إقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Optimal Use of Nanofiltration for Nitrate Removal from Gaza Strip Municipal Wells

أقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وإن هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل درجة أو لقب علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

DECLARATION

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

Student's name:
اسم الطالب:أحمد مصطفى البهنساوي

Signature:
التوقيع:

Date:
التاريخ: ٢٠١٣/٦/١٥

Islamic University of Gaza
High Studies Deanship
Faculty of Engineering
Civil Engineering Department
Water Resources Engineering

الجامعة الإسلامية بغزة
عمادة الدراسات العليا
كلية الهندسة
قسم الهندسة المدنية
هندسة مصادر المياه

Optimal Use of Nanofiltration for Nitrate Removal from Gaza Strip Municipal Wells

Prepared by
Ahmed M. Albahnasawi

Supervised by
Dr. Yunes K. Mogheir

A Thesis Submitted In Partial Fulfillment of The Requirements for The Degree of Master of Science In Civil-Water Resources Engineering.

June 2013

بسم الله الرحمن الرحيم

الجامعة الإسلامية – غزة
The Islamic University - Gaza

عمادة الدراسات العليا
هاتف داخلي: 1150

الرقم ج س غ/35/ Ref
التاريخ 2013/06/08 Date

نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة عمادة الدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **أحمد مصطفى صالح البهنساوي** لنيل درجة الماجستير في **كلية *الهندسة*** **قسم الهندسة المدنية- هندسة مصادر المياه** وموضوعها:

Optimal Use of Nanofiltration for Nitrate Removal from Gaza Strip Municipal Wells

وبعد المناقشة العلنية التي تمت اليوم السبت 29 رجب 1434هـ، الموافق 2013/06/08 الساعة الواحدة والنصف ظهراً بمبني طيبة، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

د. يونس خليل المغير	**مشرفاً ورئيساً**	....
د. فهد خضر رباح	**مناقشاً داخلياً**	....
د. عزام أحمد أبو حبيب	**مناقشاً خارجيًا**	....

وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في **كلية *الهندسة*/** قسم **الهندسة المدنية- هندسة مصادر المياه.**

واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق،،،

عميد الدراسات العليا

أ.د. فؤاد علي العاجز

ABSTRACT

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 quality of the water extracted from the aquifer varies by area and time but in general does not satisfy the WHO guideline values for drinking water quality in terms of the 50 mg/L as NO_3. The nitrate sources in the groundwater of Gaza Strip are wastewater, septic tank, sewage sludge animal manure and N-fertilizer.

The aim of this study is to optimize the use of Nanofltraiton for removal of nitrate in Gaza Strip as case study. One commercial membrane (NF90) was used in this study. The stirred dead end flow model was used in addition, two types of water was used: Aqueous solution and real water. The performance of the tested membrane was measured in terms of flux rate and nitrate rejection under different operation conditions: nitrate concentration was varied between 50-400mg/L, applied pressure (6-12) bar and TDS concentration (500-3570) mg/l.

The results showed that, in aqueous solution, increasing operating pressure posed positive effects on both nitrate rejection and flux rate performance of nanofiltration. However, increasing the feed nitrate concentration reduced the rejection and flux performance. The percentage of nitrate removal was in the range of 21.67% and 66.68% and the flux rate range between 5.39 and 14.88- L/m^2.hr. These values depend on operation conditions such as nitrate concentration and operation pressure.

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. In addition, the flux rate influenced by TDS concentration and specific chloride concentration.

NF90 was observed to be an effective membrane for nitrate removal of Gaza Strip at higher permeate flux and lower applied pressure, especially in North Gaza Strip were low TDS and Sulphat concentration were observed. In other Gaza Strip places TDS and sulphat need to be removed before using nanofiltration. The optimum operating pressure was tested by number of wells. The results indicated that NF90 is better than RO in nitrate removal and energy cost in terms of lower pressure.

الملخص

المياه الجوفية هي المصدر الوحيد لمياه الشرب بالنسبة لغالبية السكان. نوعية المياه المستخرجة من المياه الجوفية تختلف من حيث المساحة والوقت ولكن بشكل عام لا تطابق القيم الإرشادية لمنظمة الصحة العالمية لجودة مياه الشرب فيما يتعلق بالحد الأقصى للنترات في مياه الشرب 50 ملجم / لتر.

المياه العادمة و الحفر الامتصاصية و الحمأة و مخلفات الحيونات و الأسمدة النيتروجينية تعتبر من اهم مصادر تلوث الخزان الجوفي بالنترات.

الهدف من البحث دراسة الاستخدام الأمثل لاغشية النانو لإزالة النترات في قطاع غزة كدراسة حالة.

تم استخدام غشاء نانو تجاري (NF90) و كان نظام النهاية المغلقة هو النموذج المستخدم في الدراسة، نوعين من المياه تم استخدامهما (محلول مائي و مياه حقيقية)، تم فحص فعالية الغشاء من خلال قياس معدل التدفق (الإنتاجية) و قدرة الغشاء على إزالة النترات و مجموع الاملاح الذائبة تحت تأثير ظرف تشغيلية متعددة: تركيز النترات يتراوح بين(50-400) ملجم /لتر و ضغط تشغيلي يترواح بين (6-12) بار.

النتائج تشير الى انه كلما زاد الضغط اثر إيجابا على معدل التدفق و إزالة الاملاح، بينما زيادة تركيز النترات يؤثر سلبا على معدل التدفق و إزالة الاملاح أيضا. كفاءة إزالة النترات تتراوح بين 21.67% و 66.68% في المحاليل المركبة و كان معدل التدفق بين 5.39 و 14.88 لتر/م^2.الساعة و هذه القيم تعتمد على الظروف التشغيلية.

في المياه الحقيقية تشير النتائج الى ان كفاءة إزالة النترات تتأثر بشكل عام بتركيز الأملاح الذائبة و لكن لنكون أكثر دقة وجدنا ان الكبريتات لها تأثير كبير على كفاءة إزالة النترات. كلما زادت نسبة الكبريتات تقل كفاءة الغشاء في إزالة النترات. و معدل التدفق أيضا يتأثر بنسبة الكلوريد ، كلما زادت نسبة الكلوريد قل معدل التدفق.

غشاء النانو (NF90) طريقة فعالة لإزالة النترات في قطاع غزة مع معدل تدفق عال و ضغط منخفض، و خاصة في شمال القطاع الذي يمتاز بتركيز (TDS) منخفض و أيضا تركيز كبريتات قليل، في الأماكن الأخرى في قطاع غزة نحن بحاجة لأزالة (TDS) و الكبريتات قبل استخدام غشاء النانو لإزالة النترات. و نتائج الدراسة أشارت ان خيار النانو خيار أقتصادي أفضل من تقنية التناضح العكسي المستخدمة حاليا في قطاع غزة.

DEDICATION

This research is dedicated to:

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

To all of my brothers and sisters, Alaa, Mohammed, Abed Alla, Shada, Bushra and Gidaa…
To my nephews, Remass and Ahmed

TO ALL OF MY FRIENDS AND COLLEAGUES…

ACKNOWLEDGEMENTS

First, all praises and glory are due to **ALLAH** for all the bounty and support granted to me. This work would not be done without God's endless guidance and support.

I would like to take this opportunity to sincerely thank all individuals who have helped me in this effort. Primarily, I would like to thank my supervisor and mentor **Dr. Yunes K. Mogheir** for his unlimited guidance, encouragement, and support. I am really indebted to this man for his valuable advice and his vision which inspired this research.

I am deeply indebted and grateful to **Dr. Ahmed Mughari**-Department of Environmental Engineering-for his kind cooperation in facilitating my access to the experimental field, and providing me the needed data.

Next, I wish to express my unreserved gratitude to my friends, **Eng. Bassem Sirdah**, **Eng. Taleb Siam** , **Eng. Mohammed Shanan** and **Eng, Faker Alkored** for their help.

I would like to express my grateful appreciation and thanks to everyone who gave me support to bring this research into reality, especially **Dr. Azzam Abuhabib.**

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AMTA	America's Authority in Membrane Treatment
BAT	Best Available Technology
CA	Cellulose Acetate
CARIX	Carbon Dioxide Regenerated Ion Exchange
CMWU	Coastal Municipalities Water Utility
CP	Cristal Polarization
ED	Electrodialysis
EDR	Electrodialysis Reversal
EPA	Environmental Protection Agency
IX	Ion Exchange
MAC	Maximum Acceptable Concentration
MBR	Membrane Bioreactor
MED	multiple effect distillation
MF	Microfiltration
MSF	Multistage Flash Distillation
NF	Nanofiltration
NO_3	Nitrate
NOM	Neutral Organic Martial
PA	Polyamide Acetate
PWA	Palestinian Water Authority
RO	Reverse Osmoses
SBA	Strong Base Anion
TDS	Total Dissolved Solid
TOC	Total Organic Carbon
UF	Ultrafiltration
WHO	Word Health Organization

LIST OF UNITES

µm	Micrometer
Km	Kilometer
Km^2	Square Kilometer

L/c/d	Liter per capita per day
$L/m^2.hr$	Liter per square meter per hours
m/d	Meter per day
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
Meq/L	Milliequivalent per liter
mg/l	Milligrams per Liter
mm	Millimeter
nm	Nanometer
psi	Pounds per square inch
V	volume

CHAPTER 1 : Introduction

1.1 Background

Water is essential to sustain life, and a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking-water can result in tangible benefits to health. Every effort should be made to achieve a drinking-water quality as safe as practicable. Safe drinking-water, as defined by the Guidelines of Word health organization WHO Standards, does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages.

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 (Aish, 2010).

Several studies in Gaza reported high nitrate (NO_3) levels in groundwater as one of the major concerns among the public decision makers. Nitrate in contaminated water is known to cause methemoglobinemia in infants and new born babies.

To overcome this serious situation, the reverse osmosis (RO) technology is used to replace the tap water or to improve its quality. Several private Palestinian water investing companies established a small-scale reverse osmosis (RO) desalination plants to cover the shortage of good quality drinking water in the whole Gaza Strip.

Nanofiltration (NF) is a suitable method for the removal of a wide range of pollutants from groundwater or surface water. The major application of NF is softening, but NF is usually applied for the combined removal of NOM (Natural organic material), micropollutants, viruses and bacteria, nitrates and arsenic, or for partial desalination. Industrial full-scale installations have proven the reliability of NF in these areas. However, it should be taken into account that a relatively large concentrated fraction is obtained (up to 20% of the feed volume), where the initial pollutants are present in elevated concentrations. Easy methods for concentrate disposal are discharge to salt water bodies, transport to wastewater treatment plants, the use of deep injection wells, and blending for use as irrigation water (possibly after purification of the concentrate with UF). More complex applications may require the implementation of a hybrid system, e.g. in combination with adsorption or biodegradation (Bruggen and Vandecasteels, 2003). The environmental fate of the pollutants in the concentrate is usually unclear; research and practical applications should therefore focus on the further treatment of the concentrated fraction, which is inextricably bound up with the application of NF.

In the Gaza Strip there is no desalination plant using nanotechnology, The aim of this research to test if Nanofiltration membrane is suitable for nitrate removal from groundwater.

1.2 Problem Statement

The groundwater is the main water resource in the Gaza Strip. The aquifer is intensively exploited through more than four thousands of pumping wells. As a result of its intensive exploitation, the aquifer has been experiencing seawater intrusion in many locations in the Gaza Strip; In addition high nitrate is measured in many places in Gaza strip aquiferr (Aish, 2010).

Nitrate in the groundwater in the Gaza Strip has become a serious problem in the last decade. As a result of extensive use of fertilizers, discharging of wastewater from treatment plants, and leakage of wastewater form cesspools, increased levels of nitrate, up to 400 mg/L, have been detected in groundwater. Nitrate concentrations more than 50 mg/L are very harmful to infant, fetuses, and people with health problems.

One of the major options for resolving the water problems is the utilization of desalination technology for both sea and brackish water such as Ro.

Energy cost in desalination plants is about 30% to 50% of the total cost of the produced water based on the type of energy used. Fossil energy is the best type of energy for desalination from an economic point of view. To increase the efficiency of the desalination plant, it must be operated around the clock and never should be idle. Unfortunately, almost all the RO plants in Gaza are operating for only 8 hour per day, and thus the energy consumption is not optimum.

Because of that, the need of the new technology to save energy and remove nitrates efficiently, such as nanofiltration is required.

1.3 Goals

The goal of this research is **to optimize the use of Nanofltraiton for nitrate removal in Gaza Strip as case study.**

1.4 Objectives

To be more specific, the objectives of this research are:

- Optimize operational condition of nitrate removal process by NF.
- Studying the performance of NF with focus on nitrate removal and TDS effect in terms of concentration and composition.

1.5 Methodology

It is intended to achieve the objectives of the study by the following steps shown in Figure (1-1):

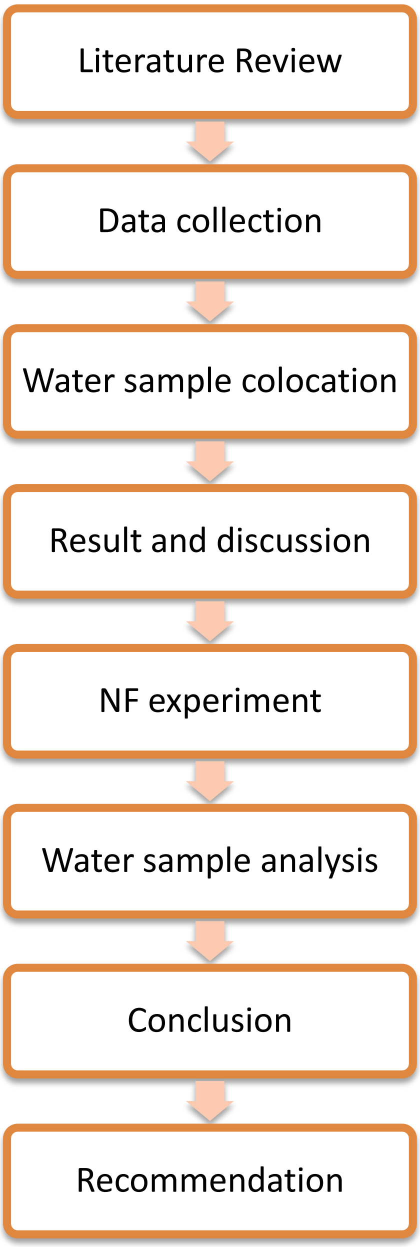


Figure (1-1): Methodology flow chart.

1.5.1 Literature Review

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

1.5.2 Data Collection

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

1.5.3 Water Sample Collection

Water samples were collected from different municipal wells distributed on all Gaza Strip governorates.

1.5.4 Water Sample Analysis

After collecting the samples, major chemical analysis was performed for these samples such as (pH, TDS, and NO_3).

1.6 NF Experiment

System Components:

The system consists of (HP4750 cell – Nitrogen gas cylinder – three way valve – NF90 membrane – Regulator).

NF Experiment:-

After analyzing the samples for major chemicals parameter, flowing steps were carried out:-

1. Filtrate each water samples at different pressures (6 – 8 – 10 – 12) bar and measured water flux at each point.
2. Filtrate each water sample at different pressure and measured nitrate and TDS concentration.
3. Determine the optimum operation pressure with best nitrate removal.

1.7 Result Discussion

Determine the factors (pH, TDS, Pressure, NO_3 concentrate) that influence the nitrate rejection. Building a connection between our results (Gaza strip) and the results of other countries.

1.8 Expected Results

1. Relation between Nitrate rejection rate and pressure.
2. Relation between TDS rejection rate and pressure.
3. Relation between Nitrate rejection rate and TDS concentration in feed water (pH and Pressure fixed).
4. Relation between flux rate and pressure.
5. Relation between Nitrate rejection rate and Nitrate concentration in feed water.
6. Relation between TDS rejection rate and TDS concentration in feed water.

1.9 Thesis Outline

The thesis is composed of the following eight chapters that cover the proposed subject as illustrated below:

1. **Chapter One (Introduction)**: Chapter one include a general background about nitrate problem in Gaza Strip follows by statement of the problem, objectives, methodology used in order to achieve the objectives and thesis outline.
2. **Chapter Two (Literature Review)**: Chapter two covers a general literature review for Desalination, RO, Nanofiltration and nitrate removal.
3. **Chapter Three (Study Area):** Chapter three describes the study area with respect to its location, population, water quality, climate and rainfall, geology and nitrate source.
4. **Chapter Four (Methodology):** Chapter four discusses the methodology of study including data collection, experiment description, data analysis and preparation, sample collection and analysis.
5. **Chapter Five (Results and Discussion):** Chapter Five presents the result of the use of nanofiltration and the factor effecting on nitrate and TDS removal.
6. **Chapter Six (Conclusions and Recommendations):** Chapter six presents the main conclusions and recommendations of study.

CHAPTER 2 : Literature Review

2.1 Desalination

Desalination is used to remove salts from brackish or saline surface water and groundwater in order to render it acceptable for human consumption or other uses. It is increasingly employed to provide drinking-water because of a growing scarcity of fresh water driven by population growth, overexploitation of water resources and climate change. Desalination facilities exist all over the world, particularly in the eastern Mediterranean region, with use increasing on all continents. Small-scale desalination is used to supply fresh water on ships and to provide additional fresh water in some hot and arid regions (WHO, 2011).

There are two main groups of technology which can be used to reduce the concentrate of dissolved solids in brackish water and sea water: membrane and thermal technology.

2.1.1 Thermal Technology:-

The simplest example of thermal process is distillation; saline water is heated to generate steam from the sea water which is the condensed to form water with a low concentration of dissolved salts. This condensed water can then be used for domestic and industrial purposes or for irrigation (Foundation for Water Research, 2011).

When saline solutions are boiled, the escaping vapor consists of pure water soluble gases and volatile organics (which are vented) while the salts and some organics remain in the un evaporated solution. The evaporation-based salt separation process yields water of very low salt content (usually below 5 mg/l of TDS) but the latent heat required to evaporate the water is high. As a result several process configurations have been developed in an attempt to minimize energy consumption (Public Health and the Environment World Health Organization, 2007).

The two most widely used thermal desalination processes are multistage flash distillation (MSF) and the multiple effect distillation (MED). Both, MSF and MED can be used for desalinating seawater and brackish water. However, majority of the existing MSF and MED plants seawater desalination facilities (Public Health and the Environment World Health Organization, 2007).

2.1.2 Membrane Technology:-

Membrane technologies have seen a significant growth and increase in application in the last two decades. Membrane systems are now available in several different forms and sizes, each uniquely fitting a particular need and application (America's Authority in Membrane Treatment, 2011).

A membrane is a thin film of porous material that allows water molecules to pass through it, but simultaneously prevents the passage of larger and undesirable molecules such as viruses, bacteria, metals, and salts (American Water Works Association 1999).

Membranes are made from a wide variety of materials such as polymeric materials that include cellulose, acetate, and nylon, and nonpolymeric 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 (Krukowski, 2001).

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 (Durancean, 2001).

There are many types of membrane technology (Martinus, 2001):

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 bars. UF is used to separate colloids like proteins from small molecules like sugars and salts.
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.

2.1.3 Other Technology:

Other desalination technologies are available (Foundation for Water Research, 2011):

- Ion Exchange.
- Thermally Regenerated.
- Capacitive Deionization.
- Solar Thermal Ionic Desalination.
- Solar Desalination.

2.2 Reverse Osmosis

Reverse osmosis (RO) 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 (Symons et al., 2001; Bebee et al., 2006; MWH, 2005; Bergman, 2007).

2.2.1 RO Membranes

A reverse osmosis membrane is a synthetic membrane used for separation. The separation capability of the process is dependent on the physical and chemical properties of the membrane (Symons et al., 2001; MWH, 2005).

RO membranes should be made of a permeable but not porous material that can reject dissolved solutes while passing the water. Typical materials for RO membranes are cellulose acetate (CA) and polyamide (PA) (MWH, 2005; Bergman, 2007).

The first RO membranes were made from CA at the University of California in 1949 for desalination of seawater. CA membranes are more hydrophilic than PA membranes, and therefore less vulnerable to fouling. Also, CA membranes can tolerate up to 1 mg/L of chlorine, while PA membranes deteriorate at any concentration of free chlorine (MWH, 2005; Bergman, 2007).

However, CA membranes may hydrolyze to acetate and lose their rejection capacity over time. Also, PA membranes are more resistant to biodegradation and tolerate wider pH ranges, and have higher removal capacities (MWH, 2005; Bergman, 2007).

2.2.2 Mechanism of Removal

The fundamental rejection mechanisms of membranes include electrostatic repulsion and diffusion. Electrostatic repulsion causes the feed water anions to be rejected at the surface of the membrane due to the negative charges of functional groups in membrane materials, and cations might be rejected to sustain electroneutrality in the water. Therefore divalent ions such as sulfate are rejected better than monovalent ions such as nitrate. Feed water and its solutes also dissolve and diffuse through the membrane. Large molecules may be rejected better due to their lower diffusion potential. Solubility of the molecule is another factor in diffusion **(**MWH**,** 2005; Bergman, 2007).

It is reported that typically nitrate cannot be rejected as well as other anions such as sulfate or chloride **(**Elyanow and Persechino, 2005).

It was also observed that nitrate could not be rejected by RO membranes as well as ammonia and total organic carbon (TOC) (Bellona et al., 2008).

Application of RO for Nitrate Removal

RO has been designated to be one of the best available technologies for removing nitrate as well as some other inorganic contaminants by EPA (USEPA, 2004). Since RO can remove several organic and inorganic contaminants, it can be a feasible alternative for removing nitrate in cases that the raw water contains high TDS, hardness, or organics, and nitrate is not the only contaminant to be removed (Cevaal et al., 1995; Darbi et al., 2003)**.** Some studies have assessed nitrate removal from drinking water by RO, and several full scale RO plants have been built and are in operation to treat nitrate in groundwater.

2.3 Nanofiltration

Nanofiltration membranes play an important role in the desalination of brackish and seawater as well as membrane mediated waste water reclamation and other industrial separations. 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 (Al-Amoudia and Lovitt, 2007**).**

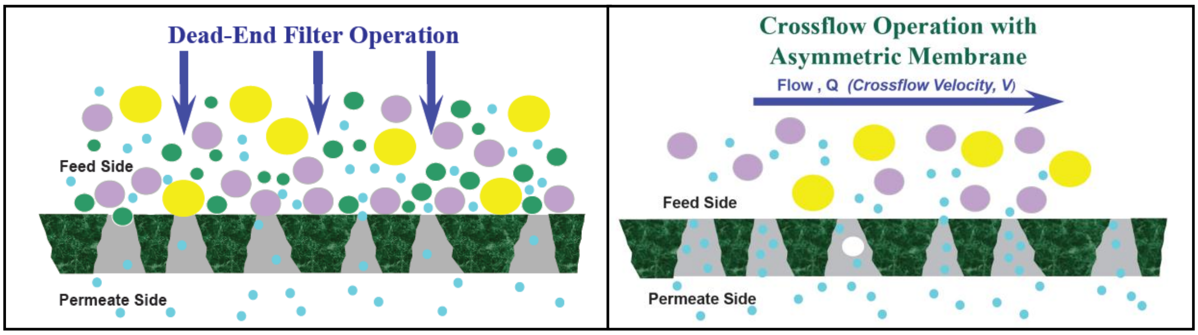
The history of nanofiltration (NF) dates back to the seventies, when reverse osmosis membranes with a reasonable water flux operating at relatively low pressures were developed. Hence, the high pressures traditionally used in reverse osmosis resulted in a considerable energy cost. On the other hand, the quality of permeate was very good, and often even too good. Thus, membranes with lower rejections of dissolved components, but with higher water permeability would be a great improvement for separation technology. Such ‘‘low-pressure reverse osmosis membranes’’ became known as nanofiltration membranes. By the second half of the eighties, nanofiltration had become established, and the first applications were reported (Bruggen et al., 2003, Paugam et al., 2004, Moros et al., 2007, Wang et al., 2009, Amouha et al., 2011).

2.3.1 Nanofiltration Definition

Nanofiltration (NF) falls between ultrafiltration (UF) and RO, its separation characteristics are based on sieve effect, but also most of commercial NF membranes are charged. So the rejection of ions by NF membranes is the consequence of the combination of electrostatic and steric interaction association with charged shielding Donnan exclusion and ion hytration. These interactions depend on the treated and the membrane itself. The different properties make difficult the use of the existing predictive models. This makes necessary to obtained experimental data to know the performance of a particular NF membrane with specific water (Paugam et al., 2004, Moros et al., 2005, Wang et al., 2009, Amouha et al., 2011, Galankis et al., 2012).

2.3.2 Flow Modes

Membrane processes separate mainly in two modes, i.e. dead-end and cross-flow modes. The difference between these modes can be seen in Figure (2-1). The dead-end mode (marked A) has its feed perpendicular to the membrane and as a result the retentate builds up on the membrane surface. This might lead to cake formation or fouling of the membrane surface due to pore clogging or increased adsorption. In the cross-flow mode (marked B) the feed flows parallel to the membrane surface, thereby decreasing the fouling or cake formation on the membrane surface. As a result, cross-flow can have longer sustained fluxes than the dead-end mode of transport (Munir, 2006).



(A) **(B)**

Figure (2-1): Dead end and cross flow module (Munir, 2006).

2.3.2.1 Dead-end 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).

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).

Theory & Equations

The dead end filtration is the one where the flow of water is perpendicular to the membrane surface. The water is pushed through the membrane by pressure. All the water that is introduced in the dead-end-cell passes through as permeate, in other words there is no rejected water. In dead end filtration the retained particles build up with time one the membrane surface or within the membrane. In either case, the particle builds results in an increased resistance to filtration and causes the permeate flux to decline, as a result dead end filtration requires the stopping of filtration in order to clean or replace the membrane therefore this type of filtration is also called batch filtration (Munir,2006).

There are two types of filtration which can be employed in a dead end cell unit; dead-end microfiltration with constant flux and dead end microfiltration with constant pressure drop. The dead end microfiltration with constant flux ensures that the permeate flux through the filter remains constant, this filtration can be achieved by positive displacement pump. As the cake build-up increases with time, the pressure drop must be increased to maintain constant flux. In dead end microfiltration with constant pressure, as the cake build-up with the time the permeate flux decreases (Munir, 2006).

Membrane Transport Mechanism

Membranes provide absolute barrier to particles greater than their pore size. A membrane process requires two bulk phases physically separated by a third phase, the membrane. The membrane phase interposed between the two-bulk phases controls the exchange of mass between the two bulk phases in a membrane process. The process allows the selective and controlled transfer of a certain species from one bulk phase to another bulk phase separated by the membrane (Munir, 2006).

2.3.2.2 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).

Module and Design

Membrane can be produced in flat sheet or cylindrical form and this determines the type of module are described and compared more details of most populate concept. The feasibility of a membrane process depends on the design of membrane module since the active separation membrane area is directly influenced by the membrane module configuration. The cost reduction of membrane module has led to the commercialization of membrane process in the 1960s and 1970s (Fance and Radovich, 1990).

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).

A. Plate-and-Frame Module

Plate-and-frame modules were among the earliest types of membrane systems and the design is principally based on conventional filter press. Membrane feed spacers and product spacers are layered together between two end plates, as shown in Figure (2-2)**.** The comparatively high production cost (as compared to others membrane modules) and leaks caused by the numerous gasket seals in the system has restricted the usage of this system to small scale application. The use of plate-and frame is now generally limited to electrodialysis and pervaporation systems (Baker et al., 1991).

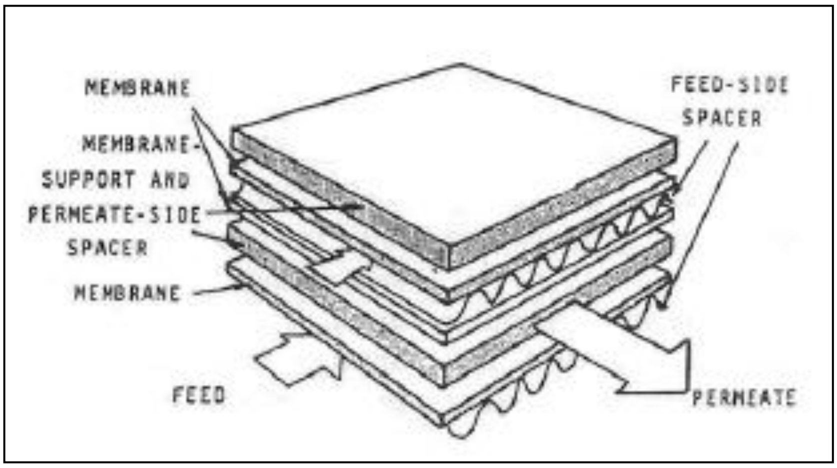


Figure (2-2): Plate and Frame membrane module (Schafer et al., 2008).

B. Tubular Module

Polymeric tubular membranes are usually made by casting a membrane onto the inside of a pre-formed tube, which is referred to as the substrate tube as shows in Figure (2-3).

These are mainly made from non-woven fabrics such as polyester or polypropylene. The diameter of tubes range from 5-25mm, with 12.5mm in common usage. There are mainly two types of housing system for tubular membrane module which known to be the supported and unsupported tubes housing system. Basically, in supported housing system, membrane tube is supported by perforated or porous stainless steel tubes. A bundle of these membrane tubes is mounted into a vessel that collect permeation and caps are fitted to the end to give different flow pattern. Exhibiting high mechanical strength, this type of module can be used at high pressure (up to 60 bar) separation process like reverse osmosis. In the unsupported housing design, the membrane is supported only by substrate tube and a cartridge is constructed by potting the ends of a bundle of tubes in an epoxy resin. These types of designs offer lower capital cost than the supported tube module but, it has a reduced tolerance to pH, pressure and temperature (Baker et al., 1991).

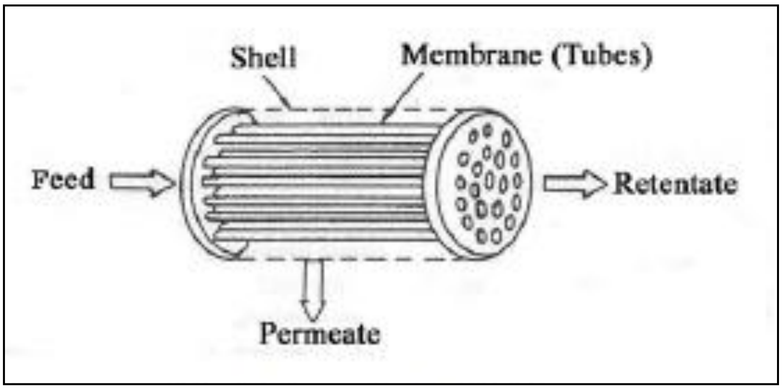


Figure (2-3): Tubular membrane module (Schafer et al., 2008).

C. Hollow Fiber Module

There are two basic configurations for hollow-fiber membrane module. The first is the closed-end design as shown in Figure (2-4). 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 permeates 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 100µ ID and ~200µm OD (Baker et al., 1991).

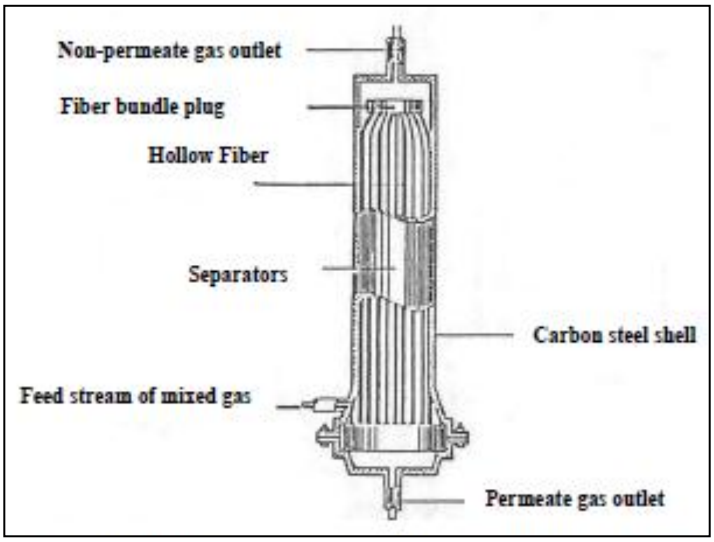


Figure (2-4): Hollow fiber module with closed end design (Scott et al., 1996).

The second basic design for hollow fiber module is more common as shown in Figure (2-5). 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 configurations are available for reverse osmosis, ultrafiltration and microfiltration applications such as seawater desalination, water clarification, fruit clarification, electrophoretic paint recovery, oil waste water treatment and etc. (Scott et al., 1996).

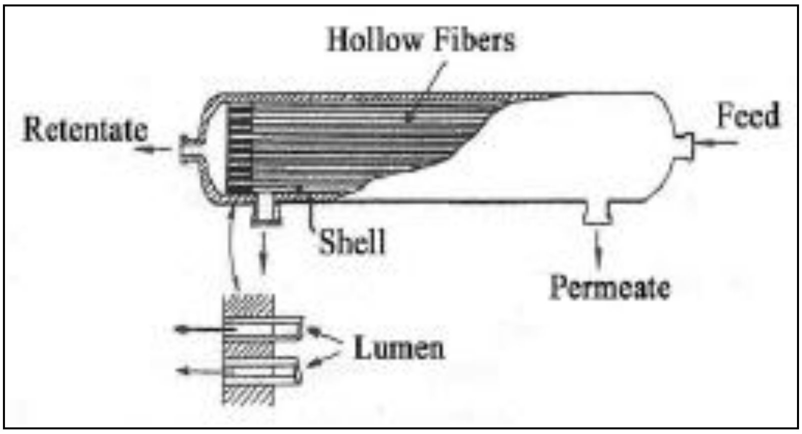


Figure (2-5): Hollow fiber module with opened end design (Scott et al., 1996).

D. Spiral Wound Module

The designs of a spiral wound membrane consist of membrane envelopes (leaves) and feed spacers which wound around a perforated central collection tube. A schematic diagram of an open spiral wound membrane is shown in Figure (2-6). Based on the figure, feed solution passes axially down the module across the membrane envelope. A portion of the feed solution permeates into the membrane envelope, where it spirals toward the center and exits through the collection tube (Scott et al., 1996).

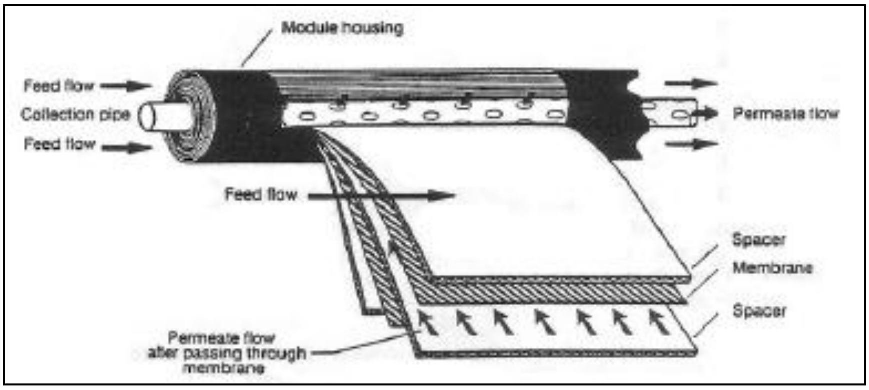


Figure (2-6): Spiral Wound Membrane Module (Scott et al., 1996).

These modules were designed in an effort to pack as much membrane surface as possible into a given volume. Small scale spiral wound modules consist of a single membrane leaf wrapped around the collection tube. In the large membrane area module, using single membrane leaf might generate large pressure drop due to the longer path taken by permeate to reach the central collection tube. Multiple short leaves have been utilized to keep the pressure in the module in a manageable level (Van der Meer and van Dijk, 1997).

Advantages in Spiral Wound Membrane

In reverse osmosis, nanofiltration and ultrafiltration, most membrane modules are fabricated in hollow fiber or spiral wound design. High packing density and low manufacturing cost are the major factors that contribute to the extensive usage of these membrane modules in various industries (refer to Table (2-1)). Plate-and-frame and tubular modules solely used in a few applications where membrane fouling is particularly severe, for example, food applications or processing of heavily contaminated industrial water **(Chaabane et al., 2006).**Fouling resistance is one of the major factors to determine the module selection **(Schwinge et al., 2002).** Generally, membrane fouling is a critical problem in liquid separations such as reverse osmosis, nanofiltration and ultrafiltration. Although plate and frame and tubular modules have better fouling control ability, these types of modules are not preferable due to high selling price except for severe fouling separation process. Comparing between the hollow fiber and spiral wound modules, spiral wound modules appear to be displacing hollow fiber design because they have more fouling resistance which apparently reduces the cost for the feed pretreatment **(Pavlova et al., 2005).**

Table (2-1): Characteristics of major membrane module (Baker et al., 1991).

	Hollow fibers	Spiral Wound	Plate-and frame	Tubular
Manufacturing cost($USD/$m^2$)	5-20	30-100	100-300	50-200
Packing density	high	moderate	low	low
Resistance to fouling	Very poor	moderate	good	Very good
Parasitic pressure drops	high	Moderate	moderate	low
Suitability for high pressure operation	yes	yes	Can be done with difficulty	Can be done with defficuty
Limitation to specific types of membranes	yes	no	no	no

Besides, the fabrication of spiral wound membrane also has less limitation to specific types of membranes as compared to the hollow fiber membrane. This added feature principally allows more types of membrane to be fabricated in spiral wound design. Enhanced stability under high pressure and moderate parasitic pressure drops in spiral wound membrane has also promoted the wide-ranging usage of this module in various sectors (Champlin et al. 2000; Bergen et al., 2004).

2.3.3 Mechanism of Removal

NF processes can be more energetically efficient than the reverse osmosis ones, because of the lower operating pressures. NF has shown its effectiveness in the removal of a great variety of undesirable components from water. Its separation mechanisms combine sieving effect, differences in diffusivity and solubility of solutes and electrostatic interactions between the membrane surface groups and the ions. In the case of negatively charged membranes, anions like nitrates can be effectively rejected. However, ionic rejection is not only influenced by interaction between the membrane and a specific ion. It is known that for ionic solutions the solute. Solute interactions and the solute. Membrane interactions are dependent on the concentration, the composition and pH value of the feed solution **(**Paugam et al., 2004, Moros, et al., 2007, Wang et al., 2009, Amouha et al., 2011, Galanakis et al., 2012).

Nanofiltration combines removal of uncharged components on nanoscale with charge effects between solution and the membrane. The removal of uncharged components may be a result from size exclusion, as known from ultrafiltration, or may be a result from differences in diffusion rates in a non-porous structure, which depend also on molecular size, rejection of ionic components in NF I obtained in a totally different way: ions are rejected as a result of charge interactions between the membrane surface and the ions (Donnan exclusion). The divalent ions (hardness, sulphates) are more efficiently removed. For tight NF membranes, size exclusion can provide an additional ion rejection (Bruggen et al., 2003, Paugam et al., 2004, Moros et al., 2007, Wang et al., 2009, Galanakis et al., 2012).

2.3.4 Recovery Rate and Rejection Rate

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 by:

$$\gamma = \frac{Q_p}{Q_f}.100\%$$

Where $\gamma - recovery(\%)$

$Q_p - permeate\ flow$ (m^2/hr)

$Q_f - Feed\ flow$ (m^2/hr)

Rejection indicates the amount of components rejected by membranes. It shows the separation efficiency of the components by the membrane. It is calculated by:

$$Re = 1 - \frac{C_p}{C_f}$$

Where Re – Rejection

C_p – concentration of components in permeate (g/m^3)

C_f – concentration of components in feed water (g/m^3)

2.3.5 Nanaofiltration Fouling

Fouling is common to all types of membrane separation. The type of fouling various from Microfiltration (MF) membrane processes where hydrodynamic force can predominate to (RO) membrane processes where hydrodynamic forces have minor effects compared to the forces associated with particles and their interaction with the membrane surface (Al-Amoudia and Lovitt, 2007).

When fouling takes place on the membrane surfaces its causes flux decline leading to an increase in production cost due to increased energy demand, chemical cleaning, reduction in membrane life expectancy and additional labor for maintenance. The types of NF Fouling can be classified on the basis of fouling material into three types (Vrouwenvelder et al., 1998, Bruggen and Vandecasteele, 2002**)**

1. Inorganic fouling due to deposition on membrane surface of inorganic scales (mainly $BaSO_4$, $CaSO_4$ and $CaCO_3$).
2. Organic fouling due to natural organic material (NOM) found in the process stream (humic acids, protein and carbohydrate.
3. Befouling due to microbial attachment to membrane surface followed thereafter by their growth and multiplication in presence of adequate supply of nutrients in the pretreated feed or nutrients that deposited on membrane surfaces.

2.3.5.1 Inorganic Fouling

Scale formation at the membrane surface is serious problem and resulting from the increased concentration of one or more species beyond their solubility limits and their ultimate precipitation onto the membranes. In order to avoid scaling, it is very important to operate NF systems at conditions lower than the critical solubility limits, unless the water chemistry and physical conditions are adjusted to prevent the type of precipitation. Currently, due to the complexity of the problem, there is no reliable way to predict the limiting concentration level at which there is no a risk of scale formation with a given membrane system and treated water. Similarly, specific antiscalant treatments are hard to define with confidence (Hasson et al., 2001).

The bulk solution followed by crystal deposition on the surface of the membrane (homogenous crystallization). Clearly, this process will be a mixture of these two extremes and will be affected by membrane morphology and process conditions (Lee et al., 1999).

If the surface of the solid substrate matches well with the crystal and the interfacial energy between the two solids is smaller than the interfacial energy between the crystal and the solution, then nucleation may take place at a lower saturation ratio on a solid substrate surface (heterogeneous crystallization) rather than in the solution (homogenous crystallization) (Dydo, et al., 2004, Alborzfar et al., 1998).

When the bulk phase becomes supersaturated due to the increasing of concentration polarization layer, it is possible that both mechanisms of crystallization simultaneously occur in NF system (Lee et al.,1999).

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. In addition to these parameters, NOM has also been considered to affect various forms of scaling (Kasper, 1993). See Table (2-2) Scaling factors.

Table (2-2): Scaling factors (Kasper, 1993).

	value	crystallization	cause
Ionic strength	High	Increased	Solubility and supersaturating
CP	High	Increased	Solubility and supersaturating
Co-precipitation	presence	Increased	Changing structure of the precipitate
pH	Higher	Increased	Solubility decreased
pressure	Higher	Increased	Increasing CP and Osmotic pressure at membrane surface (solubility and supersaturating)
Velocity (floe rate)	Higher	Decreased	Higher wall shear rate
temperature	Higher	Increased	Solubility decreased
Surface morphology	Higher	Increased	Valley blocking

2.3.5.2 Organic Fouling

In general, NF membrane are used in water treatment as alternative processes for the removal of natural organic matter NOM that cause contamination, taints and color and are vehicles for other materials that bind to these substances. Organic fouling could cause either reversible or irreversible flux decline. The reversible flux decline, due to NOM fouling, can be restored partially or fully by chemical cleaning. Whereas the irreversible flux decline cannot be restored at all even by rigorous chemical cleaning is applied to remove NOM (Roudman and DiGiano, 2000).

Membrane fouling in the presence of NOM can be influenced by: membrane characteristics, including surface structure as well as surface chemical properties, chemistry of feed solution including ionic strength, pH; the concentration of monovalent ions and divalent ions; the properties of NOM, including molecular weight and polarity; the hydrodynamics and the operating conditions at the membrane surface including permeate flux, pressure, concentration polarization, and the mass transfer properties of the fluid boundary layer. These factors either increase or decrease the fouling rate has been summarized in Table (2-3) and more information can be found elsewhere (Kasper, 1993).

Table (2-3): Natural organic matter fouling factor (D.R. Kasper, 1993).

	value	NOM fouling	Cause
Ionic concentration	low	Increased	Electrostatic repulsion
pH	High ph Low pH	Increased Increased	Hydrophobic forces Electrostatic repulsion
Divalent cation	presence	Increased	Electrostatic repulsion and bridging between NOM and membrane surface
NOM fraction	Hydrophobic Hydrophoilic	Increased Decreased	Hydrophobicity
Molecular or membrane charge	High charge	Increase	Electrostatic repulsion
CP	High	Increased	Electrostatic repulsion
Surface morphology	Higher	Increased	Valley blocking
Permeate flux (High recovery)	Higher	Increased	Hydrophobicity
Pressure	Higher	Increased	Compaction

2.3.5.3 Biofouling

Biofouling is a term used to describe all instances of fouling where biologically active organisms are involved. This is distinct from NOM fouling caused by contaminated organic matter that may be derived from biological systems. Membrane biofouling is caused by bacteria and to a lesser degree, fungi and other eukaryote microorganisms (Flemming, et al., 1997).

Biofouling is a dynamic process of microbial colonization and growth, which result in the formation of microbial biofilms. Biofilm formation invariably precedes biofouling, which becomes an issue only when biofilms reach thickness and surface coverage that may cause problems such as declined normalized flux and/or increase in normalized pressure drops during NF or RO operation (Vrouwenvelder, et al., 1998, Ridgway, 1996).

Many products from biofilms have been shown to enhance inorganic precipitation through enhanced nucleation and crystallization kinetics, e.g. carbonate and silicates. Biofouling can be controlled by (1) removal of degradable components from the feed water, (2), ensuring the relative purity of the chemicals dosed and (3) performing effective cleaning procedures. Also, it has been reported that cleaning procedures applied when fouling is not a problem might delay biofilm formation (Hilal, et al., 2004).

2.3.6 Operational Aspect of NF and Fouling

From the mechanisms of fouling process above, many operating procedures have a direct impact on fouling of membranes. This section reviews the effect of membrane process design on fouling. In most cases flux rate is considered as a key design parameters for membrane system and reflect membrane productivity. The two factors that lead to deterioration the flux rate are fouling and concentration polarization. In order to overcome these shortcomings the membrane array is to be introduced (Zhu and Nystrom, 1998, Farooque et al, 2002).

An appropriate membrane array was considered in designing membrane treatment system in order to reduce the effects of both concentration polarization and to minimize the membrane fouling. Typically, membrane systems use multiple parallel modules so that the plant performance in terms of the product quality and recovery remain identical for a single module (Straight brine stages; typically a single module contains six elements). In the tapered systems (Tapered brine stages; membrane array design 2:1, 3:2:1, 4:2:1), the feed stream is passed through the first module (or parallel set of modules) and is divided two streams. These streams are the product and the reject stream, the reject stream from first module (or parallel set of modules) is passed through as feed to the second module (or set of modules). Here the velocities are boosted at each stage by decreasing the number of modules in parallel. Thus it is possible to obtain a high recovery while still avoiding the worst effects of fouling and concentration polarization Figure (2-7).

The membrane arrangements are designed with the aim of minimizing fouling and reducing concentration polarization by increasing number of stages and reducing thenumber of elements per stage in order to maintain the same or high recovery will involve the following constraints **(Schafer et al.,2005, Taylor and Jacobs, 1996):.**

1. The flow rate should not exceed the maximum flow rate per element, $q$max, to avoid large axial pressure drops which could cause membrane element damage such as telescoping
2. There is a lower limit on the flow rate per element, $q$min, in order to control concentration polarization and scaling.
3. There is a maximum recovery for each stage as well as overall maximum recovery in order to minimize the fouling.

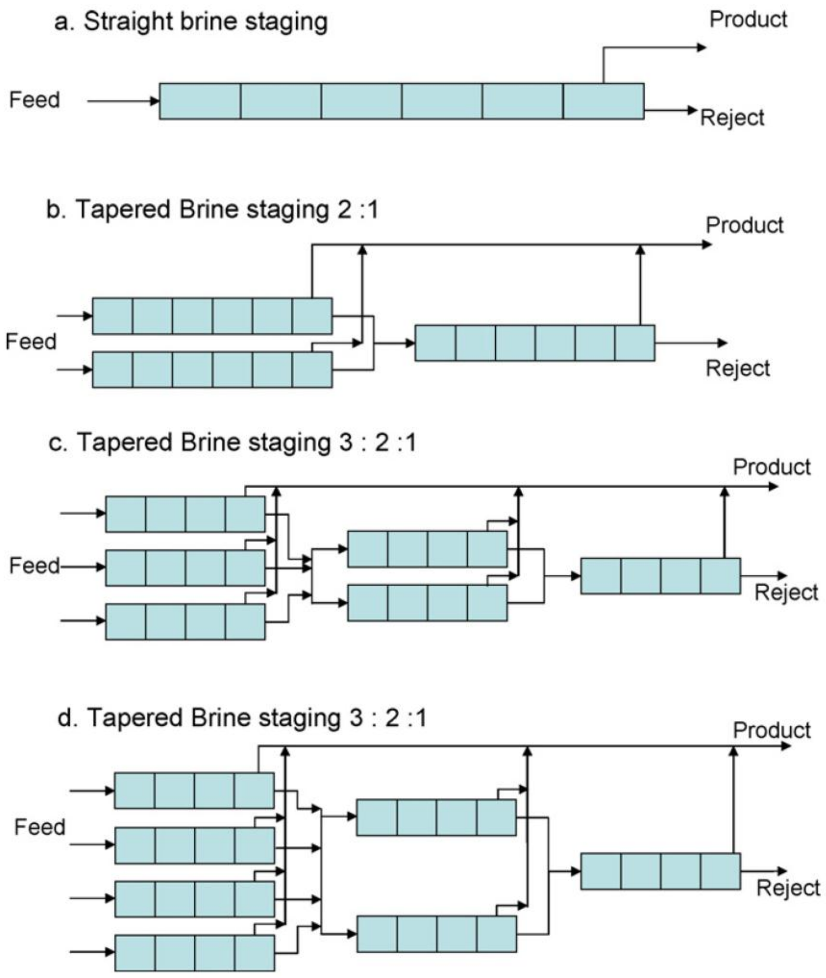


Figure (2-7): Membrane arrays—straight and tapered brine stage (Al-Amoudia and Lovitt, 2007)

2.3.7 Membrane Cleaning

Remediation is usually conducted by chemical cleaning for nearly all membrane processes and application. However, the frequency of the chemical cleaning could range from a routine daily process such as in whey processing to long term annual processes such as in desalination plant according to occurrence of fouling (Van der Bruggen, et al., 2003).

In general, much of the decline in membrane performance can be corrected by cleaning the membrane. 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).

A. 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).

B. Chemical Cleaning

Adequate pretreatment and appropriate membrane selection as mentioned above can slow the fouling rate, but the membrane cleaning is an essential step in maintaining the performance of the membrane process. The ideal cleaning processes should not only be effective against several foulants, but gentle to the membranes so as to maintain and restore their characteristics. The optimal (the least membrane damage and maximal effectiveness of cleaning) choice of the cleaning agent is a function of membrane material as well as foulants (Al-Amoudia and Lovitt, 2007).

The chemical reactions between the chemical agents and the foulant takes place either by changing the morphology of the foulant or by altering the surface chemistry of fouling layer in order to remove the foulants from the membrane surfaces (Wies et al, 2003).

An irreversible change in the porous structure of NF membranewas observed as a result of the chemical cleaning. Cleaning may make the pore surfaces more hydrophilic and charged by the adsorption of the chemical agent (KoSutic and Kunst, 2002).

In any membrane processes, the need for proper and periodical cleaning is essential regardless of the type feed be; seawater, brackish water, wastewater or industrial water. The objective of the cleaning processes is to restore membrane performance when it falls below the expected permeate yield typically by about 10%, or feed pressure increase by about 10% and/or differential pressure increase by 15–50% (Al-Amoudi and Farooque, 2005).

. Membrane replacement is a necessary part of the plant operation that is needed to maintain the quality of the product water to the protocol agreed with membrane manufacturers as well as to meet the design productivity when the cleaning processes fail to restore the declined flux (Al-Sofi, 2001).

The complexity and detailed understanding of cleaning processes has not yet been addressed by many researchers and is needed for a clear knowledge of these processes. Although cleaning is intended to restore the flux, it often deteriorates product quality and increases the cleaning frequency affecting plant availability. For example, cleaning processes sometimes takes 1–2 days to complete in large plants (Al-Amoudi and Farooque, 2005).

Desalination plant availability is usually designed to be in the range of 90–97% and varies according to the type of water being treated. However, this percentage can be reduced if the cleaning frequency is increased, but the costs routine of plant maintenance, the additional manpower utilization and energy consumed during cleaning processes can increase the overall cost of water production. In general, the chemical consumption of the plant per year is about 0.3–1% of total water treatment cost, nevertheless, the chemical consumption of the cleaning process per year is much higher than the annual chemical consumption for the overall RO process (conditioning etc.,). These general cost figures exclude the additional facilities, manpower and energy consumed for cleaning. It is well recognized that the energy cost of the plant is about 50–60% from the total water cost. Mooch stated that “power, itself, can be a half to three quarters of the operational and maintenance costs”. In general the cleaning process increases the overall system energy efficiency, regardless of the energy consumed during the cleaning. For example by reducing the net driving pressure will be reduced after cleaning by about 10–30% which is quiet considerable energy saving, especially during the plant operation (Mooch, 2003).

Factors Affecting Chemical Cleaning Efficiency

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).

2.3.8 Nanofiltration Application

The classical processes used for nitrates elimination in drinking water are ion exchange, biological denitrification and electrodialysis, but they are rather complex to execute and can also give rejections. Consequently, nanofiltration seems to be able to be used for the treatment of this pollution. Moreover, the nanofiltration allows in the same time reducing the water hardness, eliminating the pesticides and the micro-organisms and limiting thus the chemical reagents addition (Franc. et al., 2006).

2.3.9 Nanofiltration in Nitrate Removal

Table (2-4):Typical commercial nanofiltration membrane models (Schafer et al., 2008).

commercial name	Salt rejection (%)	Module flow rate (m^3/d)	Test condition	
			Pressure (bar)	Recovery (%)
DS-51 HL8040F400	98	43.5	6.9	10
NF270-400	40-60	55.6	4.8	15
NF270B-400	<45	27.7	4.8	15
NF90-400	85-95	28.4	4.8	15
ESNA1	90	37.8	5.2	15
SU-620	65	36	7.2	23.8
8040-TS80-TSA	99	34.1	7.6	15
ROGA8321LP Magnum	75	49.2	5.5	16
ROGA Magnum (proprietary)	35	49.2	4.5	16
701A(proprietary)	10	25	4.5	10
1001A(proprietary)	5	25	4.5	10
CA202	20	-	4.5	-

Only for NF90 membrane the product information indicates that it is designed to remove a high percentage of nitrate (Moros et al., 2005, Garcia et al., 2006, Moros et al., 2007).

It was shown that the NF90 membrane has a high rejection even to monovalent ions. This fact can be mainly explained by its tight pore structure and the negative charge of the membrane (Moros et al., 2007).

The most important retentions are obtained for the NF 90 membrane. For this one, the membrane pores seems to be smaller that those of the three other membranes(NF, NF90, OPMN-P, OPMN-K) and consequently the retention is higher due to screening effect and a size effect more important (Garcia et al., 2006).

The membrane NF 90 shows a very important abatement of the mineralization of the permeate since the conductivity is very weak. The conductivities obtained for the two others membranes are in the same order (Garcia et al., 2006, Moros et al., 2007).

The increase on pH yielded to higher nitrate rejection because of the increase in the negative charge of the membrane, whilst the concentration increase caused, in general, a decrease in ion rejection. It can be concluded that for the NF90 membrane the transfer mechanism involving sieving effect and electrostatic interaction effects seems to play an important role. The feed pH, concentration and the ion size determine which mechanism predominates. The NF90 membrane presents, from a qualitative point of view, similar effects to those observed in a conventional NF membrane However, the extent of these effects is smaller, approaching the behavior of the NF90 to that of a reverse osmosis membrane. The relatively high nitrate rejection and its small dependence on feed conditions make this membrane suitable to treat types of water that slightly exceed the legal limit of nitrate concentration for drinking purposes (Moros et al., 2007).

The interest of using nanofiltration for nitrate ions concentration reduction has been demonstrated. The performance of the process depends on the characteristics of nanofiltration membranes since the results differ from one membrane to the other. The best membrane has been also determined: the NF90 membrane allows strongly reducing nitrate ions concentration at high permeate fluxes (Garcia et al., 2006, Moros et al., 2007).

Surprisingly, the nitrate rejection observed for NF90 membrane with the natural water was slightly higher than the obtained with the model solution **(Moros et al., 2005).**

2.4 Nitrate Removal

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) and ammonia (one part nitrogen and three parts hydrogen – NH_3) (Water stewardship information series, 2007).

In water, nitrate has no taste or scent and can only be detected through a chemical test. The Maximum Acceptable Concentration (MAC) for nitrate in drinking water in Palestine is 70 milligrams per liter (mg/L) (PWA, 1996).

For laboratory tests reported as nitrate-nitrogen (NO_3-N, the amount of nitrogen present in nitrate) the MAC is 10 mg/L (WHO, 2011).

2.4.1 Health Concerns

Nitrate levels have increased due to increased usage of nitrogenous fertilizers, changes in land-use patterns and increased recycling of domestic wastewater. While nitrate is considered to be relatively non-toxic to adults, in infants, NO_3 is reduced to NO_2 which combines with hemoglobin in the blood to form methamoglobin and leads to a condition commonly known as "blue baby syndrome." Health and Welfare World Guidelines had established a limit of 45 mg NO_3/ L (Robert et al., 2007).

2.4.2 Treatment Technologies

Many technologies for nitrate removal from water have been adopted based on scientific developments. A brief overview of all techniques is presented in this literature review.

Nitrate is a stable and highly soluble ion with low potential for coprecipitation or adsorption. Thus conventional treatment technologies cannot be used. This reviews various techniques in terms of their effectiveness, ease of operation and cost.

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 coprecipitation or adsorption in water (Luk and Au-Yeung, 2002; USEPA, 2003).

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 (Kapoor and Viraraghavan, 1997; Luk and Au- Yeung, 2002; Samatya et al., 2006).

Among these methods, the first four have been applied at full-scale. WHO has suggested biological denitrification and IX as nitrat removal methods (WHO, 1992), while IX, RO, and ED are approved by 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, residuals handling, and post-treatment requirements.

2.4.2.1 Chemical Denitrification

The electron-donating tendency of zero-valent metals can reduce several anions. So these metals have been investigated as developing water treatment technologies to remove contaminants such as nitrate. Iron and aluminum powder are considered as effective zerovalent metals for the chemical process of nitrate removal from drinking water, known as chemical denitrification (Shrimali and Singh 2001; Luk and Au-Yeung, 2002).

Nitrate reduction can be induced under basic pH according to the following reaction:

$$3NO3- + 8Fe\ (OH)_2 + 6H2O \rightarrow NH3 + 8Fe\ (OH)_3 + OH-$$

Experimental results showed that a Fe: NO3- ratio of about 15: 1 was required in the presence of copper catalyst for the reaction to proceed. This process generated a large quantity of iron sludge and formed ammonia that requires removal by air stripping. The process was associated with high costs. In chemical denitrification by powdered aluminum ammonia was found to be the principal reaction product (60-95%) at pH of 10.25, which was removed by air stripping. The denitrification was explained on the basis of the following reactions (Murphy A P, 1991, Luk G K and Au-Yeung W C, 2002):

$$3NO_3^- + 2A1 + 3H_2O \rightarrow 3NO_2^- + 2Al\ (OH)_3$$

$$NO_2^- + 2A1 + 5H_2O \rightarrow NH3 + 2Al\ (OH)_3 + OH^-$$

$$2NO_2^- + 2A1 + 4H_2O \rightarrow N2 + 2Al\ (OH)_3 + 2OH^-$$

Aluminum reacted with water as per the following equation:

$$2A1 + 6H2O \rightarrow 2Al\ (OH)\ 3 + 3H2$$

It was shown that 1.16 g of aluminum was required for the reduction of 1 g of nitrate. Catalytic reduction of nitrate with Pd and/Cu catalysts was another removal technique13. It was found that Pd-Cu combined catalysts at a ratio of 4 can maximize the nitrate reduction into nitrogen; above 80% total nitrate removal efficiency was realized. 84% denitrification efficiency was achieved at ambient temperature and pressure using zero-valent magnesium (Mg (0)) for Mg (0):NO_3--N molar ratio of 5.8 and pH of 2.

2.4.2.2 Reverse Osmosis for Denitrifaction

Reverse osmosis (RO) 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 pressuredriven 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 (Symons et al., 2001; Bebee et al., 2006; MWH, 2005; Bergman, 2007).

Nitrates could be removed by reverse osmosis cells under pressures ranging from 300 to 1,500 psi to reverse the normal osmotic flow of water. Membranes used were made of cellulose acetate, polyamides and composite materials. Problems associated with reverse osmosis membranes included fouling, compaction and deterioration with time. These problems resulted from deposition of soluble materials, organic matter, suspended and colloidal particles, and other contaminants, pH variations and chlorine exposure; thus the reverse osmosis process required pretreatment (Archna et al., 2011).

2.4.2.3 Electrodialysis (ED) for Denitrification

Electrodialysis (ED) is a desalting process driven by an electrical potential difference between oppositely charged electrodes. Ions are transferred by electric current flow through cation and anion membranes, depending on ion charge, from a less concentrated solution to a more concentrated one, leaving a demineralized stream (Symons et al., 2001).

Similar to RO, water treatment by ED is also limited to soft waters due to membrane scaling problems. Therefore, this technology also needs pre-treatment. To minimize membrane scaling and reduce the need for pre-treatment, use of a modified ED method known as electrodialysis reversal (EDR) was investigated (Rautenbach et al., 1987; Kapoor and Viraraghavan, 1997).

Electrodialysis Reversal (EDR) is an electrodialysis process in which the electrical polarity of the electrodes is reversed on a set time cycle, thereby reversing the direction flow of ions in the system providing fouling control (Symons et al., 2001). However, operating EDR is more complicated and needs close monitoring (Rautenbach et al., 1987; Kapoor and Viraraghavan, 1997).

One of the main advantages of ED is its higher percent of recovery comparing to RO. But, both ED and RO methods generate highly concentrated wastes and need careful consideration with respect to disposal. In general, ED is a more complex system than RO and demands high energy and costs (Rautenbach et al., 1987; Kapoor and Viraraghavan, 1997; Hell et al., 1998).

To reduce the energy and costs associated, increasing the efficiency of the system by maximizing the amount of nitrate removed per membrane area was investigated. To achieve this, an ED system was developed by modifying the membranes to anion exchange membranes that could selectively remove nitrate (Eyal and Kedem, 1988).

In ED ions are transferred through membranes from a less concentrated to a concentrated solution by application of direct electric current. ED treated the water by selective removal of undesirable ions through a semi permeable membrane. An electrodialysis system required a supply of pressurized water [50-75 psi (345-578 kPa)] with pretreatment. In the electrodialysis reversal (EDR) process, the polarity of the electrodes was reversed two to four times an hour to alter the direction of ion movement. The EDR process reduced scaling and chemical usage compared with conventional ED and was used for the production of drinking water from nitrate rich water. The nitrate removal efficiency of ED and RO processes was almost the same **(**Archna et al., 2011).

2.4.2.4 Catalytic Reduction

A catalytic process was developed for the removal of nitrite and nitrate from water. Palladium - alumina catalysts were effective in reducing nitrite to nitrogen (98%) and ammonia in the presence of hydrogen. The lead (5%), copper (1.25%), A12O3 , catalyst were found to completely remove nitrate from water having an initial nitrate concentration of 100 mg/L. The reaction was completed in 50 min. The process operated effectively at a temperature of 10°C and pH 6-8 (Horold et al, 1993).

2.4.2.5 Ion Exchange Process

The ion exchange process involved passage of nitrate water through a resin bed containing strong base anion (SBA) exchange resins on which nitrate ions were exchanged for chloride or bicarbonate ions until the resin exhausted. The exhausted resin was regenerated using a concentrated solution of sodium chloride or sodium bicarbonate (Kokufuta et al., 1988).

Treatment of sulfate water with resins is difficult as the nitrate removal capacity of the resin is reduced by the sulfate ions. It was observed that sulfate selectivity was reduced by increasing the distance between ion-exchange sites and nitrate selectivity can be increased by increasing the matrix and functional group hydrophobicity. Triethyl amine resins showed an increase in the bed life by 62% when treating water containing 1.5 meq/L nitrate and 6.5 meq/L sulfate. Regenerant usage decreased by 25-50%, thus the operating cost of the ion exchange process reduced (Guter, 1987).

Ion exchange process was found to be five times more economical in comparison to RO process. A process was developed in which regeneration and exhaustion was performed in the same direction and reduced nitrate concentrations from 15.8 to 5.7 mg/L. The Carbon dioxide regenerated ion exchange resins (CARIX) process for removing nitrate, sulfate, and hardness from water was based on ion exchange principles (Wenli et al., 1994).

2.4.2.6 Biological Denitrification

Biological denitrification is one of the most effective technologies for nitrate removal since it only removes nitrate and doesn’t change concentrations of other background ions. In this method nitrate is microbially reduced to nitrogen gas. Although this process is commonly applied in wastewater treatment, its application for drinking and groundwater treatment has been investigated in lab studies and only occasionally developed in full-scale plants (Roennefahrt, 1986; Bockle et al., 1986; Janda et al., 1988; Braester and Martinell, 1988; van der Hoek et al., 1992; Liessens et al., 1993; Mateju et al., 1992; Soares, 2000).

However, potential contamination of the treated water with these microorganisms and their metabolic byproducts are the drawbacks of this technology (Shrimali and Singh, 2001; Samatya et al., 2006).

These problems result in increased disinfectant demand or the need of post-treatment of the product water by filtration. In addition, low production rates and cold temperature restrictions can also be considered as a disadvantage of biological denitrification (Kapoor and Viraraghavan, 1997; Samatya et al., 2006).

2.4.2.7 Denitrification Using A Membrane Bioreactor

Immersed heterotrophic membrane bioreactor (MBR) produced high quality product water34 when NO_3 contaminated water was made to flow through the lumen of tubular microporous membranes. NO_3 diffused through the membrane pores. Denitrification took place on the shell side of the membranes 35. The MBR achieved over 99% NO_3 removal at an influent concentration of 200 mg NO_3 /L (Boley et al., 2000).

2.4.2.8 Heterotrophic Denitrification

Most denitrifying bacteria are heterotrophic and utilize complex organic substances as oxidisable substrates such as methanol, ethanol, methane, carbon monoxide, and acetic acidfor the conversion of nitrate to nitrogen (Mateju et al., 1992).

Pilot scale studies using heterotrophic denitrification were conducted using packed and fluidized columns. The reactors required a start-up period of two weeks to establish sufficient bacterial populations. The highest denitrification rate per unit reactor volume was observed for the fluidized sand bed (160 g $N/m^3.h$ at 10°C) and lowest for the packed bed reactors (12 g $N/m^3.h$ at 10°C). Nitrate concentrations were reduced to approximately 45 mg/L (Schipper and Vukovic, 2000).

Denitrification by immobilized Pseudomonas denitrificans cells was studied using a sodium alginate polymer and ethanol as the carbon source. The nitrate concentration reduced from 104 to 0.1 mg/L. The limitations of the process being that the low rate of diffusion of substrate and reaction products through the alginate matrix and the short life span of the alginate matrix. To overcome these problems a membrane-immobilized biofilm reactor was developed in which denitrifying bacteria and carbon energy source were segregated from the water to be treated (Roising and Schroeder, 1996).

2.5 Research Contribute

As we know there is no desalination plant in Gaza strip have been used the Nanofiltration technology, so I will try to implement this technology in Gaza strip which I think it cheaper than RO technology, while when we used this technology we will save many, because the NF membrane used pressure more less than that was used in Ro membrane.

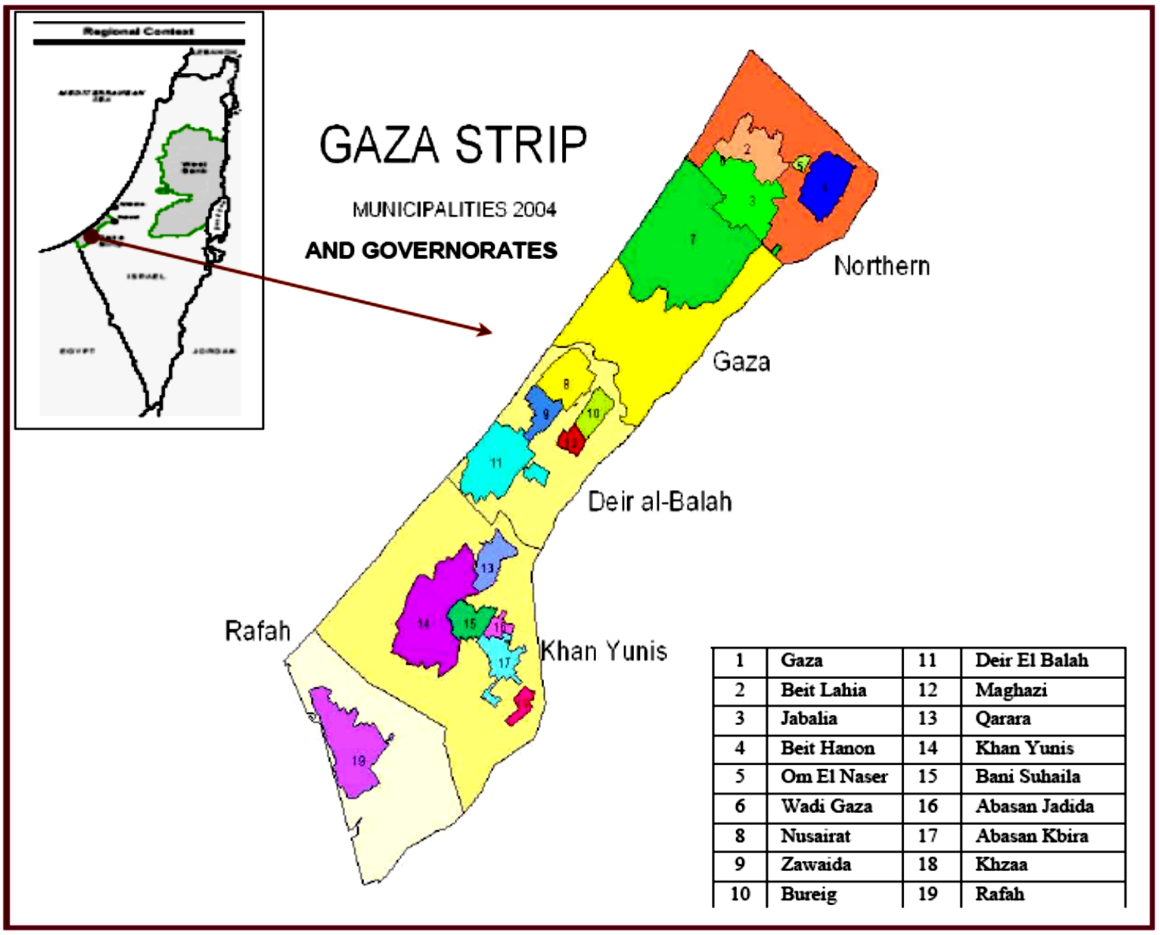
The Research contributes is test efficiency of nanofiltration to treat Gaza strip groundwater and compare results with other places that nanofiltration membrane are used in it.

CHAPTER 3 : Study Area

3.1 Location

Gaza Strip is located in a semi-arid area with scarce water resources. It is a part of the Palestinian coastal plain in the south west of Palestine as shown in Figure (3-1), where it forms a long and narrow rectangular area of about 365 km^2, with 45 km length, and between 5 and 12 km width. Nowadays, its five governorates are: Northern, Gaza, Middle, Khanyounis and Rafah. It is located on the south-eastern coast of the Mediterranean Sea, between longitudes 34° 2'' and 34° 25'' east, and latitudes 31° 16'' and 31° 45'' north. The Gaza strip is confined between the Mediterranean Sea in the west, Egypt in the south (UNEP, 2003).

Figure (3-1): Gaza Strip Municipalities and Governorates.



1	Gaza	11	Deir El Balah
2	Beit Lahia	12	Maghazi
3	Jabalia	13	Qarara
4	Beit Hanon	14	Khan Yunis
5	Om El Naser	15	Bani Suhaila
6	Wadi Gaza	16	Abasan Jadida
8	Nusairat	17	Abasan Kbira
9	Zawaida	18	Khzaa
10	Bureig	19	Rafah

3.2 Water Quality

Ongoing deterioration of the water supply of Gaza Strip poses a major challenge for water planners and sustainable management of the coastal aquifer. The aquifer is presently being overexploited, with total pumping exceeding total recharge. In addition, anthropogenic sources of pollution threaten the water supplies in major urban centers. Many water quality parameters presently exceed World Health Organization (WHO) drinking water standards. The major documented water quality problems are elevated chloride (salinity) and nitrate concentrations in the aquifer (Aish, 2004).

The highest chloride sources are expected in the areas affected by seawater intrusion and the deeper groundwater layer. High nitrate concentrations are expected in the vicinity of local anthropogenic sources including agriculture and wastewater leakages (CEP and EMCC, 2006).

3.2.1 Ground Water Salinity (Chloride)

Salinity in the Gaza strip aquifer is most often described by the concentration of chloride in groundwater. Sea water intrusion and intensive exploitation of groundwater have resulted in increased salinity in the most areas in Gaza strip. According to Coastal Municipalities Water Utility (CMWU), a generalized contour map of year 2010 is shown in Figure (3-2). Chloride concentrations are the highest along the Gaza border in the middle and south areas with concentrations exceeding 1500 mg/l. The best water quality is founded in the sand dune areas in the north of Gaza strip, mainly in the range of 50 – 250 mg/l. There are three major sources of groundwater salinity; leakage of brackish saline water lowing from adjacent aquifers along the eastern boundary of the coastal aquifer (600-2000 mg/l Chloride), sea water intrusion along the coast from the west and mixing with deeper very saline water from below and the over-exploitation of the coastal aquifer resulting in the creation of water level depressions while preventing the flushing of accumulated salts (Qahman, 2004).

Seawater Intrusion is defined as the migration of saltwater into fresh water aquifers under the influence of groundwater development. Seawater intrusion began in the late-1960s and the wedge continued to migrate inland at high rates due to increasing in municipal pumping and abstractions. Many modern studies indicate that seawater intrusion extends from 1 to 2.5 km along the western boundaries of Gaza strip along the sea, especially in Gaza city-Jabalia and Khanyounis-Rafah. These areas correspond to the largest pumping quantities where the Ground water levels are 1-6 m below the mean sea level (Metcalf & Eddy, 2000; Qahman, 2004).

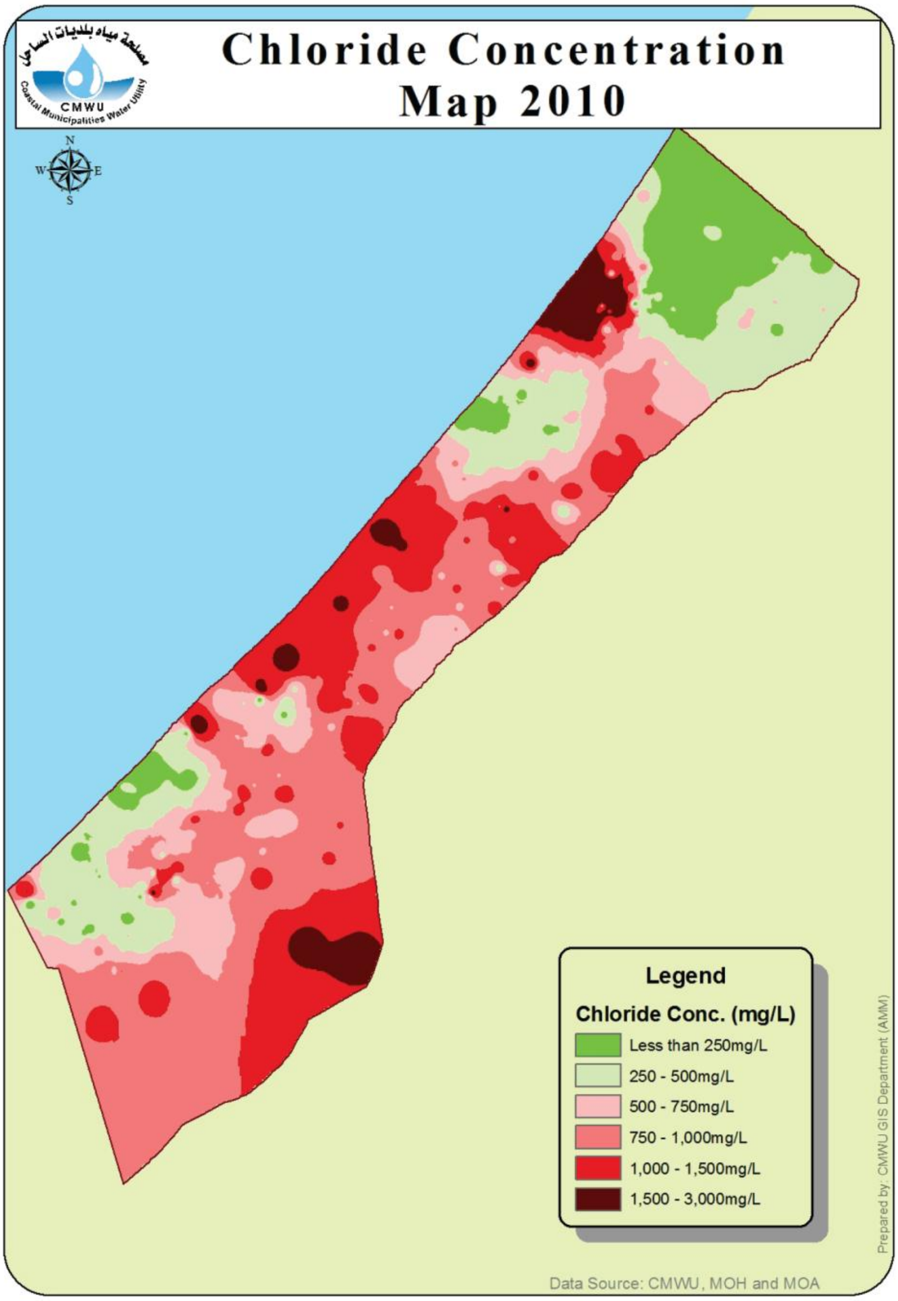


Figure (3-2): Chloride Concentrations (mg/l) for Year 2010 (CMWU, 2011).

3.2.2 Nitrate Pollution

The lateral groundwater inflow to the Gaza Strip aquifer does not contain any nitrate pollution. Therefore, it is believed that the nitrate in groundwater is of anthropogenic origin. Application of fertilizers and pesticides in agricultural areas is the main reason of increasing nitrate level in groundwater. In addition to agricultural activities, nitrogen released from wastewater discharge plays a big role in aquifer pollution. Different factors affect the amount of nitrate pollution in groundwater resulted from nitrogen load at the land surface. Such factors could be fertilizers and manure application rate, thickness of unsaturated zone, crop management, and form of applied nitrogen (Baalousha, 2006).

Increasing of nitrate is one of the most important and widespread of the numerous potential groundwater contaminants. The main causes of nitrate pollution are the excessive use of fertilizers in intensive agriculture, the irrigation with domestic wastewater and livestock farming (Rocca et. al., 2005). The problem of high nitrate concentrations in drinking water constitutes a major health risk to both humans and stock life. Nitrite reacts directly with hemoglobin in human blood and other warm-blooded animals to produce methaemoglobin. Methaemoglobin destroys the ability of red blood cells to transport oxygen. This condition is especially serious for babies under three months of age. It causes a condition known as methaemoglobinemia or "blue baby" disease. The WHO assigned the nitrate of 50 mg/L as a health significant value in drinking water. Most municipal wells in Gaza Strip show nitrate levels in excess of the WHO drinking water standard of 50 mg/l. In the worst affected areas (urban centers), NO_3 concentrations are increasing at rates of up to 10 mg/l per year. The main sources of NO_3 are fertilizers and domestic sewage effluents. The quantities of sewage that infiltrate to the water table on an annual basis through cesspits and septic tanks are significant, about 12*106 m^3/y. In contrast to salinity, groundwater flowing from the east has relatively low NO_3 levels (Mogheir, 2006). Figure (3-3) shows nitrate concentration in the Middle Governorates for year 2010.

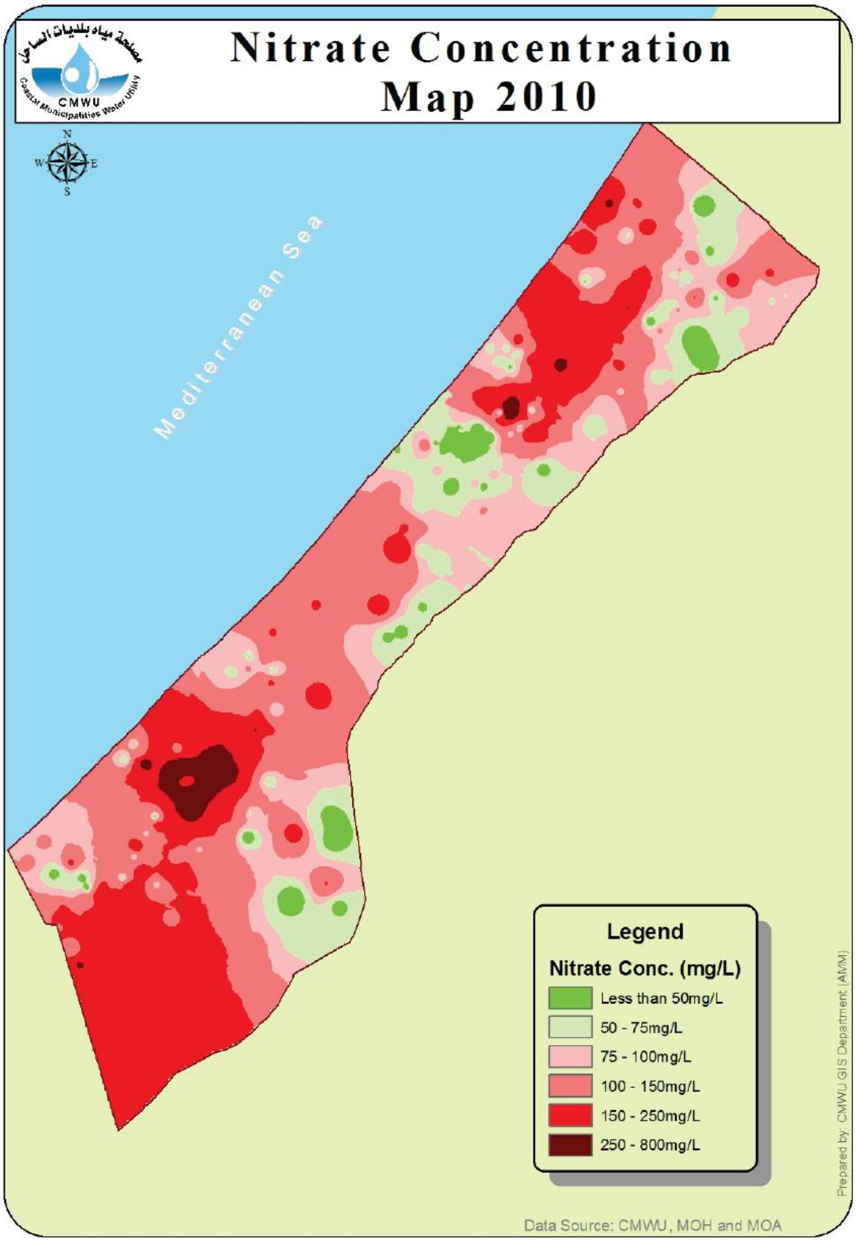


Figure (3-3): Nitrate concentration (mg/l) for Year 2010 (CMWU, 2011).

3.3 Groundwater Flow and Water Levels

Under natural conditions, groundwater flow in the Gaza strip is towards the Mediterranean Sea, where fresh groundwater discharges to the sea. However, natural flow patterns have been significantly disturbed by increasing population and over pumping in the past 40 years (Metcalf & Eddy, 2000). Within the southern part of Gaza strip), large cone of depression has formed over large area. Water levels are presently below mean sea level in many places, inducing a hydraulic gradient from the Mediterranean Sea towards the major pumping centers and municipal supply wells as shown in Figure (3-4).

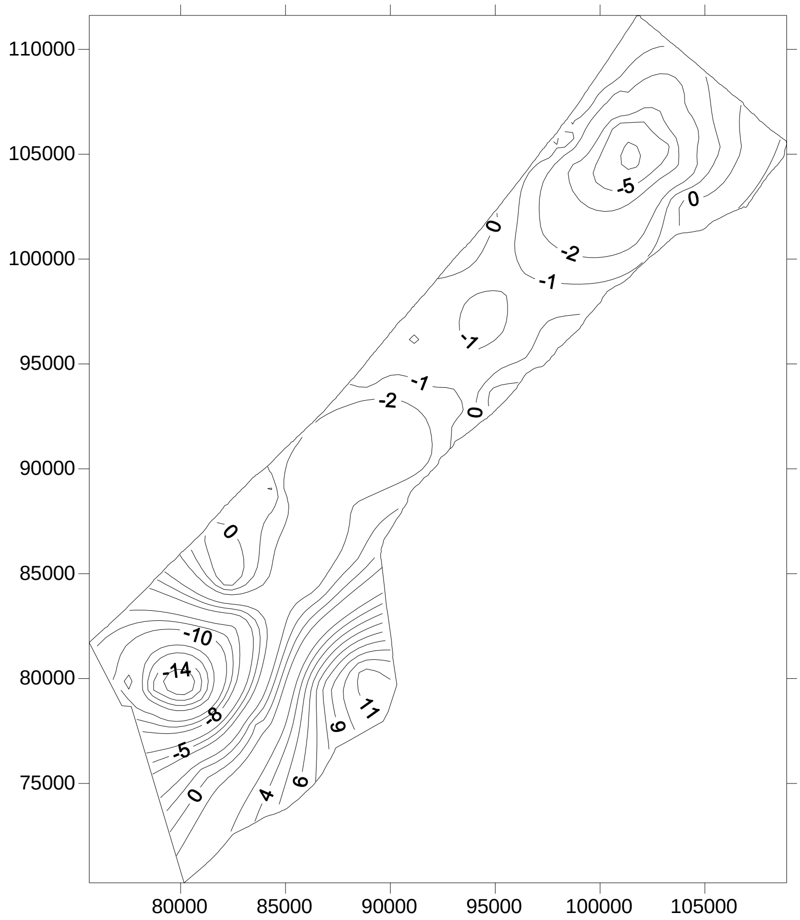


Figure (3-4): Water Level in Gaza Strip (2010).

3.4 Water Resources

Gaza's water resources are essentially limited to that part of the coastal aquifer that underlies its 360 km^2 area. The coastal aquifer holds approximately 5000 MCM of groundwater of different quality. However, only 1400 MCM of this is fresh water, with chloride content of less than 500 mg/l. This fresh groundwater typically occurs in the form of lenses that float on the top of the brackish and/or saline groundwater. That means that approximately 70% of the aquifer is brackish or saline water and only 30% is fresh water (Al-Yaqubi A., et al., 2007).

The major source of groundwater recharge to the aquifer is rainfall. Rainfall varies from one year to another (from 400 mm/y in the North to about 200 mm/y in the south). The total rainfall recharge to the aquifer is estimated to be approximately 45 MCM/y. The remaining rainwater evaporates or dissipates as run-off during the short periods of heavy rainstorms.

The lateral inflow to the aquifer is estimated at between 10-15 MCM/y. Some recharge is available from the major surface flow (Wadi Gaza). However, Because of the extensive extraction from Wadi Gaza in Israel, this recharge is limited to, at its best, 1.5-2 MCM/y during the 10 or 50 days that the Wadi actually flows in a normal year. As a result, the total fresh water recharge at present is limited to approximately 56.5- 62 MCM/y (PWA, 2000).

The water balance of the Gaza coastal aquifer has been developed based on an estimate of all water inputs and outputs to the aquifer system. The Gaza coastal aquifer is a dynamic system with continuously changing inflow and flows. The present net aquifer balance is negative; that is, there is a water deficit (Al-Yaqubi A., et al, 2007).

1. Lowering of the groundwater table.
2. Reduction in availability of fresh groundwater.
3. Increased seawater intrusion and potential intrusion of deep brines.

The net deficit has led to a lowering of the water table in the past 30-40 years and to the inland migration of seawater. Of these two factors, seawater intrusion accounts for a greater fraction of the volume loss, but it is less visible and thus tends to lessen the perception of the worsening aquifer evolution (Al-Yaqubi A., et al, 2007).

The annual deficit in water resources increases annually in addition to the continuous deterioration of the aquifer as a result of seawater intrusion and wastewater discharge. Annual input to the aquifer is expected to increase as a result of on-going desalination projects, in addition to artificial recharge. The annual safe yield of the coastal aquifer is not more than 60 million m^3. Thus, the water available in the aquifer covers only part of the needs, whereas the rest should be secured by other means. According to the PWA plan, the shortage will be eliminated through desalination of brackish water and seawater and through wastewater reuse (Baalousha, 2006).

CHAPTER 4 : Experiment Methodology

4.1 Experimental Description

The objective of this study is to optimize the use of nanofiltration for nitrate removal from Gaza strip ground water. A dead-end laboratory module system (stirred cell) which is especially designed for research purpose is to be used for the experimental works in this research. Also flat sheet membrane is to be used in this module as shown in Figure (4-1).

The system consist of (HP4750 cell – Nitrogen gas cylinder – three way valve – NF90 membrane – Regulator- pipe).

Figure (4-1): System component.

A bench scale dead end module with capacity of 0.3 L was used. The unit could be operated at pressures (6-8-10-12) bar, using pressure difference as a driving force and the pressure was obtained from a nitrogen cylinder, Magnetic stirrer is used to homogenized the feed sample, the membrane area is 0.00146 m^2. All the experiments were performed at room temperature.

4.2 Materials

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

4.2.1 Membrane

NF90 nanofiltration element is a high area, high productivity element designed to remove a high percentage of salts, nitrate, iron and organic compounds such as pesticides, herbicides and THM precursors. The high active area membrane combined with low net driving pressure of the membrane allows the removal of these compounds at low operating pressure; Properties of NF90 indicated by manufacture for cross flow module is shown in Figure (4-2).

Figure (4-2):NF90 nanofiltration membrane.

4.2.2 Chemicals

The chemical used to prepare aqueous solutions, NaCL and KNO_3 slates with purity 99 % were used to prepare 2000 mg/L NaCL solution and (50-100-150-200-250-300-350-400) mg/L NO3 solutions. Chemical used in the preparation of aqueous solution are showed in Figure (4-3).

Figure (4-3): chemical used for preparation solution.

4.2.3 Deionized Water

The de ionized water was used to prepare solution and it was brought from chemical lap in Islamic university.

4.3 Experimental Apparatus

The experimental apparatus was composed of the following:

- **HP4750:**

HP4750 Stirred Cell is a high-pressure chemical resistant stirred cell that performs a wide variety of membrane separations. With a maximum pressure rating of 69 bar (1000 psig), the HP4750 Stirred Cell is ideally suited for reverse osmosis (RO) filtration. The cell also performs nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF) separations. Stainless steel construction and chemical resistant components make the HP4750 Stirred Cell an ideal choice to filter aqueous and non-aqueous solutions; The Specification of HP4750 is shown in the Table (4-1).

Table (4-1): Specification of HP4750 (Sterlitech HP4750 stirred cell instruction manual)

Operating Parameters	
Membrane Size	49 mm diameter
Active Membrane Area	14.6 cm^2
Processing Volume	300 mL
Hold-UP Volume	1 mL
Maximum Pressure	69 bar
Maximum Temperature	121 ^oC
pH Range	Membrane Dependent
Cell Diameter	5.1 cm
Cell Height	22.4 cm

- **Nitrogen gas cylinder:**

The Nitrogen gas cylinder will provide the needed pressure for filtrate the water sample, which ranges from 1 bar to 150 bars.

- **Regulator:**

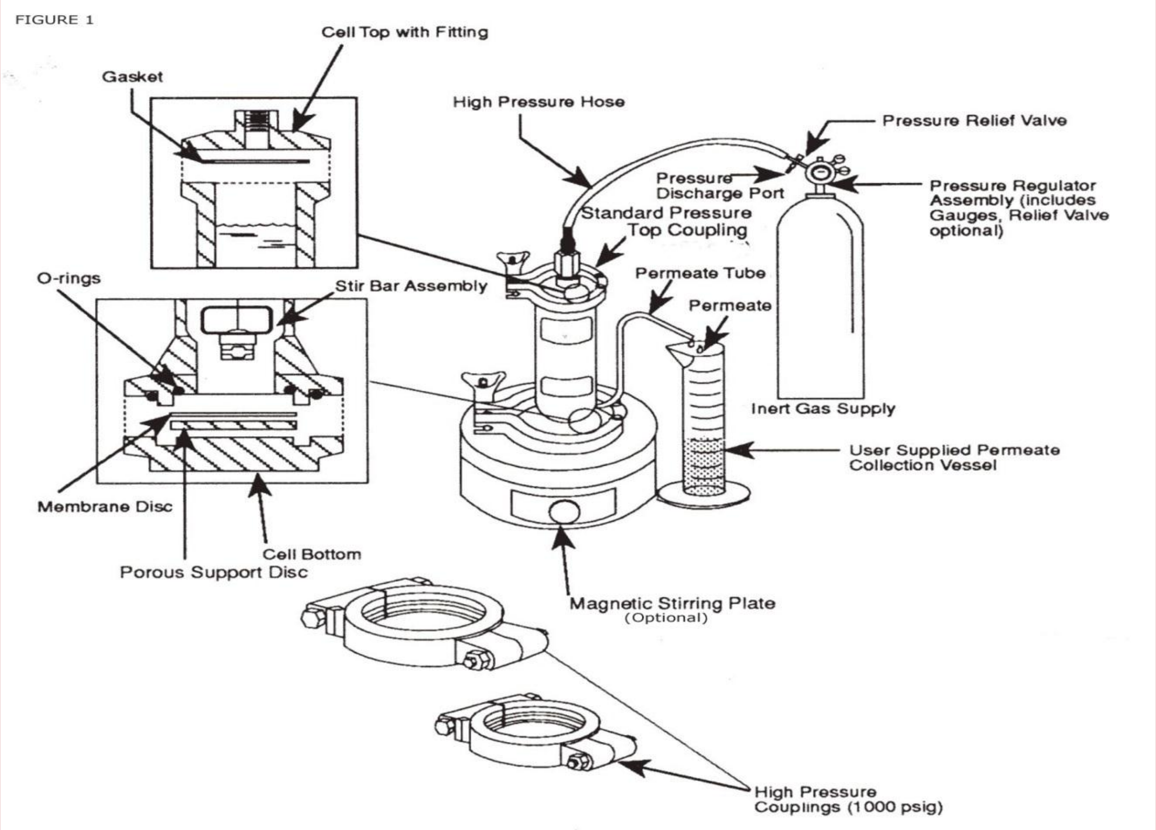
The regulator is used for controlling of pressure in the system.

- **Three way valve:**

The three way valve is used to empty the nitrogen gas from the cell.

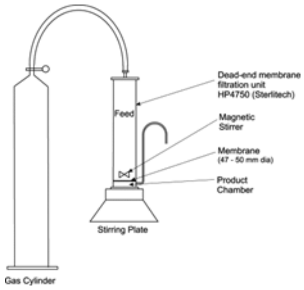
- **Pipes & fittings:**

Transport the gas to pressurize the water into the cell. Copper pipe with external diameter 6.3 mm and 2 m length (conserves the applied pressure, anti-corrosive, code STM 208). Apparatus parts are showed in). The experimental apparatus is shown in Figure (4-4).



System component

Nitrogen gas cylinder



System Schematic

NF Flat sheet membrane

HP 4750 Cell

Three Way Valves

Regulator

Figure (4-4): Experimental apparatus.

4.4 Water Sample

Water samples were collected from different municipal wells distributed on all Gaza Strip governorates and divided based on the concentration of Nitrates, the sample Nitrates concentrates are chosen every fifteen mg/L, the concentrations of Nitrates between (32-364) mg/L, The total number of samples are shown in Table (4-2).

Table (4-2): Water sample distribution on study area.

Governorate	Number of samples
North Gaza	6
Gaza	6
Middle Gaza	3
Khanyounes	5
Rafah	4
Total	24

The water samples were collected based on PWA chemical tests results in 2011. Table (4-3) shows the selected wells and chemical analysis. Figure (4-5) shows wells sample location.

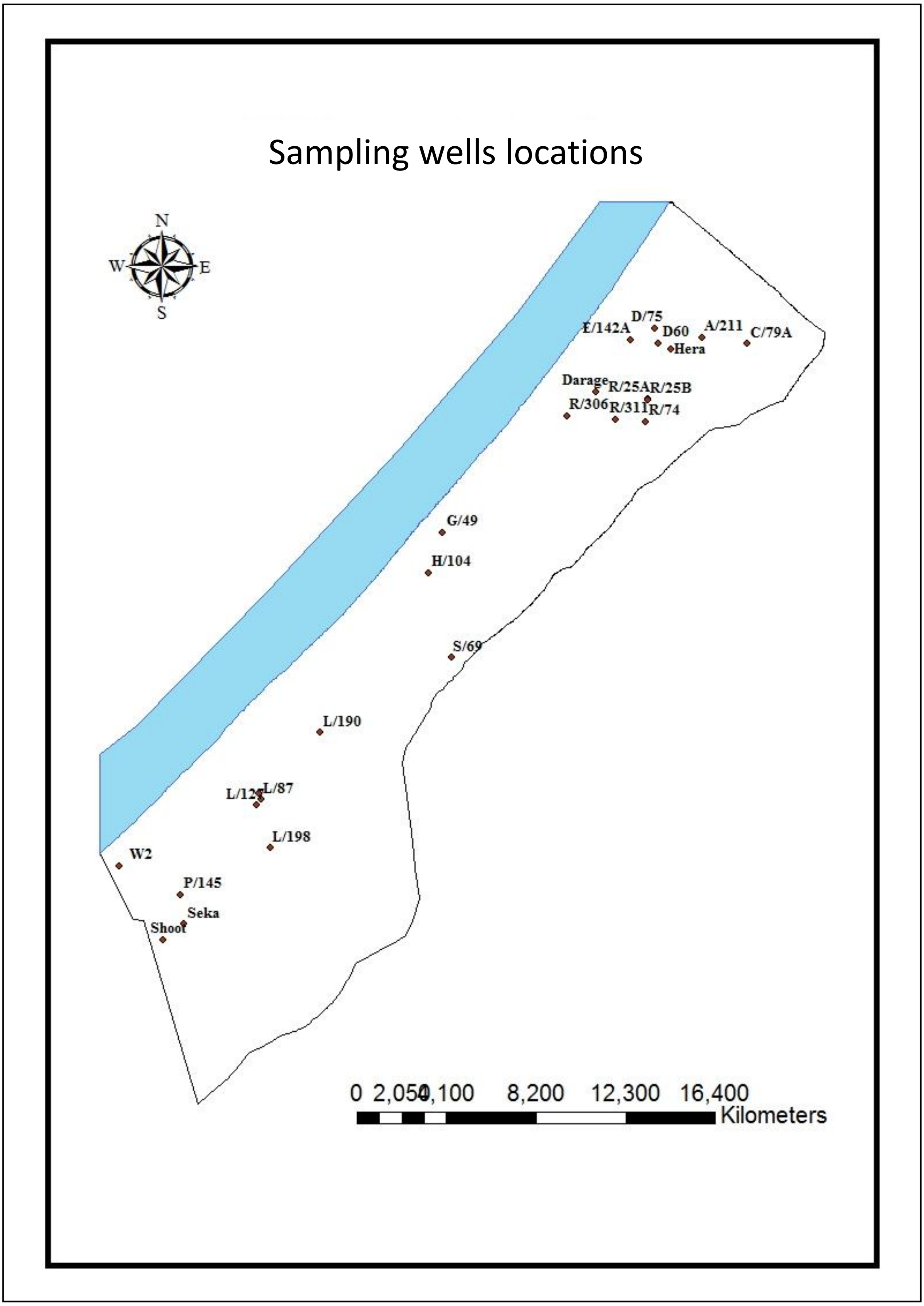


Figure (4-5): Wells sample location.

Table (4-3): Well sample chemical analysis.

Well No.	*EC (μΩ/cm)*	*TDS*	*PH*	*Calcium Ca (mg/L)*	*Magnesium Mg (mg/L)*	*Sodium Na (mg/L)*	*Potassium K (mg/L)*	*Chloride Cl (mg/L)*	*Nitrate NO3 (mg/LNO3)*	*Sulphate SO4 (mg/L)*	*Alkalinity (mg/l)*	*Hardness (mg/l)*
S69	24260	1506	7.14	62	48	380	3.6	580	32	240	274	353
A211	755	500	7.48	48	32	54	3.2	97	45	22	212	251
W2	1564	970	7.62	71.44	59	167	5.9	217	71	108	167	421
H104	3900	2454	7.98	118	102	560	5.1	967	76	394	232	715
E124A	4810	3140	7.22	214	153	560	4	1442	80	149	181	1165
R74	3690	2200	7.37	46	76	680	3.2	824	120	219	429	427
D75	971	630	7.38	78	39	70	4.7	109	133	41	232	356
R306	2560	1587	7.89	87	49	400	3.4	566	136	155	371	418
G49	4810	3010	7.67	131	121	720	5.8	1196	138	550	247	827
Astath	4570	2900	8.02	65	64	840	10.8	1174	140	407	209	427
R25A	3010	1900	7.31	43	59	520	16	565	146	269	411	351
Darage	2100	1200	6.99	106	70	230	7.5	408	178	111	333	556
L198	3370	2100	7.35	33	37	640	3.2	695	185	375	284	235
C79A	2540	1600	7.14	95	89	300	3.3	509	190	105	361	605
L190	5620	3570	7.65	65	68	1050	5.9	1346	193	628	271	441
P145	2730	1650	7.47	105	77	380	4.8	662	206	213	162	580
D60	1534	950	7.22	107	60	135	7.5	225	211	90	252	516
R311	4290	2570	7.53	114	95	640	77.9	891	217	444	521	677
R25B	3250	2020	7.11	78	104	480	26	608	226	280	413	623
Seka	4240	2673	7.38	87	69	700	5.2	964	230	359	240	503
Hera	2050	1350	7.06	114	78	190	25	309	273	135	302	605
L87	3800	2450	7.89	94	93	580	6.4	848	304	271	292	619
Shoot	3710	2574	7.69	70	66	670	4	838	332	356	225	449
L127	3140	1950	7.17	117	97	430	3.8	687	364	157	228	690

4.5 Measurement

After collecting the samples, major chemical analysis were performed for these samples such as (pH, TDS, and NO_3).

4.5.1 Nitrate Measurement

4500-NO_3 nitrogen (nitrate)*#(1) method was used in nitrate measurement. nitrate concentration was determined by CT-2600 Spectrophotometer (Figure (4-6)). The instrument was turned on and warmed up for 20 min before starting any sample measurement. The cuvette was cleaned every time before the use by rubbing the inner wall with a detergent-saturated cotton-tipped stick.

Figure (4-6): spectrophotometer.

4.5.2 TDS Measurement

Concentration of TDS was determined by Conductivity meter (Microprocessor conductivity meter BODDS-307wW (Figure (4-7)), which measure the EC.

To get the TDC value we multiply EC by (0.6).

Figure (4-7): Conductivity meter.

4.5.3 pH

pH is a logarithmic notation used to measure hydrogen activity (i.e., whether a solution is acid or basic).

$$pH = - \log [H+]$$

As a simplification, it is assumed that pH is a function of the hydrogen ion concentr tion {[H+]} when in reality it is related to the hydrogen ion activity H+.

Since pure water is slightly ionized, it is expressed as an equilibrium equation termed the ion product constant of water. The concentration of these two ions is relatively small and is expressed as a simple logarithmic notation. pH is the negtive log of the hydrogen ion **(Bailar, 1978).**

The pH was measured with (pH/ORP/ISE Graphic LCD pH Bench top Meter , HANNA instrument) pH meter(Figure (4-8)).

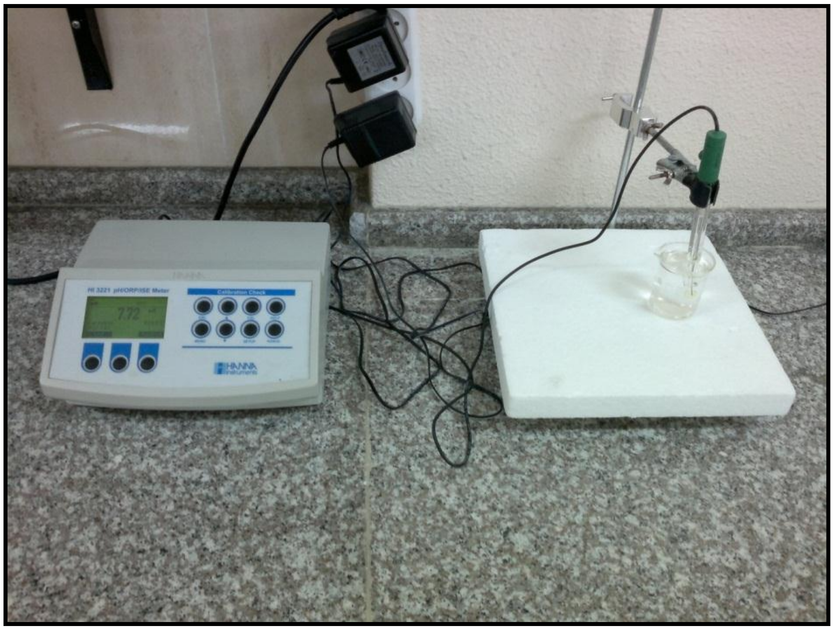


Figure (4-8): pH meter.

4.5.4 Flux Rate

Represents the volume of liquid passing through specific area of membrane at certain operating pressure during a period of time.

The flux rate of a filter is important in determining how rapidly filtration can be completed. If there is nothing in the sample stream to clog the pores, the flux rate should remain constant.

$$Flux\ rate = V/A.t\ \ (l/m^2.hr)$$

Where;

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

A: surface area of membrane *(0.00146 m^2).*

t: time of filtration*(hr).*

Note that these tests were carried out at different pressures (6, 8, 10, 12 bar), because this pressure ranges are lie in the operation pressure range of NF membrane (Filmtec membranes product information).

4.5.5 Rejection:

The same meaning of removal efficiency, 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 the following equation:

$$\%R= (1-C_p/C_f)*100$$

Where;

C_p: salt concentration in permeate *(mg/l)*.

C_f: salt concentration in feed water *(mg/l)*.

4.6 Experimental Procedure

The steps below illustrate the procedures that have been followed in order to measure flux rate, salt rejection for NF90.

4.6.1 Flux Rate

1. The membrane was cut and soaked in deionized water for 24 hr(Figure (4-9)).

Figure (4-9): Cited membrane.

2. The system was flushed with deionized water prior to any filtration experiment to remove any remainings or traces of salts.
3. The soaked membrane was placed in the cell which was filled with 250 ml of pure water solution and comoressed for 2 hours at 20 bar pressure (supplier recommended).
4. The soaked membrane was placed in the cell which was filled with 250 ml of feed solution.
5. The solution was compressed for 10 minutes at 10 bar pressure.
6. 2.5 ml of the permeate water at time (t) was collected in a cylinder flask.

Figure (4-10): system operation and collected sample.

Steps (5 and 6) were repeated for 8,10,12 bar. when changing the pressure the waiting time was 2-3 minutes Figure (4-10).

7. Same procedure was used to obtain pure water, real water, standard solution flux.

4.6.2 Rejection Rate

1. A new membrane was cut and soaked in deionized water.
2. TDS & NO_3 concentration of feed solution (real water sample and standard solution respectively) was measured.
3. The devices were installed and the NF cell was filled with 250 ml of feed water.
4. The pressure was adjusted by pressure regulator on the 6 bar. A stabilized pressure in NF cell will achieved after 10 minutes.
5. 20 ml of permeate was collected in a beaker from the outlet of the system.
6. TDS & NO_3 concentration were measured for the permeate water.
7. The rejection at 6 Bar was calculated.
8. Steps 4, 5, 6, 7 were repeated using pressure 8, 10, 12 Bar.

CHAPTER 5 : Result and discussion

This chapter shows the performance of the studied NF membrane in terms of hydraulic permeability, flux rate and salt/ion rejection. The experiment measurements described in previous chapter were used to study the performance of NF90 in nitrate and TDS rejection at deferent operating pressures and different nitrate concentrations. The results of aqueous solution and water samples of groundwater wells are discussed.

5.1 Membrane Performances in Aqueous Solution

5.1.1 Hydraulic Permeability and Flux Rate

Many factors influence the flux rate such as operating pressure and ionic concentration which were the main factors that affect the flux rate. In this section the influence and the relation between flux rate and operating pressure, the flux rate and ion concentration were developed.

5.1.1.1 Effect of Operating Pressure

The flux rate of the investigated NF90 membrane with pure water and 2000 mg/L of NaCl (aqueous solution) and different nitrate concentration varied between (50-400) mg/L concentrate. The flux rate of different solution types were tested against the change the operating pressures.

A. Pure water

The pure flux rate of the NF90 membrane was measured at pressures range of 6-12 bars Figure (5-1)illustrates the relationship between flux and pressure for NF90 membrane. As shown a linear relation (R2 is 0.99) with increasing behavior: when the pressure increases, the flux rate increases. The line slope indicated that the value of the hydraulic permeability is 1.388 (L/m2.hr.bar).

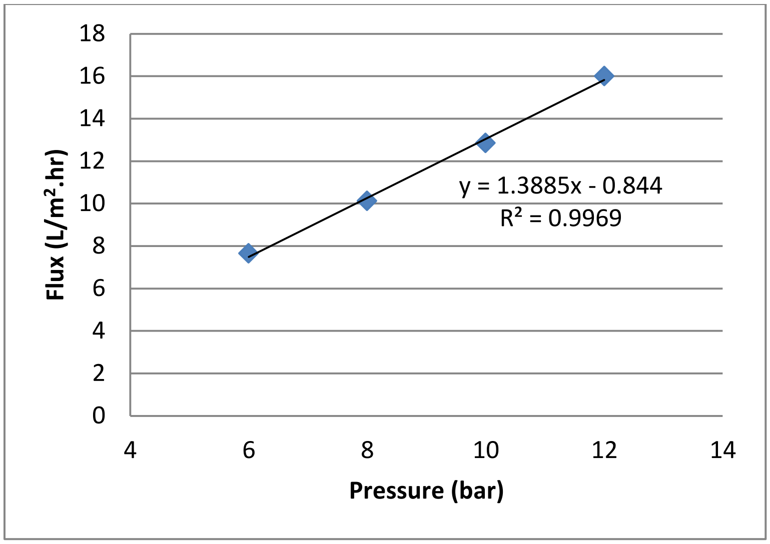


Figure (5-1): Pure water flux rate with different pressures (T=20^{0}C, pH=7).

The flux increase with a percentage of 24.61-32.28% as pressure increase by 2 bars. Such trend is commonly observed in the literature by Pontié, et al., 2007 and Hanane, 2008. It is clearly noticeable in Figure (5-1) that the pure water flux rate of NF90 ranges between (7.65-16) (L/m^2.hr).

B. NaCL Solution

A 2000 ppm of NaCl solution was used to compare results with manufacture sheet for NF90 membrane. The flux rate of the solution was measured at a pressure range between 6-12bar; in order to distinguish the difference of membrane performance between a solution of one salt and real water (mixed salts).

Figure (**5-2**) illustrates the relationship of flux rate with pressure for aqueous solution.

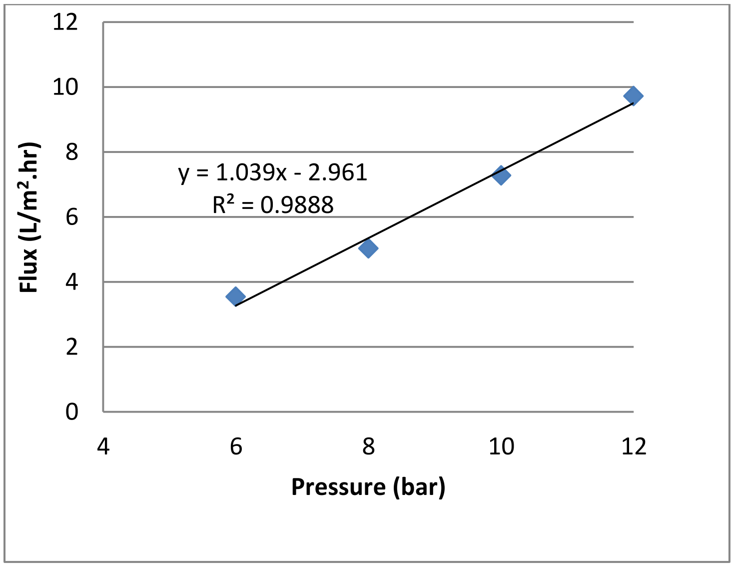


Figure (5-2): Aqueous solution flux rate with different pressures (T=20^{0}C, NaCl 2000 mg/L).

Figure (5-2) shows also a linear relationship with high correlation coefficient (R^2= 0.988). An increase of 33.7- 44.5% of flux and an increase of pressure by 2 bar for NF90 is encountered. The hydraulic permeability in aqueous solution is 1.039 (L/m^2.hr.bar) which is less than in the pure water. This reduction in flux crossing is increased when the ions is added, probably due to increasing solution osmotic pressure (Hossein et al, 2011).

C. Nitrate solution

Different concentrations of nitrate solution were prepared, varied between 50 and 400 mg/L. The flux rates of the solutions were measured at pressures range between 6 to 12 bars; in order to investigate the effect of operation pressure on flux rate. The result showed that the flux rate increase linearly by the increase of the operating pressure as shown in Figure (5-3).

Table (5-1) also illustrates the effect of operating pressure on the permeate flux for different nitrate solution (Nitrate concentration ranges between 50 to 400 mg/l). The maximum flux rate was 14.88 L/m2.hr for 12 bar pressure and 50 mg/l nitrate concentration. The minimum flux rate was 5.39 L/m2.hr for 6 bar pressure and 400 mg/l nitrate concentration.. Therefore, NF 90 flux rate does not only depend on the operating pressure but also on the influent nitrate concentration.

Table (5-1): Nitrate solution flux rate and hydraulic permeability.

Nitrate Con. (mg/L)	Pressure (Bar)				hydraulic permeability (L/m^2.hr.bar)
	6	8	10	12	
	Flux Rate (L/m2.hr)				
50	7.2	9.09	11.8	14.88	1.2875
100	6.6	8.6	11.3	13.8	1.265
150	6.36	8.3	10.8	13.52	1.249
200	6	7.95	10.5	13.37	1.233
250	5.85	7.65	10.32	13.11	1.2225
300	5.7	7.46	10.1	12.76	1.191
350	5.47	7.29	9.94	12.21	1.1435
400	5.39	7.12	9.57	11.63	1.0585

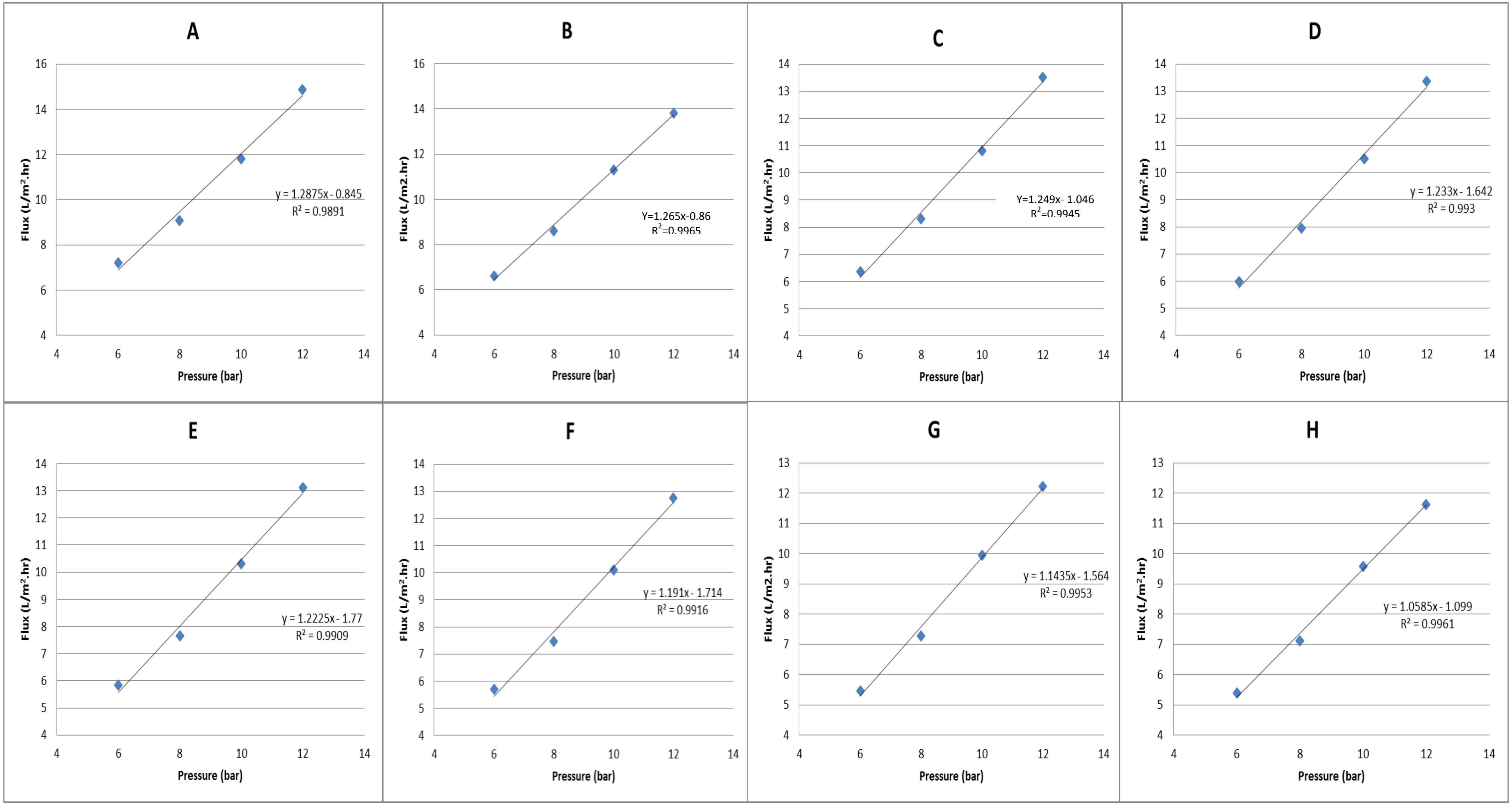


Figure (5-3): Effect of operating pressure on the permeate flux of nitrate solution for NF90 (T=200C, Nitrate concentration: A=50 mg/L, B=100mg/L, C=150mg/L, D= 200mg/L, E=250mg/L, F=300mg/L, G=350mg/L, H=400mg/L).

5.1.1.2 Effect of Ionic Concentration

The flux rate of the investigated NF90 membrane with different nitrate concentration varies between (50-400) mg/L concentrate was investigated to explain the relationship between ionic concentration and flux rate.

Nitrate Solution

Different concentration of nitrate solution was prepared, varied between 50 and 400 mg/L. The flux rates of the solutions were measured at a pressure ranges 6-12 bar; in order to investigate the effect of nitrate concentration on flux rate. The result of the experiments in Figure (5-4) showed that the flux rate decreases while the feed concentration increases. For each pressure, a linear relation can be obtained for flux rate against the feed nitrate concentration with high correlation ranges between (0.94 to 0.97). This reduction in flux crossing is increased when the ions is added, probably due to increasing solution osmotic pressure (Hossein et al, 2011).

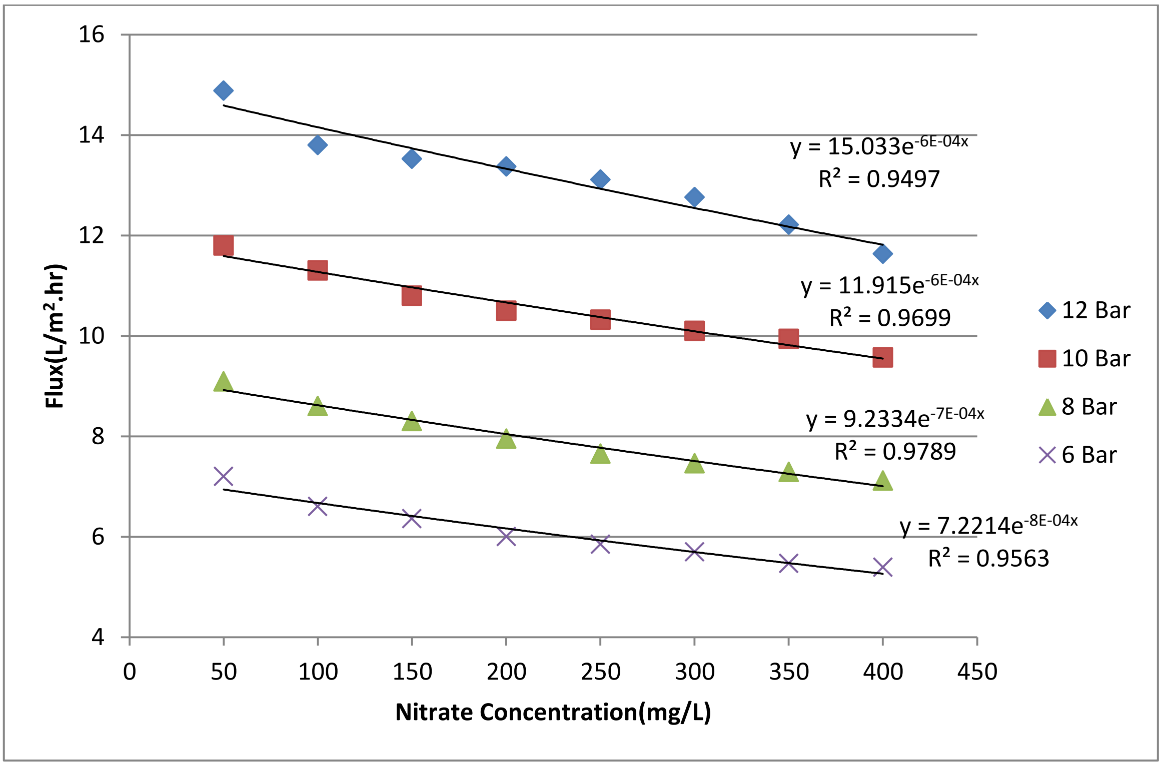


Figure (5-4): Effect of feed Nitrate concentration on flux of nitrate solution for NF90 membrane.

5.1.2 Rejection of Ionic Component

The performance characteristics of NF90 were evaluated using ion rejection for different operating pressure conditions and the characteristics of the investigated membrane. Experiments were carried out to obtain retention data of the NF90 membrane for NaCl solution and Nitrate solution for qualitatively evaluate the factors that influence the rejection.

5.1.2.1 Effect of Operating Pressure

The rejection of the ionic concentration was investigated on different pressures vary between 6-12 bar with 2000 mg/L. The rejection evaluation was carried out using different nitrate concentration vary between 50-400 mg/L with also different operating pressures.

A. NaCL Solution

The rejection of the investigated NF90 membrane for 2000 NaCl solution was plotted against the operating pressure as shown in Figure (5-5). The figure shows that the rejection increase with an increase of operating pressure (exponential relation with R^2=0.97). The minimum and maximum obtained rejection of solution was 44.2 % at 6 bar and 61% at 12 bars.

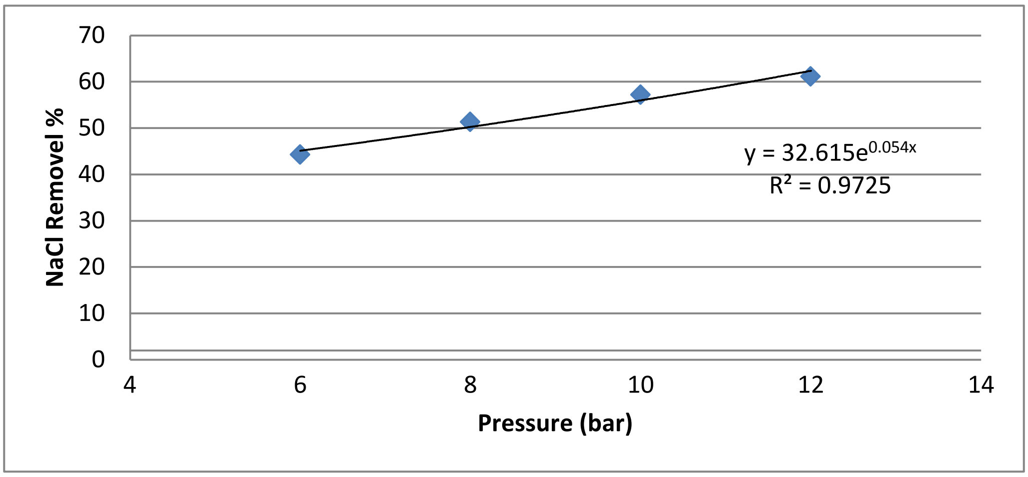


Figure (5-5): TDS removal for NF90 membrane at deference pressure

B. Nitrate Solution

Nitrate solutions were made in the lab and the concentration of nitrate ranges between 50 to 400 mg/l. The Nitrate removal (rejection %) of these solutions at different pressures were analysed.):) shows the relation between nitrate rejection % at different operating pressures and different nitrate concentrations.

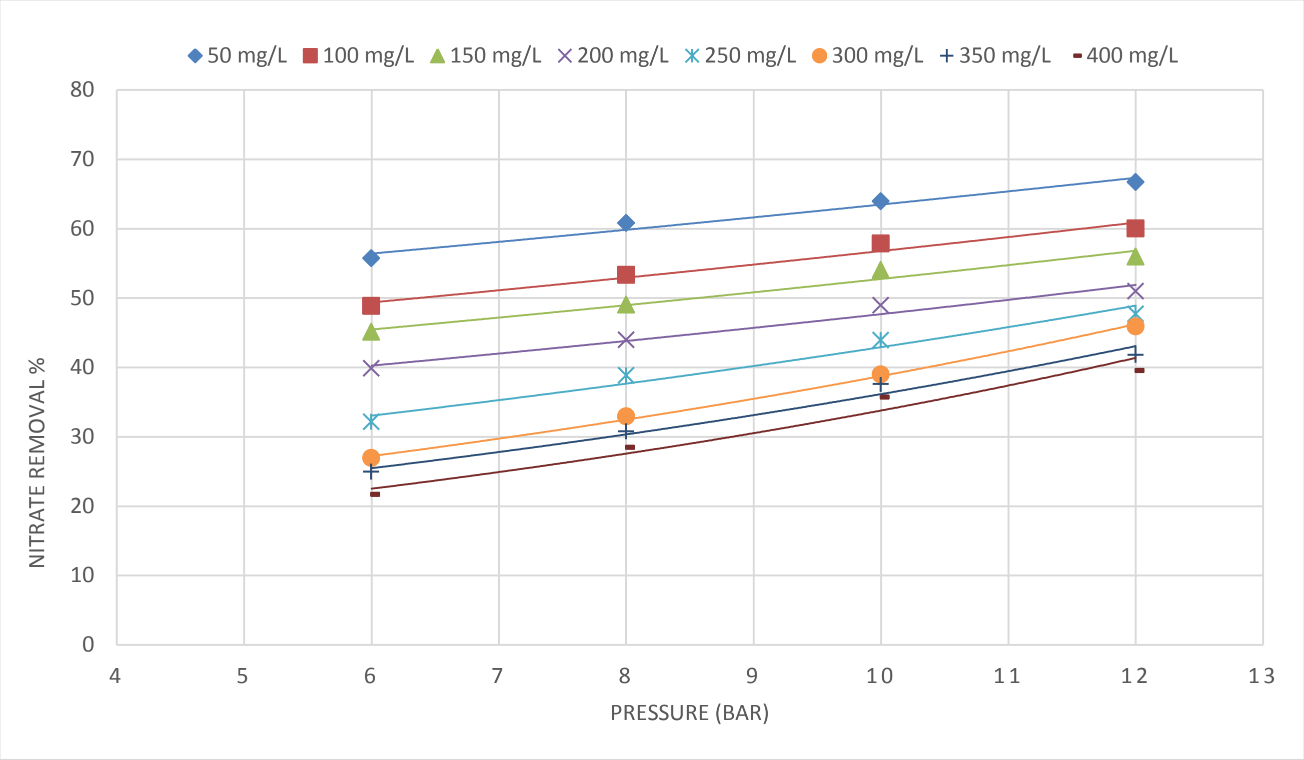


Figure (5-6): NF 90 Nitrate rejection with different operating pressures and different solution of nitrate concentrations .

Figure (5-6) illustrated that the nitrate rejection increases gradually with the increase of the applied pressures. 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 low transmembrane 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 (5-6) shows that the maximum nitrate rejections is 66.68% at pressure 12 bar and 50 mg/l nitrate concentration while the minimum rejection rate is 21.67%.at 6 bar pressure and 400 mg/l nitrate concentration.

5.1.2.2 Effect of Feed Concentration on Nitrate Removal

To investigate the effect of feed concentration on NF 90 nitrate rejection. The feed nitrate concentration was varied from 50mg/L to 400 mg/L, the result of NF 90 nitrate rejection are showed in Figure (5-7). As the nitrate concentration increase the nitrate rejection percentage decrease exponentially with high correlation ranges between 0.98 and 0.99. These were due to the characteristic of the charge membranes and Known as the screen phenomenon. With increased dissolved nitrate salts, concentrations of cations increased in the solution, the cations neutralized the negative charge on the membrane and increased passage of the nitrates ions through the membrane (Paugam et al, 2002).

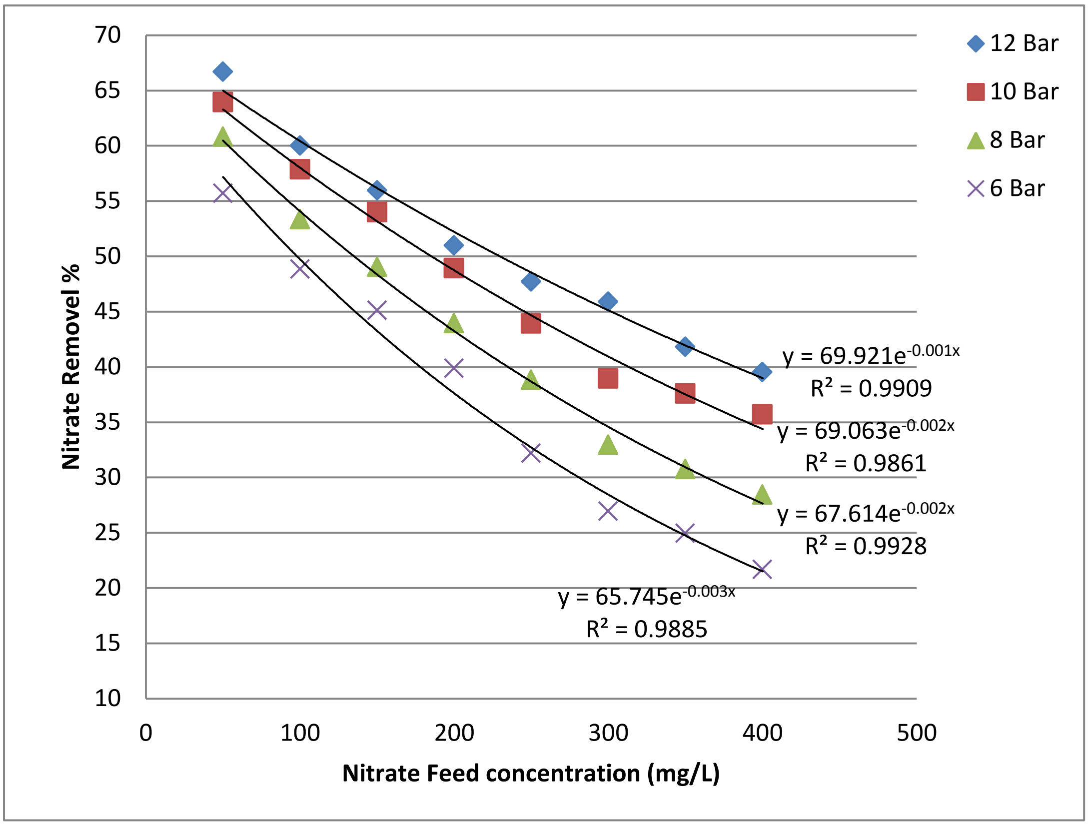


Figure (5-7): Effect of feed nitrate concentration on NF90 nitrate rejection %.

Table (5-2) show that the nitrate rejection by the NF90 decrease slightly when the slates concentration increase for more details referee to Appendix (1).

Table (5-2): initial nitrate concentration and permeate concentration at different pressures.

12 (Bar)			10 (Bar)		
Feed nitrate Con. (mg/L)	nitrate removal %	final concentration (mg/L)	Feed nitrate Con. (mg/L)	nitrate removal %	final concentration (mg/L)
50	66.68	16.66	50	63.94	18.03
100	60	40	100	57.85	42.15
150	55.95	66.075	150	53.99	69.015
200	50.98	98.04	200	48.92	102.16
250	47.69	130.775	250	43.92	140.2
300	45.88	162.36	300	38.95	183.15
350	41.79	203.735	350	37.59	218.435
400	39.51	241.96	400	35.69	257.24
8 (Bar)			**6 (Bar)**		
Feed nitrate Con. (mg/L)	nitrate removal %	final concentration (mg/L)	Feed nitrate Con. (mg/L)	nitrate removal %	final concentration (mg/L)
50	60.8	19.6	50	55.7	22.15
100	53.34	46.66	100	48.83	51.17
150	49.02	76.47	150	45.1	82.35
200	43.93	112.14	200	39.86	120.28
250	38.82	152.95	250	32.16	169.6
300	32.94	201.18	300	26.93	219.21
350	30.76	242.34	350	24.93	262.745
400	28.43	286.28	400	21.67	313.32

5.2 Membrane Performance in Real Water

In this section, the performance of NF90 for nitrate removal of Gaza Strip water was evaluated and compared with aqueous solution. 24 well samples were collected from deferent places distributed over five Governorates. Nitrate concentration of the samples varied in the rage of 32-364 mg/L and TDS from 500-3500 mg/l.

As aqueous solution, the performance of the studied NF90 membrane in terms of water flux rate and slat/ion rejection was investigated. The experiment measurements were used to study the performance of NF90 in nitrate rejection at deference operating pressures.

5.2.1 Hydraulic Permeability

Experimental data for the permeate flux with Gaza Strip water as a function of the operating pressure and ionic concentration were obtained.

5.2.1.1 Effect of Operating Pressure

Figure (5-8) shows the relation of the flux rate and the pressures for 4 random samples (well D75, Heraa, P145, and R74). The nitrate concentration of the water in these wells range between (120-237) mg/l and the TDS concentration ranges between (630-2200)mg/l. Figure (5-8) shows that in the four wells samples, the flux rate increase linearly with the increase of pressure as in the case of the aqueous solution observed in section 5.1. The higher flux rate observed at 12 Bar in A211 well, and minimum flux at 6 Bar in L190 well. A211contains lowest TDS with 500 mg/l TDS and L190 contains highest TDS with 3570 mg/l, therefore the TDS concentration has influenced the flux rate as discussed in section 5.2.1.2

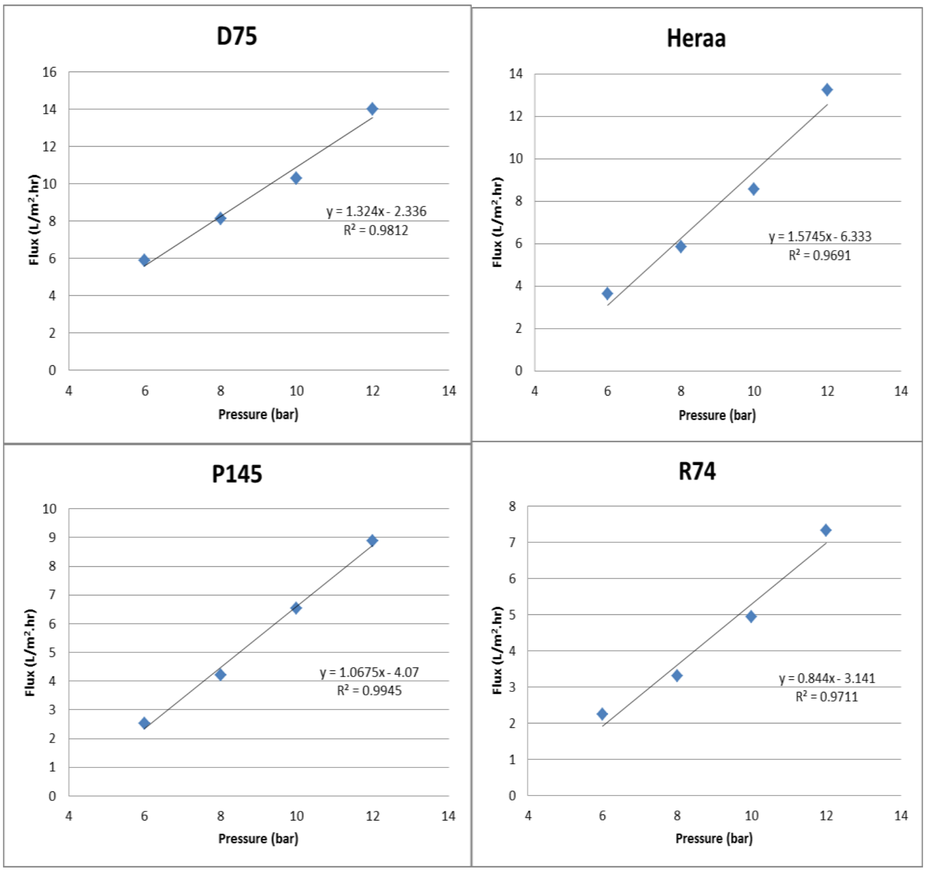


Figure (5-8): Effect of operating pressures on NF90 flux rate for Real water samples.

Table (5-3) showed the flux rate of water sample at different pressure for all 24 wells. The maximum flux rate was 14.12 L/m^2.hr obtained at A211 well and 12 bar pressure and the minimum flux rate was 1.69 L/m^2.hr at L190 well at 6 bar operation pressure.

Table (5-3): Real water flux rate (L/m^2.hr) at deferent pressures.

Well ID.	Pressure (Bar)			
	6 Bar	8 Bar	10 Bar	12 Bar
A211	6.01	8.65	10.45	14.12
D75	5.89	8.14	10.29	14
D60	3.72	5.63	8.08	13.35
W2	4.32	6.53	8.69	13.53
Darage	3.01	4.97	7.58	11.24
Hera	3.65	5.48	8.03	13.24
S69	2.61	4.5	6.43	9.45
R306	2.6	4.77	7.33	9.89
C79A	2.98	4.86	7.47	10.69
P145	2.53	4.21	6.54	8.87
R25A	2.83	4.82	7.43	10.23
L127	2.51	4.54	6.65	8.56
R25B	2.51	4.25	6.37	9.21
L198	2.43	3.41	5.54	8.42
R74	2.24	3.31	4.95	7.32
L87	2.16	3.06	4.56	6.89
H104	1.46	3	4.08	6.62
R311	1.57	3.14	4.56	6.75
Shoot	2.36	3.15	4.84	7.21
Seka	1.73	3.06	4.13	6.62
Astath	1.72	3.05	4.08	6.42
G49	1.71	3.05	4.06	6.42
E124A	1.70	3.05	4.03	6.40
L190	1.69	3.04	4	6.38

5.2.1.2 Effect of TDS Concentration

Figure (5-9) shows the relation between TDS concentration and flux rate. The result show that while the TDS concentration increases the flux rate decreases.

The result showed that TDS is not critical factor of flux when we compared two water samples. Darage well and Herra well have TDS 1200 and 1350 mg/L respectively, but flux rate in Herra is higher than in Darage well although TDS is lower. It was investigated that Cl conccentration on Herra well is less than in Darage well. This indicated that Cl concentration is determinant factors that influence the flux rate. Figure (5-10) presented the exponential decay relation between chloride concentration and flux rate at different operation pressures. The TDS relation with the flux rate is also expoenantiol decay, however, the correlation coefficient of Cl case is higher than in TDS case.

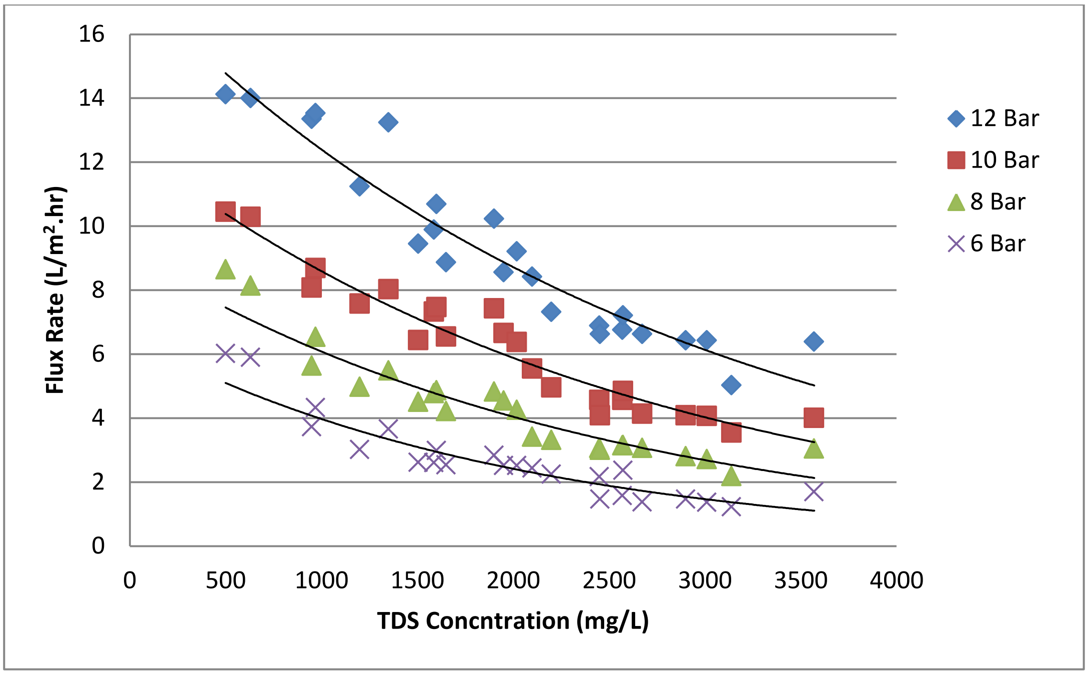


Figure (5-9): Effect of TDS concentration on flux rate for NF90 (Real water).

The maximum flux rate at minimum TDS concentration was 14.12, 10.45, 8.65 and 6.01 L/m^2.hr, respectively at 12, 10, 8, 6 bars. The minimum flux rate at maximum TDS concentration was 6.38, 4, 3.04 and 1.69 L/m^2.hr, respectively at 6, 8, 10, 12 bars. The maximum and the minimum values were obtained in wells A211 and L190, As A211 have minimum TDS and Cl and L190 have maximum TDS and high value of Cl .Table (5-8) presents the flux rate of all 24 wells.

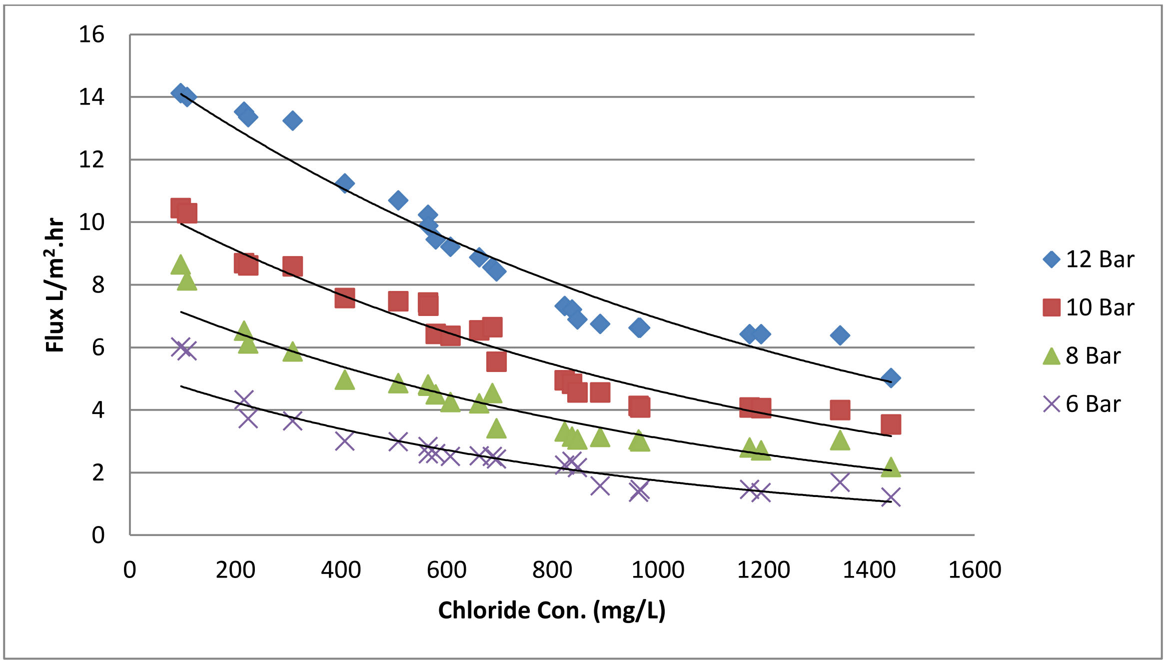


Figure (5-10): Relation between Chloride and Flux Rate for NF90 (Real water).

Table (5-4): Flux rate (L/m^2.hr), TDs and chloride.

Well ID.	***TDS***	***Chloride Cl (mg/L)***	**Pressure (Bar)**			
			6 Bar	***8 Bar***	***10 Bar***	***12 Bar***
A211	500	97	6.01	8.65	10.45	14.12
D75	630	109	5.89	8.14	10.29	14
D60	950	225	3.72	5.63	8.08	13.35
W2	970	217	4.32	6.53	8.69	13.53
Darage	1200	408	3.01	4.97	7.58	11.24
Hera	1350	309	3.65	5.48	8.03	13.24
S69	1506	580	2.61	4.5	6.43	9.45
R306	1587	566	2.6	4.77	7.33	9.89
C79A	1600	509	2.98	4.86	7.47	10.69
P145	1650	662	2.53	4.21	6.54	8.87
R25A	1900	565	2.83	4.82	7.43	10.23
L127	1950	687	2.51	4.54	6.65	8.56
R25B	2020	608	2.51	4.25	6.37	9.21
L198	2100	695	2.43	3.41	5.54	8.42
R74	2200	824	2.24	3.31	4.95	7.32
L87	2450	848	2.16	3.06	4.56	6.89
H104	2454	967	1.46	3	4.08	6.62
R311	2570	891	1.57	3.14	4.56	6.75
Shoot	2574	838	2.36	3.15	4.84	7.21
Seka	2673	964	1.37	3.06	4.13	6.62
Astath	2900	1174	1.46	2.8	4.08	6.42
G49	3010	1196	1.36	2.71	4.06	6.42
E124A	3140	1442	1.22	2.18	3.54	5.02
L190	3570	1346	1.69	3.04	4	6.38

5.2.2 Rejection of Ionic Component

The performance of NF90 in nitrate and TDS rejections was evaluated. Full chemical analyses of water samples were performed, to determine which factor may influence the nitrate and TDS rejection.

5.2.2.1 Nitrate Removal

As observed in aqueous solutions the effect of operating pressure was evaluated. In real water there were many factors that influenced the rejection percentage such as TDS concentration and other chemical concentration.

Effect of Operating Pressures

Examples of the effect of operating pressures on nitrate rejection are showed in Figure (5-11) The result show that as operation pressure increases the removal of nitrate increases. However, for other wells, the operating pressure was not the main influencing factor. TDS concentration plays an important role.

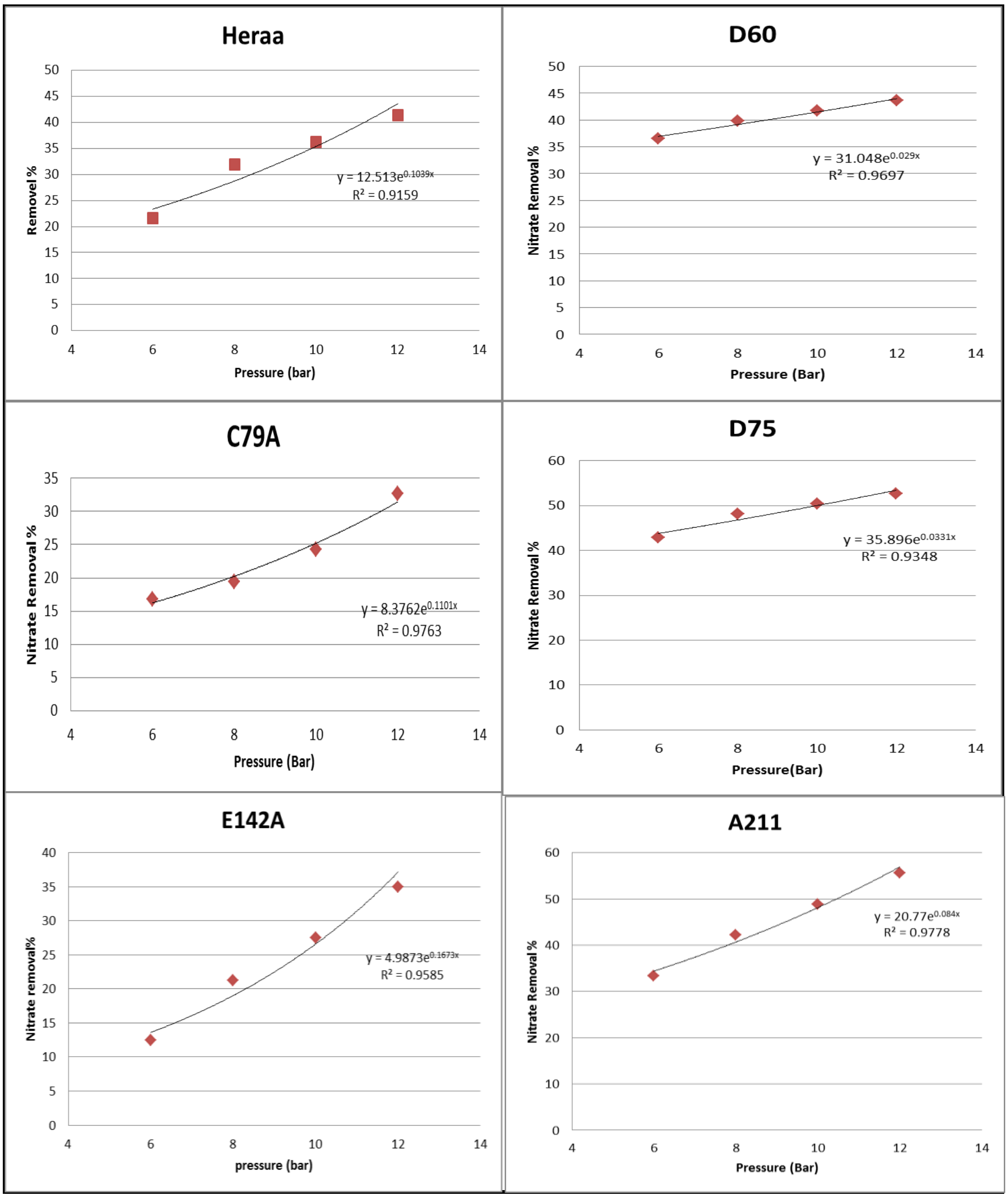


Figure (5-11): Effect of operating pressure on nitrate removal.

Table (5-5) shows the results of nitrate removal and operating pressures, The maximum rejection percentage at 12 bars was 55.56% at well A211 and the minimum nitrate rejection was zero at many wells when operating pressures was 6 bars depending to TDS concentration and composition and nitrate concentration in feed water. Section 5.2.2.1.2 illustrates the TDS effect on nitrate rejection.

Table (5-5): Nitrate removal and operation pressure.

Well ID	**Pressure (Bar)**			
	6	**8**	**10**	**12**
	Nitrate Removal %			
S69	5.35	10.6	15.15	28.13
A211	33.33	42.22	48.89	55.56
W2	18.31	28.17	39.44	42.85
H104	5.53	10.6	15.15	18.5
E124A	12.5	21.25	27.5	35
R74	5	10.83	15	18.33
D75	42.87	48.12	50.38	52.63
R306	8.09	14.71	19.85	23.53
G49	0.96	1.79	5.17	6.79
Astath	0.71	2.14	5.73	8.57
R25A	4.79	10.27	14.38	17.81
Darage	16.85	23.6	27.53	34.27
L198	1.62	4.86	8.11	10.81
C79A	16.84	19.47	24.21	36.63
P145	6.31	13.59	23.3	30.1
D60	36.49	39.81	41.71	43.6
R311	1.38	3.23	8.76	12.44
R25B	7.52	12.83	16.81	21.24
Seka	2.17	10	12.61	15.22
Hera	21.61	31.87	36.26	45.42
L87	4.61	9.21	14.47	17.76
Shoot	0.60	1.2	7.83	14.16
L127	18.68	23.9	29.67	32.97
L190	0.52	1.04	1.55	2.07

Effect of TDS Concentration and Other Chemical Compositions

The result in Figure (5-12) showed that in general that relation between TDS concentration and nitrate rejection, when we fixed the nitrate concentration in feed water. As shown in Figure (5-12) there are drop in curve, but when the effect of nitrate concentration is fixed and plot the nitrate removal and sulphate concentration, a strong relation between sulphate concentration and nitrate rejection was found (Figure (5-13)).

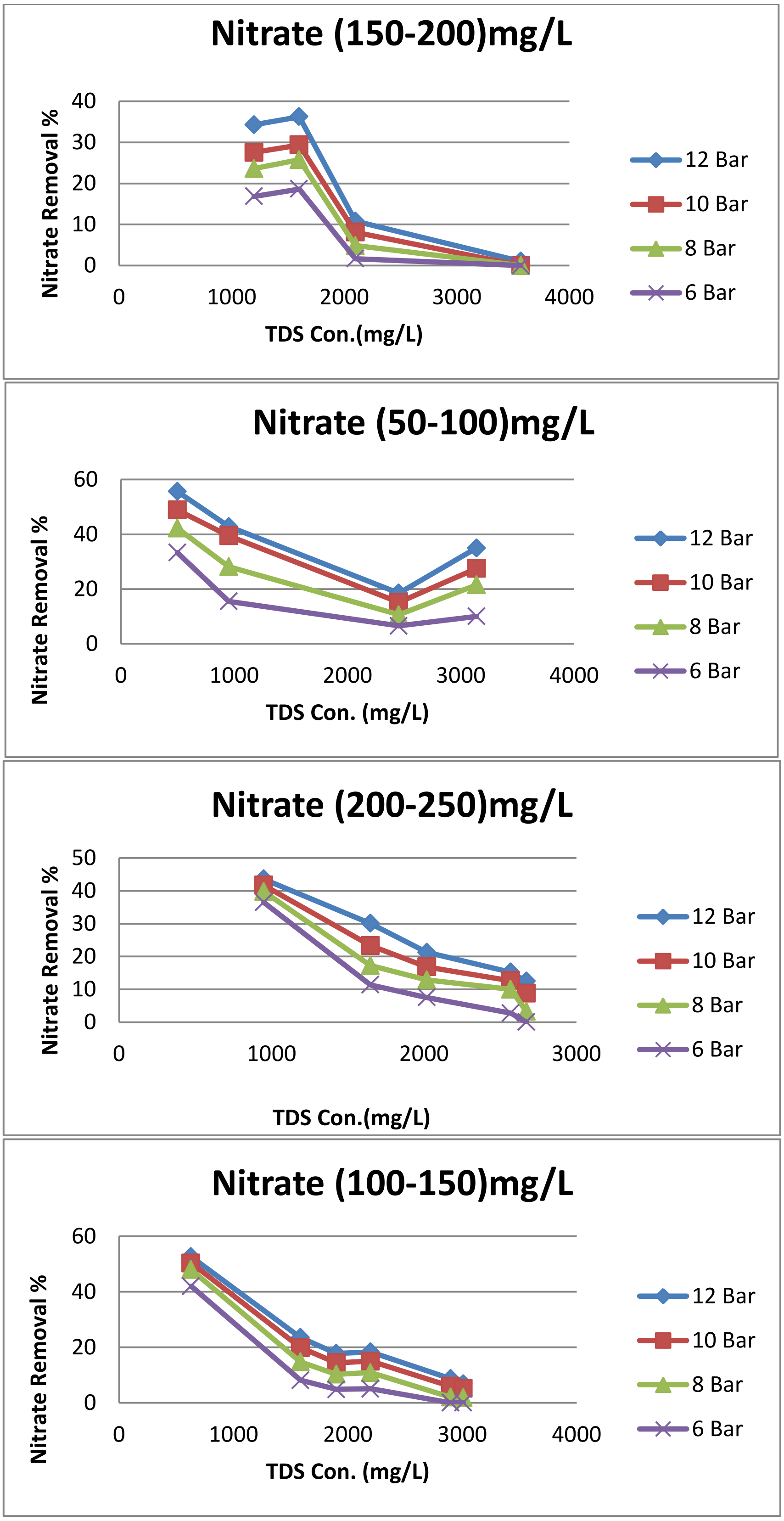


Figure (5-12): Relation between TDS concentration and nitrate rejection.

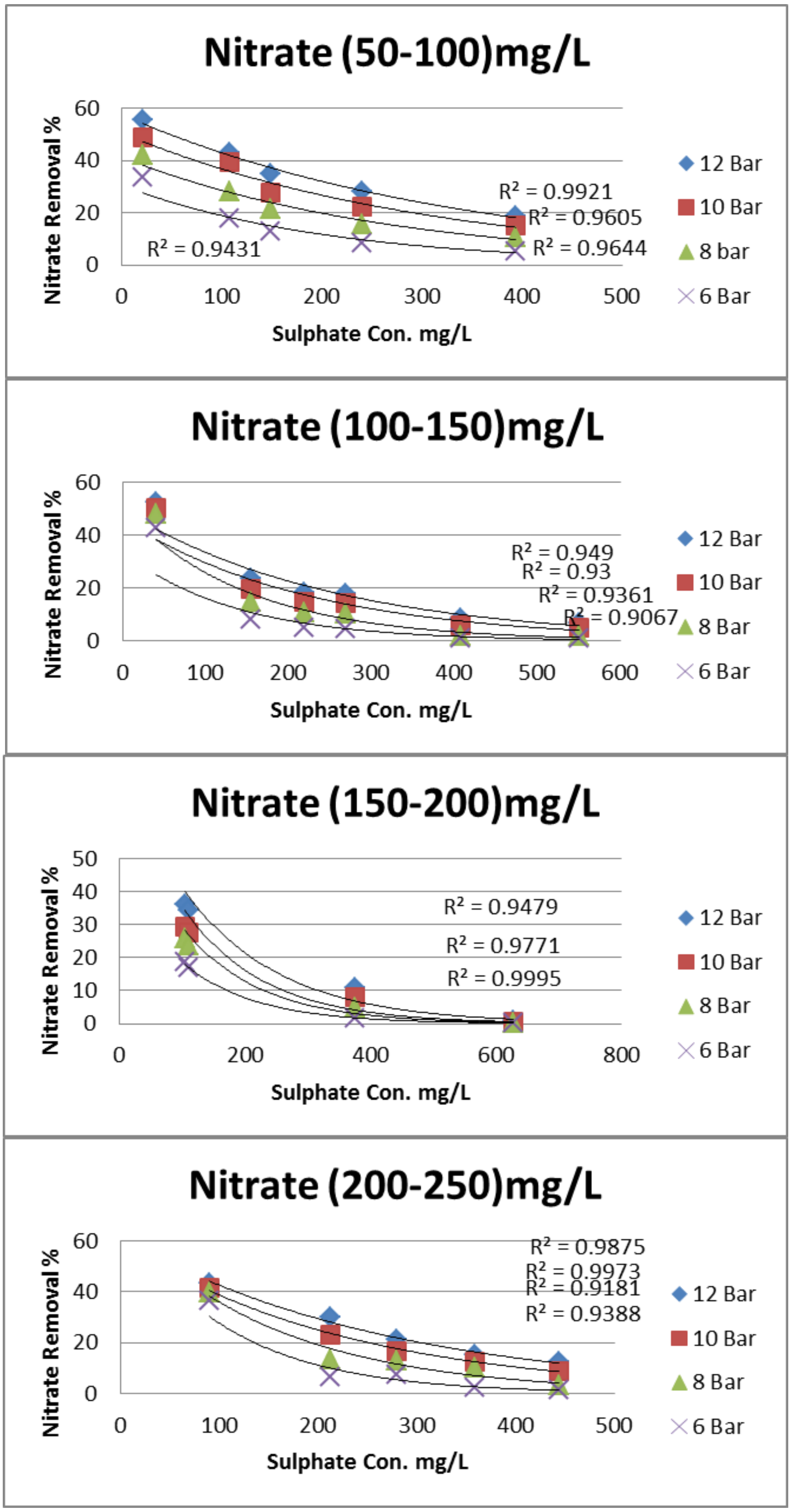


Figure (5-13): Relation between nitrate rejection and sulphat concentration.

Table (5-6) shows the nitrate rejection results against TDS and sulphat concentration. To show this relation, Nitrate concentration must be fixed. For example E124A well have 3140 mg/l as TDS concentration and S69 well has 1506 mg/l as TDS concentration, but nitrate rejection in E124A is higher than S69, although nitrate concentration in E124A is higher than in S68. This was due to that the sulphate concentration in E124A was 149 mg/L but in S69 was 240 mg/L. That means the sulphate concentration plays important role in NF90 nitrate rejection percentage.

Because of high removal of sulphate, because of their valance, nitrate are forced to pass through the membrane. The removal of monovalent such as nitrate was greatly decresed under the presence of sulphate ions. Retention of the negative sulphate ion in concentration water disturbed the electrical equilibrium on both sides of the membrane that the nitrate ions was forced through the membrane in permeate water to maintain electric equilibrium (paugman et al, 2002).

It was also observed that an increase of sulphate concentration generally decreases the chloride rejection. The retention of chloride anion is lower for the salt mixtures than for single salts experiment. It seems that the presence of high valance anion (SO_4) drives more chloride into membrane, thus decreasing its retention (krieg et al. 2004).

The sequence of rejection of monovalent anions can be written as R (F)> R (Cl)> R (NO_3), the observed retention of the three ions is similar to the ionic order and opposite to the hydration energy order for the monovalent ions, the F which has higher hydration energy is better retained than Cl and NO_3 (Diawara et al.2003, Wang et al. 2005).

From the above two paragraph it can be conclude that the chloride is better than nitrate in rejection according to rejection sequence, while sulphat has negative effect on chloride rejection so sulphate has negative effect on nitrate rejection.

Table (5-6): Nitrate rejection result with sulphat and TDS concentration.

Well No.	TDS	Nitrate NO3 (mg/LNO3)	Sulphate SO4 (mg/L)	6 Bar	8 Bar	10 Bar	12 Bar
A211	500	45	22	33.33	42.22	48.89	55.56
W2	970	71	108	18.31	28.17	39.44	42.85
E124A	3140	80	149	75	21.25	27.5	35
S69	1506	32	240	8.23	15.63	22.32	28.13
H104	2454	76	394	5.35	10.6	15.15	18.5
D75	630	133	41	42.87	48.12	50.38	52.63
R306	1587	136	155	8.09	14.71	19.85	23.53
R74	2200	120	219	5	10.83	15	18.33
R25A	1900	146	269	4.79	10.27	14.38	17.81
Astath	2900	140	407	0.71	2.14	5.73	8.57
G49	3010	138	550	0.96	1.79	5.17	6.79
C79A	1600	190	105	16.84	19.47	24.21	36.63
Darage	1200	178	111	16.85	23.6	27.53	34.27
L198	2100	185	375	1.62	4.86	8.11	10.81
L190	3570	193	628	0.52	1.04	1.55	2.07
D60	950	211	90	36.49	39.81	41.71	43.6
P145	1650	206	213	6.31	13.59	23.3	30.1
R25B	2020	226	280	7.52	12.83	16.81	21.24
Seka	2673	230	359	2.17	10	12.61	15.22
R311	2570	217	444	1.38	3.23	8.76	12.44
Hera	1350	273	135	21.61	31.87	36.26	45.42
L127	1950	364	157	18.68	23.9	29.67	32.97
L87	2450	304	271	4.61	9.21	14.47	17.76
Shoot	2574	332	356	0.60	1.2	7.83	14.16

5.2.2.2 TDS Removal

In this section, TDS removal for tested water sample was evaluated in terms of operating pressures and TDS concentration and chemical compositions.

Effect of Operation Pressure

As previous result about operating pressures and its effect on slat rejection, TDS removal increase while operating pressure increases. Figure (5-14) illustrated six samples and the effect of operating pressures on TDS removal.

Table (5-7)illustrates the relation between TDS removal and operation pressure for all water samples. The maximum TDS removal percentage was 76.83% which was obtained in well D75 at 12 bar pressure. The minimum TDS removal percentage was 44.58% which was obtained in well L190 at 6 bar operating pressure. In all water samples TDS removal is high value were in all cases the permeate TDS concentration met WHO guideline.

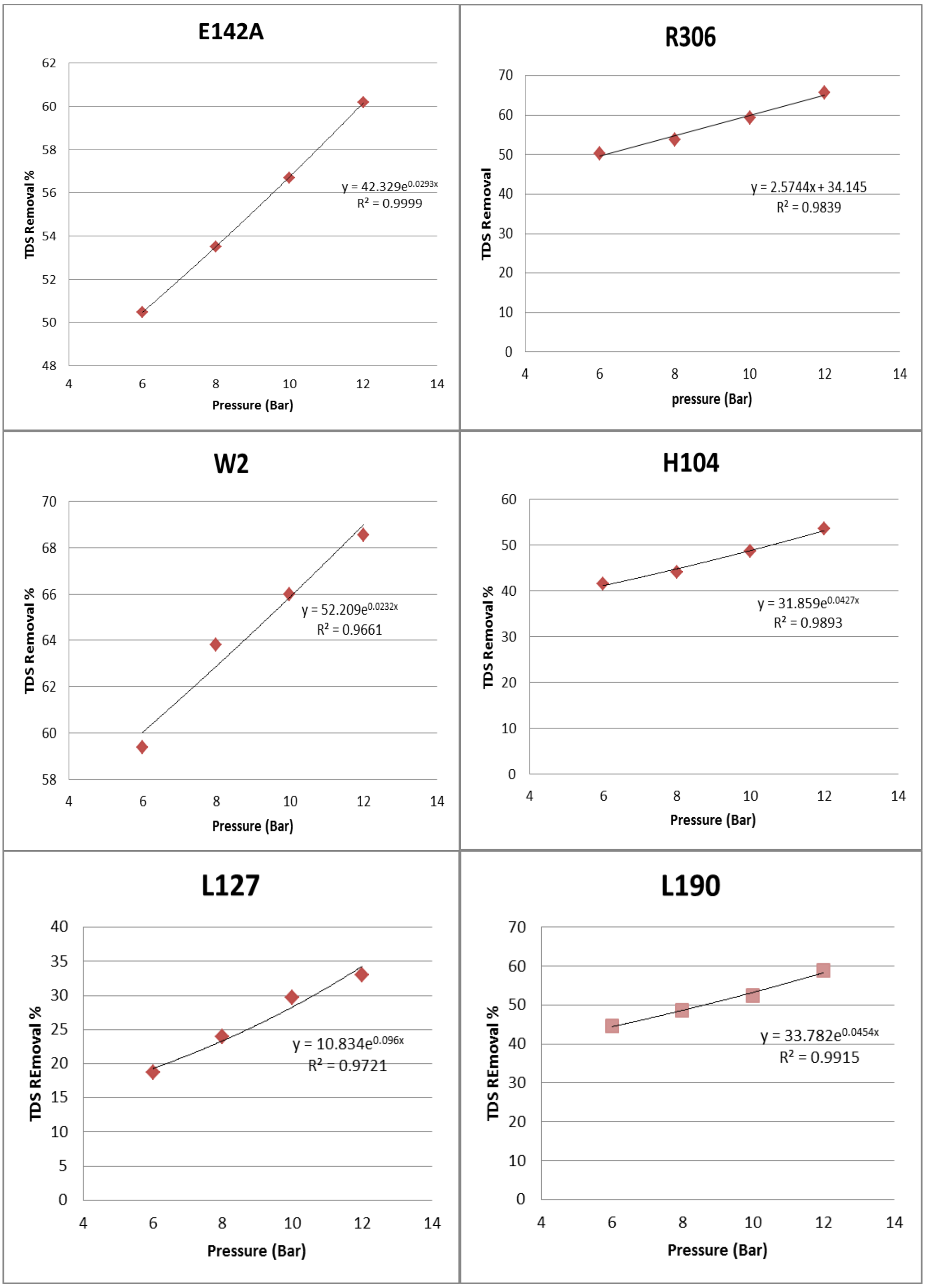


Figure (5-14): Effect of operation pressure on TDS removal.

Table (5-7): TDS removal and opreation pressure.

Well No.	Pressure (Bar)			
	6 Bar	*8 Bar*	*10 Bar*	*12 Bar*
A211	71	73	74.8	75.8
D75	71.75	73.62	75.2	76.83
D60	59.63	63.58	66.7	70
W2	59.32	63.75	65.9	68.55
Darage	62.25	66.46	68.3	71.25
Hera	59.66	63.03	66.4	68.91
S69	52.67	55.63	60.2	67.46
R306	50.36	53.86	59.3	65.73
C79A	50.21	53.85	58.7	61.54
P145	46.86	49.68	55.3	61.06
R25A	50.63	53.31	61.1	67.96
L127	42.57	46.97	53.6	62.12
R25B	48.39	52.41	60.9	65.52
L198	46.89	49.95	57.9	61.66
R74	46.37	49.19	55.9	60
L87	41.28	44.11	53.2	57.7
H104	41.59	44.17	48.7	53.55
R311	51.77	55.08	57.8	60.47
Shoot	43.79	49.88	54.6	58.7
Seka	48.81	51.2	56.8	61.2
Astath	48.57	51.37	56.1	58.79
G49	51.87	55.78	58.6	61.46
E124A	50.48	53.85	56.7	60.19
L190	44.58	48.57	52.4	58.83

Effect of TDS Concentration and Chemical Composition

The result showed that in general when TDS concentration increase, TDS rejection decreased as described above. Figure (5-15) showed the result of TDS removal at different TDS feed concentration. However, Table (5-8) indicated that another factor affect TDS removal. Hardness, in well D75 TDS concentration was 630 mg/L but the TDS rejection is higher than that in well A211 which have 500 mg/L TDS concentration. This result can be explained due to the hardness value in Well D75 is higher than in well A211. This could indicate the first use of nanofltration membrane was for softening (Hardnes removal) For more details referee to Appendix (2).

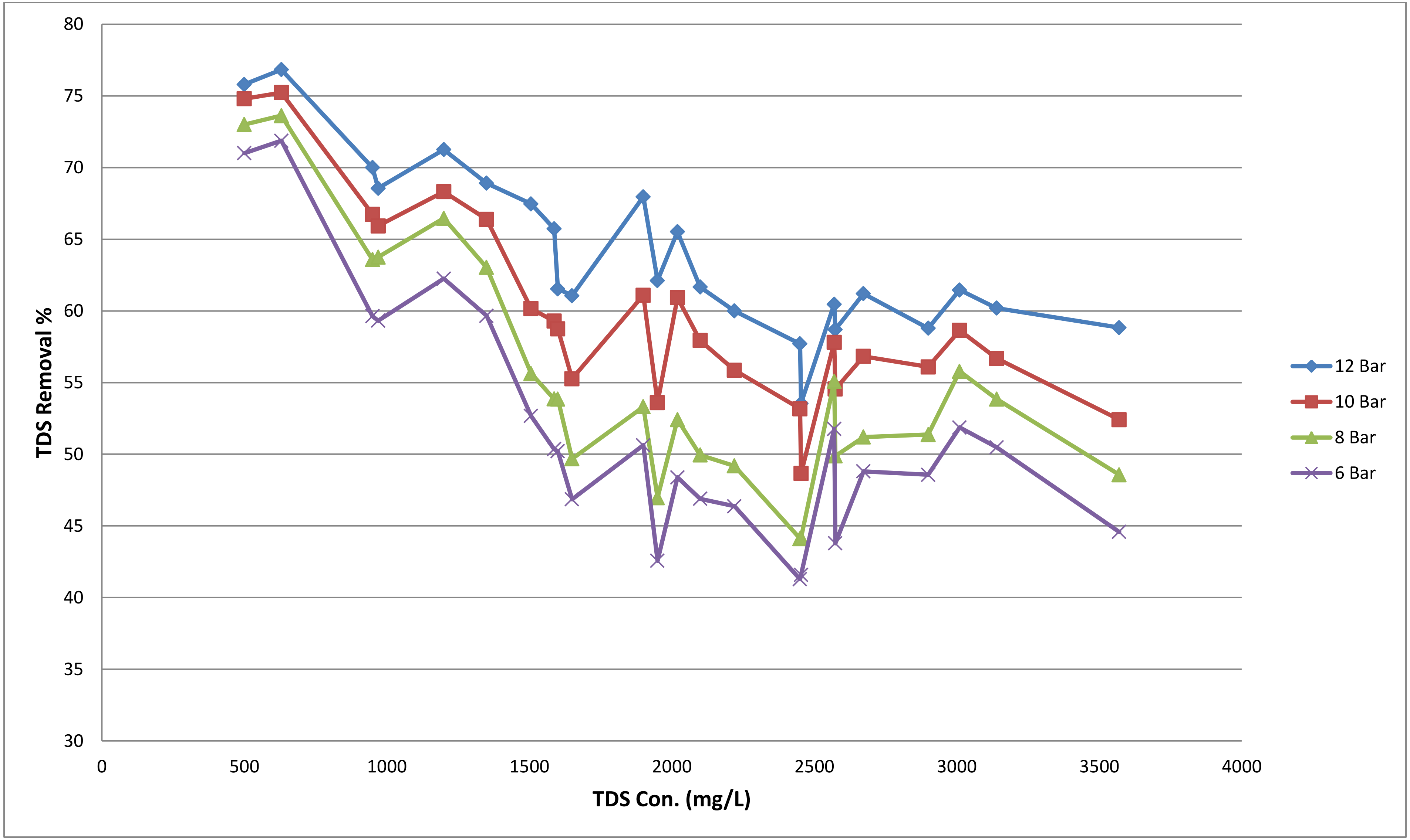


Figure (5-15): Efect of TDS concentraion on TDS removal.

Table (5-8): TDS concentration, compostion and rejecton.

Well No.	*TDS*	*Chloride Cl (mg/L)*	*Hardness*	**Pressure (Bar)**			
				6	*8*	*10*	*12*
A211	500	97	251	71	73	74.8	75.8
D75	630	109	356	71.75	73.62	75.2	76.83
D60	950	225	516	59.63	63.58	66.7	70
W2	970	217	421	59.32	63.75	65.9	68.55
Darage	1200	408	556	62.25	66.46	68.3	71.25
Hera	1350	309	605	59.66	63.03	66.4	68.91
S69	1506	580	353	52.67	55.63	60.2	67.46
R306	1587	566	418	50.36	53.86	59.3	65.73
C79A	1600	509	605	50.21	53.85	58.7	61.54
P145	1650	662	580	46.86	49.68	55.3	61.06
R25A	1900	565	351	50.63	53.31	61.1	67.96
L127	1950	687	690	42.57	46.97	53.6	62.12
R25B	2020	608	623	48.39	52.41	60.9	65.52
L198	2100	695	235	46.89	49.95	57.9	61.66
R74	2200	824	427	46.37	49.19	55.9	60
L87	2450	848	619	41.28	44.11	53.2	57.7
H104	2454	967	715	41.59	44.17	48.7	53.55
R311	2570	891	677	51.77	55.08	57.8	60.47
Shoot	2574	838	449	43.79	49.88	54.6	58.7
Seka	2673	964	503	48.81	51.2	56.8	61.2
Astath	2900	1174	427	48.57	51.37	56.1	58.79
G49	3010	1196	827	51.87	55.78	58.6	61.46
E124A	3140	1442	1165	50.48	53.85	56.7	60.19
L190	3570	1346	441	44.58	48.57	52.4	58.83

5.3 Comparison between Real water and Aqueous Solutions

5.3.1 Flux Rate

The performance of NF90 membrane varied in terms of flux rate. Consequently, the pure water flux rate was higher than the real water flux rate.

As the water contains more salts or other substances, the flux rate decreases. At this pattern the membrane performance, so the pure flux rate was higher than of real water flux. 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 12 bar (16 L/m^2.hr) for pure water and minimum flux rate was obtained at 6bar (3.54 L/m^2.hr).

The maximum flux rate for real water was obtained at 12 bar (14.12 L/m^2.hr) for A211 and minimum flux rate was obtained at 6 bar (1.22 L/m^2.hr) for E142A.

5.3.2 Nitrate Rejection

Generally, the overall rejection percentages of the NF90 membrane of aqueous solutions were found to be higher than the rejection of real water. For aqueous solution the maximum and minimum nitrate rejection of aqueous solution was 66.68% and 21.67% respectively, while for real water the maximum and minimum nitrate rejection of were 55.56% and 0 % respectively.

The characteristics of feed water significantly affect the membrane rejection such as the content of sulphate and hardness. This explains the difference of rejection between real water and aqueous solution. In addition, real water may contain some colloids and many other substances that can negatively affect the membrane rejection.

5.4 Optimization Process

Optimization is the process used to obtained the lowest operation pressure applied to produce water, the water must achieve the stander limit for slats concentration, the Palestinian standard state that maximum concentration of nitrate in drinking water 70 mg/L and maximum concentration of TDS 1500 mg/L.

As dead end system was used, a disadvantage of the stirred cells that it doesn’t simulated large scale modules, particularly in terms of the boundary layer mass transfer coefficient. The stirred cell would tend to achieve lower retention and experience more fouling than large scale Spiral Wound Modules (Schafer et al, 2008).

So to develop optimization process cross flow syste is needed which represent the actual case in desalination plant. In this research guide value to optimization process was developed.

5.4.1 Aqueous Solutions

As 70 mg/l is maximum nitrate concentration limit, so when we plot initial concentration against final concentration, all point below 70 mg/l satisfy standard, figure (5-16) showed minimum requirement for nitrate solution.

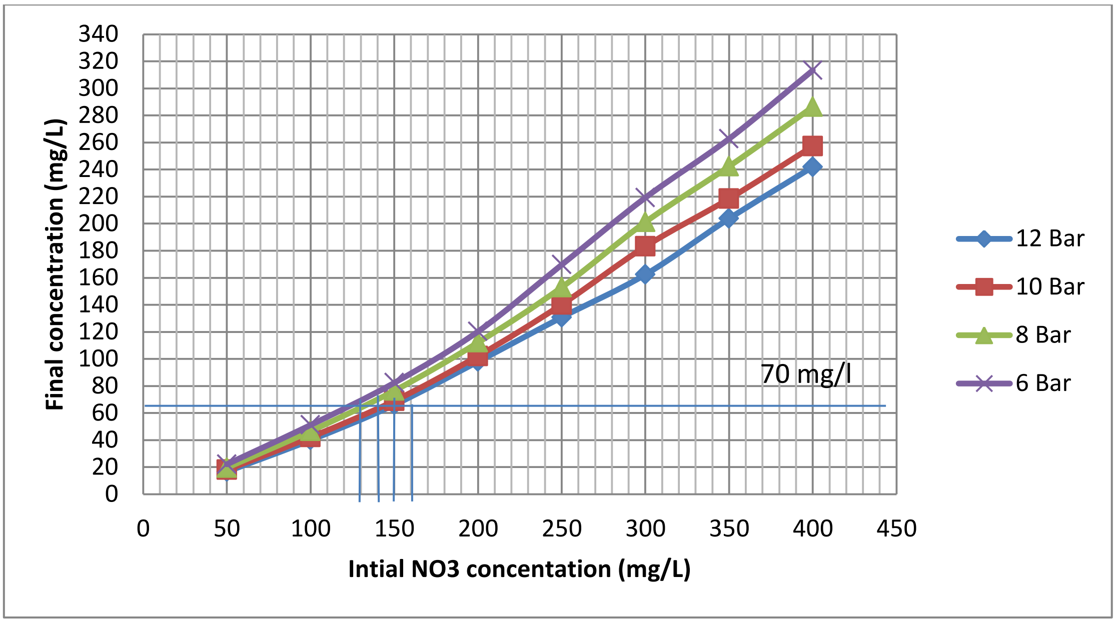


Figure (5-16): maximum feed concentration.

So from figure (5-16) to get water satisfy standard, the nitrate feed concentration must be 160,150,140,130 for pressure 12, 10, 8, 6 bar.

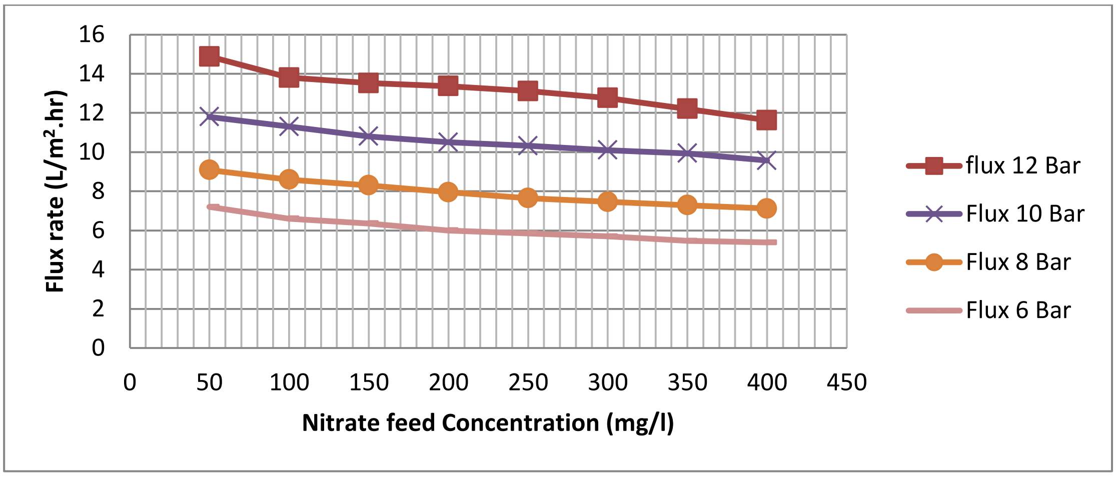


Figure 5-17): Nitrate feed concentration with flux rate.

From figure (5-17) we conclude that, the best operation point for 12, 10, 8, 6 bar operation pressure were 160,150,140,130 nitrate feed concentration with 13.5, 10.7, 8.5, 6.5 flux rate as showed in table (5-9).

Table (5-9): optimum limit for aqueous solution.

Initial nitrate concentration(mg/l)	Final nitrate concentration(mg/l)	Operation pressure (bar)	Flux rate(L/m^2.hr)
160	70	12	13.5
150	70	10	10.7
140	70	8	8.5
130	70	6	6.5

5.4.2 Real Water

Three wells were used to illustrate the optimizing procedure: H104, E142A, D75. In these well concentration of sulphate and TDS are low which enhance the selection of the best operating pressure.

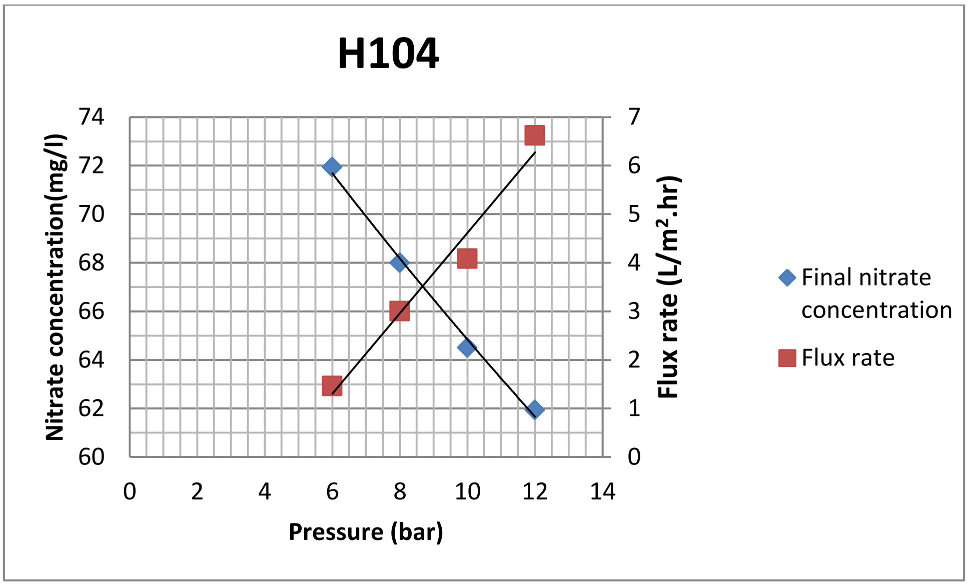


Figure (5-18): H104 operation diagram. (Initial nitrate concentration 76 mg/l).

Figure (5-18) shows that the best operating point for well H104 is at 8.6 bar (operating bar) with flux rate 3.5 L/m2.hr. The nitrate concentration in permeate water will be 70 mg/l, when the influence water concentration is 76mg/l.

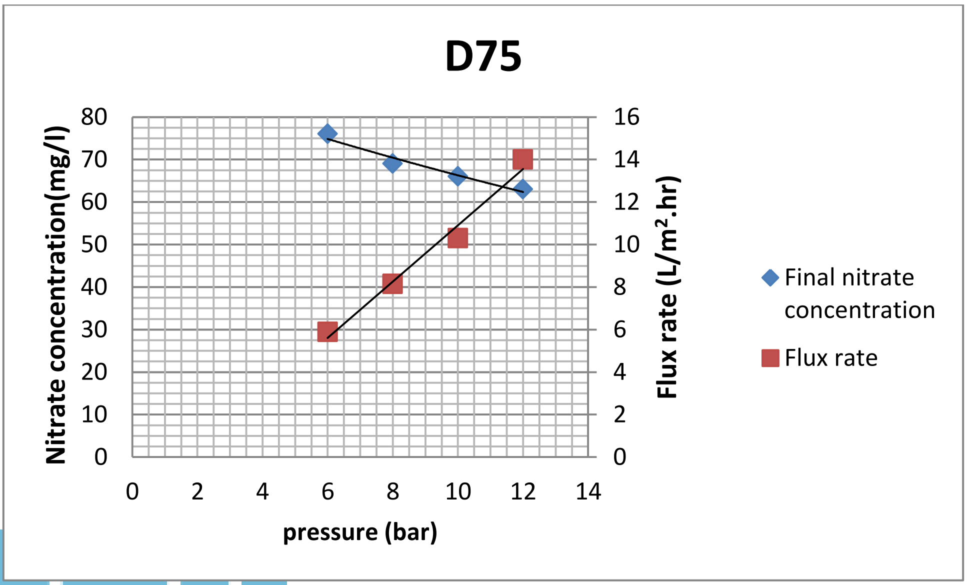


Figure (5-19): D75 operation diagram.(initial nitrate concentration 133 mg/l).

Figure (5-19) illustrates the operation diagram for well D15, the feed water nitrate concentration is 133 mg/l, the best operating point is at 11.5 bar with flux rate 12.5 L/m2.hr and nitrate concentration in the permeate water is 62 mg/l.

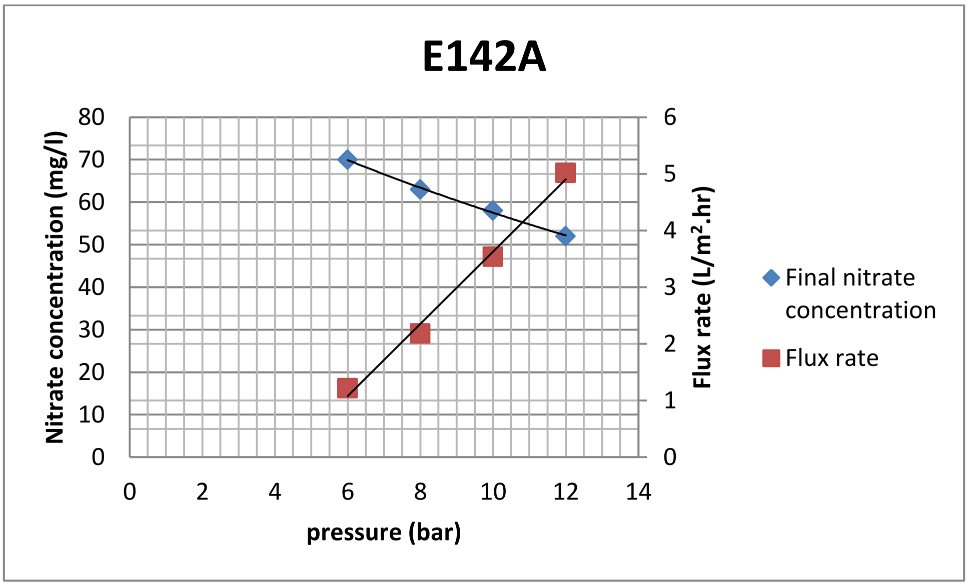


Figure (5-20): E142A operation diagram.(initial nitrate concentration 80 mg/l)

Figure (5-20) illustrate the operation diagram for well E142A, the feed water nitrate concentration is 80 mg/l, the best operating point is at 10.8 bar with flux rate 4.1 L/m^2.hr and nitrate concentration in the permeate water is 55 mg/l.

CHAPTER 6 : Conclusion and Recommendation

6.1 Conclusion

- The optimum operating pressures are 8.6, 11.6 and 10.8 at H104, E142A and D75 well. Which achieve Palestine stander (70 mg/L) and high flux rate 3.5, 12.5 and 4.1 L/m^2.hr NF90 membrane showed good result for nitrate removal in aqueous solution, which varied between 21.6% and 66.68% depening on operating pressure and initial nitrate concentration, flux rate varied between 5.39and 14.88 L/m^2.hr.
- NF90 membrane showed good results for nitrate removal in real water, which varied between 0.62% and 55%, and flux rate between1.22 and 14.12 L/m^2.hr, when the operating pressure varied between 6 and 12 bar.
- It can be concluded that the rejection of chloride is better than in nitrate, The sulphate has negative effect on chloride rejection and on nitrate rejection.
- As the real water contains more salts or other substance, the flux rate decrease. At this pattern the membrane performance, so the pure flux rate was higher than of real water flux. Also complexity of water character play a good role in membrane behavior and that is why the nitrate and NaCl solutions flux rate are higher than real water flux rate.
- NF90 was observed to be an effective method to nitrate removal of Gaza Strip at higher permeate flux and lower applied pressure, especially in North Gaza Strip were low TDS and Sulphat concentration were observed. In other Gaza Strip places TDS and sulphat should be removed before using nanofiltration to nitrate removal.
- The characteristics of feed water significantly affect the membrane rejection such as the content of sulphate and hardness. This explains the difference of rejection between real water and aqueous solution
- Sensitivity of the system to the circumstances like temperature, quality of deionized water used in system flushing, regular insurance of zero leakage of pressure , the period of using membrane, using tools washed by deionized water , all these restriction make the test harder.
- The importance of testing Nanofiltration membranes as new emerging technology in Gaza strip is to improve the overall desalination quality with acceptable cost; carrying out tests helps to understand the behavior of NF90 for nitrate removal.
- Desalination of brackish water using Nanofiltration technique is seen as one of the promising solution that can assist Gaza in filling the gap between the growing needs for water, limited water recourses, limited energy resource, the standard of domestic water and unacceptable water quality.

6.2 Recommendation

- A Spiral Wound Model is recommended to be implemented as NF unit in desalination plants.
- NF cross flow system should be test against Ro system.
- For high sulphate concentration sulphate should be removed by other technigues before using NF90 to remove nitrate.
- Use the operational diagram on optimizing the operation condition of NF desalination process.
- Develop researches in the field of nanotechnology as a prelude to use this technology in desalination plant of Gaza.

REFERENCES

1. Abdul-Kareem M. Al-Sofi (2001), Seawater desalination—SWCC experience and vision, Desalination 135 (1–3) 121–139.
2. Abuhabib A. A, A. W. Mohammad, Rakmi Abd. Rahman, and Ahmad H. El-Shafie(2011) “Effect of UV Grafting modification on Nanofiltration (NF) Membranes Wettability for Brackish Desalination” Postgraduate Colloquium of Environmental Research (POCER), Nottingham University – Malaysia campus.
3. Abuhabib A. A., A. W. Mohammad, Rakmi Abd. Rahman, and Ahmad H. El-Shafie(2013) “Prediction & comparison of Nanofiltration Membranes Performance before & after Modification by UV Grafting using ANN in Brackish Water Desalination” Membrane technology for desalination, Elsevier conferences, Spain.
4. Abuhabib A. A., A.W. Mohammad, and Rakmi Abd. Rahman (2010) “Characterization of Nanofiltration membranes for Brackish Water Desalination”. 8th International conference on Membrane Science & Technology (MST), Bandung, Indonesia.
5. Abuhabib A. A., A.W. Mohammad, and Rakmi Abd. Rahman(2011) “Potential of Nanofiltration for Brackish Water Desalination in Gaza Strip” journal of Advanced Materials Research, vol. 233-235.
6. Abuhabib A. A., Mostafa Ghasemi, Rakmi Abd. Rahman, Manal Ismail, and A. W. Mohammad (2013) “Desalination of brackish water using Nanofiltration – performance comparison of different Membranes” Arabian Journal of Science and Engineering, DOI 10.1007.
7. Aish, A, (2010), “Water Quality Evaluation Of Small Scale Desalination Plants In The Gaza Strip Palestine” Department of Geology, Faculty of Science, Al Azhar University, P.O. Box 1277 Gaza, Palestine.
8. Aish. Adnan M., (2004), Hydrogeological Study and Artificial Recharge Modeling of the Gaza Coastal Aquifer Using GIS and MODFLOW, Doctorate theses.
9. Al-Amoudi, A.S., A.M. Farooque, (2005),“Performance, restoration and autopsy of NF membranes used in seawater pretreatment, Desalination 178 261–271.

10. Al-Amoudia, A., R.W. Lovitt, (2007), ”Fouling strategies and the cleaning system of NF membranes and factors affecting cleaning efficiency, J. Membr. Sci. 303-4–28.
11. Alborzfar,M., G. Jonsson, C. GrOn,(1998)”Removal of natural organic matter from two types of humic ground waters by nanofiltration”, Water Res. 32 (10) 2983–2994.
12. Al-Yaqubi, Ahmad., Amjad Aliewi and Ziad Mimi, (2007). “Bridging the Domestic Water Demand Gap in Gaza Strip-Palestine”. Water International, Vol. 32, Number 2, P. 219-229.
13. America’s Authority in Membrane Treatment, (2011), ”Application of membrane technology”.Florida.
14. American Water Works Association. (1999). Manual of Water Supply Practices: Reverse Osmosis and Nanofiltration. AWWA M46:173.
15. Baalousha H., (2006), “Desalination Status in the Gaza Strip and its Environmental Impact”. Desalination, Vol. 196, Issues 1-3, P. 1-12.
16. Baalousha, H. (2006) “Desalination status in the Gaza Strip and its environmental impact. Desalination” 196, pp. 1-12.
17. Bailar, John, C. Jr., (1978), Chemistry, Academy Press, New York, New York.
18. Bebee, J., B. Alspach, S. Diamond, C. Milller, T. O’Neill, and C. Parker, (2006), “Using Reverse Osmosis and Ion Exchange as Parallel Processes to remove high Nitrate Levels. in Desalination of Seawater and Brackish Water”. Lauer., W.C. (Editor),AWWA, Denver, Colorado.
19. Bellona, C., J.E. Drewes, G. Oelker, J. Luna, G. Filteau, and G. Amy, (2008). “Comparing Nanofiltration and Reverse Osmosis for Drinking Water Augmentation” Journal AWWA. 100(9):102-116.
20. Bergman, R., (2007). “Reverse Osmosis and Nanofiltration”. AWWA, Denver, Colorado.
21. Bockle R., U. Rohmann, and A. Wertz, (1986). “A Process for Restoring Nitrate Contamination Ground Waters by Means of Heterotrophic Denitrification in an Activated Carbon Filter and Aerobic Post-Treatment Underground”. Journal of Water Supply: Research and Technology-AQUA. 5:286-287.
22. Boley A, Nuller W R and Haider G, Aquacult Eng., (2000), 22, 75-85.

23. Braester C., and R. Martinell, (1988). The Vyredox and Nitredox Methods of In Situ Treatment of Groundwater. Water Science and Technology. 20(3):149-163.
24. Bruggen, B,Van der., K. Everaert, D. Wilms, C. Vandecasteel (2001) "Application of nanofiltration for removel of pesticides, nitrate and hardness from ground water: rejection properties and economic evaluation".
25. Bruggen, B. Van der,(2003) “Direct nanofiltration of surface water using capillary membranes: comparison with flat sheet membranes”, Sep. Purif. Technol. 31 (2) (193–201.
26. CEP and EMCC (2006) Water Facility Master Planning In Deir EL-Balah Governorate Final Report. Gaza, Palestine.
27. Cevaal, J.N., W.B. Suratt, and J.E. Burke, (1995).” Nitrate Removal and Water Quality Improvements with Reverse Osmosis for Brighton”, Clorado. Desalination. 103(1- 2):101-111.
28. Champlin, T.L., (2000) “Using circulation tests to model natural organic matter adsorption and particle deposition by spiral-wound nanofiltration membrane elements”, Desalination 131 (1–3) 105–115.
29. Charis M. Galanakis, Georgios Fountoulis, Vassillis Gekas(2012)"Nanofiltration of brackich groundwater by using a polypiperazine membrane".
30. Coastal Municipalities Water Utility (CMWU) (2011) “Summary about Water and Wastewater Situation in Gaza Strip”.
31. Cristina T M, Svetlozar Velizarov, João G Crespo and Maria A M Reis, Water Res., 2006, 40(2), 231-240.
32. Darbi, A., T. Viraraghavan, R. Butler, and D. Corkal, (2003). “Pilot-scale Evaluation of Select Nitrate Removal Technologies”. Journal of Environmental Science and Health. A38 (9):1703-1715.
33. Diawara, C. K., Sidy Lô, M., Rumeau, M., Pontie, M. and Sarr, O., (2003), A
34. Duranceau, S. J. (2001). “Reverse Osmosis and Nanofiltration Technology: Inorganic, Softening and Organic Control”. (paper presented at the American Membrane Technology Association’s Annual Symposium, Isle of Palms, S.C.
35. Dydo, P., (2004) “The nucleation kinetic aspects of gypsum nanofiltration membrane scaling, Desalination 164 (1) -41–52.
36. Elyanow, D., and J. Persechino, (2005). “Advances in Nitrate Removal. GE Water and Process Technologies”. TP1033EN 0601.

37. Eyal, A., and O. Kedem, (1988). “Nitrate-selective Anion-exchange Membranes. Desalination”. 38:101-111.
38. Fance, A and J Radovich,(1990) “Membrane system, Chapter 8 in Asenlo,j(ed), sepration processes in Biotechnology”, Marcel Dekker Inc, 209-262.
39. Flemming,H.C.,(1997)“Biofouling—the Achilles heel of membrane processes, Desalination” 113 (2/3) (1997) 215–225.
40. Foundation of water research (2011)”A Review of current knowledge desalination for water supply”Allen House, the Listons, Mara low Bucks, SL 7 1FD, U.K.
41. Guter G A, EPA/600/S2-87/034, U.S. Envir. Protection Agency (EPA), Cincinnati, Ohio, 1987b.
42. Hasson, D., A. Drak, R. Semiat,(2001) “Inception of CaSO4 scaling on RO membranes at various water recovery levels, Desalination” 139 (1–3) (73–81.
43. Hilal, N.,(2004) “A comprehensive review of nanofiltration membranes: treatment”, pretreatment, modelling, and atomic force microscopy, Desalination 170 (3)-281–308.
44. Horold S, Tacke T and Vorlop K D, Envir Technol., 1993, 14(10), 931-939.
45. Janda, V., J. Rudovsky, J. Wanner, and K. Marha, (1988). In Situ Denitrification of Drinking Water. Water Science and Technology. 20(3):215-219.
46. Kapoor, A., and T. Viraraghavan, (1997). “Nitrate Removal from Drinking Water—Review”. Journal of Environmental Engineering. 123(4):371-380.
47. Kasper, D.R.,(1993) “Pre-and posttreatment processes for membrane water treatment system membrane technology conference proceeding”, Baltimor.
48. Kokufuta E, Shimohashi M and Nakamura I, Biotechnol Bioeng., (1988), 31, 382-384.
49. KoSutic, K., B. Kunst,(2002)”RO and NF membrane fouling and cleaning and pore size distribution variations”, Desalination 150 - 113–120.
50. Krieg. H.M, Modise.S.J, Keizer, K and Neomagus, H.W.J.P, (2004), Salt rejection in nanofiltration for single and binary salt mixtures in view of sulfates removal, Desalination,171, 205-215.
51. Krukowski, J. (2001). “Opening the Black Box: Regulations and Recycling Drive Use of Membrane Technologies’. Pollution Engineering 33:20-25.

52. lau kok keong Thesis,(2007)" Feed spacer of spiral wound membrane module for nanofiltration and reverse osmosis: modeling, simulation and design",
53. Lee, s., J. Kim, C.-H. Lee,(1999)"Analysis of CaSO4 scale formation mechanism in various nanofiltration modules", J. Membr. Sci. 163 (1) 63–74.
54. Liessens, J.; Germonpre, R.; Beernaert, S.; Verstraete, W., (1993)." Removing Nitrate With a Methylotrophic Fluidized Bed: Technology and Operating Performance". Journal AWWA. 85(4):144-154.
55. Luk, G.K., and W.C. Au-Yeung, (2002). "Experimental Investigation on the Chemical Reduction of Nitrate from Groundwater". Advances in Environmental Research. 6(4):441-453.
56. Maryam A. Amouha, Gholam Reza Nabi Bidhendi, Behnam Hooshyari(2011)"Nanofiltration Efficiency in Nitrate Removel from Groundwater : A Semi-Industrial Case Study".
57. Mateju V, Cizinska S, Krejci J and Janoch T, Enzyme Microbiol Technol., 1992, 14, 170-183.
58. Mateju, V., S. Cizinska, J. Krejci, and T. Janoch, (1992)."Biological Water Denitrification" - A Review. Enzyme and Microbial Technology. 14(3):170–183.
59. Metcalf and Eddy (2000) Costal Aquifer Management Program, Final Report: Modelling of Gaza
60. Mogheir Y., Singh V. P. and de Lima J. L. M. P. (2006) Spatial assessment and redesign of groundwater quality network using the entropy theory. Hydrogeology Journal, 14(5), pp. 700- 712.
61. Moghier Yonis, Ahmed A. Foul, A. A. Abuhabib, and A. W. Mohammad (2013)"Assessment of large scale brackish desalination plants in the Gaza Strip" Journal of Desalination, 314 - 96–100.
62. Mohammadi, T., S.S. Madaeni, M.K. Moghadam,(2003)"Investigation of membrane fouling, Desalination 153–160 - 155.
63. Mooch,I.,(2003) A 21st Century study of global seawater reverse osmosis operating and capital costs, in: IDA Conference, Singapore.
64. Moros, Santafé., J.M. Gozálvez-Zafrilla., J. Lora-García (2007) "Nitrate removal from ternary ionic solutions by a tight nanofiltration membrane"
65. Munir, A (2006)" Dead End Membrane Filtration "report.
66. Murphy, A.P., (1991). "Chemical Removal of Nitrate from Water". Nature. 350(6315):223- 225.

67. MWH, (2005). "Water Treatment Principles and Design". John Wiley & Sons, New Jersey.

68. Paugam, . Taha,. Dorange, p. Jaouen, F. Quemeneur(2004)"Mechanisim of nitrate ions transfer in nanofiltration depending on pressure, PH, concentration and medium composition".

69. Paugam,L., S. Taha, G. Dorange, p. Jaouen, F. Quemeneur(2004)"Mechanisim of nitrate ions transfer in nanofiltration depending on pressure, PH, concentration and medium composition"

70. Peeters, J. M. M., Boom, J. P., Mulder, M. H. V. and Strathmann, H., (1998), Retention measurements of nanofiltration membranes with electrolyte solutions, Journal of Membrane Science, 145, 199-209.

71. Public Health and the Environment World Health Organization, (2007)."Desalination for Safe Water Supply",Geneva

72. Qahman, K., (2004). 'Aspects of hydrogeology, modeling, and management of seawater intrusion for Gaza aquifer- Palestine". Unpublished Dissertation (PhD), LIMEN, Ecole Mohammadia D'Ingenieurs, Université Mohammed V - Morocco.

73. Rautenbach R, Kopp W, Van Opbergen G and Hellekes R, Desalination, 1987, 65, 241-258.

74. Ridgway,H.F., H.C.(1996) "Flemming, Membrane Biofouling inWater Treatment Membrane Processes", McGraw Hill, New York.

75. Rocca, C. D., , Belgiorno, V., Meriç, S. (2005) Overview of insitu applicable nitrate removal processes. Desalination,204, pp. 46-62.

76. Roennefahrt,K.W., (1986). "Nitrate Elimination with heterotrophic aquatic Microorganisms in Fixed Bed Reactors with Buoyant Carriers". Journal of Water Supply: Research and Technology-AQUA. 5:283-285.

77. Roising A. R and Schroeder E D, J Environ Eng ASCE, (1996), 122(7), 599-604.

78. Roudman,A.R., F.A. DiGiano,(2000)"Surface energy of experimental and commercial nanofiltration membranes: effects of wetting and natural organic matter fouling, J. Membr. Sci. 175 (1) 61–73.

79. Samatya, S., N. Kabay, U. Yuksel, M. Arda, and M. Yuksel, 2006. Removal of Nitrate from Aqueous Solution by Nitrate Selective Ion Exchange Resins. Reactive and Functional Polymer. 66(11):1206-1214.

80. Santafe Moros, J.M. Goza lvez-Zafrilla, J. Lora-Garcıa (2005) “Performance of commercial nanofiltration membranes in the removal of nitrate ions”.
81. Schaep, J., Van der Brugen,B., Uyetherhoven, S., Croux, R., Vandecasteele, C., Wilms, D., Van Houtte, E. and Vanlerberghe, F.,(1998), “Removal of hardness from groundwater by nanofiltration’, Desalination, 119,295-301.
82. Schafer, A.I., A.G. Fane, T.D.Waite,(2005)Nanofiltration—Principle and Applications, Elsevier Advanced Technology, pp. 1–543.
83. Schafer, Al., AG Fone., T.D Waite(2008) ”Nanofiltration Principles and Application”
84. Shrimali, M., and K.P. Singh, (2001). “New Methods of Nitrate Removal from Water. Environmental Pollution”. 112(3):351-359.
85. Soares M I M, Brenner A, Yevzori A, Messalem R, Leroux Y and Abeliovich A, Water Sci Technol., 2000, 42(1-2), 353-359.
86. Soares, M.I.M., (2000). “Biological Denitrification of Groundwater. Water Air Soil Pollution”. 123(1-4):183–193.
87. Symons, J.M., L.C. Bradley Jr., T.C. Cleveland, (2001). “The Drinking Water Dictionary”. AWWA, McGraw-Hill, New York.
88. Taylor,J.S., E.P. Jacobs,(1996)” Reverse osmosis and nanofiltration, chapter 9 in water treatment membrane processes”, ed. P.E.O.a.M.R.W.e. J. mallevialle, McGraw Hill.
89. Timmer, Johannes M.K. (2001)”Properties of nanofiltration membranes ; model development and industrial application : Technische Universiteit Eindhoven, Proefschrift. - ISBN 90-386-2872-2 NUGI 813. Doctoral these.
90. U.S. Environmental Protection Agency (USEPA), (2003). “National Pollutant Discharge Elimination System Permit Regulation and Effluent Limitation Guidelines and Standards for Concentrated Animal Feeding Operations (CAFOs)”. USEPA. Federal Register Environmental Documents 68(29):7175-7274.
91. U.S. Environmental Protection Agency (USEPA). (2004). “National Primary Drinking Water Regulations: Maximum Contaminant Levels for Inorganic Contaminants”. Code of Federal Regulations. Title 40, Part 141.62(b).
92. U.S. Environmental Protection Agency (USEPA). 2004. National Primary Drinking Water Regulations: Maximum Contaminant Levels for Inorganic Contaminants. Code of Federal Regulations. Title 40, Part 141.62(b).

93. United Nations Environment Programm (UNEP) (2003), Desk study on the Environment in the Occupied Palestinian Territories. Available.
94. van der Hoek J.P., W.A.M. Hinjen, C.A. van Bennekom, and B.J. Mijnarends, (1992).“Optimization of the Sulfur-limestone Filtration Process for Nitrate Removal from Groundwater. Journal of Water Supply: Research and Technology-AQUA. 41(4):209- 218.
95. Van Gestel, T., Vandecasteele, C., Buekenhoudt, A.,.Dotremont, C., Luyten, J., Leysen, R., Van der Bruggen, B. and Maes, G., (2002), “Salt retention in nanofiltration with multilayer ceramic TiO2 membranes, Journal of Membrane Science”, 209, 379-389.
96. Wang, M. Su, Z.Y. Yu, X.L. Wang, M. Ando and T. Shintani, (2005),”Separation performance of a nanofiltration membrane influenced by species and concentration of ions’, Desalination 175, 219.
97. Wang, Xiao- Lin., Wei- Juan Shange, Da-Xin Wang, Ling Wu, Cong- Hui TU(2009)"Characterization and application of nanofiltration membranes: state of the art".
98. Water stewardship information series,(2007).” Nitrate in Groundwater”. Report.
99. Wenli G, Wensheng H and Holl W H, Water SRT-Aqua., (1994), 43(2), 95-101.
100. Wies, A., M.R. Bird, M. Nystrom,(2003)”The chemical cleaning of polymeric UFmembranes fouled with spent sulphite liquor over multiple operational cycles”, J. Membr. Sci. 216 - 67–79.
101. World Health Organization (WHO). (2011) “Guidelines for Drinking-water Quality 3rd Edition”. Geneva.
102. World Health Organization, (1992). “Revisions of the WHO Guidelines for Drinking-Water Quality - Report on a WHO consultation”. WHO Regional Office for Europe. Medmenham, U.K.
103. Zhu,H., M. Nystrom,(1998) “Cleaning results characterized by flux, streaming potential and FTIR measurements”, Colloids Surf. A: Physicochem. Eng. Aspects 138 (2/3) (1998) 309–321.

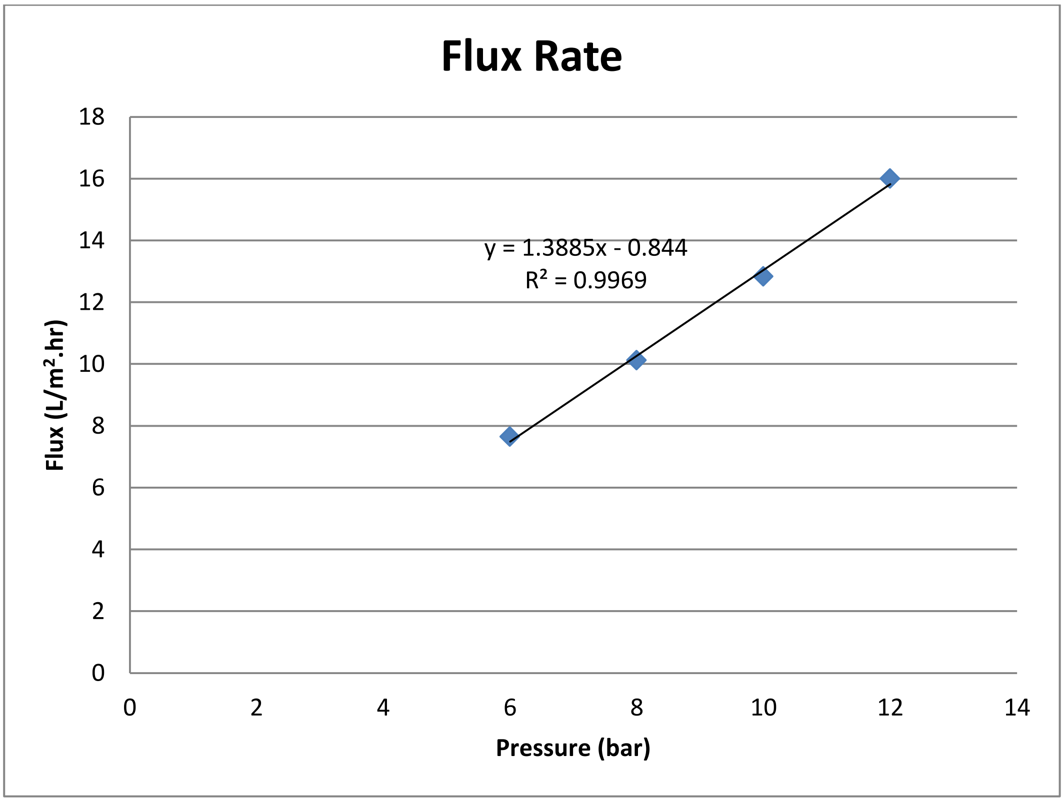
Appendix

APPENDIX (1)

: Aqueous solution result

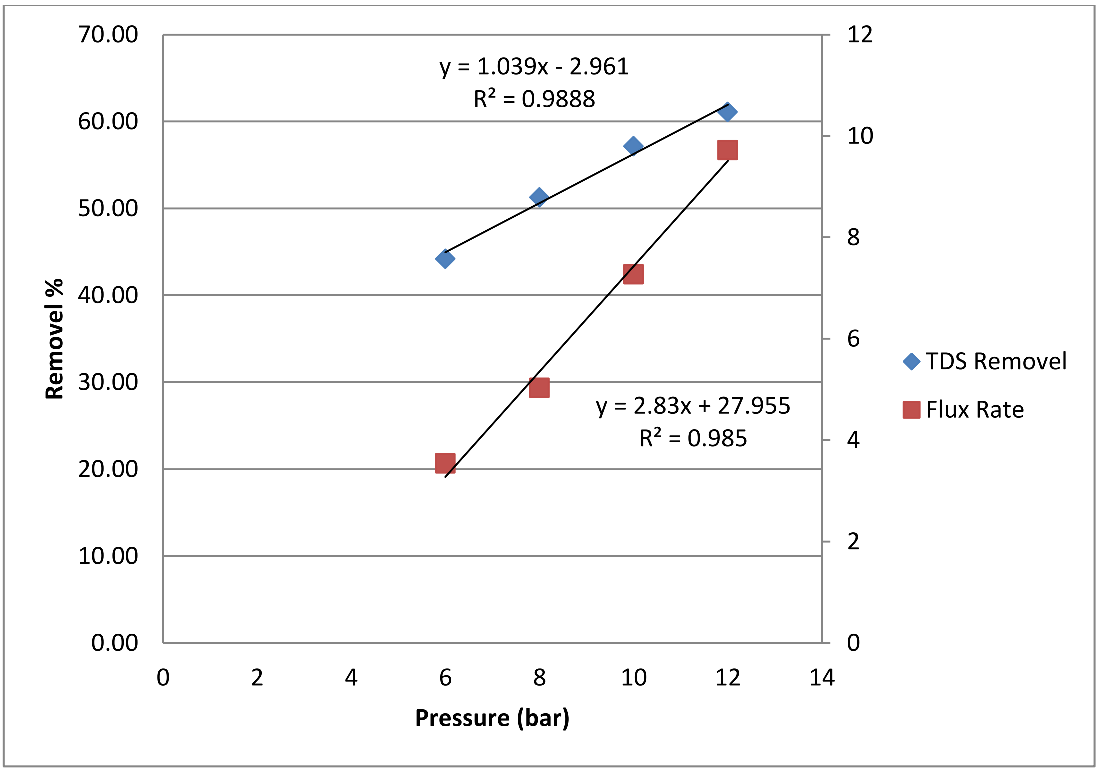
1) Pure water

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)
12	6.3	16
10	8.02	12.84
8	10.15	10.12
6	13.38	7.65



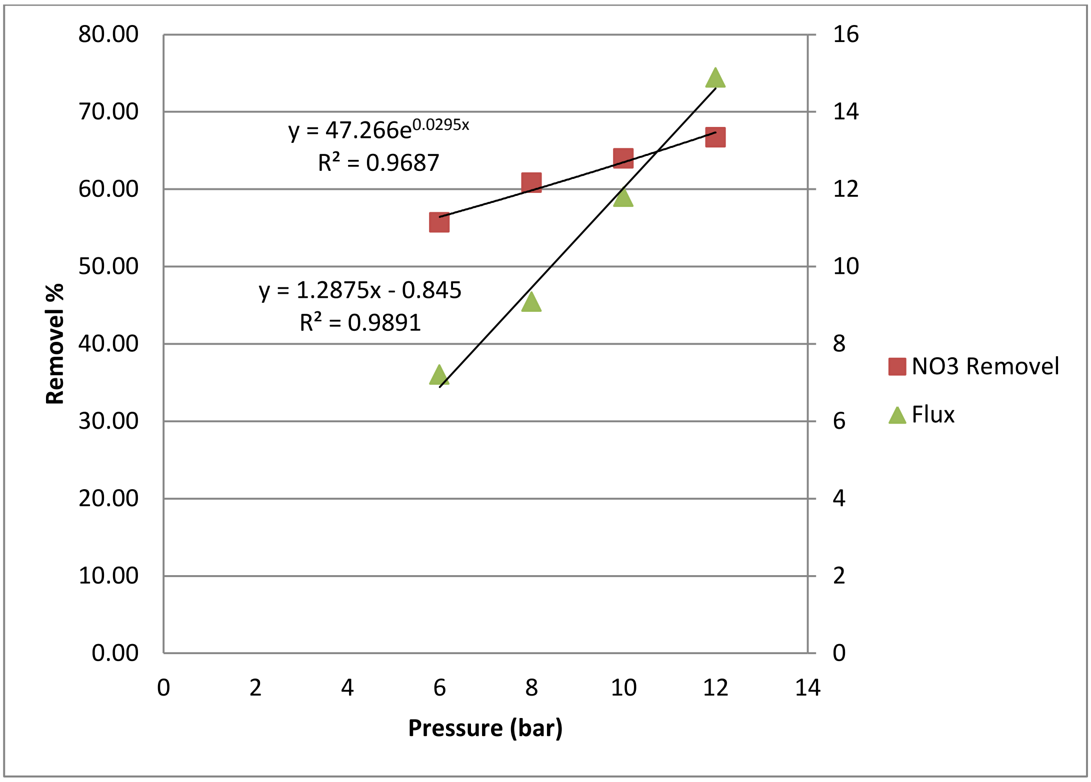
2) 2000 mg/l NaCl solution

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %
12	10.56	9.72	778	61.10
10	14.11	7.27	857	57.15
8	20.45	5.03	975	51.25
6	29	3.54	1116	44.20



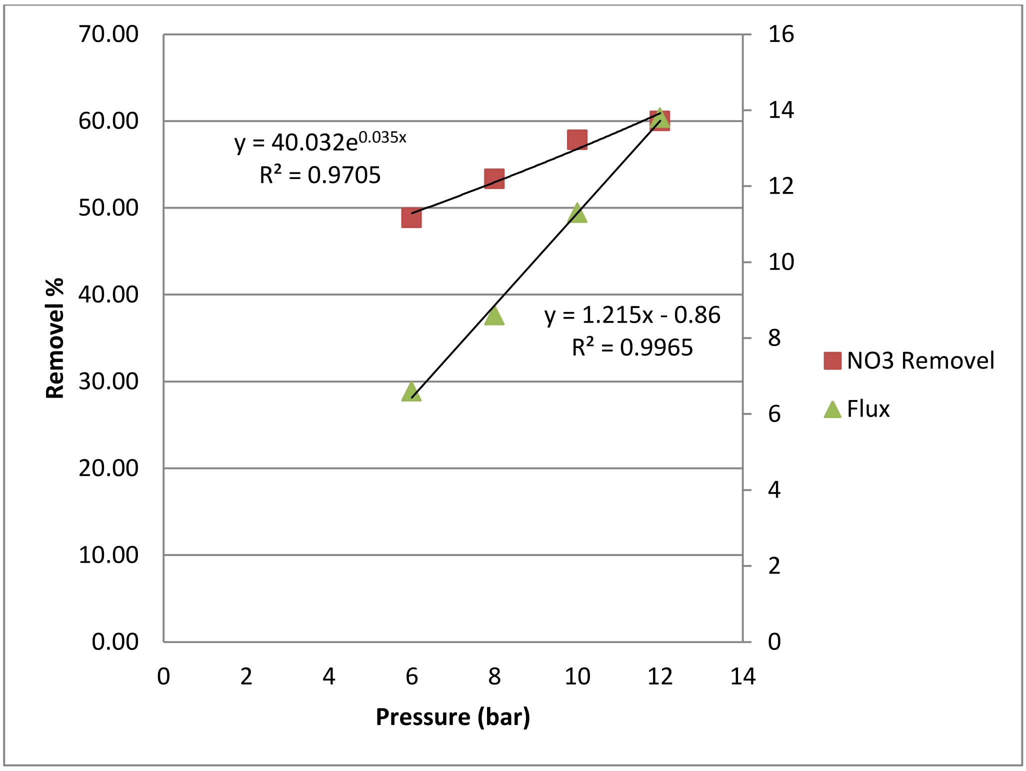
3) Nitrate solution (50mg/l)

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	NO_3(mg/L)	NO_3 Removal
12	6.92	14.88	16.66	66.68
10	8.71	11.8	18.03	63.94
8	11.35	9.09	19.6	60.80
6	14.16	7.20	22.15	55.70



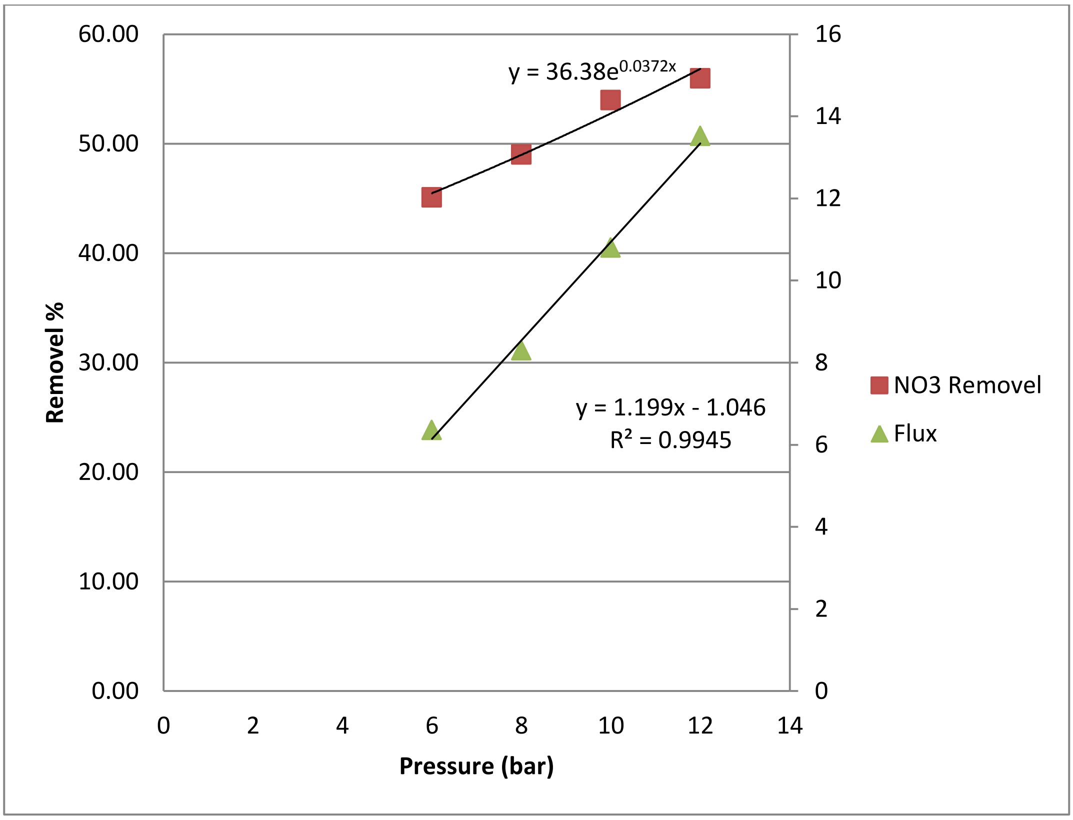
4) Nitrate solution (100mg/l)

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	NO$_3$(mg/L)	NO$_3$ Removal
12	7.41	13.8	40	60.00
10	9.1	11.3	42.15	57.85
8	11.91	8.6	46.66	53.34
6	15.66	6.60	51.17	48.83



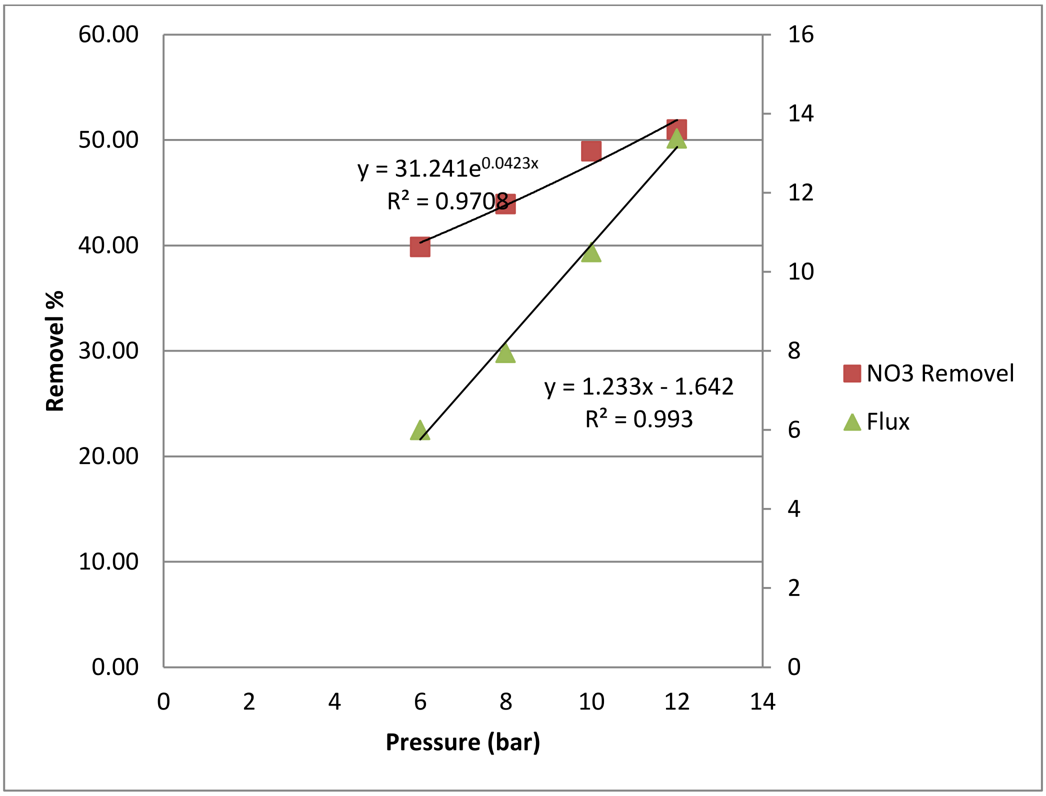
5) Nitrate solution (150 mg/l)

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	NO$_3$(mg/L)	NO$_3$ Removal%
12	7.58	13.52	66.07	55.95
10	9.83	10.8	69.01	53.99
8	12.41	8.3	76.47	49.02
6	16.16	6.36	82.35	45.10



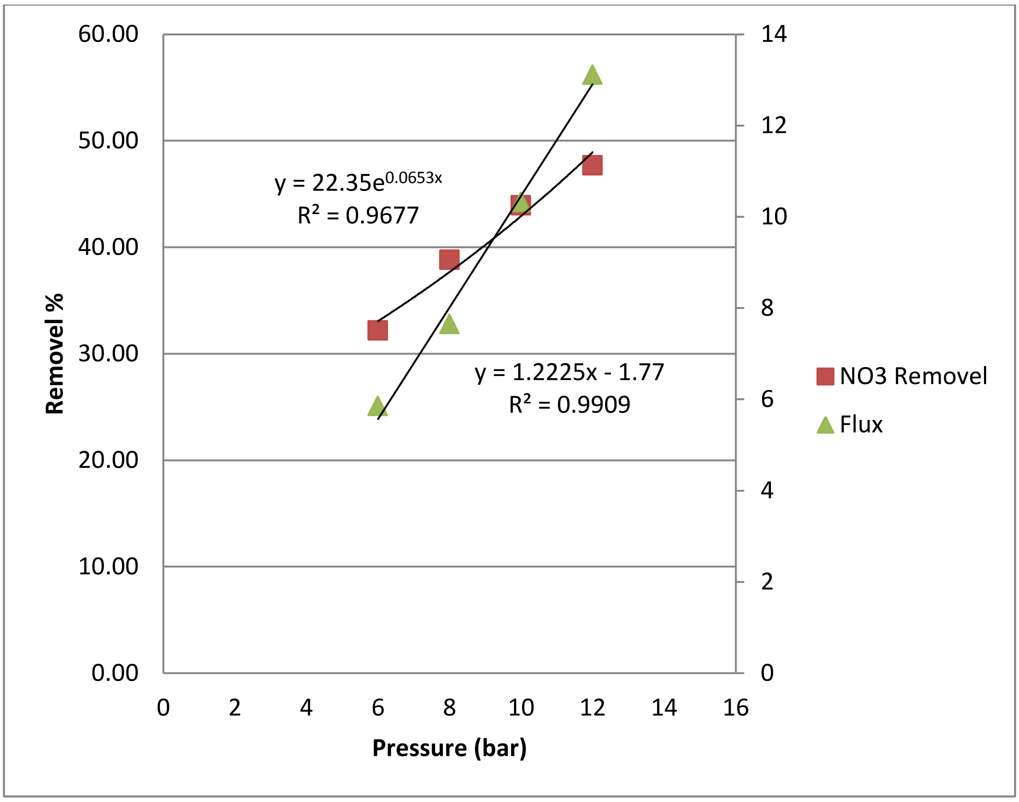
6) Nitrate solution (200 mg/l)

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	NO$_3$(mg/L)	NO$_3$ Removal%
12	7.68	13.37	98.04	50.98
10	9.78	10.5	102.16	48.92
8	12.91	7.95	112.15	43.93
6	17	6.00	120.28	39.86



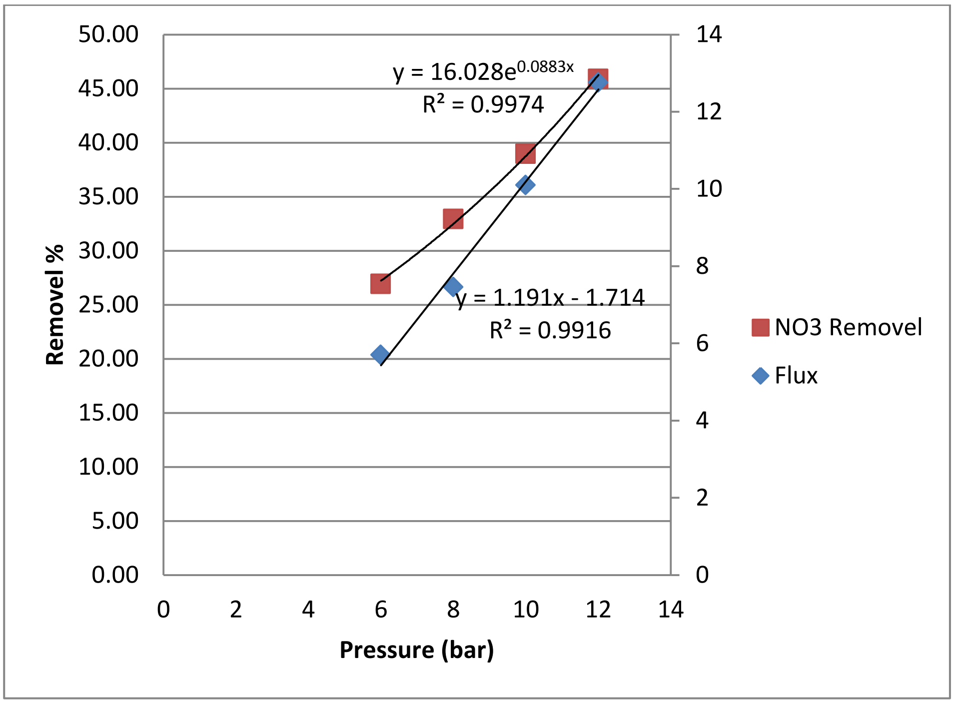
7) Nitrate solution (250 mg/l)

Pressure(Bar)	Average time(minute)	Flux($L/m^2.hr$)	NO_3(mg/L)	NO_3 Removal%
12	7.82	13.11	130.78	47.69
10	9.91	10.32	140.19	43.92
8	13.41	7.65	152.94	38.82
6	17.5	5.85	169.6	32.16



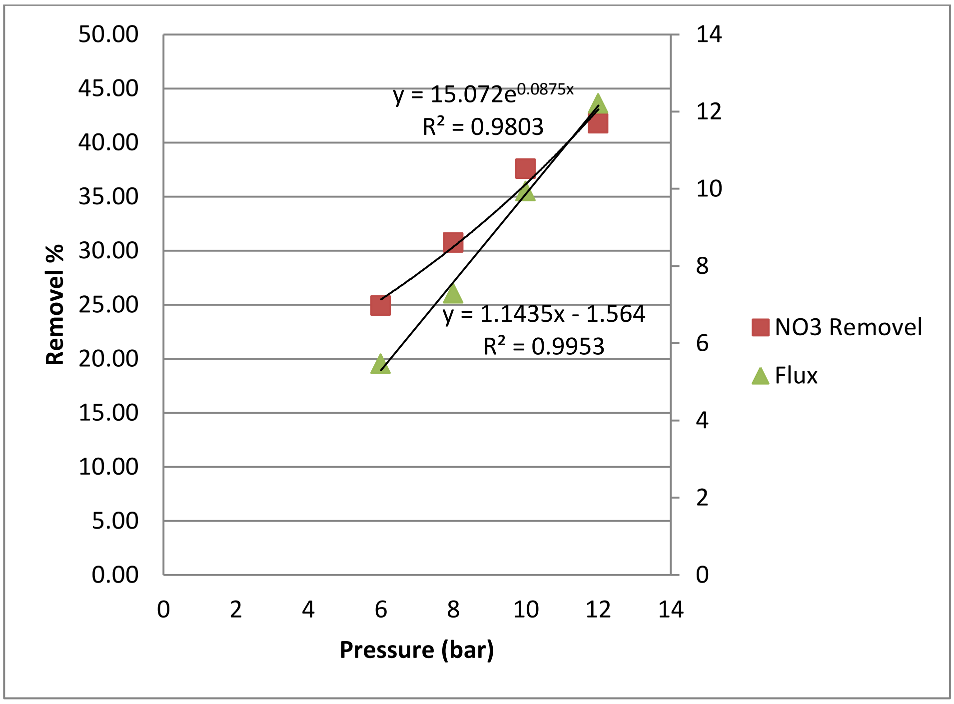
8) Nitrate solution (300 mg/l)

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	NO_3(mg/L)	NO_3 Removal%
12	8.06	12.76	162.35	45.88
10	10.25	10.1	183.14	38.95
8	13.78	7.46	201.17	32.94
6	18.03	5.70	219.21	26.93



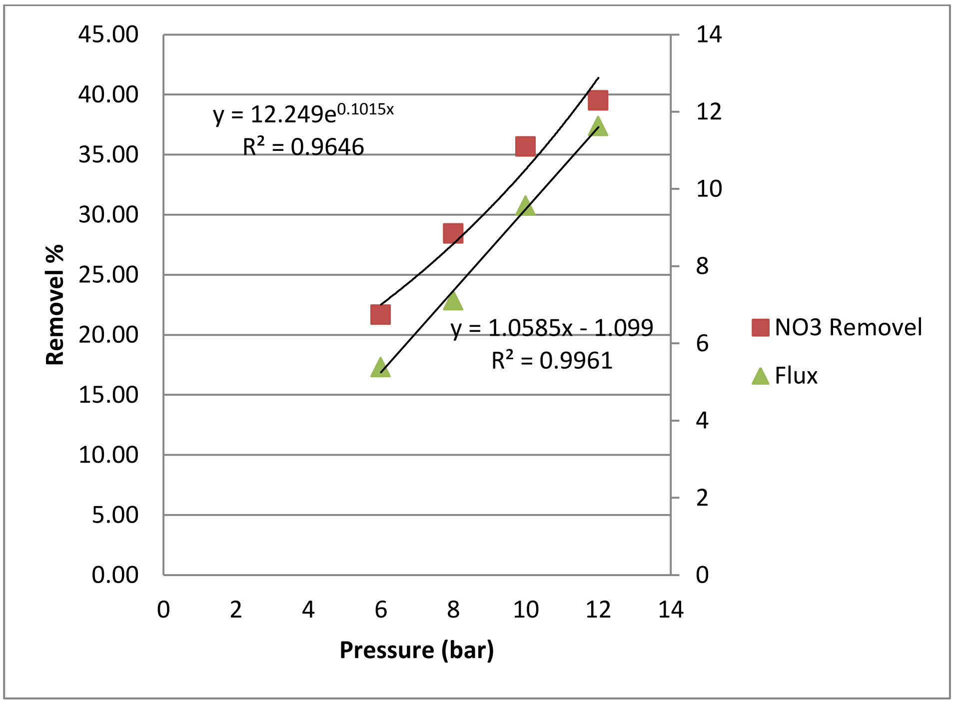
9) Nitrate solution (350 mg/l)

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	NO$_3$(mg/L)	NO$_3$ Removal%
12	8.43	12.21	203.74	41.79
10	10.32	9.94	218.43	37.59
8	14.09	7.29	242.35	30.76
6	18.75	5.47	262.74	24.93



10) Nitrate solution (400 mg/l)

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	NO_3(mg/L)	NO_3 Removal%
12	8.83	11.63	241.96	39.51
10	10.73	9.57	257.25	35.69
8	14.42	7.12	286.27	28.43
6	19.03	5.39	313.33	21.67

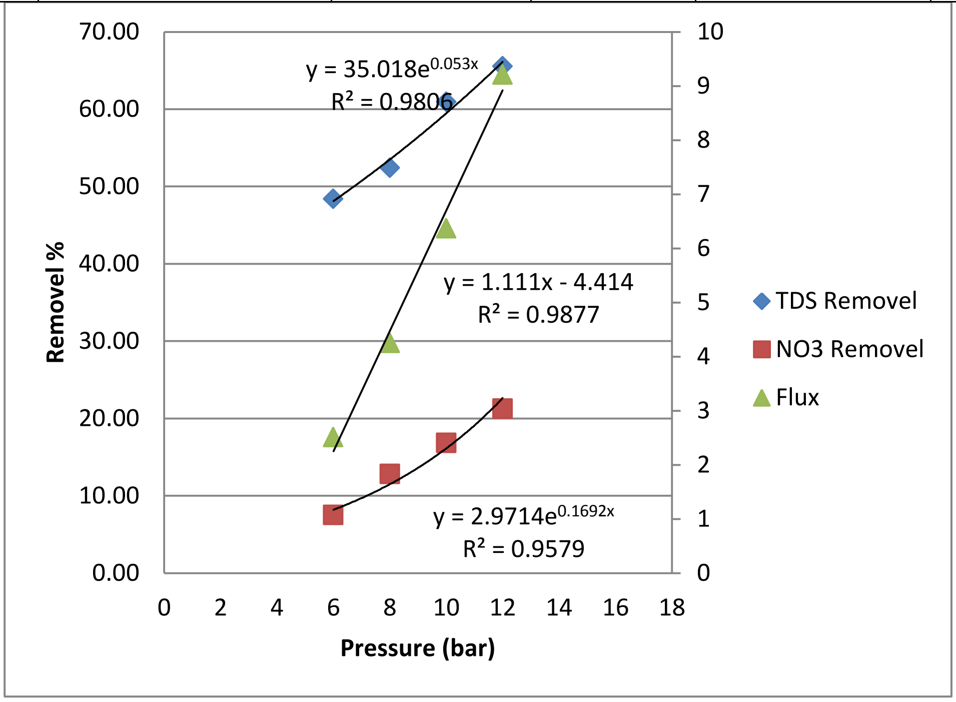


APPENDIX (2)

Real water result

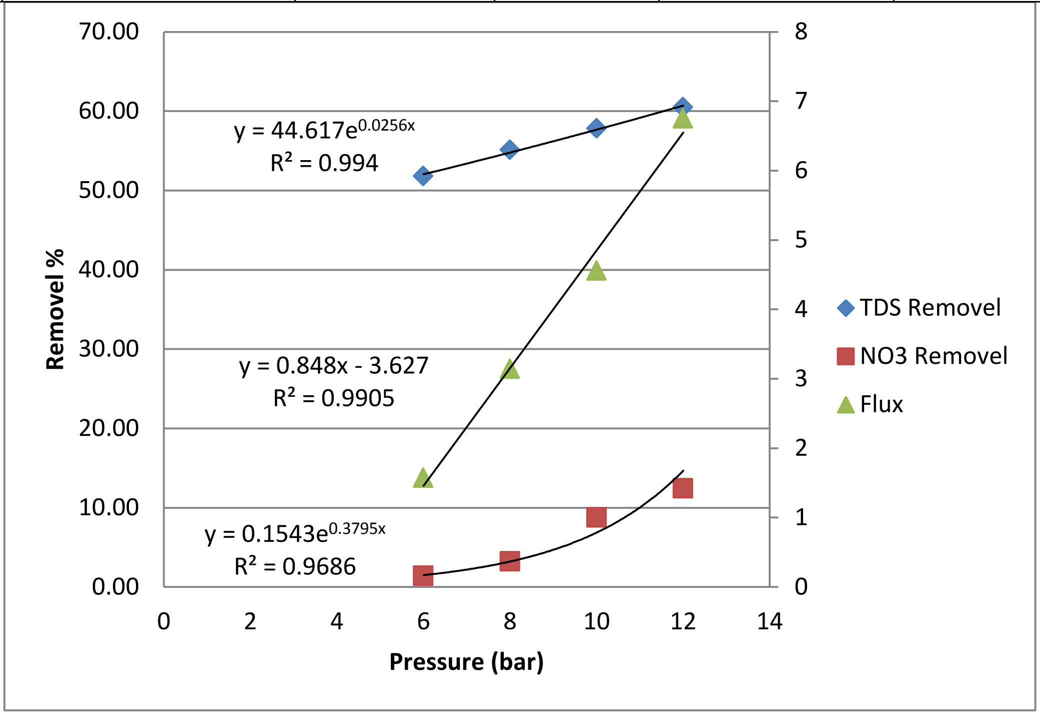
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
R25B	Gaza	1740	226

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	11.15	9.21	600	65.52	178	21.24
10	16.12	6.37	680	60.92	188	16.81
8	24.17	4.25	828	52.41	197	12.83
6	40.93	2.51	898	48.39	209	7.52



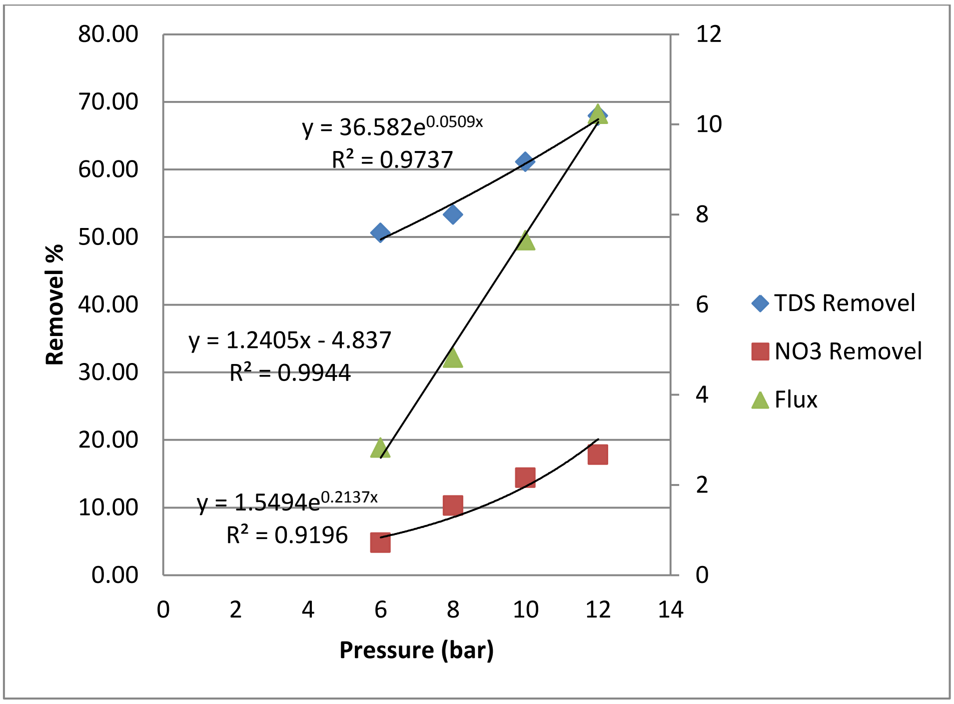
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
R311	Gaza	2570	217

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO_3(mg/L)	NO_3 Removal%
12	15.95	6.75	1016	60.47	190	12.44
10	22.05	4.56	1084	57.82	198	8.76
8	32.71	3.14	1154	55.10	210	3.23
6	65.43	1.57	1239	51.79	214	1.38



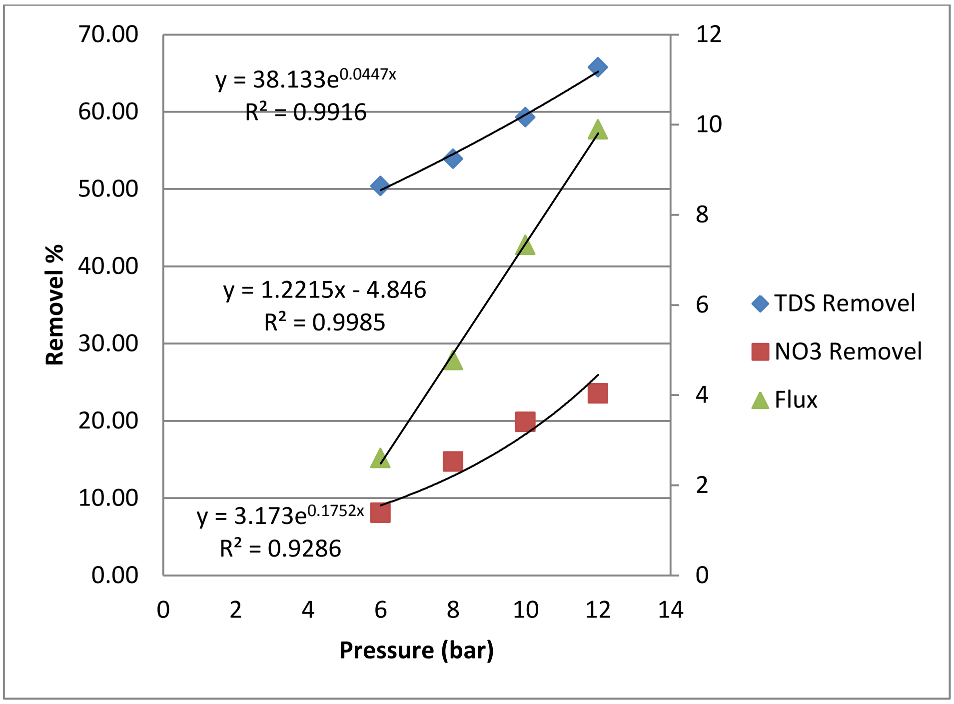
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
R25A	Gaza	1900	146

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	10.04	10.23	609	67.95	120	17.81
10	13.82	7.43	739	61.11	125	14.38
8	21.31	4.82	887	53.32	131	10.27
6	36.3	2.83	938	50.63	139	4.79



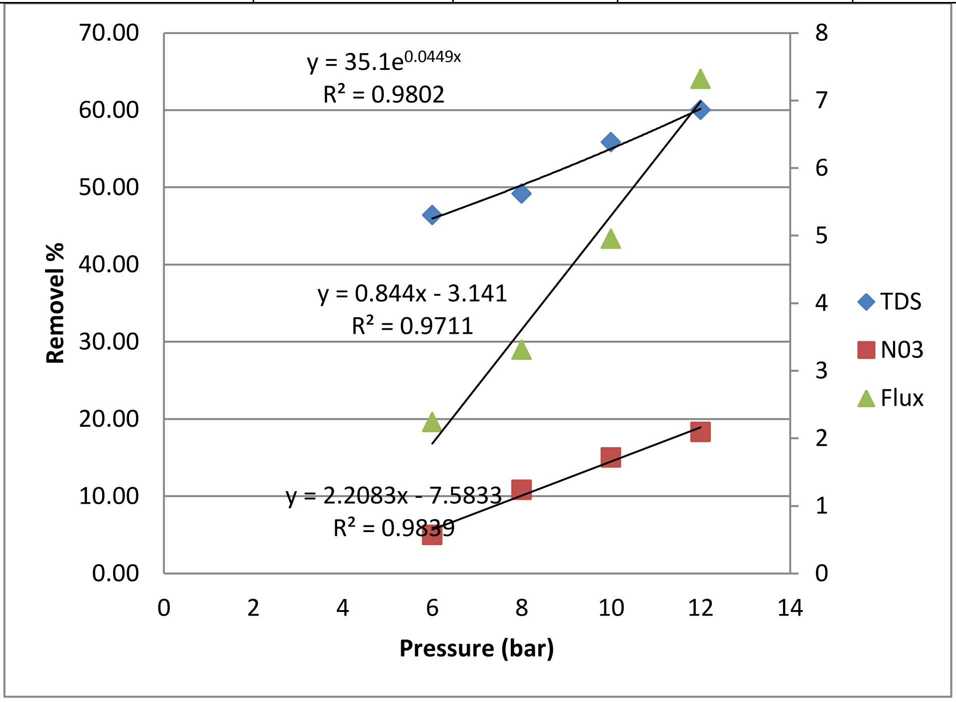
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
R306	Gaza	1587	136

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	10.38	9.89	544	65.72	104	23.53
10	14.01	7.33	646	59.29	109	19.85
8	21.53	4.77	732	53.88	116	14.71
6	39.51	2.60	787.7	50.37	125	8.09



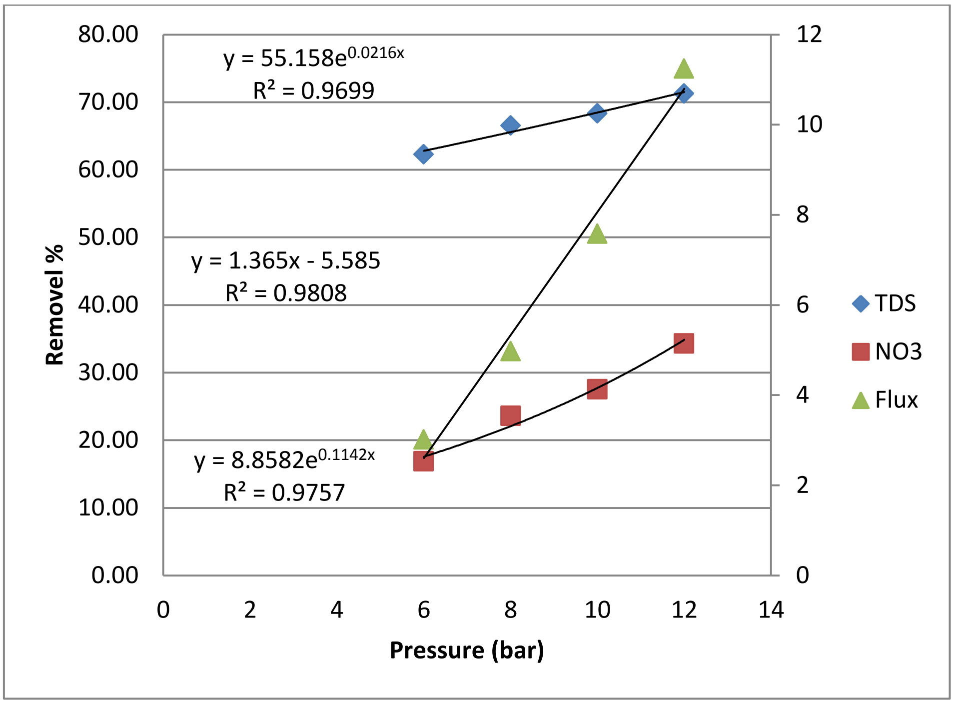
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
R74	Gaza	2220	120

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO_3(mg/L)	NO_3 Removal%
12	14.03	7.32	888	60.00	98	18.33
10	20.75	4.95	980	55.86	102	15.00
8	31.03	3.31	1128	49.19	107	10.83
6	45.86	2.24	1190	46.40	114	5.00



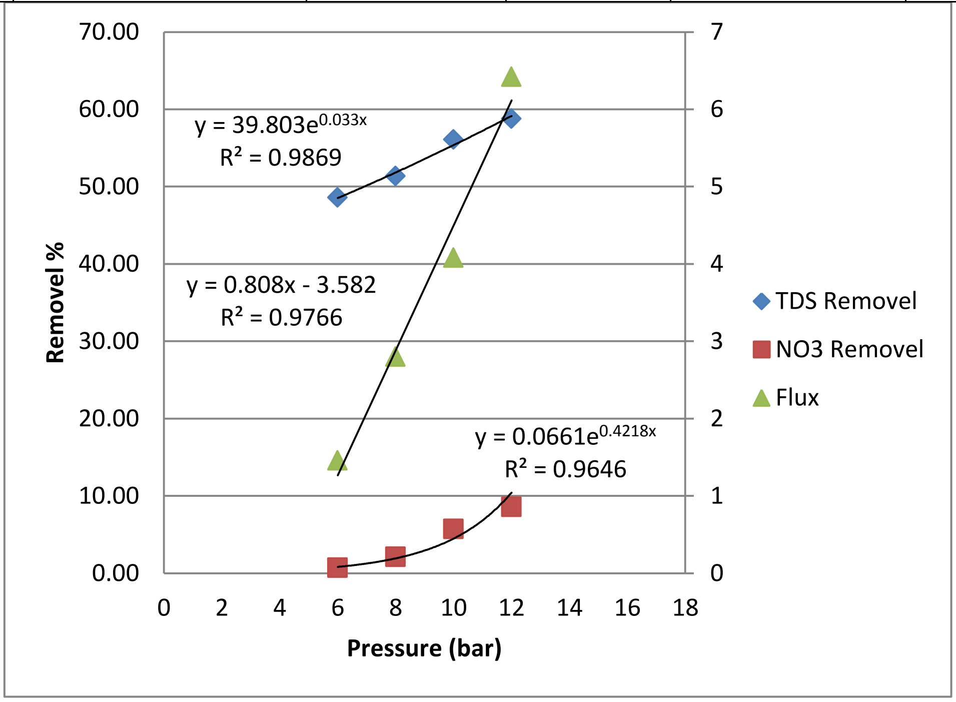
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
Dareeg	Gaza	1200	178

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	9.14	11.24	345	71.25	117	34.27
10	13.55	7.58	380	68.33	129	27.53
8	20.67	4.97	402	66.50	136	23.60
6	34.13	3.01	453	62.25	148	16.85



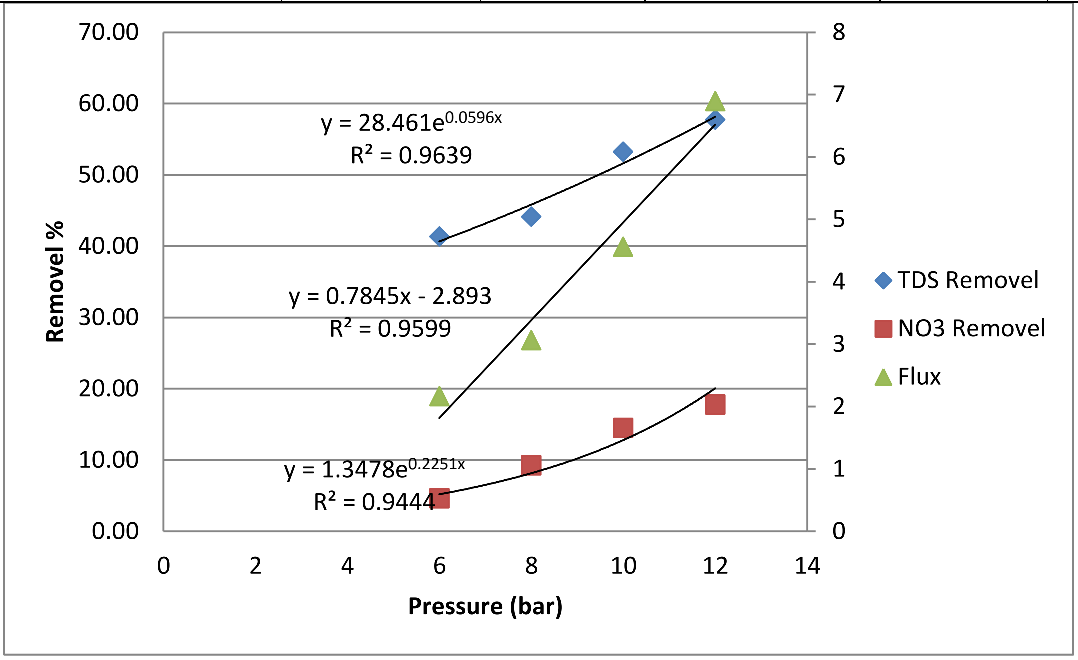
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
Astath	Khanyounes	2900	140

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO_3(mg/L)	NO_3 Removal%
12	16	6.42	1195	58.79	128	8.57
10	25.16	4.08	1273	56.10	132	5.71
8	36.73	2.8	1410	51.38	137	2.14
6	70	1.46	1491	48.59	139	0.71



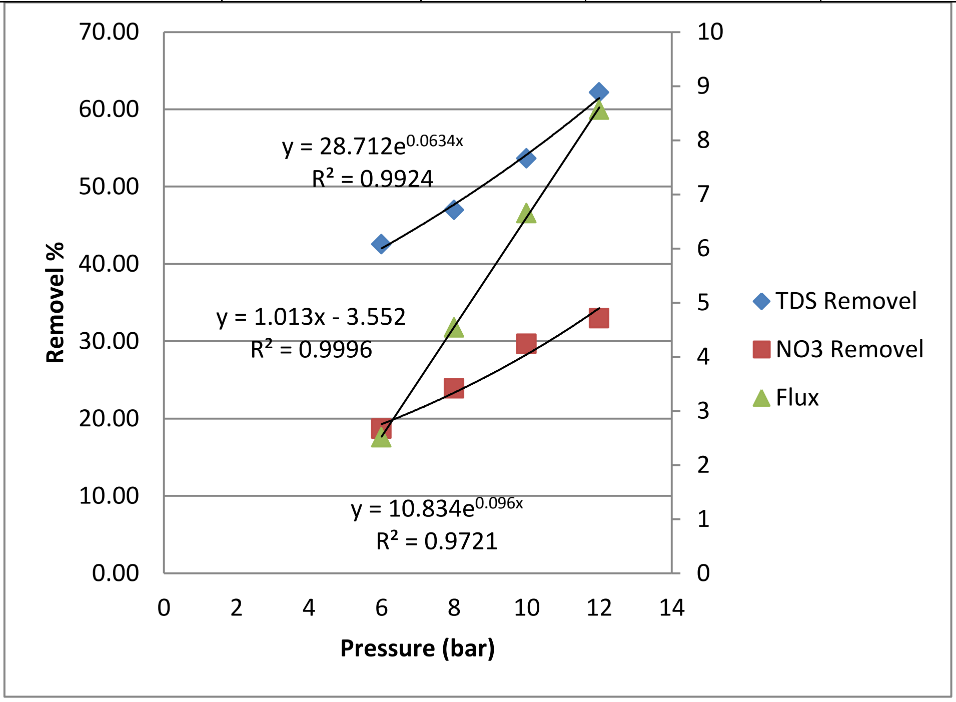
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
L87	Khanyounes	2450	304

Pressure	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	14.91	6.89	1036	57.71	250	17.76
10	22.53	4.56	1146	53.22	260	14.47
8	33.57	3.06	1369	44.12	276	9.21
6	47.56	2.16	1438	41.31	290	4.61



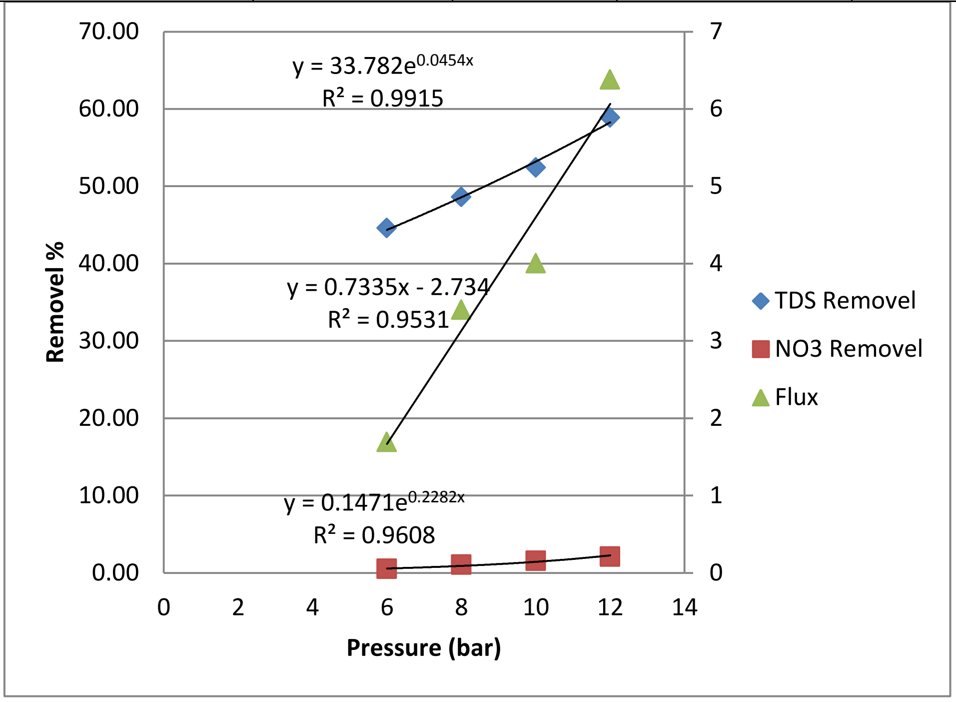
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
L127	Khanyounes	1950	364

Pressure	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	12	8.56	738	62.15	244	32.97
10	15.44	6.65	904	53.64	256	29.67
8	22.62	4.54	1034	46.97	277	23.90
6	40.93	2.51	1120	42.56	296	18.68



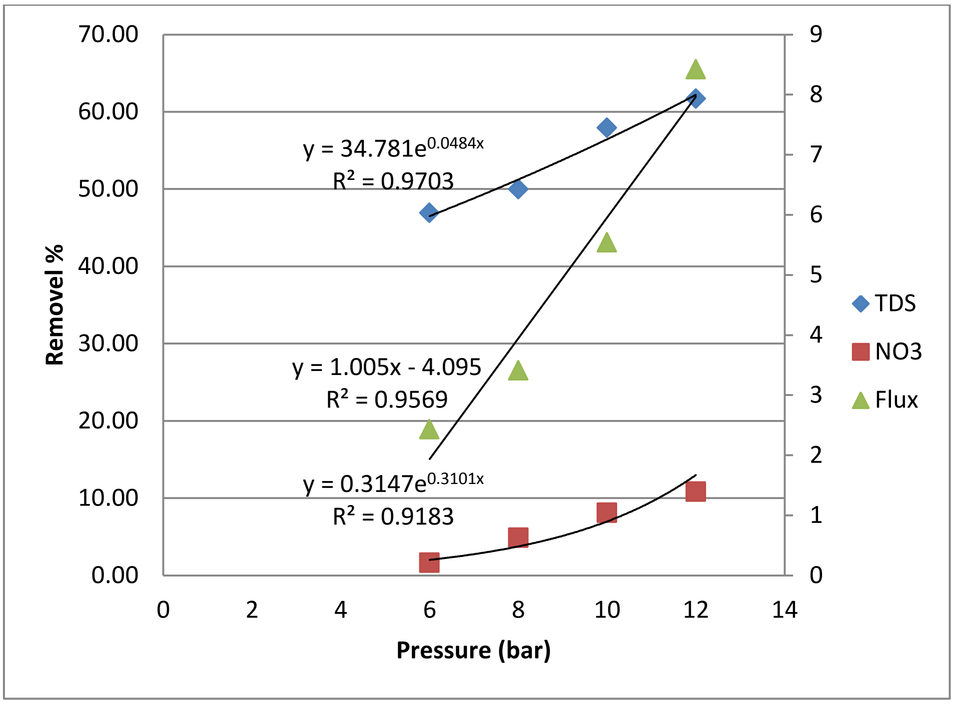
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
L190	Khanyounes	3570	193

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO_3(mg/L)	NO_3 Removal%
12	16.06	6.38	1469	58.85	189	2.07
10	23.11	4	1699	52.41	190	1.55
8	33.75	3.4	1836	48.57	191	1.04
6	72.48	1.69	1978	44.59	192	0.52



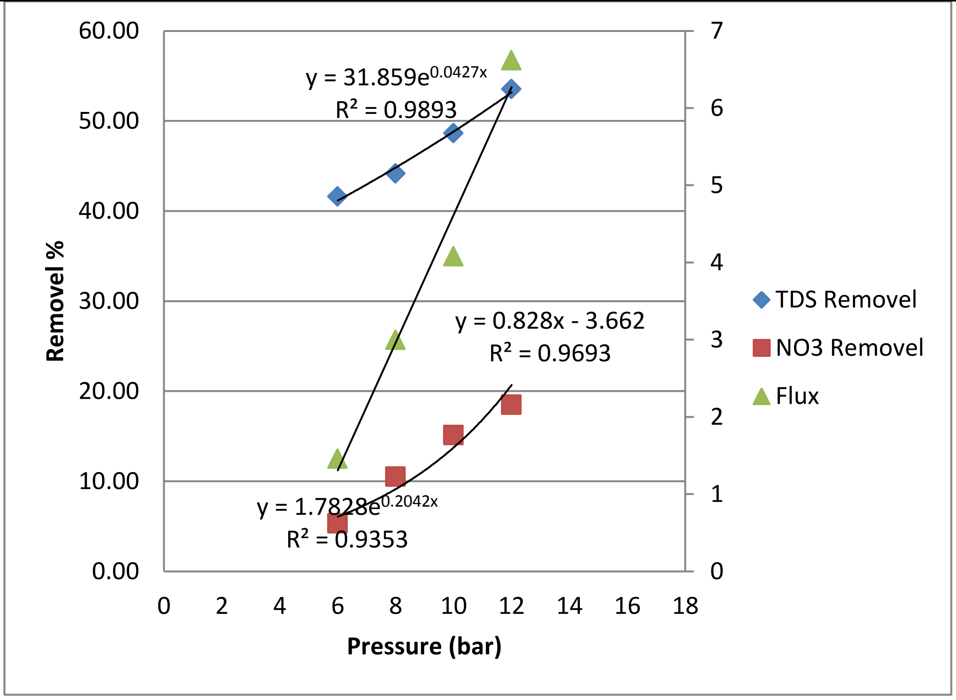
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
L198	Khanyounes	2100	185

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	12.2	8.42	805	61.67	165	10.81
10	18.54	5.54	884	57.90	170	8.11
8	30.12	3.41	1051	49.95	176	4.86
6	42.27	2.43	1115	46.90	182	1.62



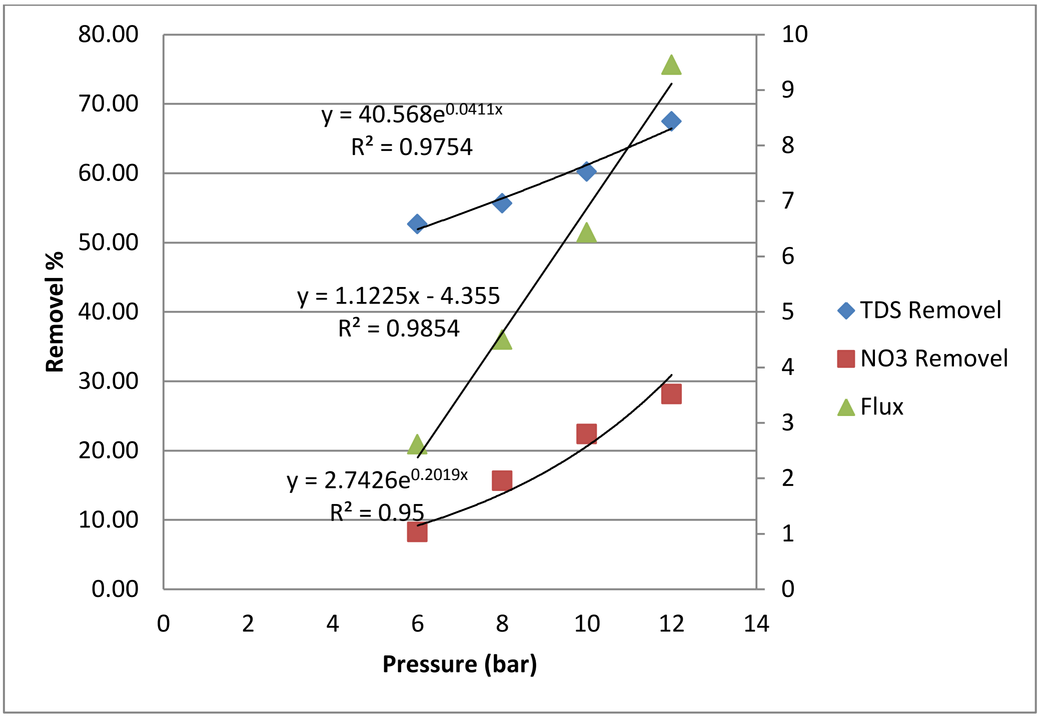
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
H104	Middle	2454	76

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	15.5	6.62	1140	53.55	61.94	18.50
10	25.16	4.08	1260	48.66	64.5	15.13
8	34.15	3	1370	44.17	68	10.53
6	70	1.46	1433	41.61	71.934	5.35



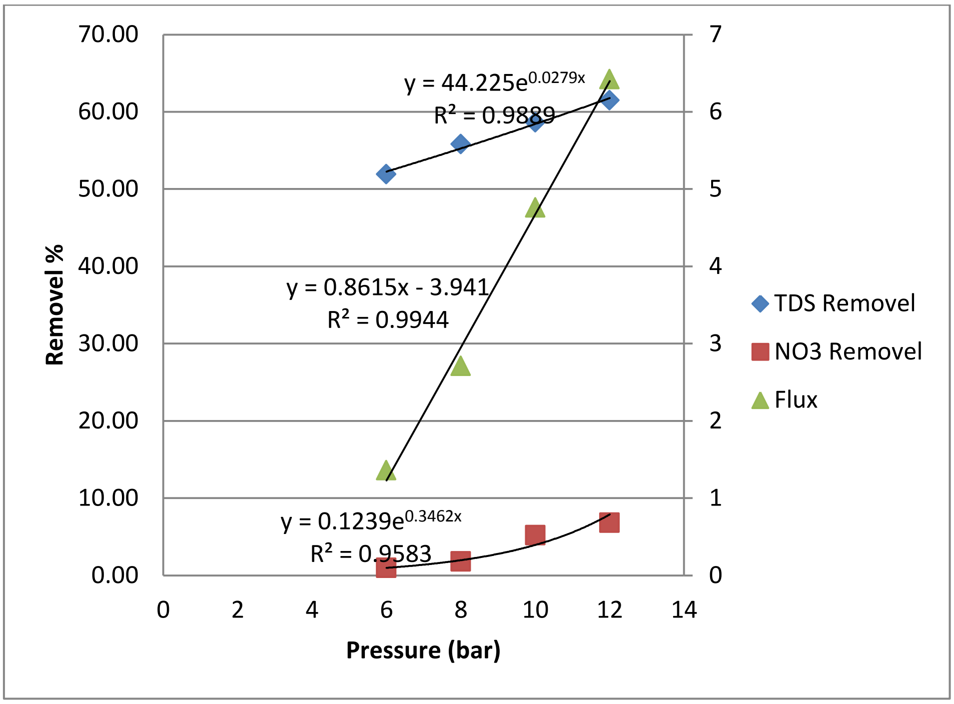
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
S69	Middle	1506	32

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removel %	NO_3(mg/L)	NO_3 Removel%
12	10.87	9.45	490	67.46	23	28.13
10	15.97	6.43	599	60.23	24.85	22.34
8	22.83	4.5	668	55.64	27	15.63
6	39.33	2.61	713	52.66	29.36	8.25



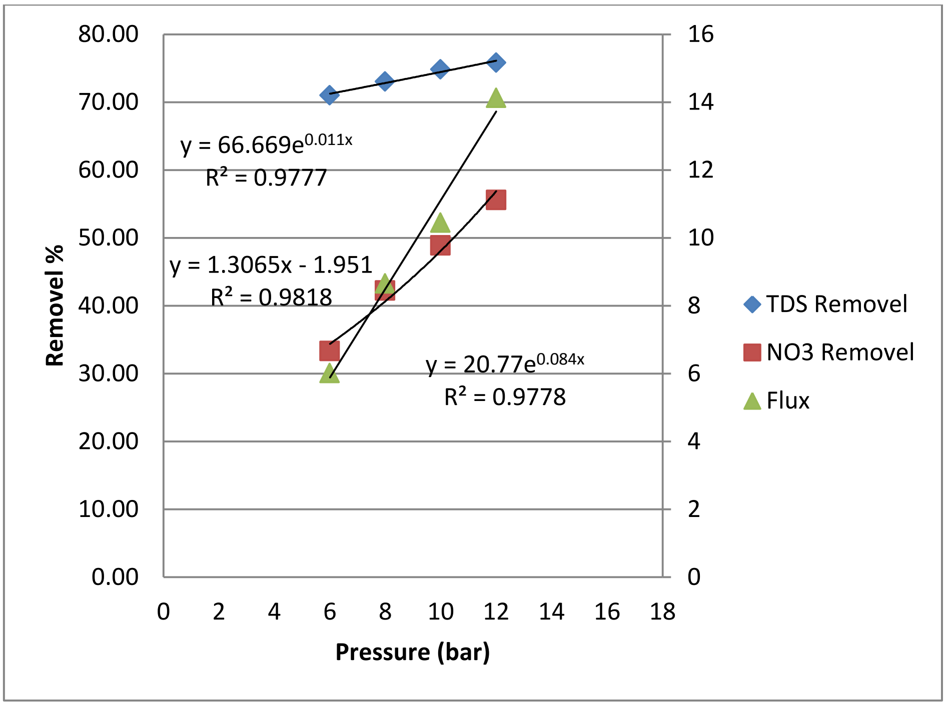
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
G49	Middle	3010	138

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO_3(mg/L)	NO_3 Removal%
12	16	6.42	1160	61.46	128.6	6.81
10	21.58	4.76	1246	58.60	130.86	5.17
8	37.91	2.71	1331	55.78	135.52	1.80
6	75.54	1.36	1448	51.89	136.67	0.96



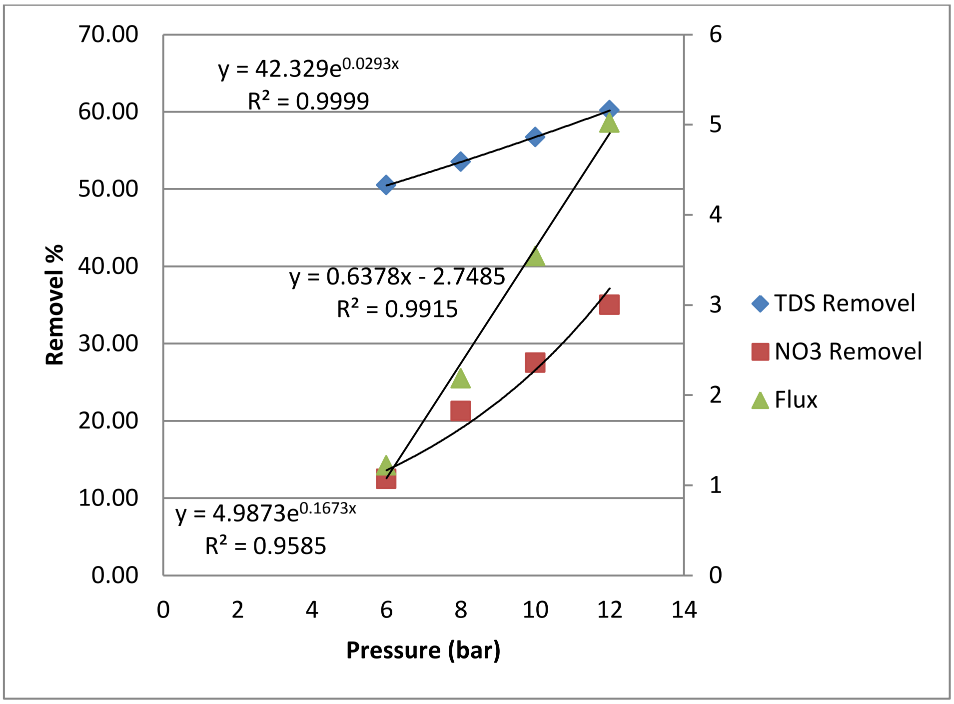
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
A211	North Gaza	3010	138

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	7.27	14.12	121	75.80	20	55.56
10	9.83	10.45	126	74.80	23	48.89
8	11.87	8.65	135	73.00	26	42.22
6	17.09	6.01	145	71.00	30	33.33



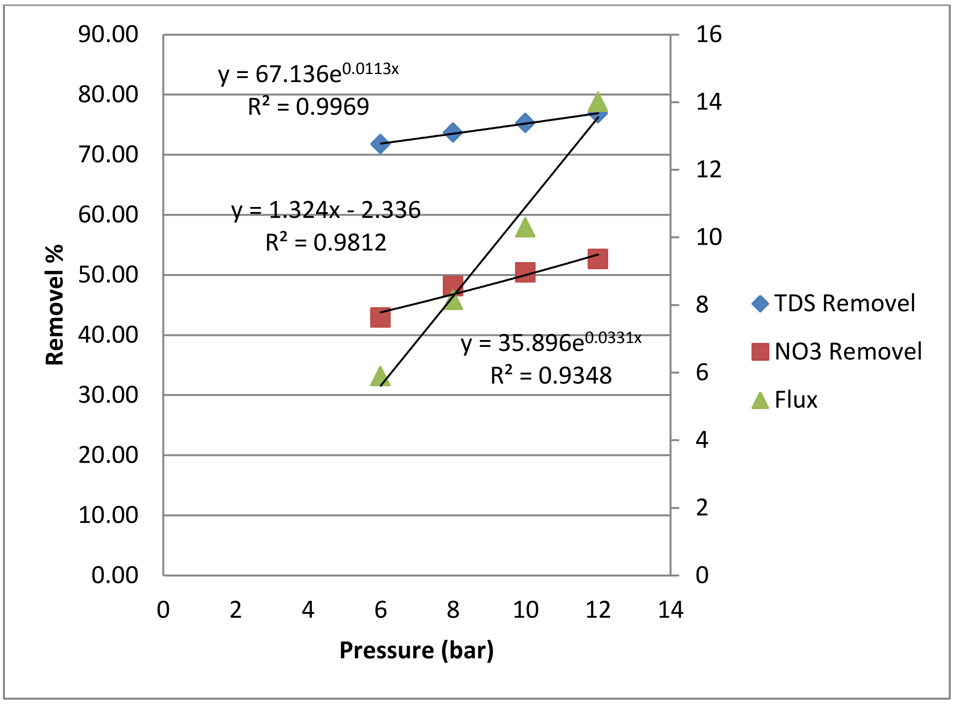
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
E142A	North Gaza	3140	80

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	20.46	5.02	1250	60.19	52	35.00
10	29	3.54	1360	56.69	58	27.50
8	47	2.185	1460	53.50	63	21.25
6	84	1.22	1555	50.48	70	12.50



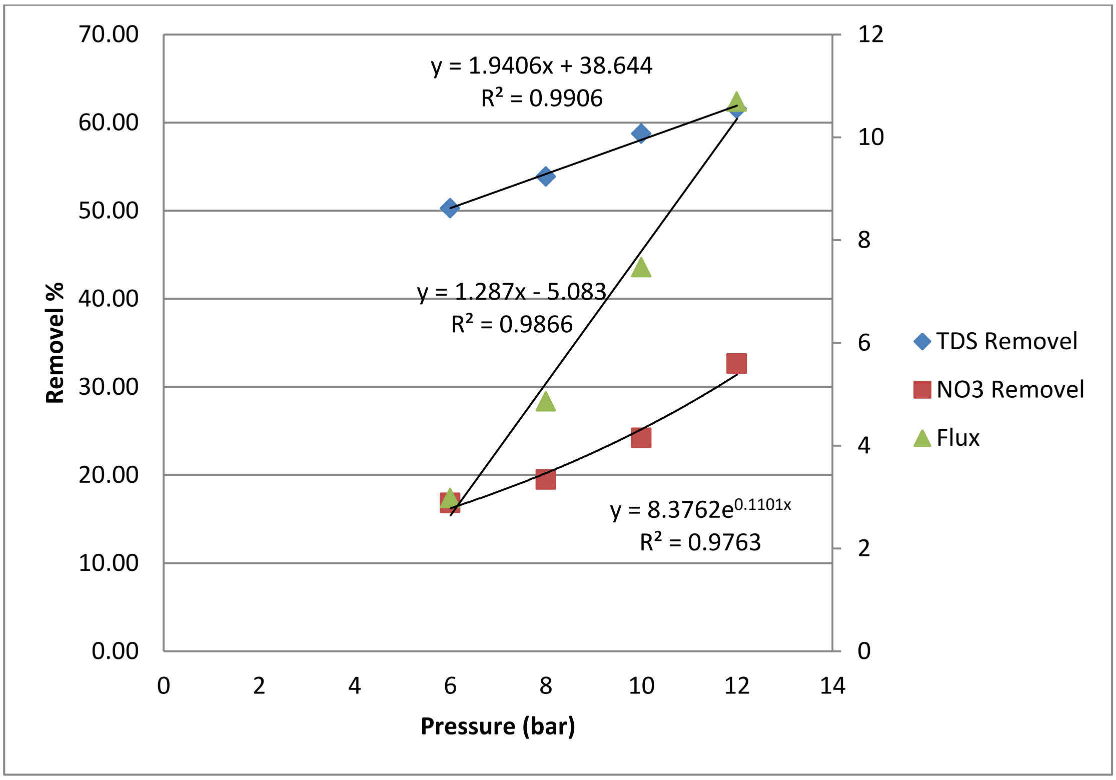
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
D75	North Gaza	630	133

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	7.33	14	146	76.83	63	52.63
10	9.98	10.29	156	75.24	66	50.38
8	12.61	8.14	166	73.65	69	48.12
6	17.43	5.89	178	71.75	76	42.86



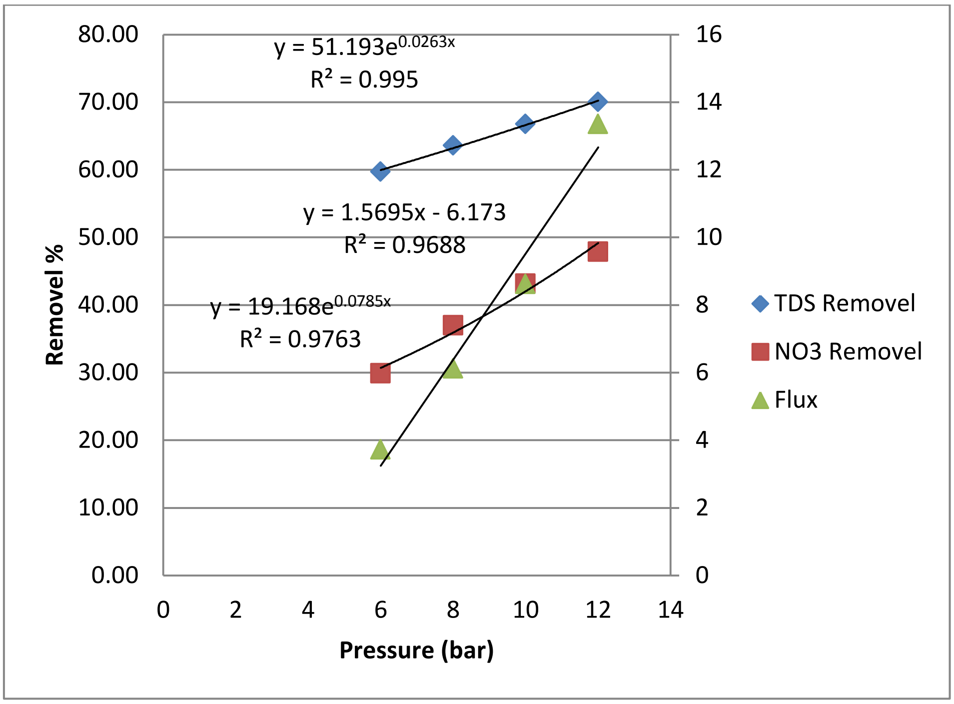
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
C79A	North Gaza	1600	190

Pressure	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO_3(mg/L)	NO_3 Removal%
12	9.61	10.69	615	61.56	128	32.63
10	13.75	7.47	660	58.75	144	24.21
8	21.13	4.86	738	53.88	153	19.47
6	36.47	2.98	796	50.25	158	16.84



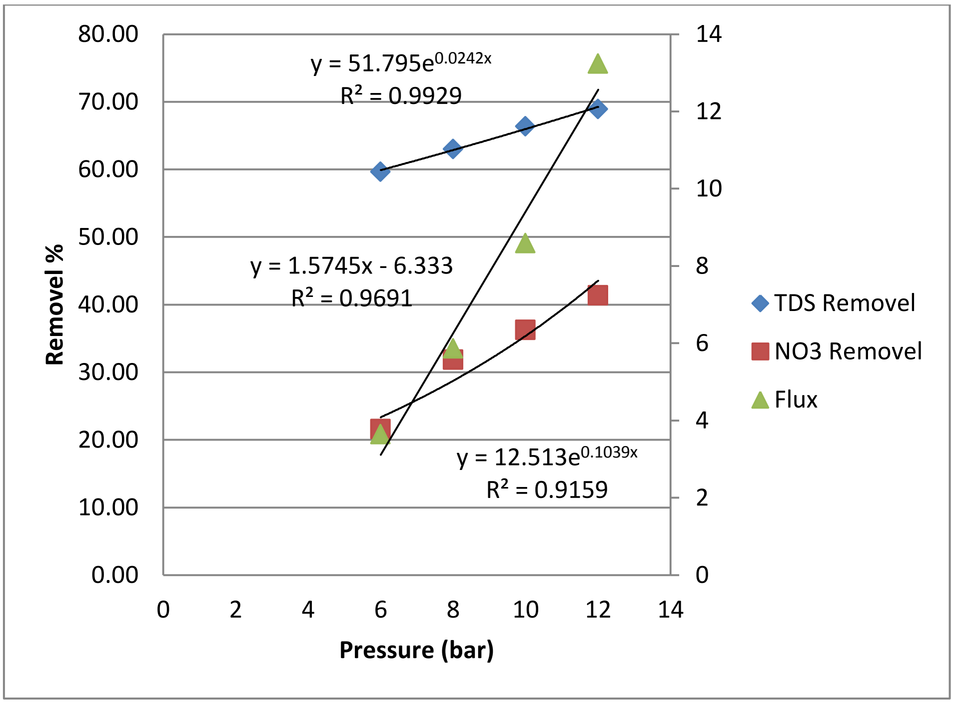
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
D60	North Gaza	950	211

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	7.69	13.35	285	70.00	119	43.60
10	11.91	8.62	316	66.74	123	41.71
8	16.78	6.12	346	63.58	127	39.81
6	27.61	3.72	383	59.68	134	36.49



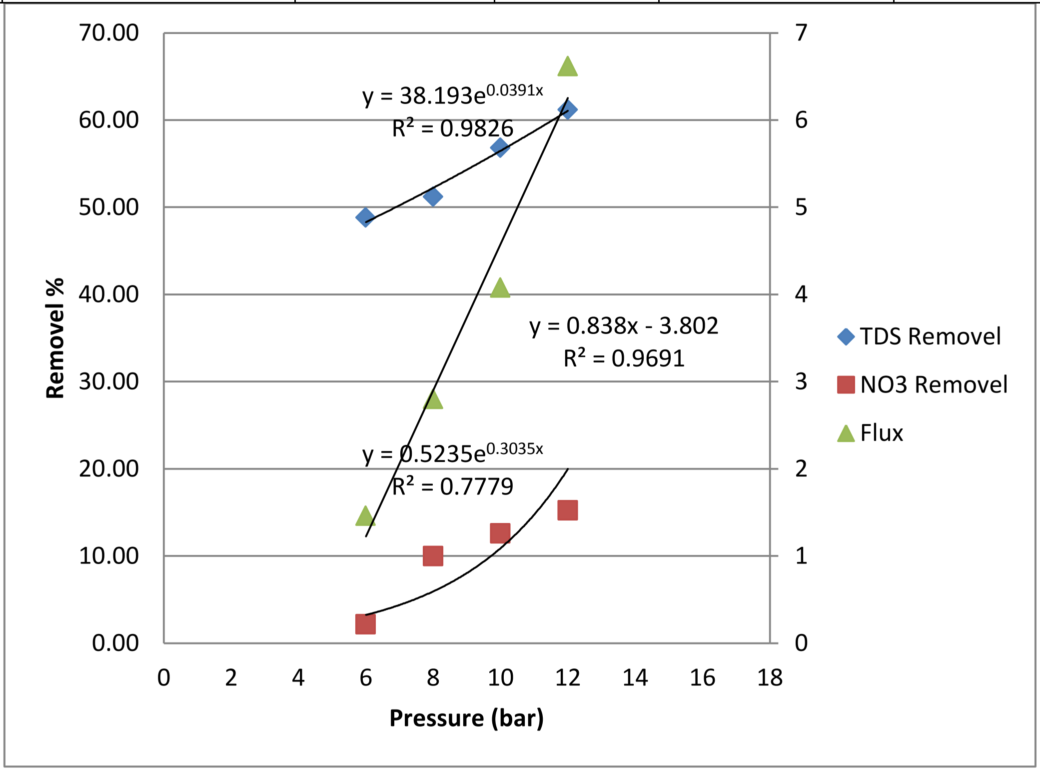
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
Heraa	North Gaza	1350	273

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO_3(mg/L)	NO_3 Removal
12	7.75	13.24	419.7479	68.91	160	41.39
10	11.95	8.59	453.7815	66.39	174	36.26
8	17.5	5.87	499.1597	63.03	186	31.87
6	28.03	3.65	544.5378	59.66	214	21.61



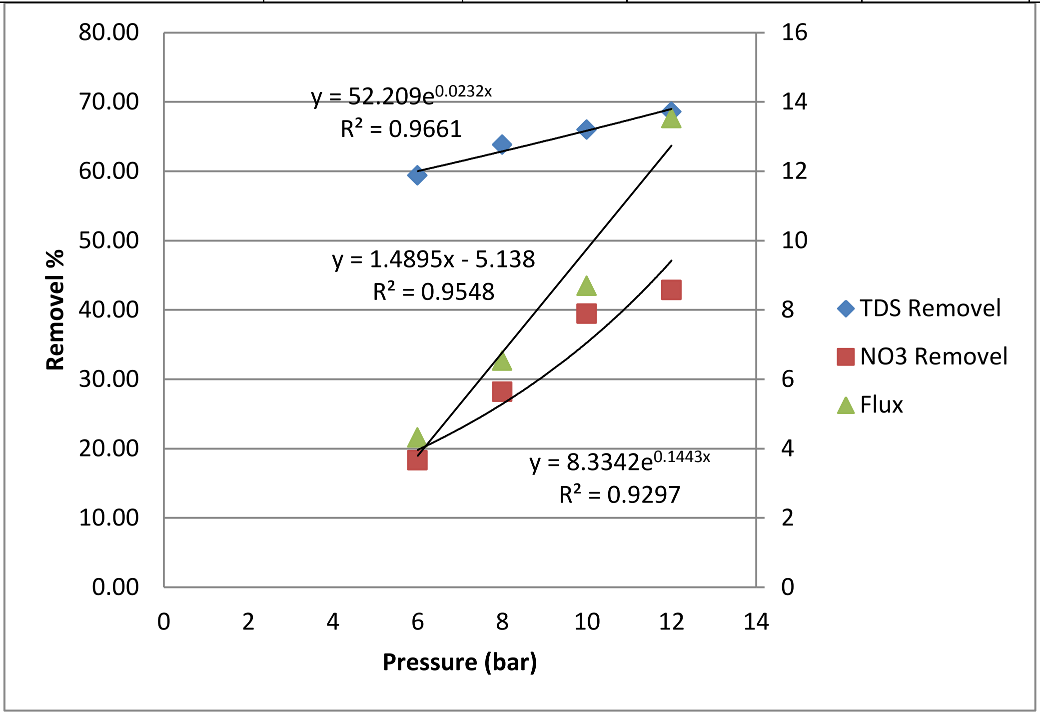
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
Sekaa	Rafah	2673	230

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO_3(mg/L)	NO_3 Removal%
12	15.51	6.62	1037	61.20	195	15.22
10	25.18	4.08	1154	56.83	201	12.61
8	36.73	2.8	1304	51.22	207	10.00
6	74.63	1.46	1368	48.82	225	2.17



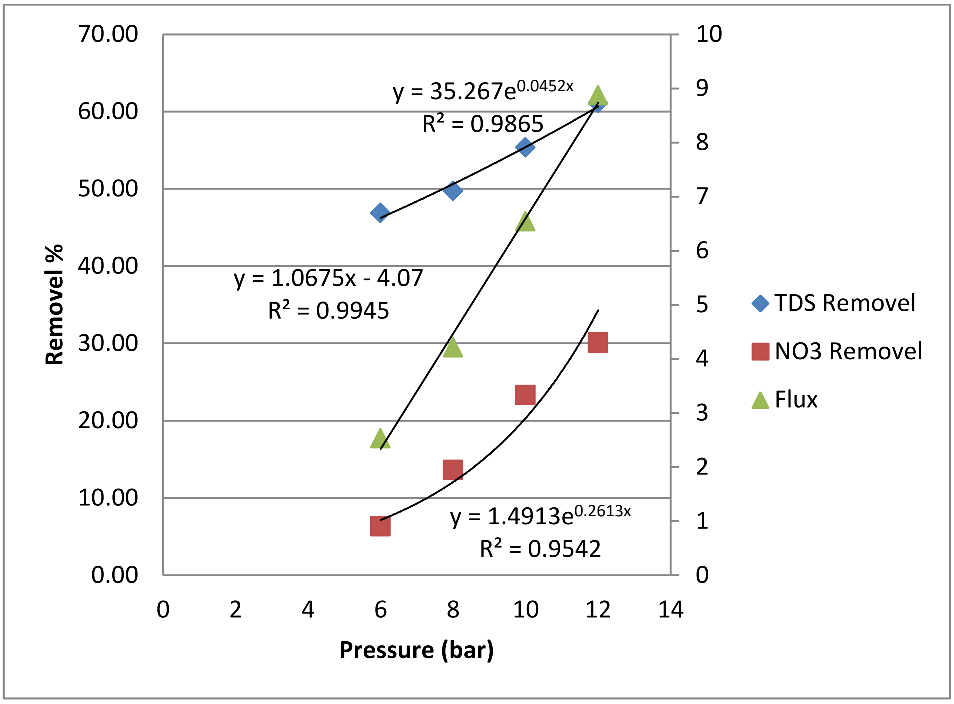
Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
W2	Rafah	970	71

Pressure	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	7.59	13.53	305	68.56	40.58	42.85
10	11.82	8.69	330	65.98	43	39.44
8	15.73	6.53	351	63.81	51	28.17
6	23.78	4.32	394	59.38	58	18.31



Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
W2	Rafah	970	71

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	11.93	8.87	642	61.09	144	30.10
10	15.7	6.54	737	55.33	158	23.30
8	24.41	4.21	830	49.70	178	13.59
6	40.05	2.53	877	46.85	193	6.31



Well ID	Location	TDS (mg/l)	Nitrate (mg/l)
Shoot	Rafah	2574	332

Pressure(Bar)	Average time(minute)	Flux(L/m^2.hr)	TDS(mg/L)	TDS Removal %	NO$_3$(mg/L)	NO$_3$ Removal%
12	14.24	7.21	1063	58.70	285	14.16
10	21.22	4.84	1170	54.55	306	7.83
8	32.61	3.15	1290	49.88	328	1.20
6	43.53	2.36	1446	43.82	330	0.60