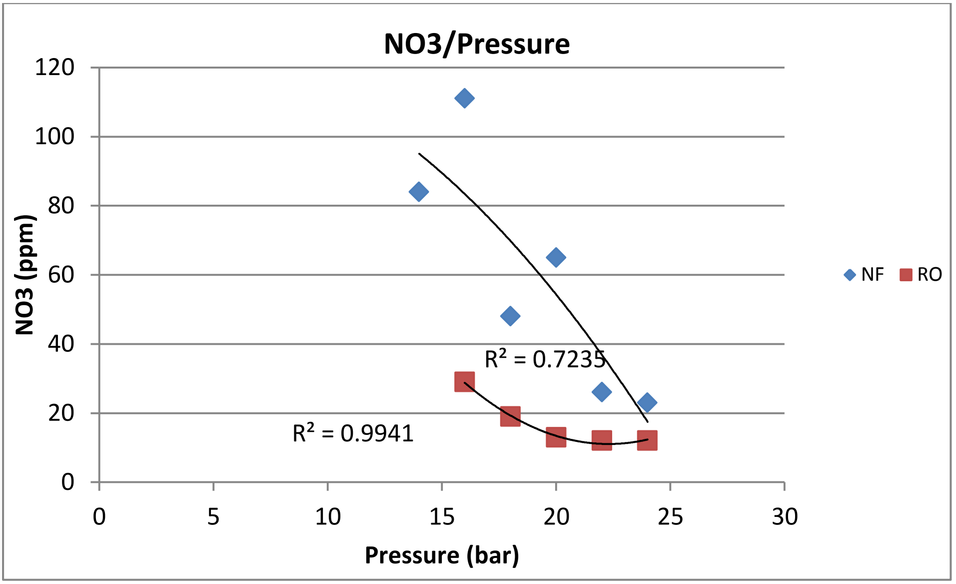

Chloride Rejection
Chloride Rejection %
100
98
96
94
92
90
88
86
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.9987
R² = 0.9933
NF
RO


Producte water flux rate
Flux L/(m2.hr)
35
30
25
20
15
10
5
0
0
10
20
30
Pressure (bar)
y = 2.5883x - 32.271
R² = 0.9957
y = 1.8x - 24.975
R² = 0.9983
NF
RO

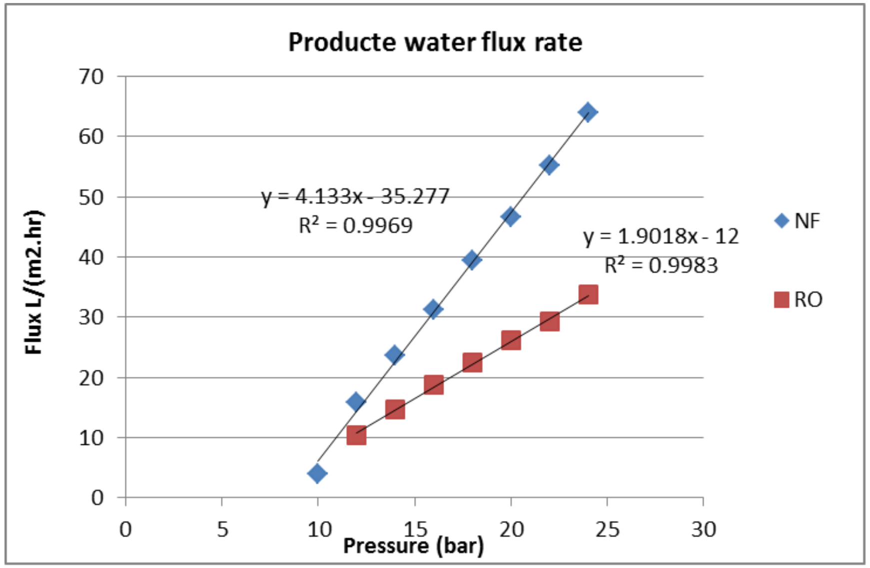

TDS Rejection/Electricity consumption
TDS Rejection (%)
100
98
96
94
92
90
88
86
84
82
y = -3.9927x² + 14.604x + 84.704
R² = 0.9985
y = -11.726x² + 42.734x + 57.221
R² = 0.98
NF
RO
0.0
0.5
1.0
1.5
2.0
2.5
Electricity consumption(KW/hr)

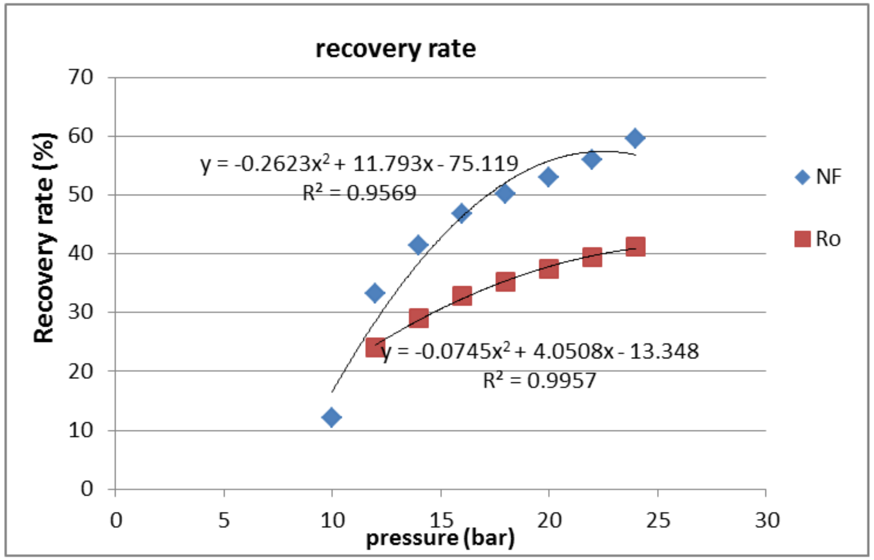

Electricity consumption/Flux rate
Flux rate L/(m2.hr)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
y = 22.516x - 14.794
R² = 0.9935
y = 16.295x - 12.892
R² = 0.9927
NF
RO
0.00
0.50
1.00
1.50
2.00
2.50
Electricity consumption(KWh)

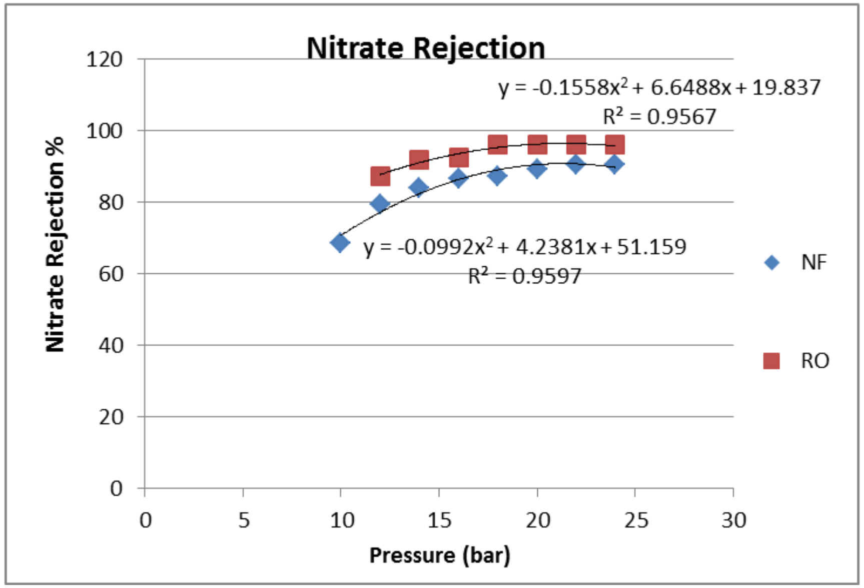

TDS/Pressure
TDS (ppm)
3000
2500
2000
1500
1000
500
0
0
10
20
30
Pressure (bar)
R² = 0.9893
R² = 0.9988
◆ NF
■ RO

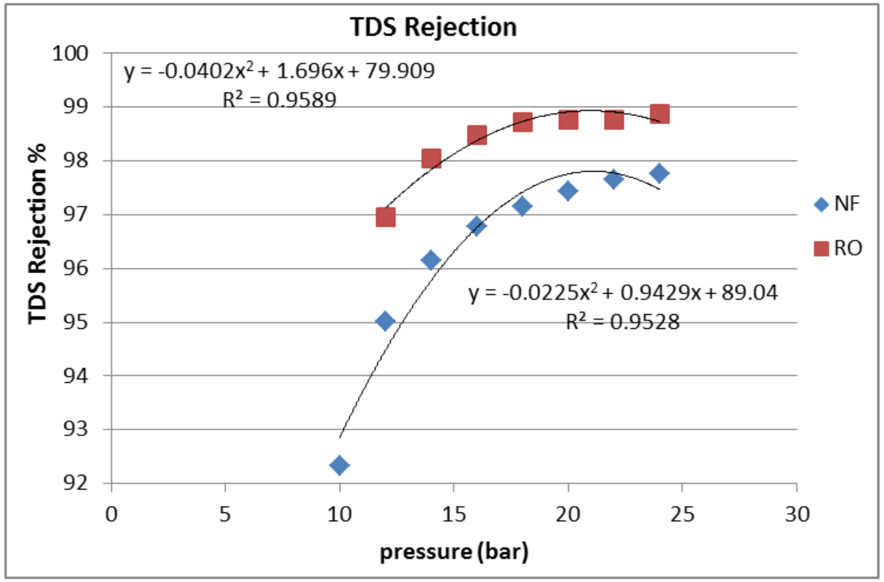

NO3/Pressure
NO3 (ppm)
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.7235
R² = 0.9941
◆ NF
■ RO

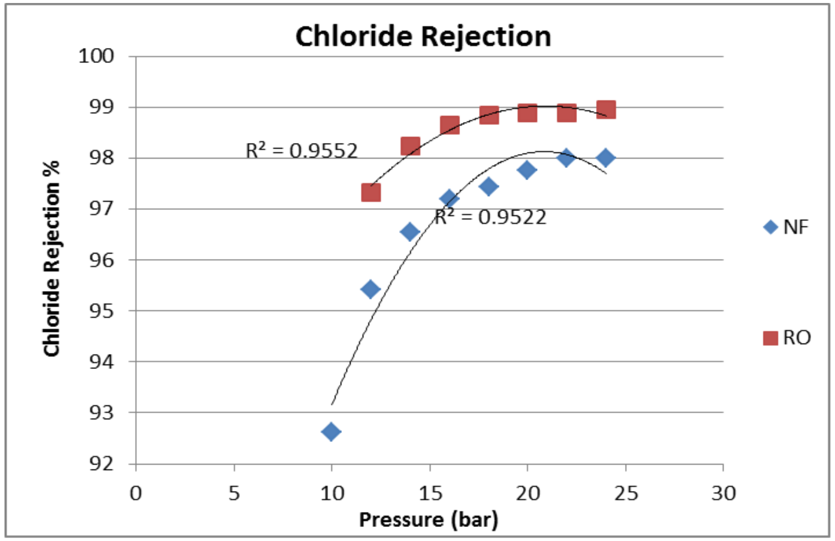
well Name	**solution 2**	**Time**	**10 min**	**Membrane**		**NF**	**Temperature**		**16C**	**Date**	**23/02/2014**	
TDS	**11500**	**NO3**	**150**	**Chloride**		**6355**	**PH**		**7.56**	**membrane area**	**15.2**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
10	1	7.2	0.59	881	47	469	6.21	12.20	92.34	68.67	92.62	3.95
12	4	8	0.75	574	31	291	6.37	33.33	95.01	79.33	95.42	15.79
14	6	8.5	0.99	442	24	220	6.29	41.38	96.16	84.00	96.54	23.68
16	7.9	9	1.25	371	20	178	6.25	46.75	96.77	86.67	97.20	31.18
18	10	9.9	1.52	327	19	163	6.13	50.25	97.16	87.33	97.44	39.47
20	11.8	10.5	1.76	296	16	142	6.09	52.91	97.43	89.33	97.77	46.58
22	14	11	2.11	269	14	128	5.98	56.00	97.66	90.67	97.99	55.26
24	16.2	11	2.52	257	14	128	6.22	59.56	97.77	90.67	97.99	63.95
well Name	**solution 2**	**Time**	**10 min**	**Membrane**		**RO**	**Temperature**		**16C**	**Date**	**22/02/2014**	
TDS	**11500**	**NO3**	**150**	**Chloride**		**6355**	**PH**		**7.56**	**membrane area**	**16**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
12	2.8	8.8	0.78	350	19	170	6.62	24.14	96.96	87.33	97.32	10.50
14	3.9	9.5	0.96	226	12	112	6.26	29.10	98.03	92.00	98.24	14.63
16	5	10.2	1.15	175	11	86	6.25	32.89	98.48	92.67	98.65	18.75
18	6	11	1.36	146	6	73	6.37	35.29	98.73	96.00	98.85	22.50
20	7	11.7	1.61	141	6	71	6.62	37.43	98.77	96.00	98.88	26.25
22	7.8	12	1.65	141	6	71	6.16	39.39	98.77	96.00	98.88	29.25
24	9	12.8	1.87	130	6	67	5.56	41.28	98.87	96.00	98.95	33.75


Producte water flux rate
Flux L/(m2.hr)
Pressure (bar)
y = 4.133x - 35.277
R² = 0.9969
y = 1.9018x - 12
R² = 0.9983
◆ NF
■ RO
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30

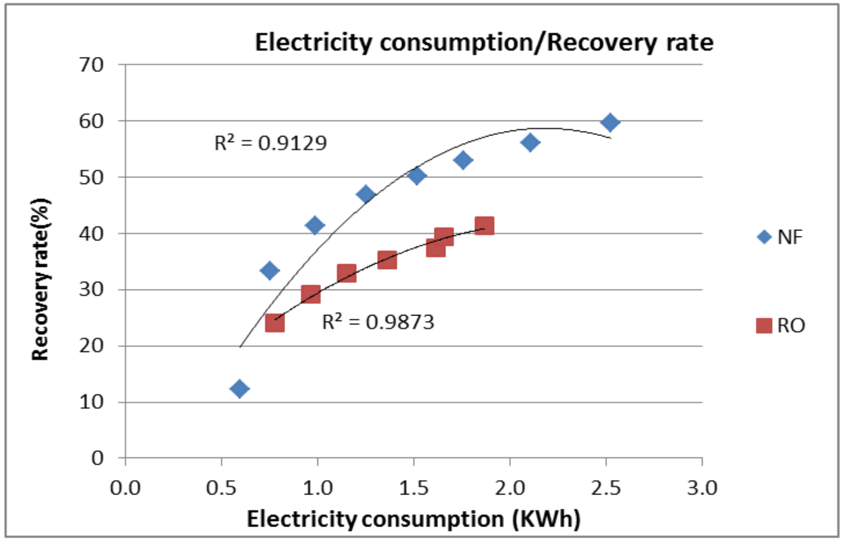

recovery rate
Recovery rate (%)
pressure (bar)
y = -0.2623x² + 11.793x - 75.119
R² = 0.9569
y = -0.0745x² + 4.0508x - 13.348
R² = 0.9957
◆ NF
■ Ro
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30


Nitrate Rejection
Nitrate Rejection %
Pressure (bar)
y = -0.1558x² + 6.6488x + 19.837
R² = 0.9567
y = -0.0992x² + 4.2381x + 51.159
R² = 0.9597
◆ NF
■ RO
0
20
40
60
80
100
120
0
5
10
15
20
25
30

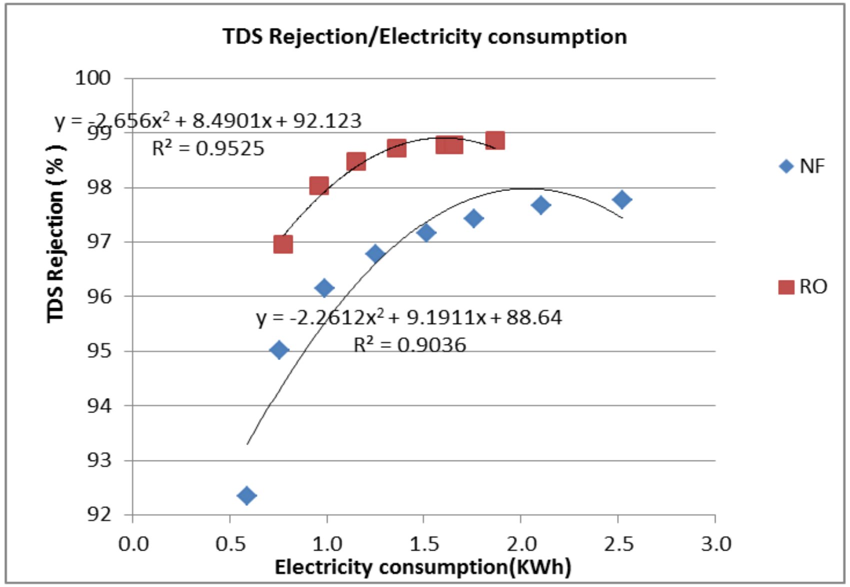

TDS Rejection
TDS Rejection %
pressure (bar)
y = -0.0402x² + 1.696x + 79.909
R² = 0.9589
y = -0.0225x² + 0.9429x + 89.04
R² = 0.9528
◆ NF
■ RO
92
93
94
95
96
97
98
99
100
0
5
10
15
20
25
30



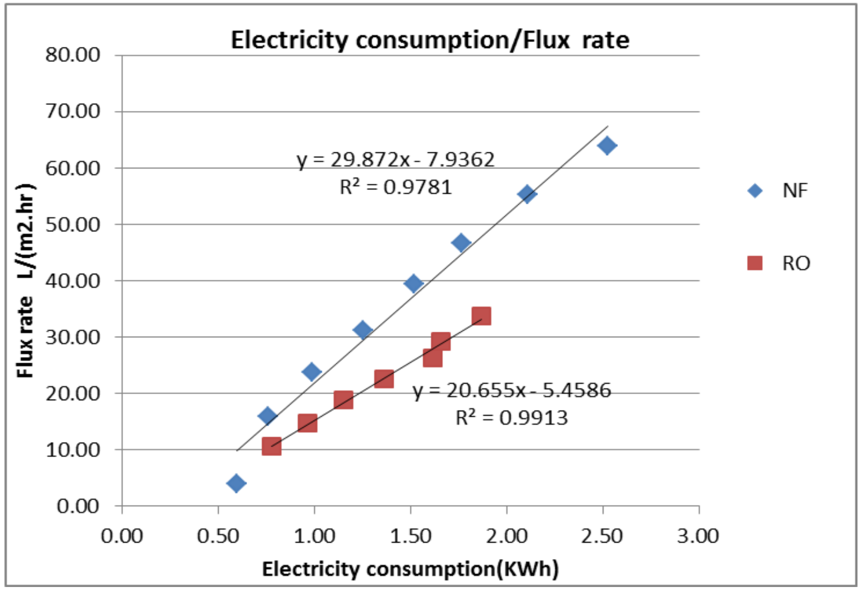
Chloride Rejection



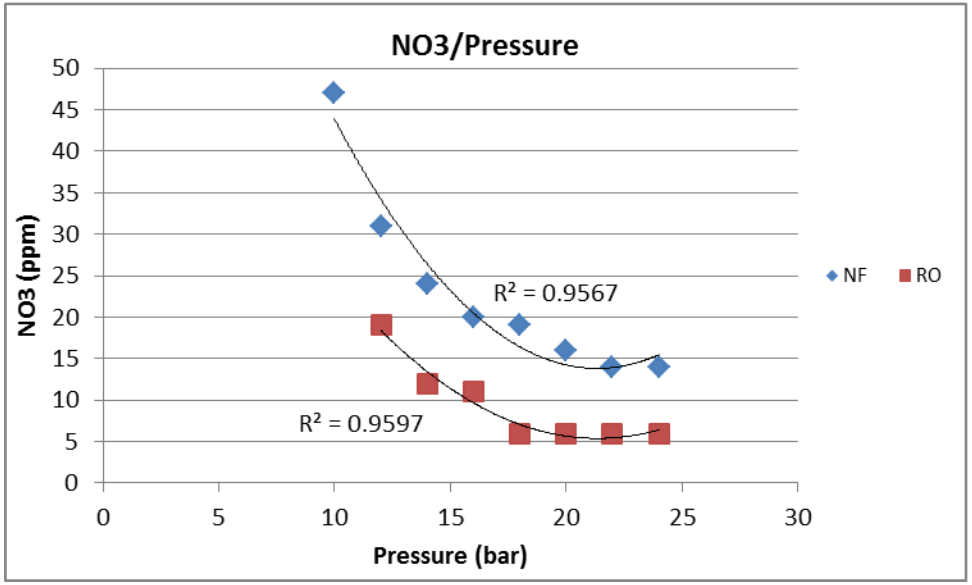
Electricity consumption/Recovery rate

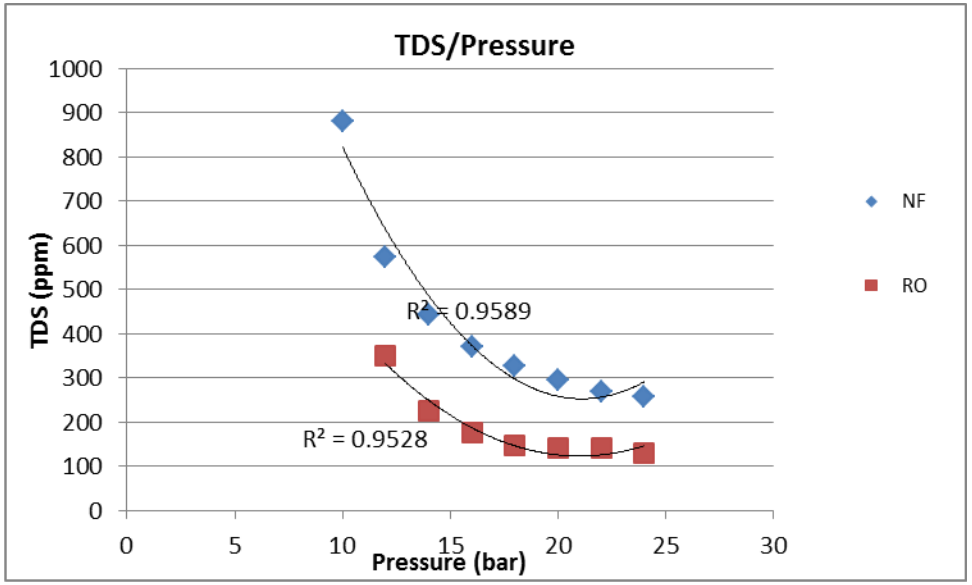


TDS Rejection/Electricity consumption



Electricity consumption/Flux rate

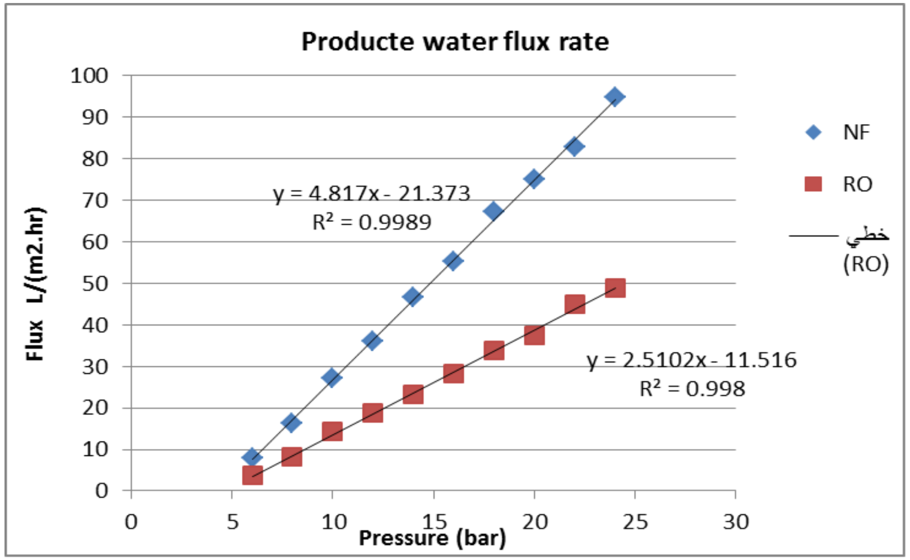

NO3/Pressure
NO3 (ppm)
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.9567
R² = 0.9597
NF
RO

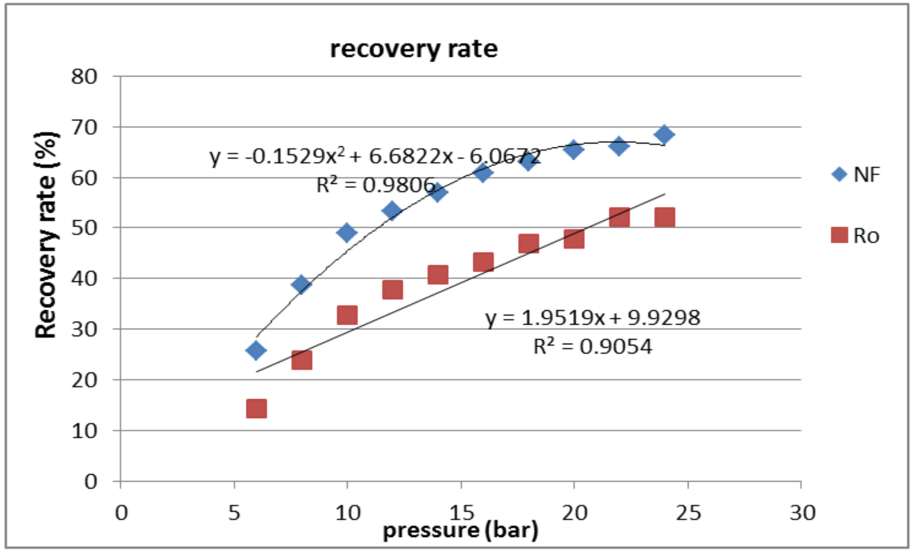

TDS/Pressure
TDS (ppm)
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.9589
R² = 0.9528
NF
RO

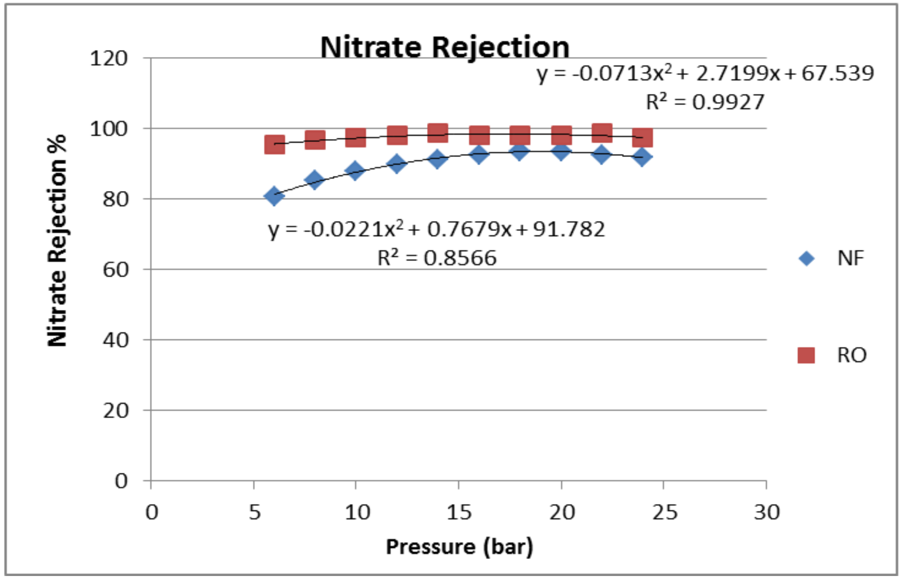
well Name	solution 3	**Time**	**10 min**	**Membrane**		**NF**	**Temperature**		**16C**	**Date**	**25/02/2014**	
TDS	**4500**	**NO3**	**150**	**Chloride**		**2237**	**PH**		**6.63**	**membrane area**	**15.2**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
6	**2**	**5.8**	**0.36**	**353**	**29**	**163**	**6.2**	**25.64**	**92.16**	**80.67**	**92.71**	**7.89**
8	**4.1**	**6.5**	**0.51**	**202**	**22**	**105**	**6.1**	**38.68**	**95.51**	**85.33**	**95.31**	**16.18**
10	**6.9**	**7.2**	**0.52**	**153**	**18**	**69**	**5.86**	**48.94**	**96.60**	**88.00**	**96.92**	**27.24**
12	**9.1**	**8**	**0.90**	**130**	**15**	**61**	**5.8**	**53.22**	**97.11**	**90.00**	**97.27**	**35.92**
14	**11.8**	**8.9**	**1.15**	**112**	**13**	**53**	**5.7**	**57.00**	**97.51**	**91.33**	**97.63**	**46.58**
16	**14**	**9**	**1.38**	**109**	**11**	**50**	**5.9**	**60.87**	**97.58**	**92.67**	**97.76**	**55.26**
18	**17**	**9.9**	**1.70**	**103**	**10**	**47**	**6.09**	**63.20**	**97.71**	**93.33**	**97.90**	**67.11**
20	**19**	**10.1**	**1.99**	**100**	**10**	**47**	**6.08**	**65.29**	**97.78**	**93.33**	**97.90**	**75.00**
22	**21**	**10.8**	**2.33**	**99**	**11**	**49**	**5.84**	**66.04**	**97.80**	**92.67**	**97.81**	**82.89**
24	**24**	**11.1**	**2.80**	**102**	**12**	**49**	**5.97**	**68.38**	**97.73**	**92.00**	**97.81**	**94.74**

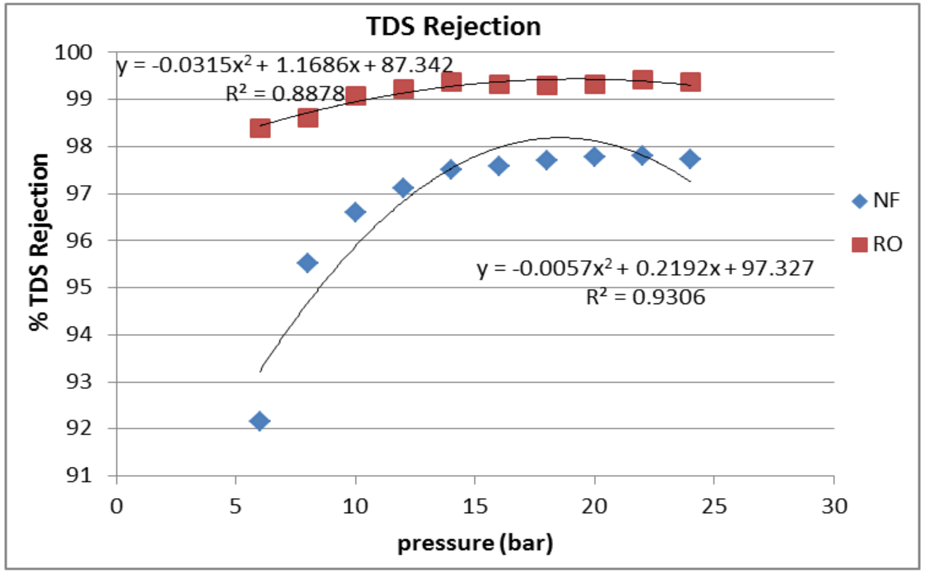
well Name	solution 3	**Time**	**10 min**	**Membrane**		**RO**	**Temperature**		**16C**	**Date**	**25/02/2014**	
TDS	**4500**	**NO3**	**150**	**Chloride**		**2237**	**PH**		**6.63**	**membrane area**	**16**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
6	**1**	**6**	**0.27**	**72**	**7**	**35**	**6.29**	**14.29**	**98.40**	**95.33**	**98.44**	**3.75**
8	**2.2**	**7**	**0.46**	**62**	**5**	**31**	**6.25**	**23.91**	**98.62**	**96.67**	**98.61**	**8.25**
10	**3.8**	**7.8**	**0.58**	**42**	**4**	**24**	**6.23**	**32.76**	**99.07**	**97.33**	**98.93**	**14.25**
12	**5**	**8.2**	**0.78**	**35**	**3**	**21**	**6.02**	**37.88**	**99.22**	**98.00**	**99.06**	**18.75**
14	**6.2**	**9**	**0.98**	**28**	**2**	**16**	**5.86**	**40.79**	**99.38**	**98.67**	**99.28**	**23.25**
16	**7.5**	**9.8**	**1.19**	**30**	**3**	**18**	**6**	**43.35**	**99.33**	**98.00**	**99.20**	**28.13**
18	**9**	**10.2**	**1.45**	**32**	**3**	**18**	**6**	**46.88**	**99.29**	**98.00**	**99.20**	**33.75**
20	**10**	**10.9**	**1.71**	**30**	**3**	**17**		**47.85**	**99.33**	**98.00**	**99.24**	**37.50**

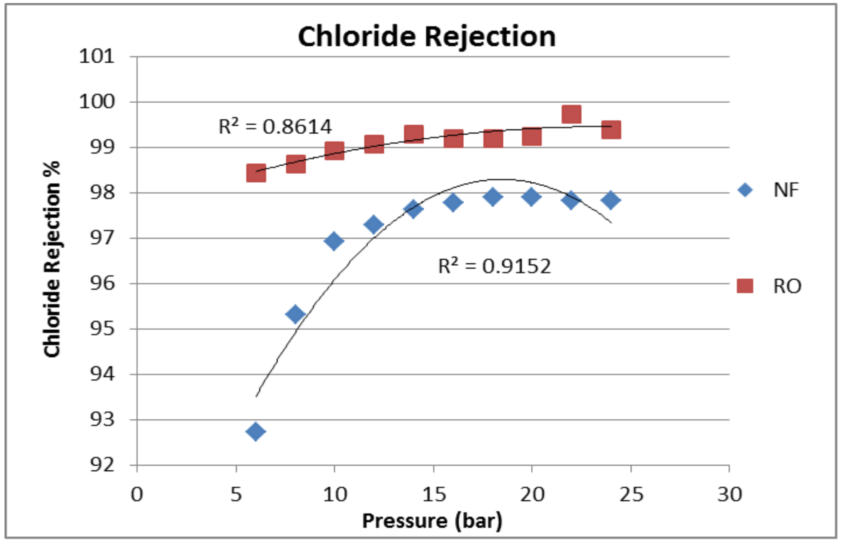
22	12	11	2.00	26	2	6	5.86	52.17	99.42	98.67	99.73	45.00
24	13	11.9	2.21	28	4	14	6.06	52.21	99.38	97.33	99.37	48.75

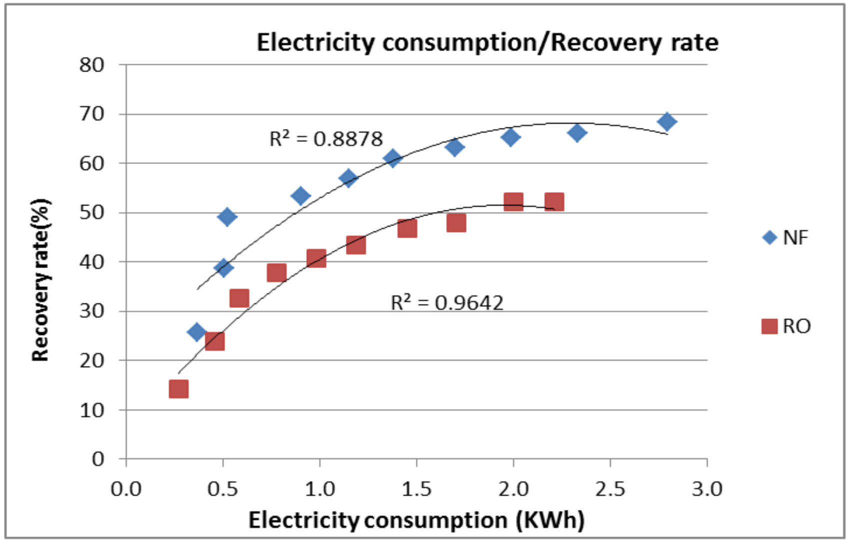

Producte water flux rate
Flux L/(m2.hr)
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Pressure (bar)
y = 4.817x - 21.373
R² = 0.9989
y = 2.5102x - 11.516
R² = 0.998
NF
RO
خطي (RO)

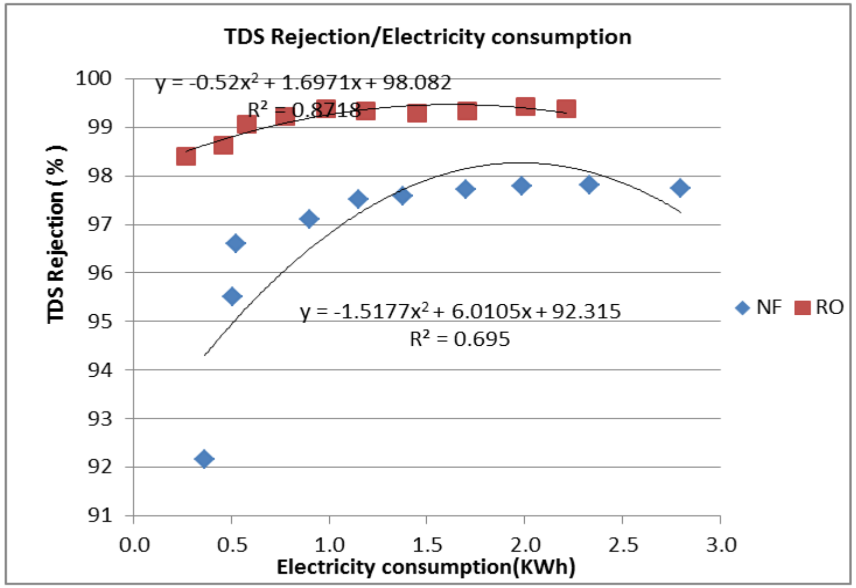

recovery rate
Recovery rate (%)
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
pressure (bar)
y = -0.1529x² + 6.6822x - 6.0672
R² = 0.9806
y = 1.9519x + 9.9298
R² = 0.9054
NF
Ro

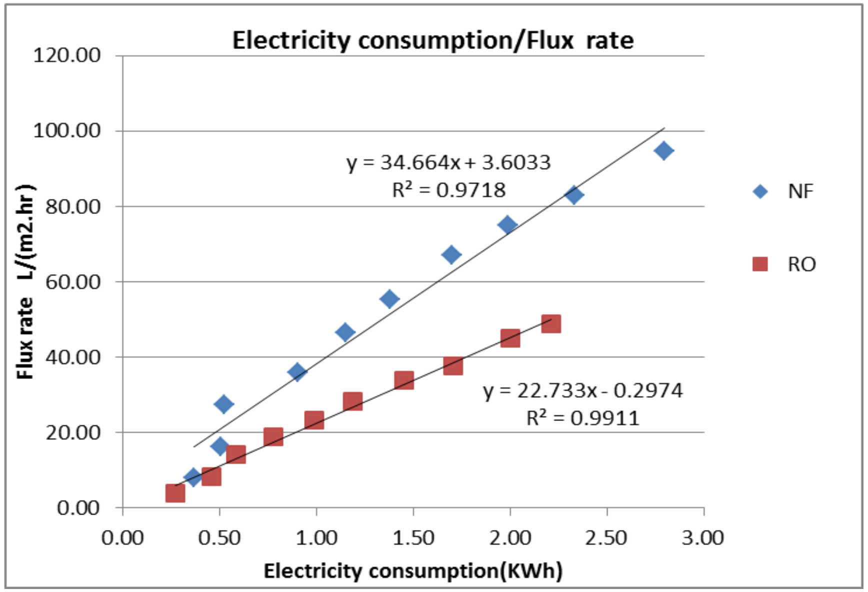

Nitrate Rejection
Nitrate Rejection %
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Pressure (bar)
y = -0.0713x² + 2.7199x + 67.539
R² = 0.9927
y = -0.0221x² + 0.7679x + 91.782
R² = 0.8566
NF
RO

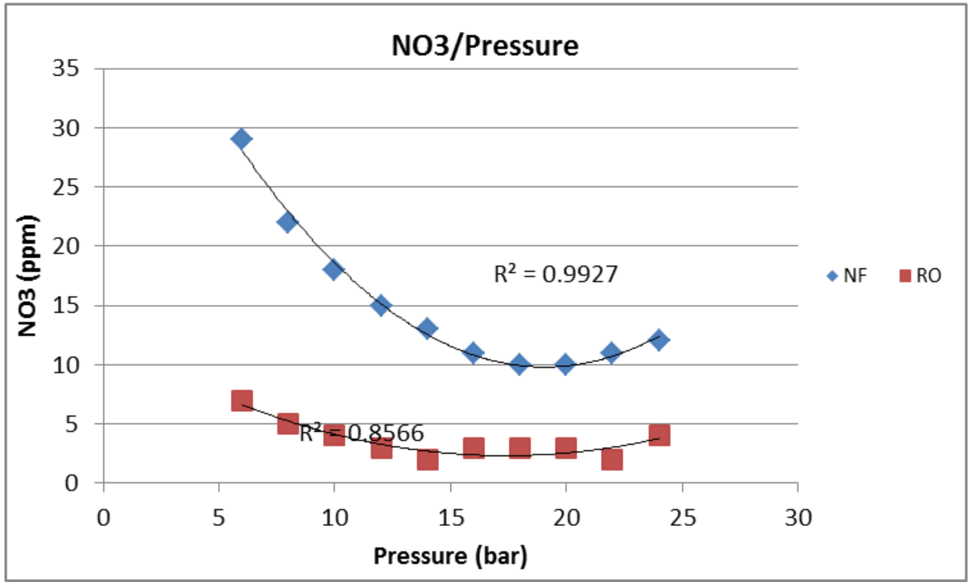

TDS Rejection
% TDS Rejection
100
99
98
97
96
95
94
93
92
91
0
5
10
15
20
25
30
pressure (bar)
y = -0.0315x² + 1.1686x + 87.342
R² = 0.8878
y = -0.0057x² + 0.2192x + 97.327
R² = 0.9306
NF
RO

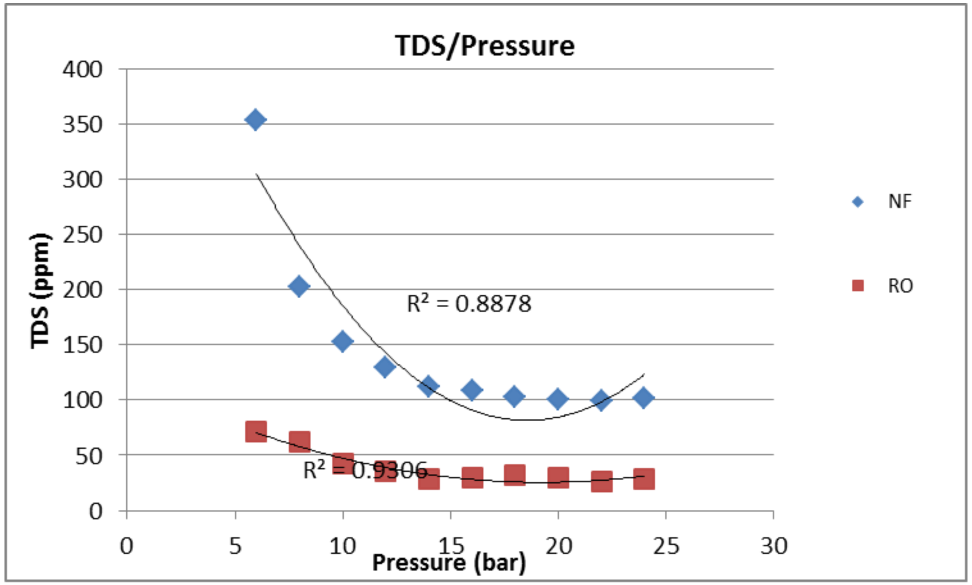

Chloride Rejection
Chloride Rejection %
101
100
99
98
97
96
95
94
93
92
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.8614
R² = 0.9152
NF
RO


Electricity consumption/Recovery rate
Recovery rate(%)
80
70
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Electricity consumption (KWh)
R² = 0.8878
R² = 0.9642
NF
RO


TDS Rejection/Electricity consumption
TDS Rejection (%)
y = -0.52x² + 1.6971x + 98.082
R² = 0.8718
y = -1.5177x² + 6.0105x + 92.315
R² = 0.695
100
99
98
97
96
95
94
93
92
91
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Electricity consumption(KWh)
NF
RO

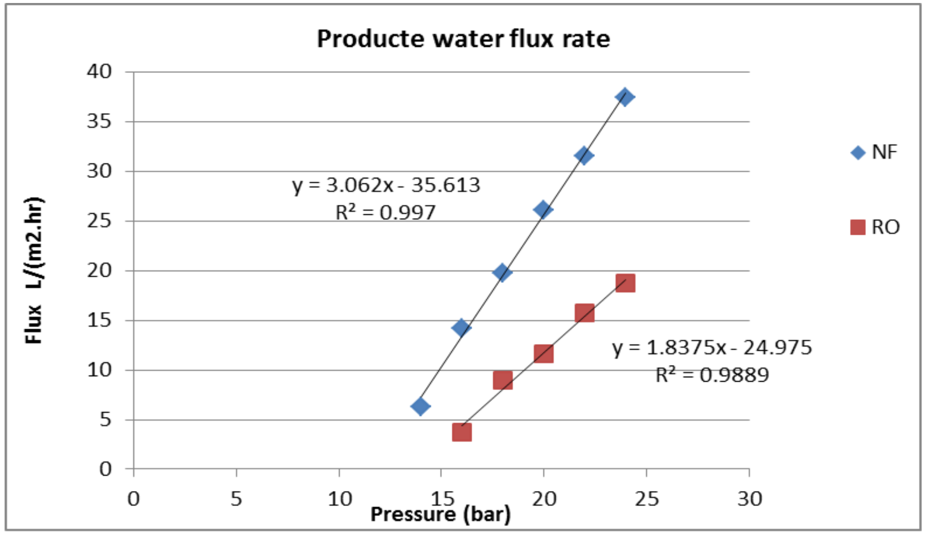

Electricity consumption/Flux rate
Flux rate L/(m2.hr)
y = 34.664x + 3.6033
R² = 0.9718
y = 22.733x - 0.2974
R² = 0.9911
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Electricity consumption(KWh)
NF
RO

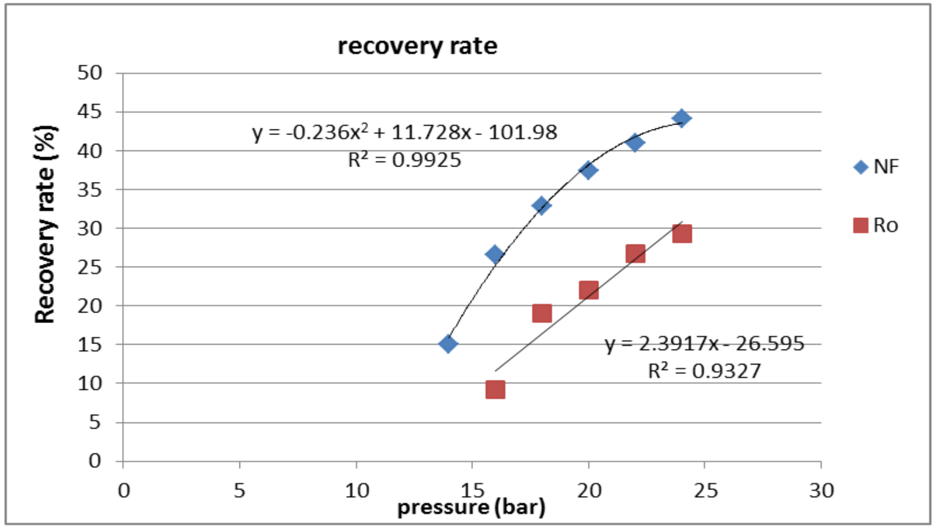

NO3/Pressure
NO3 (ppm)
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.9927
R² = 0.8566
◆ NF
■ RO

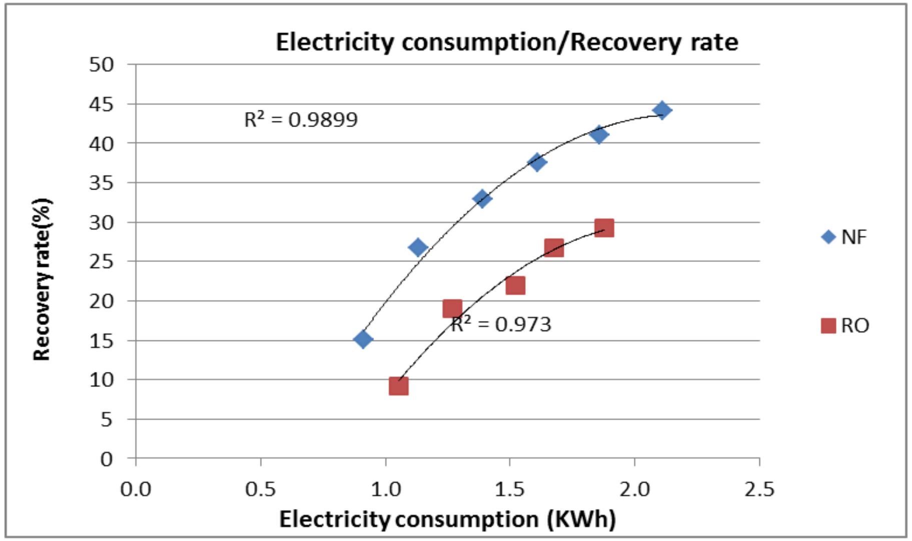

TDS/Pressure
TDS (ppm)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.8878
R² = 0.9306
◆ NF
■ RO

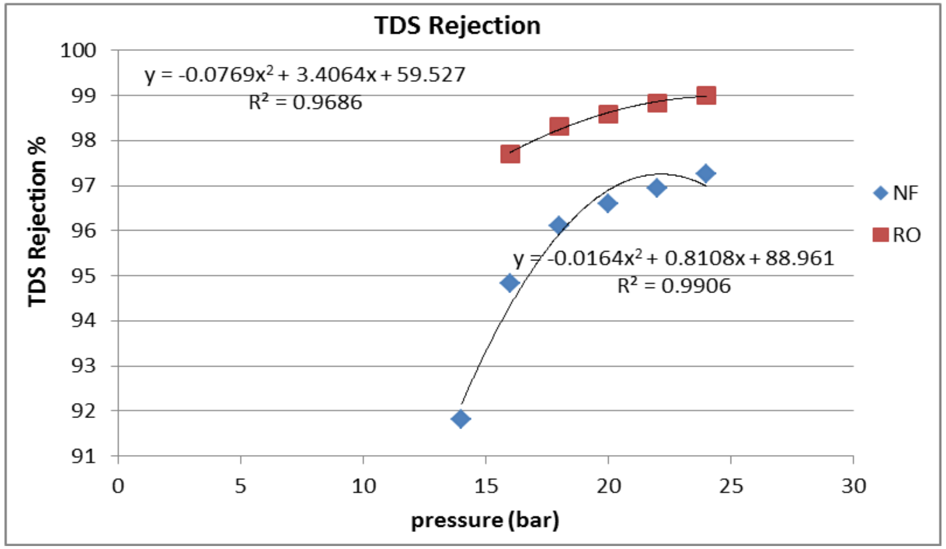
well Name	**solution 4**	**Time**	**10 min**	**Membrane**		**NF**	
TDS	**17000**	**NO3**	**0**	**Chloride**			
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	Recovery rate	Rejection rate(TDS)	Flux L/(m2.hr)
14	1.6	9	0.91	1390	15.09	91.82	6.32
16	3.6	9.9	1.13	877	26.67	94.84	14.21
18	5	10.2	1.39	660	32.89	96.12	19.74
20	6.6	11	1.61	580	37.50	96.59	26.05
22	8	11.5	1.86	520	41.03	96.94	31.58
24	9.5	12	2.11	467	44.19	97.25	37.50

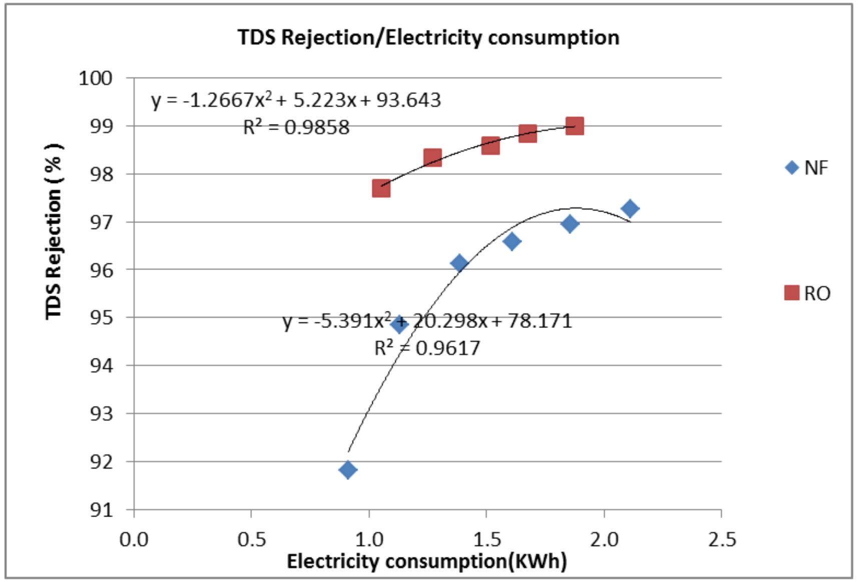
well Name	**solution 4**	**Time**	**10 min**	**Membrane**		**RO**	
TDS	**17000**	**NO3**	**0**	**Chloride**		**0**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption(kwh)	TDS	Recovery rate	Rejection rate(TDS)	Flux L/(m2.hr)
16	1	9.9	1.05	390	9.17	97.71	3.75
18	2.4	10.2	1.27	285	19.05	98.32	9.00
20	3.1	11	1.52	241	21.99	98.58	11.63
22	4.2	11.5	1.68	197	26.75	98.84	15.75
24	5	12.1	1.88	170	29.24	99.00	18.75

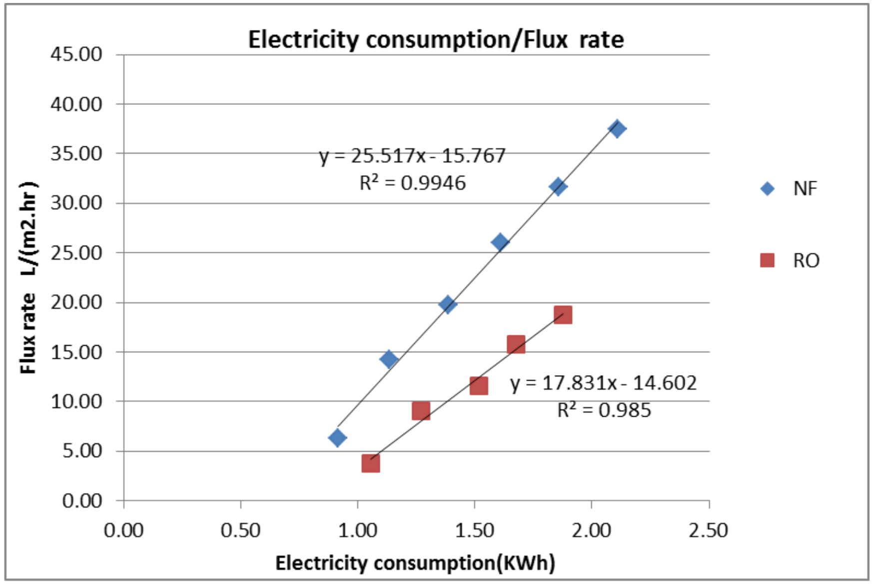

Producte water flux rate
Flux L/(m2.hr)
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Pressure (bar)
y = 3.062x - 35.613
R² = 0.997
y = 1.8375x - 24.975
R² = 0.9889
◆ NF
■ RO

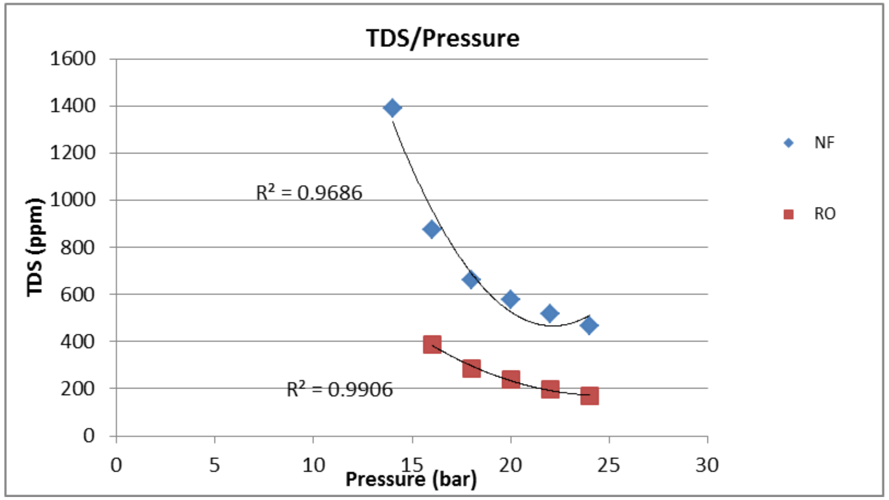

recovery rate
Recovery rate (%)
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
pressure (bar)
y = -0.236x² + 11.728x - 101.98
R² = 0.9925
y = 2.3917x - 26.595
R² = 0.9327
◆ NF
■ Ro


Electricity consumption/Recovery rate
Recovery rate(%)
50
45
40
35
30
25
20
15
10
5
0
0.0
0.5
1.0
1.5
2.0
2.5
Electricity consumption (KWh)
R² = 0.9899
R² = 0.973
◆ NF
■ RO


TDS Rejection
TDS Rejection %
100
99
98
97
96
95
94
93
92
91
0
5
10
15
20
25
30
pressure (bar)
y = -0.0769x² + 3.4064x + 59.527
R² = 0.9686
y = -0.0164x² + 0.8108x + 88.961
R² = 0.9906
◆ NF
■ RO

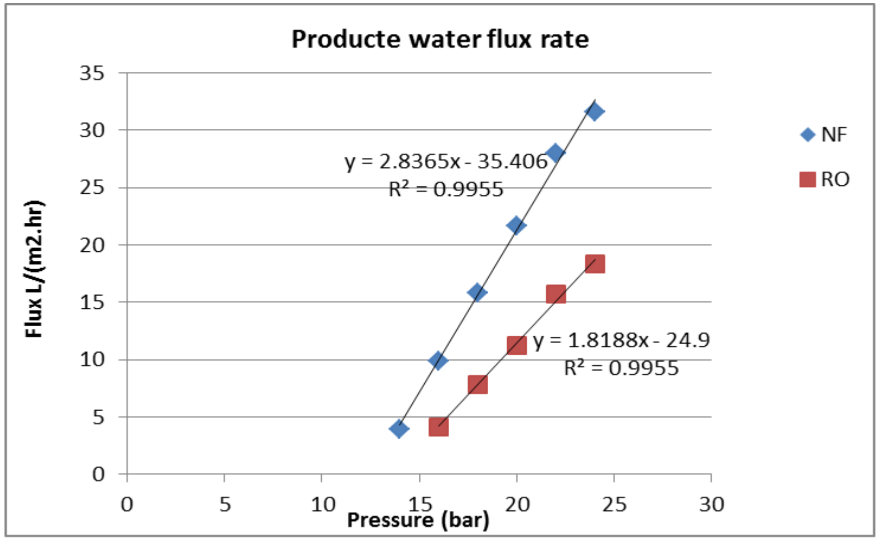

TDS Rejection/Electricity consumption
TDS Rejection (%)
100
99
98
97
96
95
94
93
92
91
0.0
0.5
1.0
1.5
2.0
2.5
Electricity consumption(KWh)
y = -1.2667x² + 5.223x + 93.643
R² = 0.9858
y = -5.391x² + 20.298x + 78.171
R² = 0.9617
NF
RO

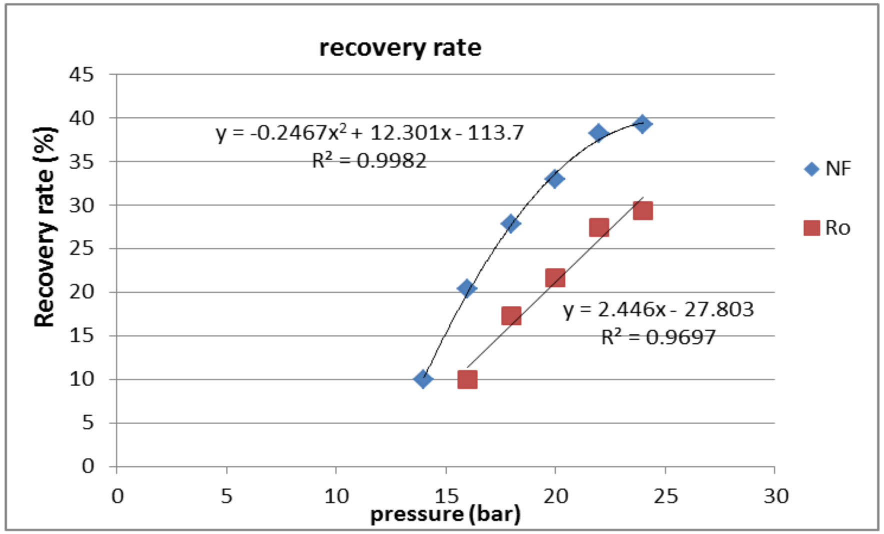

Electricity consumption/Flux rate
Flux rate L/(m2.hr)
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
Electricity consumption(KWh)
y = 25.517x - 15.767
R² = 0.9946
y = 17.831x - 14.602
R² = 0.985
NF
RO

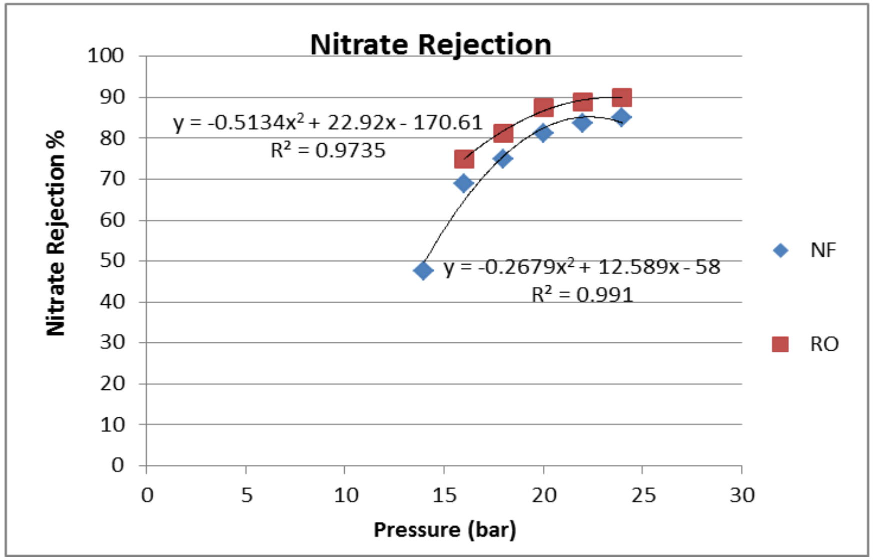

TDS/Pressure
TDS (ppm)
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.9686
R² = 0.9906
NF
RO

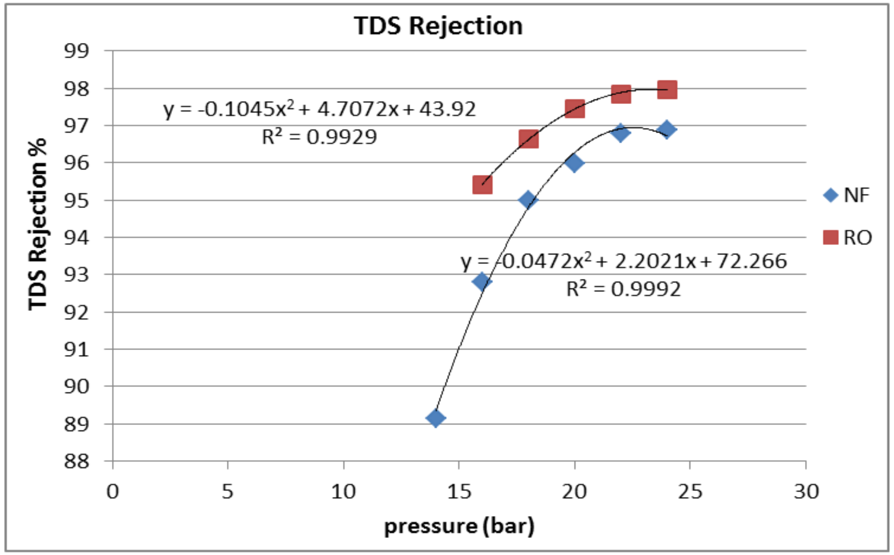
well Name	**solution 7**	**Time**	**10 min**	**Membrane**		**NF**	**Temperature**		**16C**	**Date**	**25/03/2014**	
TDS	**17000**	**NO3**	**80**	**Chloride**		**10295**	**PH**		**0**	**membrane area**	**15.2**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
14	**1**	**9**	**0.88**	**1848**	**42**	**994**	**6.45**	**10.00**	**89.13**	**47.50**	**90.34**	**3.95**
16	**2.5**	**9.8**	**1.06**	**1222**	**25**	**653**	**5.82**	**20.33**	**92.81**	**68.75**	**93.66**	**9.87**
18	**4**	**10.4**	**1.31**	**852**	**20**	**447**	**6.16**	**27.78**	**94.99**	**75.00**	**95.66**	**15.79**
20	**5.5**	**11.2**	**1.54**	**685**	**15**	**355**	**6.06**	**32.93**	**95.97**	**81.25**	**96.55**	**21.71**
22	**7.1**	**11.5**	**1.82**	**547**	**13**	**277**	**6.02**	**38.17**	**96.78**	**83.75**	**97.31**	**28.03**
24	**8**	**12.4**	**2.09**	**531**	**12**	**277**	**5.92**	**39.22**	**96.88**	**85.00**	**97.31**	**31.58**

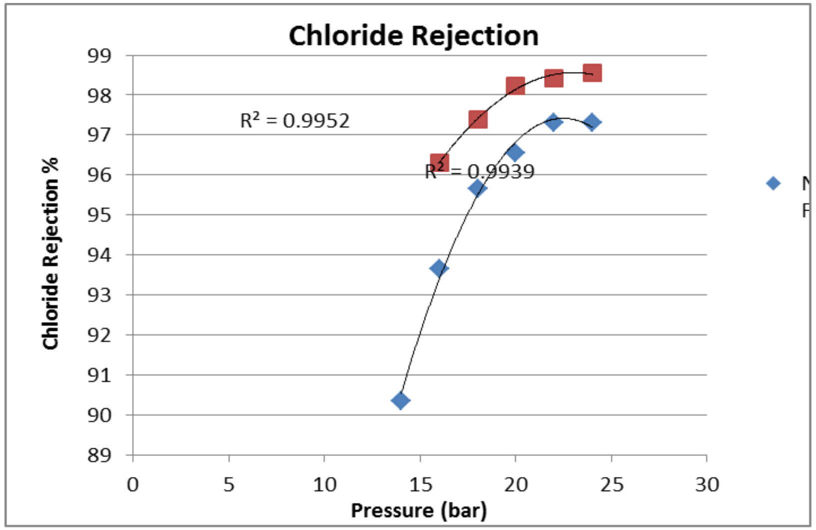
well Name	**solution 7**	**Time**	**10 min**	**Membrane**		**RO**	**Temperature**		**16C**	**Date**	**15/02/2014**	
TDS	**17000**	**NO3**	**80**	**Chloride**		**10295**	**PH**		**0**	**membrane area**	**16**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
16	**1.1**	**9.9**	**1.07**	**780**	**20**	**380**	**6.06**	**10.00**	**95.41**	**75.00**	**96.31**	**4.13**
18	**2.1**	**10.1**	**1.28**	**570**	**15**	**270**	**4.41**	**17.21**	**96.65**	**81.25**	**97.38**	**7.88**
20	**3**	**10.9**	**1.51**	**432**	**10**	**182**	**5.86**	**21.58**	**97.46**	**87.50**	**98.23**	**11.25**
22	**4.2**	**11.1**	**1.75**	**367**	**9**	**162**	**6.28**	**27.45**	**97.84**	**88.75**	**98.43**	**15.75**
24	**4.9**	**11.8**	**1.99**	**345**	**8**	**150**	**5.63**	**29.34**	**97.97**	**90.00**	**98.54**	**18.38**

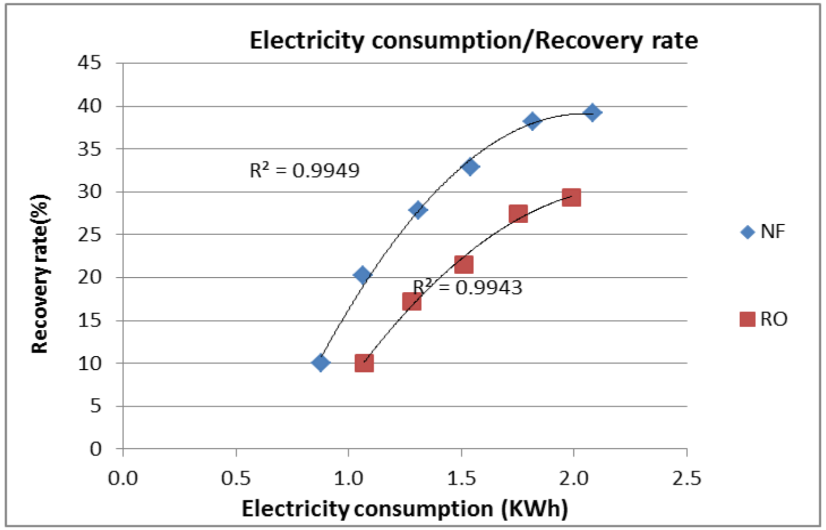

Producte water flux rate
Flux L/(m2.hr)
Pressure (bar)
y = 2.8365x - 35.406
R² = 0.9955
y = 1.8188x - 24.9
R² = 0.9955
NF
RO
0
5
10
15
20
25
30
35
0
5
10
15
20
25
30

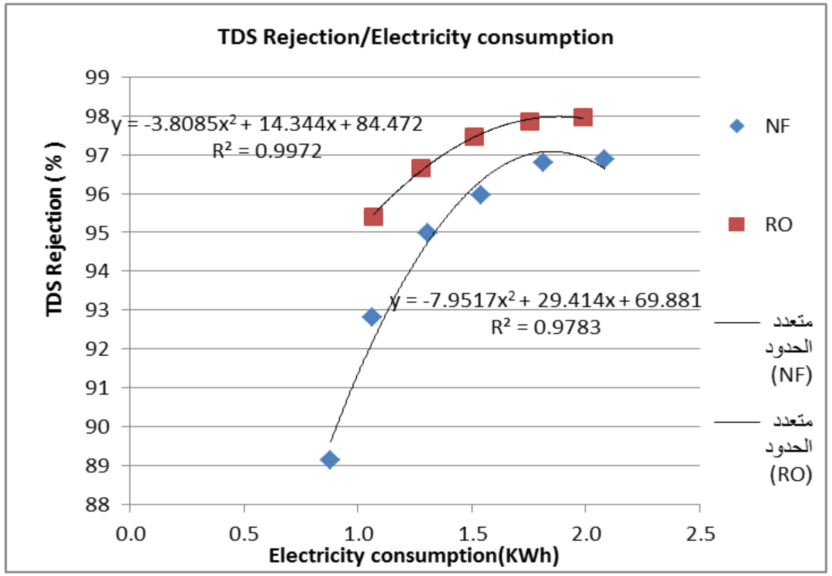

recovery rate
Recovery rate (%)
pressure (bar)
y = -0.2467x² + 12.301x - 113.7
R² = 0.9982
y = 2.446x - 27.803
R² = 0.9697
NF
Ro
0
5
10
15
20
25
30
35
40
45
0
5
10
15
20
25
30

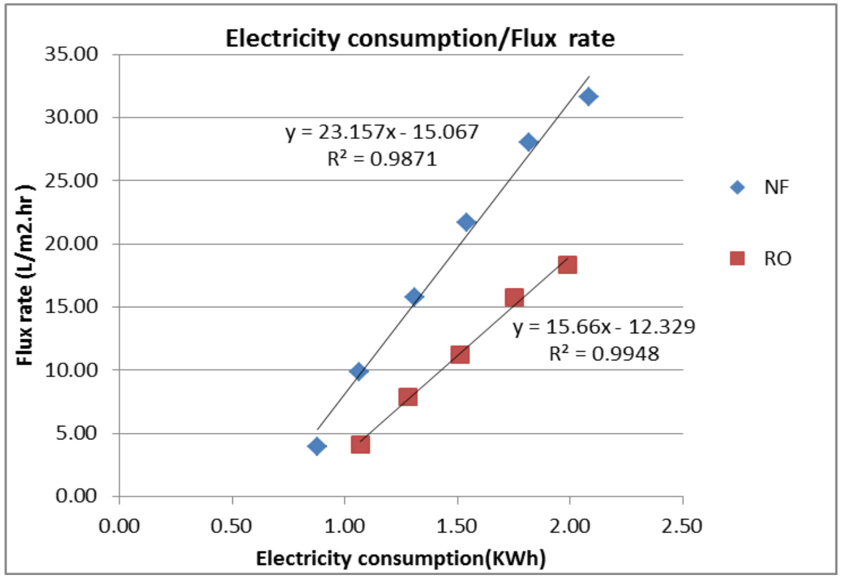

Nitrate Rejection
Nitrate Rejection %
Pressure (bar)
y = -0.5134x² + 22.92x - 170.61
R² = 0.9735
y = -0.2679x² + 12.589x - 58
R² = 0.991
NF
RO
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30

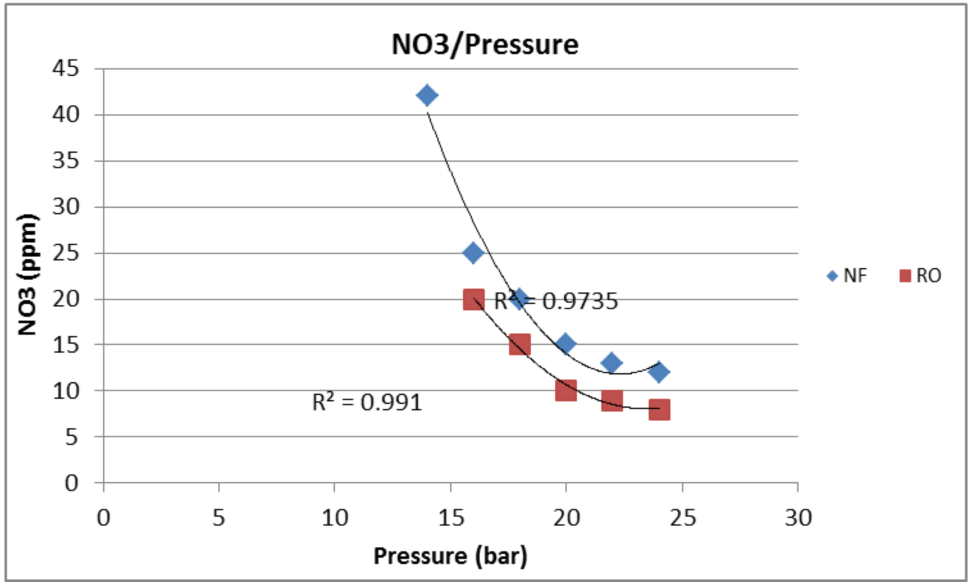

TDS Rejection
TDS Rejection %
pressure (bar)
y = -0.1045x² + 4.7072x + 43.92
R² = 0.9929
y = -0.0472x² + 2.2021x + 72.266
R² = 0.9992
NF
RO
88
89
90
91
92
93
94
95
96
97
98
99
0
5
10
15
20
25
30

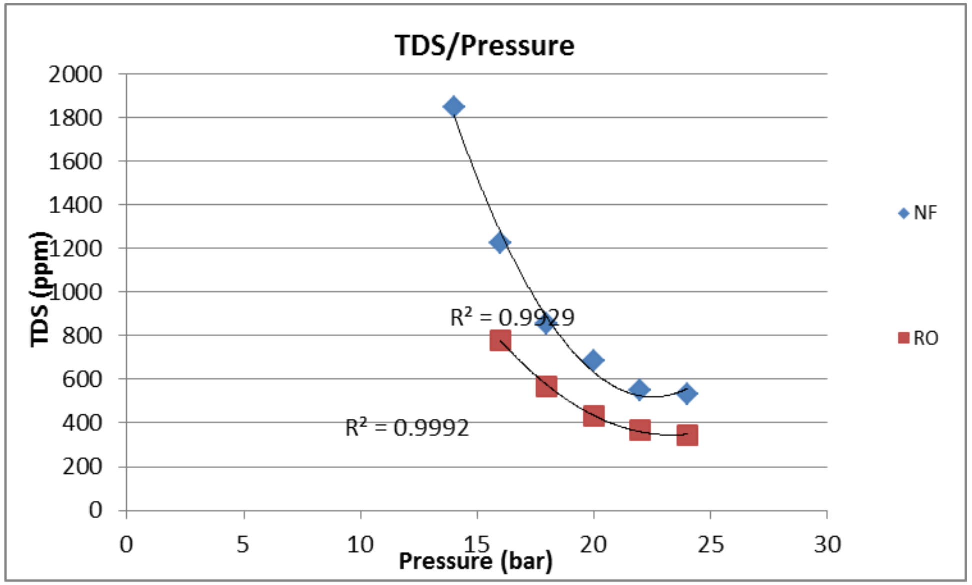

Chloride Rejection
Chloride Rejection %
Pressure (bar)
99
98
97
96
95
94
93
92
91
90
89
0
5
10
15
20
25
30
R² = 0.9952
R² = 0.9939
N
F


Electricity consumption/Recovery rate
Recovery rate(%)
Electricity consumption (KWh)
45
40
35
30
25
20
15
10
5
0
0.0
0.5
1.0
1.5
2.0
2.5
R² = 0.9949
R² = 0.9943
NF
RO


TDS Rejection/Electricity consumption
TDS Rejection (%)
Electricity consumption(KWh)
99
98
97
96
95
94
93
92
91
90
89
88
0.0
0.5
1.0
1.5
2.0
2.5
y = -3.8085x² + 14.344x + 84.472
R² = 0.9972
y = -7.9517x² + 29.414x + 69.881
R² = 0.9783
NF
RO
متعدد الحدود (NF)
متعدد الحدود (RO)


Electricity consumption/Flux rate
Flux rate (L/m2.hr)
Electricity consumption(KWh)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
y = 23.157x - 15.067
R² = 0.9871
y = 15.66x - 12.329
R² = 0.9948
NF
RO


NO3/Pressure
NO3 (ppm)
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Pressure (bar)
◆ NF
■ RO
R² = 0.9735
R² = 0.991


TDS/Pressure
TDS (ppm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
Pressure (bar)
◆ NF
■ RO
R² = 0.9929
R² = 0.9992

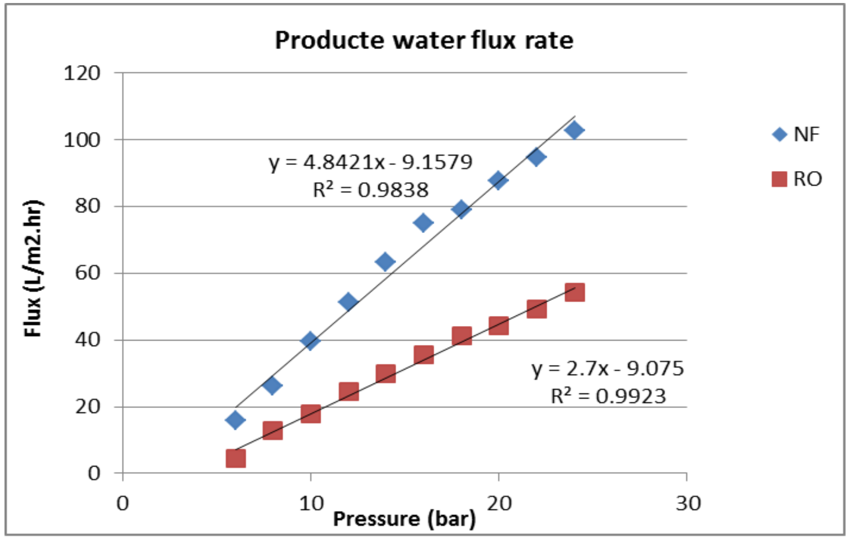
APPENDIX (2)

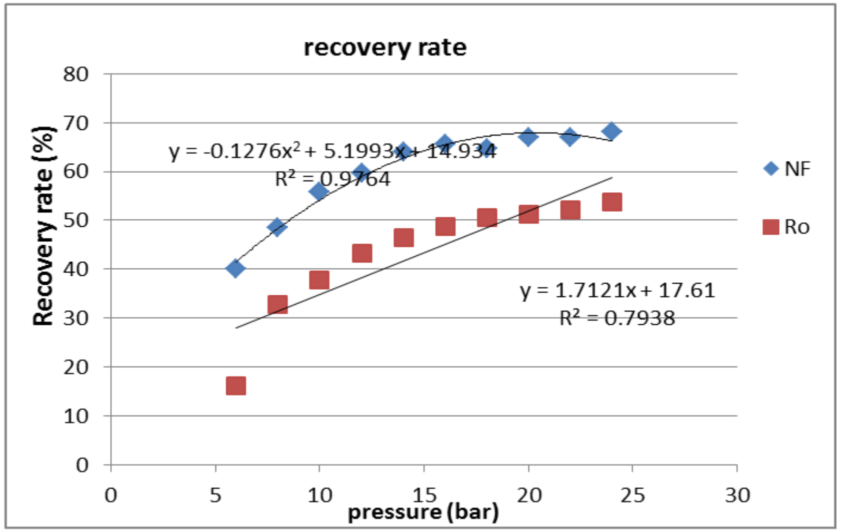
Real water result

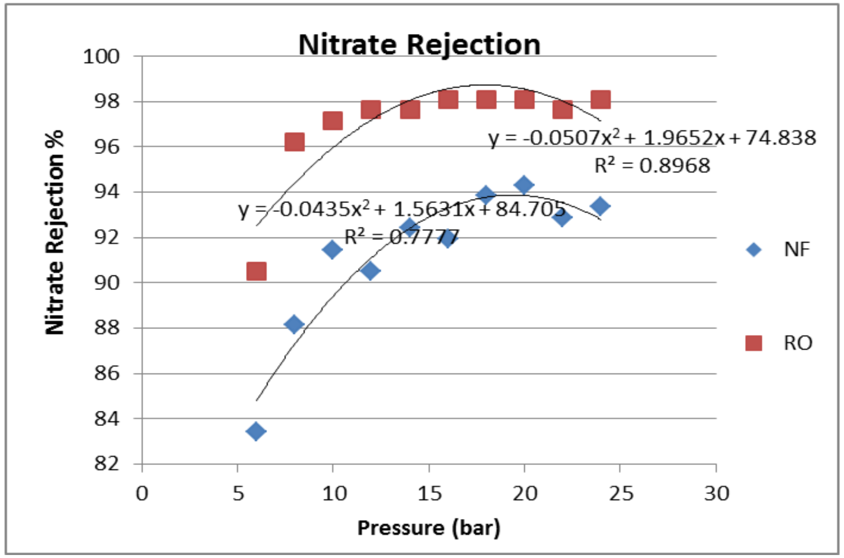
well Name	sabra 3	Time	10 min	Membrane		NF	Temperature		16C	Date	05/03/2014	
TDS	1724	NO3	211	Chloride		504	PH		7.34	membrane area	15.2	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
6	4	6	0.33	154	35	59	6.56	40.00	91.07	83.41	88.29	15.79
8	6.6	7	0.54	105	25	39	6.58	48.53	93.91	88.15	92.26	26.05
10	10	7.9	0.78	79	18	31	6.35	55.87	95.42	91.47	93.85	39.47
12	13	8.8	1.03	72	20	27	6.41	59.63	95.82	90.52	94.64	51.32
14	16	9	1.31	67	16	27	6.38	64.00	96.11	92.42	94.64	63.16
16	19	10	1.64	65	17	26	6.61	65.52	96.23	91.94	94.84	75.00
18	20	10.9	1.90	55	13	22	6.32	64.72	96.81	93.84	95.63	78.95
20	22.2	11	2.24	56	12	24	6.45	66.87	96.75	94.31	95.24	87.63
22	24	11.9	2.69	56	15	24	6.02	66.85	96.75	92.89	95.24	94.74
24	26	12.2	2.95	52	14	24	6.02	68.06	96.98	93.36	95.24	102.63

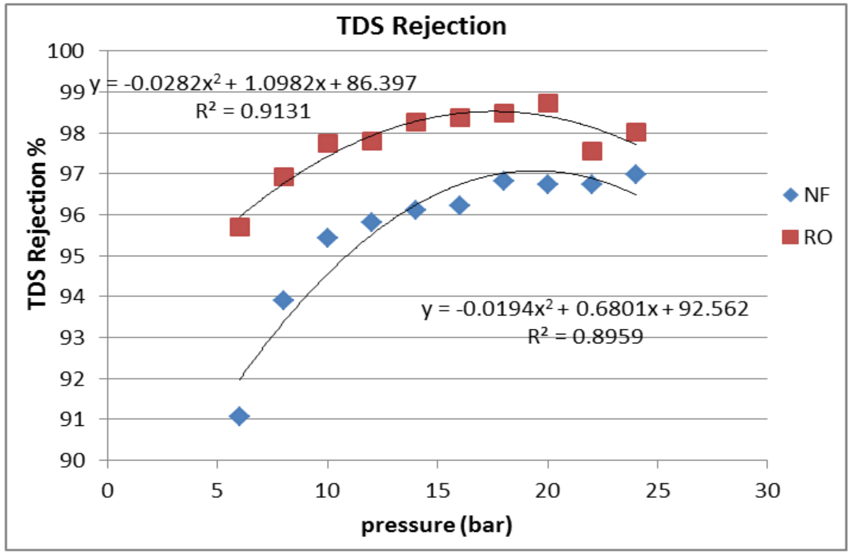
well Name	sabra 3	Time	10 min	Membrane		RO	Temperature		16C	Date	05/03/2014	
TDS	1724	NO3	211	Chloride		504	PH		7.34	membrane area	16	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
6	1.2	6.2	0.31	74	20	27	6.55	16.22	95.71	90.52	94.64	4.50
8	3.4	7	0.52	53	8	20	6.36	32.69	96.93	96.21	96.03	12.75
10	4.8	7.9	0.66	39	6	16	6.18	37.80	97.74	97.16	96.83	18.00
12	6.5	8.5	0.84	38	5	14	6.1	43.33	97.80	97.63	97.22	24.38
14	8	9.2	1.11	30	5	14	6.53	46.51	98.26	97.63	97.22	30.00
16	9.5	10	1.37	28	4	16	5.94	48.72	98.38	98.10	96.83	35.63
18	11	10.8	1.63	26	4	12	5.97	50.46	98.49	98.10	97.62	41.25

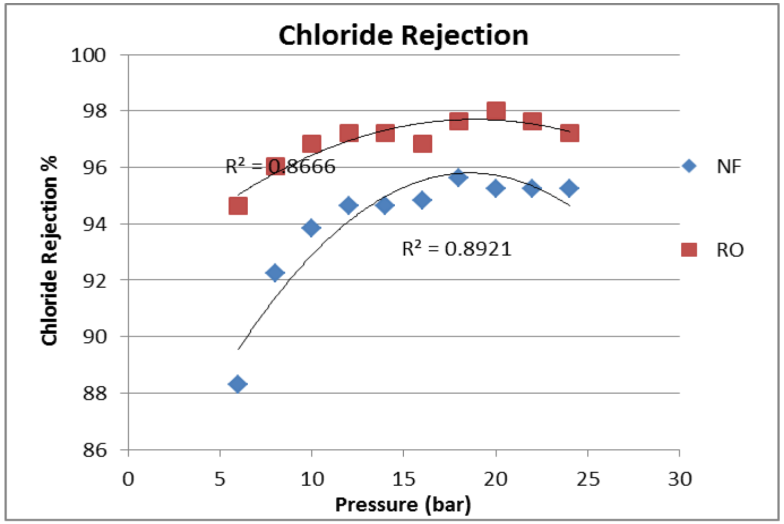
20	**11.8**	**11.2**	**1.86**	**22**	**4**	**10**	**6.1**	**51.30**	**98.72**	**98.10**	**98.02**	**44.25**
22	**13.1**	**12**	**2.14**	**42**	**5**	**12**	**6.76**	**52.19**	**97.56**	**97.63**	**97.62**	**49.13**
24	**14.5**	**12.5**	**2.51**	**34**	**4**	**14**	**7.38**	**53.70**	**98.03**	**98.10**	**97.22**	**54.38**

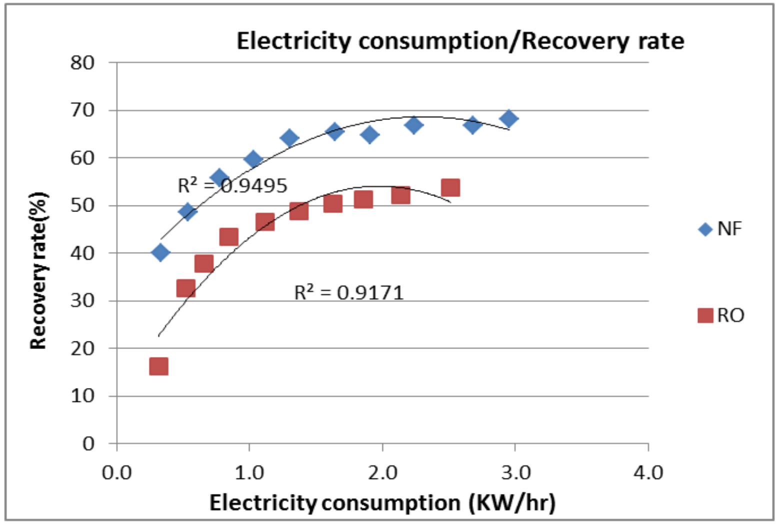

Producte water flux rate
Flux (L/m2.hr)
Pressure (bar)
0
20
40
60
80
100
120
0
10
20
30
NF
RO
y = 4.8421x - 9.1579
R² = 0.9838
y = 2.7x - 9.075
R² = 0.9923

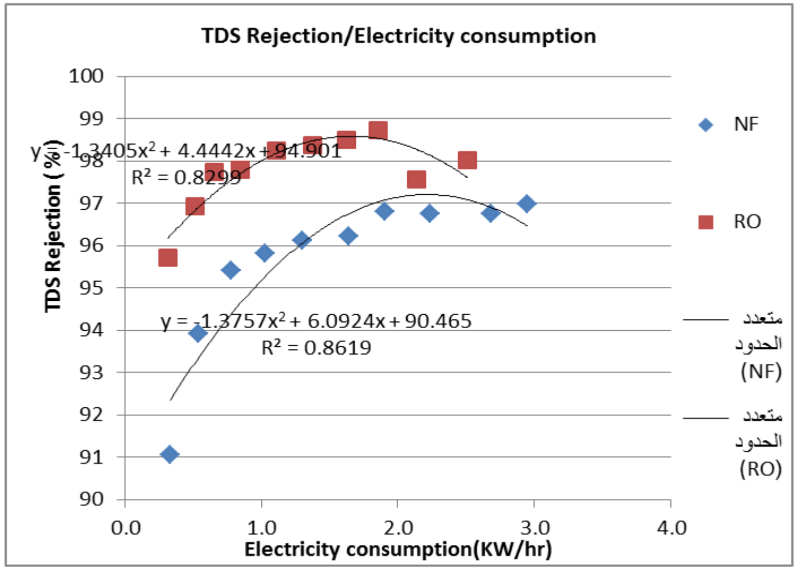

recovery rate
Recovery rate (%)
pressure (bar)
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30
NF
Ro
y = -0.1276x² + 5.1993x + 14.934
R² = 0.9764
y = 1.7121x + 17.61
R² = 0.7938

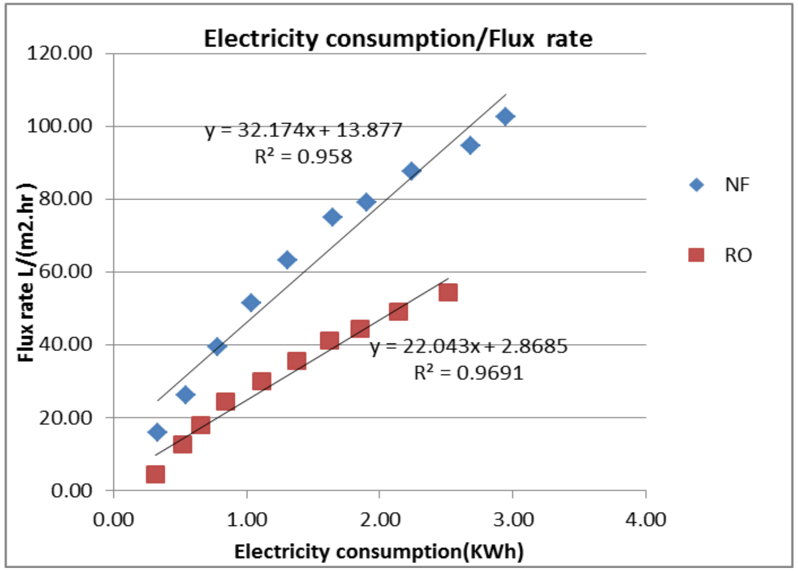

Nitrate Rejection
Nitrate Rejection %
Pressure (bar)
82
84
86
88
90
92
94
96
98
100
0
5
10
15
20
25
30
NF
RO
y = -0.0507x² + 1.9652x + 74.838
R² = 0.8968
y = -0.0435x² + 1.5631x + 84.705
R² = 0.7777

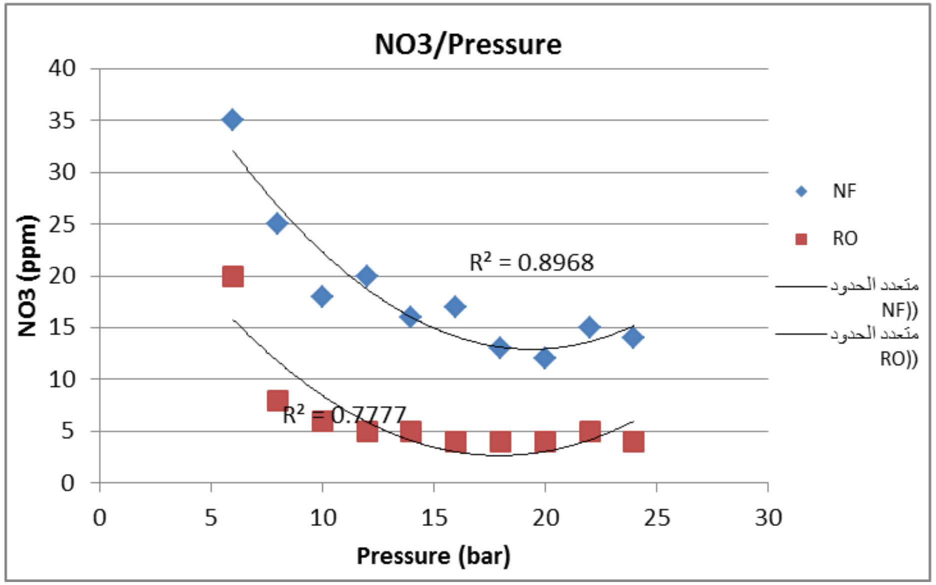

TDS Rejection
TDS Rejection %
pressure (bar)
90
91
92
93
94
95
96
97
98
99
100
0
5
10
15
20
25
30
NF
RO
y = -0.0282x² + 1.0982x + 86.397
R² = 0.9131
y = -0.0194x² + 0.6801x + 92.562
R² = 0.8959

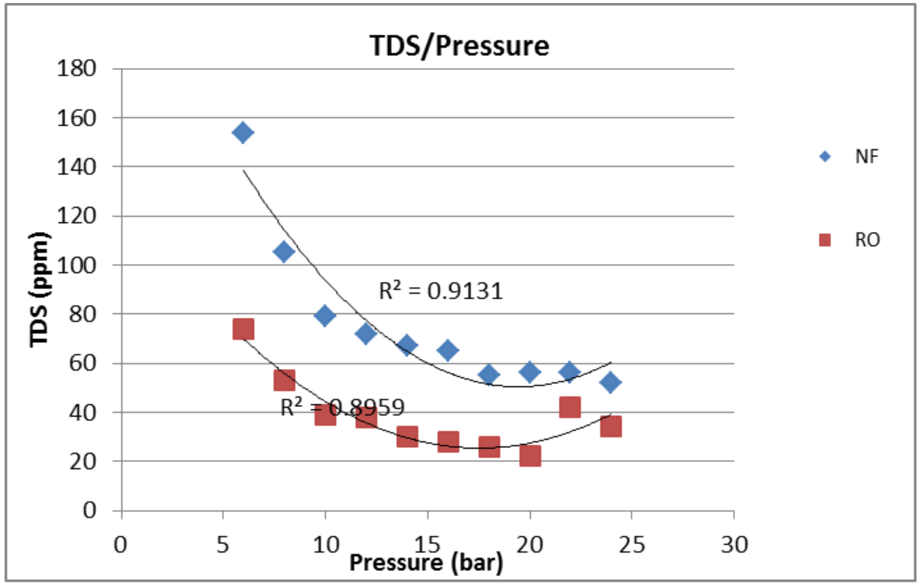

Chloride Rejection
Chloride Rejection %
100
98
96
94
92
90
88
86
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.8666
R² = 0.8921
NF
RO


Electricity consumption/Recovery rate
Recovery rate(%)
80
70
60
50
40
30
20
10
0
0.0
1.0
2.0
3.0
4.0
Electricity consumption (KW/hr)
R² = 0.9495
R² = 0.9171
NF
RO

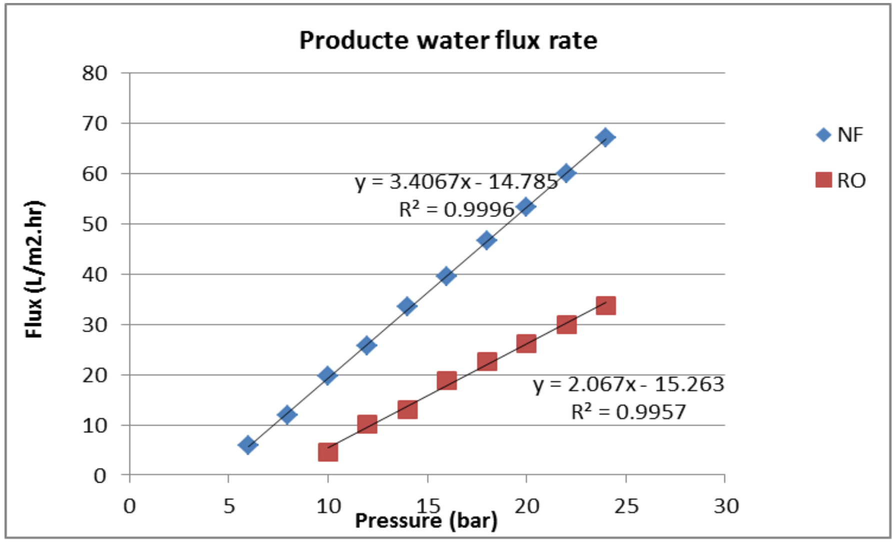

TDS Rejection/Electricity consumption
TDS Rejection (%)
100
99
98
97
96
95
94
93
92
91
90
0.0
1.0
2.0
3.0
4.0
Electricity consumption(KW/hr)
y = -1.3405x² + 4.4442x + 94.901
R² = 0.8299
y = -1.3757x² + 6.0924x + 90.465
R² = 0.8619
NF
RO
متعدد الحدود (NF)
متعدد الحدود (RO)

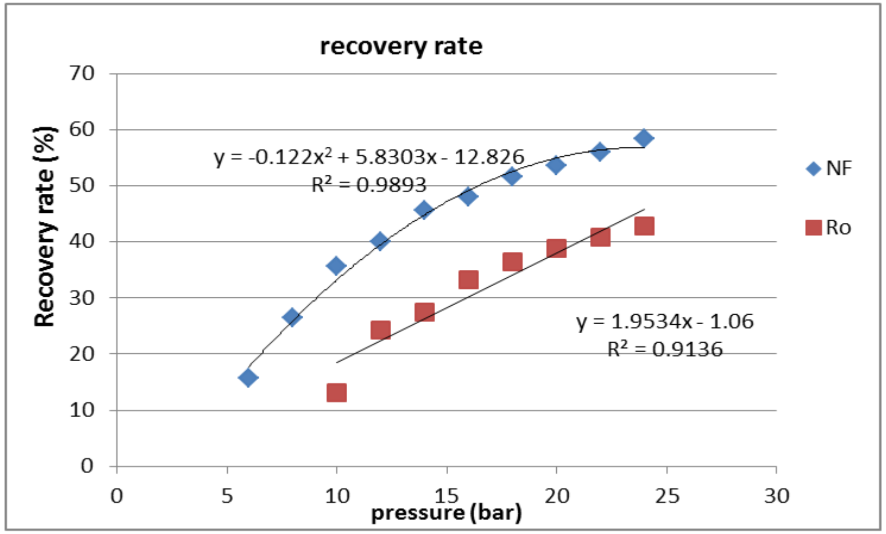

Electricity consumption/Flux rate
Flux rate L/(m2.hr)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0.00
1.00
2.00
3.00
4.00
Electricity consumption(KWh)
y = 32.174x + 13.877
R² = 0.958
y = 22.043x + 2.8685
R² = 0.9691
NF
RO

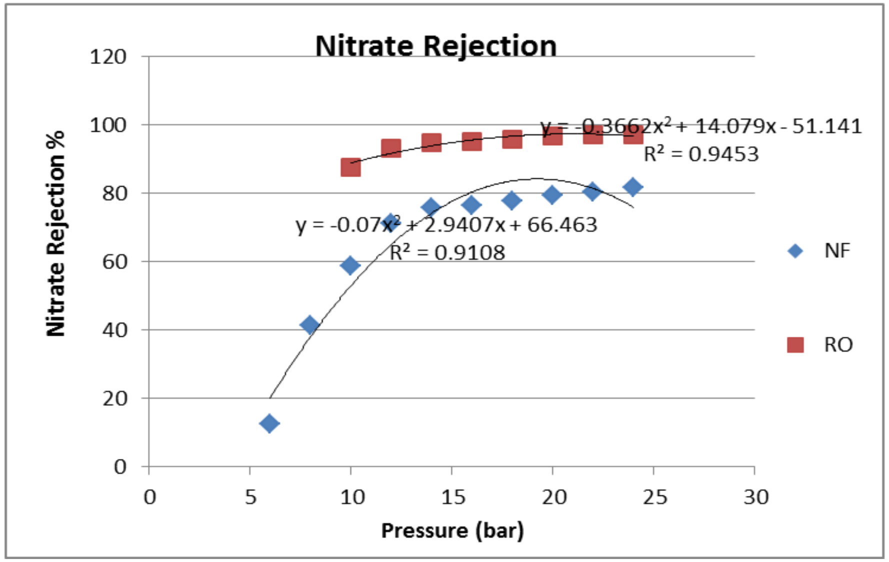

NO3/Pressure
NO3 (ppm)
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.8968
R² = 0.7777
NF
RO
متعدد الحدود (NF)
متعدد الحدود (RO)

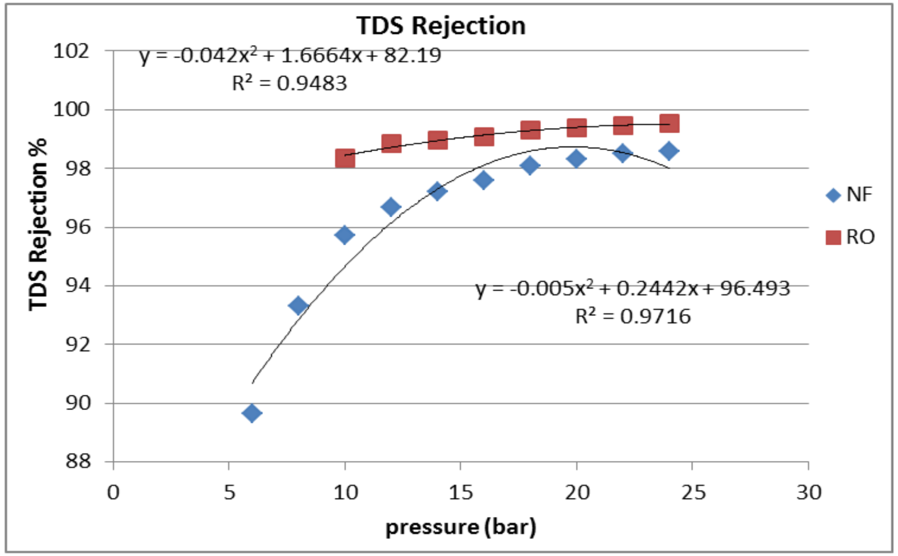

TDS/Pressure
TDS (ppm)
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.9131
R² = 0.8959
NF
RO

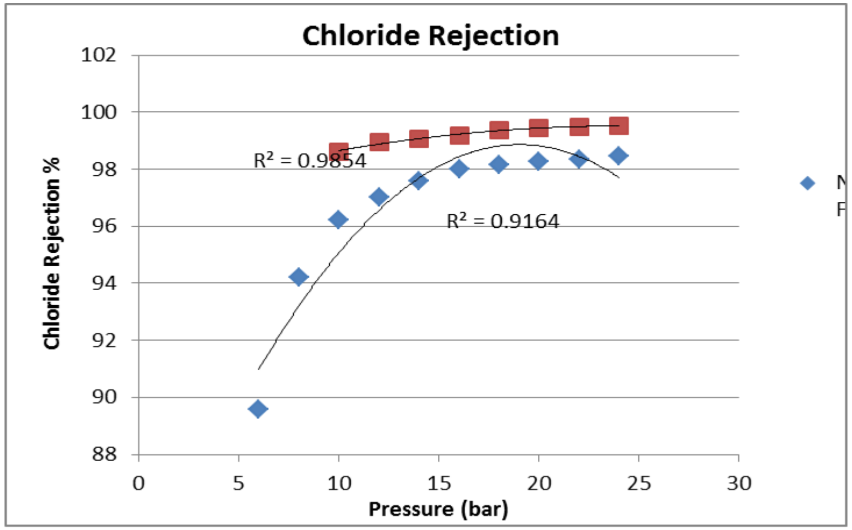
well Name	**Redwan 8**	**Time**	**10 min**	**Membrane**		**NF**	**Temperature**		**16C**	**Date**	**25/01/2014**	
TDS	**6764**	**NO3**	**72.2**	**Chloride**		**3528**	**PH**		**7.77**	**membrane area**	**15.2**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
6	**1.5**	**8**	**0.45**	**701**	**63.2**	**368**	**8.37**	**15.79**	**89.64**	**12.47**	**89.57**	**5.92**
8	**3**	**8.3**	**0.6**	**452**	**42.4**	**205**	**7.84**	**26.55**	**93.32**	**41.27**	**94.19**	**11.84**
10	**5**	**9**	**0.74**	**290**	**29.7**	**134**	**7.25**	**35.71**	**95.71**	**58.86**	**96.20**	**19.74**
12	**6.5**	**9.7**	**1.09**	**225**	**20.8**	**106**	**6.71**	**40.12**	**96.67**	**71.19**	**97.00**	**25.66**
14	**8.5**	**10.1**	**1.28**	**190**	**17.4**	**85**	**6.33**	**45.70**	**97.19**	**75.90**	**97.59**	**33.55**
16	**10**	**10.8**	**1.62**	**164**	**16.9**	**71**	**6.12**	**48.08**	**97.58**	**76.59**	**97.99**	**39.47**
18	**11.8**	**11.1**	**1.85**	**130**	**16**	**65**	**6.09**	**51.53**	**98.08**	**77.84**	**98.16**	**46.58**
20	**13.5**	**11.7**	**2.05**	**115**	**14.9**	**61**	**6.02**	**53.57**	**98.30**	**79.36**	**98.27**	**53.29**
22	**15.2**	**11.9**	**2.3**	**102**	**14.1**	**58**	**5.95**	**56.09**	**98.49**	**80.47**	**98.36**	**60.00**
24	**17**	**12.1**	**2.62**	**95**	**13.2**	**55**	**5.95**	**58.42**	**98.60**	**81.72**	**98.44**	**67.11**
well Name	**Redwan 8**	**Time**	**10 min**	**Membrane**		**RO**	**Temperature**		**16C**	**Date**	**26/01/2014**	
TDS	**6764**	**NO3**	**72.2**	**Chloride**		**3528**	**PH**		**7.77**	**membrane area**	**16**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
10	**1.2**	**8**	**0.65**	**111**	**9**	**49**	**6.95**	**13.04**	**98.36**	**87.53**	**98.61**	**4.50**
12	**2.7**	**8.4**	**0.83**	**78**	**4.9**	**37**	**6.53**	**24.32**	**98.85**	**93.21**	**98.95**	**10.13**
14	**3.5**	**9.2**	**1.02**	**71**	**3.68**	**33**	**6.41**	**27.56**	**98.95**	**94.90**	**99.06**	**13.13**
16	**5**	**10**	**1.24**	**63**	**3.4**	**29**	**6.48**	**33.33**	**99.07**	**95.29**	**99.18**	**18.75**
18	**6**	**10.5**	**1.52**	**48**	**3**	**22**	**6.42**	**36.36**	**99.29**	**95.84**	**99.38**	**22.50**
20	**7**	**11**	**1.78**	**41**	**2.3**	**20**	**6.51**	**38.89**	**99.39**	**96.81**	**99.43**	**26.25**
22	**8**	**11.6**	**2.01**	**37**	**2**	**18**	**6.5**	**40.82**	**99.45**	**97.23**	**99.49**	**30.00**
24	**9**	**12**	**2.32**	**32**	**2**	**17**	**6.42**	**42.86**	**99.53**	**97.23**	**99.52**	**33.75**

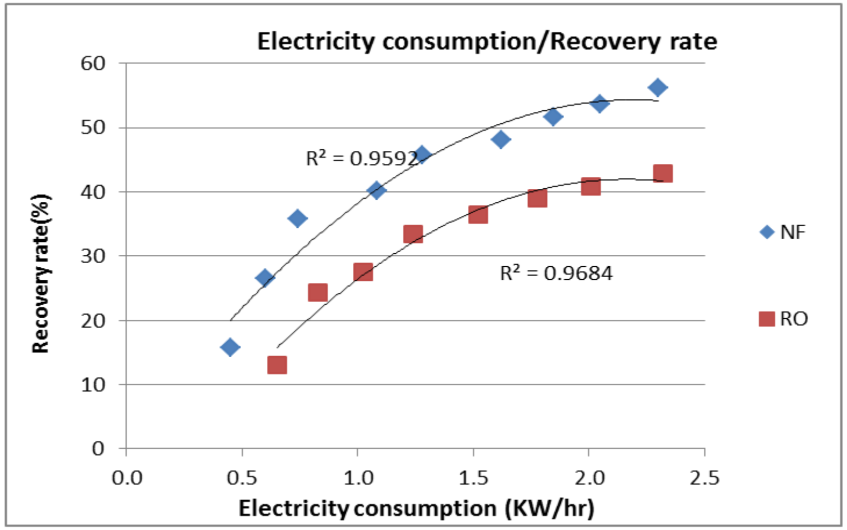

Producte water flux rate
Flux (L/m2.hr)
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Pressure (bar)
y = 3.4067x - 14.785
R² = 0.9996
y = 2.067x - 15.263
R² = 0.9957
◆ NF
■ RO

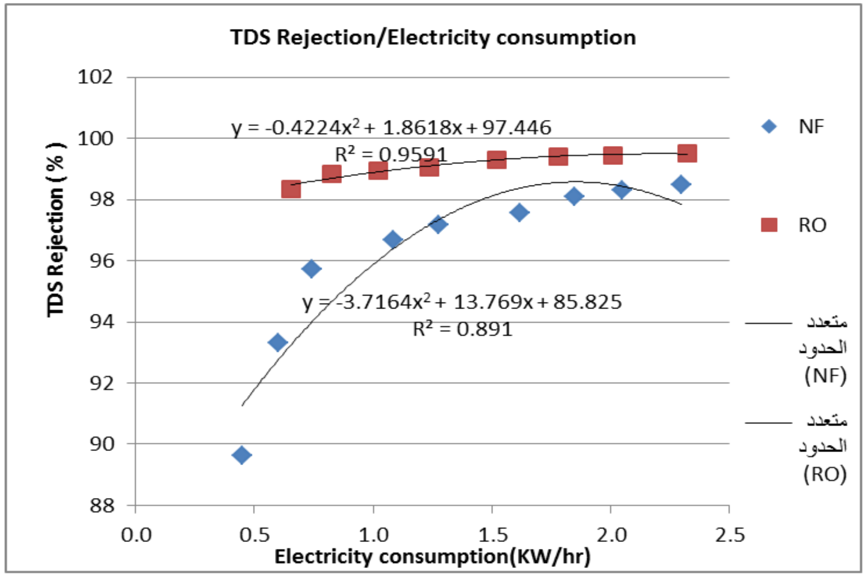

recovery rate
Recovery rate (%)
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
pressure (bar)
y = -0.122x² + 5.8303x - 12.826
R² = 0.9893
y = 1.9534x - 1.06
R² = 0.9136
◆ NF
■ Ro

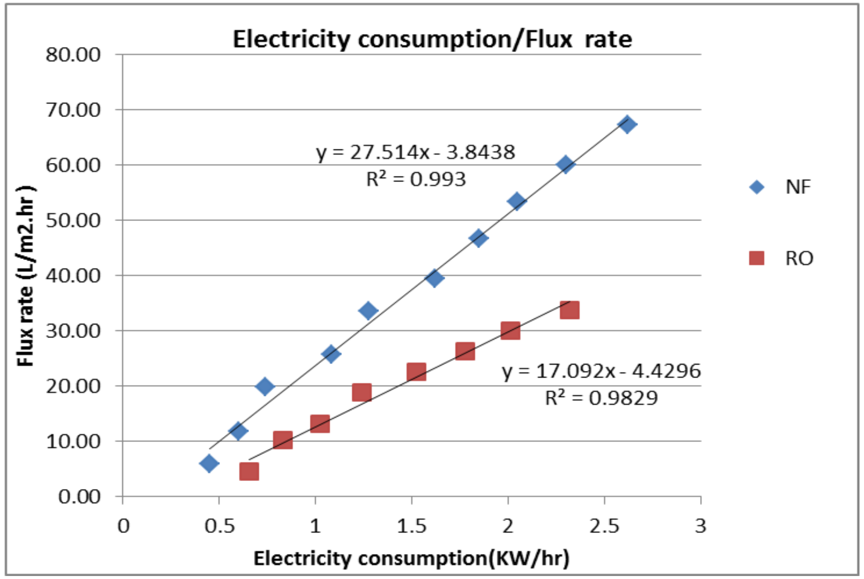

Nitrate Rejection
Nitrate Rejection %
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Pressure (bar)
y = -0.3662x² + 14.079x - 51.141
R² = 0.9453
y = -0.07x² + 2.9407x + 66.463
R² = 0.9108
◆ NF
■ RO

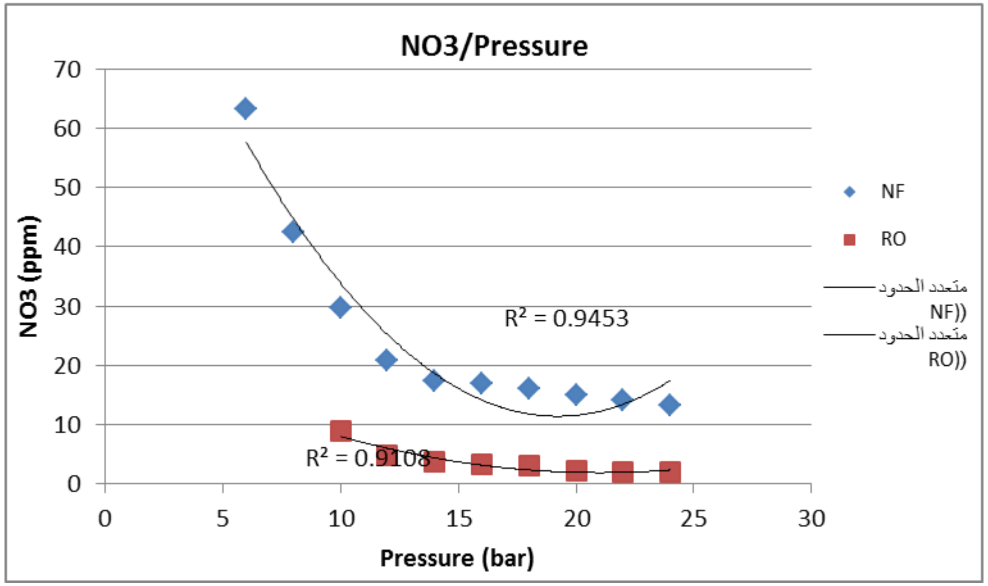

TDS Rejection
TDS Rejection %
102
100
98
96
94
92
90
88
0
5
10
15
20
25
30
pressure (bar)
y = -0.042x² + 1.6664x + 82.19
R² = 0.9483
y = -0.005x² + 0.2442x + 96.493
R² = 0.9716
◆ NF
■ RO

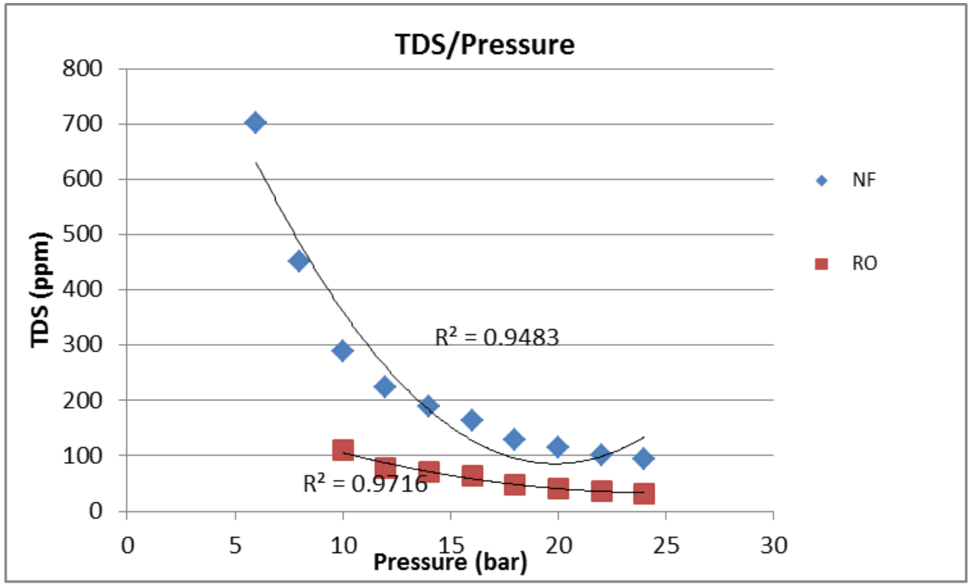

Chloride Rejection
Chloride Rejection %
Pressure (bar)
102
100
98
96
94
92
90
88
0
5
10
15
20
25
30
R² = 0.9854
R² = 0.9164
N
F


Electricity consumption/Recovery rate
Recovery rate(%)
Electricity consumption (KW/hr)
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
2.5
R² = 0.9592
R² = 0.9684
NF
RO


TDS Rejection/Electricity consumption
TDS Rejection (%)
Electricity consumption(KW/hr)
102
100
98
96
94
92
90
88
0.0
0.5
1.0
1.5
2.0
2.5
y = -0.4224x² + 1.8618x + 97.446
R² = 0.9591
y = -3.7164x² + 13.769x + 85.825
R² = 0.891
NF
RO
متعدد الحدود (NF)
متعدد الحدود (RO)

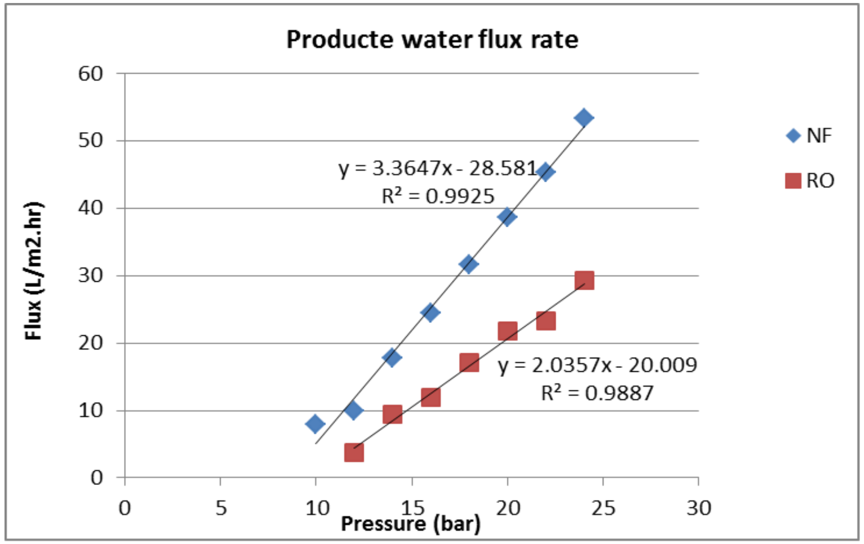

Electricity consumption/Flux rate
Flux rate (L/m2.hr)
Electricity consumption(KW/hr)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
0.5
1
1.5
2
2.5
3
y = 27.514x - 3.8438
R² = 0.993
y = 17.092x - 4.4296
R² = 0.9829
NF
RO

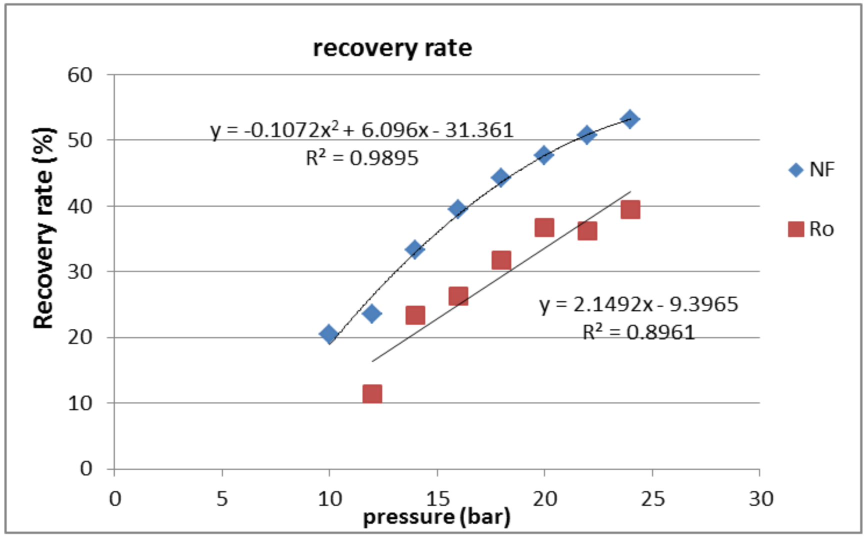

NO3/Pressure
NO3 (ppm)
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.9453
R² = 0.9108
NF
RO
متعدد الحدود (NF)
متعدد الحدود (RO)

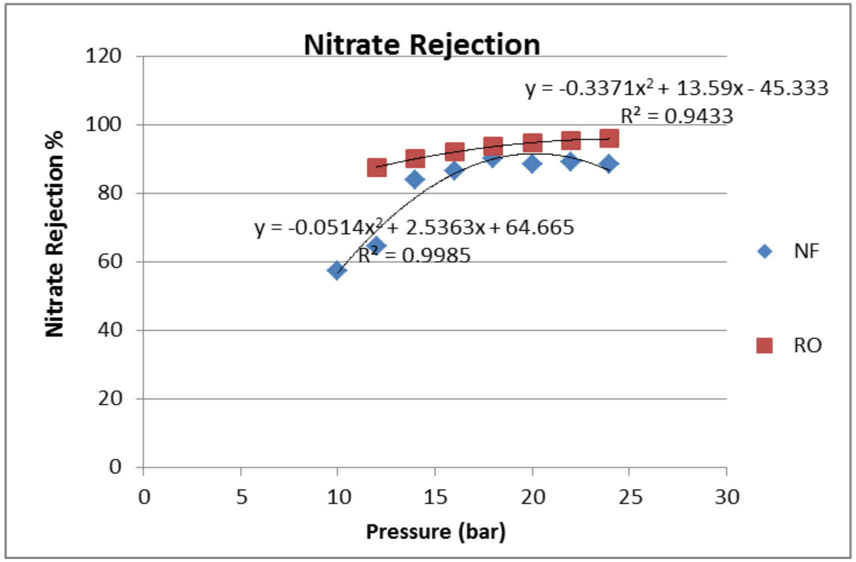

TDS/Pressure
TDS (ppm)
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.9483
R² = 0.9716
NF
RO

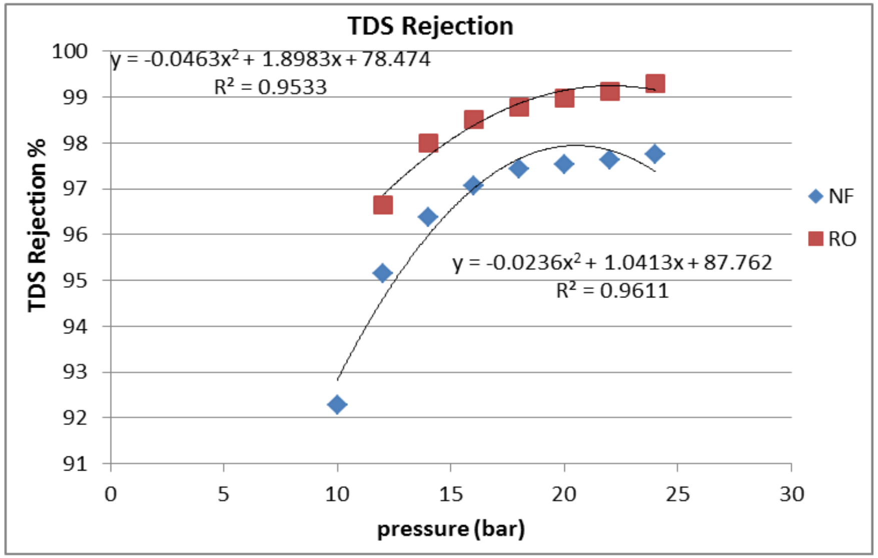
well Name	Amen Am	**Time**	**10 min**	**Membrane**		**NF**	**Temperature**		**16C**	**Date**	**05/02/2014**	
TDS	**9281**	**NO3**	**113**	**Chloride**		**4914**	**PH**		**7.14**	**membrane area**	**15.2**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
10	**2**	**7.8**	**0.24**	**716**	**48**	**354**	**5.16**	**20.41**	**92.29**	**57.52**	**92.80**	**7.89**
12	**2.5**	**8.1**	**0.76**	**451**	**40**	**226**	**6.04**	**23.58**	**95.14**	**64.60**	**95.40**	**9.87**
14	**4.5**	**9**	**0.97**	**337**	**18**	**163**	**6.2**	**33.33**	**96.37**	**84.07**	**96.68**	**17.76**
16	**6.2**	**9.5**	**1.19**	**272**	**15**	**127**	**5.71**	**39.49**	**97.07**	**86.73**	**97.42**	**24.47**
18	**8**	**10.1**	**1.42**	**239**	**11**	**113**	**6.07**	**44.20**	**97.42**	**90.27**	**97.70**	**31.58**
20	**9.8**	**10.8**	**1.68**	**229**	**13**	**106**	**6.02**	**47.57**	**97.53**	**88.50**	**97.84**	**38.68**
22	**11.5**	**11.2**	**1.97**	**220**	**12**	**147**	**7.8**	**50.66**	**97.63**	**89.38**	**97.01**	**45.39**
24	**13.5**	**11.9**	**2.31**	**208**	**13**	**126**	**7.05**	**53.15**	**97.76**	**88.50**	**97.44**	**53.29**

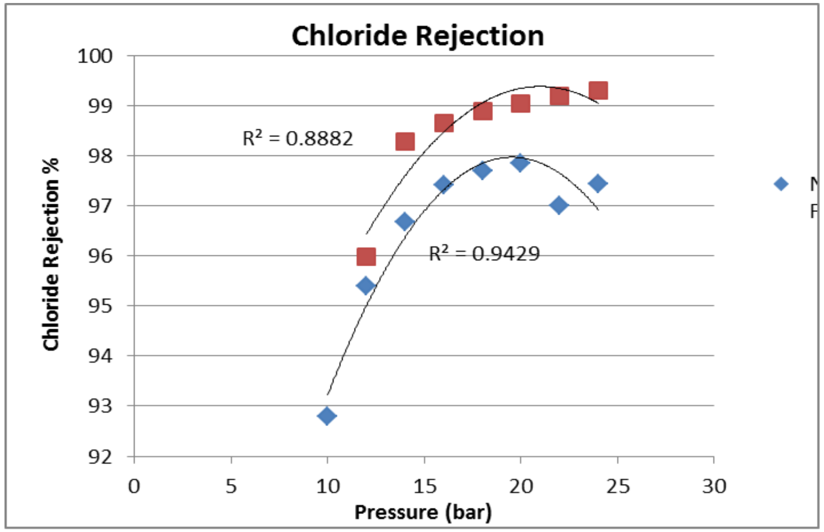
well Name	Amen Am	**Time**	**10 min**	**Membrane**		**RO**	**Temperature**		**16C**	**Date**	**03/02/2014**	
TDS	**9281**	**NO3**	**113**	**Chloride**		**4914**	**PH**		**7.14**	**membrane area**	**16**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
12	**1**	**7.8**	**0.71**	**311**	**14**	**198**	**5.83**	**11.36**	**96.65**	**87.61**	**95.97**	**3.75**
14	**2.5**	**8.2**	**0.91**	**187**	**11**	**85**	**6.24**	**23.36**	**97.99**	**90.27**	**98.27**	**9.38**
16	**3.2**	**9**	**1.07**	**138**	**9**	**67**	**6.02**	**26.23**	**98.51**	**92.04**	**98.64**	**12.00**
18	**4.55**	**9.8**	**1.30**	**112**	**7**	**55**	**5.91**	**31.71**	**98.79**	**93.81**	**98.88**	**17.06**
20	**5.8**	**10**	**1.52**	**94**	**6**	**47**	**5.85**	**36.71**	**98.99**	**94.69**	**99.04**	**21.75**
22	**6.2**	**10.9**	**1.78**	**80**	**5**	**40**	**5.6**	**36.26**	**99.14**	**95.58**	**99.19**	**23.25**
24	**7.8**	**12**	**2.04**	**65**	**4.5**	**35**	**5.5**	**39.39**	**99.30**	**96.02**	**99.29**	**29.25**

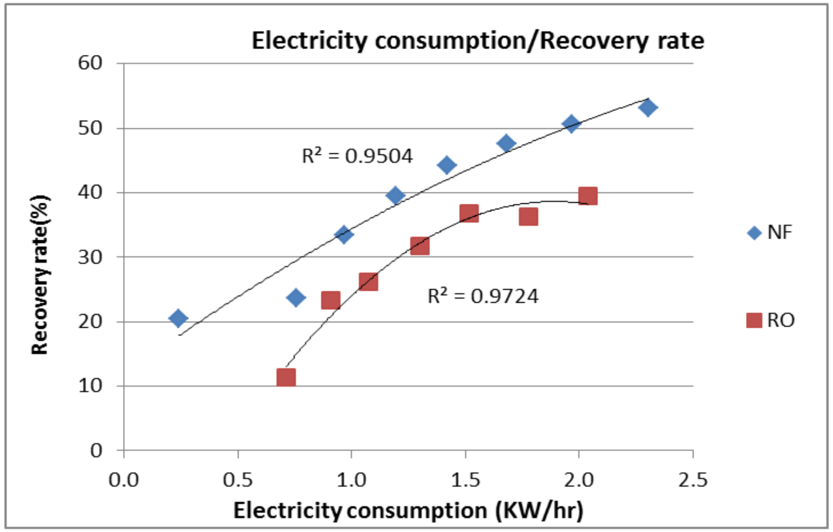

Producte water flux rate
Flux (L/m2.hr)
60
50
40
30
20
10
0
y = 3.3647x - 28.581
R² = 0.9925
y = 2.0357x - 20.009
R² = 0.9887
NF
RO
0
5
10
15
20
25
30
Pressure (bar)

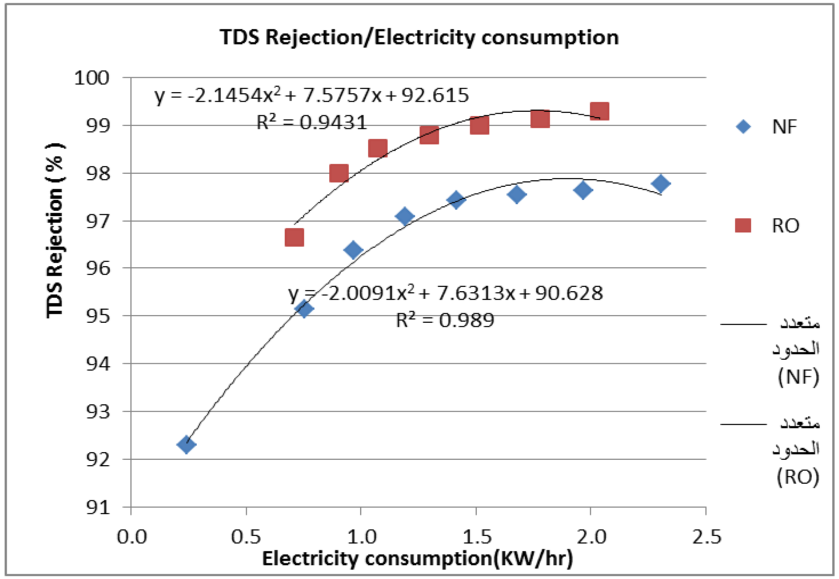

recovery rate
Recovery rate (%)
60
50
40
30
20
10
0
y = -0.1072x² + 6.096x - 31.361
R² = 0.9895
y = 2.1492x - 9.3965
R² = 0.8961
NF
Ro
0
5
10
15
20
25
30
pressure (bar)

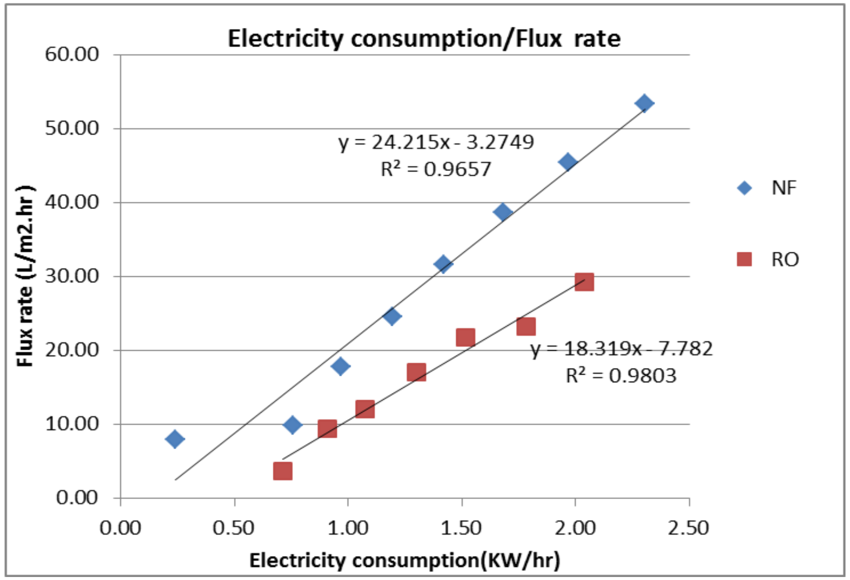

Nitrate Rejection
Nitrate Rejection %
120
100
80
60
40
20
0
y = -0.3371x² + 13.59x - 45.333
R² = 0.9433
y = -0.0514x² + 2.5363x + 64.665
R² = 0.9985
NF
RO
0
5
10
15
20
25
30
Pressure (bar)

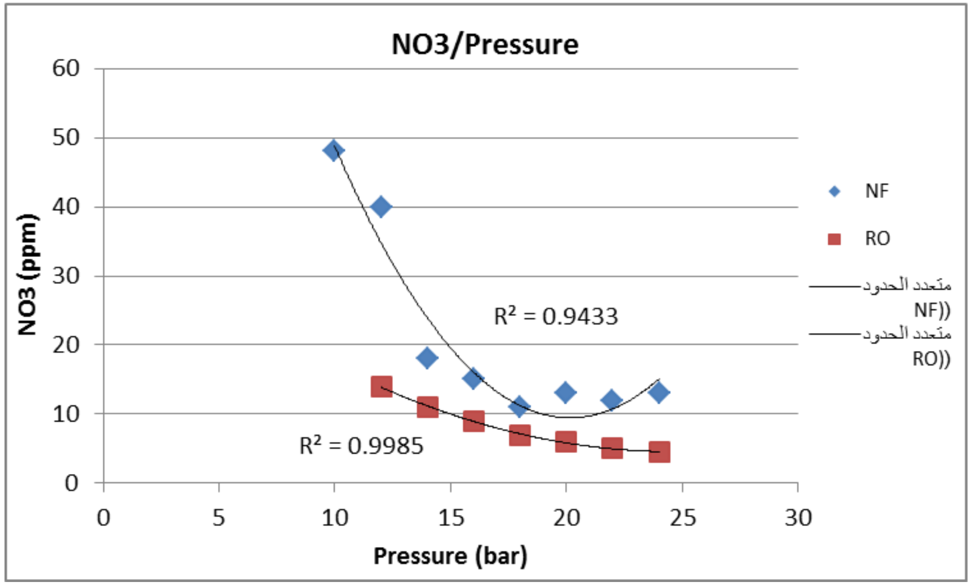

TDS Rejection
TDS Rejection %
100
99
98
97
96
95
94
93
92
91
y = -0.0463x² + 1.8983x + 78.474
R² = 0.9533
y = -0.0236x² + 1.0413x + 87.762
R² = 0.9611
NF
RO
0
5
10
15
20
25
30
pressure (bar)

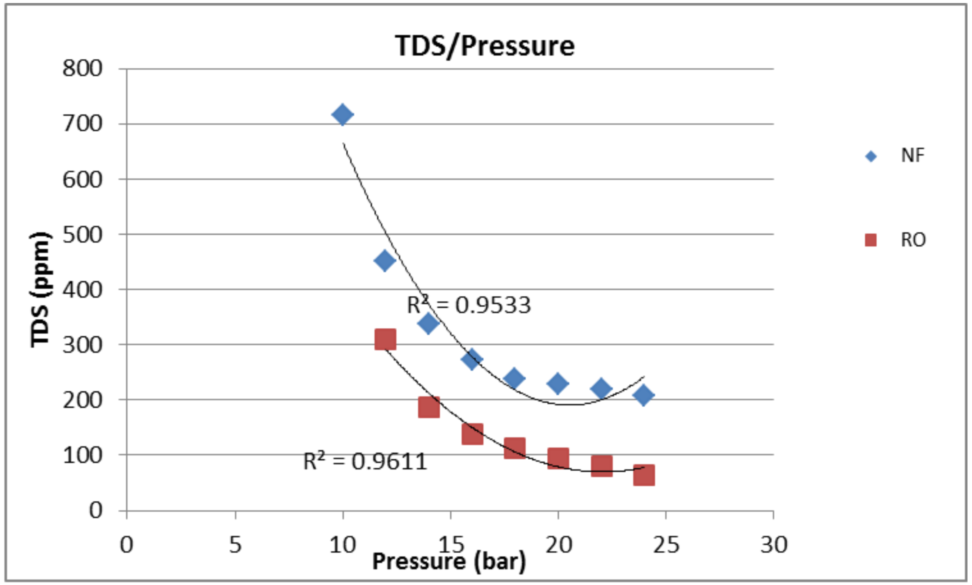

Chloride Rejection
Chloride Rejection %
100
99
98
97
96
95
94
93
92
R² = 0.8882
R² = 0.9429
0
5
10
15
20
25
30
Pressure (bar)
N
F


Electricity consumption/Recovery rate
Recovery rate(%)
60
50
40
30
20
10
0
R² = 0.9504
R² = 0.9724
0.0
0.5
1.0
1.5
2.0
2.5
Electricity consumption (KW/hr)
NF
RO


TDS Rejection/Electricity consumption
TDS Rejection (%)
100
99
98
97
96
95
94
93
92
91
y = -2.1454x² + 7.5757x + 92.615
R² = 0.9431
y = -2.0091x² + 7.6313x + 90.628
R² = 0.989
0.0
0.5
1.0
1.5
2.0
2.5
Electricity consumption(KW/hr)
NF
RO
متعدد الحدود (NF)
متعدد الحدود (RO)


Electricity consumption/Flux rate
Flux rate (L/m2.hr)
60.00
50.00
40.00
30.00
20.00
10.00
0.00
y = 24.215x - 3.2749
R² = 0.9657
y = 18.319x - 7.782
R² = 0.9803
0.00
0.50
1.00
1.50
2.00
2.50
Electricity consumption(KW/hr)
NF
RO


NO3/Pressure
NO3 (ppm)
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Pressure (bar)
NF
RO
متعدد الحدود NF))
متعدد الحدود RO))
R² = 0.9433
R² = 0.9985

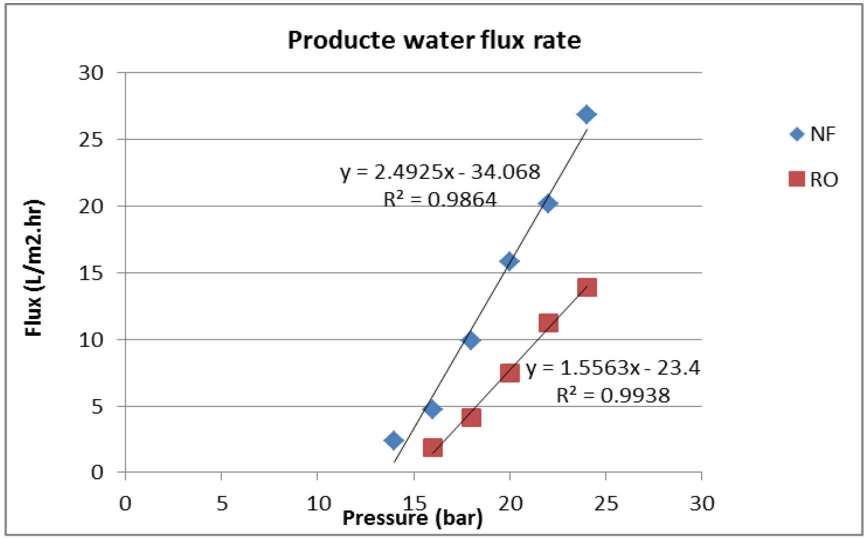

TDS/Pressure
TDS (ppm)
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
Pressure (bar)
NF
RO
R² = 0.9533
R² = 0.9611

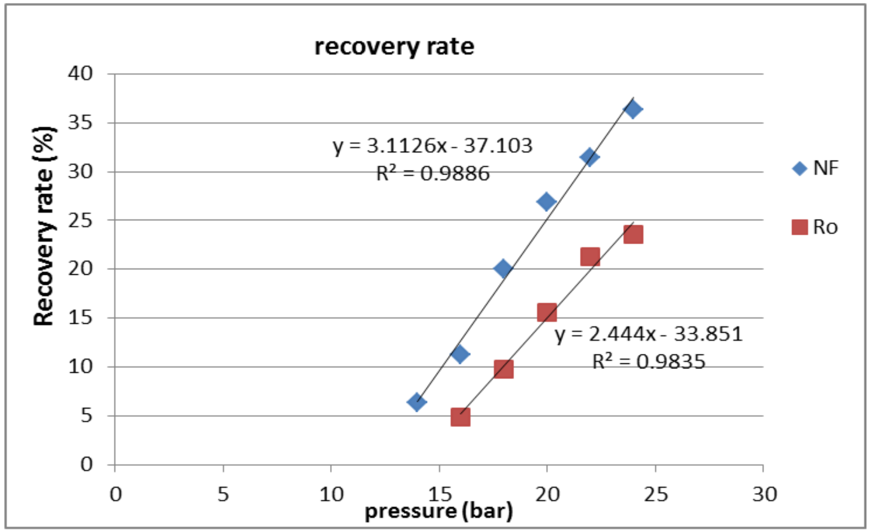
well Name	**Remal 3**	**Time**	**10 min**	**Membrane**	**NF**	**Temperature**	**16C**	**Date**	**12/02/2014**
TDS	**16492**	**NO3**	**99**	**Chloride**	**9191**	**PH**	**7.25**	**membrane area**	**15.2**

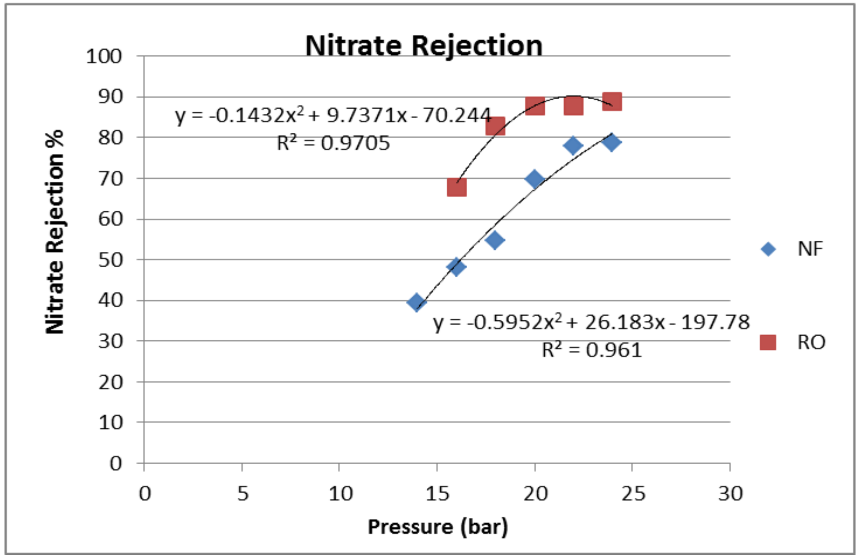
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
14	**0.6**	**8.9**	**1.14**	**3677**	**60**	**1874**	**6.06**	**6.32**	**77.70**	**39.39**	**79.61**	**2.37**
16	**1.2**	**9.5**	**1.27**	**2077**	**51**	**1108**	**6.5**	**11.21**	**87.41**	**48.23**	**87.94**	**4.74**
18	**2.5**	**10**	**1.55**	**1389**	**45**	**724**	**6.47**	**20.00**	**91.58**	**54.55**	**92.12**	**9.87**
20	**4**	**10.9**	**1.70**	**1066**	**30**	**540**	**4.56**	**26.85**	**93.54**	**69.70**	**94.12**	**15.79**
22	**5.1**	**11.1**	**1.93**	**847**	**22**	**424**	**6.26**	**31.48**	**94.86**	**77.78**	**95.39**	**20.13**
24	**6.8**	**11.9**	**2.25**	**717**	**21**	**382**	**6.45**	**36.36**	**95.65**	**78.79**	**95.84**	**26.84**

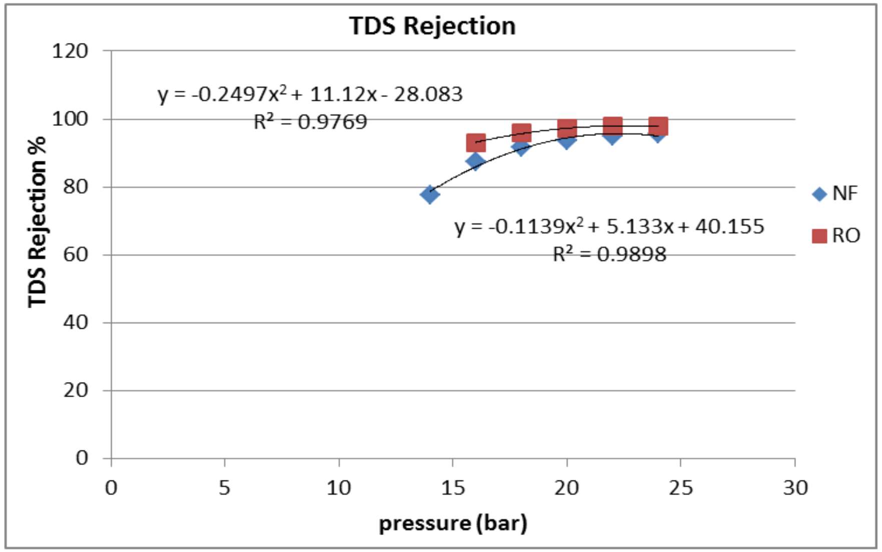
well Name	**Remal 3**	**Time**	**10 min**	**Membrane**	**RO**	**Temperature**	**16C**	**Date**	**11/02/2014**
TDS	**16492**	**NO3**	**99**	**Chloride**	**9191**	**PH**	**7.25**	**membrane area**	**16**

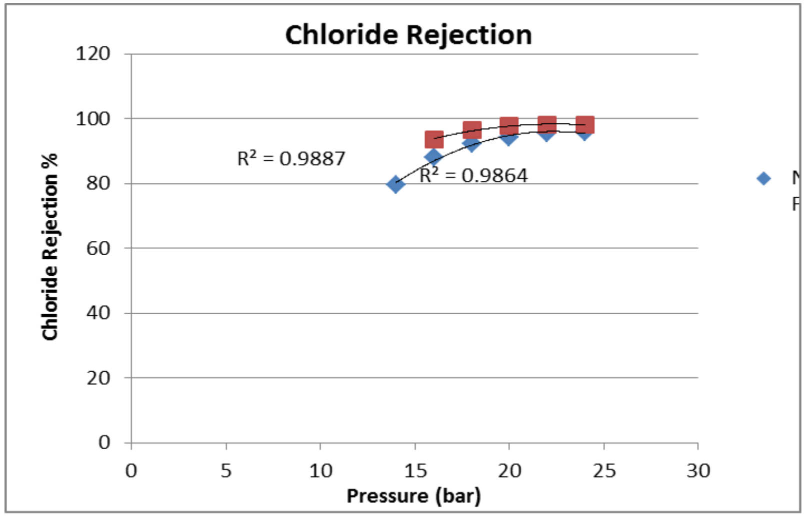
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
16	**0.5**	**9.8**	**1.20**	**1157**	**32**	**582**	**6.53**	**4.85**	**92.98**	**67.68**	**93.67**	**1.88**
18	**1.1**	**10.1**	**1.45**	**669**	**17**	**327**	**6.47**	**9.82**	**95.94**	**82.83**	**96.44**	**4.13**
20	**2**	**10.8**	**1.61**	**466**	**12**	**220**	**6.34**	**15.63**	**97.17**	**87.88**	**97.61**	**7.50**
22	**3**	**11.1**	**1.85**	**371**	**12**	**178**	**4.89**	**21.28**	**97.75**	**87.88**	**98.06**	**11.25**
24	**3.7**	**12**	**2.14**	**355**	**11**	**170**	**5.42**	**23.57**	**97.85**	**88.89**	**98.15**	**13.88**

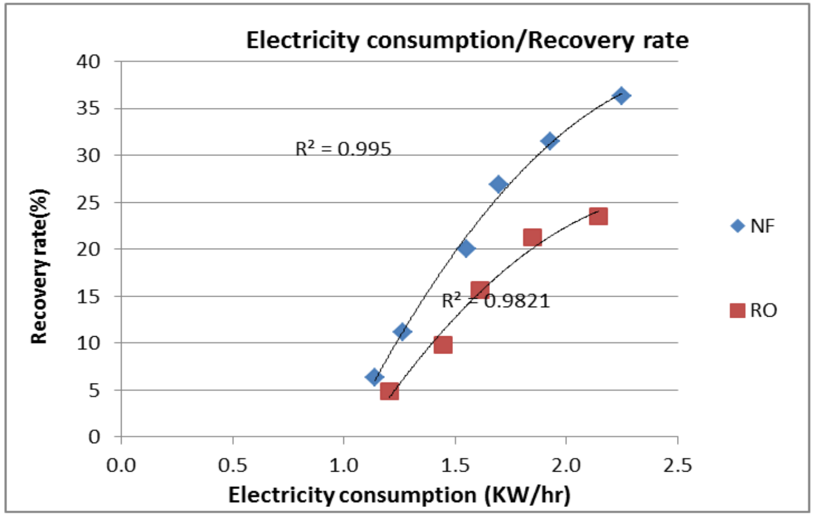

Producte water flux rate
Flux (L/m2.hr)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Pressure (bar)
y = 2.4925x - 34.068
R² = 0.9864
y = 1.5563x - 23.4
R² = 0.9938
NF
RO

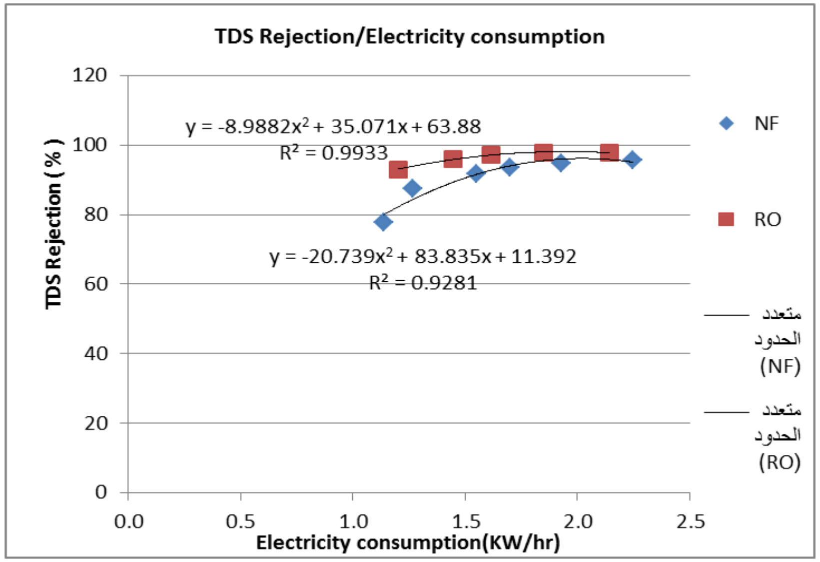

recovery rate
Recovery rate (%)
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
pressure (bar)
y = 3.1126x - 37.103
R² = 0.9886
y = 2.444x - 33.851
R² = 0.9835
NF
Ro

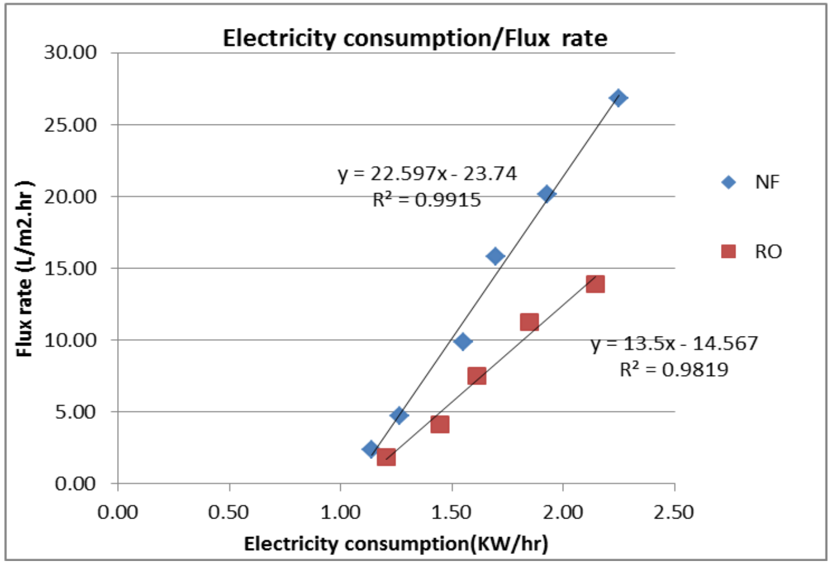

Nitrate Rejection
Nitrate Rejection %
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Pressure (bar)
y = -0.1432x² + 9.7371x - 70.244
R² = 0.9705
y = -0.5952x² + 26.183x - 197.78
R² = 0.961
NF
RO

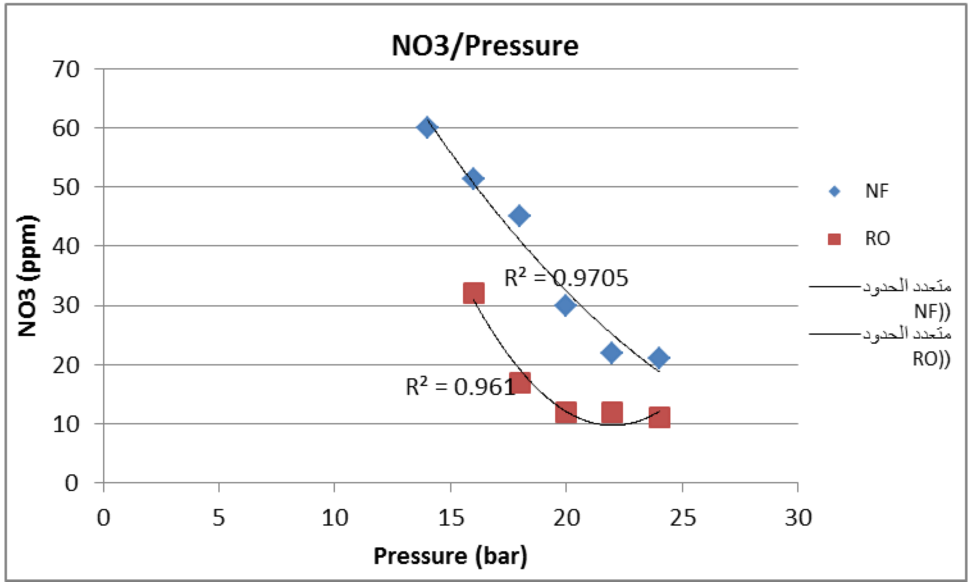

TDS Rejection
TDS Rejection %
120
100
80
60
40
20
0
0
5
10
15
20
25
30
pressure (bar)
y = -0.2497x² + 11.12x - 28.083
R² = 0.9769
y = -0.1139x² + 5.133x + 40.155
R² = 0.9898
NF
RO

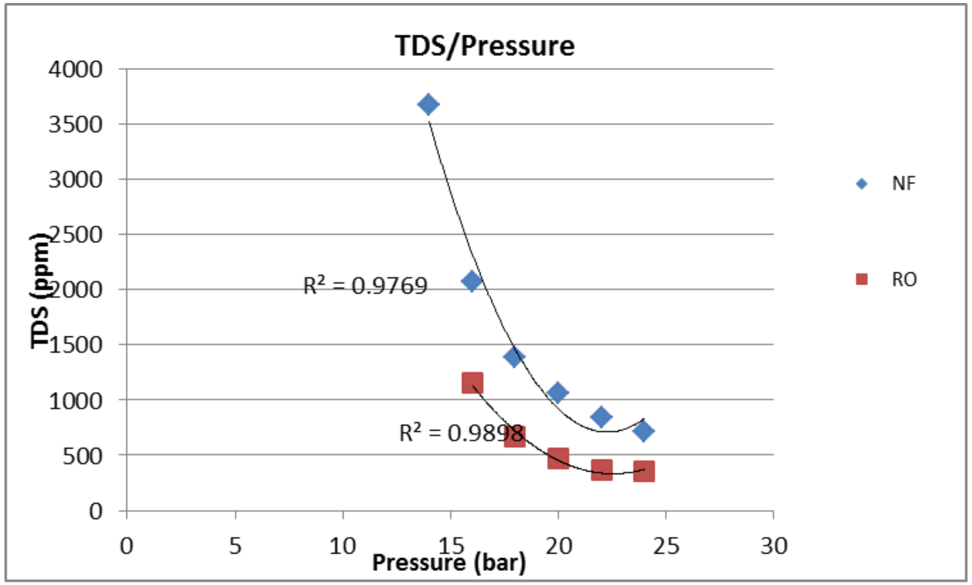

Chloride Rejection
Chloride Rejection %
Pressure (bar)
0
20
40
60
80
100
120
0
5
10
15
20
25
30
R² = 0.9887
R² = 0.9864


Electricity consumption/Recovery rate
Recovery rate(%)
Electricity consumption (KW/hr)
0
5
10
15
20
25
30
35
40
0.0
0.5
1.0
1.5
2.0
2.5
R² = 0.995
R² = 0.9821
◆ NF
■ RO


TDS Rejection/Electricity consumption
TDS Rejection (%)
Electricity consumption(KW/hr)
0
20
40
60
80
100
120
0.0
0.5
1.0
1.5
2.0
2.5
y = -8.9882x² + 35.071x + 63.88
R² = 0.9933
y = -20.739x² + 83.835x + 11.392
R² = 0.9281
◆ NF
■ RO
متعدد الحدود (NF)
متعدد الحدود (RO)

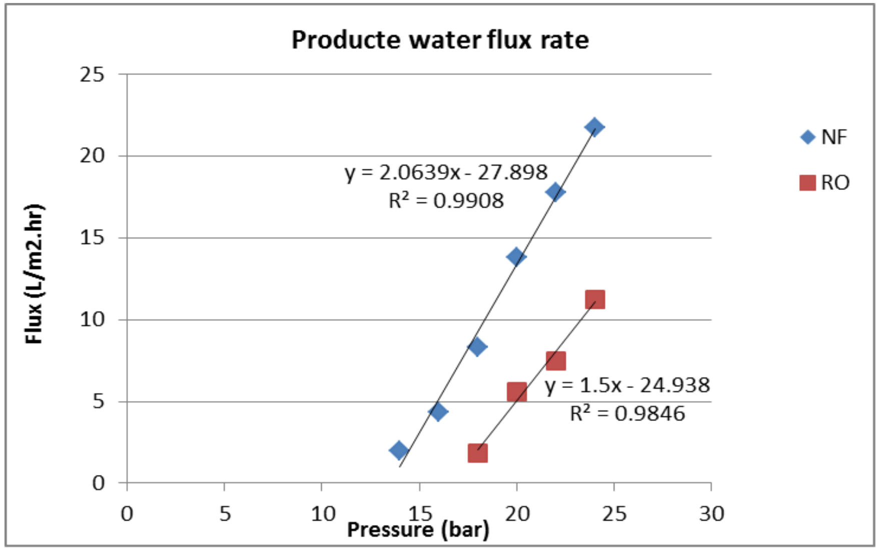

Electricity consumption/Flux rate
Flux rate (L/m2.hr)
Electricity consumption(KW/hr)
0.00
5.00
10.00
15.00
20.00
25.00
30.00
0.00
0.50
1.00
1.50
2.00
2.50
y = 22.597x - 23.74
R² = 0.9915
y = 13.5x - 14.567
R² = 0.9819
◆ NF
■ RO

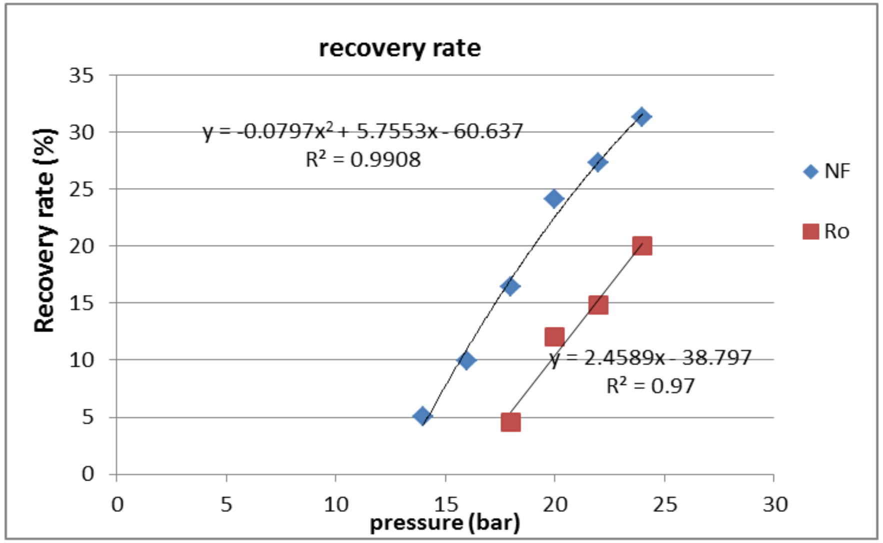

NO3/Pressure
NO3 (ppm)
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.9705
R² = 0.961
NF
RO
متعدد الحدود (NF)
متعدد الحدود (RO)

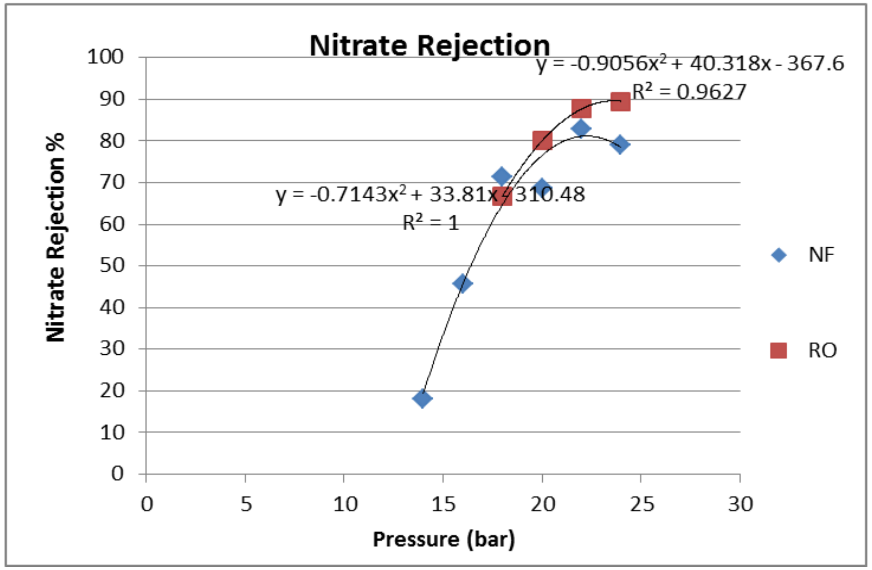

TDS/Pressure
TDS (ppm)
4000
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.9769
R² = 0.9898
NF
RO

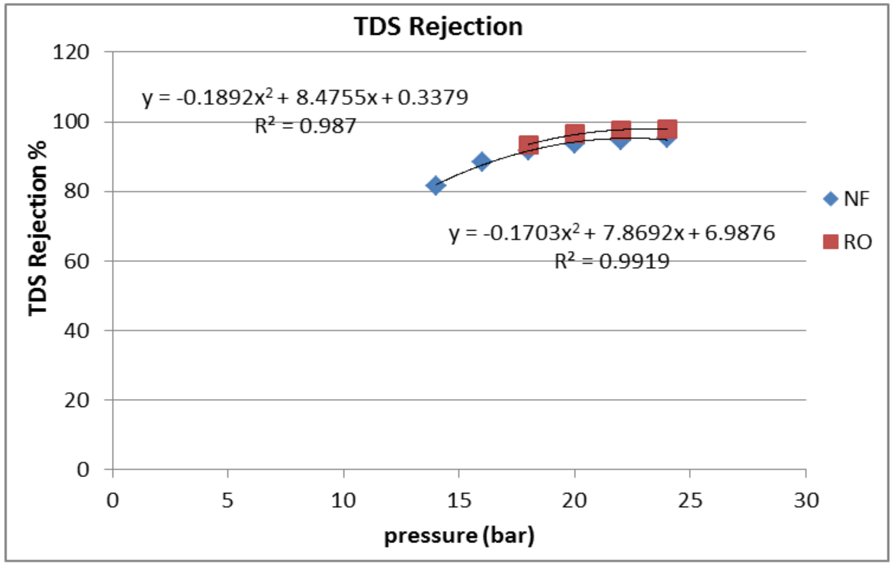
well Name	Redwan 5	**Time**	**10 min**	**Membrane**		**NF**	**Temperature**		**16C**	**Date**	**06/02/2013**	
TDS	**19964**	**NO3**	**105**	**Chloride**		**11418**	**PH**		**6.91**	**membrane area**	**15.2**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
14	**0.5**	**9.4**	**0.88**	**3721**	**86**	**2036**	**5.91**	**5.05**	**81.36**	**18.10**	**82.17**	**1.97**
16	**1.1**	**10**	**1.06**	**2325**	**57**	**1237**	**5.35**	**9.91**	**88.35**	**45.71**	**89.17**	**4.34**
18	**2.1**	**10.7**	**1.28**	**1637**	**30**	**855**	**4.89**	**16.41**	**91.80**	**71.43**	**92.51**	**8.29**
20	**3.5**	**11**	**1.51**	**1245**	**33**	**665**	**6.41**	**24.14**	**93.76**	**68.57**	**94.18**	**13.82**
22	**4.5**	**12**	**1.74**	**1079**	**18**	**551**	**4.99**	**27.27**	**94.60**	**82.86**	**95.17**	**17.76**
24	**5.5**	**12.1**	**2.02**	**958**	**22**	**488**	**6.42**	**31.25**	**95.20**	**79.05**	**95.73**	**21.71**

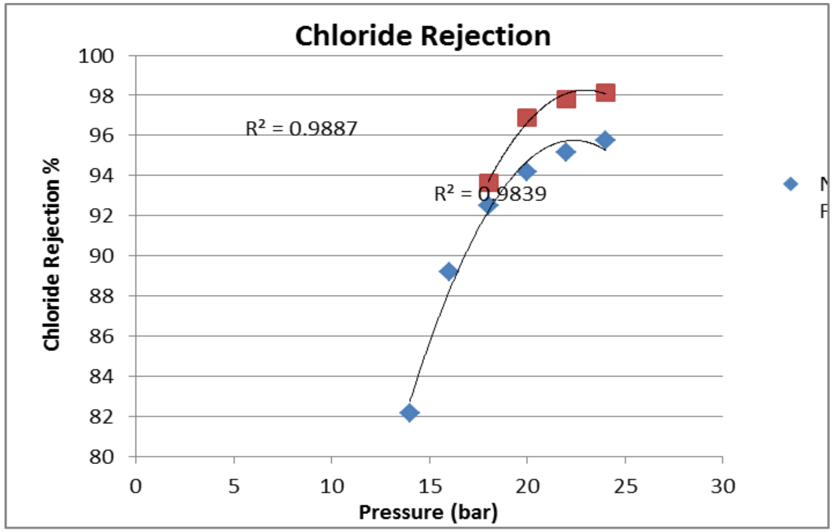
well Name	Redwan 5	**Time**	**10 min**	**Membrane**		**RO**	**Temperature**		**16C**	**Date**	**03/02/2014**	
TDS	**19964**	**NO3**	**105**	**Chloride**		**11418**	**PH**		**6.91**	**membrane area**	**16**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
18	**0.5**	**10.5**	**1.20**	**1321**	**35**	**728**	**5.64**	**4.55**	**93.38**	**66.67**	**93.62**	**1.88**
20	**1.5**	**11**	**1.39**	**707**	**21**	**354**	**6.05**	**12.00**	**96.46**	**80.00**	**96.90**	**5.63**
22	**2**	**11.5**	**1.64**	**505**	**13**	**247**	**5.19**	**14.81**	**97.47**	**87.62**	**97.84**	**7.50**
24	**3**	**12**	**1.90**	**435**	**11**	**212**	**5.24**	**20.00**	**97.82**	**89.52**	**98.14**	**11.25**

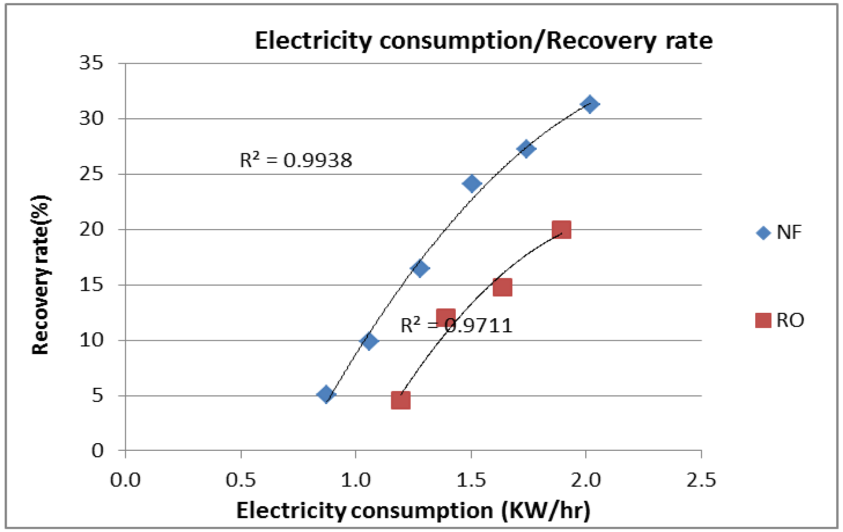

Producte water flux rate
Flux (L/m2.hr)
Pressure (bar)
0
5
10
15
20
25
0
5
10
15
20
25
30
◆ NF
■ RO
y = 2.0639x - 27.898
R² = 0.9908
y = 1.5x - 24.938
R² = 0.9846

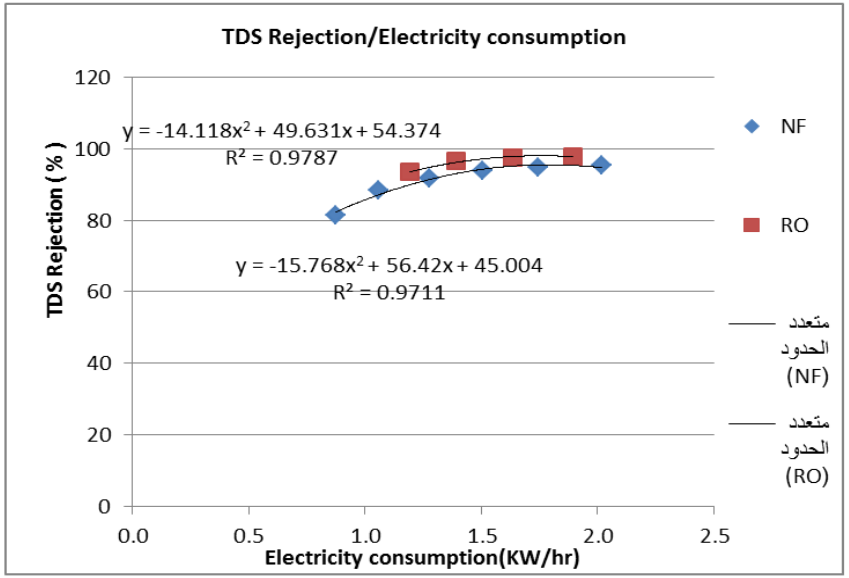

recovery rate
Recovery rate (%)
pressure (bar)
0
5
10
15
20
25
30
35
0
5
10
15
20
25
30
◆ NF
■ Ro
y = -0.0797x² + 5.7553x - 60.637
R² = 0.9908
y = 2.4589x - 38.797
R² = 0.97

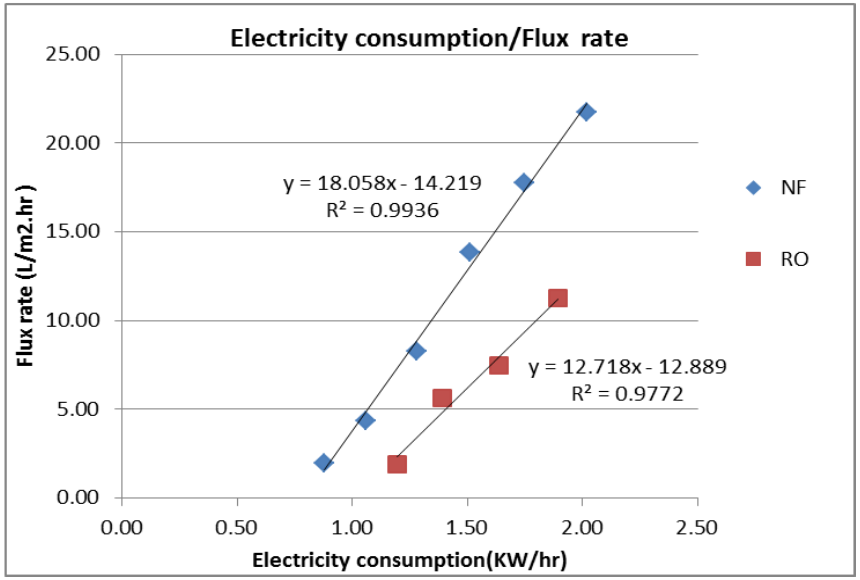

Nitrate Rejection
Nitrate Rejection %
Pressure (bar)
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
◆ NF
■ RO
y = -0.9056x² + 40.318x - 367.6
R² = 0.9627
y = -0.7143x² + 33.81x - 310.48
R² = 1

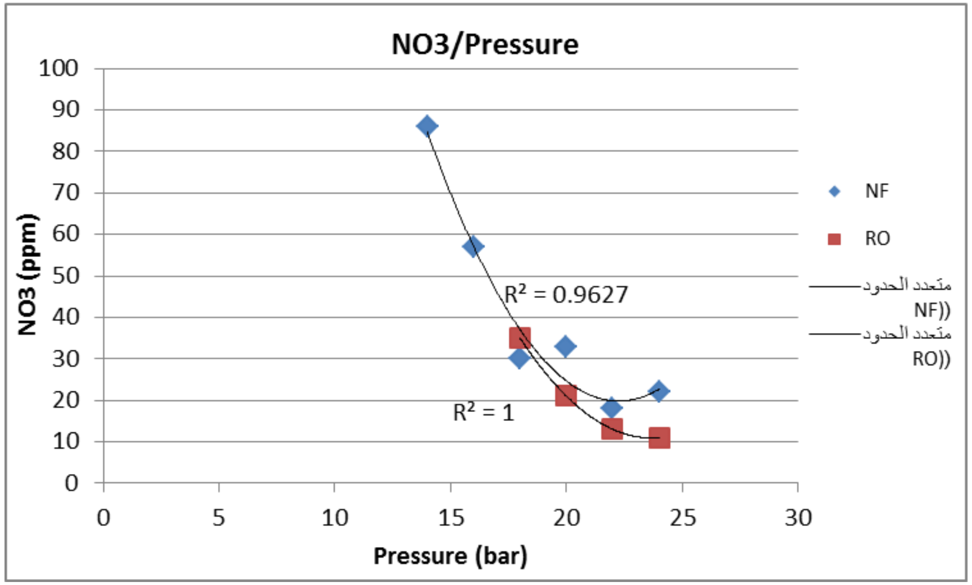

TDS Rejection
TDS Rejection %
pressure (bar)
0
20
40
60
80
100
120
0
5
10
15
20
25
30
◆ NF
■ RO
y = -0.1892x² + 8.4755x + 0.3379
R² = 0.987
y = -0.1703x² + 7.8692x + 6.9876
R² = 0.9919

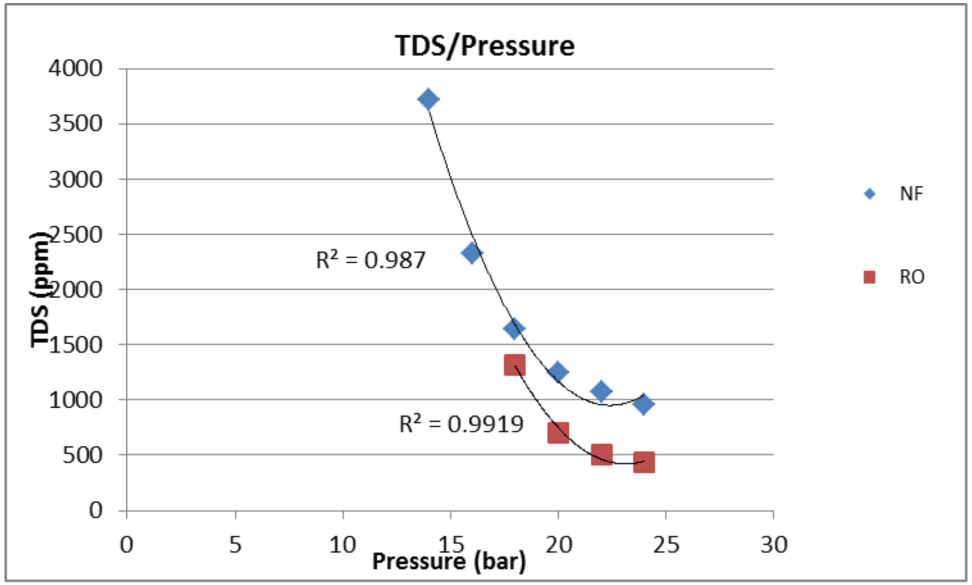

Chloride Rejection
Chloride Rejection %
100
98
96
94
92
90
88
86
84
82
80
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.9887
R² = 0.9839
N
F


Electricity consumption/Recovery rate
Recovery rate(%)
35
30
25
20
15
10
5
0
0.0
0.5
1.0
1.5
2.0
2.5
Electricity consumption (KW/hr)
R² = 0.9938
R² = 0.9711
NF
RO


TDS Rejection/Electricity consumption
TDS Rejection (%)
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
2.5
Electricity consumption(KW/hr)
y = -14.118x² + 49.631x + 54.374
R² = 0.9787
y = -15.768x² + 56.42x + 45.004
R² = 0.9711
NF
RO
متعدد الحدود (NF)
متعدد الحدود (RO)


Electricity consumption/Flux rate
Flux rate (L/m2.hr)
25.00
20.00
15.00
10.00
5.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
Electricity consumption(KW/hr)
y = 18.058x - 14.219
R² = 0.9936
y = 12.718x - 12.889
R² = 0.9772
NF
RO

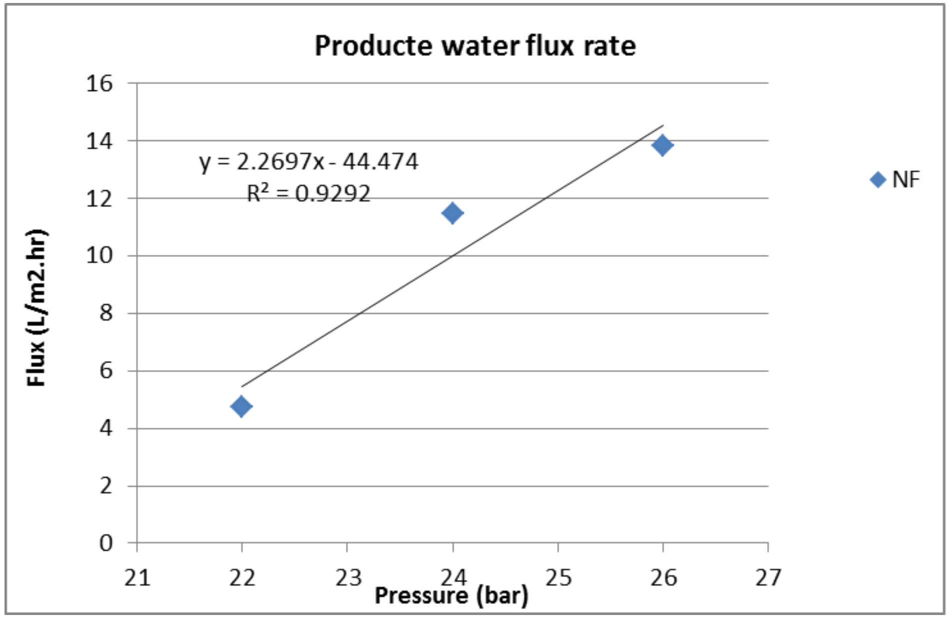

NO3/Pressure
NO3 (ppm)
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.9627
R² = 1
NF
RO
متعدد الحدود (NF)
متعدد الحدود (RO)

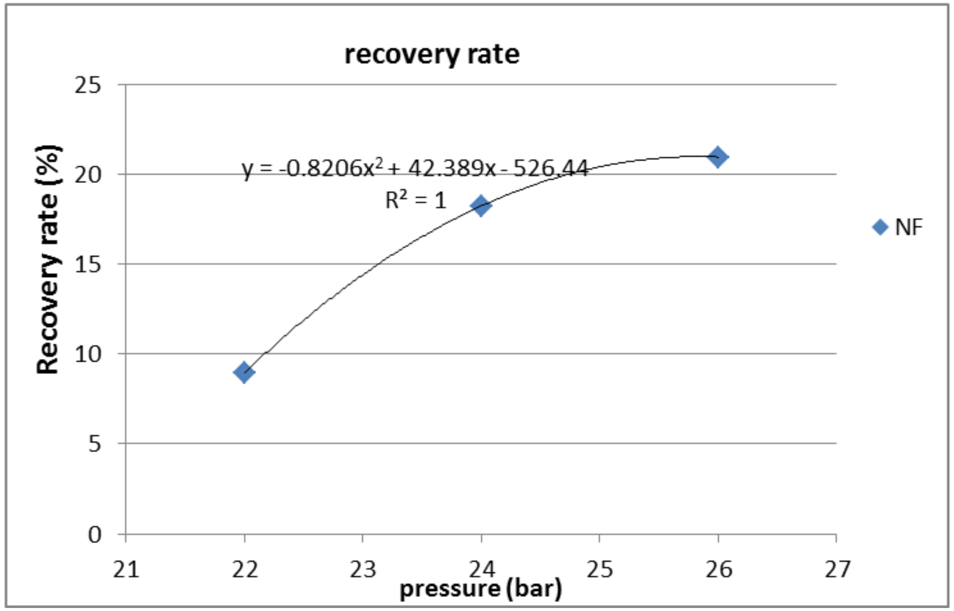

TDS/Pressure
TDS (ppm)
4000
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 0.987
R² = 0.9919
NF
RO

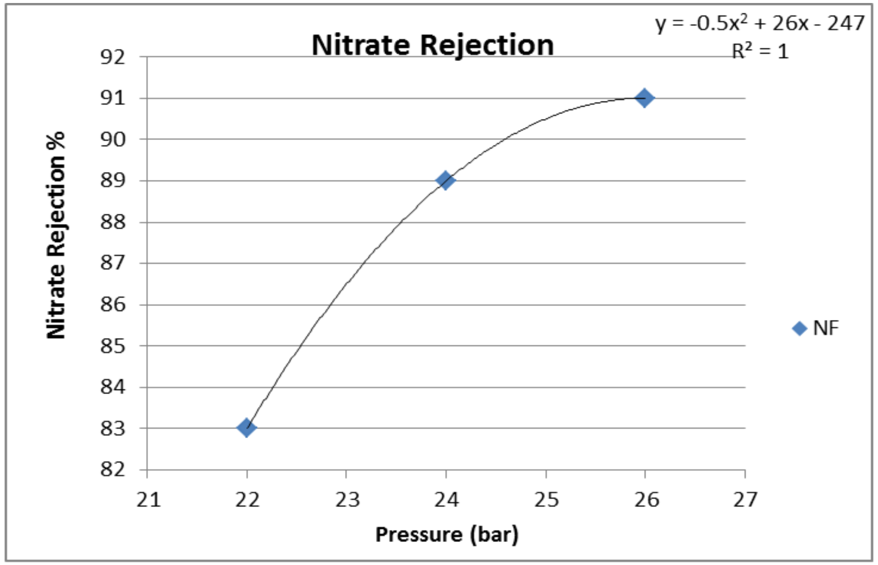
APPENDIX (3)

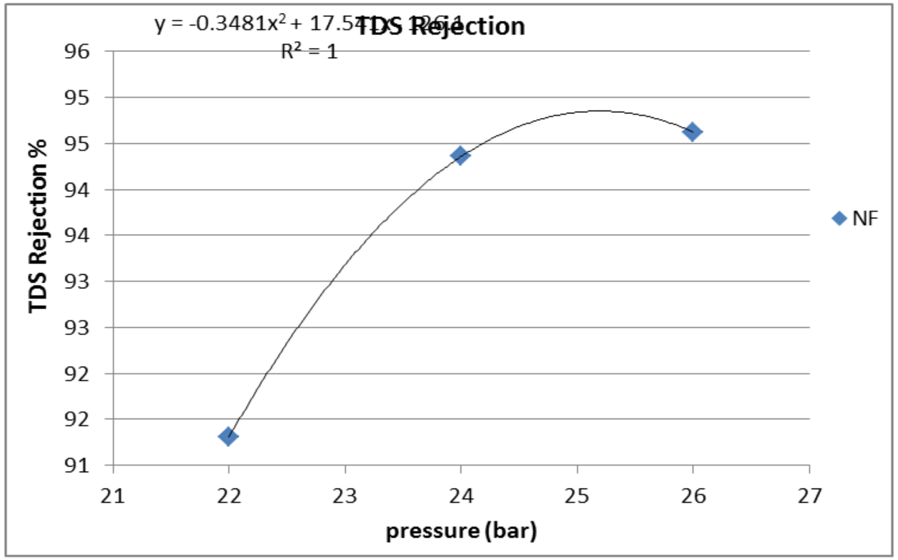
Sea water result

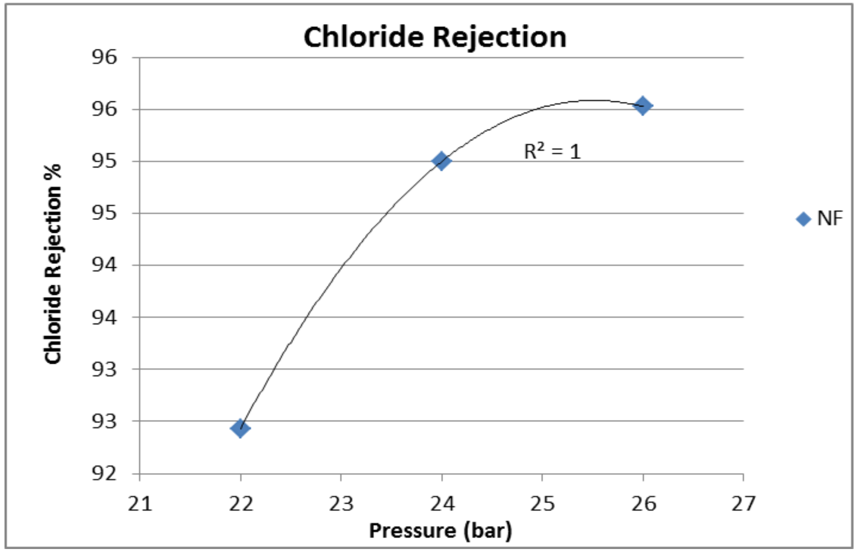
well Name	**Sea**	**Time**	**10 min**	**Membrane**		**NF**	**Temperature**		**16C**	**Date**	**12/03/2014**	
TDS	**34720**	**NO3**	**10**	**Chloride**		**21584**	**PH**		**7.87**	**membrane area**	**15.2**	
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	TDS	NO3	Chloride	PH	Recovery rate	Rejection rate (TDS)	Rejection rate (NO3)	Rejection rate(cl)	Flux L/(m2.hr)
22	**1.2**	**12.2**	**1.66**	**3019**	**1.7**	**1633**	**6.72**	**8.96**	**91.30**	**83.00**	**92.43**	**4.74**
24	**2.9**	**13**	**1.88**	**1959**	**1.1**	**1079**	**6.33**	**18.24**	**94.36**	**89.00**	**95.00**	**11.45**
26	**3.5**	**13.2**	**2.22**	**1866**	**0.9**	**966**	**6.21**	**20.96**	**94.63**	**91.00**	**95.52**	**13.82**

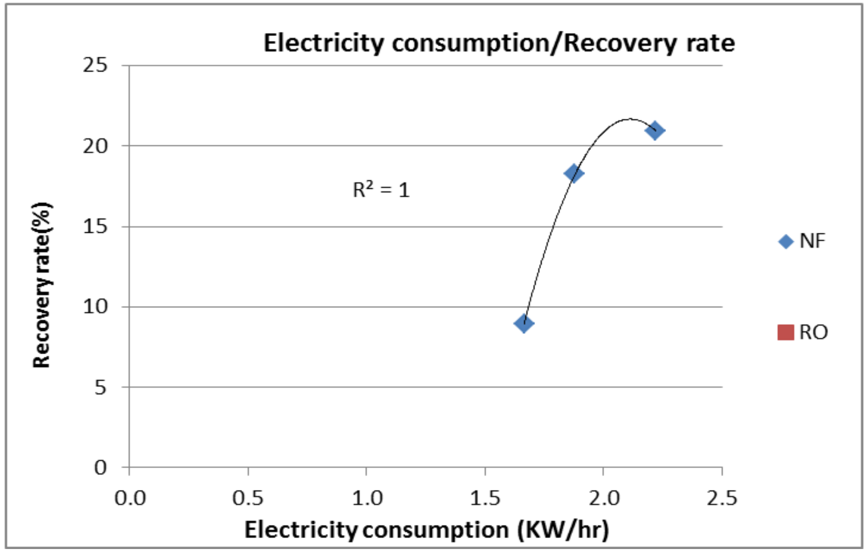

Producte water flux rate
Flux (L/m2.hr)
Pressure (bar)
y = 2.2697x - 44.474
R² = 0.9292
NF
0
2
4
6
8
10
12
14
16
21
22
23
24
25
26
27

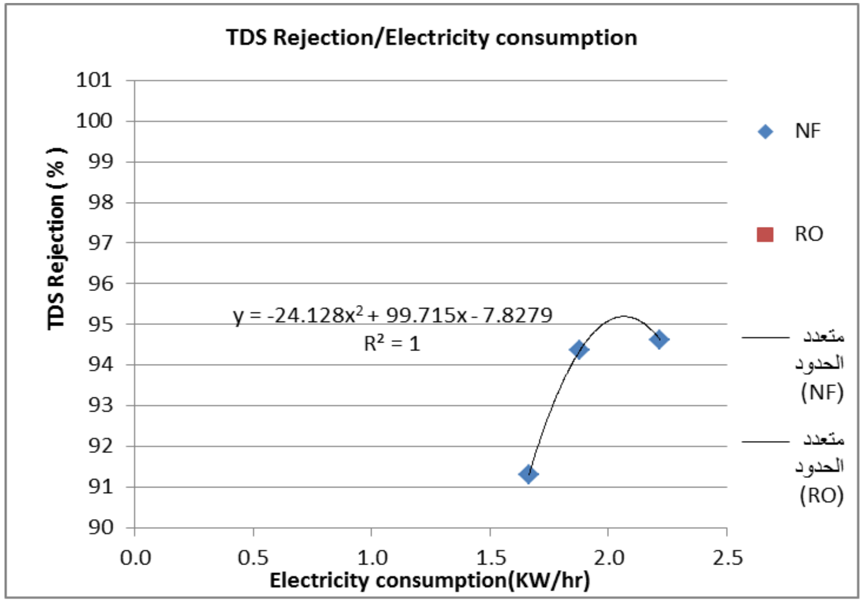

recovery rate
Recovery rate (%)
pressure (bar)
y = -0.8206x² + 42.389x - 526.44
R² = 1
NF
0
5
10
15
20
25
21
22
23
24
25
26
27

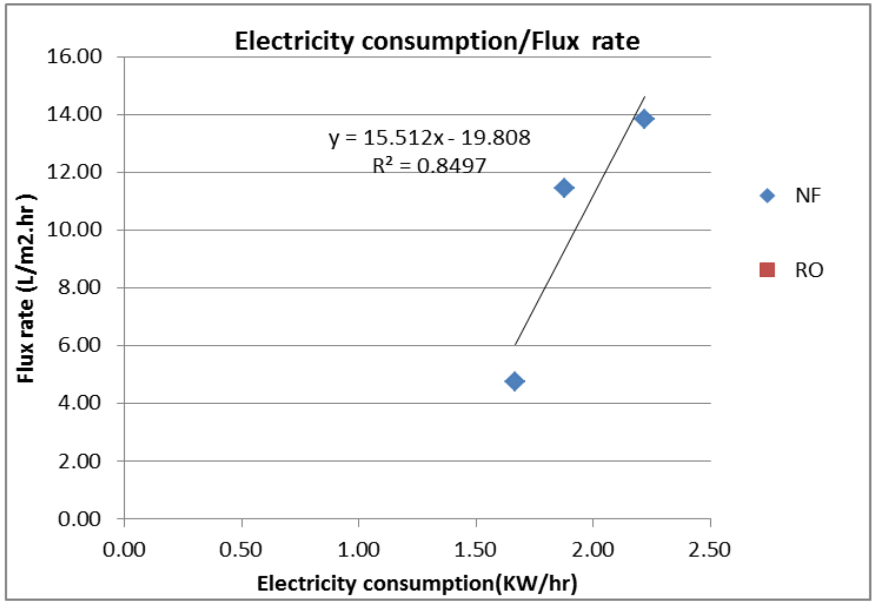

Nitrate Rejection
y = -0.5x² + 26x - 247
R² = 1
Nitrate Rejection %
92
91
90
89
88
87
86
85
84
83
82
21
22
23
24
25
26
27
Pressure (bar)
◆ NF

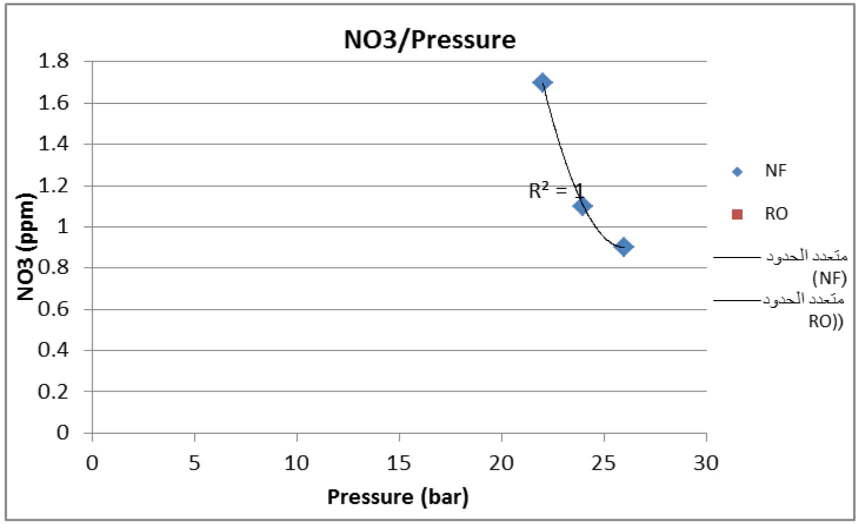

TDS Rejection
y = -0.3481x² + 17.54
R² = 1
TDS Rejection %
96
95
95
94
94
93
93
92
92
91
21
22
23
24
25
26
27
pressure (bar)
◆ NF

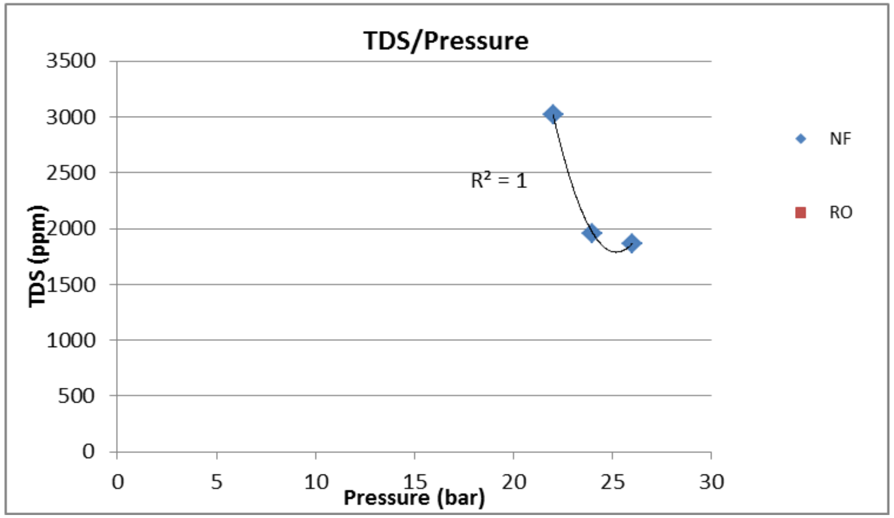

Chloride Rejection
R² = 1
Chloride Rejection %
96
96
95
95
94
94
93
93
92
21
22
23
24
25
26
27
Pressure (bar)
◆ NF


Electricity consumption/Recovery rate
R² = 1
Recovery rate(%)
25
20
15
10
5
0
0.0
0.5
1.0
1.5
2.0
2.5
Electricity consumption (KW/hr)
◆ NF
🟥 RO


TDS Rejection/Electricity consumption
TDS Rejection (%)
101
100
99
98
97
96
95
94
93
92
91
90
0.0
0.5
1.0
1.5
2.0
2.5
Electricity consumption(KW/hr)
y = -24.128x² + 99.715x - 7.8279
R² = 1
NF
RO
متعدد الحدود (NF)
متعدد الحدود (RO)


Electricity consumption/Flux rate
Flux rate (L/m2.hr)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
Electricity consumption(KW/hr)
y = 15.512x - 19.808
R² = 0.8497
NF
RO


NO3/Pressure
NO3 (ppm)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 1
NF
RO
متعدد الحدود (NF)
متعدد الحدود RO))

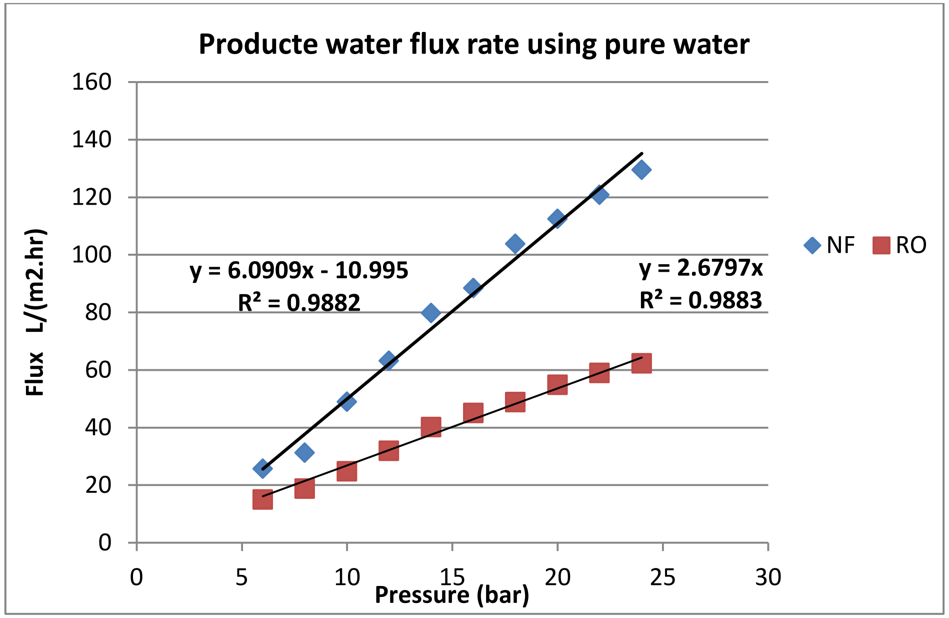

TDS/Pressure
TDS (ppm)
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
Pressure (bar)
R² = 1
NF
RO

APPENDIX (4)

Pure water result

well Name	pure water	**Time**	10 min	**membrane**
TDS	**0**	**NO3**	0	NF
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	Flux L/(m2.hr)
6	6.5	6.2	0.36	25.66
8	7.9	6.9	0.51	31.18
10	12.4	7.5	0.52	48.95
12	16	8.3	0.90	63.16
14	20.2	9.2	1.15	79.74
16	22.4	9.5	1.38	88.42
18	26.3	10.2	1.70	103.82
20	28.5	10.6	1.99	112.50
22	30.6	11.2	2.33	120.79
24	32.8	11.6	2.80	129.47

well Name	pure water	**Time**	10 min	**membrane**
TDS	0	**NO3**	0	RO
pressure bar	Flow rate (lpm) product	Flow rate (lpm) concentrate	Electricity consumption (kwh)	Flux L/(m2.hr)
6	4	6	0.27	15.00
8	5	7	0.46	18.75
10	6.6	7.8	0.58	24.75
12	8.5	8.2	0.78	31.88
14	10.7	9	0.98	40.13
16	12	9.8	1.19	45.00
18	13	10.2	1.45	48.75
20	14.6	10.9	1.71	54.75
22	15.7	11	2.00	58.88
24	16.6	11.9	2.21	62.25


Producte water flux rate using pure water
Flux L/(m2.hr)
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Pressure (bar)
y = 6.0909x - 10.995
R^2 = 0.9882
y = 2.6797x
R^2 = 0.9883
NF
RO

	Pressure									
TDS =6764 ppm	6	8	10	12	14	16	18	20	22	24
	Flux L/m^2.hr									
solution (NF)	23.68	31.58	39.47	47.37	55.26	63.16	71.05	78.95	86.84	94.74
solution (RO)	6.59	10.58	14.60	19.19	24.91	29.78	33.53	36.88	41.08	44.60
real water (NF)	5.92	11.84	19.74	25.66	33.55	39.47	46.58	53.29	60.00	67.11
real water (RO)			4.50	10.13	13.13	18.75	22.50	26.25	30.00	33.75