Towards Promotion of Reverse Osmosis Process Efficiency, Cost Effectiveness and Environmental Safety

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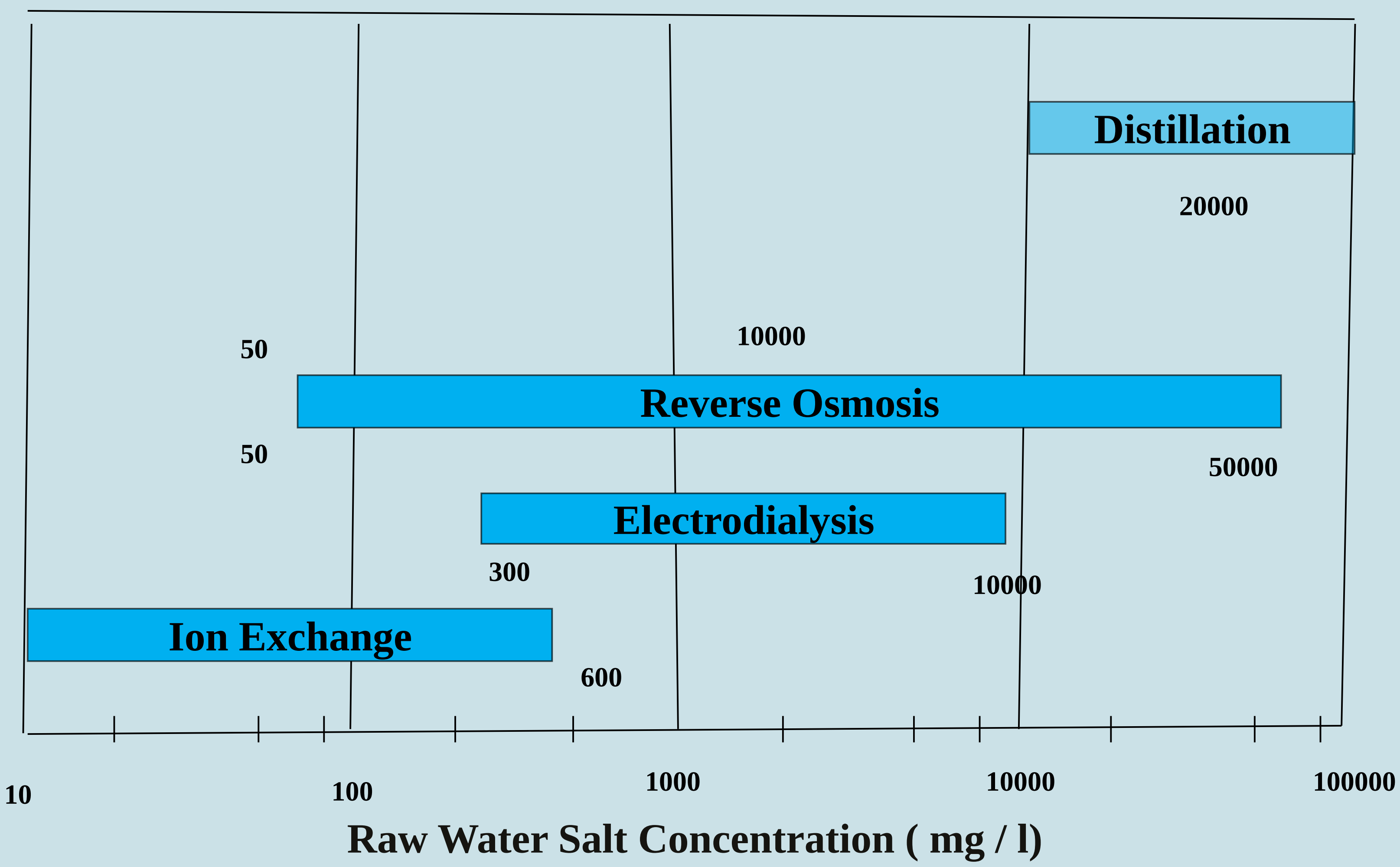
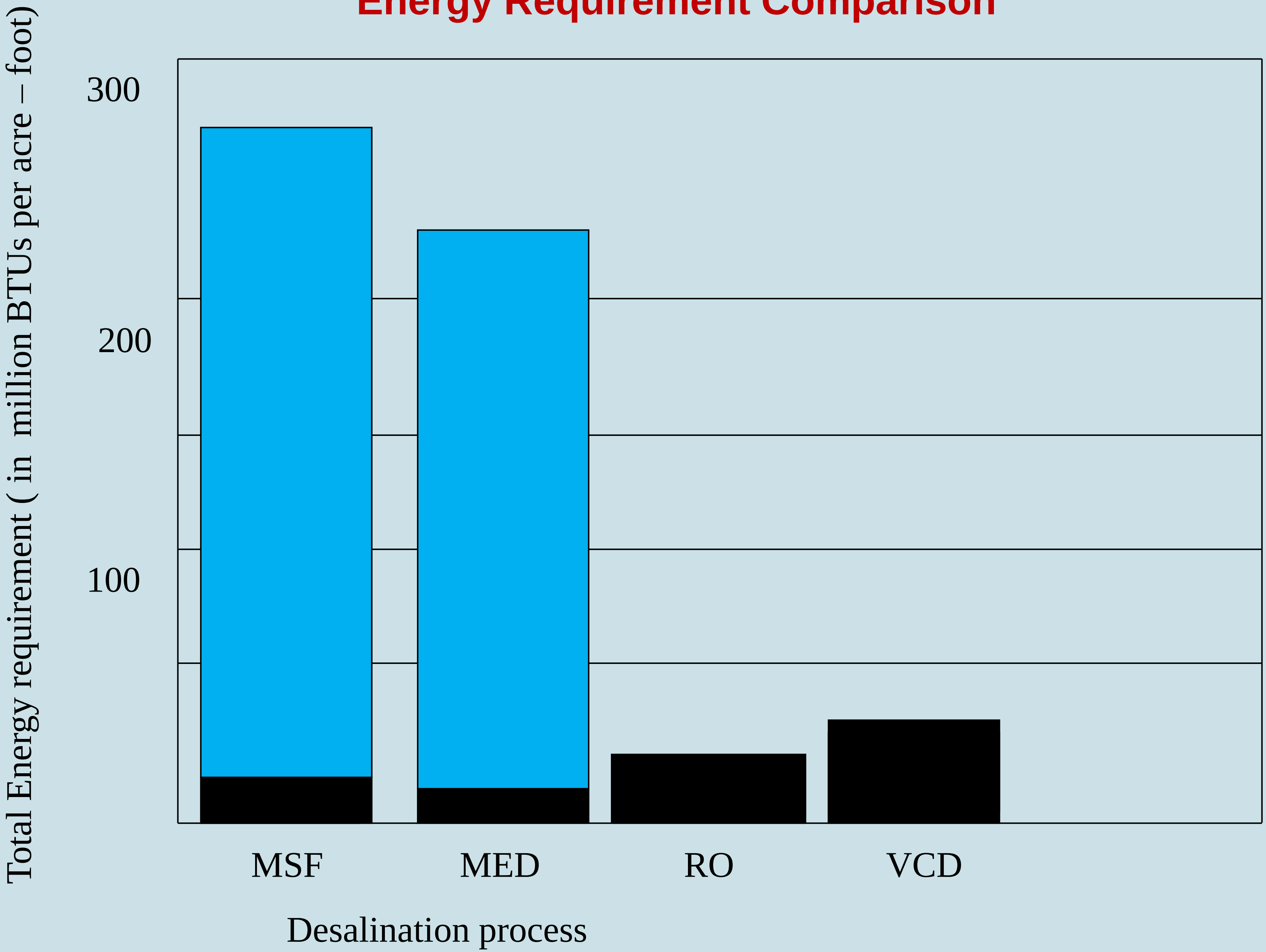
Webinar organized by Aqua Energy Expo

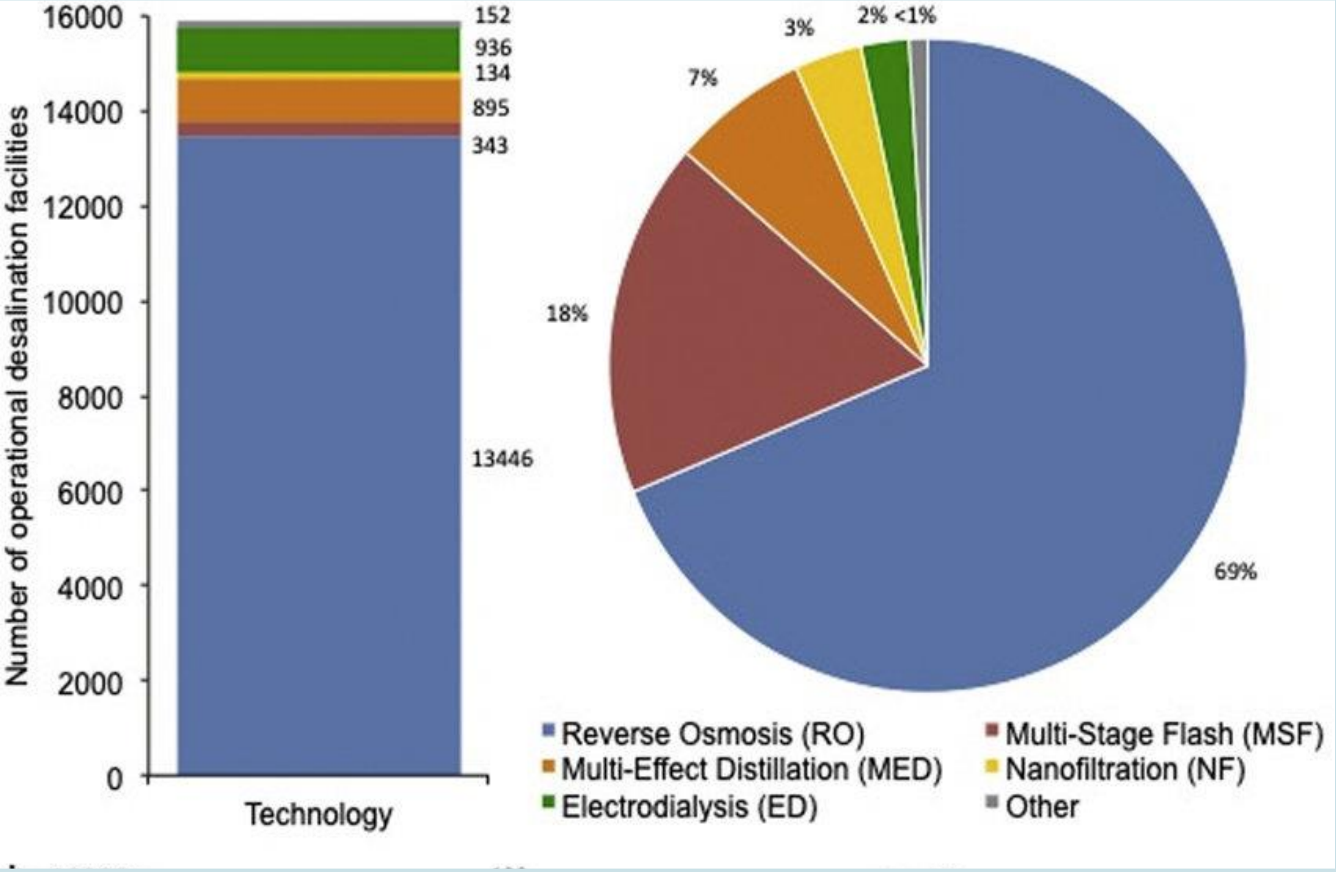
Range of validity of the different desalination methods



Energy Requirement Comparison



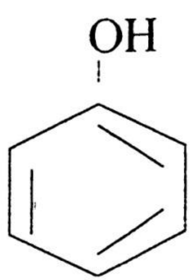
The world relative distribution of desalination technologies



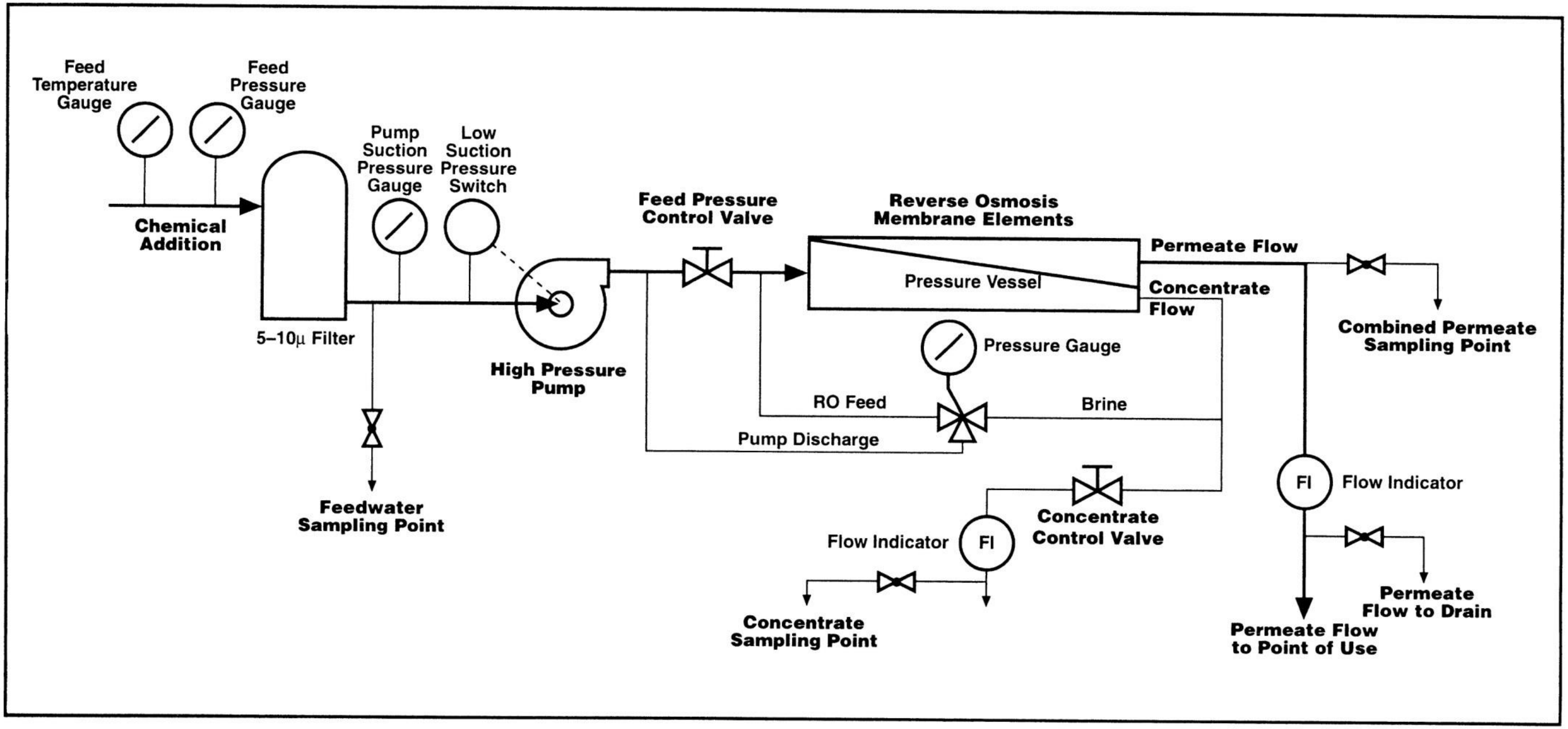
Advantages of RO for Water Desalination

- Simplicity of principle.
- Low energy need. Development trend is towards lower application pressures.
- Desalination of both brackish and sea water.
- Modular process.
- Removal of non charged particles.
- Continuous process.
- Do not require excessive chemical dosing.

Order of Rejection of Ions and Molecules in RO

1. $Na^+ < Ca^{2+} < Fe^{3+}$
2. $Na^+ > K^+ > Rb^+ > Cs^+$
3. $Mg^{2+} > Ca^{2+} > Sr^{2+} > Ba^{2+}$
4. $CH_3\text{-}NH_2 < CH_3\text{-}CH_2\text{-}NH_2$
5. $CH_3\text{-}OH > \begin{array}{c} OH \\ | \\ CH_2 \\ | \\ OH \end{array}$
6.  $< H_2O$

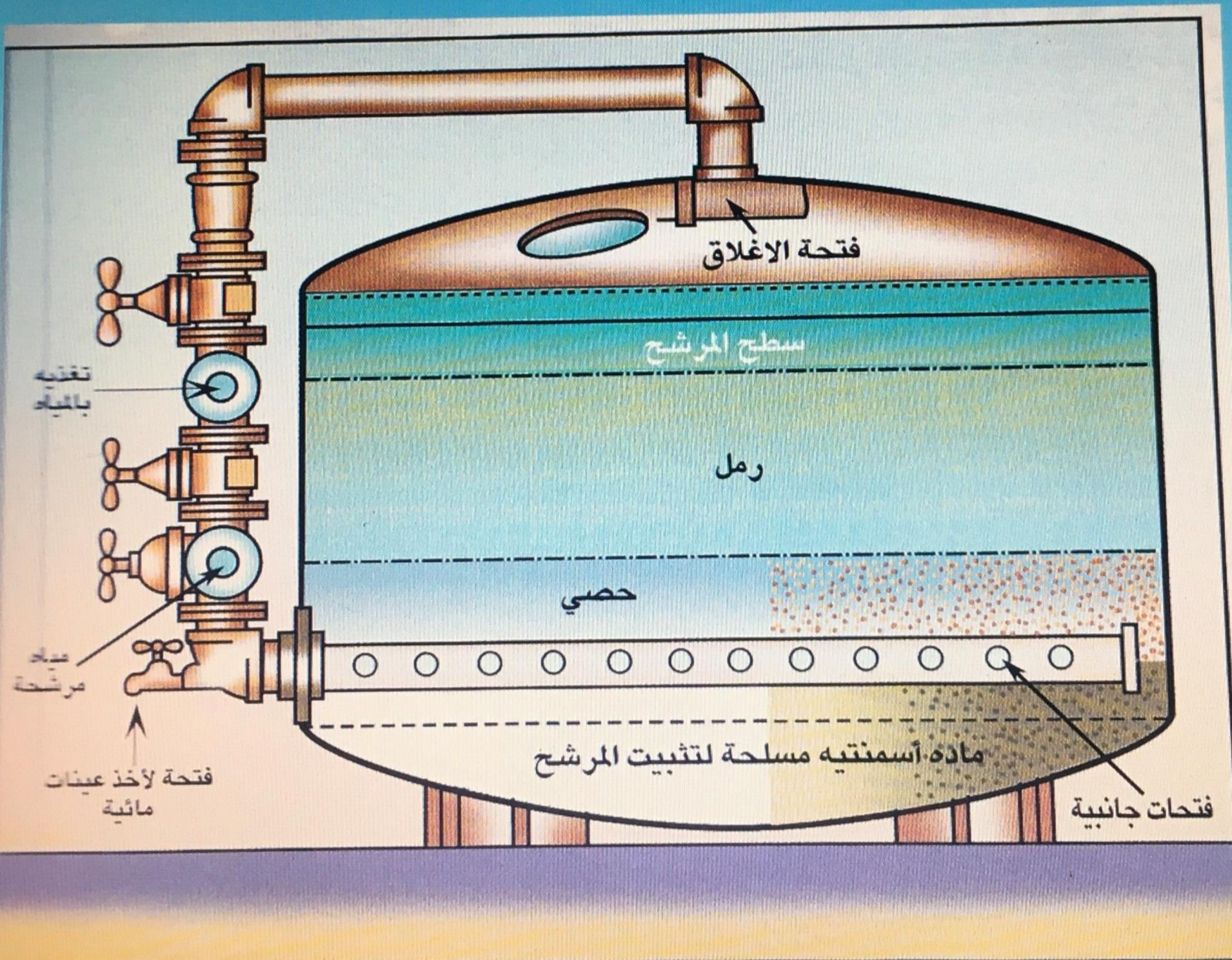
Typical RO System



General Chemical Composition of Natural Water Sources

1. Dissolved Salts mainly inorganic.
2. Non ionic Inorganic Components.
3. Non ionic Organic Components.
4. Dissolved Gasses.
5. Suspended Matter.
6. Colloidal Matter.
7. Micro Organisms.

Media (sand) filter



I- Chlorination:

The most commonly applied disinfection technology in view of its relatively lower cost, ease of application stocking and transportation and its residual sanitizing effect.

Cl_2 gas dissolves in water to give hypochlorous acid HOCL and hypochlorite which are

together known as (**Free Available Chlorine, FAC**)

$$Cl_2 + H_2O \rightarrow HOCl + HCl$$

$$HOCl \rightarrow H^+ + OCl^-$$

Cl_2 gas reacts with ammonia to give chloramines

NH_3	+	$HOCI$	$\rightarrow$	NH_2CI	+	H_2O
Ammonia		Hypochlorous acid		Monochloramine		
NH_2CI	+	$HOCI$	$\rightarrow$	$NHCI_2$	+	H_2O
Monochloramine		Hypochlorous acid		Dichloramine		
$NHCI_2$	+	$HOCI$	$\rightarrow$	NCI_3	+	H_2O
Dichlogamine		Hypochlorous Acid		Trichloramine		

NH_2 Cl and NH Cl2 together are known as (Combined Available Chlorine) They have disinfecting action but quite weaker than that of FAC.

Action of Chlorination

Cl_2 reacts with certain enzymes in the bacteria cell wall forming toxic chlorocompounds which destroy the bacteria completely depending on Cl_2 concentration, contact time, and susceptibility of microorganisms

Factors which influence chlorination

1. Water pH,
2. Temperature
3. Turbidity
4. Water composition

- Cl_2 oxidizes organics to give chloro-organic compounds with slight sanitizing effect.

  Cl_2 then oxidizes nitrogen derivatives like ammonia to give combined available chlorine.
- Remaining Cl_2 will sanitize water
- A residual dose of about 0.5 ppm should remain in product water as protection against recontamination.

Advantages of disinfection by Cl_2

1. Low cost
2. Residual effect

Disadvantages of disinfection by Cl_2

1. Bad taste and odor of water.
2. Chlorinated organics (THM).

Dechlorination:

The only chemical sensitivities of the polyamide RO membranes are:

a- Oxidizing agents

they damage thin film by an oxidation dissolution mechanism with loss of selectivity.

b- Extreme pH values

out of the range 4-10 in continuous operation and 2-11 in cleaning, the PA thin film suffers chemical degradation by a hydrolysis mechanism.

Dechlorination of RO feed stream (up to zero) after sanitization by Cl_2 is essential to protect the membranes.

The most common dechlorinating agents and the concentration required to neutralize mg/L of Cl_2 are:

Compound	**ppm Chemical/ppm Chlorine**
Sodium Sulfite	1.77
Sodium bisulfite	1.46
Sodium metabisulfite	0.70

pH Adjustment:

Purpose of pH adjustment is to stabilize the chemical characteristics of the later in order not to cause deposition of scales ($CaCO_3$) in RO membranes or in pipes or tanks.

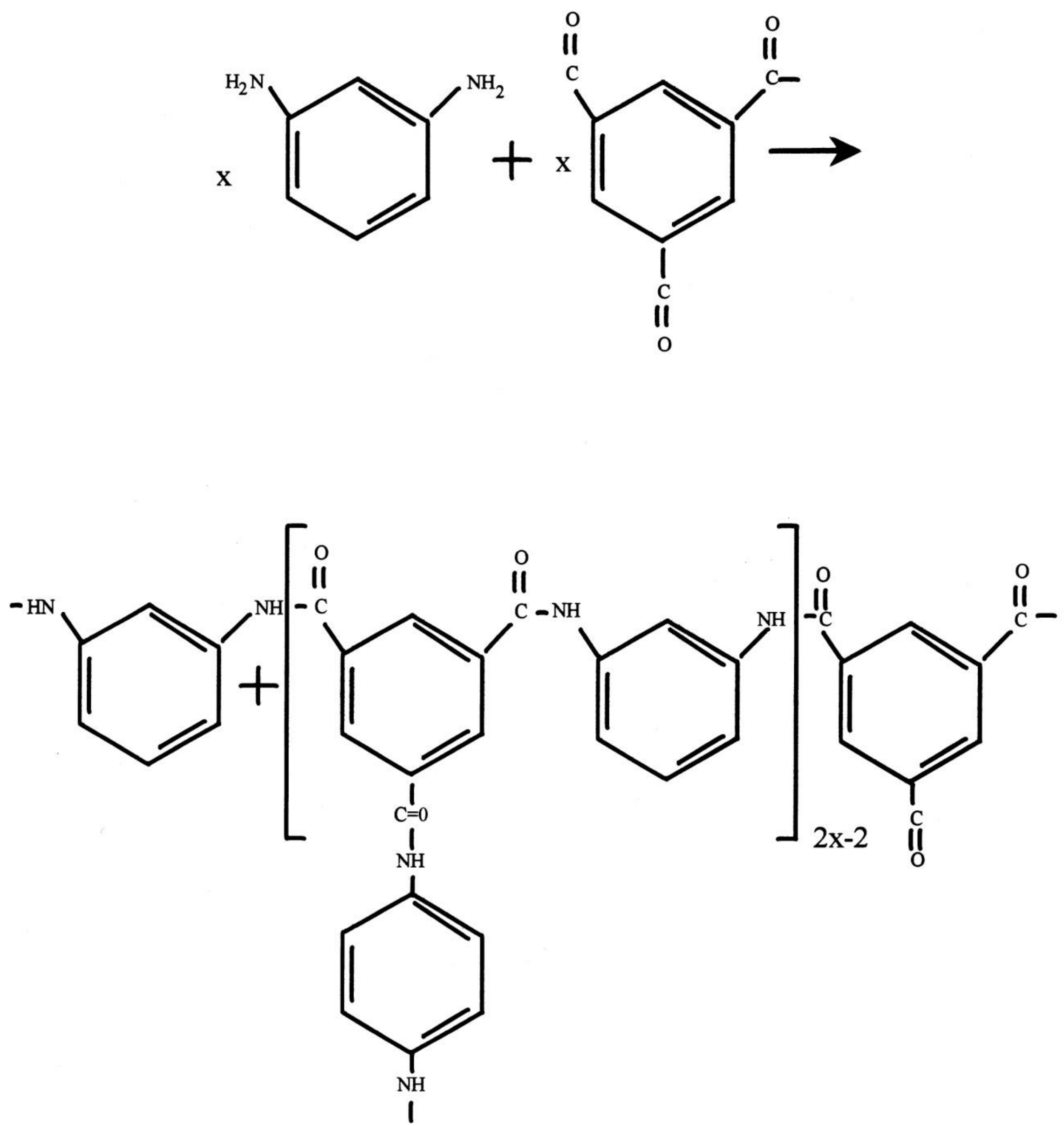
Langleir Saturation Index, LSI depends on assumption that each water has a particular pH value, called saturation pHs, at which water does not deposit $CaCO_3$ nor cause corrosion. pHs depends on Ca hardness, alkalinity and temperature.

LSI = pH - pHs

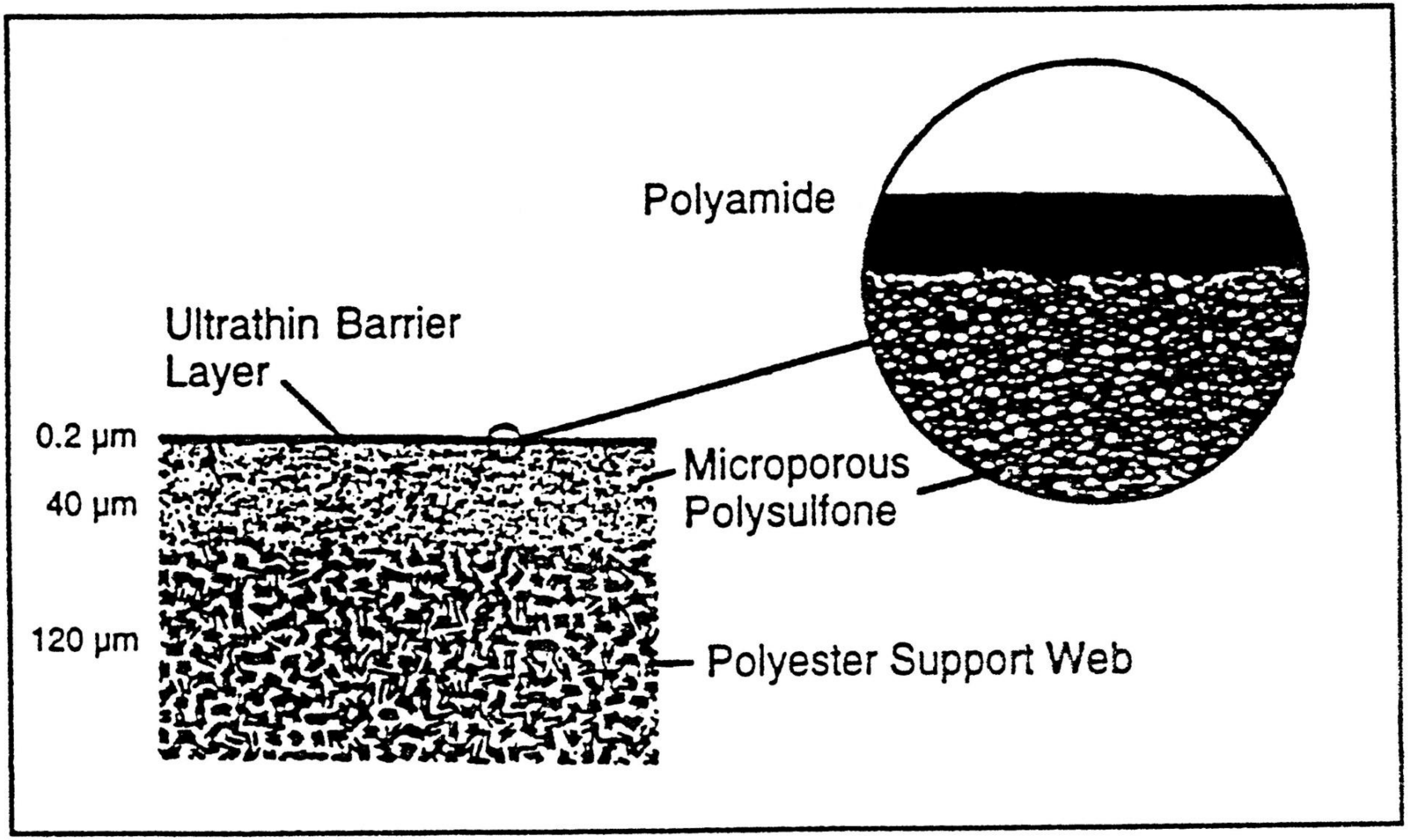
- ve LSI → Corrosion of metal pipes

+ ve LSI → Scale deposition on membranes or on solid surfaces

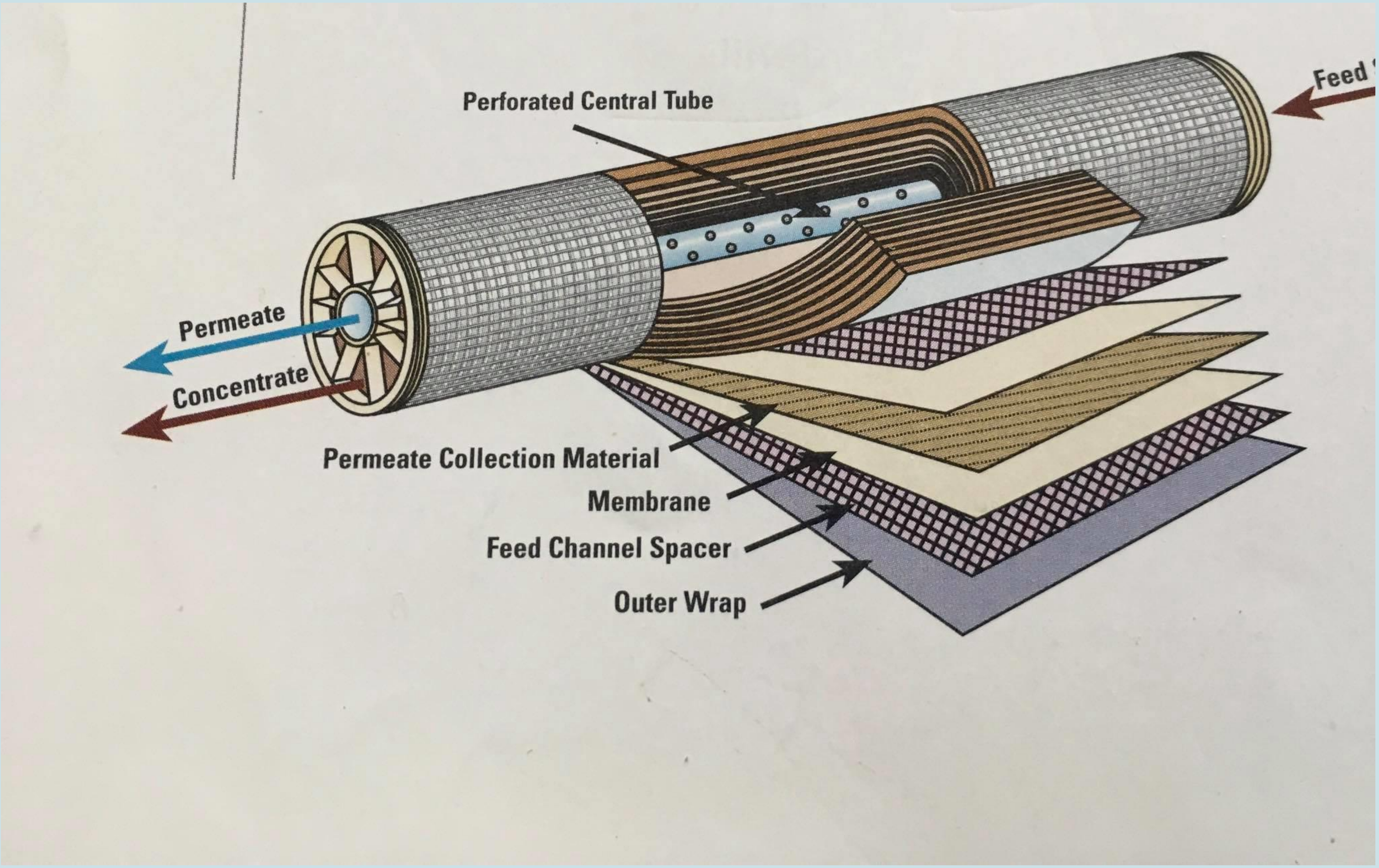
Reaction of preparation of polyamide Thin Film



Thin film composite, polyamide membrane



Thin Film Composite, Spiral wound, Polyamide RO membrane element



Membrane fouling problems in reverse-osmosis desalination applications

Prof. Dr. M. Gamal Khedr, Saudi Industries for Desalination Membranes & Systems Ltd, Saudi Arabia

Editor's Note

Control of membrane fouling has been a holy grail of RO practitioners for a long time. Efforts to raise efficiency in the RO process too often raise the incidence of fouling as well. Prof. Khedr's research is looking at the underlying causes of fouling and has developing a tentative mechanism for the development of the fouling film matrix on membrane surfaces with some recommendations for prevention. Even so, he also concludes that many aspects still require a much better understanding.

Introduction

Although reverse osmosis is currently approved as the standard procedure for brackish water desalination, for seawater it is only competitive only with MSF dual-purpose. Inspection of plant performance and analysis of cases of failure reveals that the most common problem is membrane fouling, see Table 1.

As can be seen, membrane instability (hydrolysis or oxidation) makes only a minor contribution, and membrane mechanical damage (leak problems or telescoping) makes up the total.

Membrane fouling is not predicted by RO system design projections. An empirical 'Fouling Factor' is taken into account to lower the product rate by a fixed percentage each year in order to ease warranty considerations. Additionally, fouling is a function of membrane configuration. The best resistance to membrane fouling is provided by the most modern and best performing thin-film composite spiral-wound RO element.

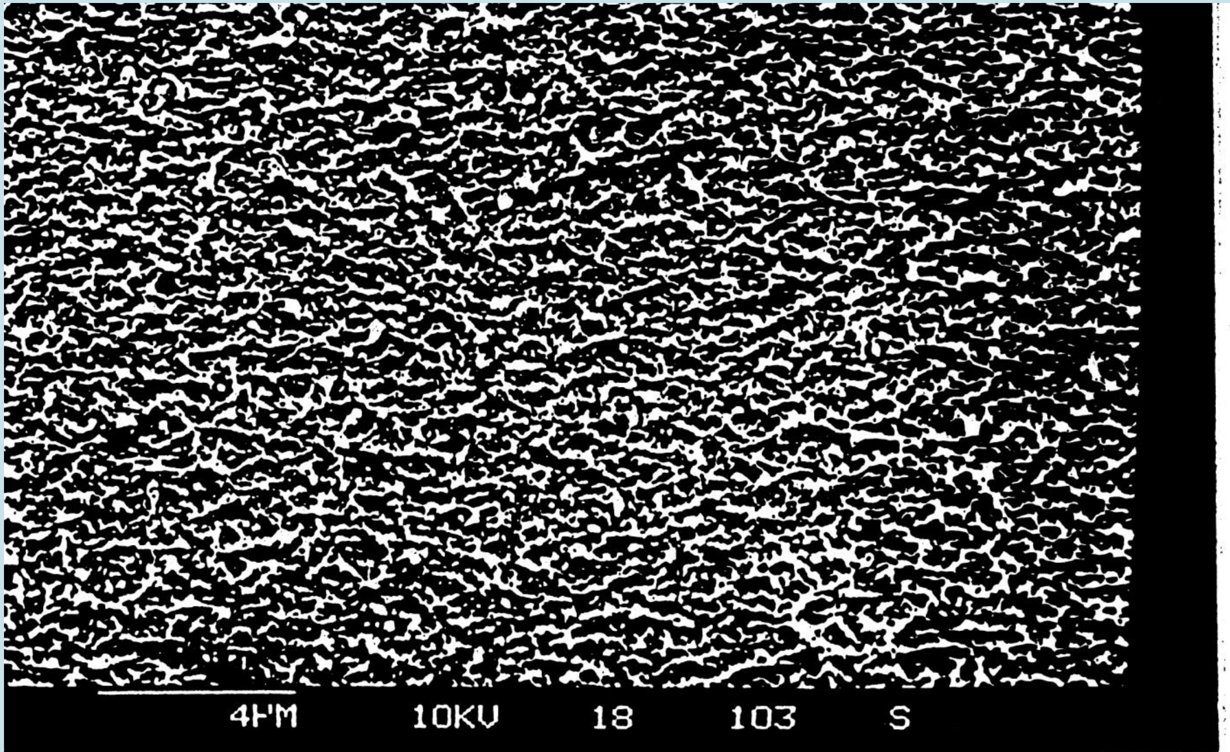
The purpose of this contribution is to characterise the development of the complex fouling on membrane surfaces in RO, based on our pilot and laboratory test results as well as field inspection and membrane autopsy results.

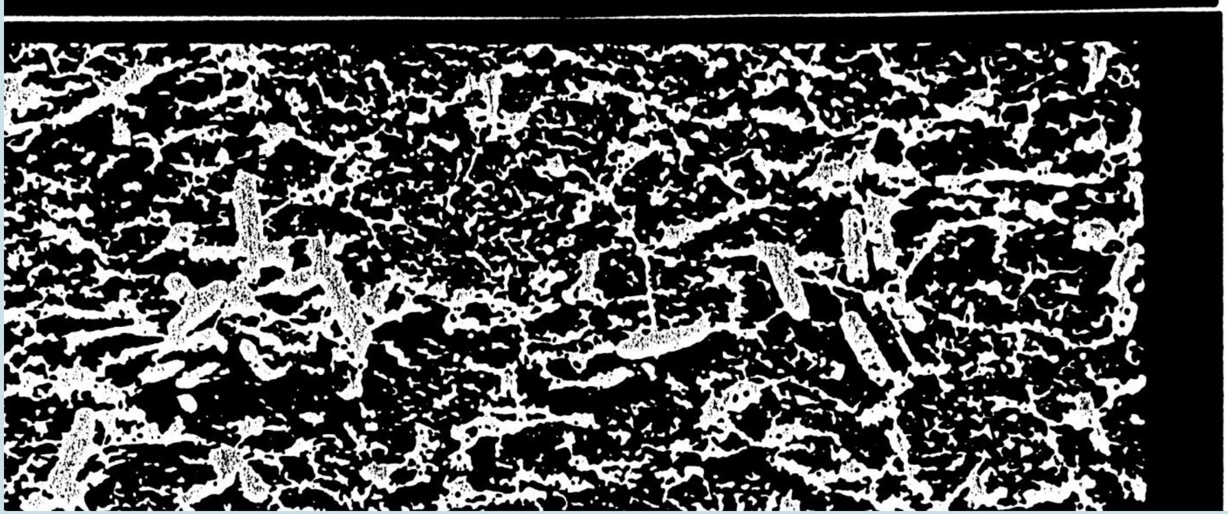
Table 1 Factors in performance decline in RO desalination plants

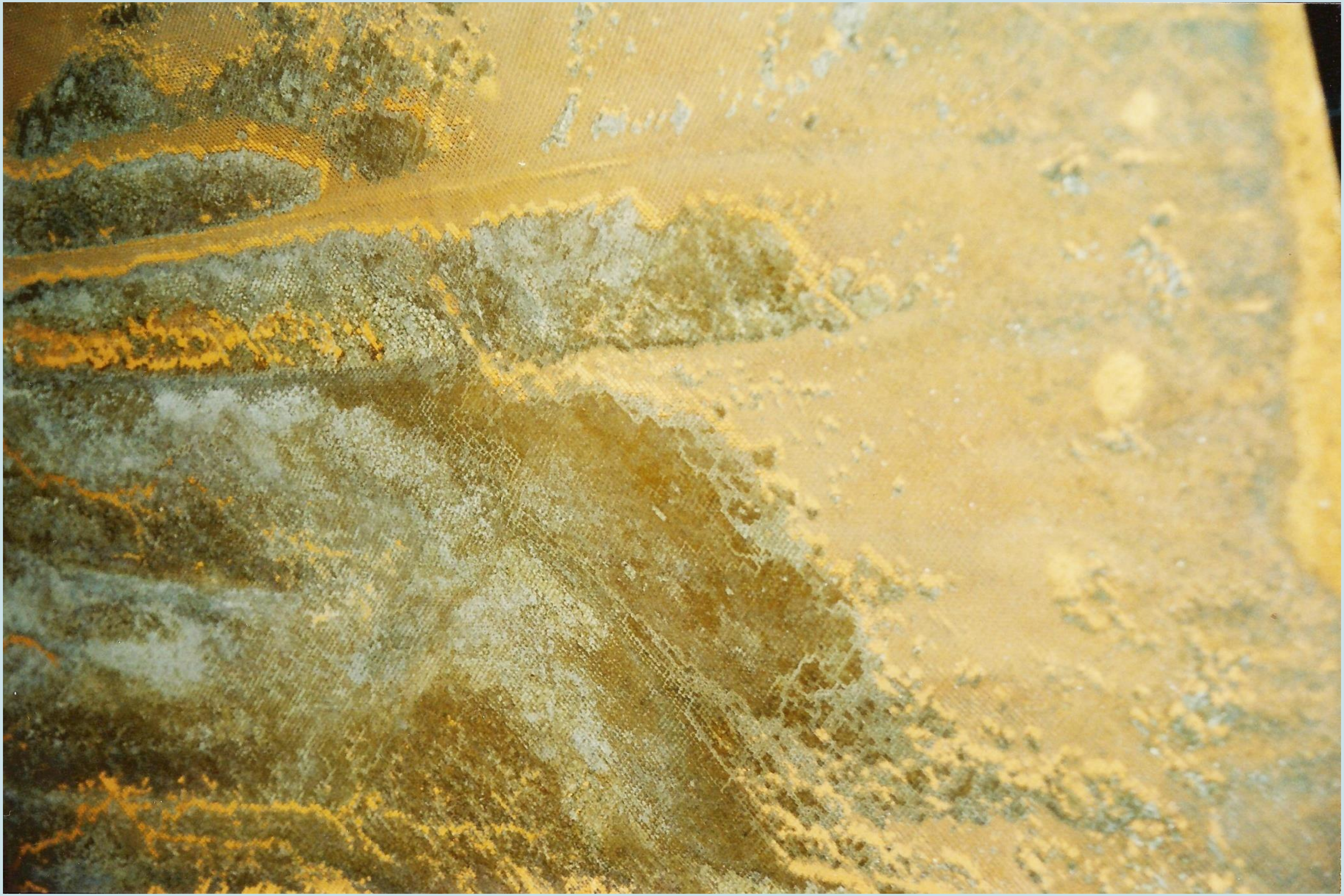
SN	Factors in RO performance decline	Occurrence (%)
1	Mechanical damage (water hammer, telescoping etc)	4.1
2	Membrane degradation (oxidation and/or hydrolysis)	18.2
3	Membrane fouling	
a	Inorganic colloids	13.8
b	Adsorbed organics	11.4
C	Coagulants	4.0
D	Biofouling	33.5
E	Silica scale or silica fouling	10.0
F	Other inorganic scale and fouling with waste water	5.0

Experimental

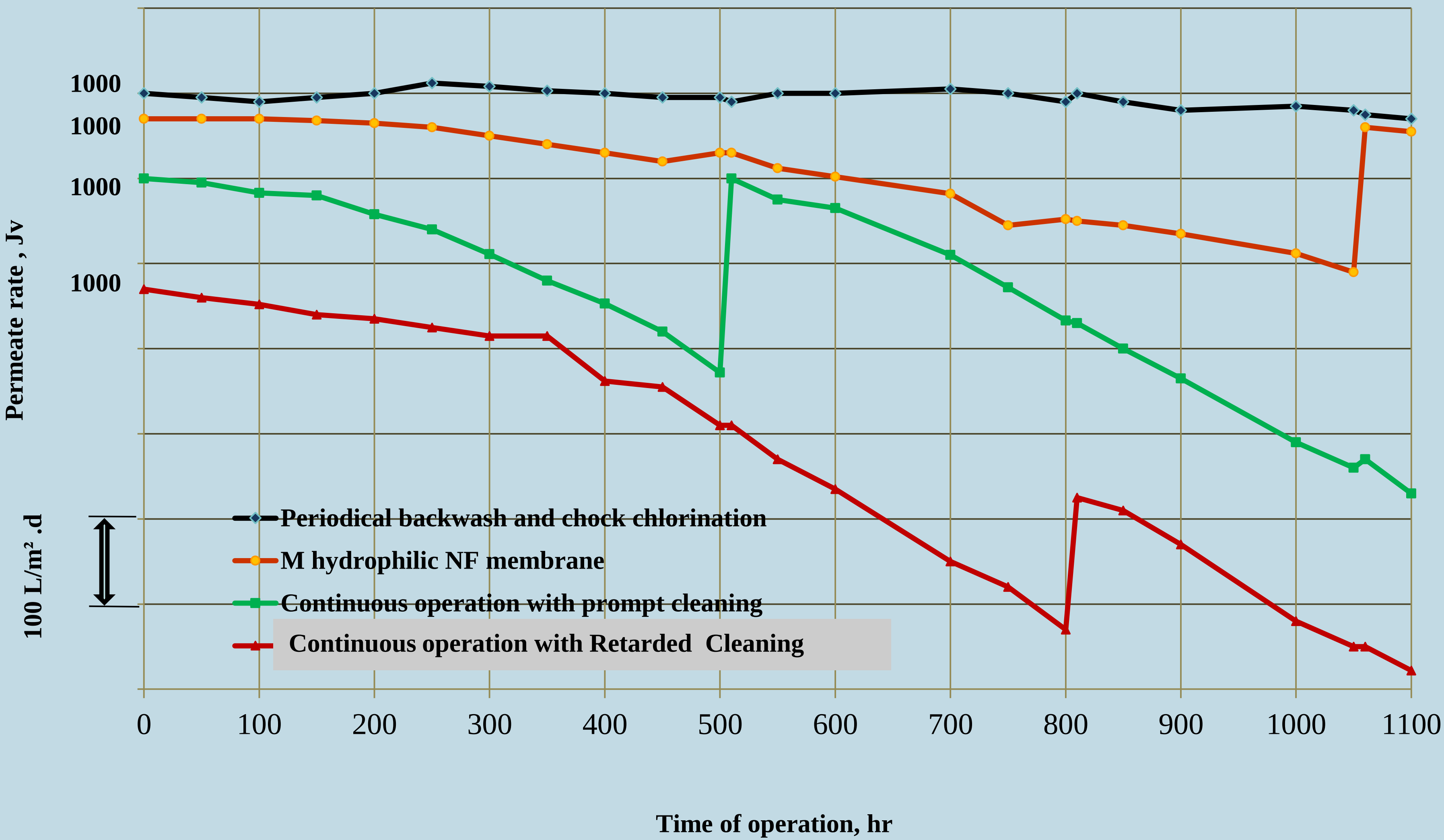
Both RO runs and laboratory bench-tests were conducted using a two-stage pilot RO unit and a bench-testing system, which have been described elsewhere.[3,4] Thin composite membrane


4µM 10KV 18 103 S





Blocking of the feed spacer in RO membrane bioorganic fouling



Decline of product rate for various types of NF membranes upon fouling

Naturally Occurring Radioactive Materials (NORM)

Uranium 238
α emitter
Half life of
4.5×10^9 years

$\xrightarrow[\text{decay}]{\alpha}$

Radium 226
α emitter
Half life of
1,620 years

$\xrightarrow[\text{decay}]{\alpha}$

Radon 222
α emitter
Half life of
3.8 days

Thorium 232

$\xrightarrow[\text{decay}]{\alpha}$

Radium 228
β emitter
Half life of
6.7 years

Health risks encountered in the consumption of Ra, U and Rn

If radon 222 gas is directly respired its disintegration product will remain in the lungs and increase the risk of lung cancer. US Surgeon General Stated that Rn is the second cause of the lung cancer in USA. The consumption of Rn contaminated water in drinking water in drinking increase the risk of stomach cancer.

On the other hand, radium 226-228 is a bone seeker. It accumulates in the same organs as calcium. Ingestion of radium may lead to the development of bone abnormalities, cancer, or death.

Uranium 238 is nephrotoxic, it has a chemical poisoning effect at conc. of 20 ppb (30 pCi/l) which leads to kidneys failure. At 250 ppb, on the other hand, U 238 in drinking water increases the probability of kidney cancer.

In order to minimize risks to human health, the exposure levels to these component s must be reduced to the lowest level. The norms of permissible MCLs are, in fact, periodically revised, and progressively lowered parallel to the advance in methods of analysis and processes of separation.

MCLs of dissolved radionuclides in drinking water and in air according to the US– EPA regulations.

S/N	Radionuclide	Current MCLs in drinking water
1	Radium 226 and 228 (combined)	5 pCi/l
	Uranium 238 chemical poisoning limit. Radiation limit	20 ppb 250 ppb
3	Radon 222	300 pCi/l

S/N	Gas Radionuclide	Current MCL in air
1	Radon 222	4 pCi/l

Best Available Technologies for Removal of Radionuclides

(BAT) US - EPA

Radionuclide	BAT
Radium -226 **Radium -228**	Reverse Osmosis Lime Softening Ion Exchange
Radon-222	Aeration
Uranium-238	Reverse Osmosis Coagulation/Settling/Filtration Anion Exchange Lime Softening

Special aspects of contamination of groundwater by radionuclides

According to our present and previous results the main aspects of this contamination which complicate the processes of water treatment, increase the cost of treatment, represent public health risks upon consumption of contaminated water and threat to environment upon disposal of wastewaters or sludge, are the following:

1- Radioactivity at a level that is dangerous for drinking is due, in fact, to an ultratrace contaminant concentration. This is usually in picograms/L in mixture with other dissolved salts of more than 10 orders of magnitude higher concentration which would lead to severe masking upon treatment for decontamination. Selective membrane techniques were shown to avoid this problem.

2- In such low concentration isotopes may be present in mixture with other ions of the same chemical nature as $Ra^{2+}_{226,\ 228}$ with Ca^{2+}, both being alkaline earth metals, which would introduce strong interference with the processes of isotope removal. Selective membrane techniques were shown to avoid this problem.

3- Removal of radionuclides leads to their concentration in form of sludge, solid deposit or WW stream which, according to its activity, should be discharged to either of surface water, storm sewers, sanitary sewers, deep wells, land filling or in low-level radioactive waste disposal facility with particular precautions in collection, storage, transportation, and disposal of such waste.

Selective Membrane Methods

3.1.Reverse Osmosis

3.2.Nanofiltration

Rejection of radioactive isotopes takes place at high efficiency in the same system of desalination without extra equipment or process steps..

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Nanofiltration and low energy reverse osmosis for rejection of radioactive isotopes and heavy metal cations from drinking water sources

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ABSTRACT

While nanofiltration (NF) and low energy reverse osmosis (LERO) have only moderate rejection for monovalent salts, they have been shown to be highly effective in water dehardening and in removal of polyvalent contaminant ion species. The present work is a part of a long-term investigation of the treatment of contaminated ground waters and certain grades of industrial waste waters for rejection of radioactive isotopes and heavy metal cations (HMC) and for determination of efficient and environmentally safe waste disposal methods. In fact several technical challenges remain with regards to the efficiency and cost of conventional methods for removal of certain contaminants, NF is thought to offer higher efficiency and lead to lower cost. Separation of radium (Ra^{2+} 226 and Ra^{2+} 228), uranium 238 (UO_2^{2+} or its carbonate complex anions at pH 7.5 to 8, $UO_2(CO_3)_2^{2-}/UO_2(CO_3)_3^{4-}$, Cd^{2+}, Cu^{2+}, Hg^{2+} and other cations from mixture salt solutions was investigated as a function of water composition and concentration by NF and LERO. Results were compared to those of separation by conventional methods of chemical precipitation, softening with the hot lime method (HLM), coagulation, and separation by chelating ion-exchange resins (IERs) determined under the same conditions. Membrane methods gave higher rejection of radionuclides and HMCs ranging from 92% to 99%. Contaminant concentration in permeate water was lowered than the maximum contaminant level (MCL) of the US Environmental Protection Agency at system recoveries which attained 90%. In case of separation by IERs a loss of process efficiency which attained 24% was observed in view of interference with separation of similar valency ions such as Ca^{2+} and SO_4^{2-}. The higher the efficiency of the resin to retain the radionuclide, the more its regeneration was difficult, resulting in a higher volume of contaminated spent solution. With NF and LERO, on the other hand, parallel rejection of polyvalent ions did not practically impact that of radionuclides or HMCs, and membranes do not require regeneration. Results of rejection of radionuclides and HMCs showed several significant advantages of membrane methods over that by IER, coagulation, chemical precipitation, and softening. These are the absence of chemical dosing specific to rejection, absence of sludge formation which is contaminated and requires disposal, mechanism does not include slow steps like settling, no need of subsequent filtration or of expensive installations, and the ability to realize parallel water desalination. The study will extend to the evaluation of the waste disposal alternatives. In view of the concentration of the contaminants in the waste stream, selection of environmentally safe disposal methods will be determined.

Keywords: Nanofiltration; Low energy reverse osmosis; HMC removal; Radionuclides removal

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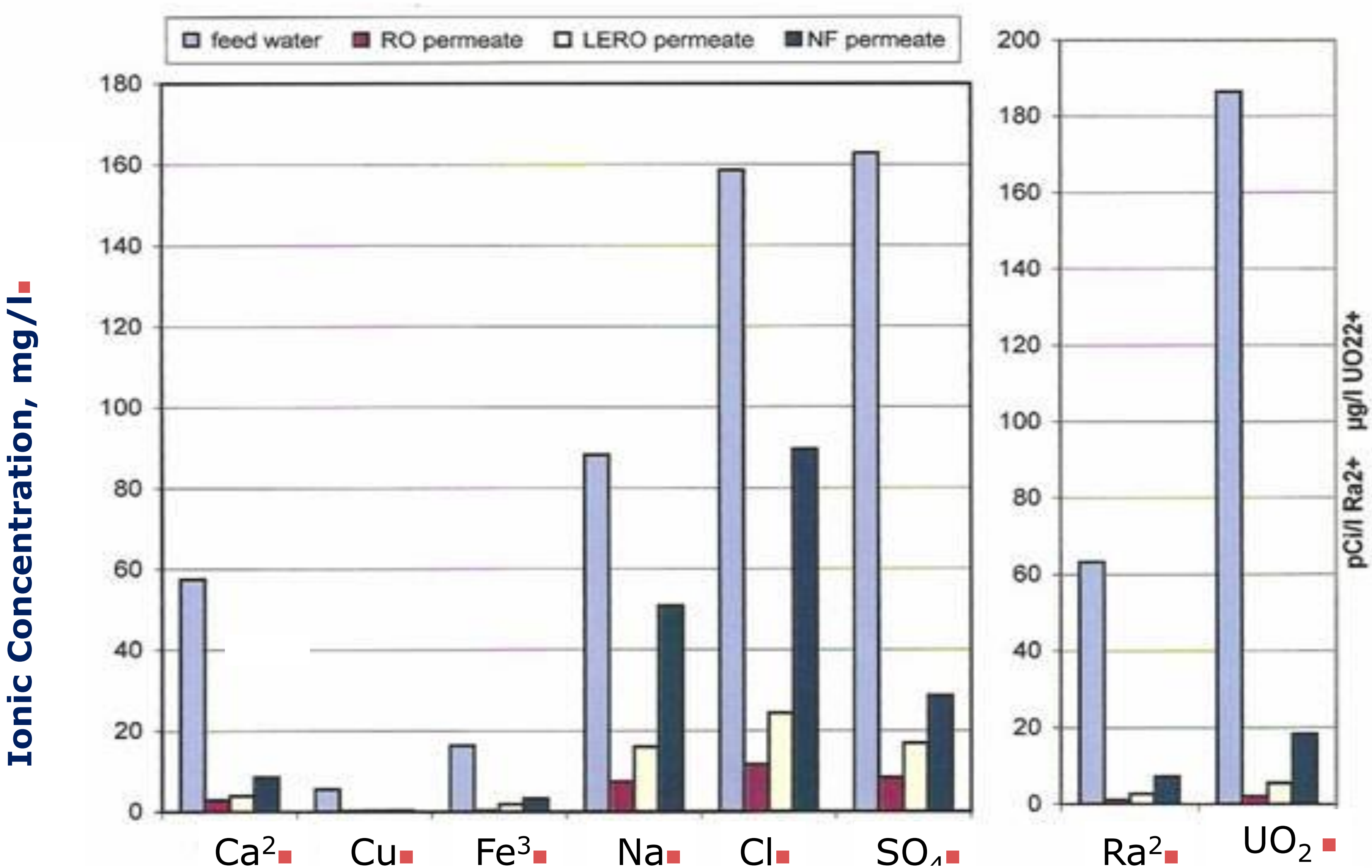

Comparison of Performance of Membrane Methods RO, LERO, and NF in Treatment of Contaminated water

Comparison between the behavior of RO, LERO, and NF membranes id rejection of polyvalent radioactive cations

Parameter of Comparison	Normal Brackish RO Membrane	Low Energy RO Membrane	Nanofiltration Membrane
Process percent recovery	85 Or higher	85 Or higher	85 Or higher
Feed pressure (bar)	12.5	8.1	6.2
Permeate TDS (ppm)	50.1	94.1	303.8
Percent TDS rejection	95.1	88.4	45.7
Percent rejection of divalent cations	98.6	94.4	89.4
Blending with feed stream	Blending or TDS adjustment usually required for drinking purpose	NA	NA

Advantages of removal of radioactive contaminates by NF

1- Parallel total water desalination

2- High rejection efficiency to polyvalent radionuclide

3- Lower operation pressure than RO

4- Not sensitive to TDS and ionic composition of the contaminated water

5- Continuous process with no shutdown for regeneration

6- No chemical dosing specific to radionuclide rejection, no settling and no sludge formation

7- Low footprint and space requirements

8- Easy process of high design flexibility

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Radioactive contamination of groundwater, special aspects and advantages of removal by reverse osmosis and nanofiltration

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HIGHLIGHTS

- ▶ Maximum contaminant levels of radionuclides in water and air and health risks of higher consumption
- ▶ Technical challenges encountered in removal of radionuclides by conventional methods
- ▶ Advantages of rejection of radionuclides from groundwater by reverse osmosis and nanofiltration
- ▶ Conclusion of special characteristics of radioactive contamination of groundwater
- ▶ Proposed design precautions of RO desalination plants for optimum rejection of radionuclides and environmental protection.

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ABSTRACT

Contamination of drinking groundwater sources by naturally occurring radioactive materials (NORM) is a rather common problem in several regions in the Middle East and the Arabian Gulf. This contamination which represents public health risks and threat to environment complicates the processes of water treatment and increases their cost. The present work summarizes results of treatment of contaminated groundwater for rejection of radioisotopes.

The removal of radium,Ra^{2+} $_{226}$, $_{228}$, uranium, as uranyl cation, UO_2^{2+}, or carbonate complexes, $UO_2(CO_3)_2^{2-}$ and $UO_2(CO_3)_3^{4-}$, and radon, Rn_{222}, was investigated by reverse osmosis (RO) and nanofiltration (NF) in comparison with the most common conventional methods of ion exchange resins (IERs), chemical precipitation/softening, coagulation, and adsorption on surface active media.

IERs and chemical softening realized radionuclide rejection from 32 to 95%, but with loss of process efficiency which attained 24% due to undesired parallel removal of similar ions. Removal by IERs was too dependent on resin form and water pH and required periodical shutdown for regeneration of resin which was slow and seldom complete. Softening required chemical dosing stoichiometric to isotope removal, disposal of contaminated sludge and subsequent water filtration. Coagulation failed to remove Ra. Its removal of U ranged from zero to 93% depending on pH due to formation of different U complexes.

Only RO, parallel to water desalination, showed steady, high rejection of all isotopes which attained 99% without interference of similar ions, regeneration, or subsequent filtration. NF showed similar behavior, but with lower water desalination.

1. Introduction

Reverse osmosis (RO) is a mature selective membrane technology which has been used for decades for water desalination and is currently considered among the most efficient and cost effective methods of water desalination. While efficiently reject solutes, RO membranes pass water at a high rate under pressure. Nanofiltration (NF), on the other hand, has an only moderate rejection of total dissolved solids (TDS) at a quite lower operation pressure through porous membranes of a high surface charge.

In fact, RO and NF have been progressively developed according to the trends of: 1— higher solute rejection, 2— lower energy consumption, 3— lower fouling susceptibility, and 4— longer membrane lifetime. Since salt rejection in both RO and NF is particularly pronounced for polyvalent components, these methods are selected in the in hand investigation for treatment of groundwater contaminated with radionuclides and heavy metal cations (HMC), both being polyvalent ionic species [1–3].

Since several technical challenges remain with application of the conventional methods of chemical precipitation, softening, coagulation/filtration and ion exchange resins (IERs) for the removal

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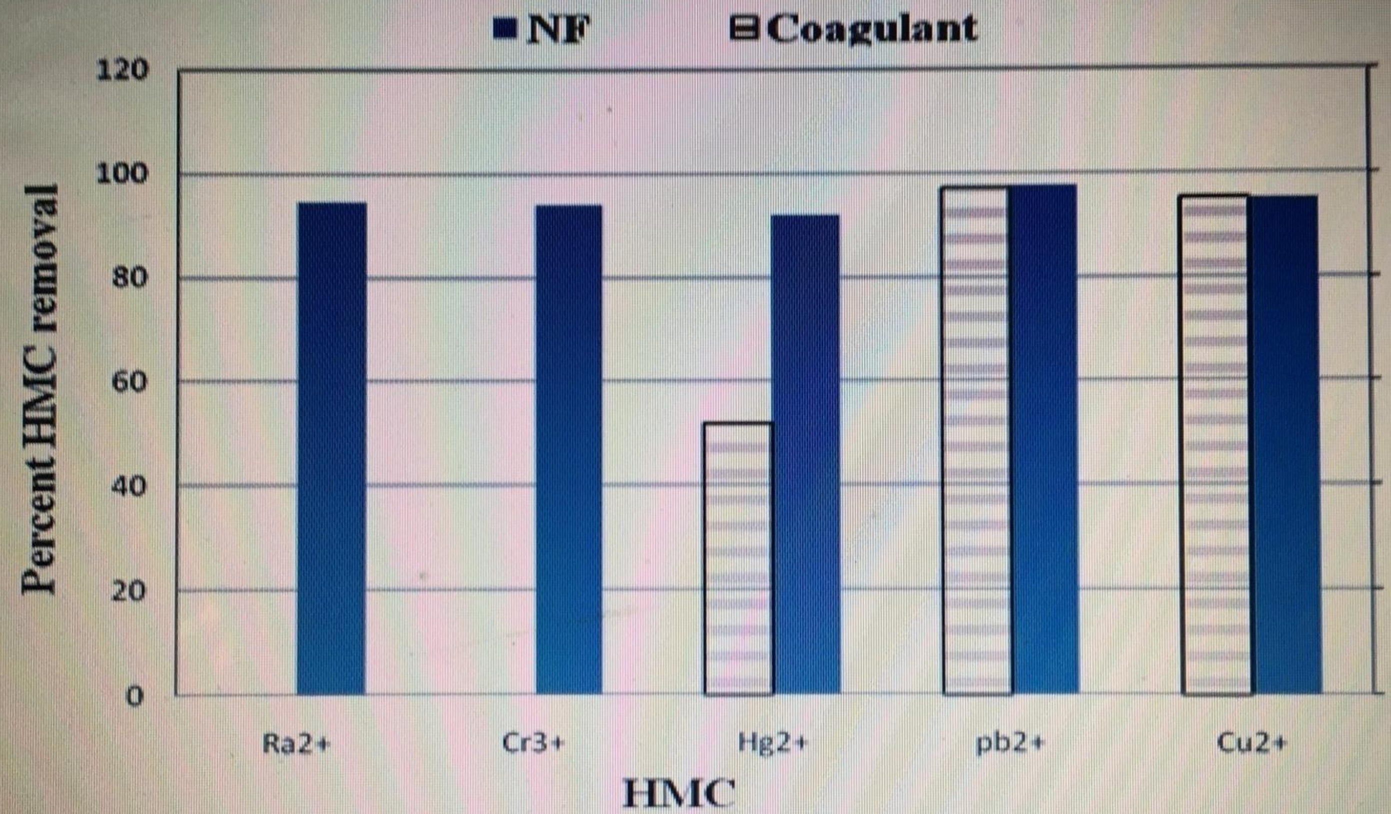
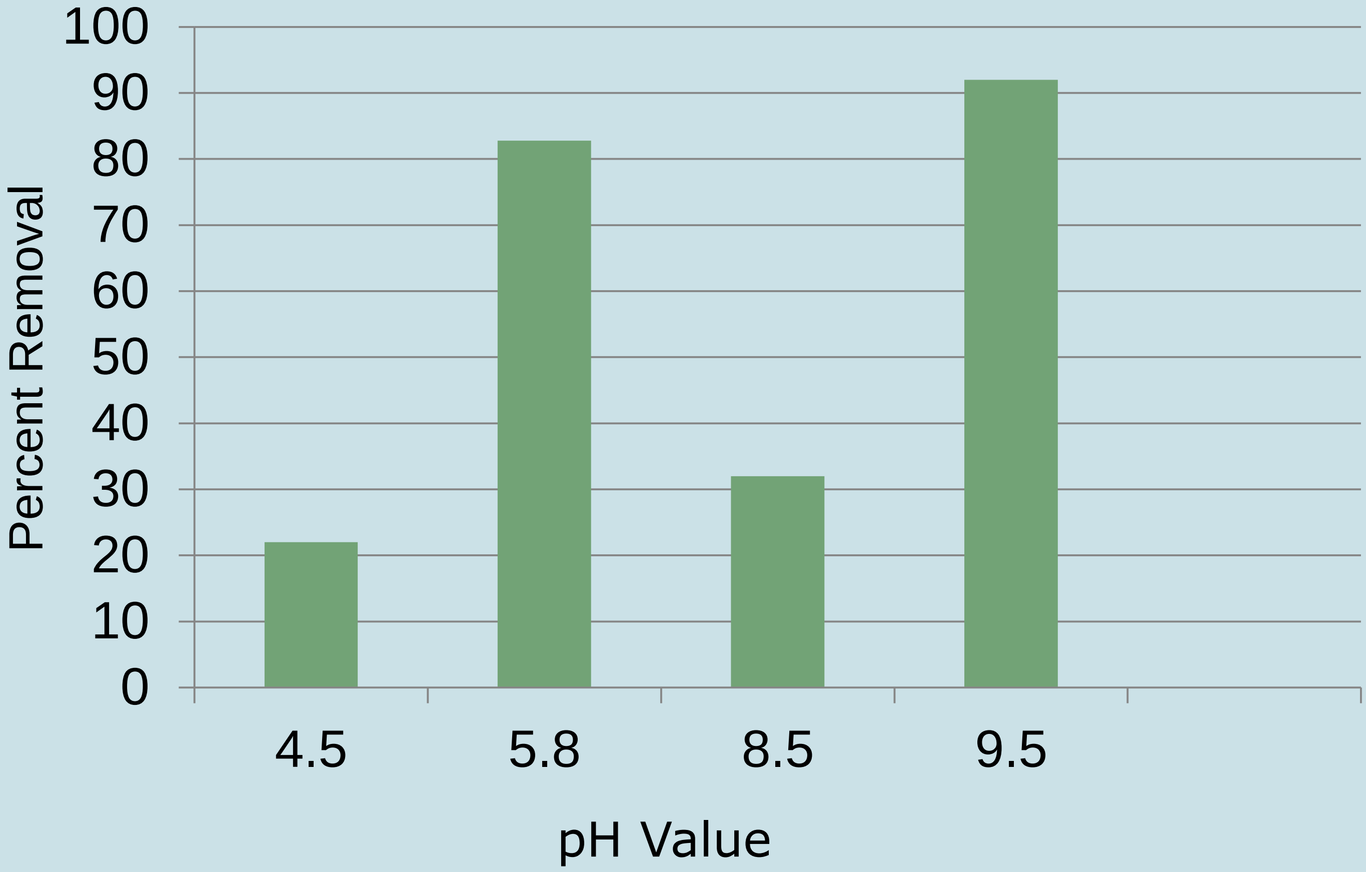


Fig (8): Comparison between removal of HMCs and Radioisotopes by NF and by coagulation.

Influence of pH of groundwater on Uranium removal by Coagulation { $Fe_2(SO_4)_3$ or $Al_2(SO_4)_3$ Coagulants }



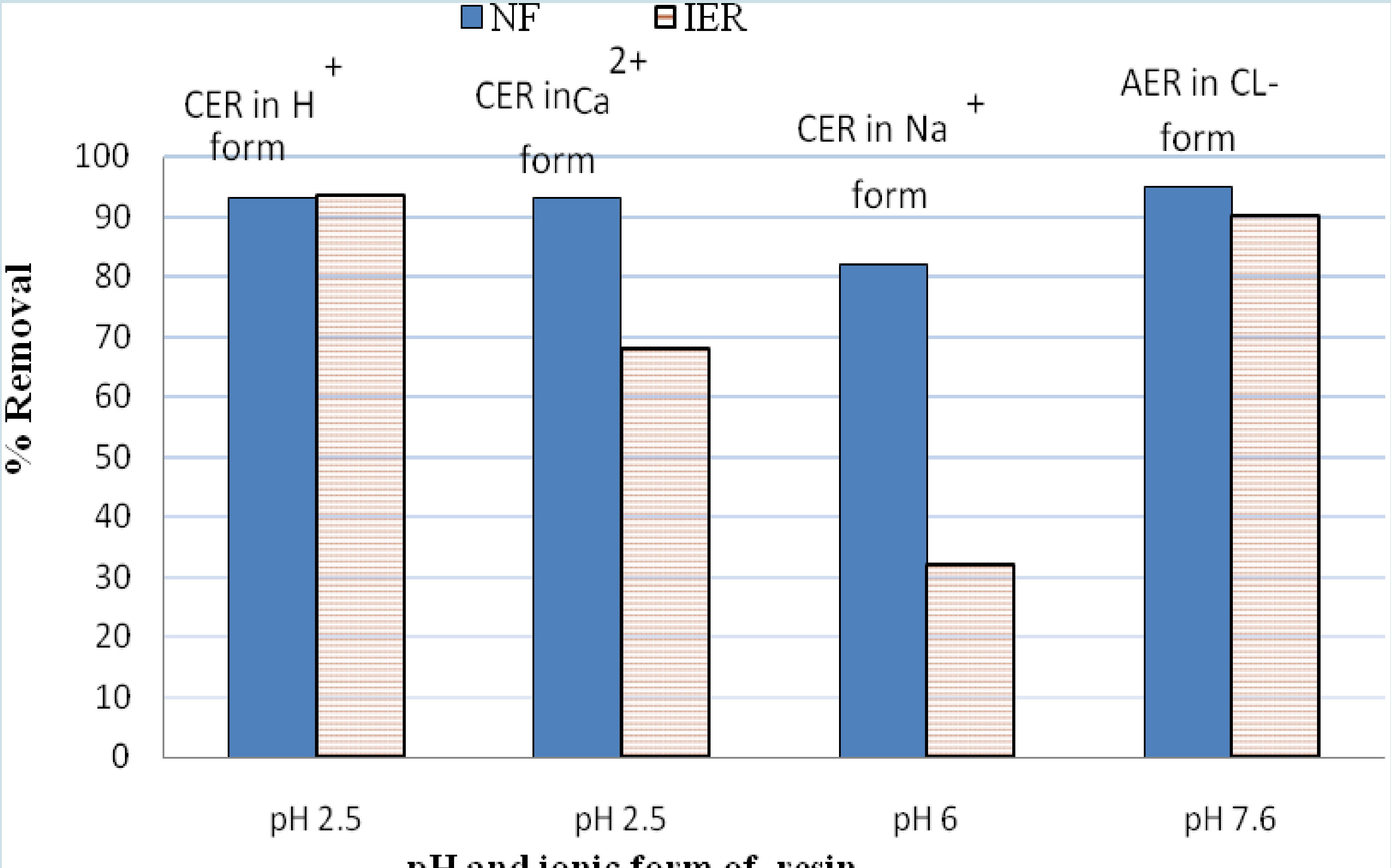
Problems of Removal of U-238 by Coagulation / Settling / Filtration

1. Separation of uranium by coagulation is highly dependent on case by case conditions like type and valence state of contaminant, water composition, pH, type and dose of coagulant.

2. Settling step upon coagulation is a slow step. Additives may be used for acceleration of settling.

3. Subsequent filtration is required.

4. No water desalination takes place parallel to decontamination.



Comparison between Removal of U238 by NF and IERs

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Processing of Desalination Reject Brine for Optimization of Process Efficiency, Cost Effectiveness and Environmental Safety

M. Gamal Khedr

Additional information is available at the end of the chapter

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1. Introduction

Reverse Osmosis (RO) is currently confirmed and generally approved as the most feasible technology for desalination of brackish groundwater being the most economic for its range of salinity over a wide range of production capacities, and in view of its lowest requirements of energy, and its application ease.

The currently acceptable norm of recovery of desalted water in projects of brackish water reverse osmosis (BWRO) ranges usually between 65 to 85 % according to raw water quality, level of chemical pretreatment and concept of plant design/operation, would it be intended to be a sophisticated facility of low operation cost or vice versa. The balance of 15 %, or above, the desalination reject stream in which the RO rejected components are concentrated, is disposed as a wastewater (WW). Among the disposal options selected to get rid of the desalination reject stream are: 1) Sewer stream, 2) Land application including percolation, 3) Deep well injection and, 4) Evaporation ponds. The last option is the most common in the Middle East in view of:

- The rather common high temperature
- The low ambient humidity
- The relatively low cost of land in desert areas

Disposal of RO reject water aims, in most of the alternatives, to just get rid of that stream without further water recovery which wastes the cost of initial pumping and chemical treatment. It is, therefore, evident that the increase of desalted water recovery is a main factor in determining the process cost effectiveness. On the other hand, a too high recovery would

Processing of Reverse Osmosis Reject Stream

1- In fact, after 85 % recovery, we reject to evaporation ponds the 15 % reject water of medium salinity of about 100 million m^3 /year and we desalt sea water of higher salinity while RO reject is already filtered and sanitized. We investigated further processing of desalination reject in brackish water RO plants,

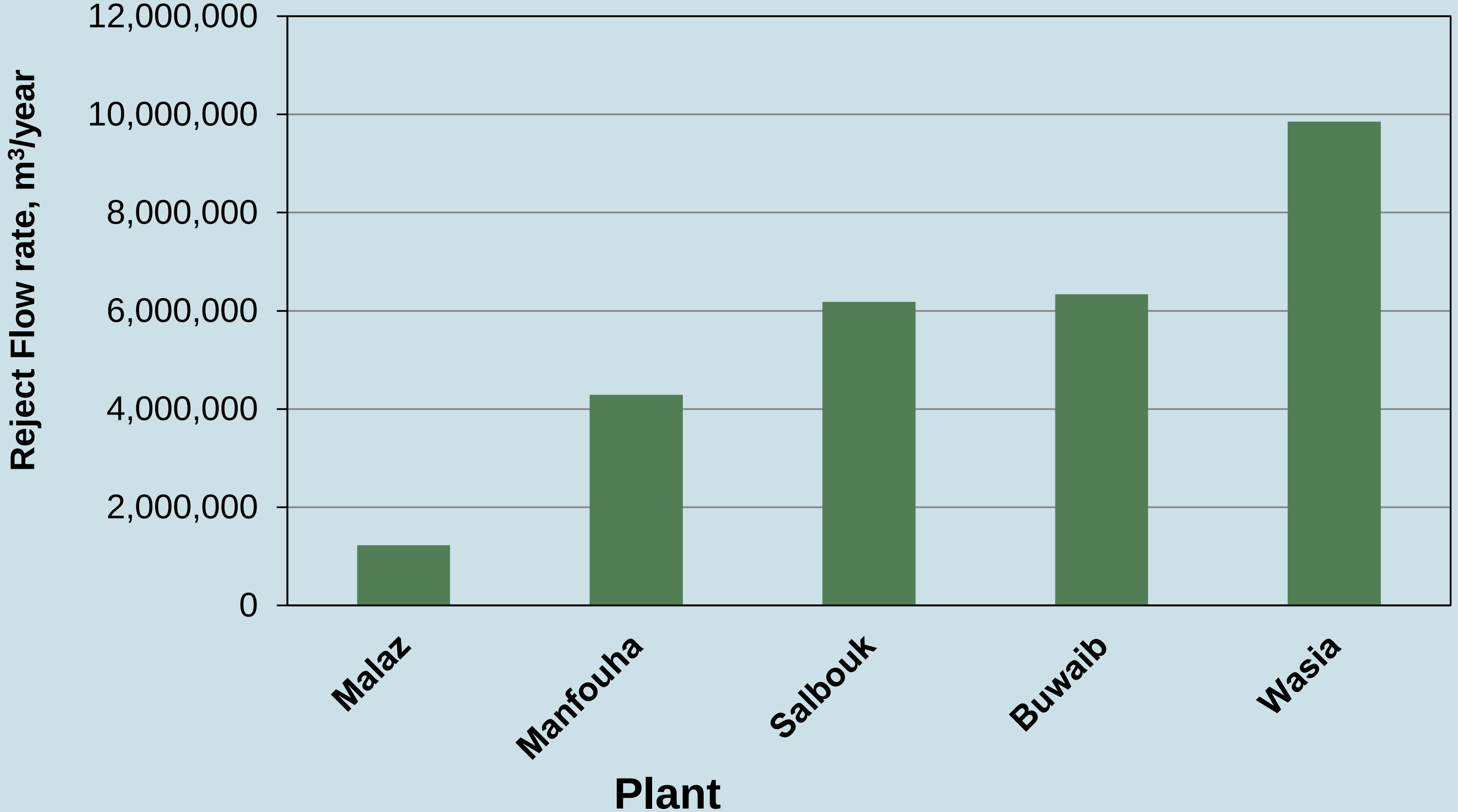
2- Processing is done by an independent RO unit or in already present plant where there is no place for new units, processing is done by recycling reject in the low pressure feed stream to raise % recovery and decrease ground raw water consumption.

3- Processing increased production of permeate water and % recovery was shown to attain > 95%.

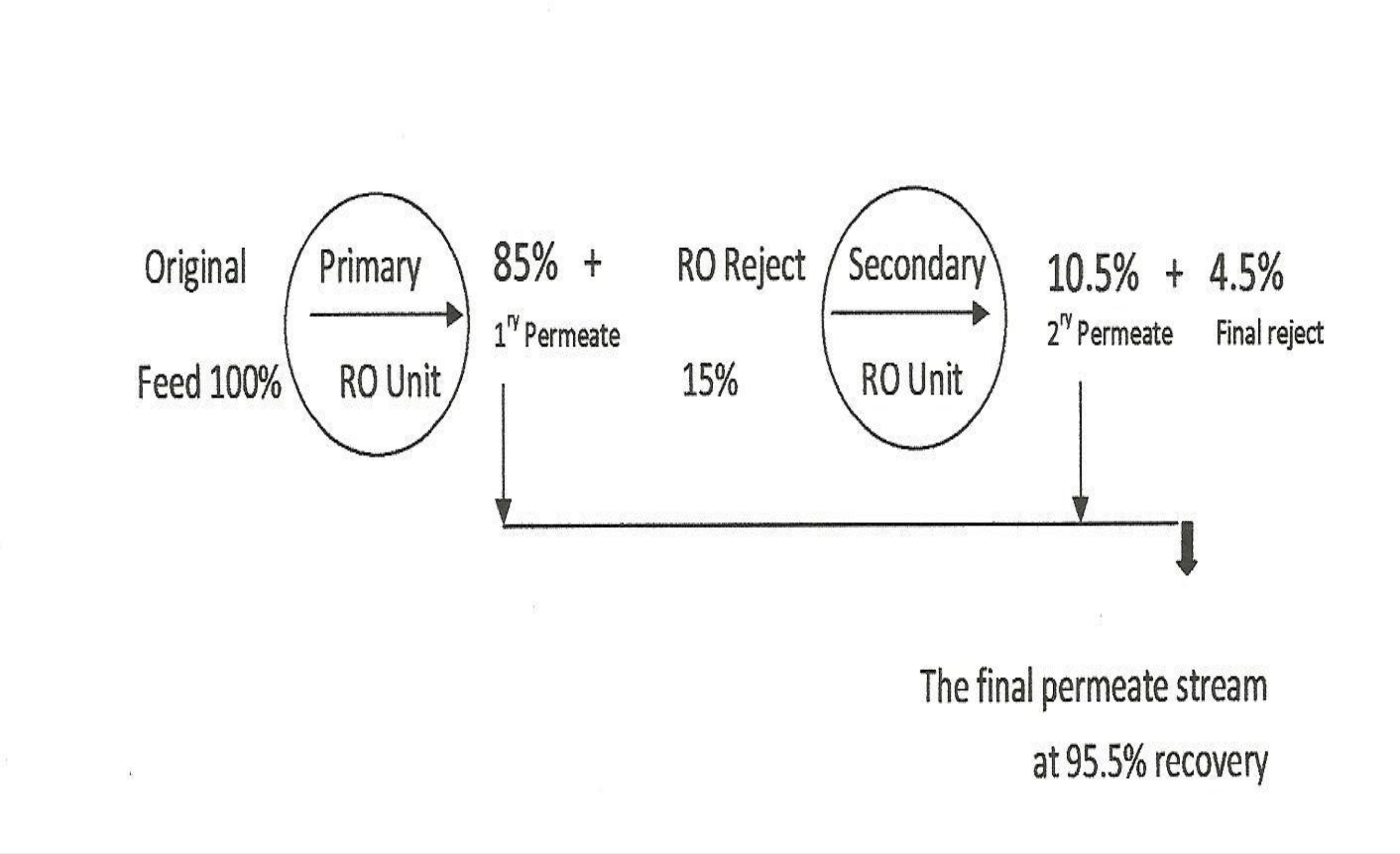
4- The secondary RO permeate of slightly higher TDS than the primary one, but since its amount is much smaller only insignificant increase of the total permeate is observed.

5- Reject processing lowered to the third the surface area of the evaporation pond which decreases cost of installation and maintenance and promotes environmental safety.

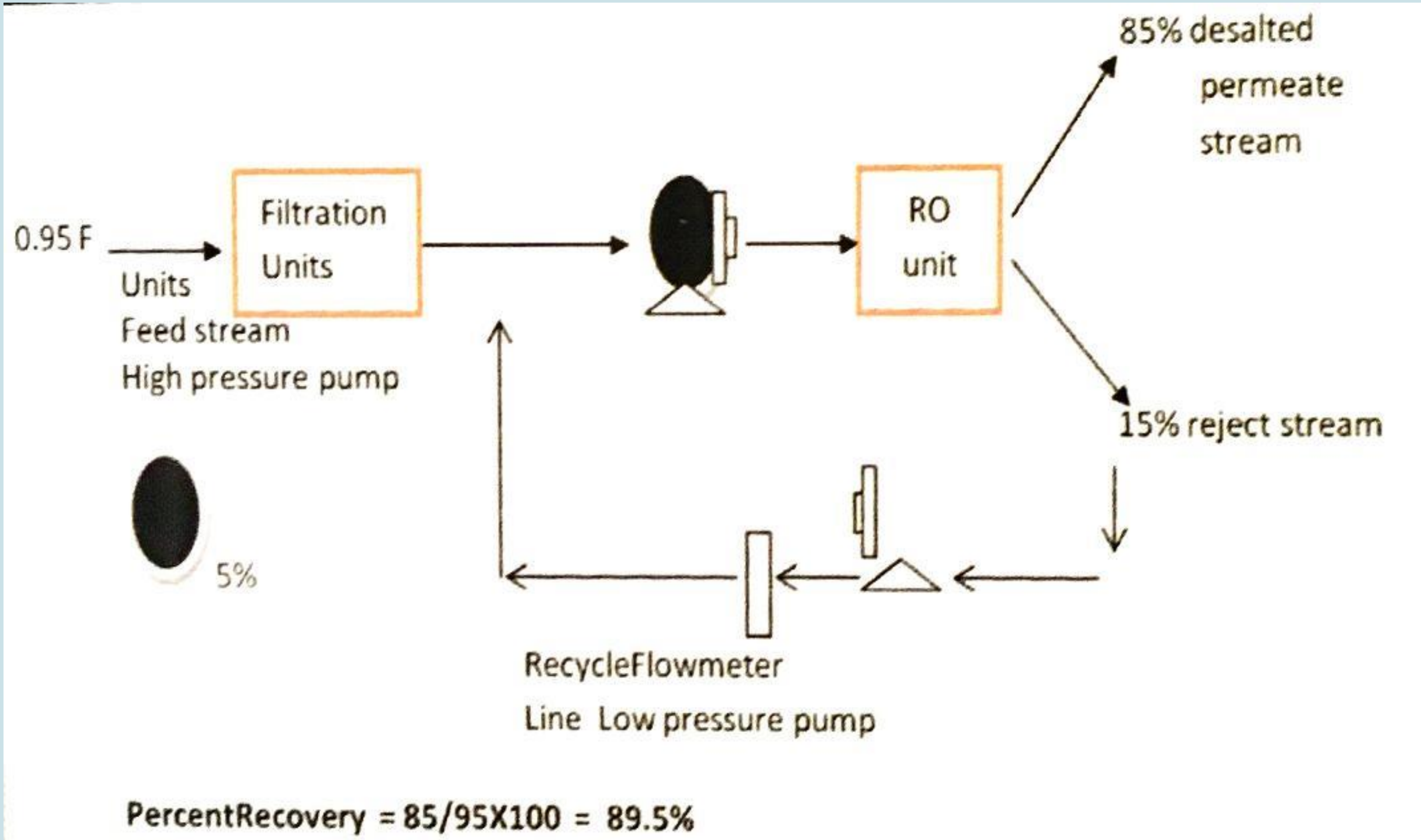
Design Reject Flow Rate (m^3/Year)



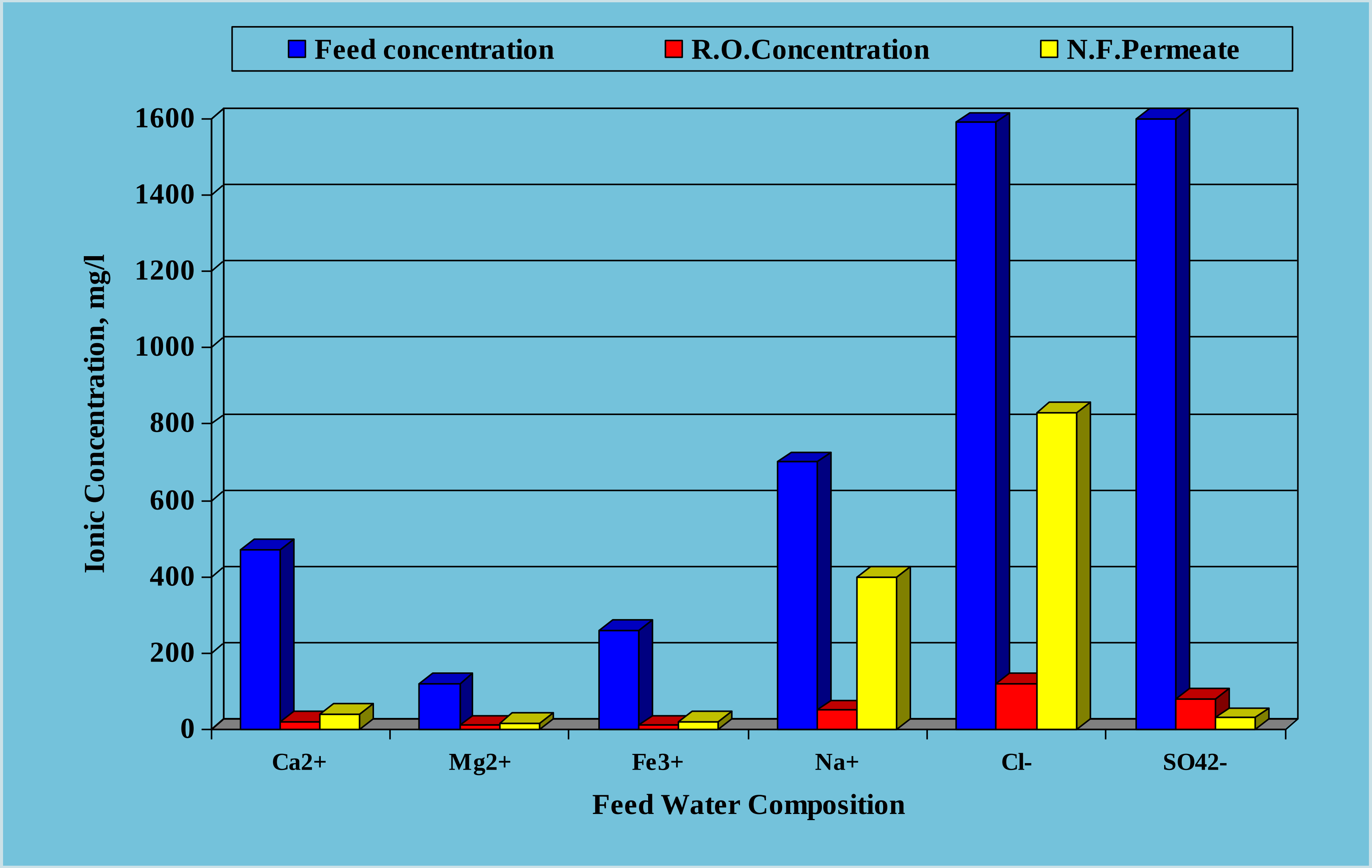
Processing of Primary RO Reject by Secondary RO



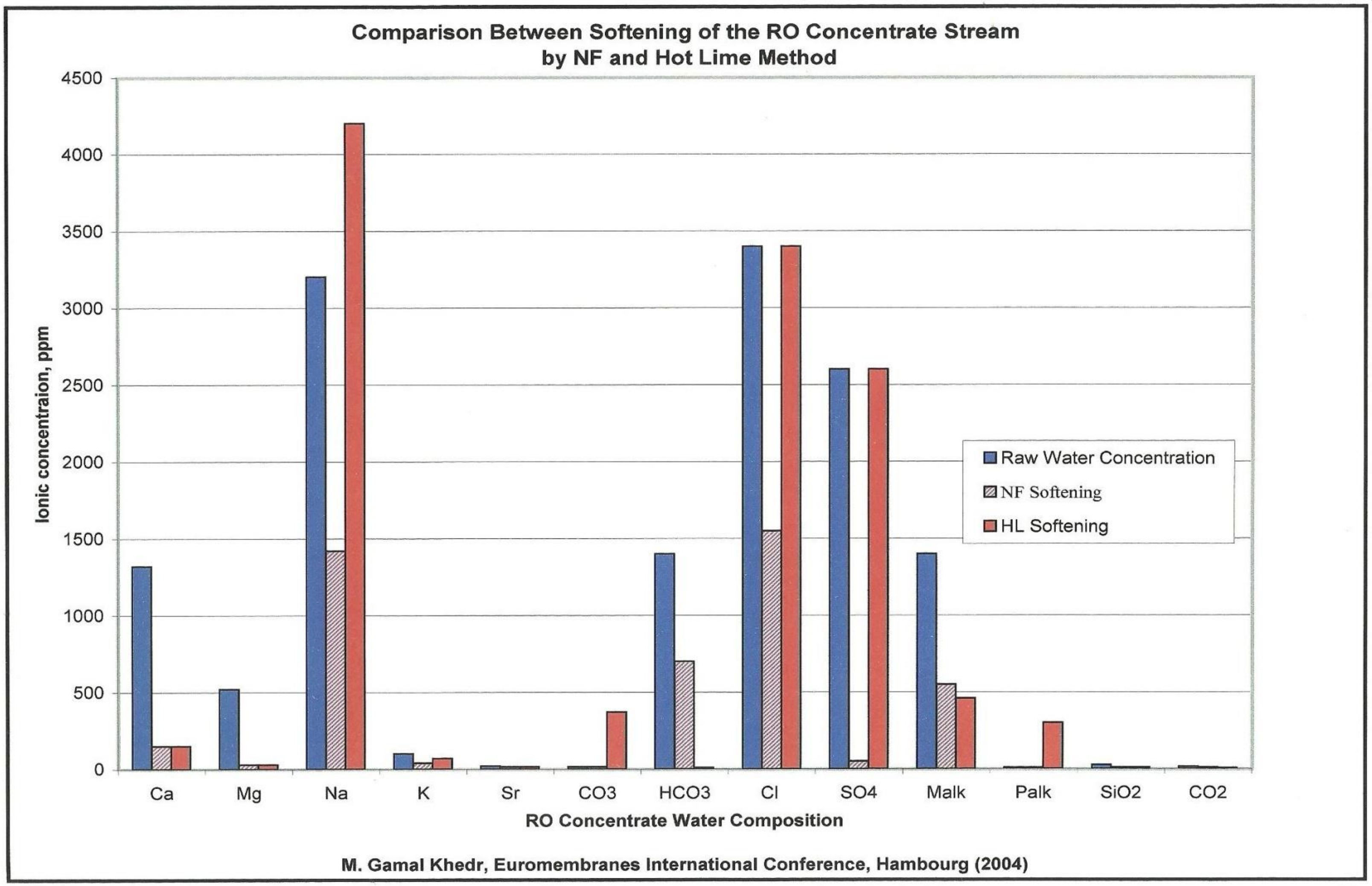
Processing of Desalination Reject by Recycling



Comparison between Individual Ionic Rejection by RO and NF in Salt Mixture Solution



M.Gamal Khedr, Euromembranes International Conference, Hamburg (2004)


Comparison Between Softening of the RO Concentrate Stream
by NF and Hot Lime Method
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Ionic concentraion, ppm
Raw Water Concentration
NF Softening
HL Softening
Ca
Mg
Na
K
Sr
CO3
HCO3
Cl
SO4
Malk
Palk
SiO2
CO2
RO Concentrate Water Composition
M. Gamal Khedr, Euromembranes International Conference, Hambourg (2004)

Advantages of NF rejection of contaminants over removal by HLS

1- Parallel water desalination.

2- No continuous chemical dosing stoichiometric to rejection is required and consequently no sludge formation which is contaminated and represents a disposal problem.

3- Do not require increasing of pH for removal of SiO_2 on which also Mg is adsorbed.

4- No slow steps like settling are included in NF mechanism.

5- No subsequent filtration is required.

6- In case of HLS, efficient decontamination requires high chemical dosing and bigger softening installations .

7- Trace radionuclides are rejected parallel to other species without interference.

Nanofiltration Pretreatment of SWRO Feed Stream
Ummlujj NF/RO project by SWCC

1. Ahead of RO unit, NF pretreatment removes at a high efficiency most of problem making components from the feed stream:
   - Scale forming ions (hardness components) and Silica.
   - Organic substances.
   - Colloidal particles, organic and inorganic.
   - Suspended matter (TSS).
   - Microorganisms (bacteria and Algae).

2. The RO pretreated feed stream with high rejection of the fouling components enables the subsequent RO process to be realized at a higher recovery (60 to 65 %) i.e., at higher process efficiency.

3. Rejection of hardness components by NF enable to attain such high RO recovery without need of antiscalant dosing.

4. The parallel partial desalination of the feed stream by NF enables better TDS rejection by RO at lower feed pressure.

5. The rate of shutdown of RO for maintenance is much lowered after NF pretreatment and more steady operation is realized.

6. NF pretreatment enables already existing RO plants to promote the total process efficiency without additional investment in increasing intake and pretreatment systems.

High Temperature Reverse Osmosis and Control of Membrane Fouling

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Summary

High temperature reverse osmosis, HTRO, would be of economic interest for hot countries or generally any case where the feed water is hot and needs, otherwise, to be cooled before treatment. Saving in system and energy consumption are expected.

The present work has investigated the RO performance at high temperatures in the range of 30-65^{o}C, in feed water of various compositions through periodical examination of the membrane surface by SE microscopy, analysis of the fouling deposit by Energy Dispersive X-ray and Fourier Transform Infra red Spectroscopy. The influence on tendency of scale deposition and extent of biofouling, the latter being specially important at high ambient temperatures, have been determined.

The RO operation at high temperatures with different thin film membranes, led to parallel acceleration of the product flux, Jv, according to an Arhenius type relation. Jv varies linearly with the reciprocal of membrane thickness in conformity with the Solution and Diffusion Model.

In case of single salt solutions, the increase of feed temperature results in a rather linear decrease of salt rejection, at a lower rate the higher the ion valencies. In mixed salt solutions, on the other hand, beyond a definite temperature the acceleration of Jv, which dilutes the product stream, overcomes the decline of salt rejection. The knowledge of the feed composition would enable the selection of the correct temperature range of HTRO for the optimum product rate and rejection performance.

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• جانب من وحدات التبريد بمحطة مياه صلبوخ

High Temperature Reverse Osmosis

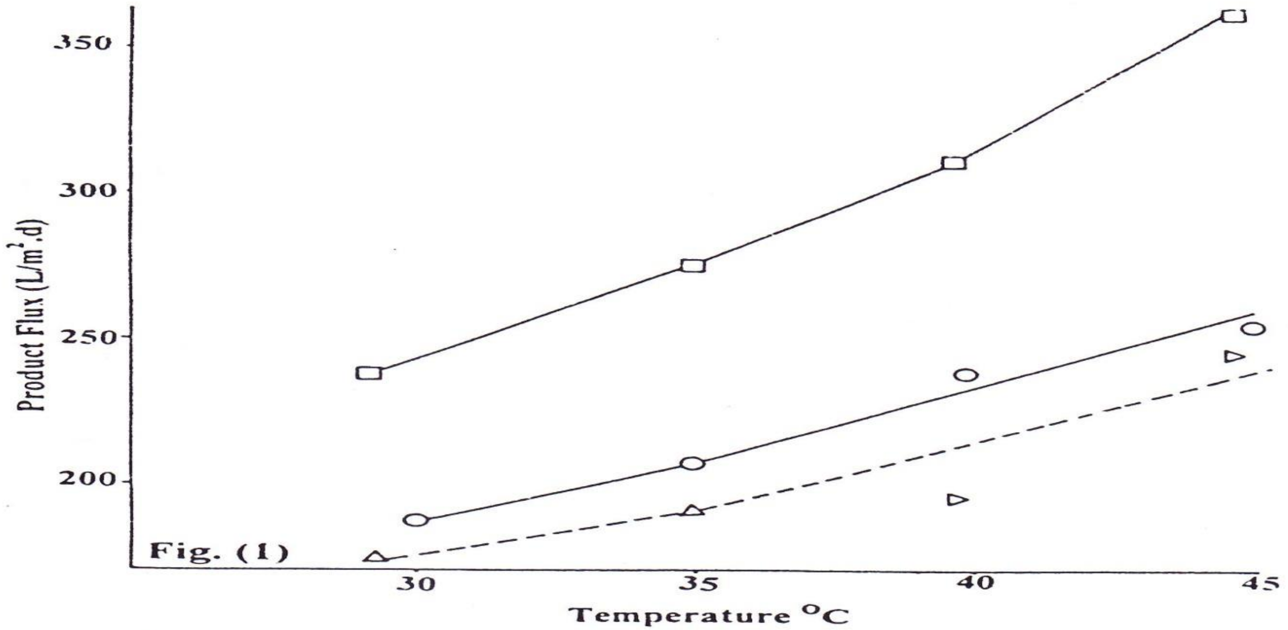


Fig. (1)

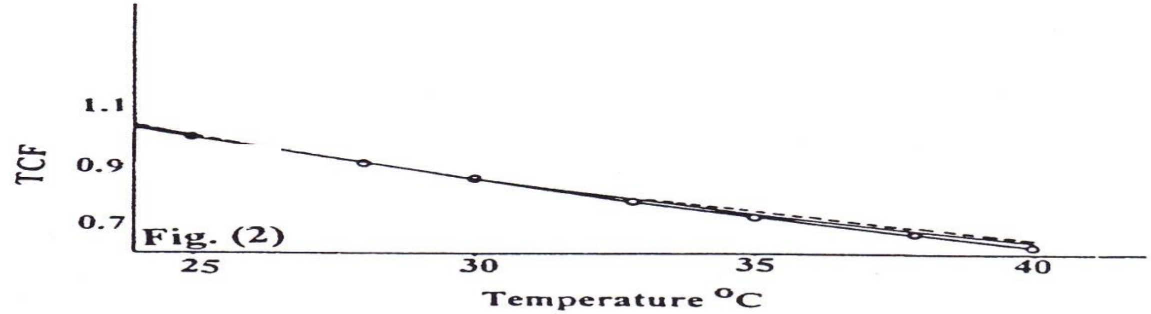
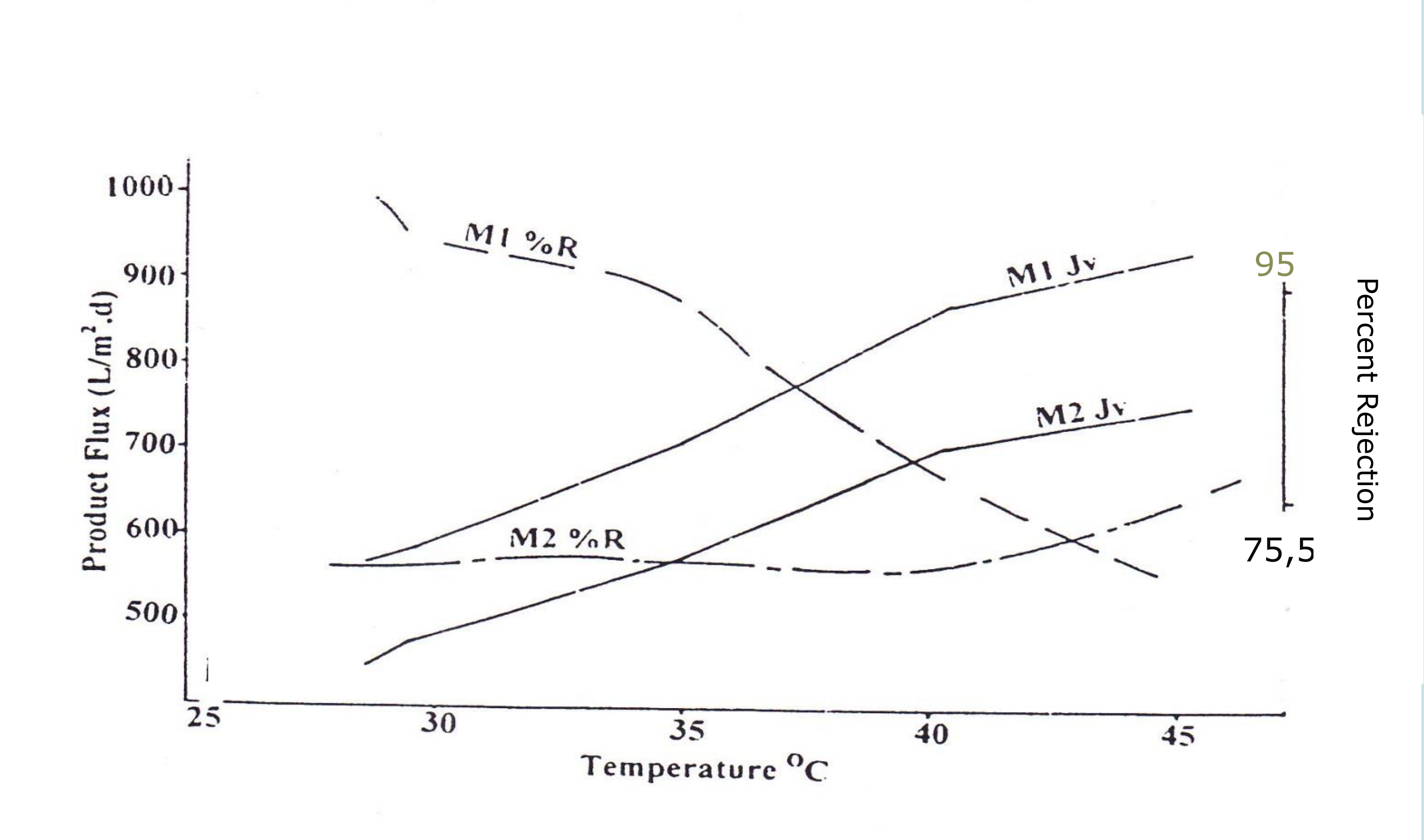
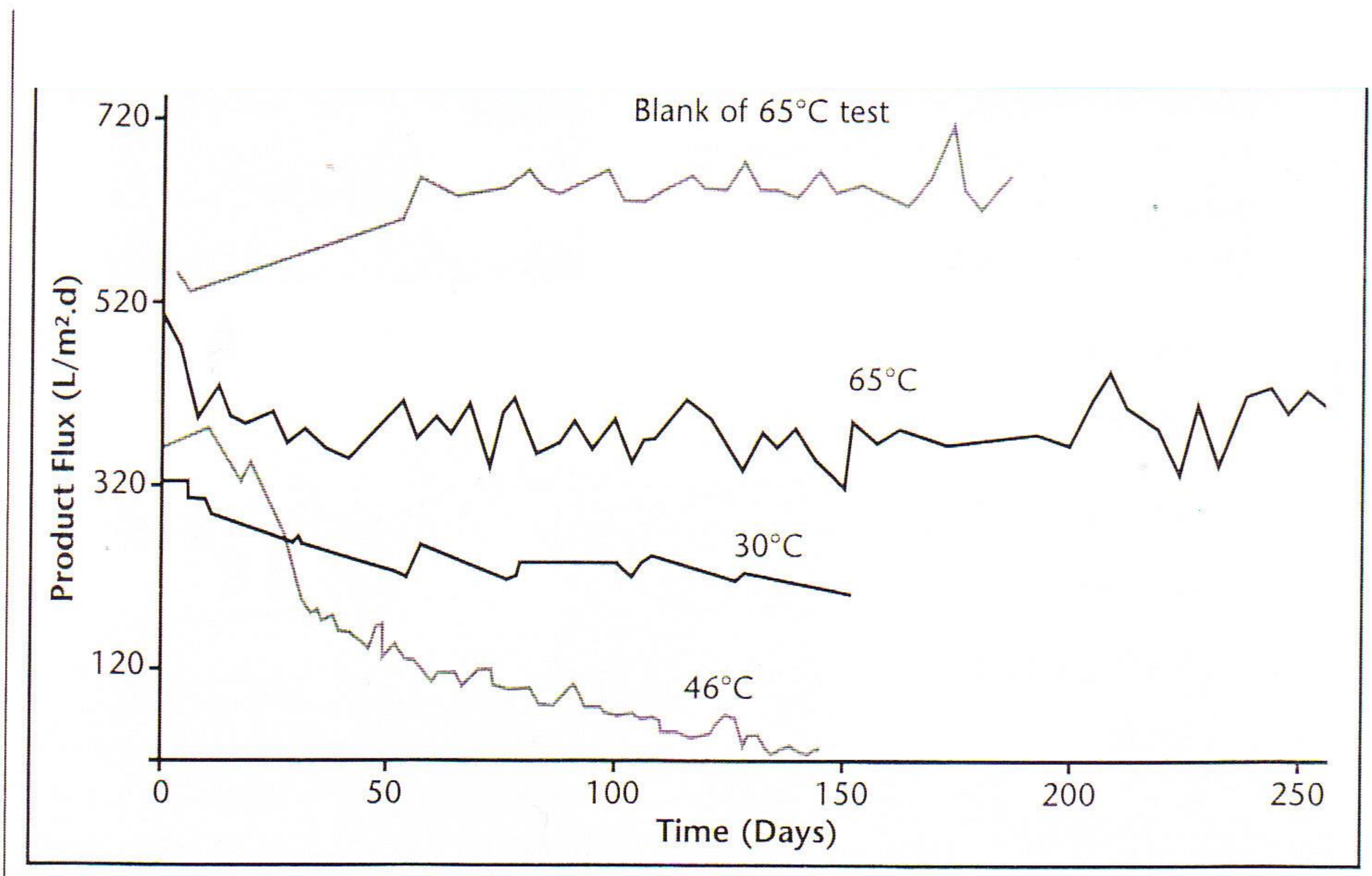


Fig. (2)

High Temperature Reverse Osmosis



High Temperature Reverse Osmosis, Control of Biofouling



Typical Analysis of Oil Field – Produced Water

Table 1
Typical analysis of PW (ppm)

Components	Concentration	Components	Concentration
K	472.86	NO_3	–
Na	30,807.64	Cl	52,190.39
Mg	2,908.47	SO_4	7,087.5
Ca	874.57	Suspended solids	20.2
Sr	9.51	Free oil droplets	120.4
Ba	5.371	Dissolved organics (including hydrocarbon and soluble oil)	268.2
Cu	0.74	SiO_2	134.36
Ni	1.13	pH	8.7
CO_3	530.71	TDS	96,472.6
HCO_3	954.08	Uranium 238	12.5 ppb

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Nanofiltration of oil field-produced water for reinjection and optimum protection of oil formation

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ABSTRACT

In view of the increasingly stringent norms of disposal of effluent from petroleum activities and interest in water conservation, the treatment of the oilfield-produced water (PW), the largest wastewater (WW) stream associated with oil and gas industry in the Suez Gulf, was investigated for injection in the oil formation to enhance oil production and other environmental-friendly reuse purposes. Long-term laboratory and pilot testing of treatment of PW and Gulf water (GW) by coagulation/filtration and coagulation/filtration/nanofiltration (NF) aimed to avoid blocking of the porous oil formation upon injection and to inhibit the detected corrosion and biomass accumulation on the internal wall of the injection piping, which was shown to re-contaminate the treated injection water. Analysis of PW showed the concentrations of TDS, organics including hydrocarbons, oil droplets, sulfate, silica, Boron, and suspended solids (SS) of 96472.6, 268.2, 120.4, 7087.5, 134.4, 29.3, and 20.2, respectively. The high sulfate content of both PW and GW would explain the observed hardness scale, on the well casing and pipelines. Only trace concentrations of U_{238} as complex carbonates and heavy metals as copper, vanadium, nickel, and lead were detected in GW. The thick biofilm detected inside the injection pipes consists of biomass of 92% water, extracellular polymer substance (EPS) of mainly anaerobic sulfate-reducing bacteria (SRB) of 1.8×10^9 MPN/gm, and iron compounds due to steel corrosion. The dry film includes high concentrations of iron, sulfur, and a remarkably high radioactivity of uranium 238 of 6,740 pCi/gm, heavy metals such as copper, chromium, lead, and vanadium at concentrations much higher than in GW. Results confirmed that SRB enzymatically reduced the trace uranium and the other soluble cations in PW and concentrated them in the biofilm with parallel depolarization of the cathodic-controlled corrosion of steel to produce ferric sulfide and other iron compounds. Coagulation of PW efficiently removed SS, organics including hydrocarbons and oil. Only partial removal of uranium took place, which was too pH dependent. However, since coagulation did not suppress the biofilm formation and the related phenomena of microbial corrosion and accumulation of radioactivity, the release of these components recontaminated the treated PW. On the other hand, the proposed process of "intermittent chlorination/coagulation/NF" of PW efficiently rejected sulfate, uranium, and other metal cations and polished the removal of SS, bacteria, and organics. This process inhibited the formation of scales and biofilm as well as the related undesirable phenomena and, therefore, stopped the recontamination of the PW prior to injection. Only poor

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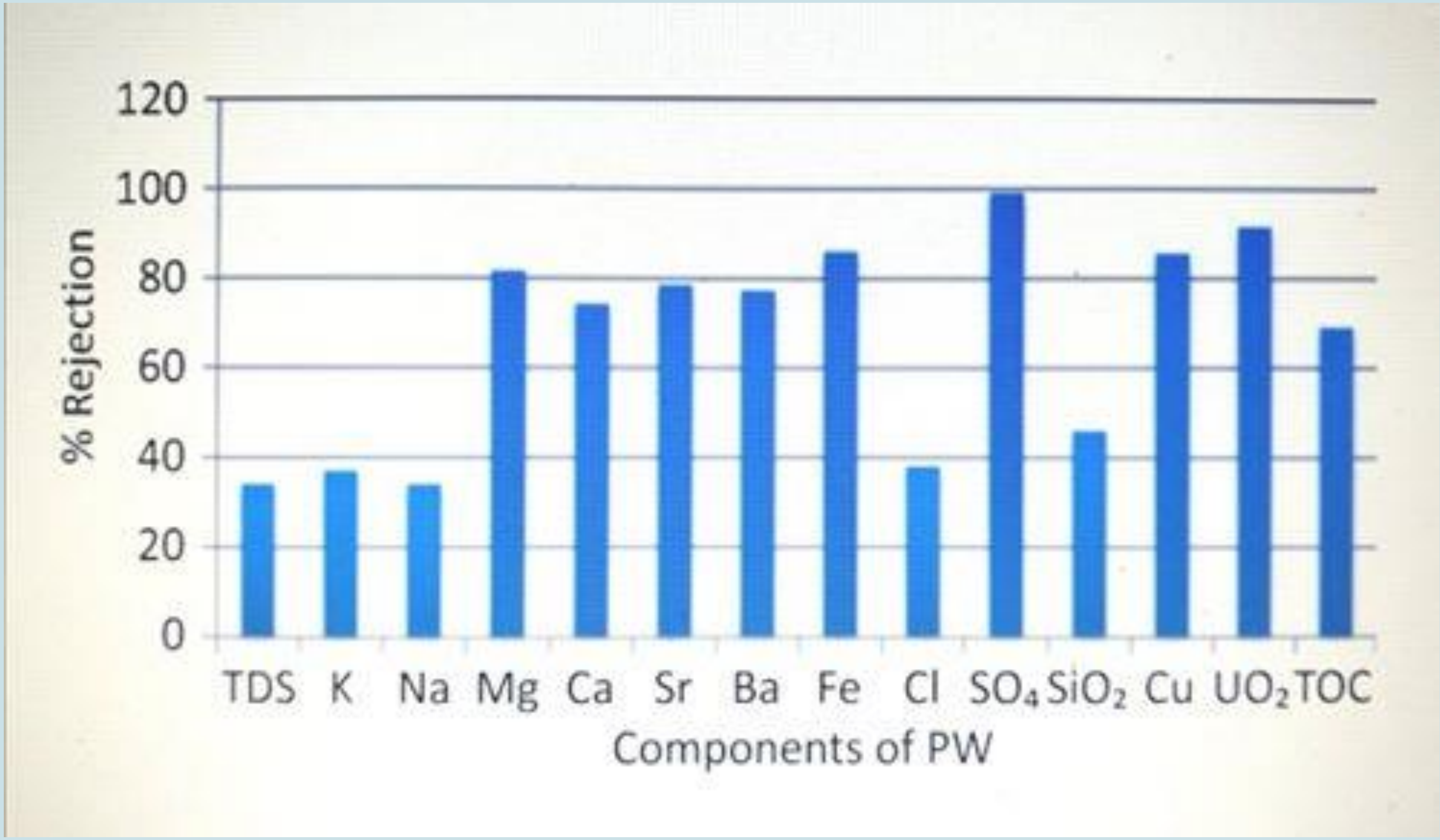
Nanofiltration gives efficient rejection of different contaminants in oil field produced water



M. Gamal Khedr, Nanofiltration of oil field produced water for reinjection and optimum protection of oil formation,,jounal of Desalination & Water Treatment(2014),1-9.

Innovations in SWRO membranes and plants (Sorek plant)

A 25 year BOT SWRO plant of 624,000 m^3/d, the world largest SW desalination plant.

Technical features which contributed to the low production cost of 0.5 €/m^3 are selected based on scientific research and pilot testing.

1- 16 inch RO elements and pressure vessels of local manufacture. Membranes give 4.3 times larger flow rate than 8 inch ones at the same feed pressure and operating conditions.

2- Innovative design of vertical fixing of pressure vessels which adds gravity effect to the efficiency of agitation at the membrane surface.

3- To reduce chemicals dosing micro organisms are removed by use of volcanic lava rocks filters.

4- The plant is designed with energy recovery devices throughout the desalination process.

5- Corrosion of intake structure is inhibited by cathodic protection.

Sorek Reverse Osmosis Plant

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Graphene membrane network