MINI REVIEW OF MEMBRANE TECHNOLOGY IN WATER AND WASTEWATER TREATMENT

استعراض مختصر لتكنولوجيا الأغشية في مجال معالجة المياه ومياه الصرف الصحي

FOUAD AL SALEH
& KHALED AL DHOWALIA Co.
ENGINEERING CONSULTANTS

شركة فؤاد الصالح وخالد الضويلع
للاستشارات الهندسية

المديرية العامة للمياه بمنطقة القصيم

4 جماد الأولى 1435
5 مارس 2014

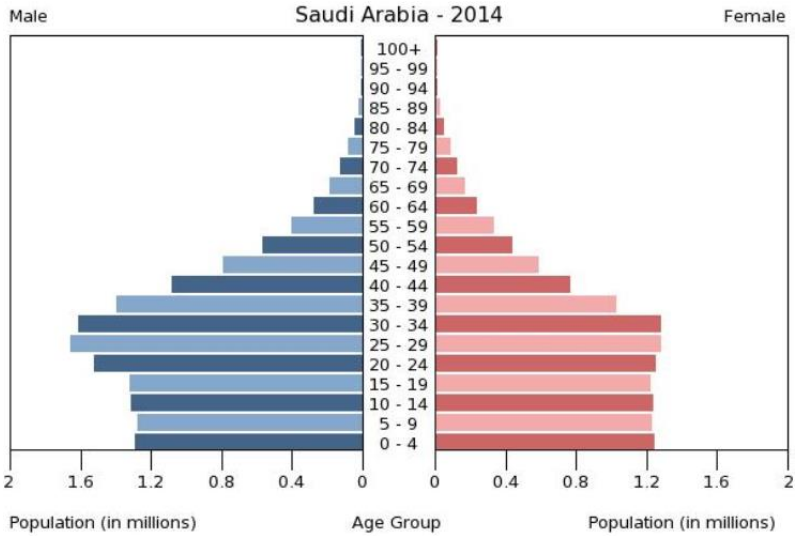
Increasing Population

Age Structure for SA

28.2% (0-14 yr)

19.6% (15-24 yr)

Source: CIA World Factbook

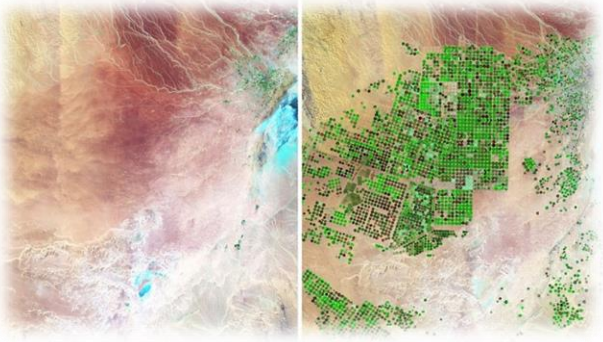


As we develop we need WATER

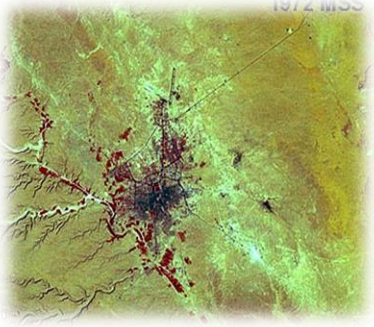
Economic Growth

Water is Priority

Agricultural Practices



Urbanization



We have two options only to get water:

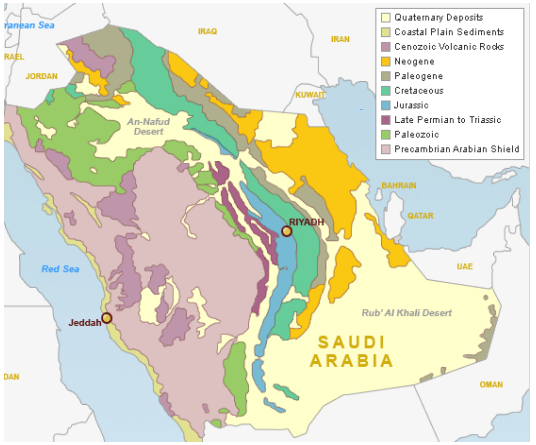
Through Membrane

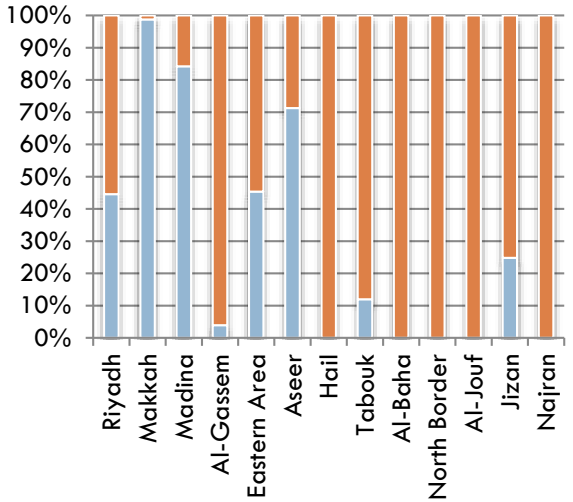
Or

Through Distillation

Water Sources in Saudi Arabia

- **Groundwater** (deep/shallow wells)
  - May contain Ca^{++}, Mg^{++} (hard water), iron & manganese, Radionuclide, etc.
- **Seawater**
  - TDS > 40,000 mg/L.
  - More affordable to costal cities.
- **Reclaimed Wastewater**
  - Can be used in industry, agriculture, and for some municipal applications (irrigation, toilet flushing, etc.)
- **Rainwater harvesting**
  - Can be found in some of South-Western region of Saudi Arabia.





Water Salinity Classification

Type of Water	TDS, mg/l	Example
Fresh water	< 1,000	lakes, rivers, ponds, streams, groundwater
Brackish water	1,000 – 30,000	groundwater, brackish lake, estuaries
Brine water (seawater)	> 30,000	seawater, salt lakes, brine pools

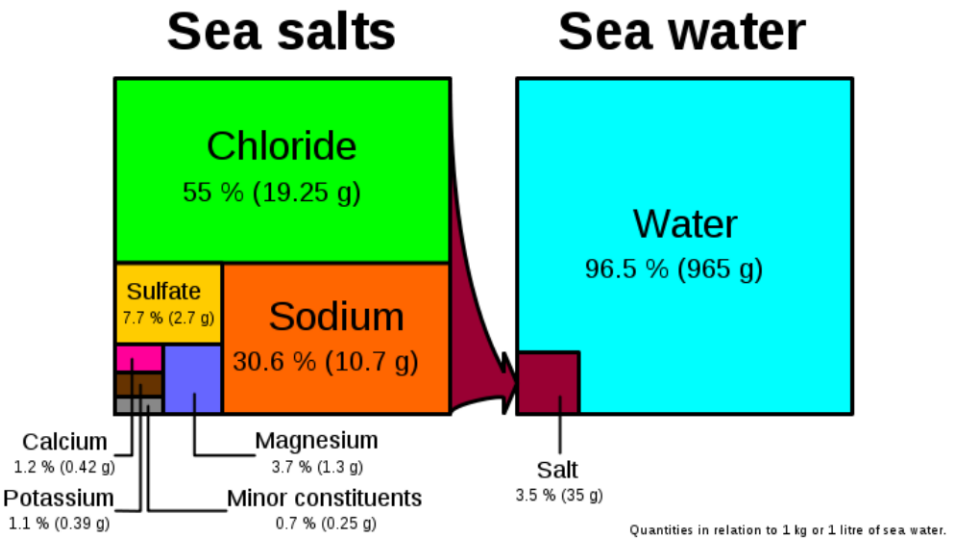
Source: ASTM D1129-02a, Standard Terminology Relating to Water

Concentrations of salt ions in seawater & groundwater

Parameter	Seawater	Groundwater
TDS (mg/L)	40,000 – 45,000	500 – 20,000
Monovalent	80 – 90 %	10 – 20 %
Multivalent	10 – 20 %	80 – 90 %

Cl, Na, …

Ca, Mg, SO_4, …



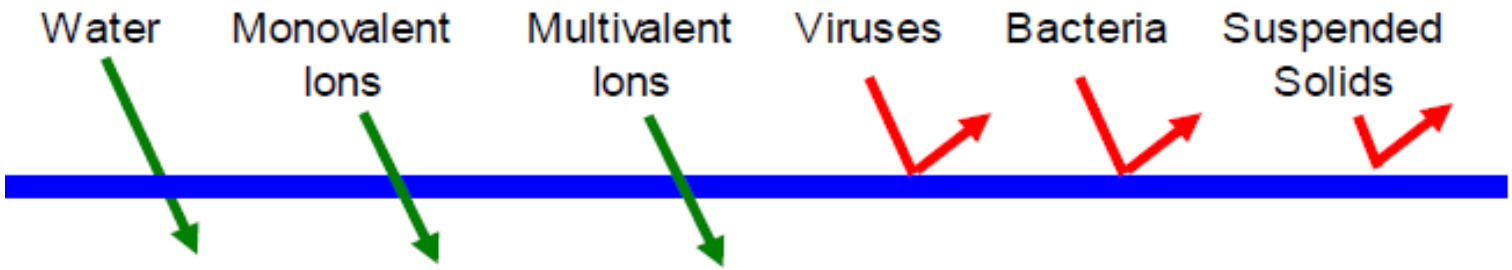
TDS (mg/L)

Red Sea: 41,000–42,000

Arabian Gulf: 42,000–45,000

What is Membrane

Selective barrier that allows entities to pass through while **restricting** the passage of others



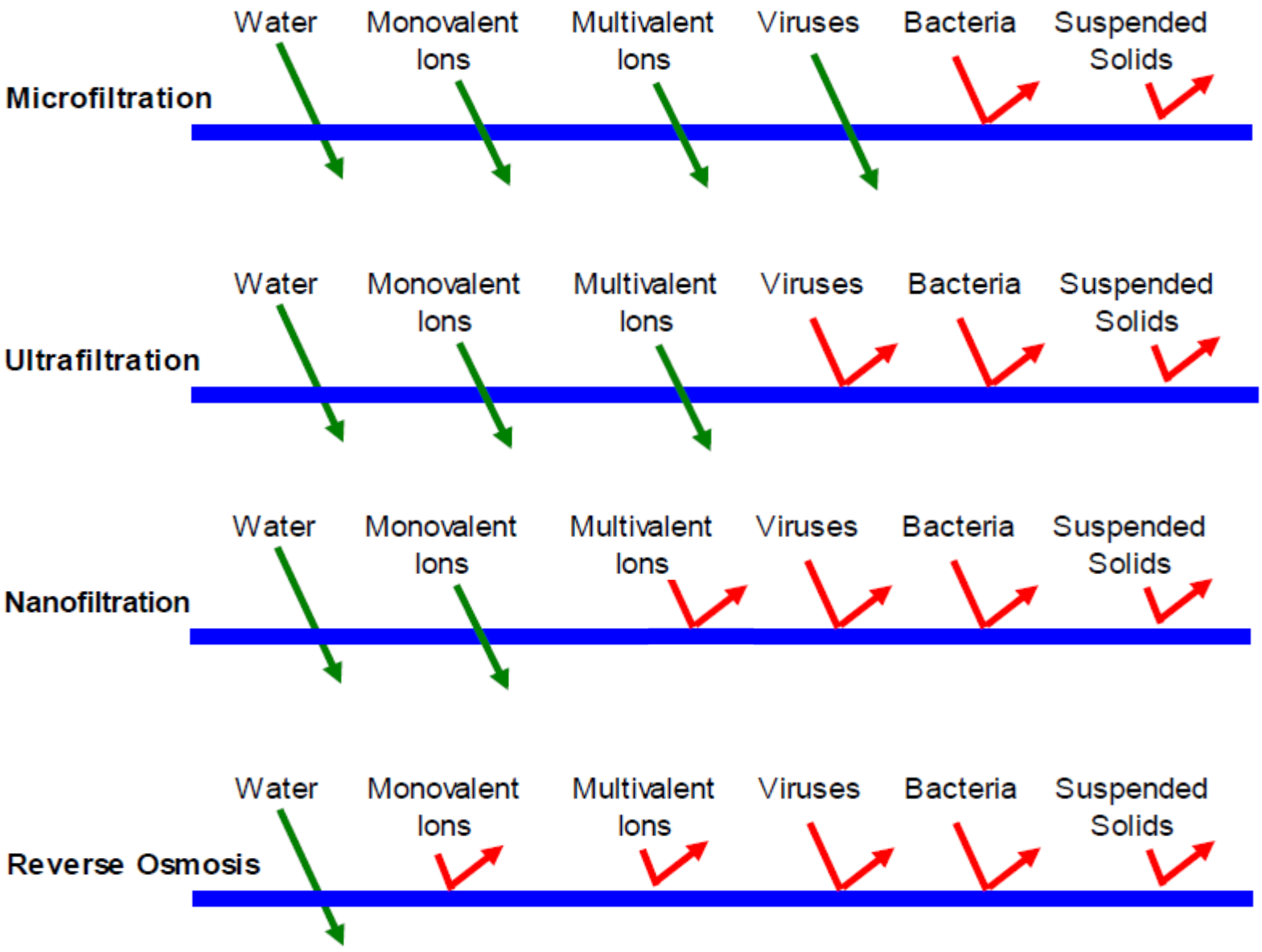
What membrane reject and what it pass are depend on pore size of membrane

Classification of Membrane Driving Force Classification

Pressure Driven Membrane	Diffusional Membrane	Electrical Membrane
• Microfiltration • Ultrafiltration • Nanofiltration • Reverse Osmosis	• Dialysis • Pervaporation (PV) • Fuel Cells	• Electrodialysis Reversal (EDR) • Electrodeionization
Hydraulic pressure	**Concentration**	**Electric potential**

Membrane pore size classification for Pressure Driven Membrane

Filtration class	Smallest particle capture size	Typical contaminants removed	Operating pressure ranges
Microfiltration (MF)	0.1 µm	suspended solids, bacteria, protozoa	0.1-2 bar
Ultrafiltration (UF)	0.01 µm	colloids, proteins, polysaccharides, most bacteria, viruses (partially)	1-5 bar
Nanofiltration (NF)	0.001 µm	viruses, natural organic matter, multivalent ions (including hardness)	5-20 bar
Reverse osmosis (RO)	0.0001 µm	almost all impurities, including monovalent ions	10-100 bar


Microfiltration
Water
Monovalent Ions
Multivalent Ions
Viruses
Bacteria
Suspended Solids
Ultrafiltration
Water
Monovalent Ions
Multivalent Ions
Viruses
Bacteria
Suspended Solids
Nanofiltration
Water
Monovalent Ions
Multivalent Ions
Viruses
Bacteria
Suspended Solids
Reverse Osmosis
Water
Monovalent Ions
Multivalent Ions
Viruses
Bacteria
Suspended Solids

Membrane Material

- **Organic**
  - Cellulosic membrane
    - Cellulose Acetate (CA)
  - Polymeric membrane
    - **Polysulfone (PS)**
    - Polyethersulfone (PES)
    - Polyvinylidene fluoride (PVDF)
    - Polyacrilonitile (PAN)
    - Ploypropylene (PP)
    - Polyethylene (PE)
- **Inorganic**
  - Ceramic membrane (TiO_2, Al_2O_3 , ZrO_2, SiO_2)
  - Stainless steel
- **Organic-Inorganic hybrid**

Remarks about membrane material

- Most membrane materials are organic polymers.
- Polysulfone membrane are most widely used because of
  - high tolerance to pH,
  - resistance to oxidants,
  - can withstand temperatures up to about 75 °C.
- Organic polymers membrane they must be **stored wet** or be filled with a wetting agent.

Comparison between ceramic & polymeric membranes

Ceramic membranes	Polymeric membranes
More resistant to chemical	Less resistant to chemical
Thermal resistant	less resistant to high temperature
high permeation	Low permeation
Require lower pressure	Require high pressure
High mechanical strength	Low mechanical strength
Longer lifespan	Shorter lifespan
Can not remove dissolved ions	**Can remove dissolved ions**
High capital cost	**Low capital cost**

Membrane Forms & Modules

- Tubular membrane
  - Tube capillary module
  - Hollow fiber module

- Flat membrane
  - Plate module
  - Spiral wound module
  - Disc module

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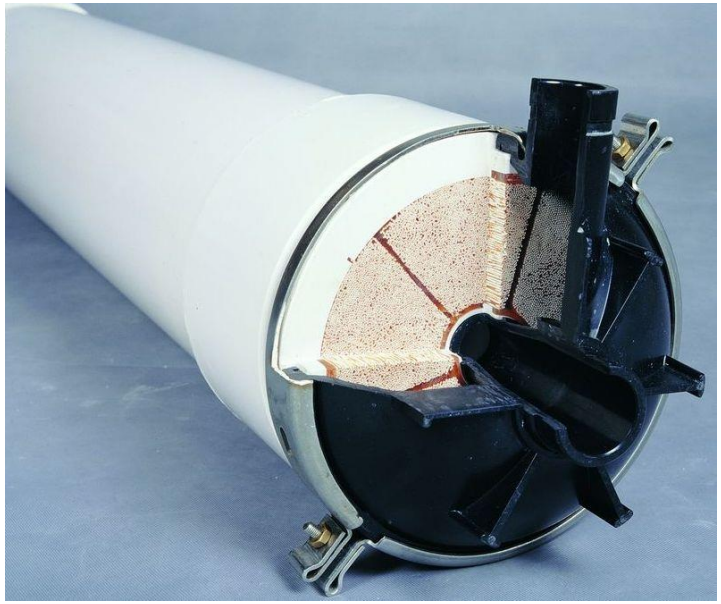

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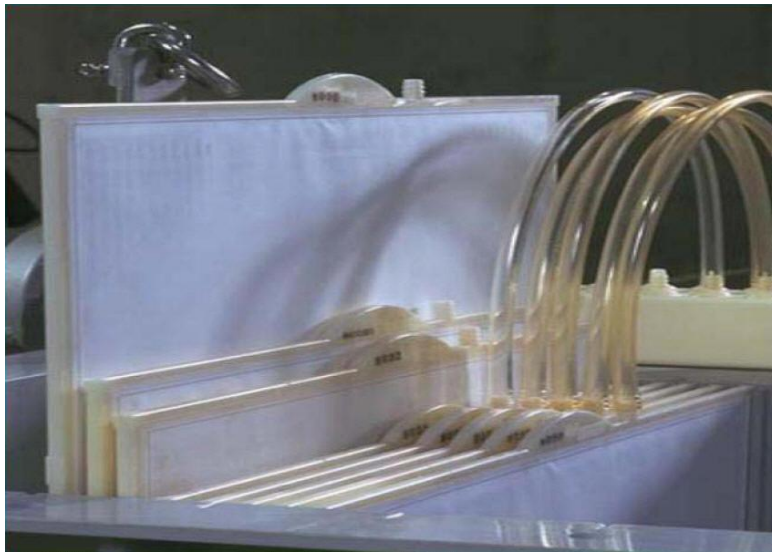

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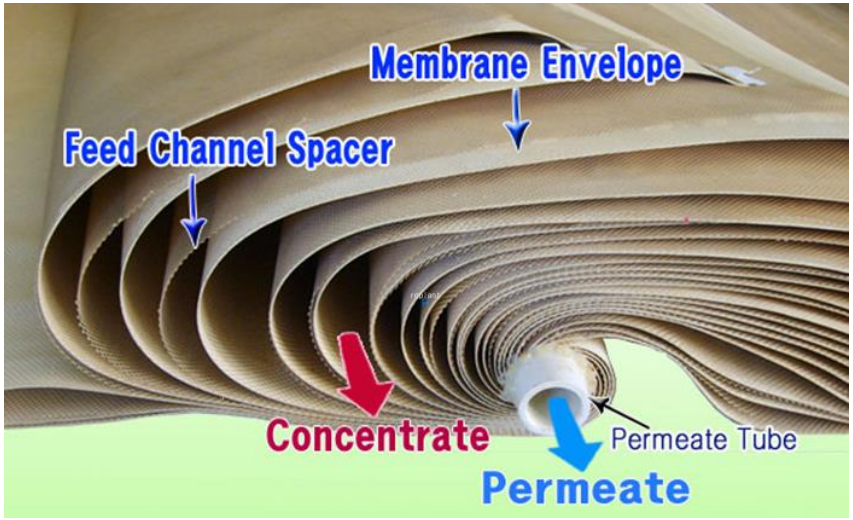

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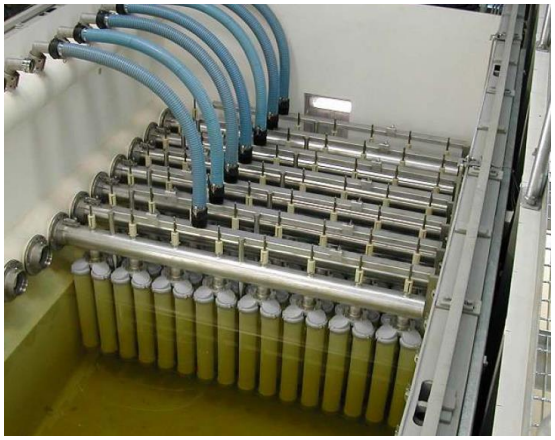
  - Disc module

Membrane Permeation System

- Side stream membrane (pressure driven)
  - Mainly for Dissolved ions
  - High pressure is required
  - Flux range 51-59 $L/m^2 h$

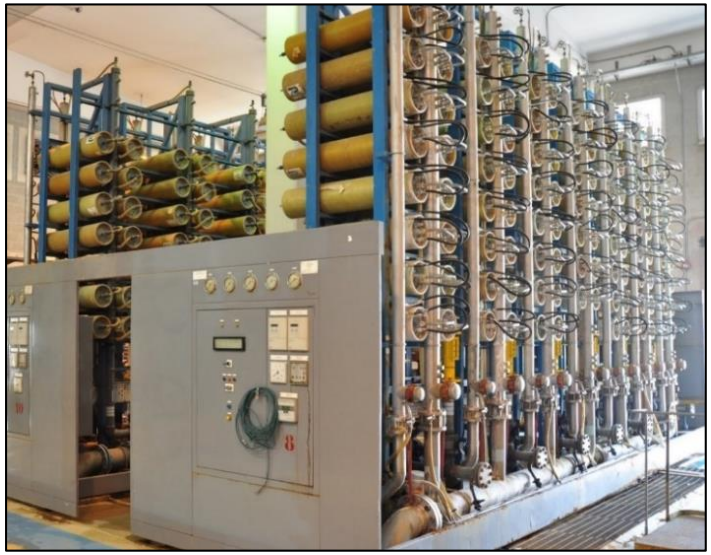
- Immersed membrane (vacuum driven)
  - Mainly for suspended solids
  - Is used for pretreatment module in water purification
  - Most of MBR module are immersed
  - Low pressure system
  - Flux range 27 - 41 $L/m^2 h$



Membrane Technologies for Water Applications

Membrane type at glance

- RO
  - Dominates desalination:
    - 44% share in world desalting production capacity (Greenlee, 2009)
    - 80% share in the total number of desalination plants installed worldwide (Greenlee, 2009)
  - Designed to reject 90-99% of the salt
- NF
  - Contributes in the softening (hardness removal)
  - Removes trace contaminants from major surface water streams
- UF
  - Pretreatment for desalination processes
  - Water reuse and high end solution for pathogen removal in drinking water.

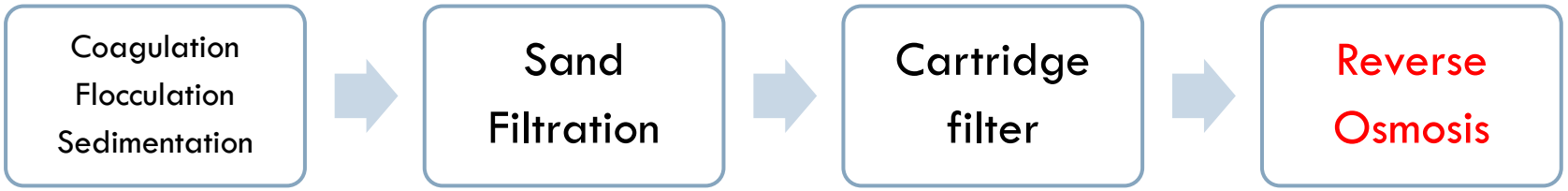


RO Feed Water Requirements

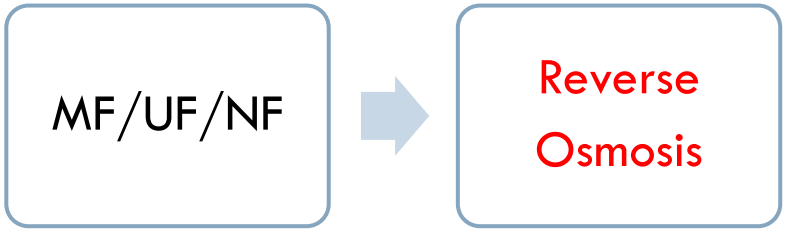
- Chlorine < 0.1 ppm (Sodium metabisulfite)
- pH 2-11
- SDI < 5
- Scaling and fouling prevention:
  - Antiscalant addition: organophosphonates, polyacrylates
  - Scale control: $CaCO_3$, $CaSO_4$, $SrSO_4$, $BaSO_4$, …
- Prefiltration:
  - Media filtration (Sand, Anthracite)
  - Cartridge filter
  - MF/UF/NF

Two scenario for RO pretreatment

(1) Conventional pretreatment



(2) A new trend in pretreatment has been a movement towards the use of larger pore size membranes (MF, UF, and NF) to pretreat RO feed water



Ceramic membrane can be used as pretreatment for RO

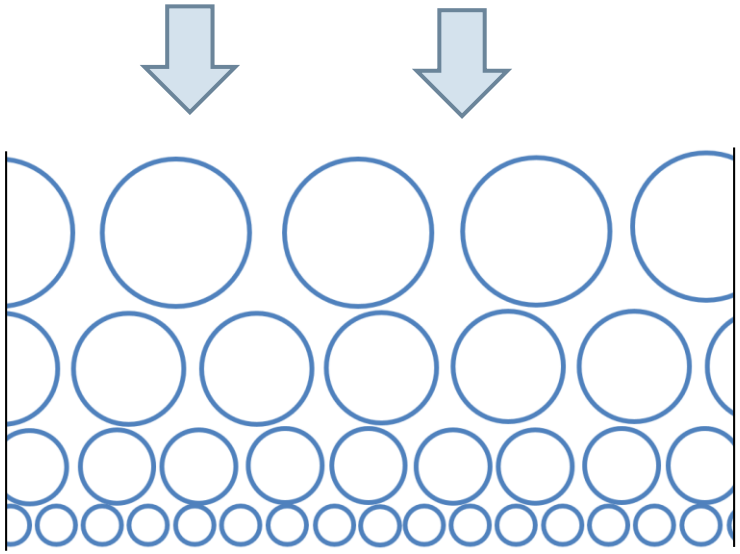
Contaminant Removal Capability of ceramic membrane:

- What they will remove
  - Suspended solids
  - Bacteria and viruses
  - Metal oxides (Ferric oxide, Manganese oxide, …)
  - Organic carbon (to some degree)
- What they will NOT remove
  - Dissolved ions

Despite of high capital cost of ceramic membrane, the overall running cost for water purification plant using this type of membrane could be less if compared to others

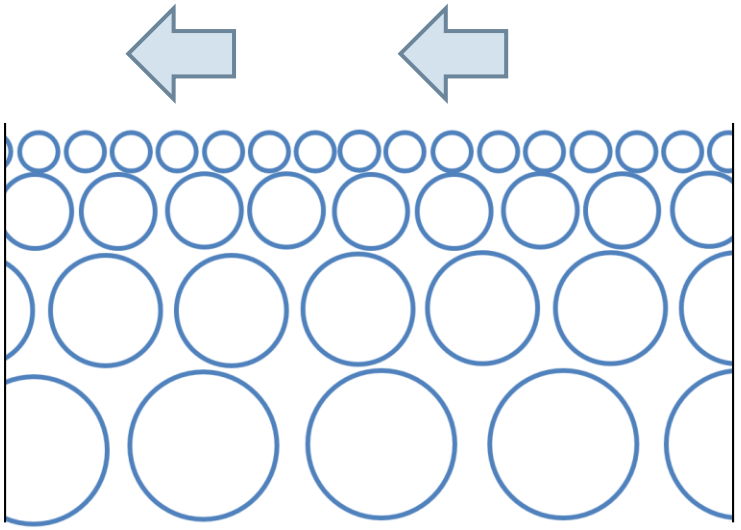
Filtration Processes

Dead end filtration



Depth filtration

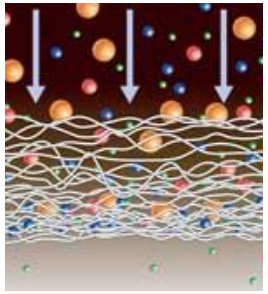
Cross flow filtration



Surface filtration

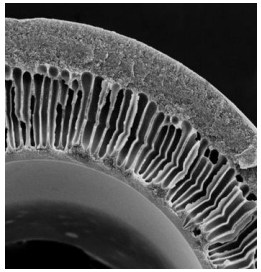
By filter medium

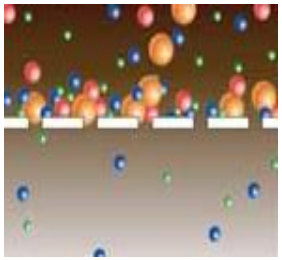
Cartridge filter



By Skin layer

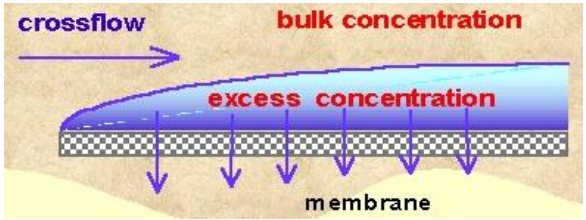
RO membrane





Operational problems of membrane

- Concentration polarization
  - refers to the concentration gradient of salts on the high pressure side of the membrane surface
- Membrane fouling
  - accumulation of unwanted material on membrane surfaces or membrane pores (colloidal fouling, organic fouling, biofouling, scaling).

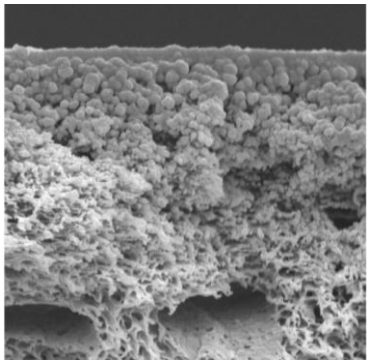


Concentration polarization


Membrane fouling

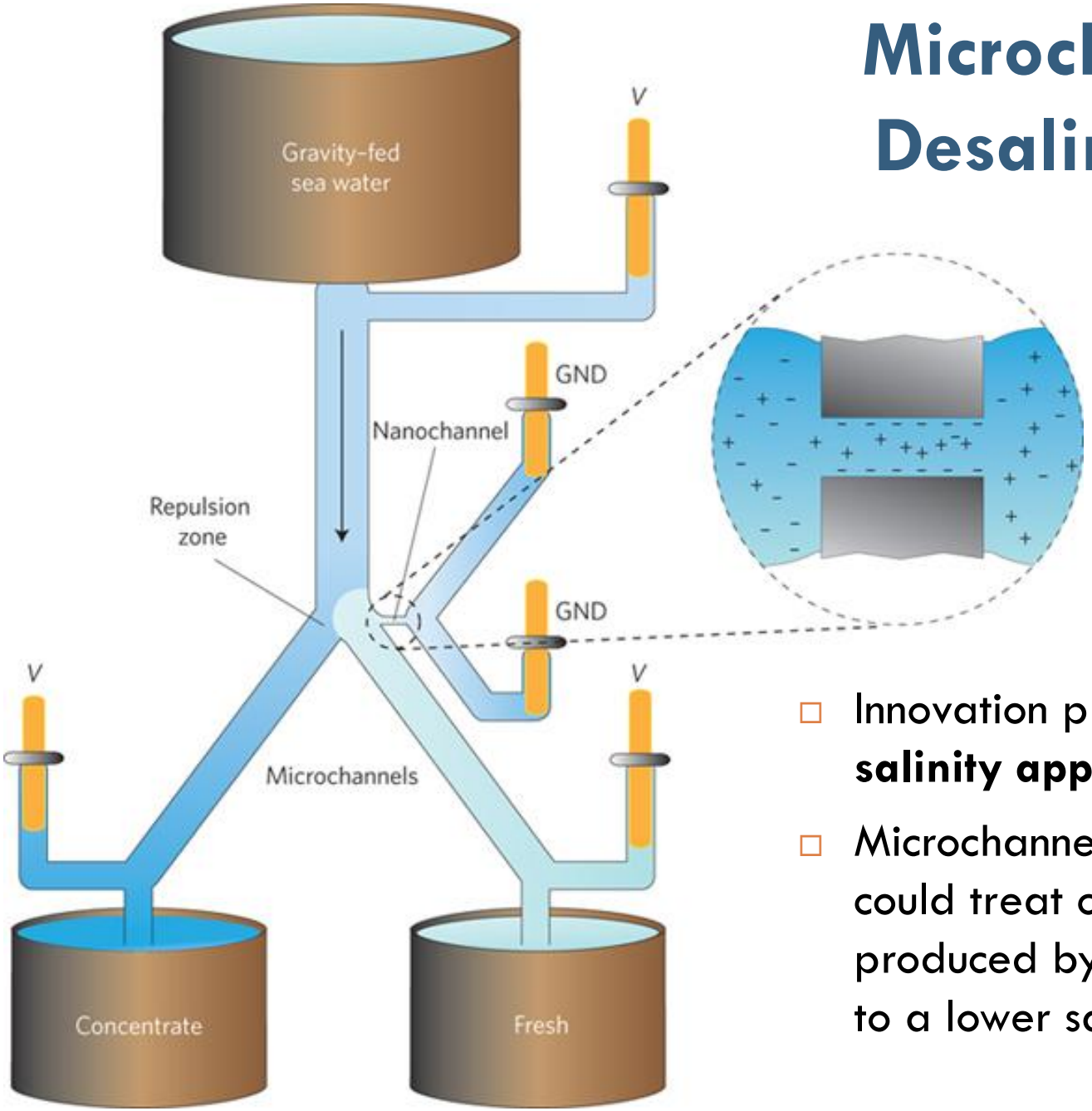
Membrane technology development in last decade

- Membrane coating with **non-porous** hydrophilic polyamide to reduce fouling
- Development of **energy recovery** devices
- Membrane module design, including **larger diameter** spiral wound modules and high-flux membranes



New Process

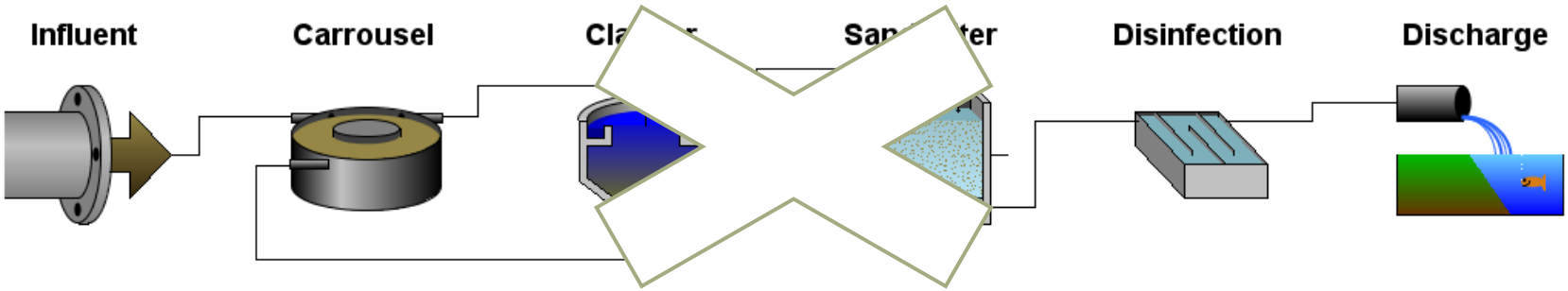
Microchannel Desalination

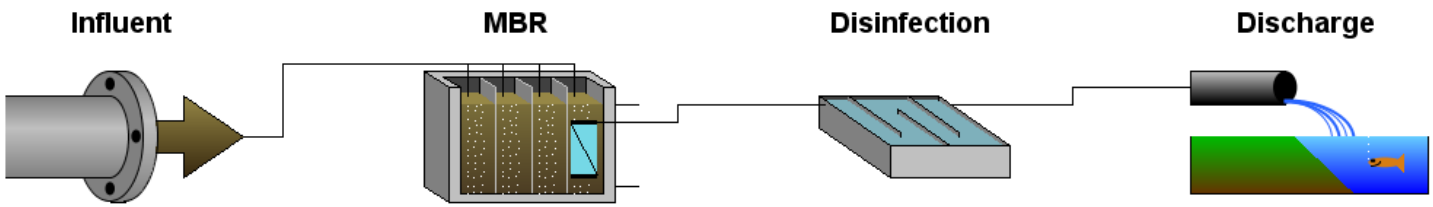


- Innovation process for **high-salinity applications.**
- Microchannel desalination could treat concentrated **brine** produced by reverse osmosis to a lower salinity level

Membrane Technologies for Wastewater Applications

Wastewater Treatment Plant
Carrousel Vs Membrane Bioreactor





Membrane bioreactor (MBR) is a combination of a membrane process with a suspended growth bioreactor. The purpose of MBR is to return solids in the aeration tank

MBR Advantages & Disadvantages

Advantages:

- High MLSS enable to reduce the HRT
- High MLSS and SRT enable the system to treat hardly biodegradable pollutants
- Reduction in the system footprint
- Good quality effluent suitable for reuse options
- Low sludge production

Disadvantages

- High operation cost
- **Membrane fouling** and periodic replacement
- Required skilled labor

Membrane Configuration for MBR

Hollow fiber configurations

Multitube configurations

Flat sheet configurations

Multitube (MT) membranes

- Multitube (MT) membranes technologies are only sidestream configurations for MBR.
- Water flows from **inside to outside** the membrane tubes
- For treating **small effluent flows from industrial installations** on the basis of their robustness and operational flexibility and control.
- Recently **multi-channel ceramic** membranes have been introduced for some sidestream MBR applications.

New Trend

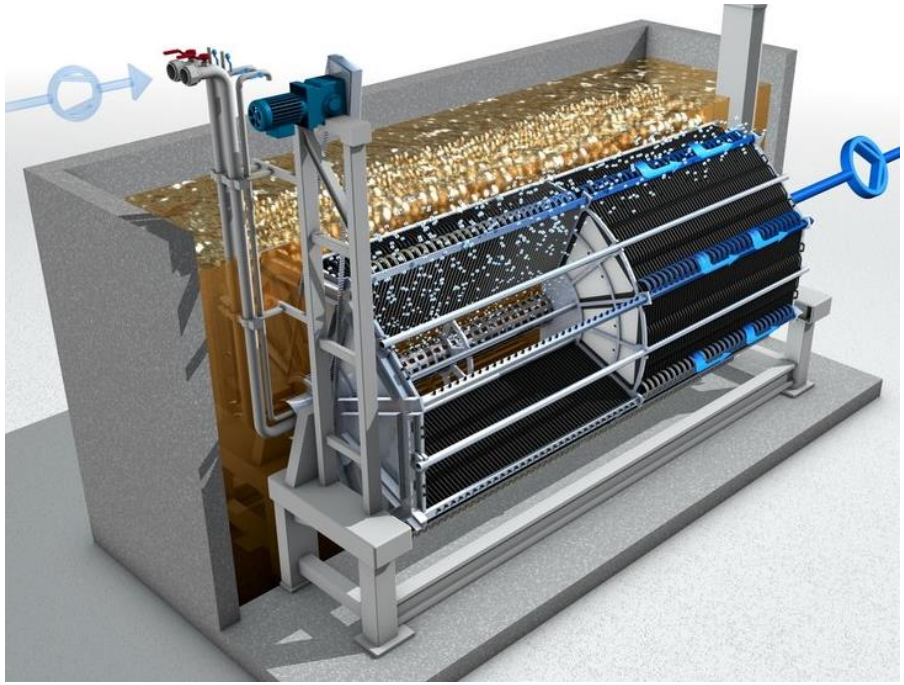
Ceramic Flat Membranes can be used for MBR

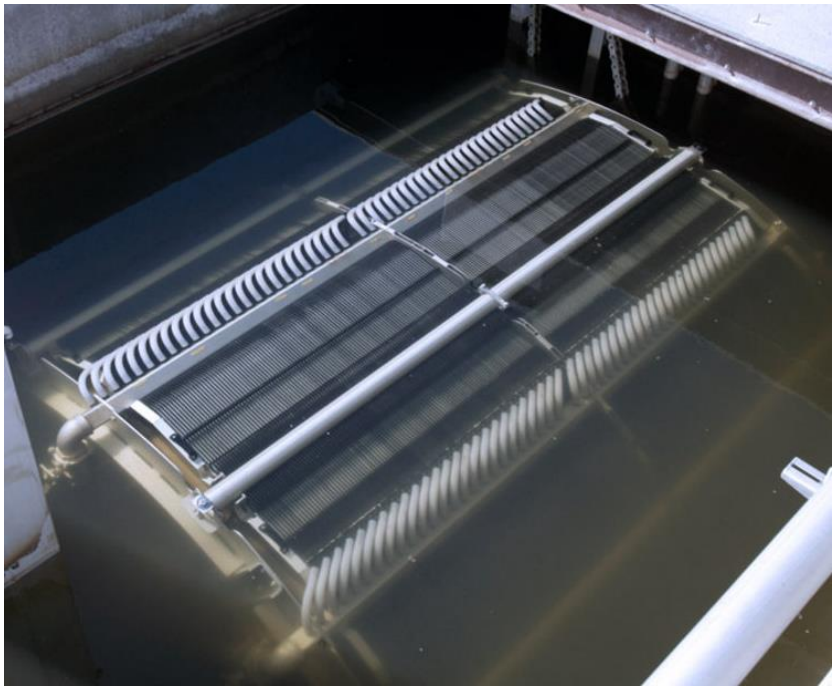
Ceramic membranes for WWTP effluent treatment

- Due to the robustness of ceramic membranes, strong oxidants such as ozone can be used as pretreatment to reduce the membrane fouling.
- Ozone pretreatment for ceramic membranes is effective at degrading colloidal natural organic matter (NOM) which are likely responsible for the majority of membrane fouling.
- Ozone pretreatment allow to extent the lifespan of ceramic membrane

New Trend

Rotating flat sheet membrane filter





Cloth Filter

Cloth filter can replace sand filter

Membrane-Based Treatment and Advanced Oxidation for Water Reclamation

- Multi-barrier approach (MBA) for water reclamation for indirect potable reuse and direct potable reuse (IPR/DPR) schemes.
- Integrating MBR, RO, and AOP (advanced oxidation processes) technologies within a multi-barrier approach to potable reclamation schemes.
- The multi-barrier approach, for contaminant removal in water reclamation schemes, is widely accepted and has demonstrated its benefits and merits.

SOME OF MEMBRANE RELATED PROJECT SUPERVISED BY

FOUD AL-SALEH & KHALED AL-DHOWALIA CO.

ENGINEERING CONSULTANTS

North of Buraydah Water Purification Plant

Client	General Directorate of Water in Qassim Region
Consultant	Foud Al-Saleh & Khaled Al-Dhowalia Company
Contractor	Mohammad Abdulmohsen Al-Kharafi & Sons Co.
Date of operation	Jumada I, 1432 – April 2011
Design capacity	50,000 m^3/day
Raw water TDS	1000 - 1500 mg/L

Process Flow Diagram
North Buraydah Water Purification Plant

Aeration + Oxidation Tank → Coagulation Flocculation Sediment. → Fine Mechanical Screen → Immersed UF → Reverse Osmosis → Disinfection

Water Quality Parameters

Parameter	Unit	Inlet concentration	outlet concentration
TDS	mg/L	1000-1500	≤ 400
Ra (226 + 228)	pCi/L	50-100	2 – 5

After Operation, it was found that it is more efficient to replace the polymeric UF with ceramic one

Al-Shamel Water Purification Plant

Project location	Al-Shqeq field - Hail
Client	General Directorate of Water in Hail Region
Consultant	Foud Al-Saleh & Khaled Al-Dhowalia Company
Contractor	Saudi Bin Laden Group
Date of operation	Dhu Al-hijah 1432 – November 2011
Design capacity	150,000 m^3/day
Raw water TDS	600 mg/L (roughly)

Al-Shamel Water Purification Plant

(1) Aeration

(2) Sand filtration

(3) Cartridge filtration

(4) NF filtration

Laila Water Purification Plant

Project location	Laila – AL-Aflaj
Client	General Directorate of Water in Riyadh Region
Consultant	Foud Al-Saleh & Khaled Al-Dhowalia Company
Contractor	General Enterprises and Trading Company Ltd (GETCO)
Design capacity	50,000 m^3/day (1st & 2nd stage)
Raw water TDS	5000 mg/L (roughly)

Process Flow Diagram
Laila Water Purification Plant

Coagulation
Flocculation
Sedimentation

→ Sand Filter → Cartridge filter → Reverse Osmosis → Disinfection

Water Quality Parameters

Parameter	Unit	Inlet concentration	outlet concentration
TDS	mg/L	5000	≤ 400
Ra (226 + 228)	pCi/L	6.5	≤ 2
Rn	pCi/L	18	

Thank you for Attention

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