Deanship of Graduate Studies

Al-Quds University

Reverse osmosis membrane fouling reduction using Kinetic Degradation Fluxion

Rawan Nizar Mahmoud Abu Eisheh

M.Sc. Thesis

Jerusalem-Palestine

1438/2017

Reverse osmosis membrane fouling reduction using Kinetic Degradation Fluxion

Prepared by:

Rawan Nizar Mahmoud Abu Eisheh

B.Sc. Palestine Polytechnic University - Palestine

Supervisor:
Dr. Jawad Shoqier

A thesis Submitted in Partial fulfillment of requirement for the degree of Master of Environmental Studies - Faculty of Earth and Science, Al-Quds University.

Jerusalem-Palestine

1438/2017

Al-Quds University
Deanship of Graduate Studies
Applied and Industrial Technology Program

Thesis Approval

Reverse osmosis membrane fouling reduction using Kinetic Degradation Fluxion

Prepared By: RawanNizar Mahmoud Abu Eisheh

Registration No: 21220283

Supervisor: Dr. JawadShoqier

Master thesis submitted and accepted, Date: 10/04/2017
The names and signatures of the committee members are as follows:

Head of Committee: Dr. .Jawad Shoqier Signature……………
Internal Examiner: Dr.Amer Marei Signature……………
External Examiner: Dr.Subhi Samhan Signature………… Subhi Samhan

Jerusalem-Palestine

1438/2017

Dedication

To my lovely hometown Palestine, and to the soul of martyrs.

Rawan Abu Eisheh

Declaration

I certify that this thesis submitted for the degree of Master is the result of my own research, except where otherwise acknowledged and that this thesis (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed………

Rawan Nizar Mahmoud Abu Eisheh

Date: 10/04/2017

Acknowledgment

I wish to express my heartfelt gratitude to my family, my father, my mother, my brothers, and my sisters for their constant affection, inspiration, encouragement to put my all the best efforts for achieving betterment in life.

I would like to express my keen appreciation to my supervisor Dr. Jawad Shoqier, who was eager to support my wish to implement the project at the department. I am grateful to him for his patience and understanding.

I would like to say many thanks to who assisted me in my work especially to the Laboratory assistant Mrs. Diyaa Radaida.

I acknowledge the Palestinian Water Authority (PAW) and the Middle East Desalination Research Center (MEDRC) for their financial support as well as for their continuous technical support.

List of abbreviation

Abbreviation	Full Name
ANSI	American National Standards Institute
BOD	Biological Oxygen Demand
Ca	Calcium
Cl	Chloride
Cl_2	Chlorine
COD	Chemical Oxygen Demand
EC	Electrical Conductivity
EDTA	Ethylenediaminetetraacetic acid
Fe	Iron
FI	Fouling Index
gm	Gram
gpd	Gallons Per Day
HCO_3	Bicarbonate
K	Potassium
KDF	Kinetic Degradation Fluxion
L/h	Liter per hour
LSI	Langelier Saturation Index
meq/L	Milliequivalent per Liter
mg	Milligram
Mg	Magnesium
mg /l	Milligram per Liter
Mn	Manganese
mS/cm	Milli-Siemens per Centimeter
Na	Sodium

NH_4	Ammonium
NO_2	Nitrite
NSF	National Sanitation Foundation
NTU	Nephelometric Turbidity Unit
pH	Power of Hydrogen
Psi	Pounds per Square Inch
Psig	Pounds per Square Inch
PWA	Palestinian Water Authority
RO	Reverse Osmosis
RO-KDF	Reverse osmosis system with pretreatment step
RO-only	Reverse osmosis system without pretreatment step
S&DSI	Stiff & Davis Saturation Index
SDI	Silt Density Index
SO_4	Sulphate
TDS	Total Dissolved Solids
TOC	Total Organic Carbon

Abstract

Nowadays reverse osmosis is one of the most used technologies for water treatment and it is a favored method for potable water production from seawater. However, membrane fouling is a critical problem associated with Reverse Osmosis (RO) plants, since it has many negative impacts on RO efficiency, effectiveness and operation costs. Moreover, membrane cleaning techniques used to overcome fouling reduce the membrane life time, and sometimes it damage the membrane, also these techniques may create environmental issues related to the waste chemical disposal.

In this study the effectiveness of applying Kinetic Degradation Fluxion (KDF) as pretreatment step for reducing fouling caused by scaling and high dosage of Cl_2 in RO system was investigated. Each test was carried out using two membranes, reference or control membrane in which feed solution moved directly inside without passing through the KDF media (RO-only), and pretreatment membrane with feed solution passing through KDF media (RO-KDF).

Positive results were obtained in Cl_2 experiments, comparing the two systems after 41 running hour's with high chlorinated feed solution shows that RO-KDF system was operating with full capacity, in terms of salt rejection and permeate flow, while salt rejection and permeate flow in RO-only system indicates that the membrane was degraded due to Cl_2 oxidation. The effectiveness of KDF media in Cl_2 removal was 73-100%, one disc of KDF media was enough to filter 1237L of high chlorinated feed solution then it is able to extend the lifetime of TW30-1812-50 FILMTEC™ RO membrane once, therefore the applied KDF media can be considered as effective pretreatment method for Cl_2 reduction in RO system.

In scaling reduction experiments the operating performance parameters in the RO-KDF system was better than that in RO-only system, so after 40 running hours the salt rejection in RO-KDF system was 96.8% and the permeate flow reduction was 16%, while it was 94.1% and 41% respectively in RO-only system. However, the applied KDF media cannot be considered as an effective method for scaling reduction since 10 discs of KDF media were fully oxidized and degraded after filtering 1349L, and these 10 discs increase the lifetime of TW30-1812-50 FILMTEC™ RO membrane only once.

Table of Contents

List of Tables

List of Figures:

List of Appendices

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 Background

Membrane life is a function of feed water source, pretreatment, frequency of cleaning, system design, and operating conditions (Abanmy.2001). Pretreatment is a key step in Reverse Osmosis (RO) plants, it involves proper techniques that can change the characteristics of RO feed water, so RO systems must be protected from biological contaminants, the potential for scale formation, and excessive fouling. In case pretreatment was inadequate, higher frequency of cleanings will be necessary, and the membrane performance will be dropped which will lead to complete failure of RO system. (Abanmyet al.1990). Chemical pretreatment can be performed by adding anti-scaling, this practice can probably be optimized in terms of anti-scalant type and dosage rate, but it will remain problematic for operators, plant management, cost and environment, Therefore, an intense research work is being done to develop new pretreatment methods, called non-conventional or emerging techniques (Arnel et al.2011), more efficient and more environmental safe, most of these techniques are physical involve applying magnetic field, electric field, ultrasonic and adding proper metal ion like copper (Cu) and zinc (Zn). It has been proven in many fields of water treatment that the use of Kinetic Degradation Fluxion (KDF) media can improve feed water characteristics; using KDF in water treatment systems removes chlorine (Cl_2), chloramines, Iron (Fe), Lead, bacteria, Hydrogen Sulfide, and other contaminants from the water supply. It also reduces scale and hardness (KDF fluid treatment.2003).

1.1.1 Membrane technology

Membrane technology is a term that refers to a number of different filtration processes that are used to separate substances. With this technology, membranes are used as filters in separation processes, with a wide variety of applications, both industrial and scientific. They provide effective alternatives to related technologies such as adsorption, ion exchangers, and sand filters. The membranes used in membrane technology may be regarded as barriers separating two fluids and allowing certain substances to be transported across the membrane (Melin et al.2007).

At its simplest, the technological use of membranes may consist of setting up a permeable membranous filter which allows water to flow through, but traps suspended solids Figure (1.1). There are various forces which may be used to cause water to penetrate through the membrane. These may include gravity, pressure, electrical current, or maintaining a concentration gradient across the membrane (Barker. 2004).

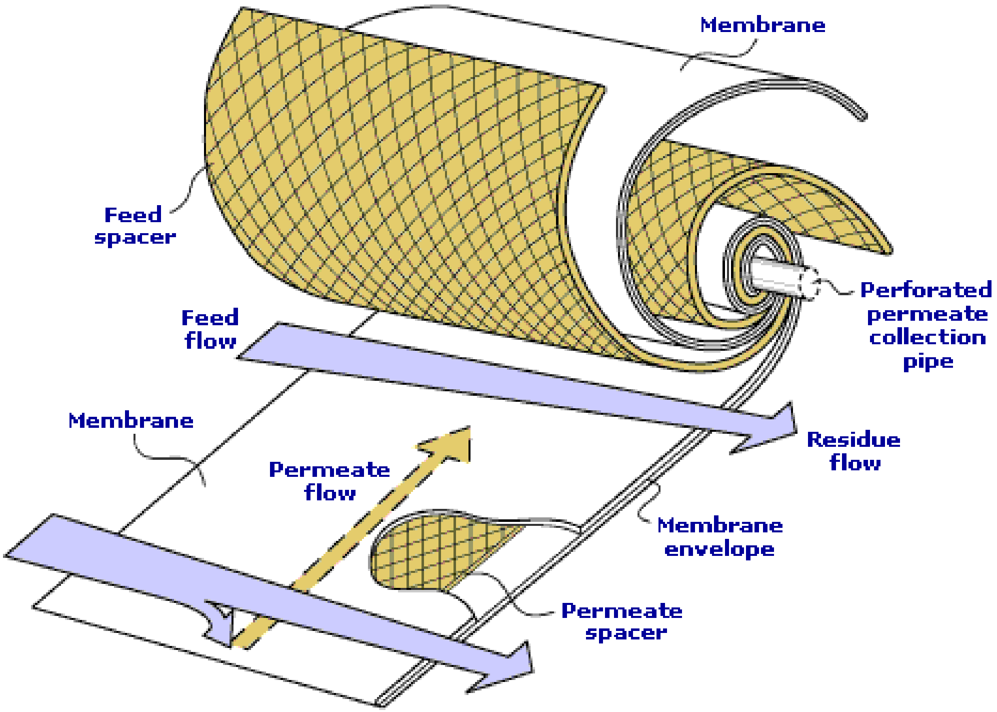


Figure (1. 1): Spiral would RO membrane construction.

One of the major uses of this type of technology is in the field of water filtration and purification. This includes desalination, or creation of drinking water from salt water, as well as purification of ground water or waste water (European Commission.2010). Other areas of industry that utilize membrane technologies include biotechnology, food and drink manufacturing, and medical uses such as dialysis for kidney failure patients.

1.1.2 Reverse Osmosis (RO)

Diffusion is the movement of molecules from a region of higher concentration to a region of lower concentration. Osmosis is a special case of diffusion in which the molecules are water and the concentration gradient occurs across a semi permeable membrane Figure (1.2) (Mulder.1996). The semi permeable membrane allows the passage of water, but not ions or larger molecules (e.g., glucose, urea, bacteria). Diffusion and osmosis are thermodynamically favorable and will continue until equilibrium is reached. Osmosis can be slowed, stopped, or even reversed if sufficient pressure is applied to the membrane from the 'concentrated' side of the membrane.

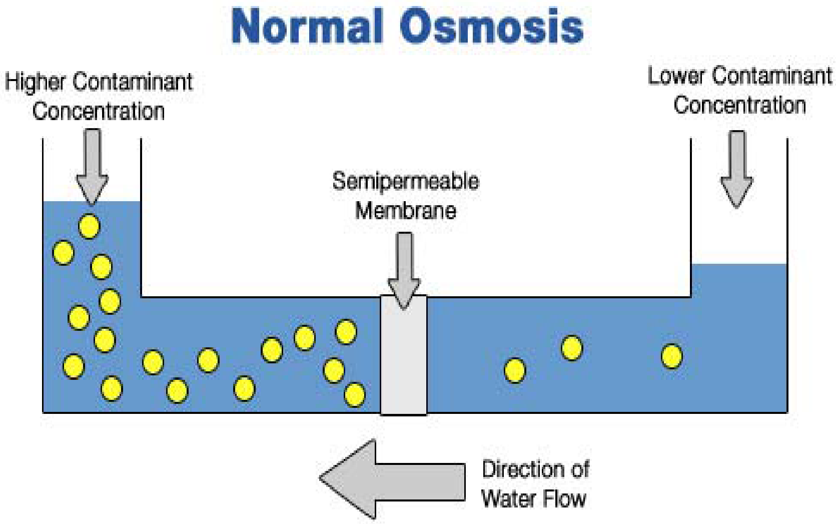


Figure (1. 2): Normal osmosis operation.

RO occurs when the water is moved across the membrane against the concentration gradient, from lower concentration to higher concentration Figure (1.3). To illustrate, imagine a semi permeable membrane with fresh water on one side and a concentrated aqueous solution on the other side. If normal osmosis takes place, the fresh water will cross the membrane to dilute the concentrated solution. In RO, pressure is exerted on the side with the concentrated solution to force the water molecules across the membrane to the fresh water side. RO is a technology that is found virtually anywhere pure water is needed (European Commission.2010).

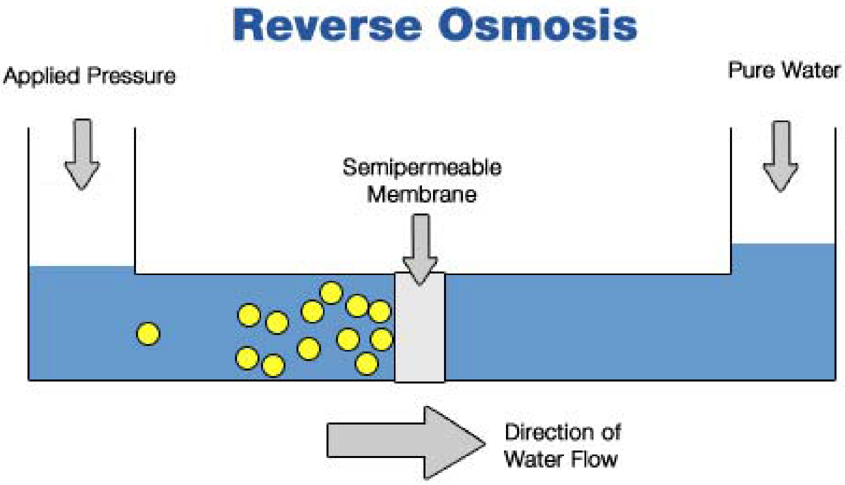


Figure (1. 3): Normal osmosis operation.

1.1.3 Membrane fouling

Membrane fouling is one phenomenon which always found after operation of membrane in a time. Fouling of RO membranes is defined operationally herein as the reduction in water transport per unit area of membrane (flux), caused by a substance or substances in the feed water that accumulate either on or in the membrane as shown in Figure (1.4) (Abanmy et al.1990). It was considered an importance drawback of membrane technology because it causes declination of water flux which can affect the quality of produced water. There are many types of foulants such as colloid and organic which can be taken place due to physic-chemical reaction. Also, microorganisms can cause severe fouling. Many parameters will affect the fouling, such as concentration, temperature, pH, ionic strength, and specific interactions.

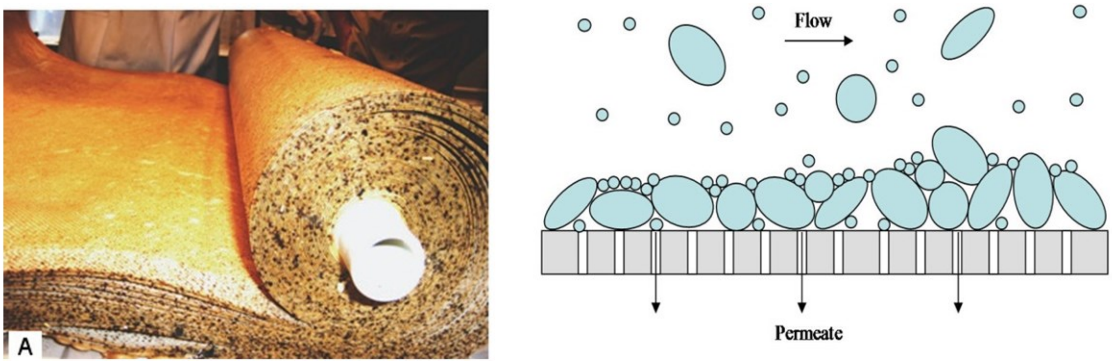


Figure (1. 4): Fouling mechanism on RO membrane.

In addition, fouling can be divided into reversible and irreversible fouling based on the attachment strength of particles to the membrane surface (United States Environmental Protection Agency (USEPA). 2003). Reversible fouling can be removed by means of strong shear force or backwashing. Formation of a strong matrix of fouling layer with the solute during continuous filtration process will result in reversible fouling being transformed into irreversible fouling layer. Irreversible fouling is normally caused by strong attachment of particles, which is impossible to be removed by physical cleaning method (Meng et al.2009).

In general, fouling removal must be done when some of the following situations are reached (Arnal et al.2001):

- 10-15% of permeate flux decline.
- 10-15% of permeate solute concentration increasing.
- 15-20% of pressure drop increase in a pressure vessel.

When some of these situations occurred, membrane must be cleaned to restore system performance. The cleaning procedure depends mainly on the type of fouling and the cleaning procedures.

Membrane cleaning methods can be divided into physical, chemical and physio-chemical. In practice, physical cleaning methods followed by chemical cleaning methods are widely used in membrane applications (Arnal et al.2001).

1.1.4 Kinetic Degradation Fluxion (KDF)

Patented KDF is a chemical compound consists of a high-purity alloy of both Cu and Zn, used in a flaked or granulated particulate form, usually appearing gold or brass in color as in Figure (1.5). KDF often used in water filtration applications along with activated carbon to maximize the filters efficiency. Generally KDF is used in a purification system as a prefilter, before another, finer stage of filtration, for example, RO, deionization and ion exchange systems (KDF fluid treatment. 2003). According to copper percentage in the KDF media two types are available; KDF85 with 85% copper and 15% zinc and KDF55 which consists of 55% copper and 45% zinc.

Figure (1.5): KDF gold particulate form.

KDF55 was designed specifically for removing or reducing chlorine and water soluble heavy metals. It controls scale, bacteria and algae, even in hot water and KDF85 removes or reduces iron and hydrogen sulfide from municipal or other water supplies. Also controls scale, bacteria and algae (KDF fluid treatment.2003).

KDF is regarded as being one of the newer developments in water treatment and filtration, since its development in 1984; it has grown to be widely regarded as one of the best filtration media available. KDF was invented by Don Heskett in 1984(Weber.2012). He initially discovered the potential of KDF media when he dipped one of his brass pen refills into a glass of chlorinated water containing Cl2 reagent tablets(hence colored pink), and observed the color dissipate. It was at this moment that Don realized that the brass pen refill had some form of potential to absorb impurities from water, in this case, Cl2. Over the next 36 months Heskett developed and researched his discovery, slowly refining it until he came to the product now known as KDF media.

- *Oxidation-Reduction of KDF Process Medium*

In the filtration process, zinc acts as an anode and copper as a cathode in an electrolytic cell as in Figure (1.6). Ionic contaminants are removed by electron exchange (a redox reaction), in which they are converted to a more physiologically inert form (Coleman D.et al.2007).

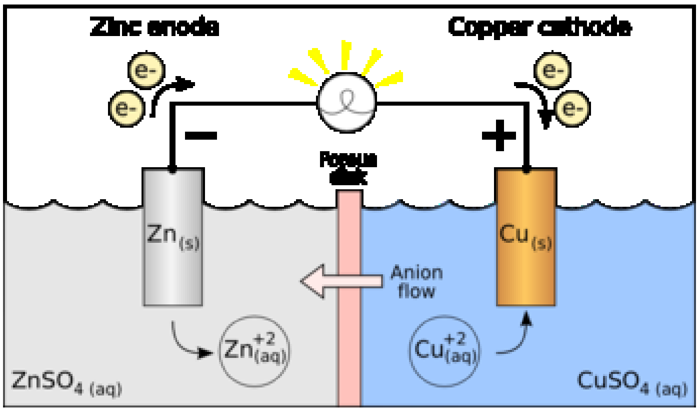


Figure (1.6): The electrolytic cell consists in KDF filtration process.

This redox reaction generates an electric potential of about 300mV, which may be responsible for the partial antimicrobial effect, along with hydroxyl radicals that form during the process.

Oxidation-reduction of the media is a naturally occurring process. Because the copper and zinc in the alloy are chemically dissimilar and are in direct electrical contact with the water (electrolyte) a galvanic cell is established.

Reaction between the medium and water occurs through these three basic steps:

1. A neutral zinc ion (Zn) from the alloy is oxidized to a positive two valance state; (Zn^{+2}).
2. As a result of the oxidation of Zn to Zn^{+2}, two electrons are released and these flow through the alloy to the cathodic area (Cu).
3. Water in contact with the cathode completes the electric circuit by using the electrons to form hydroxyl ions.

This sequence occurs through the reaction of the alloy with dissolved oxygen and/or other oxidizing agents in the water. The cathodic area of the medium can be much larger as compared to that of the anode. As a result, more water and electrons are made available for reaction. Subsequently, increasing the flow of electrons from the anode increases the release of zinc and hydroxyl ions (Kemmer F.1988). The set of half cell reactions for this process can be written as:

$Zn \rightarrow Zn^{+2} + 2e$ (oxidation)

$O_2 + 2\,H_2O + 4e \rightarrow 4OH$ (reduction)

$2Zn + 2\,H_2O + O_2 + 4e \rightarrow 2\,Zn^{+2} + 4e + 4OH$ (net reduction)

- *Mechanisms for the Control of Scale Formation by KDF*

In order for calcium carbonate to precipitate out of solution a driving force for the reaction must be present (Nicholson R. et.al. 1982). This driving force can be direct, such as the addition of calcium or carbonate, or indirect such as an increase in pH or a decrease in carbon dioxide (Nicholson R. et.al. 1982). Metal ions present in the water can also act as a driving force. Previous studies of the influence of impurities on the growth rate of calcite have shown that zinc, even in low concentrations can inhibit calcium carbonate crystal formation. Foreign ions, such as zinc, influence reaction rates in two different ways. The first being in the solution where they can form complexes with the reaction ions altering both activity coefficients and the rate at which transformation reactions occur(Reeder R. 1990). Secondly, the foreign ion can be adsorbed onto the surface of the reacting solid. If this foreign ion is a cation, such as zinc, it can cause an increase in the surface carbonate concentration (Reeder R. 1990).

- *Microbial Control Mechanisms*

Contact with the Medium Surface KDF process medium produces up to a 500-mVdrop in the oxidation-reduction potential as measured in the medium. This is caused by the previously discussed galvanic cell formation the by-product of which is negatively charged electrons being made available at the medium's surface. Bacteria that directly contacting these electrons could have their cellular structures disrupted through depolarization. Also, as water molecules are involved in the initial galvanic reaction through dissociation into hydroxide ions, a concentration gradient is formed at the interface. The concentration of water in the bacterial cell would be greater than that surrounding the medium resulting in rapid diffusion leading to lysis, rupture, of the bacterial cellular membrane. Radicals and hydrogen peroxide studies conducted at the university of Notre Dame in South Bend, Indiana, on the ability of KDF process medium to reduce iron concentrations of water showed that hydroxyl radicals and hydrogen peroxide are produced during the oxidation of ferrous iron to ferric iron by the medium (James T.2000). Other research also indicates that oxidation reactions involving dissolved oxygen in groundwater systems may include an intermediate product such as hydrogen peroxide (James T.2000). This would help explain the media's ability to control organisms that lack catalase, the obligate anaerobes, but not the coliforms. Also, due to the reactivity of hydrogen peroxide and radicals, this effect would only be evident in the medium bed and any residual affect in effluent waters would be minimal.

Bacteria that are zinc intolerant will be impacted by the release of zinc by the medium. Intolerance for a metal ion is dependent upon whether or not an organism has an active transport mechanism to regulate its concentration within its cellular structure. Zinc, and other heavy metals denature proteins through the disruption of hydrogen and disulfide bonds resulting in the functional shape of the protein being destroyed (James T.2000). Since much of a cell as well as all its enzymes are proteins the regulation of heavy metals into and out of cells is important. In the instance of KDF process medium, the zinc concentrations may not be sufficient to permanently denature proteins, bactericidal, but only temporarily, bacteriostatic. Again, different species will have different levels of tolerance therefore not all bacteria are affected equally.

As other studies have shown a residual effect of the medium on bacterial populations the actions of zinc as an enzyme inhibitor may have to be taken into consideration as a primary factor (James T.2000). Since one of the similarities in the coliforms is that they are mixed acid fermentors, it is likely that zinc may interfere with this process as an enzyme inhibitor. Enzyme inhibition takes two forms, competitive and noncompetitive. AS a competitive inhibitor the zinc would bind to an enzyme at an allosteric site blocking the normal substrate from attaching to the enzyme thus stopping its further reaction. Substrates are the substances upon which enzymes react forming products organisms use for their metabolism. Noncompetitive inhibition would involve the zinc ion binding in a place other than the allosteric site that then changes the shape of the enzyme enough to inhibit the normal substrate from attaching to the enzyme.

- *KDF limitations*

Copper zinc water filtration does not remove organic chemicals, such as pesticides and disinfection byproducts, nor is it effective against the parasitic cysts of giardia or cryptosporidium (Tikkanen M.2001). KDF filters must be periodically backwashed with hot water to clean them, which also reduces their efficiency, and the pollutants dislodged by washing can lead to water contamination (Catenacci A.2014).

There is also concern for environmental damage due to the release of zinc in areas with high concentrations of metals or certain pollutants, in particular copper and chlorine. Publications of the American Water Works Association do not recommend the use of copper zinc water filtration systems to treat chlorinated water that outflows to streams (James T.2000).

1.1.5 Water scaling

Scaling of an RO membrane may occur when sparingly soluble salts are concentrated in the RO element beyond their solubility limit. Sparingly soluble salts are listed below in the order of decreasing scaling problem:

$CaCO_3$ > $CaSO_4$ > Silica > $SrCO_3$ > $BaSO_4$ > $SrSO_4$ > CaF_2 > $CaSiO_3$ > $MgSiO_3$ > $MgSiO_3$ >$Ca_3(PO_4)_2$ > $Fe(OH)_2$.

The most frequent scaling problems come from calcium carbonate ($CaCO_3$) because it precipitates fast, once concentrated beyond its solubility limit and also most natural waters are almost saturated with respect to $CaCO_3$ (Express Customer Satisfaction Membranes (CSM).2006).

Alkalinity consists of negative ions which include bicarbonate (HCO_3), carbonate and hydroxide. Most of the alkalinity in naturally occurring water sources is in the form of HCO_3. Below a pH of 8.3, the HCO_3 alkalinity will be in equilibrium with a certain concentration of dissolved carbon dioxide. At a pH greater than 8.3, HCO_3 will be converted to the carbonate form (CO_3^{-2}). With water sources of pH above 11.3, hydroxide (OH-) will be present (CSM.2006).

Water can dissolve carbon dioxide from the air, forming carbonic acid (H_2CO_3). The acidic water will tend to dissolve $CaCO_3$ from the ground as it passes over or through the $CaCO_3$ rock. Most naturally occurring water sources are close to saturation in $CaCO_3$ which is in equilibrium with HCO_3, depending on the pH of the water. Calcium bicarbonate is much more soluble in water than $CaCO_3$. It the water is concentrated in an RO system, $CaCO_3$ salt is likely to precipitate in the system. Thus the use of a scale inhibitor or lowering the pH below 8 by an acid injection is required in most RO systems (CSM.2006).

The solubility of $CaCO_3$ depends on the pH as shown in the following equation.

$CaCO_3 + H \rightleftharpoons Ca^2 + HCO_3^-$ Eq(1.1)

The equilibrium can be shifted to the right side to convert $CaCO_3$ to soluble $Ca(HCO_3)_2$ by adding an acid (lowering pH). The acid used should be of food grade quality. Sulfuric acid is commonly employed (USEPA. 2003).

In order to avoid $CaCO_3$ scaling, the pH of the concentrate stream in an RO system should be lower than the pH of saturation (pHs) where the water of the concentrate stream is in equilibrium with $CaCO_3$. This relationship is expressed by the Langelier Saturation Index (LSI) for brackish waters and Stiff & Davis Saturation Index (S&DSI) for sea waters. (Dow Water & Process Solutions. Form No. 609-00071- 0416)

LSI is an approximate indicator of the degree of saturation of $CaCO_3$ in water. It is calculated using the pH, alkalinity, Ca concentration, Total Dissolved Solids (TDS), and water temperature of a water sample collected at the tap. If the; LSI is negative, then the water is under saturated with $CaCO_3$ and will tend to be corrosive in the distribution system. (Dow Water & Process Solutions. Form No. 609-00055-498XQRP0)

LSI is positive, then the water is over saturated with $CaCO_3$ and will tend to deposit $CaCO_3$ forming scales in the distribution system. If LSI is close to zero, then the water is just saturated with $CaCO_3$ and will neither be strongly corrosive or scale forming (CSM.2006).

$LSI = pH - pHs$ Eq(1.2)

$pHs = (9.3 + A + B) - (C + D)$ Eq(1.3)

Where

$A = \log_{10} (TDS) - 1/10$

$B = -13.12 \times \log_{10} (^{0}C + 273) + 34.55$

$C = \log_{10} (CaCO_3) - 0.4$

$D = \log_{10} (CaCO_3)$ (American Society for Testing and Materials International (ASTM) D3739-88)

In scaling experiments feed water stream with LSI in range 0.5-1 was applied which indicates high scaling potential. No chemical agents were added for pH adjustment.

Silt Density Index (SDI), also known as the fouling index, is a good guide line to determine the colloidal fouling potential of RO feed water (USEPA.2003). The source of colloids in RO feed waters are varied and often include bacteria, clay, colloidal silica and Fe corrosion products. Pretreatment chemicals used in a clarifier such as alum, ferric chloride or cationic polyelectrolytes can also cause colloidal fouling if not removed in the clarifier or through proper media filtration.

1.1.6 Water chlorination

As a halogen, Cl_2 is a highly efficient disinfectant, it is added to public water supplies to kill disease-causing pathogens, such as bacteria, viruses, and protozoans, that commonly grow in water supply reservoirs, on the walls of water mains and in storage tanks The microscopic agents of many diseases such as cholera, typhoid fever, and dysentery killed countless people annually before disinfection methods were employed routinely (White.1986). Water chlorination is performed by mixing a large amount of hypochlorite into the water. The hypochlorite can be in the form of a powder or a liquid such as Cl_2 bleach which solution of sodium hypochlorite (NaOCl) in water.

As a strong oxidizing agent, Cl_2 kills via the oxidation of organic molecules. Cl_2 and hydrolysis product hypochlorous acid are neutrally charged and therefore easily penetrate the negatively charged surface of pathogens (Contre La Faim.2005). It is able to disintegrate the lipids that compose the cell wall and react with intracellular enzymes and proteins, making them nonfunctional. Microorganisms then either die or are no longer able to multiply. Disinfection by chlorination can be problematic, in some circumstances. Cl_2 can react with naturally occurring organic compounds found in the water supply to produce compounds known as disinfection by-products (DBPs) (Contre La Faim.2005). The most common DBPs are trihalomethanes (THMs) and haloacetic acids (HAAs), which are mainly responsible for health hazards. When dissolved in water, Cl_2 converts to an equilibrium mixture of Cl_2, hypochlorous acid (HOCl), and hydrochloric acid (HCl):

$Cl_2 + H_2O \rightleftharpoons HOCl + HCl$ Eq(1.4) (Dow Water & Process Solutions. Form No. 609-00071- 0416)

Cl_2 has been used for many years to treat municipal and industrial water and waste waters to control microorganisms because of its capacity to inactivate most pathogenic microorganisms quickly. The effectiveness of Cl_2 is dependent on the Cl_2 concentration, time of exposure, and the pH of the water.

In an industrial water treatment scheme, fouling of water intake lines, heat exchangers, sand filters, etc., may be prevented by maintaining a free residual Cl_2 concentration of 0.5–1.0 mg/l or higher, dependent on the organic content of the incoming water (White.1986).

Chlorination for RO/NF pretreatment has been applied usually where biological fouling prevention is required (i.e., typically for surface waters). Cl_2 is added continuously at the intake, and a reaction time of 20–30 minutes should be allowed. A free residual Cl_2 concentration of 0.5–1.0 mg/l should be maintained through the whole pretreatment line (Dow Water & Process Solutions. Form No 609-02110-0905).

Dechlorination upstream of the membranes is required, however, to protect the membranes from oxidation. Membrane can withstand short-term exposure to free Cl_2; however, its resistance is limited. The membrane can be used successfully in installations where system upsets result in temporary exposure to free Cl_2. (Dow Water & Process Solutions. Form No. 609-00071- 0416)

The rate of Cl_2 attack depends on various feed water characteristics. Under alkaline pH conditions, Cl_2 attack is faster than at neutral or acidic pH. Cl_2 attack is also faster when Fe or other transition metals are present either in the water or on the membrane surface; these metals catalyze membrane degradation. Because of the risk of membrane oxidation, Cl_2 is not recommended for membrane systems (USEPA. 2003).

Cl_2 is most commonly available as Cl_2 gas and the hypochlorite of Na and Ca. In water, they hydrolyze instantaneously to hypochlorous acid:

$Cl_2 + H_2O \rightarrow HOCl + HCl$

$NaOCl + H_2O \rightarrow HOCl + NaOH$

$Ca(OCl)_2 + 2\ H2O \rightarrow 2\ HOCl + Ca(OH)_2$ Eq(1.5)

Under certain conditions, the presence of free Cl_2 and other oxidizing agents will cause premature membrane failure. Since oxidation damage is not covered under warranty it is recommended removing residual free Cl_2 by pretreatment prior to membrane exposure.

1.2 Research question and identified problems

Membranes are the heart and kidney of the RO system, so protect them is investment, the most serious phenomenon affecting membrane performance is fouling, membrane cleaning after fouling is cost and destructive thus reducing or delaying fouling is effective process for extending periods of time between membrane cleanings, and keeping membrane healthy. KDF media is capable in reducing RO membrane fouling due its electrochemical and catalytic potential of the redox alloy is the hypothesis of this study is .

Main questions are:

- Is it effective to apply KDF media as pretreatment method for RO fouling reduction?
- What kind of fouling can KDF media be more effective?

1.3 Objectives

1.3.1 Main objective

The main objective of this study is to investigate the effectiveness of applying KDF media as pretreatment step in RO system for membrane fouling reduction.

1.3.2 Specific objectives

The specific objectives of this study are:

- Determine the effectiveness of KDF media in removing Cl_2.
- Determine the time life of KDF media.

1.4 Scope of work

There are various types of foulants: colloidal caused by clays and floc, biological caused by bacteria and fungi, organic caused by oils, polyelectrolytes, and humics, and scaling caused by mineral precipitates (Baker.2004), in this study the effectiveness of KDF in reducing fouling caused by scaling and high dosage of Cl_2 will be tested.

1.5 Literature review

Many scientifically conducted and documented researches on RO membrane are available these researches concern mainly on membrane fouling as critical and global issue, also for Cu and Zn some studies had been performed to ensure the effectiveness of this technique on water treatment and water quality improvement, most of these studies focused on the antiscale behavior of treated water. However, a limited number of researches had been conducted to investigate the impact of Cu and/or Zn treatment on RO system improvement, for Cu and Zn as a combination there is no previous study relating to their effects on RO membrane.

Palanisamy K. et al. (2016) studied the $CaCO_3$ scale deposition from its sludge on copper substrate. Ethylenediamminetetraacetic acid (EDTA) was used as chelating agent and tested for its influence on the deposition. The experiments were carried out at 60 and 100 °C and the effect of direct heating and indirect heating was studied. The samples were characterized by X-ray Diffraction, and scanning electron microscope techniques. The data revealed that the complex forming nature of EDTA, the shape of the crystallite and area of contact are the key factors for the deposition of $CaCO_3$ on metal surface.

Zeppenfeld. (2016) discussed in his study the literature data on nucleation and precipitation rates of $CaCO_3$ in presence of Zn(II) and Cu(II) are. The experimental results of six types of water with different supersaturation and initial pH values are compared. At high pH ($\approx$ 8.3) neutral $ZnCO_3$ and $CuCO_3$ complexes are adsorbed onto the active growth sites of the $CaCO_3$ surface, while at lower pH ($\approx$ 7.5) uncomplexed Zn^{+2} and Cu^{+2} ions exchange with Ca^{+2} in the surface adsorbed layer on $CaCO_3$. As a consequence nucleation is retarded and precipitation is inhibited. As a result of nucleation catalysis, $Cu(OH)_2$ particles promote the formation of $CaCO_3$ nuclear crystals that counteract the inhibition process.

Semine Ras et al. **(2012)** studied the effect of Cu and Zn on the precipitation of $CaCO_3$ by using the test of rapid controlled precipitation and scaling tests on polyethylene. The test of rapid precipitation controlled in the presence of metal cations (Cu, Zn) at low concentrations (0.5mg/l of Cu, 0.15mg/l of Zn), retracted the precipitation of $CaCO_3$, while the test of scaling on polyethylene in the presence of Cu and Zn reached an efficiency of 100% which reflects the pronounced inhibitory effect of these ions.

Liu et al. **(2010)** investigated the effectiveness of Cu and Zn ions on inhibiting the scaling of drinking water. The results indicated that Zn and Cu ions, at low concentrations, were highly efficient inhibitors in a 300 mL solution (Ca concentration of 126.5 mg/l). To obtain higher inhibition efficiency, the concentration was 0.9 mg/l for Cu ion, and 0.4 mg/l for Zn ion. The analysis by infrared absorption spectrometry showed that Cu and Zn ions could affect the $CaCO_3$ germination and change the crystal morphology, which indicated that Cu and Zn ions had participated in the composition of the crystal; however, the quantity of Cu or Zn ion in the precipitate was so small that it was difficult to observe them.

Zeppenfeld et al. **(2009)** described the influence of trace amounts of Cu ions on the precipitation of calcite in an aqueous and supersaturated $CaCO_3$/NaCl system and in natural water of moderate hardness .Furthermore the influence of Zn ions on $CaCO_3$ precipitation in the $CaCO_3$/NaCl system was examined and the results may be explained, that Cu ions are more effective for scale prevention than Zn ions.

Yang et al. **(2006)** investigated the inhibition of $CaCO_3$ precipitation by Zn ions in RO system. The results represent that the Zn ion concentration of 2mg/l was able to exert a marked suppression effect on both bulk precipitation of $CaCO_3$ and on membrane scaling on waters of moderate hardness.

Coetzee et al. **(2006)** reported that a minimum Zn/Ca mass ratio of 0.06 x 10^{-3} was required for Zn to cause measurable effects, but Cu was found to be only half as effective as Zn and until now there is no obvious correlation was found between the physical and chemical properties of the ions and their effect.

CHAPTER TWO

MATERIALS AND METHODOLGY

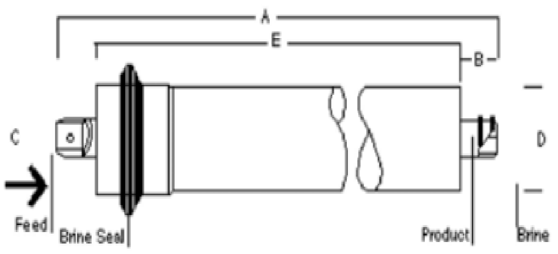
2.1 Materials

2.1.1 RO membrane

TW30-1812-50 FILMTEC™ RO membrane was used in all experiments. FILMTEC™ RO membrane elements for home drinking water are considered as one of the industry’s most reliable. Advanced membrane technology and automated fabrication allow these elements to deliver consistent performance that equipment suppliers, water treatment dealers and residential customers can rely on. These elements are National Sanitation Foundation (NSF) / American National Standards Institute (ANSI) Standard 58 listed. (Dow Water & Process Solutions. Form No. 609-00055-498XQRP)

Figure (2.1) shows the dimension of TW30-1812-50 FILMTEC™ RO membrane, its length is 11.74 inch while its width is 1.75 inch. 1812 membrane series are residential membrane elements that mainly applicable to various small sized systems.

Figure 1



NSF
COMPONENT
Tested and Certified to
ANSI/NSF Standard 58

Dimensions – Inches (mm)

Product	A	B	C	D	E
TW30-1812	11.74 (298)	0.87 (22)	0.68 (17)	1.75 (44.5)	10.0 (254)

1. TW30-1812 Home Drinking Water Elements fit nominal 2-inch I.D. pressure vessels.

1 inch = 25.4 mm

Figure (2. 1): TW30-1812-50 FILMTEC™ RO membrane dimensions. (Dow Water & Process Solutions.Form No. 609-09010-0406)

These membranes can work under actually low pressure to reach high salt rejection rate up to at least 96%, and permeate flows up to 50 gallons per day (gpd), table (2.1) described the limitations and operation conditions for TW30-1812-50 FILMTEC™ RO membrane. permeate flows for individual elements may vary +/-20%. Figure (2.2) shows detailed drawing for TW30-1812-50 FILMTEC™ RO membrane structure.

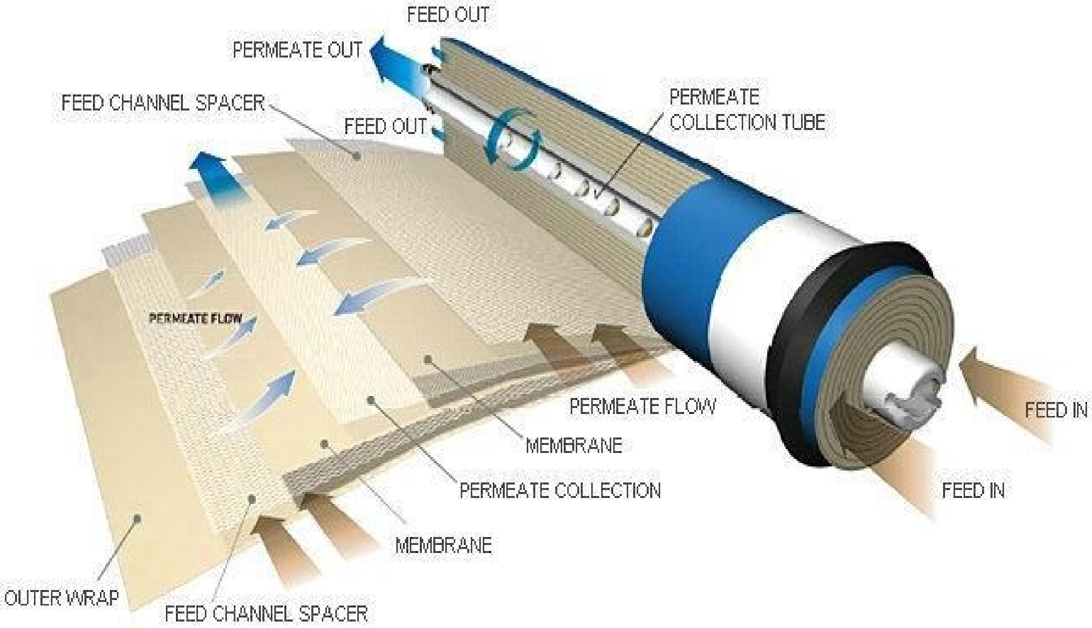


Figure (2. 2): Detailed drawing for TW30-1812-50 FILMTEC™ RO membrane.

Table (2. 1): TW30-1812-50 FILMTEC™ RO membrane operating limits. (Dow Water & Process Solutions.Form No. 609-09010-0406).

Maximum Operating Temperature	113°F (45°C)
Maximum Operating Pressure	300 (psig) (21 bar)
Maximum Feed Flow Rate	7.6 liter per minutes
pH Range, Continuous Operation	2 - 11
SDI	5
Free Cl_2 Tolerance	< 0.1 ppm
Chemical Oxygen Demand (COD)	<10 mg/l
Ferrous iron	< 4 mg/l
Ferric iron	< 0.05 mg/l
Manganese (Mn)	< 0.05 mg/l
Al	< 0.05 mg/l
Total Organic Carbon (TOC)	< 3mg/l

2.1.2 KDF media

CuZn filter for drinking water was used in all experiments. The CuZn filter consists of 11 patented reticulated discs with 2 inch diameter and 0.5 inch height for each disc as in Figure (2.3). The discs are flexible, slightly oversized, lightweight, porous nature, earth friendly, and easy for installation.

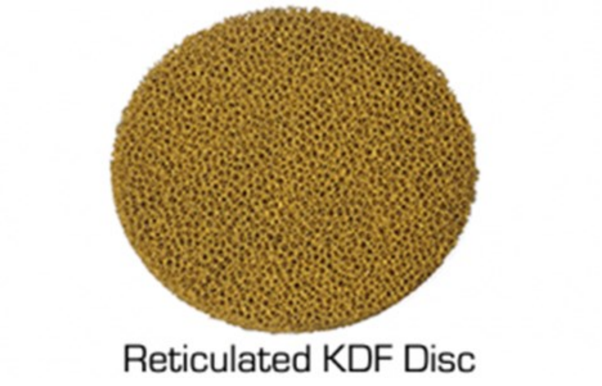


Figure (2. 3): Patented reticulated porous KDF disc.

2.2 Methodology

KDF media was investigated as RO membrane antifoulant, different types of fouling were tested to determine the efficiency of KDF media on fouling reduction, usually the main sources for fouling in RO system are water hardness which causes scaling, microorganism which causes microfouling, and Cl_2 attack which oxides the membrane, scaling and Cl_2 attack were studied individually on separate membrane with specific different feed solution characteristics and RO operating conditions, in Cl_2 experiments a high chlorinated solution with 5 mg/l will be applied, this value considered as a very high and it is exceeded the maximum allowable value recommended by World Health Organization (WHO) and Palestinian Water Authority (PWA) for drinking water which is 0.8 mg/l, this was done as to save time and water, in $CaCO_3$ experiments a $CaCo_3$ supersaturared solution with LSI value between 0.5 and 1 which indicates high potential scaling was applied. Each test was conducted using two membranes, reference or control membrane in which feed water moved directly inside without passing through the KDF media (RO-only), and pretreatment membrane with feed water passing through KDF media (RO-KDF), Figure (2.4) shows a simplified schematic of the experiment design and layout.

Since the decline in salt rejection and flux rate results from the blockage of the membrane surface by lateral growth of the fouling on the membrane, then this decline will be considered as the main RO performance parameter to determine the effect of KDF media on RO membrane fouling reduction thus the effectiveness of KDF media on fouling reduction can be roughly assessed by comparing the salt rejection and permeate flow rate in the absence and in the presence of KDF media. Commercially available chemical antiscalants may be also tested at the recommended dosage rates to obtain further reference results. Many tests were performed during each experiment, major anion and cations, free Cl_2, temperature, pH, Electrical Conductivity (EC), TDS and Dissolved Oxygen (DO), were measured for all experiments in different steps as shown in Figure (2.4) regarding the source of fouling, other parameters were measured or computed depending on each fouling type. As in Figure (2.4) test1 performed for tap water before any addition of chemicals while test 2 performed after preparing specific solution with high Cl_2 concentration or supersaturation with $CaCO_3$, test3 conducted after the solution passed through KDF and the last test which is test4 included the permeate flow measurements.

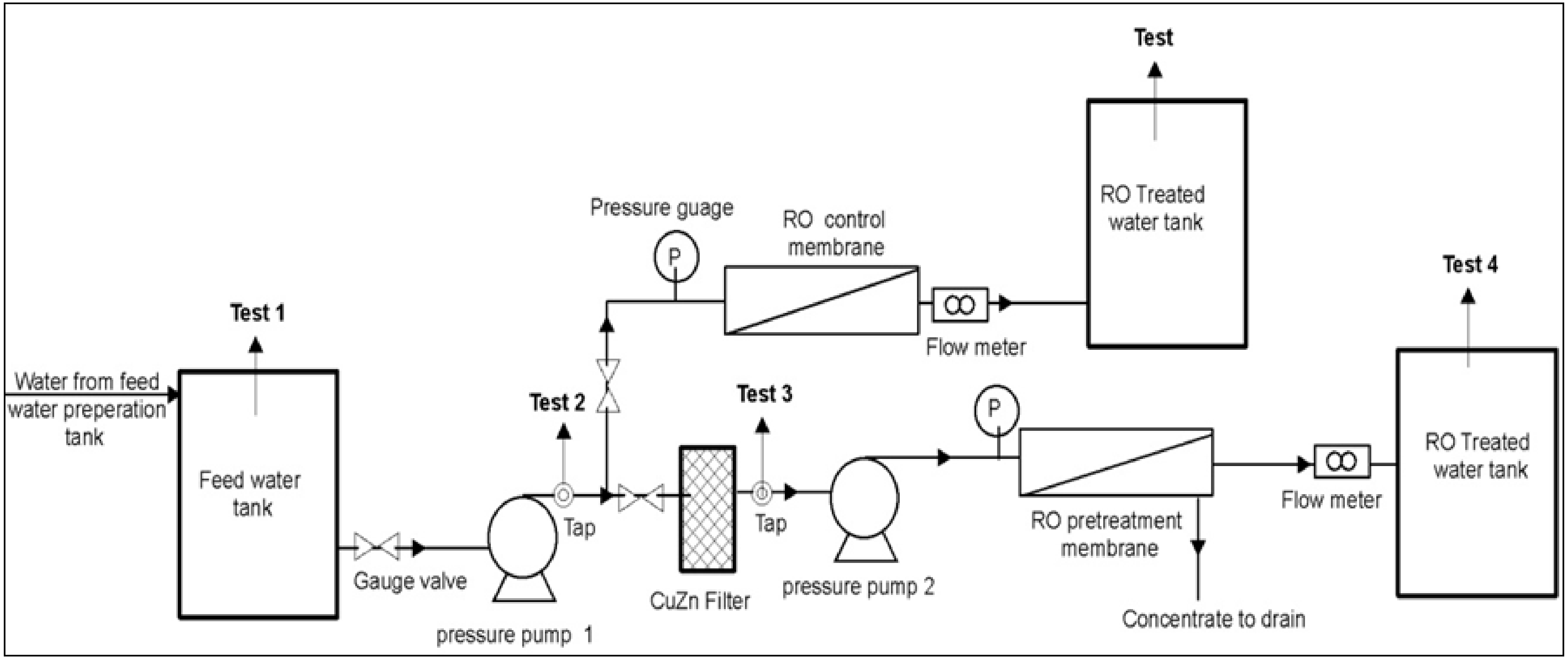


Figure (2. 4): Experiments schematic design for RO system. (Abu Eisheh et al. 2015)

2.3 Laboratory work

The laboratory work included the preparation of the required feed solution for each experiment, and running the two systems with recording all the necessary measurements.

2.3.1 Feed solutions preparation

a. Feed solution for Cl_2 experiments

A feed solution with a high potential of membrane oxidation by Cl_2 was prepared by adding 2.5 ml of Cl_2 to 50L water tank in order to attain a solution with Cl_2 concentration near 5 mg/l, this value was calculated according to the following dilution equation:

$C_1V_1 = C_2V_2$ Eq(2.1)

Where:

C_1= the initial concentration of the solution.

V_1= the initial volume of the solution.

C_2= the final concentration of the solution.

V_2=the initial volume of the solution.

assuming tap water is Cl_2 free, the initial value of Cl_2 concentration will be 5 mg/l ($C_1=5$ mg/l), the volume of the feed tank was 50L ($V_1=50L$), the concentration of the used NaOCl was 10,0000 mg/l ($C_2=100000$ mg/l), by applying Eq(2.1) the required volume of NaOCl will be 2.5 ml ($V_2=2.5$ ml). This dosage of Cl_2 was not added directly into the tank, first it was diluted in 2L of distilled water, then the 2L of chlorinated water was added gradually during filling the tank along with well mixing. The feed tank was fully closed since Cl_2 is volatile. The system is supposed to start running as the reaction time is completed. The reaction time was nearly 30 minutes.

b. Feed solution for scaling experiments

Supersaturated $CaCO_3$ feed solution with a high scaling potential was prepared by dissolving 16 gm of $CaCO_3$ in 50L of tap water with rapidly mixing, $CaCO_3$ is the major source for Ca thus adding $CaCO_3$ to water will increase the level of both Ca and HCO_3 which is a fundamental parameter that controls LSI value as indicated in Eq(1.2), the average concentration of Ca and HCO_3 in tap water was 45 mg/l and 300 mg/l respectively, but it increased to 174 mg/l for Ca and 600 mg/l for HCO_3 in the supersaturated feed solution, the experiments were carried out with initial pH value in the range of 7–7.5 to achieve a critical LSI value in the range of 0.5-1. The feed tank was fully closed to maintain the LSI level constant throughout the experiment. The values of all LSI equation parameters in the 40 running hours are shown in appendix (1) and appendix (2).

CHAPTER THREE

RO SYSTEM DESIGN

3.1 RO basic principles

RO systems should be operated with proper design flow and recovery rates in order to ensure trouble-free operation, if the performance of the membrane system is not satisfactory, the first step is to evaluate the performance and the operation of the entire system. This is done on the basis of normalized system data. When the actual normalized system performance is compared against the performance at start-up, any significant performance deterioration can be identified.

If the normalized actual performance has deteriorated too much compared to the initial performance, or the measured actual performance does not match close enough with the projected performance, the following basic principles must be checked:

1. Flow Rate

Feed flow is defined as the rate of water entering the RO system. Permeate flow is defined as the rate of water passing through the RO membrane, and concentrate flow is defined as the rate of flow which has not passed through the RO membrane, and comes out from the RO system with rejected ions (El-Dessouky et.al 2002). Feed flow rate, permeate flow rate and concentrate flow will be measured. Mathematically Feed flow rate can be calculated as follow:

Feed flow rate = permeate flow rate + concentrate flow Eq(3.1)

2. Salt Rejection

Salt rejection is a percentage which describes the amount of solute retained by the RO membrane which is the salt removed from the RO feed water. A well designed RO system with properly functioning RO membranes will reject 95% to 99% of most feed water salts. the salt rejection of RO membranes can be calculated by the following equation:

Salt Rejection (%) = (conductivity of feed water – conductivity of permeate water x 100) / conductivity of feed   Eq(3.2) (El-Dessouky et.al 2002)

A high value of the salt rejection indicates that the performance of the RO system is good while the low value of salt rejection indicates that the membrane needs cleaning or replacement. Salt passage is the opposite of salt rejection, it is defined as the ratio of concentration of salt on the permeate side of the membrane relative to the average feed concentration is, also it is the percentage that describes the amount of salts that are passing through the RO system. Mathematically, it is expressed in Eq(3.3):

Salt passage (%) = (1- Salt rejection %)   Eq(3.3)

The lower the salt passage, the better the system is performing. In order for Eq(3.3) to be valid, conductivity measurements should be taken after all chemical additions and accurately reflects the feed water.

3. Permeate recovery rate

Permeate recovery is a very important parameter in the design and operation of RO systems. Recovery or conversion rate of feed water to product (permeate) is defined by Eq(3.4).

Recovery (%) = (permeate flow rate x 100) / feed flow rate   Eq(3.4) (El-Dessouky et.al 2002)

The recovery rate affects salt passage and product flow. As the recovery rate increases, the salt concentration on the feed side of the membrane increases, which causes an increase in salt flow rate across the membrane as indicated by Eq(3.4). Also, a higher salt concentration in the feed solution increases the osmotic pressure, reducing the net driving pressure and consequently reducing the product water flow rate according (El-Dessouky et.al2002).

The concentration factor is related to the RO system recovery and it is an essential factor for RO system design. The more water is recovered as permeate the higher the recovery rate, the more concentrated salts and contaminants in the concentrate flow. This can lead to higher potential for scaling on the surface of the RO membrane, when the concentration factor is too high for the system design and feed water composition. Concentration factor is calculated by the following equation:

Concentration factor = (1 / (1- Recovery %) Eq(3.5) (Dow Water & Process Solutions. Form No. 609-00071- 0416)

For example, if the feed flow is 100 L/h and the permeate flow is 75 L/h, then the recovery is (75/100) x 100 = 75% and the concentration factor would be 1 ÷ (1-75%) = 4. Which means that the concentrate stream will be 4 times more concentrated than the feed water. Recovery is the ratio of permeate flow to feed flow. In the case of increasing recovery, the permeate flux will decrease and stop if the salt concentration reaches a value where the osmotic pressure of the concentrate is as high as the applied feed pressure. The salt rejection will drop with increasing recovery.

4. Mass balance

A simple mass balance equation is used to confirm the accuracy of RO system flow rate and salt rejection measured values if these values are not accurate then the conductivity and flow meters may need calibration or its indicator for troubleshoot in the RO system like fouling. (Dow Water & Process Solutions. Form No. 609-02110-0905)

(Feed flow x Feed Conductivity) = (Permeate Flow x Permeate Conductivity) + (Concentrate Flow x Concentrate Conductivity) Eq(3.6)

3.2 Feed water analysis

Complete and accurate tap water measurements were performed as first and essential step before an RO system is designed, this analysis included the type and the concentration of all constituents in the water, table (3.1) describes the method applied to measure each element and table (3.2) contains the average values for all tap water measurements, table (3.1) describes the method applied to measure each element.

Table (3. 1): The method applied for water measurements.

Element	Method of measurements
EC, pH, TDS, temperature	Hach
Magnesium (Mg), Ca	Ethylenediaminetetraacetic acid (EDTA) titration
HCO_3	HCl titration
Chloride (Cl)	$AgNO_3$ titration
Cl_2, NH_4, SO_4, NO_2, Fe, turbidity	Hach
Na, Potassium (K)	Flame photometer

Table (3. 2): Cations and anions average concentration.

Cations and anions	Average concentration (mg/l)
Mg	34.3
Ca	47.2
Na	30.6
K	2.2
HCO_3	297.3
NO_3	0.5
Cl	54.1
NH_4	0
SO_4	0
Fe	0.08

Cation-anion balance and many other ratios were calculated as reliability checks to ensure that the measured values are within the correct and acceptable range as in appendix(5).

The results obtained by feed water analysis can be as used guidelines to determine the potential of different types of fouling that must be avoided as follow:

- Metal fouling

Fe and Mn are present in water either in a divalent state, which is soluble in water, or in a trivalent state, which forms insoluble hydroxides. The soluble iron (Fe^{+2}) can come from either well water or the rust of pump, piping and tanks, especially if acid is injected upstream of the equipment. If the iron or manganese concentration is greater than 0.05 mg/l in an RO feed water and they are oxidized by air or an oxidizing agent to the trivalent state (CMS.2006), then the insoluble hydroxides $FeOH_3$ and $MnOH_3$ will precipitate in the system causing metal oxide fouling, when the water pH is neutral or higher. They can also catalyze the oxidative effects of residual oxidizing agents, possibly accelerating the membrane degradation. Thus Fe and Mn must be removed at the pretreatment step.

Fe and Mn levels in feed solution stream is limited to less than 0.05 mg/l as shown in table (2.1), for total iron it was only 0.07 mg/l in tap water, Fe and Mn often occur together in water but manganese usually occurs in much lower concentrations than iron, according to that metal fouling and other bad effects due to Fe and Mn presence in water are not expected to occur.

Al with its valence of $^{+}3$ like iron Fe^{+3}, will form very insoluble hydroxide ($AlOH_3$) at the normal operating pH range of 5.3 to 8.5 in an RO system (CMS.2006). Al is typically not found in any significant concentrations in well or surface water; furthermore a concentration of Al greater than 0.01mg/l in the dialysis water is a health concern for kidney dialysis patients.

Copper and Zinc are not appreciably detected in natural water sources. Sometimes, it is possible to pick up trace amounts from piping materials. Their hydroxides $CuOH_2$ and $ZnOH_2$ will drop out of solution over the operating pH range of 5.3 to 8.5. Because of the low concentrations of copper and zinc, their precipitants will foul an RO system only if allowed to precipitate over an extended period of time without cleaning the system. Generally metal fouling due to Fe, Al, Cu and Zn is not expected to occur and its potentiality is too low.

- Microbial fouling

Biological Oxygen Demand(BOD) and COD levels in tap water was very low and can be considered as negotiable which indicates that microbial fouling will not tend to occur.

- Colloidal fouling

Examples of organic compounds in the feed water are oils, surfactants, water soluble polymers, and humic acid. The organic compounds are collectively analyzed by TOC. Removal of the organic compounds from the feed water at the pretreatment step should be considered when TOC exceeds 3 mg/l (Dow Water & Process Solutions. Form No. 609-00071- 0416). TOC was not measured but it is expected that tap water which is used for drinking is TOC free thus colloidal fouling potential is low.

- Cl_2 attack

The membrane shows some resistance to short-term attack by Cl_2 (Dow Water & Process Solutions. Form No. 609-00055-498XQRP0). Continuous exposure, however, may damage the membrane and should be avoided. Cl_2 is added to tap water in disinfection stage, the average concentration of free Cl_2 in tap water was 0.09 ppm, in summer season Cl_2 concentration was less than 1ppm with 0.07 ppm along the season, while it increased to 0.13ppm along winter season which is a bit more than the allowable tolerance. The chemical attack by Cl_2 is possible in winter season when the Cl_2 concentration is more than 1ppm.

- Scaling

LSI and turbidity are scaling indicator, average LSI for tap water was negative and the turbidity was always less than 1 Nephelometric Turbidity Units (NTU) indicated that scaling potential is low (USEPA.2003), but it is possible on the long term so that pretreatment step for scale inhibition is preferable as shown Figure (3.1) which illustrated system operating design checked by ROSA8 application.

3.3 Reverse Osmosis System Analysis (ROSA)

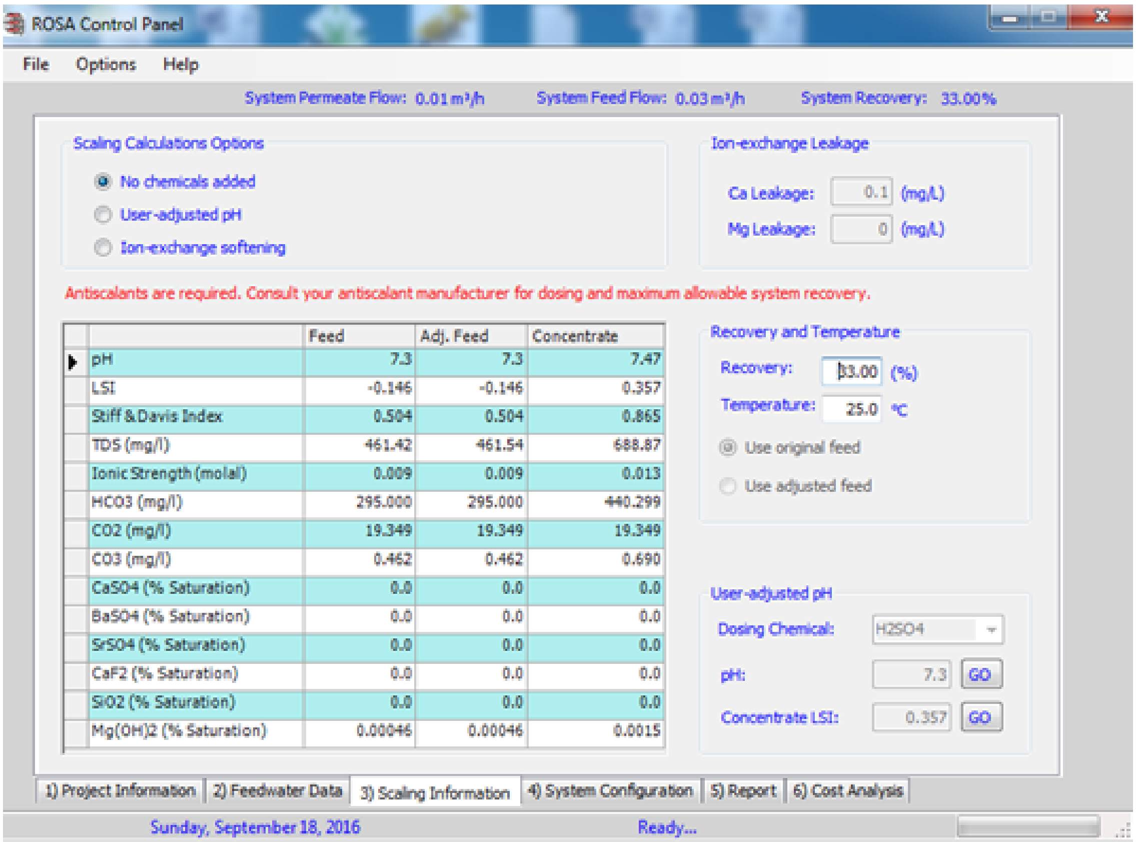
ROSA8(2012) is software developed by Dow Water & Process Solutions to help making the right choice that meets water treatment needs and specifications, and to monitor the health of FILMTEC™ membrane. It is a powerful tool used to estimate stabilized performance for a specific RO system under design or actual conditions. This projected performance is based on a nominal performance specification for the FILMTEC™ element(s) used in that system as standard database. Membrane behavior as a function of pH, ionic strength, and temperature is incorporated into the ROSA simulation model for improved accuracy, furthermore, ROSA8(2012) is equipped to add recirculation streams, split permeate streams and vessels with Internally-Staged Design (mixing element types in the same vessel), keeping up with the latest design concepts.

The data entries for ROSA8(2012) were the concentration of ions, pH, temperature, and the type of FILMTEC™ element, ROSA does all complex math and calculate the required operating parameters.

3.4 System optimization

the optimized operating parameters was generated by ROSA8(2012) application, according to ROSA8(2012) the recovery rate was 33% as shown Figure (3.1), then full efficacy typ2600booster pump was used to generate operating pressures in the range of

60-65psig, providing initial permeate flow in the range of 9-12 L/h. Feed velocity in the various runs was in the range of 0.9-1 liter per minute results in 60 L/h as a max feed stream flow. The highest temperature of the feed solution was 31°C and average pH value for the tap water was 7.3-7.6 which is neutral. All operating parameters values are acceptable and compatible with the operating limits in table (2.1).



System Permeate Flow: 0.01 m³/h
System Feed Flow: 0.03 m³/h
System Recovery: 33.00%

● No chemicals added
○ User-adjusted pH
○ Ion-exchange softening

Ca Leakage: 0.1 (mg/L)
Mg Leakage: 0 (mg/L)

Antiscalants are required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

	Feed	Adj. Feed	Concentrate
pH	7.3	7.3	7.47
LSI	-0.146	-0.146	0.357
Stiff & Davis Index	0.504	0.504	0.865
TDS (mg/l)	461.42	461.54	688.87
Ionic Strength (molal)	0.009	0.009	0.013
HCO3 (mg/l)	295.000	295.000	440.299
CO2 (mg/l)	19.349	19.349	19.349
CO3 (mg/l)	0.462	0.462	0.690
CaSO4 (% Saturation)	0.0	0.0	0.0
BaSO4 (% Saturation)	0.0	0.0	0.0
SrSO4 (% Saturation)	0.0	0.0	0.0
CaF2 (% Saturation)	0.0	0.0	0.0
SiO2 (% Saturation)	0.0	0.0	0.0
Mg(OH)2 (% Saturation)	0.00046	0.00046	0.0015

Recovery: 33.00 (%)
Temperature: 25.0 °C
● Use original feed
○ Use adjusted feed

Dosing Chemical: H2SO4
pH: 7.3
Concentrate LSI: 0.357

Sunday, September 18, 2016
Ready...

Figure (3. 1): System operating parameters optimized by in ROSA8(2012).

Figure (3. 2): The full designed plant for RO-only system.

Figure (3. 3): The full designed plant for RO-KDF system.

3.5 RO Systems basic principles check

a. RO basic principles for Ro-only system

The mass balance for RO-only system was calculated according to Eq(3.6), as in appendix (1) all calculated values were less than 5% then it is considered to be accepted.

The system was designed with 33% recovery rate and 1.5 concentration factor, the recovery rate for each running hour was checked using Eq(3.4), and all calculated values were between 30% and 33%, Eq(3.5) was applied to calculate concentration factor, another check was applied for the concentration factor by dividing the EC of concentrate by the EC of input feed solution, and again all the values were in the range (1.3-1.5).

The values for mass balance, recovery and concentration factor were all accepted, indicating that RO-only system was operating without any technical problems or troubleshooting in pumping, piping, designed velocity..etc, furthermore the collected data were accurate and measured by calibrated instruments.

b. RO basic principles for RO-KDF

RO basic principles were applied as accuracy check to ensure that the RO-KDF system is running without any problems relating to the system design. Mass balance, recovery rate and concentration factor were calculated, the results of calculation as in appendix (1) ensure that RO-KDF system is operating well and the instruments used for measurements are calibrated, hence any change in the system efficiency actually not relating to the operating parameters.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 RO membrane performance parameters in scaling experiments

Scaling experiments were carried out in the period from 23/5/2016 to 29/7/2016 in soil and hydrology laboratory-Al-Quds University for 40 running hours; the critical parameter in these experiments was the LSI which should be in the range of 0.5-1 for feed stream which indicates high potential scaling.

4.1.1 Salt rejection

a. RO-only salt rejection

it is recommended that the membrane should be run for 3 hours to obtain the proper salt rejection, the initial salt rejection with tap water used as feed solution was 92.5% then it is increased to 96.8% as optimal salt rejection in the 3th running hour, when feeding the system with $CaCO_3$ supersaturated solution in the 4th running hour the salt rejection of the permeate flow slightly reduced to 95.2%, then the salt rejection was almost constant as shown in Figure (4.1), generally the salt rejection in RO-only with feed solution of high scaling potential was in the range 94.1%-96.8%, and it is considered as a high salt rejection.

$CaCO_3$ supersaturated solution does not affect the material and composition of the polyimide membrane chemically, therefore the system completed 40 running hours with a high capability of salt rejection.

b. RO-KDF salt rejection

The optimal salt rejection (96.8%) was achieved in the 3th hour. The $CaCO_3$ supersaturated solution was first used for system feeding in the 4th running hour. As shown in Figure (4.1) there was no significant reduction in salt rejection during the 40 running hours for the RO-KDF system; the salt rejection was between 95.8% and 96.8% with only 1% reduction in salt rejection.

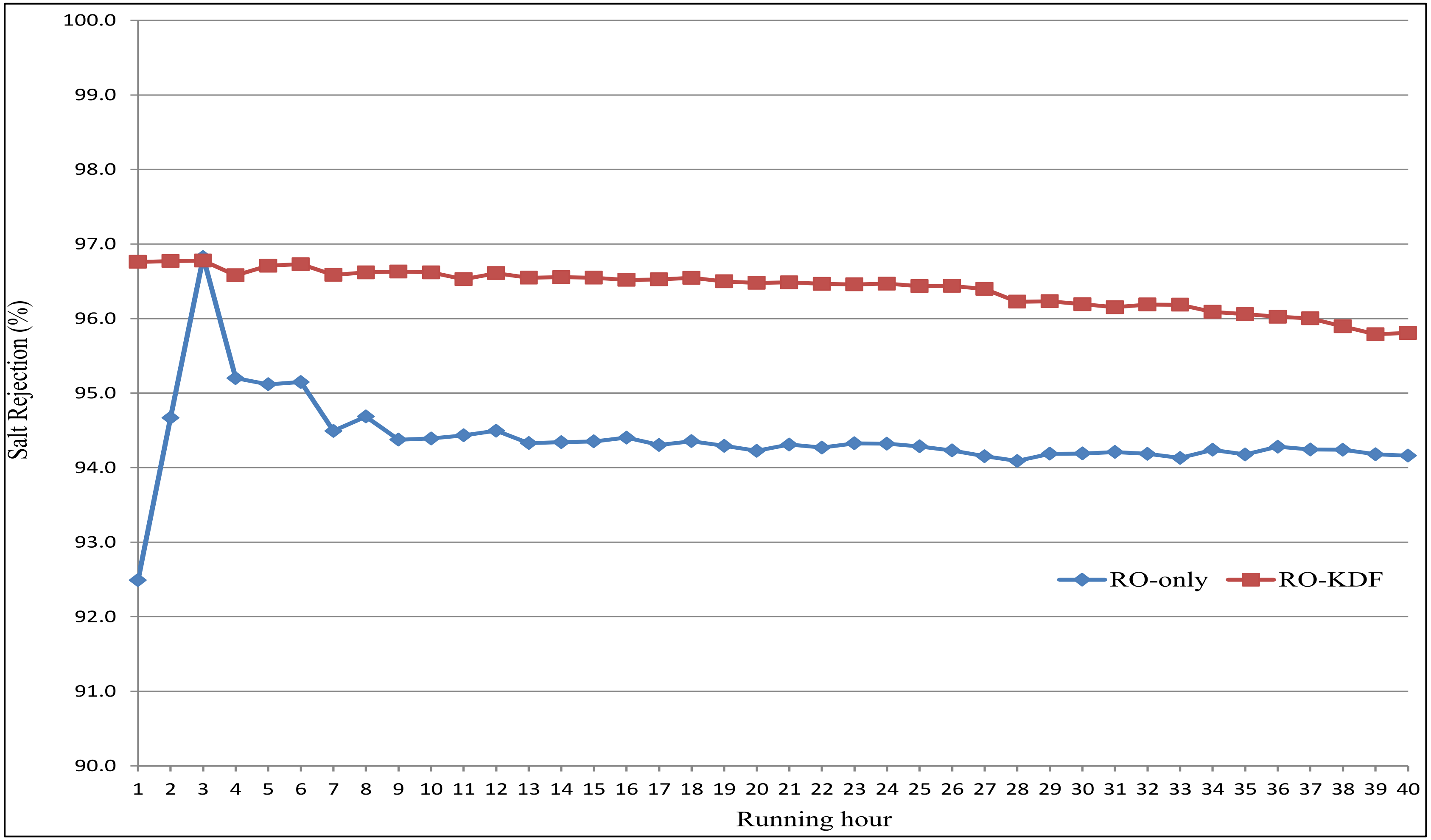


Figure (4. 1): Salt rejection obtained by RO-only and RO-KDF systems in scaling experiments.

4.1.2 Permeate flow

a. RO-only permeate flow

The maximum permeate flow in RO-only was 12 L/h it was obtained in the first hour of running, the feed solution was tap water with negative LSI, the system maintained running with the maximum permeate flow for 3 hours only after $CaCO_3$ feed solution with high scaling potential was used, then it was reduced to 11 L/h in the 7th hour of running as shown in Figure (4.2), in the 13th running hour the membrane was cleaned by backwashing as a simple physical cleaning method without any chemical addition this operation directly affected the permeate flow by increasing it to 12 L/h, which indicates that performing the backwashing contribute in partly removal of precipitation and deposition within the membrane. In the 10th running hour the permeate flow decreased to 10 L/h and it kept decreasing to record 9 L/h after 22 running hour, again backwashing was performed after 23 running hours leading to better performance and more permeate flow.

Positive results were achieved by backwashing for the first 2 times then it became ineffective after 33 running hours since strong attachment of particles was occurred by the more $CaCO_3$ feed solution passing through the system result in reversible fouling being transformed into irreversible fouling layer which is impossible to be removed by physical cleaning method.

The reduction in permeate flow is a main performance parameter that indicates fouling since scale deposition and accumulation induces a continuous decline in permeate flow rate, 15% permeate flow reduction is enough to think about fouling as mentioned in (1.1.3), according to the performed feed water analysis (see 3.2) metal fouling, microbial fouling, and colloidal fouling have very low potentiality to occur then the fouling was due to scaling caused by CaCO3 supersaturated solution. In CaCO3 experiments the minimum. In $CaCO_3$ experiments the minimum permeate flow was 7 L/h it was first measured in the 38th running hour then it kept constant to the end of the experiments in the 40th running hour, 7 L/h permeate flow means 41% reduction in permeate flow which ensures that fouling was actually occurred.

It is obvious that during the same working day in the laboratory the decline in the permeate flow was slight since the continuous flow reduced $CaCO_3$ scaling precipitation, but the decline in permeate flow increased within the next day of laboratory working regardless the period of time in between.

The experiments was ended after 40 running hours, with a total passing feed solution of 1250.5L, 393.5L were permeate flow and the rest were concentrate as in appendix (1). The average permeate flow for the running hour was 9.8L while it was 21.4L for concentrate.

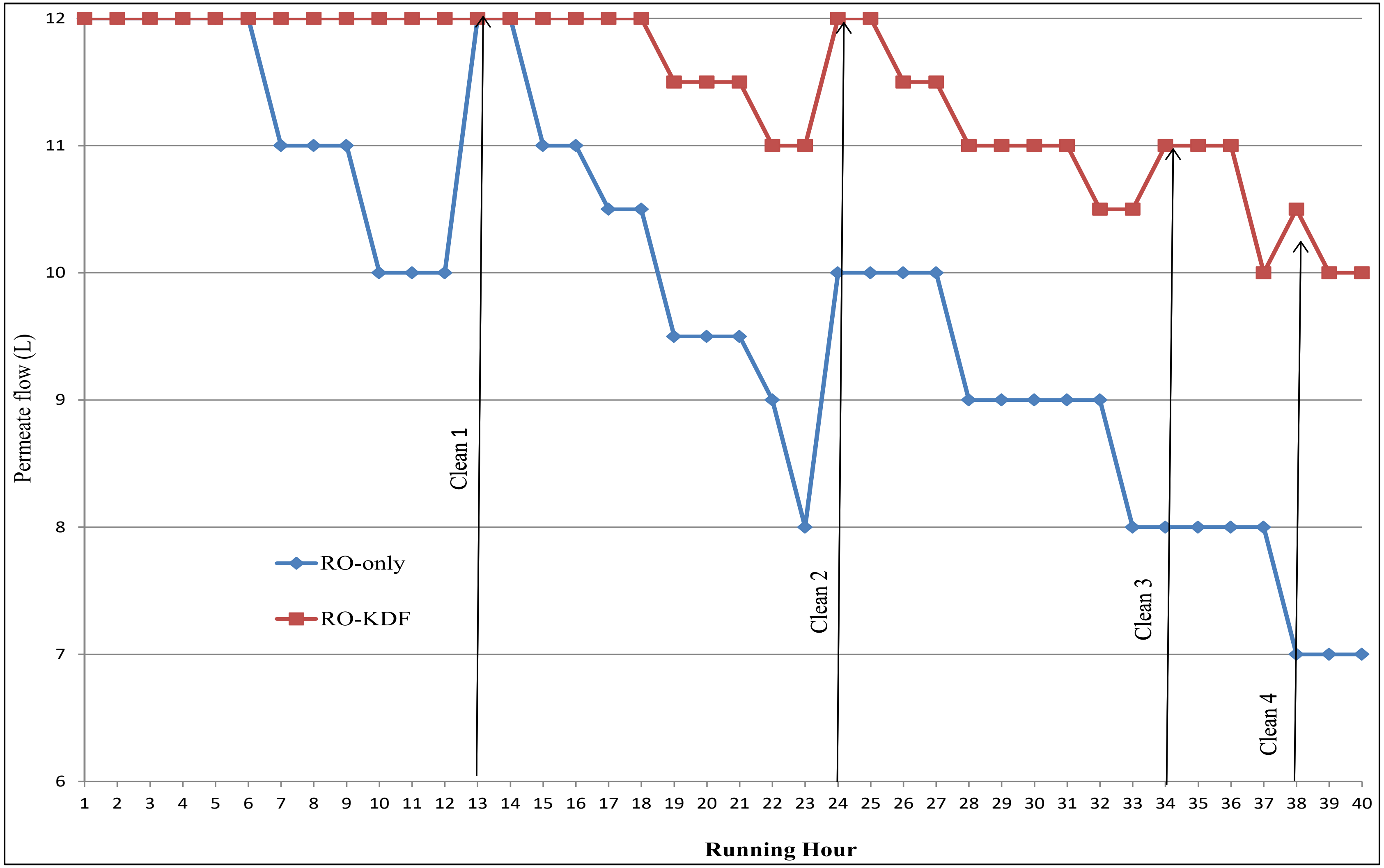


Figure (4. 2): Permeate flow produced by RO-only and RO-KDF systems in scaling experiments.

b. RO-KDF permeate flow

For the first 18 running hours the RO-KDF produced 12 L/h as a maximum permeate flow during this period one backwashing operation was performed, 8% reduction in permeate flow was reached after 22 running hours as illustrated in Figure (4.2), then permeate flow retained again to 12 L/h when the second backwashing was applied.

The maximum reduction of permeate flow in RO-KDF system was only 16% with 10 L/h, this value was measured in the last 2 running hours. For the backwashing it was effective in all stages indicates that the fouling was still reversible.

The experiments was ended after 40 running hours, with a total passing feed solution of 1382L, 458L were permeate flow in addition to 924L were concentrate as in appendix (2). The average permeate flow for the running hour was 11.5L while it was 22.2L for concentrate.

4.1.3 $CaCO_3$ removal by KDF media

In $CaCO_3$ experiments 1382L were filtered by KDF media, no change on water composition was occurred, from the permeate flow results it is concluded that the KDF media improved the efficiency of the membrane by prevent the formation and accumulation of mineral hardness scale, primarily $CaCO_3$.

Hardness scale is formed by relatively large, irregularly shaped acicular crystals of Ca and Mg mineral salts. These salts form a hard, insoluble and interlocking network of vitreous limestone. KDF media alters the morphology of insoluble Ca and Mg carbonate and sulfate crystals to relatively small, evenly shaped, and rounded grains and rods. These form an unconsolidated powdery compound that won't adhere to surfaces and can be removed, therefore the RO-KDF fouling was reversible and can be partly removed by means of physical cleaning until the end of the experiment, while the fouling in the RO-only converted to irreversible by the third time of backwashing, on the other hand the permeate flow rate in the RO-KDF was higher than that in RO-only system because the blockage of the membrane surface by lateral growth of the scaling on the membrane was less than the blockage of the RO-only membrane.

The KDF media was damaged rapidly in $CaCO_3$ experiments. During the 40 running hours 10 discs of KDF media were fully oxidized and degraded as in Figure (4.3), with average 4 hours only for each disc which is considered as short lifetime.

Figure (4. 3): The 10 discs of KDF media fully oxidized in the end of $CaCO_3$ experiments.

4.2 RO membrane performance parameters in Cl_2 experiments

The Cl_2 experiments was carried out in the period from 22/7/2015 to 8/3/2016, highly chlorinated solution with 5mg/l concentration of Cl_2 was used for feeding the systems.

4.2.1 Salt rejection

a. RO-only salt rejection

73.7% was the minimum recorded salt rejection for RO-only system; logically it was obtained with the end of the experiment in the 41th running hour as more chlorinated feed solution contacted with the membrane, in the initial hours of running the salt rejection reached 98.6% as a maximum value, salt rejection was slightly reduced during the first 16 running hours as membrane shows some resistance to short-term attack by Cl_2 as in

Figure (4.4), then the salt rejection was continuously decreased due to the continuous oxidation by Cl_2, 15% reduction in salt rejection is a fouling indicator therefore it was supposed that fouling was occurred in RO-only system within the 41th running hour as the salt rejection was 73.7% with 26.3% reduction.

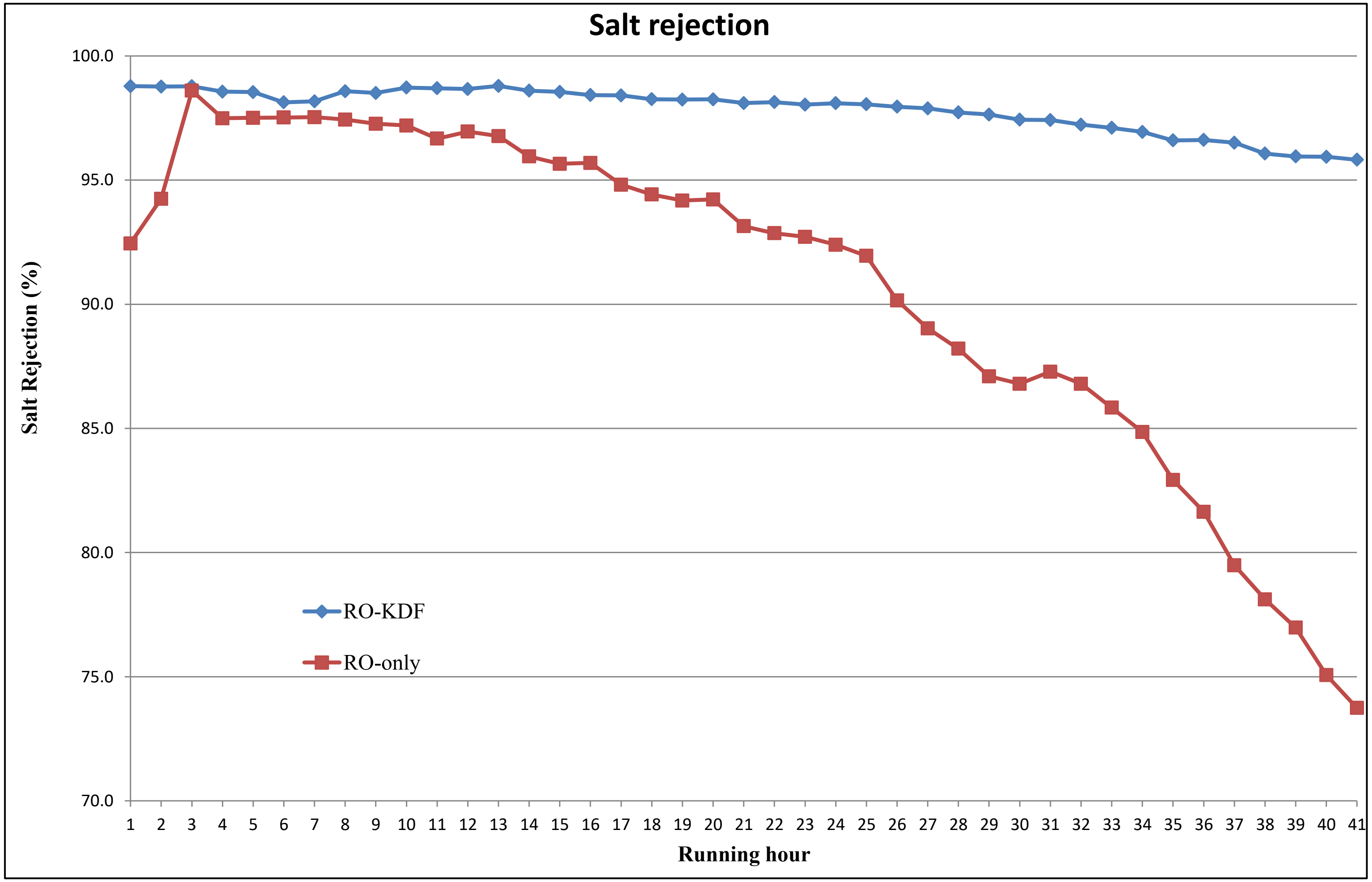


Figure (4. 4): Salt rejection obtained by RO-only and RO-KDF systems in Cl_2 experiments.

b. RO-KDF salt rejection

The RO-KDF system was running for the first 23 hours with the absolutely maximum value of the salt rejection which was between 98% and 98.8% as shown in Figure (4.4), after 34 running hours a slight change in salt rejection occurred so it became 97.1 % which is still considered as a very high salt rejection value. During the last 7 running hours the salt rejection was reduced to 95.8% which was the minimum measured value for salt rejection in RO-KDF system. For salt rejection any value greater than 90% can be considered as high therefore salt rejection level in RO-KDF system kept high after 41 running hours with 5mg/l Cl_2 concentration.

The reduction rate of salt rejection was increased as Cl_2 removal by KDF media decreased thus the membrane attacked by more Cl_2, as shown in Figure (4.4) and Figure (4.8) the initial Cl_2 removal by KDF media was 100%, then it began decreasing. From the 17th running hour the Cl_2 concentration in the feed solution filtered by KDF media exceeded the allowable limit (1ppm), and it was increased as running hours increased resulting in higher reduction rate in salt rejection.

4.2.2 Permeate flow

RO permeate is a function of temperature, generally permeate flow increase as temperature increase, the experiments were carried out in range of temperature from 12.2°C to 28.7°C. Typical permeate flow at 60psi is plotted to show the proper permeate flow at each temperature degree according to company recommendation.

a. RO-only permeate flow

There was no difference in permeate flow of RO and the typical permeate flow at the first running hour, while the maximum difference was 2L in the 5 last running hours, with higher permeate flow produced by the RO-only system than the recommended one because the pores of the RO membrane were enlarged by the oxidative degradation of polyamide RO membranes leading to more permeate flow passed through the membrane. The difference is increased as more chlorinated feed solution was filtered by the RO membrane.

The permeate flow of RO-only was higher than the recommended one after 41 running hour with 1327L of high chlorinated feed solution, 440L as permeate flow and 887L as concentrate, the average permeate flow for one running hour was 10.7L and it was 21.6L for concentrate see appendix (4) for details.

b. RO-KDF permeate flow

As shown in Figure (4.5) the difference in permeate flow of RO-KDF and the typical permeate flow is less than 1L for all the running period. The maximum difference was 0.8L this value was measured 2 times in the 9th and 8th running hour. The difference was not regular so the permeate flow of RO-KDF may be more or less than the recommended one.

The permeate flow of RO-KDF is still compatible with the recommended one after 41 running hour with 1237L of high chlorinated feed solution, 409L as permeate flow and 828L as concentrate, the average permeate flow for one running hour was 9.9L and it was 20.2L for concentrate see appendix (3) for details.

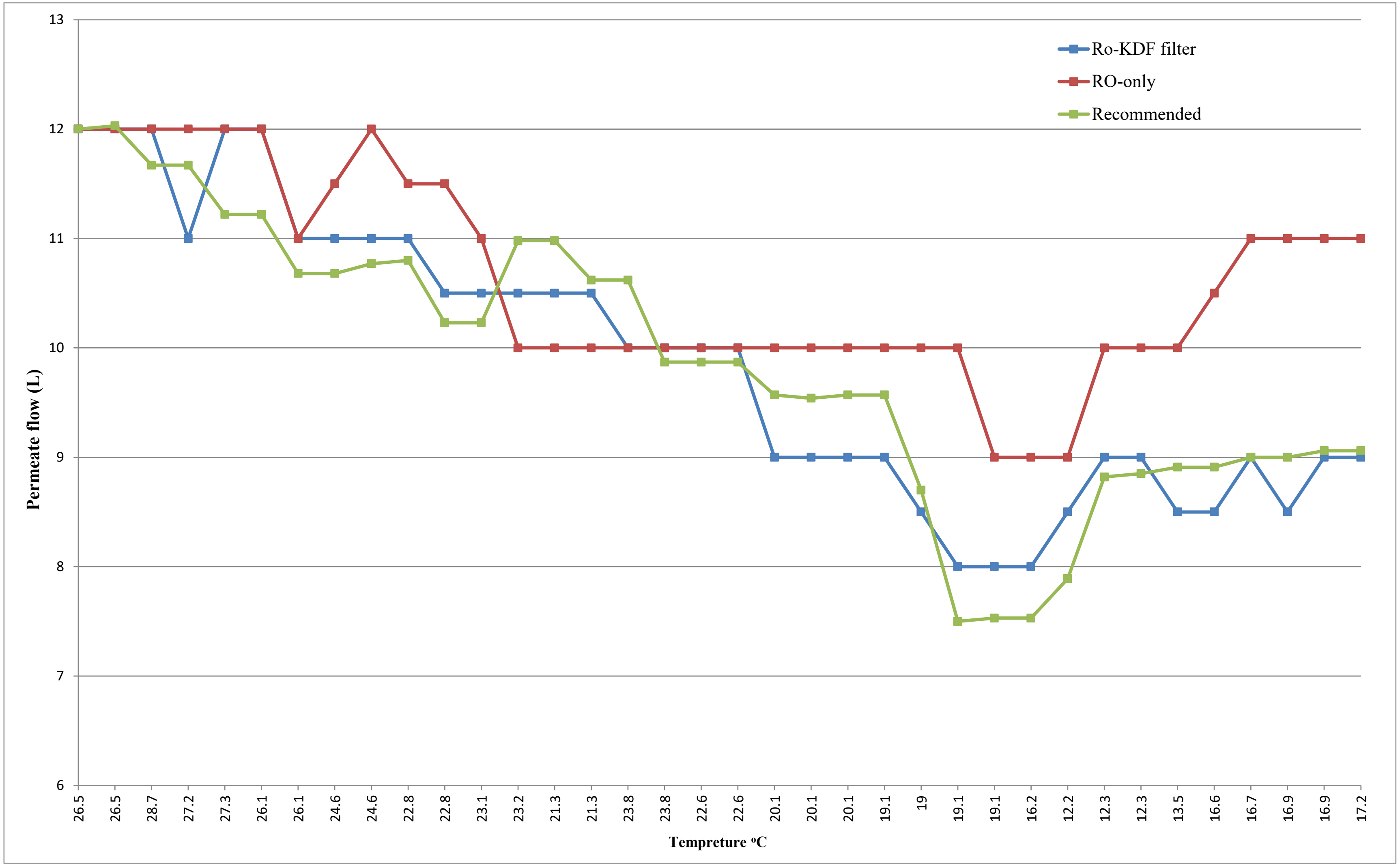


Figure (4. 5): Permeate flow produced by RO-only and RO-KDF systems in Cl_2 experiments.

4.2.3 Cl_2 removal by KDF

KDF redox media is unique combination of copper and zinc that creates an electro-chemical reaction. During this reaction, electrons are transferred between molecules, and new elements are created. Some harmful contaminants are changed into harmless components. Free Cl_2 is changed into benign, water-soluble chloride, which is then carried harmlessly through the water supply as in Figure (4.6) and Eq(4.1). After chlorinated feed solution is filtered by KDF media EC is slightly increased due to the transformation of Cl_2 to Cl^-.

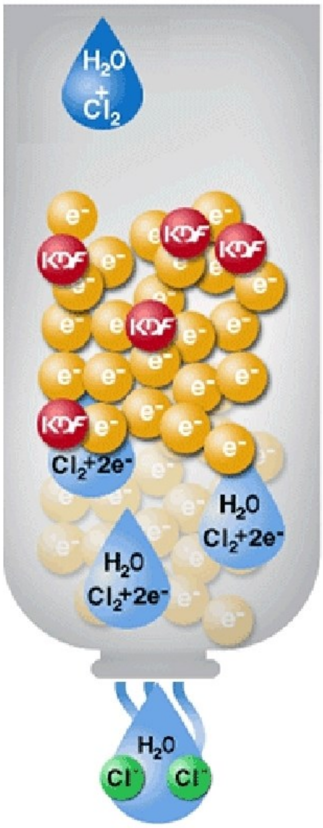


Figure (4. 6): Harmful Cl_2 is changed into Cl ion by reduction.

$$Cl_2 + H_2O + 2e \rightarrow H_2O + 2Cl^- \qquad \text{Eq(4.1)}$$

The Cl_2 removal by KDF media was 100% for the first 13 running hours then it decreased to 73% after 41 running hours, the RO-KDF membrane was exposed to 1.6mg/l of Cl_2 as a maximum dosage and this value is actually greater than the allowed Cl_2 tolerance for RO membrane, but the maximum concentration of Cl_2 in the final permeate flow was less than 0.8 mg/l and it is accepted according to PWA for drinking water. Cl_2 concentration in the permeate flow in RO-only exceeded the limited value after 7 running hour only as in Figure (4.8), the Cl_2 rejection by RO-only membrane almost stopped by the 25th running hour so the concentration of Cl_2 in the permeate flow was nearly equal to that in the feed solution.

From the 11 discs of the KDF media only one was oxidized by Cl_2 during the 41 running hours with 1237L of high chlorinated feed solution passed through it. Figure (4.7) shows the increasing rate of oxidation on the disc used in Cl_2 experiments.

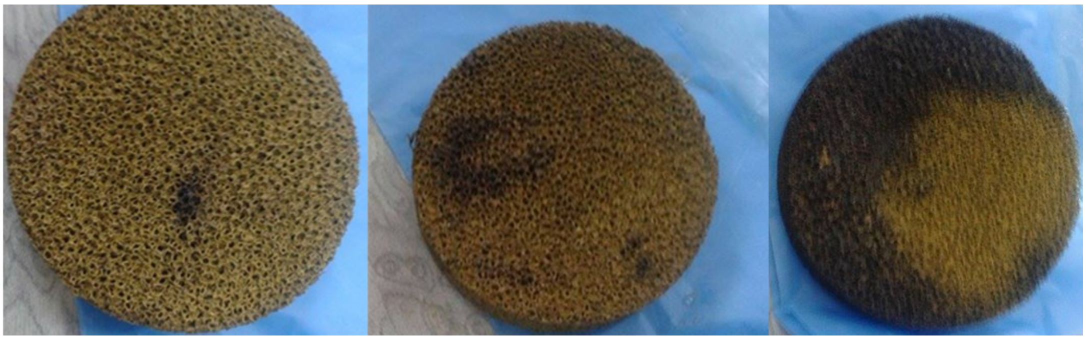


Figure (4. 7): First disc of KDF media oxidization by Cl_2 in steps.

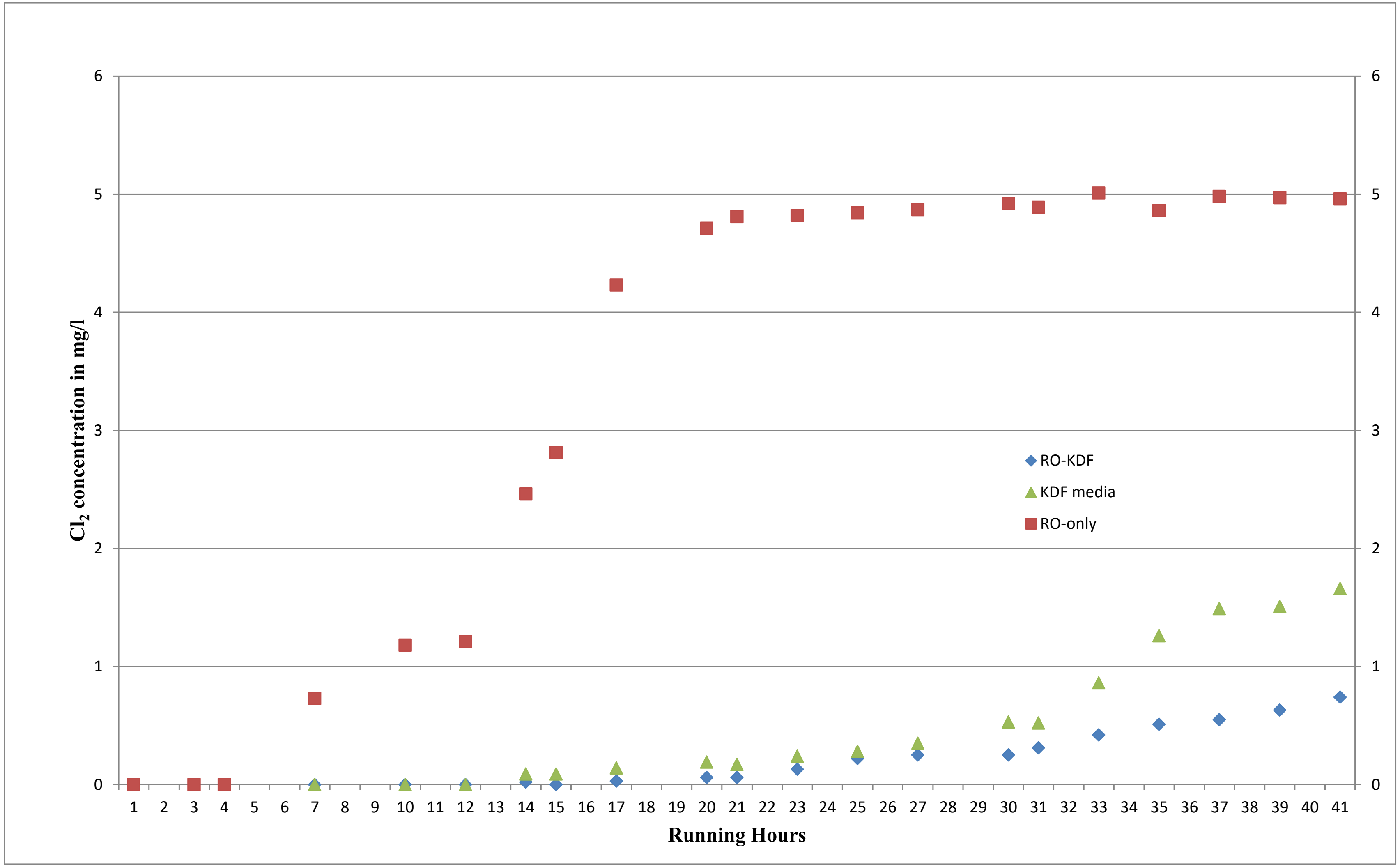


Figure (4. 8): Cl$_2$ concentration in permeate flow in RO-only and RO-KDF.

4.3 Cation-anion removal by RO membrane

General separation properties of RO Membrane are:

- Inorganic solutes are rejected by RO membrane better than organic solutes. Organic solutes with molecular weight larger than 100 are also well rejected by the membrane.
- Ionizable solutes are rejected better than non-ionizable solutes.
- Ionizable solutes with higher charges are rejected better than lower charges. For examples, Al^{+3} is rejected better than Mg^{+2} which is in turn rejected better than Na^{+1}.
- The rejection of inorganic solutes depends also on the size of the ions and the size of hydrated ions. The bigger the ions and the hydrated ions, the better they are rejected.
- The bigger the non-ionizable solutes (the higher the molecular weight), the better the rejection.
- Gases with MW lower than 100 can easily permeate through the membrane. For example, the rejection of ammonia, Cl_2, carbon dioxide, oxygen and hydrogen sulfide is very low.
- The rejection of weak acids is low, which also depends on the MW of the acids. The rejection of the following acids is decreasing in the order of citric acid, tartaric acid and acetic acid as the MW of the acids decreases.

The ascending order of cation-anion removal for the both systems was as follow:

1. *HCO_3*

HCO_3 anion with a negative charge, 60 g/mol molecular weight, and concentration more than 290 mg/l in feed solution. HCO_3 was never been absolutely removed from the permeate flow in all experiments for both systems. It was always found in permeate flow with different levels depending on the salt rejection value since HCO_3 concentration was increased as salt rejection decreased. The lowest measured concentration of HCO_3 was 6 mg/l it was recorded the first hours of operating Cl_2 experiments in both systems, the salt rejection was 98.8% which is the maximum measured value for salt rejection, EC was 6, and TDS was 3mg/l. the highest concentration of HCO_3 was correlated with the lowest salt rejection in the last hour of operating Cl_2 experiments. Typical HCO_3 removal by RO is in the range of 90 - 98%.

2. *Na and Cl*

Both Na and Cl are divalent with negative charge for Cl and positive charge for Na, Cl has a higher molecular weight (35.45g/mol) than Na (22.99g/mol). Cl was present in permeate flow from the first hour of running, 100% removal of Cl was not achieved, while Na removal was 100% when salt rejection is more than 97%, the removal of both Na and Cl decreased as salt rejection decreased.

3. *Mg and Ca*

100% removal of Ca and Mg was achieved in all experiments, Ca and Mg were never present in permeate flow, their concentration was always 0 mg/l. both are monovalent, with positive charge, Ca has a higher molecular weight (40.08g/mol) than Mg (24.31 g/mol).

4.4 Output water characteristics

The pH for output in Cl_2 experiments and scaling experiments in both systems was almost equal, so it was between 7.7 and 7.9 in Cl_2 experiments and in range 7.3-7.5 in scaling experiments and its considered as accepted for drinking water, also for temperature in all cases the temperature for output was nearly equal the temperature for feed solution, for turbidity it was zero for all samples of output in all experiments. DO was correlated with

EC and temperature but generally always the DO for RO-KDF output was higher which indicates purer water, the maximum recorded DO value was
5.6 mg/l.

The produced output water with the end of all experiments was accepted as drinking water according to PWA standards expect for output produced by RO-only system in Cl_2 experiments since the concentration of free Cl_2 exceeded the maximum allowable value recommended by PWA so it reached 5mg/l.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

The efficiency and life of RO system depends on effective pretreatment of the feed water. The pretreatment includes any process which can minimize fouling, scaling and membrane degradation to optimize product flow, salt rejection, product recovery and operating costs.

KDf media was applied as a key step for pretreatment, it was tested for Cl_2 removal and scaling inhibition depending on the results and discussion we conclude the following:

- In $CaCO_3$ experiments the RO-KDF membrane was kept healthy with high efficiency for 40 hours after 10 discs of KDF was degraded while the fouling problems was a raised RO-only system within 20 hours only so KDF media improve the effectiveness of RO membrane and extends its lifetime once at least.
- The concentrate produced by RO-KDF system had less scaling potential than the concentrate produced by RO-only system therefore the fouling in the whole plant will be minimized.
- KDF media can be considered as ineffective pretreatment step in RO system for $CaCO_3$ inhibition since 10 discs of KDF required to extend the lifetime of the membrane once only.
- KDF media as disc shape has a limited capability in $CaCO_3$ inhibition.
- In the Cl_2 experiments both permeate flow and salt rejection in RO-KDF were improved so after 41 running hours the salt rejection was high and the permeate flow was adequate while fouling indicators raised early on RO-only system.

- Only one disc from KDF media was degraded in Cl_2 experiments so it's expected that full media will extend the lifetime of the membrane 3 times at least, thus KDF media can be considered as effective pretreatment step in RO system for Cl_2 removal.
- KDF media capability in Cl_2 removal is very high.

5.2 Recommendations

- It is better to perform such experiments in RO plants with recirculation system to investigate the effect of KDF media in the whole plants.
- KDF media capability in removing heavy metal, bacteria, chlorimines and THMs should be investigated.
- Further studies are still needed to determine the effectiveness of KDF media in scaling inhibition; it can be performed by using different levels of scaling and different kinds of KDF media.
- KDF55 and KDF85 should be investigated separately to determine the effectiveness and capabilities of each one.
- Cu and Zn effects on water quality improvements should be studied by adding different concentration of each ion to water.
- The effect of KDF on the concentrate flow can be investigated by studying the characteristics of concentrate flow.
- Comparison between the effect of KDF and chemical antiscalants on membrane fouling reduction can be investigated.
- Cost benefits analysis for the whole system should be performed.

References

- Abanmy A. & Paul D.(1990). Reverse osmosis membrane fouling. Ultra Pure Water, Vol.7, issue 3, pp. 25-36.

- Abu Eisheh R.; Shoqier J.(2017). Reverse osmosis membrane chlorine effects reduction using Kinetic Degradation Fluxion Media. International Journal of Advanced Engineering, Management and Science (IJAEMS).Vol.3,pp. 50-54. ISSN : 2454-1311.

- Adeyeye K. (2014). Water efficiency in buildings: theory and practice. John Wiley & Sons. ISBN 978-1-118-45657-6.

- Arnal J., Garcia-Fayos B. & Sancho M. (2011). Membrane cleaning, expanding issues in Desalination, Prof. Robert Y. Ning (Ed.), ISBN 978-953-307-624-9.

- Baker R. (2004). Membrane technology and applications. 2nd Edition. Wiley-VCH. ISBN 0-470-85445-6.

- Catenacci A.(2014). Heavy metal removal from water: characterization and applicability of unconventional media, Politecnico di Milano, Department of Civil and Environmental Engineering, p. 18.

- Coetzee PP., Yacopy M., Howell S. & Mubenga S. (1996). Scale reduction and scale modification effects induced by Zn and other metal species in physical water treatment. Water SA, Vol.24, Issue 1, pp. 77–84. ISSN 0378-4738.

- Coleman D., Donnell M., Shore A., &Swan J., Russell R.(2007).The role of manufacturers in reducing biofilms in dental chair waterlines. Dentistry, Vol.35,pp 701–711.

- Contre La Faim A. (2005). Water sanitation and hygiene for populations at risk. Hermann Editeurs Des Sciences et des Arts, Paris. ISBN 2 7056 6499 8.
- Dow Water & Process Solutions. Factors Affecting RO Membrane Performance.Form No. 609-00055-498XQRP
- Dow Water & Process Solutions. FILMTEC Home Drinking Water RO Elements. Form No. 609-09010-0406.
- Dow Water & Process Solutions. FILMTEC™ Reverse Osmosis Membranes Technical Manual, Form No. 609-00071- 0416. (http://msdssearch.dow.com/PublishedLiteratureDOWCOM/)
- Dow Water & Process Solutions. FILMTEC™ Reverse Osmosis Membranes : Troubleshooting: Evaluation of System Performance and Operation, Form No. 609-02110-0905.
- El-Dessouky H.& Ettouney H.(2002). Fundamentals of salt water desalination. Elsevier.ISBN 0444508104 9780444508102
- European Commission, Directorate-General for Research and Innovation (2010). Membrane Technologies for water applications. Publications Office of the European Union. Luxembourg. ISBN 978-92-79-17087-4.
- Express Customer Satisfaction Membranes (CSM). (2006). Technology manual for membranes. Saehan industries, Korea.
- Goldi I., Aziz M., Abozirda A., Sanderezon R. (2008). Antiscaling studies on high $CaCO_3$ waters in spiral-warp membrane systems. ISBN 978-1-77005-763-0.
- http://www.lenntech.com/Data-sheets/Dow-Filmtec-TW30-1812-xx%20series.pdf

http://www.saehancsm.com

- James T.(2000). Performance of KDF® 55 Filters for control of bacteria growth Director of research and development, KDF Fluid Treatment, Inc.
- KDF fluid treatment.(2003). KDF Process Media. (http://www.kdfft.com/pdfs/KDFProcessMedia.pdf)
- Kemmer F.(1988). The Nalco Water Handbook.McGraw-Hill, ISBN 9780070458727.
- Lisitsin D., Yang Q., Hasson D. & Semiat R. (2005). Inhibition of CaC03 Scaling in Reverse Osmosis System by Zinc Ion. Desalination, Vol.183, Issue 2, pp. 289-300.
- Liu D., Hui F., Ledion J. & Li F. (2011). Effectiveness of copper and zinc ions in preventing scaling of drinking water. Environmental Technology, Vol.32, Issue 6, pp.609–616, ISSN 0959-3330.
- Mulder M.(1996). Basic principles of membrane technology. Kluwer Academic Publishers. Netherlands. ISBN 978-94-009-1766-8.
- Nicholson R., Cherry J., &Reardon E. (1983). Migration of Contaminants in Groundwater at a Landfill: A case study. Hydrology, Vol. 63, pp131-176.
- Palanisamy K. & Subramanian V.K. (2016). CaCO3 scale deposition on copper metal surface; effect of morphology, size and area of contact under the influence of EDTA. Powder Technology, Vol.294, pp. 221–225.
- Reeder R. (1990). Carbonates: Mineralogy and Chemistry. Reviews in Mineralogy, Vol.11, pp 241-244.

- Semine Rasa H., Ghizellaouia S. (2012). Influence of copper and zinc on the power furring of encrusting water. Energy Procedia, Vol.18, pp. 1511 – 1522, ISSN 1876-6102.

- Tikkanen M.(2001). Guidance Manual for Disposal of Chlorinated Water. American Water Works Association. p. 118.

- United States Environmental Protection Agency (USEPA). (2003). Membrane filtration guidance manual. DIANE Publishing, ISBN 1428900136, 9781428900134.

- Viktor K. & Nunes P. (2010). Membranes for water treatment. Volume 4Wiley-VCH. ISBN: 978-3-527-31483-6.

- Weber K. (2012). Last call at the Oasis: the global water crisis and where we go from Here. PublicAffairs. ISBN 978-1-61039-144-3

- White G.C. (1986). The Handbook of Chlorination. 2nd Edition. Van Nostrand Reinhold. New York. ISBN 978-0442292850.

- World Health Organization (WHO). (2013). Guidelines for drinking water quality, 4th Edition. Geneva. ISBN 978 92 4 154815 1.

- Yang Q., Lisitsin D., Hasson D. & Semiat R. (2005). Inhibition of CaC03 Scaling in Reverse Osmosis System by Zinc Ion. Chem Eng,Vol.14, Issue 2,pp. 178-183, ISSN 0011-9164

- Zeppenfeld K. (2009). Prevention of $CaCO_3$ scale formation by trace amounts of copper (II) in comparison to zinc (II). Desalination, Vol.252, Issue 1-3, pp.60-65, ISSN 0011-9164.

- Zeppenfeld K.(2016). Inhibition of CaCO3 scaling by zinc(II) and copper(II): A comparative review, Physikalische und Energetische Wasserbehandlungsverfahren für Wärmeübertrager und Rohrleitungen in der gewerblichen und industriellen Anwendung, 2nd Edition, pp.4-20.

Appendices

Appendix (1): RO-only measurements and basic principles calculation for scaling experiments.

Measured											Calculated					
Hour	EC for input (ms/cm)	EC for output (ms/cm)	input initail pH	input Ca (mg/l)	input HCO_3 (mg/l)	input T (0C)	input TDS (mg/l)	Concentrate (L)	flow(L)	total volume (L)	Salt Rejection (%)*1	LSI *2	Recovery (%) *3	concentration factor1 *4	concentration factor2 *5	mass balance *6
1	566	42.5	7.43				367.9	24	12.00	36.00	92.5		33.3	1.5	1.4	2.58
2	572	30.5	7.45				371.8	24	12.00	36.00	94.7		33.3	1.5	1.4	2.43
3	573	18.2	7.4				372.5	24	12.00	36.00	96.8		33.3	1.5	1.4	2.36
4	625	30	7.32	170.6	605.1	29.2	406.3	25	12.00	37.00	95.2	0.8	32.4	1.5	1.4	2.79
5	633	30.9	7.41	172.7	598.7	29.6	411.5	26	12.00	38.00	95.1	0.9	31.6	1.5	1.3	3.37
6	641	31.1	7.36	174.0	607.3	30.0	416.7	26	12.00	38.00	95.1	0.9	31.6	1.5	1.3	3.56
7	621	34.2	7.33	166.7	610.6	27.9	403.7	25	11.00	36.00	94.5	0.8	30.6	1.4	1.4	2.24
8	636	33.8	7.29	168.2	603.9	28.2	413.4	25	11.00	36.00	94.7	0.7	30.6	1.4	1.3	2.48
9	624	35.1	7.35	164.6	596.8	28.9	405.6	24	11.00	35.00	94.4	0.8	31.4	1.5	1.3	3.31
10	633	35.5	7.25	173.4	603.0	27.9	411.5	23	10.00	33.00	94.4	0.7	30.3	1.4	1.3	2.74
11	627	34.9	7.31	176.3	607.6	28.1	407.6	23	10.00	33.00	94.4	0.8	30.3	1.4	1.3	3.35
12	645	35.5	7.37	175.3	610.8	28.7	419.3	23	10.00	33.00	94.5	0.9	30.3	1.4	1.3	3.44
13	619	35.1	7.41	180.0	601.3	28.9	402.4	25	12.00	37.00	94.3	0.9	32.4	1.5	1.3	4.03
14	631	35.7	7.34	176.1	598.4	29.2	410.2	25	12.00	37.00	94.3	0.8	32.4	1.5	1.3	4.13
15	641	36.2	7.37	173.1	615.3	27.9	416.7	23	11.00	34.00	94.4	0.8	32.4	1.5	1.3	4.47
16	636	35.6	7.26	178.0	611.7	28.0	413.4	24	11.00	35.00	94.4	0.7	31.4	1.5	1.3	4.45
17	639	36.4	7.3	172.6	604.3	28.2	415.4	24	10.50	34.50	94.3	0.8	30.4	1.4	1.3	3.76
18	643	36.3	7.42	176.5	611.0	28.4	418.0	23	10.50	33.50	94.4	0.9	31.3	1.5	1.3	4.60
19	629	35.9	7.38	177.1	608.1	28.7	408.9	21	9.50	30.50	94.3	0.9	31.1	1.5	1.3	4.11

20	620	35.8	7.33	173.7	610.7	27.8	403.0	21	9.50	30.50	94.2	0.8	31.1	1.5	1.3	4.24
21	631	35.9	7.28	174.9	601.3	27.9	410.2	20	9.50	29.50	94.3	0.7	32.2	1.5	1.3	4.68
22	623	35.7	7.21	171.4	603.8	28.3	405.0	20	9.00	29.00	94.3	0.7	31.0	1.5	1.3	3.45
23	638	36.2	7.37	177.1	609.4	28.1	414.7	17	8.00	25.00	94.3	0.8	32.0	1.5	1.3	4.58
24	641	36.4	7.33	169.9	603.5	28.5	416.7	21	10.00	31.00	94.3	0.8	32.3	1.5	1.3	4.79
25	630	36	7.28	174.9	610.5	28.6	409.5	20	10.00	30.00	94.3	0.8	33.3	1.5	1.4	4.04
26	643	37.1	7.34	178.2	607.0	29.0	418.0	20	10.00	30.00	94.2	0.8	33.3	1.5	1.4	3.98
27	638	37.3	7.22	173.3	609.1	29.3	414.7	21	10.00	31.00	94.2	0.7	32.3	1.5	1.3	4.02
28	626	37	7.32	178.6	611.3	28.1	406.9	21	9.00	30.00	94.1	0.8	30.0	1.4	1.3	3.68
29	633	36.8	7.31	177.2	606.8	28.3	411.5	20	9.00	29.00	94.2	0.8	31.0	1.5	1.3	4.46
30	635	36.9	7.35	171.9	604.3	28.6	412.8	20	9.00	29.00	94.2	0.8	31.0	1.5	1.3	4.16
31	639	37	7.28	173.2	607.9	28.9	415.4	20	9.00	29.00	94.2	0.8	31.0	1.5	1.3	4.10
32	638	37.1	7.39	172.7	607.3	29.3	414.7	21	9.00	30.00	94.2	0.9	30.0	1.4	1.3	3.38
33	627	36.8	7.27	175.8	601.6	29.3	407.6	18	8.00	26.00	94.1	0.8	30.8	1.4	1.3	3.92
34	644	37.1	7.39	178.7	603.5	27.5	418.6	18	8.00	26.00	94.2	0.9	30.8	1.4	1.3	4.07
35	632	36.8	7.37	176.1	602.5	27.8	410.8	18	8.00	26.00	94.2	0.8	30.8	1.4	1.3	3.78
36	647	37	7.19	173.8	607.7	28.1	420.6	18	8.00	26.00	94.3	0.7	30.8	1.4	1.3	3.84
37	641	36.9	7.34	178.5	609.6	28.2	416.7	18	8.00	26.00	94.2	0.8	30.8	1.4	1.3	4.25
38	639	36.8	7.44	179.3	600.8	27.7	415.4	16	7.00	23.00	94.2	0.9	30.4	1.4	1.3	3.69
39	634	36.9	7.32	173.5	607.2	27.8	412.1	16	7.00	23.00	94.2	0.8	30.4	1.4	1.3	3.59
40	625	36.5	7.22	175.5	597.5	28.1	406.3	16	7.00	23.00	94.2	0.7	30.4	1.4	1.3	3.45
Total								857	393.50	1250.50						

*[1] Salt rejection(%):calculated as in Eq(3.2).

*[2] LSI: calculated by ROSA8(2012).

*[3] Recovery: calculated as in Eq(3.4).

*[4] Concentration factor1: calculated as in Eq(3.5).

*[5] Concentration factor2= EC for concentrate / EC for input

*[6] Mass balance: calculated as in Eq(3.6).

Appendix (2): RO-KDF measuremnts and basic principles calculation for scaling experiments.

Measured												Calculated					
Hour	EC for input (ms/cm)	EC for output (ms/cm)	EC for concentrate (ms/cm)	concentrate (L)	Flow (L)	total volume (L)	Input initial pH	Input Ca (mg/l)	Input HCO3 (mg/l)	Input T (0C)	Input TDS (mg/l)	Salt Rejection (%)	Recovery (%)	mass balance (L)	LSI	concentration factor1	concentration factor2
1	568	831.8	868.8	18.4	12.0	37.0	7.4				369.2	96.8	32.4	2.2		1.5	1.5
2	573	850.3	886.3	18.5	12.0	36.0	7.5				372.5	96.8	33.3	2.1		1.5	1.5
3	574	851.8	887.8	18.5	12.0	36.0	7.4				373.1	96.8	33.3	2.0		1.5	1.5
4	620	896.4	934.4	21.2	12.0	38.0	7.2	172.4	607.4	29.2	403.0	96.6	31.6	2.1	0.7	1.5	1.5
5	635	918.4	956.4	20.9	12.0	38.0	7.4	173.2	601.7	29.6	412.8	96.7	31.6	2.0	0.9	1.5	1.5
6	639	924.3	962.3	20.9	12.0	38.0	7.3	171.9	610.4	30.0	415.4	96.7	31.6	2.0	0.8	1.5	1.5
7	624	913.3	950.3	21.3	12.0	37.0	7.4	169.0	606.7	27.9	405.6	96.6	32.4	2.0	0.8	1.5	1.5
8	630	922.2	959.2	21.3	12.0	37.0	7.3	167.1	603.9	28.2	409.5	96.6	32.4	1.9	0.7	1.5	1.5
9	629	909.5	947.5	21.2	12.0	38.0	7.4	166.3	599.2	28.9	408.9	96.6	31.6	2.0	0.8	1.5	1.5
10	636	943.3	979.3	21.5	12.0	36.0	7.3	171.3	605.4	27.9	413.4	96.6	33.3	1.9	0.7	1.5	1.5
11	628	931.1	967.1	21.8	12.0	36.0	7.3	178.0	610.2	28.1	408.2	96.5	33.3	1.9	0.8	1.5	1.5
12	640	949.2	985.2	21.7	12.0	36.0	7.4	176.9	611.4	28.7	416.0	96.6	33.3	1.8	0.9	1.5	1.5
13	623	923.8	959.8	21.5	12.0	36.0	7.4	176.3	604.5	28.9	405.0	96.5	33.3	1.9	0.9	1.5	1.5
14	633	938.6	974.6	21.8	12.0	36.0	7.3	178.1	599.1	29.2	411.5	96.6	33.3	1.9	0.8	1.5	1.5
15	646	971.4	1006.4	22.3	12.0	35.0	7.4	172.8	598.5	27.9	419.9	96.5	34.3	1.7	0.9	1.5	1.6
16	632	937.0	973.0	22	12.0	36.0	7.2	179.6	609.4	28.0	410.8	96.5	33.3	1.9	0.7	1.5	1.5
17	636	943.0	979.0	22.1	12.0	36.0	7.3	173.3	606.1	28.2	413.4	96.5	33.3	1.9	0.8	1.5	1.5
18	640	962.4	997.4	22.1	12.0	35.0	7.4	177.5	612.8	28.4	416.0	96.5	34.3	1.8	0.9	1.5	1.6
19	637	958.3	991.8	22.3	11.5	33.5	7.3	176.0	610.4	28.7	414.1	96.5	34.3	1.7	0.8	1.5	1.6
20	622	935.7	969.2	21.9	11.5	33.5	7.3	172.5	609.2	27.8	404.3	96.5	34.3	1.7	0.7	1.5	1.6
21	629	932.5	967.0	22.1	11.5	34.5	7.3	176.1	605.2	27.9	408.9	96.5	33.3	1.8	0.8	1.5	1.5
22	628	930.9	963.9	22.2	11.0	33.0	7.3	170.6	604.0	28.3	408.2	96.5	33.3	1.7	0.7	1.5	1.5
23	638	945.7	978.7	22.6	11.0	33.0	7.3	179.6	608.2	28.1	414.7	96.5	33.3	1.7	0.8	1.5	1.5
24	637	944.3	980.3	22.5	12.0	36.0	7.4	170.0	603.5	28.5	414.1	96.5	33.3	1.8	0.9	1.5	1.5
25	634	939.7	975.7	22.6	12.0	36.0	7.2	172.3	608.8	28.6	412.1	96.4	33.3	1.9	0.7	1.5	1.5
26	640	948.6	983.1	22.8	11.5	34.5	7.4	178.9	603.5	29.0	416.0	96.4	33.3	1.8	0.9	1.5	1.5

27	644	968.5	1002.0	23.2	11.5	33.5	7.2	170.4	611.2	29.3	418.6	96.4	34.3	1.7	0.7	1.5	1.6
28	628	930.2	963.2	23.7	11.0	33.0	7.4	177.4	610.6	28.1	408.2	96.2	33.3	1.7	0.8	1.5	1.5
29	629	931.7	964.7	23.7	11.0	33.0	7.4	175.9	606.8	28.3	408.9	96.2	33.3	1.7	0.8	1.5	1.5
30	633	937.5	970.5	24.1	11.0	33.0	7.3	172.8	600.8	28.6	411.5	96.2	33.3	1.7	0.8	1.5	1.5
31	629	931.4	964.4	24.2	11.0	33.0	7.3	174.1	609.4	28.9	408.9	96.2	33.3	1.7	0.8	1.5	1.5
32	635	955.7	986.2	24.2	10.5	30.5	7.4	176.4	600.1	29.3	412.8	96.2	34.4	1.6	0.9	1.5	1.6
33	637	958.7	989.2	24.3	10.5	30.5	7.2	175.1	603.6	29.3	414.1	96.2	34.4	1.5	0.7	1.5	1.6
34	642	950.5	983.5	25.1	11.0	33.0	7.4	179.6	609.5	27.5	417.3	96.1	33.3	1.7	0.9	1.5	1.5
35	637	943.0	976.0	25.1	11.0	33.0	7.3	176.0	600.8	27.8	414.1	96.1	33.3	1.7	0.8	1.5	1.5
36	644	967.9	999.9	25.6	11.0	32.0	7.3	173.3	603.8	28.1	418.6	96.0	34.4	1.6	0.7	1.5	1.6
37	643	937.0	968.0	25.7	10.0	31.0	7.3	179.2	608.7	28.2	418.0	96.0	32.3	1.6	0.8	1.5	1.5
38	636	941.0	972.5	26.1	10.5	31.5	7.4	179.3	599.6	27.7	413.4	95.9	33.3	1.6	0.8	1.5	1.5
39	627	900.0	932.0	26.4	10.0	32.0	7.3	173.7	605.4	27.8	407.6	95.8	31.3	1.7	0.8	1.5	1.5
40	632	907.2	939.2	26.5	10.0	32.0	7.3	176.7	598.8	28.1	410.8	95.8	31.3	1.7	0.7	1.5	1.5
Total				905.9	458.0	1382.0											

Appendix (3): RO-KDF measuremnts and basic principles calculation for Cl_2 experiments.

Hour	EC for input (ms/cm)	EC for output (ms/cm)	Salt Rejection (%)	EC for concentrate (ms/cm)	Cl_2 in output (mg/l)	flow(L)	concentrate (L)	total volume(L)	mass balance	recovery	concentration factor1	concentration factor2	T(^{0}C)
1	560	6.84	99	760	0.07	12	24	36	4.8	33.3	1.5	1.4	26.5
2	567	7.01	99	637	0.07	12	24	36	14.1	33.3	1.5	1.1	26.5
3	562	6.88	99	670	0.07	12	24	36	11.2	33.3	1.5	1.2	28.7
4	592	8.53	99	789	4.95	12	24	36	5.6	33.3	1.5	1.3	27.2
5	598	8.72	99	745	4.82	12	24	36	9.0	33.3	1.5	1.2	27.3
6	599	11.21	98	704	4.96	12	24	36	11.7	33.3	1.5	1.2	26.1
7	595	10.9	98	722	4.85	11	22	33	10.2	33.3	1.5	1.2	26.1
8	600	8.54	99	780	4.93	12	24	36	6.9	33.3	1.5	1.3	24.6
9	590	8.81	99	736	4.86	12	24	36	8.9	33.3	1.5	1.2	24.6
10	602	7.68	99	775	5.01	11	22	33	7.4	33.3	1.5	1.3	22.8
11	601	7.83	99	762	5.02	11	22	33	8.1	33.3	1.5	1.3	22.8
12	592	7.91	99	790	4.89	11	22	33	5.6	33.3	1.5	1.3	23.1
13	586	7.1	99	791	4.91	11	22	33	5.0	33.3	1.5	1.3	23.2
14	585	8.2	99	761	4.96	10.5	22	32.5	6.1	32.3	1.5	1.3	21.3
15	587	8.5	99	757	4.93	10.5	22	32.5	6.5	32.3	1.5	1.3	21.3
16	589	9.3	98	740	4.95	10.5	22	32.5	7.8	32.3	1.5	1.3	23.8
17	591	9.4	98	740	5.04	10.5	21	31.5	8.7	33.3	1.5	1.3	23.8
18	578	10.1	98	731	4.9	10.5	22	32.5	7.4	32.3	1.5	1.3	22.6
19	586	10.3	98	713	4.94	10	21	31	9.3	32.3	1.5	1.2	22.6
20	589	10.3	98	722	4.95	10	21	31	8.9	32.3	1.5	1.2	20.1
21	584	11.1	98	707	5.09	10	20	30	10.3	33.3	1.5	1.2	20.1
22	586	10.9	98	710	5.08	10	20	30	10.3	33.3	1.5	1.2	20.1
23	580	11.4	98	702	4.88	9	19	28	9.4	32.1	1.5	1.2	19.1
24	588	11.2	98	708	4.93	9	19	28	9.7	32.1	1.5	1.2	19

25	584	11.4	98	701	4.98	9	18	27	10.7	33.3	1.5	1.2	19.1
26	581	11.9	98	704	4.83	9	18	27	10.2	33.3	1.5	1.2	19.1
27	586	12.4	98	710	4.92	8.5	18	26.5	9.3	32.1	1.5	1.2	16.2
28	579	13.2	98	695	4.97	8	16	24	10.6	33.3	1.5	1.2	12.2
29	584	13.8	98	698	4.96	8	16	24	10.8	33.3	1.5	1.2	12.3
30	576	14.8	97	701	4.95	8	16	24	9.9	33.3	1.5	1.2	12.3
31	577	14.9	97	698	4.92	8.5	16	24.5	11.2	34.7	1.5	1.2	13.5
32	581	16.1	97	692	5.01	9	18	27	10.9	33.3	1.5	1.2	16.6
33	580	16.8	97	695	5.03	9	19	28	9.7	32.1	1.5	1.2	16.7
34	585	17.9	97	689	4.97	8.5	17	25.5	11.4	33.3	1.5	1.2	16.9
35	579	19.7	97	692	4.89	8.5	17	25.5	10.6	33.3	1.5	1.2	16.9
36	588	19.9	97	685	5.04	9	18	27	11.9	33.3	1.5	1.2	17.2
37	589	20.6	97	682	5.03	8.5	17	25.5	12.1	33.3	1.5	1.2	17.2
38	587	23.1	96	683	5	9	19	28	11.0	32.1	1.5	1.2	17.4
39	590	23.9	96	682	5.01	9	18	27	12.1	33.3	1.5	1.2	17.4
40	586	23.8	96	673	5.02	9	18	27	12.4	33.3	1.5	1.1	
41	588	24.6	96	672	4.99	9	18	27	12.6	33.3	1.5	1.1	
Total						409	828	1237					

Appendix (4): RO-only measurments and basic principles calculation for Cl_2 experiments.

Hour	EC for input (ms/cm)	EC for ouput (ms/cm)	EC for concentrate(ms/cm)	Cl_2 in output (mg/l)	Salt Rejection (%)	flow(L)	concentrate(L)	total volume(L)	mass balance	recovery	concentration factor1	concentration factor2	T(^{0}C)
1	560	42.3	800	0.07	92.4	12	24	36	1.1	33.3	1.5	1.4	26.5
2	570	32.8	766	0.07	94.2	12	24	36	4.4	33.3	1.5	1.3	26.5
3	560	7.85	762	0.07	98.6	12	24	36	4.6	33.3	1.5	1.4	28.7
4	593	14.9	847	4.95	97.5	12	24	36	2.0	33.3	1.5	1.4	27.2
5	593	14.8	851	4.82	97.5	12	24	36	1.8	33.3	1.5	1.4	27.3
6	600	14.9	845	4.96	97.5	12	24	36	2.7	33.3	1.5	1.4	26.1
7	596	14.7	833	4.85	97.5	12	24	36	3.1	33.3	1.5	1.4	26.1
8	596	15.3	839	4.93	97.4	12	24	36	2.7	33.3	1.5	1.4	24.6
9	589	16.1	826	4.86	97.3	12	24	36	2.9	33.3	1.5	1.4	24.6
10	599	16.8	817	5.01	97.2	11	24	35	2.9	31.4	1.5	1.4	22.8
11	603	20.1	836	5.02	96.7	11.5	22	33.5	4.1	34.3	1.5	1.4	22.8
12	594	18.1	804	4.89	97.0	12	24	36	4.6	33.3	1.5	1.4	23.1
13	588	19	824	4.91	96.8	11.5	22	33.5	3.6	34.3	1.5	1.4	23.2
14	580	23.5	785	4.86	95.9	11.5	23	34.5	4.4	33.3	1.5	1.4	21.3
15	589	25.6	788	4.93	95.7	11	22	33	4.9	33.3	1.5	1.3	21.3
16	589	25.4	777	4.95	95.7	10	21	31	4.8	32.3	1.5	1.3	23.8
17	586	30.4	773	5.04	94.8	10	21	31	4.7	32.3	1.5	1.3	23.8
18	575	32.1	754	4.9	94.4	10	21	31	4.9	32.3	1.5	1.3	22.6
19	587	34.2	775	4.94	94.2	10	21	31	4.5	32.3	1.5	1.3	22.6
20	590	34.1	789	4.95	94.2	10	20	30	4.7	33.3	1.5	1.3	20.1
21	582	39.9	786	4.89	93.1	10	20	30	4.0	33.3	1.5	1.4	20.1
22	584	41.7	778	5.08	92.9	10	20	30	4.6	33.3	1.5	1.3	20.1
23	579	42.2	758	4.88	92.7	10	21	31	4.7	32.3	1.5	1.3	19.1
24	589	44.8	769	4.93	92.4	10	21	31	4.8	32.3	1.5	1.3	19

25	586	47.2	771	4.98	91.9	10	20	30	5.0	33.3	1.5	1.3	19.1
26	584	57.5	721	4.83	90.2	10	20	30	7.8	33.3	1.5	1.2	19.1
27	586	64.3	769	4.92	89.0	10	20	30	4.6	33.3	1.5	1.3	16.2
28	581	68.5	760	4.97	88.2	10	20	30	4.6	33.3	1.5	1.3	12.2
29	582	75.1	741	4.96	87.1	9	19	28	5.0	32.1	1.5	1.3	12.3
30	577	76.2	733	4.95	86.8	9	19	28	5.0	32.1	1.5	1.3	12.3
31	578	73.5	727	4.92	87.3	9	20	29	4.9	31.0	1.5	1.3	13.5
32	587	77.5	760	5.01	86.8	10	20	30	4.9	33.3	1.5	1.3	16.6
33	581	82.3	751	5.03	85.8	10	20	30	4.8	33.3	1.5	1.3	16.7
34	583	88.3	763	4.97	84.9	10	20	30	4.0	33.3	1.5	1.3	16.9
35	581	99.2	740	4.89	82.9	10.5	20	30.5	5.6	34.4	1.5	1.3	16.9
36	585	107.4	748	5.04	81.6	11	22	33	4.5	33.3	1.5	1.3	17.2
37	586	120.2	735	5.03	79.5	11	22	33	5.0	33.3	1.5	1.3	17.2
38	584	127.8	735	5	78.1	11	22	33	4.6	33.3	1.5	1.3	17.4
39	589	135.6	745	5.01	77.0	11	22	33	4.2	33.3	1.5	1.3	17.4
40	588	146.6	733	4.99	75.1	11	21	32	5.1	34.4	1.5	1.2	17.4
41	588	154.4	731	4.98	73.7	11	21	32	4.9	34.4	1.5	1.2	17.4
Total						440	887	1327					0

Appendix (5): Cations and anions measuremnts with cation-anion Balance check.

Cations (meq/L)					Anions(meq/L)					
Na	K	Mg	Ca	Total (meq/L)	Cl	HCO_3	SO_4	NO_3	Total (meq/L)	Cation-anion Balance(%)*[1]
1.35	0.06	2.81	2.36	6.57	1.53	4.92	0.0	0.01	6.46	0.90
1.31	0.06	2.86	2.33	6.55	1.52	4.84	0.0	0.01	6.37	1.39
1.33	0.05	2.83	2.34	6.55	1.53	4.90	0.0	0.01	6.44	0.84
1.31	0.05	2.79	2.29	6.44	1.52	4.88	0.0	0.01	6.41	0.25
1.35	0.05	2.75	2.29	6.45	1.55	4.90	0.0	0.01	6.46	-0.12
1.35	0.05	2.78	2.36	6.54	1.50	4.89	0.0	0.01	6.40	1.08
1.34	0.05	2.85	2.37	6.61	1.52	4.87	0.0	0.01	6.39	1.66
1.36	0.05	2.89	2.35	6.64	1.52	4.87	0.0	0.01	6.39	1.90
1.30	0.06	2.84	2.38	6.57	1.53	4.89	0.0	0.01	6.43	1.07
1.30	0.05	2.83	2.39	6.57	1.51	4.88	0.0	0.01	6.39	1.40
1.31	0.05	2.86	2.34	6.57	1.52	4.87	0.0	0.01	6.40	1.31
1.31	0.05	2.86	2.31	6.53	1.51	4.86	0.0	0.01	6.38	1.18
1.26	0.06	2.85	2.27	6.43	1.53	4.86	0.0	0.01	6.40	0.28
1.26	0.06	2.79	2.29	6.39	1.49	4.85	0.0	0.01	6.35	0.32
1.32	0.05	2.85	2.39	6.61	1.52	4.88	0.0	0.01	6.41	1.60
1.33	0.06	2.84	2.40	6.63	1.53	4.87	0.0	0.01	6.40	1.73
1.35	0.06	2.77	2.39	6.57	1.56	4.83	0.0	0.01	6.40	1.33
1.34	0.05	2.79	2.41	6.59	1.52	4.81	0.0	0.01	6.34	1.97
1.31	0.06	2.86	2.40	6.63	1.53	4.89	0.0	0.01	6.43	1.54
1.28	0.05	2.86	2.39	6.58	1.56	4.91	0.0	0.01	6.47	0.81
1.31	0.06	2.87	2.35	6.60	1.51	4.92	0.0	0.01	6.45	1.19
1.33	0.05	2.77	2.38	6.53	1.50	4.89	0.0	0.01	6.39	1.02
1.37	0.06	2.77	2.36	6.56	1.51	4.84	0.0	0.01	6.36	1.58
1.38	0.05	2.80	2.38	6.61	1.54	4.88	0.0	0.01	6.42	1.43
1.32	0.07	2.86	2.35	6.60	1.53	4.90	0.0	0.01	6.43	1.26
1.32	0.07	2.85	2.37	6.60	1.55	4.91	0.0	0.01	6.46	1.10
1.27	0.06	2.81	2.34	6.48	1.55	4.78	0.0	0.01	6.34	1.11
1.30	0.08	2.77	2.38	6.52	1.50	4.91	0.0	0.01	6.42	0.83
1.36	0.05	2.72	2.40	6.53	1.52	4.92	0.0	0.01	6.45	0.60
1.39	0.06	2.78	2.37	6.61	1.53	4.79	0.0	0.01	6.32	2.18
1.36	0.06	2.79	2.36	6.57	1.51	4.90	0.0	0.01	6.42	1.20
1.32	0.07	2.85	2.39	6.62	1.53	4.86	0.0	0.01	6.40	1.70
1.34	0.06	2.83	2.34	6.56	1.55	4.91	0.0	0.01	6.47	0.72
1.37	0.05	2.87	2.33	6.62	1.55	4.88	0.0	0.01	6.44	1.35
1.39	0.05	2.81	2.36	6.60	1.52	4.87	0.0	0.01	6.40	1.55
1.31	0.06	2.87	2.39	6.63	1.54	4.86	0.0	0.01	6.41	1.68
1.33	0.06	2.82	2.37	6.59	1.54	4.89	0.0	0.01	6.44	1.12

*[1] Cation-anion Balance = ((Total Cation – Total Anion)/(Total Cation + Total Anion))*100%

تقليل تلوث غشاء التناضح العكسي باستخدام
(Kinetic Degradation Fluxion Media)

اعداد: روان نزار محمود أبو عيشة

المشرف: د. جواد شقير

الملخص

يعتبر التناضح العكسي من اكثر التقنيات استخداما في مجال معالجة المياه وهي المفضلة في مجال انتاج مياه الشرب عن طريق تحلية مياه البحر كما ويعتبر تلوث غشاء التناضح العكسي من ابرز المشاكل التي تواجه انظمة ومحطات التناضح العكسي حيث ان تلوث غشاء التناضح يؤثر سلبا على كفاءة وفعالية المحطة ويزيد من التكلفة التشغيلية وتؤدي عملية تنظيف الغشاء بهدف ازالة التلوث والتخفيف منه عادة الى انقاص عمر الغشاء واحيانا تؤدي الى تلفه بالكامل بالإضافة الى استخدام مواد كيميائية اثناء عملية التنظيف تتسبب في مشاكل بيئية.

اجريت هذه الدراسة بهدف استنتاج كفاءة استخدام (Kinetic Degradation Fluxion - KDF) كخطوة معالجة اولية في انظمة التناضح العكسي للتقليل من التلوث الناتج من التكلس وتقليل التأثيرات السلبية الناتجة من جرعة كلور زائدة على غشاء التناضح العكسي وتم استخدام غشائين في جميع الفحوصات احدهما غشاء مرجعي يتم تمرير المحلول فيه مباشرة دون معالجة والاخر يتم فيه تمرير المحلول في مرحلة المعالجة بـ (KDF) .

واظهرت تجارب الكلور نتائج ايجابية حيث حافظ النظام المزود بالمعالجة على كفاءته بعد انهاء 41 ساعة تشغيلية استنادا الى قيم حجب الملح وكمية المياه الناتج بينما في النظام الاخر الذي يعمل دون معالجة اظهرت قيم حجب الملح وكمية الناتج ان هناك خلل في الغشاء التناضحي وان الغشاء بدأ يتلف نتيجة تأكسده بفعل جرعة الكلور الزائدة, وفيما (KDF) تراوحت كفاءته في ازالة الكلور بين 73% و100% وتمكن القرص الواحد من (KDF) من ازالة الكلور من 1237 لتر من المياه المكلورة وبشكل عام يمكن لقرص واحد من (KDF) اطالة عمر الغشاء التناضحي مرة واحدة وهذا يؤكد كفاءة استخدام (KDF) كمعالج اولي في انظمة ومحطات التحلية في حال زيادة نسبة الكلور في مياه التغذية.

و فيما يخص تجربة التكلس اشارت العوامل التشغيلية المتمثلة بقيم حجب الملح وكمية المياه الناتج ان وضع الغشاء التناضحي في النظام المزود بالمعالجة افضل من ذلك الذي يعمل بدون معالجة حيث

انه بعد مرور 40 ساعة تشغيلية كانت قيمة حجب الملح والتناقص في كمية المياه الناتج في النظام المعالج هي 96.8% و16% على التوالي بينما كانت 94.1% و41% في النظام غير المزود بالمعالجة وعلى الرغم من ذلك يعتبر استخدام (KDF) في تثبيط التكلس غير مجدي حيث تأكسدت 10 اقراص من (KDF) مقابل زيادة عمر غشاء التناضح مرة واحدة فقط.