WSTA 15th – Gulf Water Conference

Revolutionizing Desalination: KISR's Breakthrough Projects Addressing Water Crisis Challenges

Dr. Mansour Ahmad

Water Research Center (WRC)

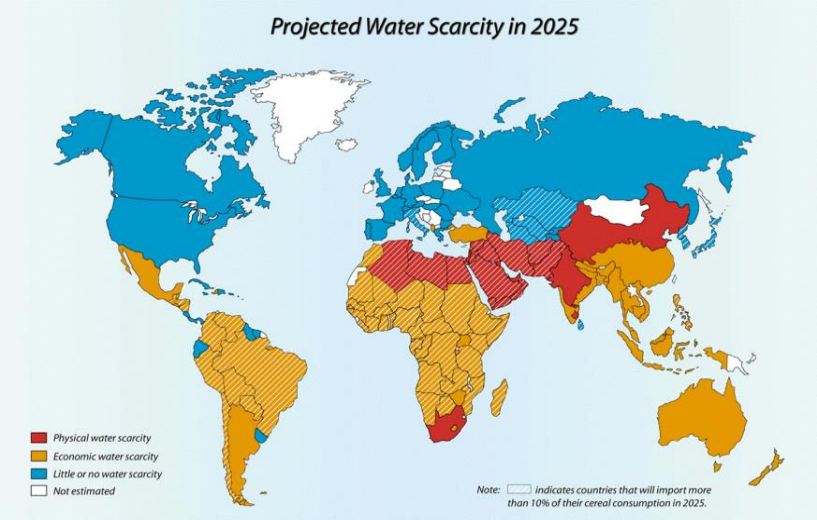
Kuwait Institute for Scientific Research (KISR)

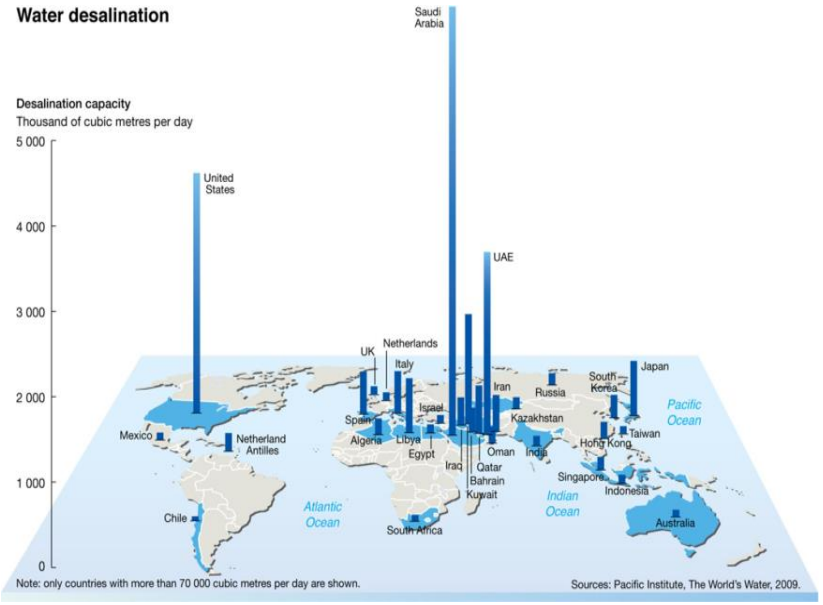
P.O. Box 24885, 13109 Safat, Kuwait

29th April 2024

Agenda

- Introduction
- Water Research Center’s Solution Areas
- Development of Innovative Desalination Technologies at KISR
- Conclusions
- Recommendations





Kuwait Desalination

- Kuwait is situated in an arid region with
  - Extremely hot weather;
  - Very little rainfall; and
  - Very limited natural fresh water resources
- Kuwait has been fully dependent on conventional desalination technologies for the past six decades.
- Desalination Technologies in Kuwait:
  - Multistage Flash Distillation (MSF) (468 MIGPD);
  - Reverse Osmosis (RO) (120 MIGPD); and
  - Multi-Effect Distillation (MED) (107 MIGPD)
- Kuwait has the fourth largest seawater desalination capacity on a global scale.

Kuwait Desalination (cont'd)

Desalination Plants in Kuwait (MIGPD)

Year		2014	2015	2016	2017	2018	2020	Technology
No.	Station							
1	Shuwaikh	49.5	49.5	49.5	49.5	49.5	49.5	MSF & RO
2	Shuaiba	36	36	36	36	36	36	MSF
3	Doha East	42	42	42	42	42	42	MSF
4	Doha West	110.4	110.4	110.4	110.4	110.4	170.4	MSF & RO
5	Az-Zour South	145.2	145.2	145.2	145.2	145.2	145.2	MSF & RO
6	Az-Zour North			107	107	107	107	MED
7	Sabiya	100	100	100	100	100	100	MSF
8	Shuaiba North	45	45	45	45	45	45	MSF
Total Installed Capacity		528.1	528.1	635.1	635.1	635.1	695.1	

Desalination Challenges

- Conventional Desalination Challenges
  - Expensive and energy intensive processes;
  - Corrosion, scaling, and fouling problems;
  - Osmotic pressure (RO membrane);
  - Top brine temperature (Thermal); and
  - Limited water recovery ratio.
- Desalination Brines Challenges
  - Produce large volumes of brine (>2 BIGPD)
  - High salt concentration and high degree of hardness.
  - Contains pre-treatment chemical additives.
  - Temperature of brine is higher than seawater in the case of thermal desalination.
  - Contains undesired suspended substances at

Water Research Center's Solution Areas …

- Innovative Membrane & Thermal Desalination Technologies;
- Turbid Seawater Treatment & Desalination Processes;
- Salts and Minerals Extraction Technologies;
- Minimal Liquid Discharge (MLD) Technologies;
- Zero Liquid Discharge (ZLD) Processes;
- Desalination Technologies using Renewable Energy;
- Innovative Desalting Processes using Waste Heat; and
- Innovative Desalination Technologies for Emergency.

Solution Area

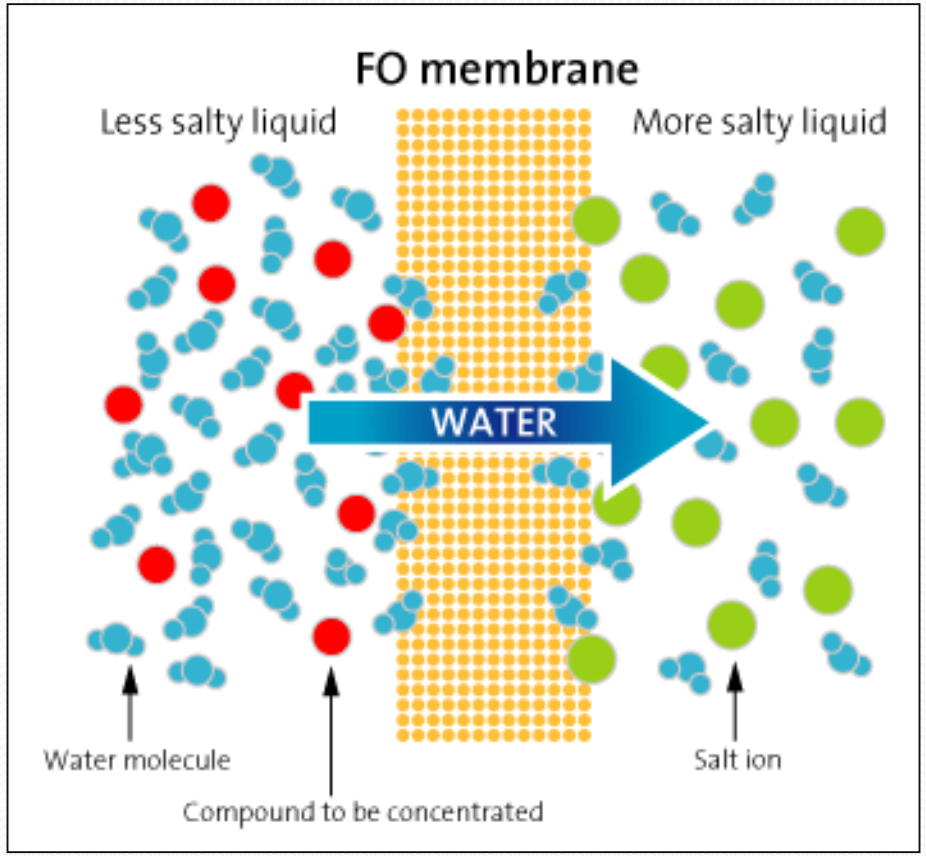
Innovative Membrane
&
Thermal Desalination Technologies

Development of Forward Osmosis Desalination Technologies:

Forward Osmosis Principle and Applications

Applications:

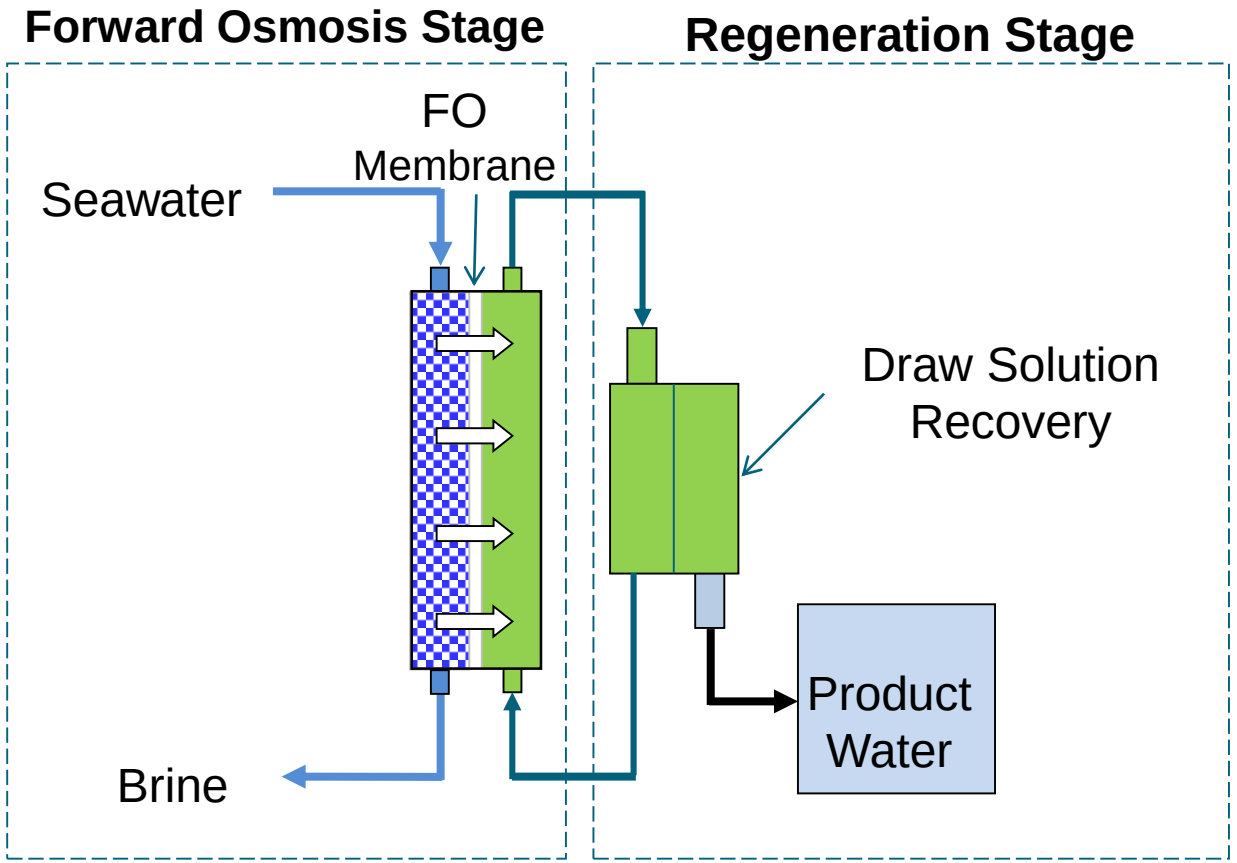
- Seawater desalination
- Emergency drinks
- Power generation
- Enhanced oil recovery
- Produced brine treatment
- Fluid concentration
- Water softening
- Water substitution



Solvent Flow in Forward Osmosis

Forward Osmosis Technology for Desalination Applications:

Forward Osmosis Stage and Regeneration Stage



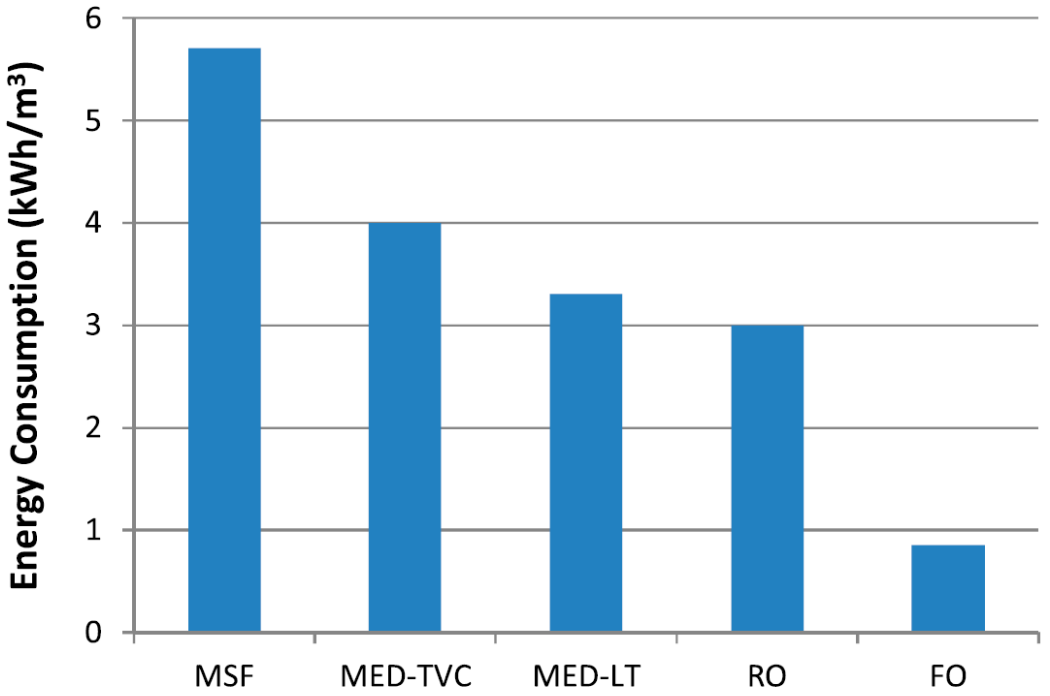
Waste Heat Utilization:
Comparison between Conventional Thermal Desalination Technologies and FO Process on Low Grade Heat Utilization

Technology	Gain Output Ratio	Water Production Rate (tonne/h)
Multi-Stage Flash Distillation (MSF)	8 – 12	64.9 – 97.4
Multi Effect Distillation (MED)	6 – 12	105.6 – 211.1
Forward Osmosis (FO)	10 – 14.8	222.4 – 329.2

Thermodynamic Analysis was conducted using UNISIM together with OLI property package
Source: M.Y. Park et al., *Applied Energy, 154 (2015), 51–61*.

Equivalent Work:

Energy Consumption by Desalination Technologies



Source: McGinnis and Elimelech, Desalination, 207 (2007), 370-382.

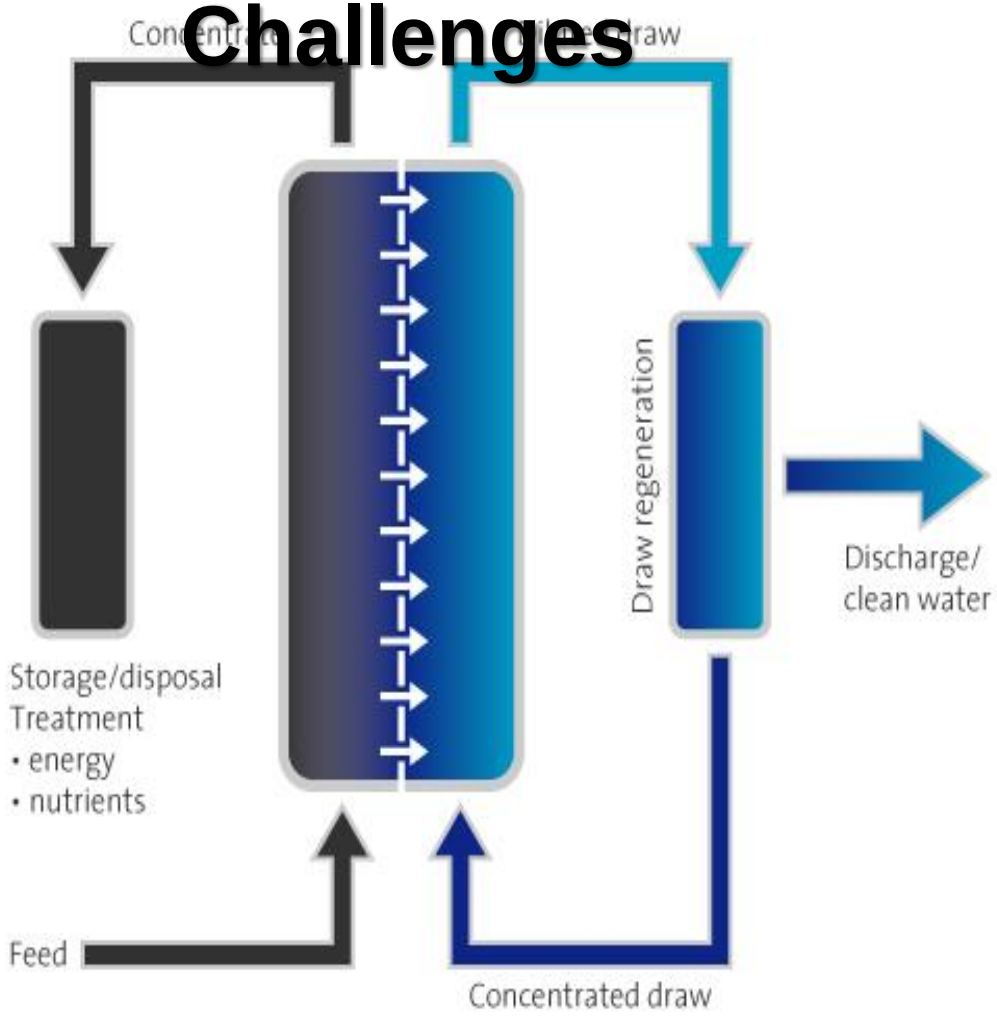
FO Pilot-Scale Results (cont'd):

Major Physiochemical Analysis of Water Samples for Feed and Product

Parameter	Units	Feed	Product Water
EC	mS/cm	58.6	0.2
TDS	mg/L	45,400	100
Ca^{2+}	mg/L	936	4
Mg^{2+}	mg/L	1,312	1
Na^{+}	mg/L	13,560	22
$(SO_4)^{2-}$	mg/L	2,000	0
$(HCO_3)^{-}$	mg/l as CaCO3	130.8	2.4
Cl^{-}	mg/L	25,100	77
NO^{3-}	mg/L	4	2
F^{-}	mg/L	1.70	0.50
Cu^{2+}	mg/L	<0.05	<0.05
Cr^{6+}	mg/L	<0.05	<0.05
Fe	mg/L	<0.05	<0.05
SiO_2	mg/L	23.1	1.2

FO Challenges

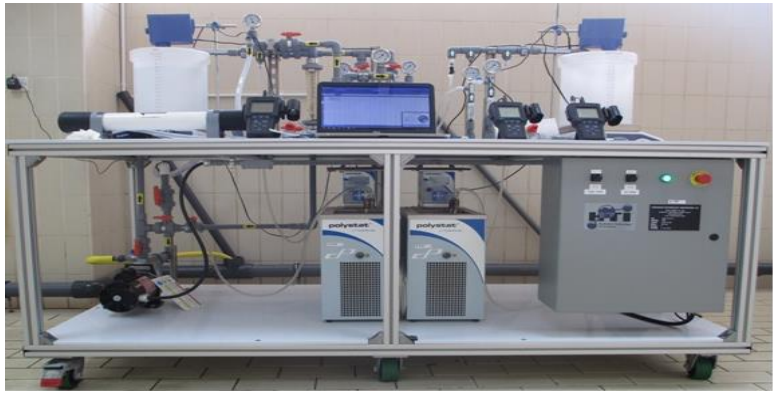
- Membrane performance
  - Material CTA/TFC
  - ICP/ECP
  - Thickness
  - Scaling & Fouling
- Module Selection
  - Flat sheet, Spiral Wound
  - Tubular, Hollow Fiber
- Draw Solution Recovery
  - Organic/Inorganic
- Membrane Process
  - (RO, NF, MD)
- Thermal Process
  - MSF, MED, Distillation



Principle of FO Technology

Development of FO Technologies for Desalination at KISR

Lab-Scale FO Test Unit



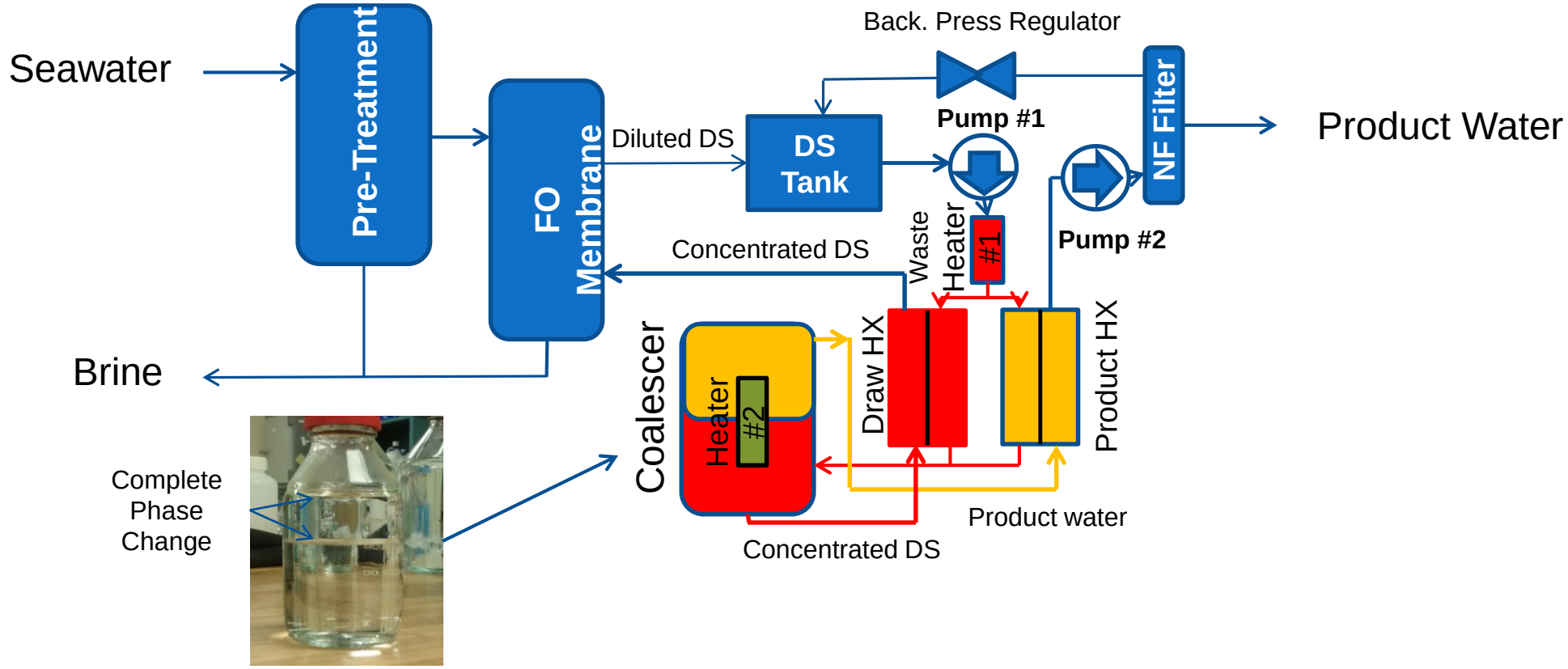
Semi-Pilot FO Test Unit

FO Pilot Test Plant

- KISR has made extensive research in collaboration with international partners in the areas of development of FO membrane technologies for seawater desalination.
- Efforts involve development of the state of the art of several FO membrane technologies.
- KISR Vision: establishment of FO membrane desalination technologies powered by renewable energy on a commercial-scale.

FO-Thermal Separation (TS) Pilot-Scale Investigations at KISR

Integration of FO-TS Systems for Desalination



Schematic Diagram of the investigated FO Pilot Plant Test Unit at KISR

FO-TS Pilot-Scale Investigations at KISR (cont'd)

Integration of FO-TS Systems for Desalination

Investigated FO Pilot Plant Test Unit at KISR

FO-TS Pilot-Scale Investigations at KISR (cont'd)

Integration of FO-TS Systems for Desalination

Pre-Treatment System

Commercial-Scale FO Membrane

Post-Treatment System

Control & Data Acquisition Systems

Investigated FO Pilot Plant Test Unit at KISR

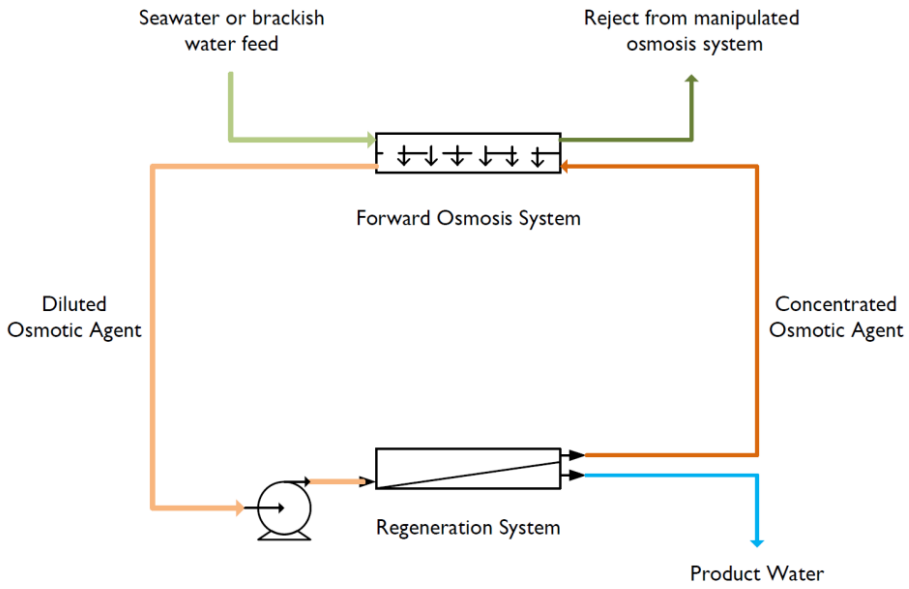
FO-TS Pilot-Scale Results:

Main Findings & Overall Experimental Results

- **Main Findings:**
  - High water recovery and high purity water production using a single FO membrane in a single-stage operation.
  - The total energy consumption was 1.4 kWh/m^3 (without electrical heater).
  - It was recommended to integrate the FO process with low-grade heat source such as solar energy and waste-heat.
  - Techno-economical study showed that the proposed systems is feasible for commercial-scale applications (1 MIGD) with a use of low-grade heat sources.
- **Overall Experimental Results:**
  - Feed TDS = 45,400 ppm, Product TDS = 100 ppm, Salt Rejection = 99.8%, and Water recovery = 50%

FO-RO Pilot-Scale Investigations at KISR

Integration FO-RO Membranes Systems for Desalination Applications



Schematic Diagram of FO-RO for Desalination

Image of the FO-RO Pilot Test Unit at KISR

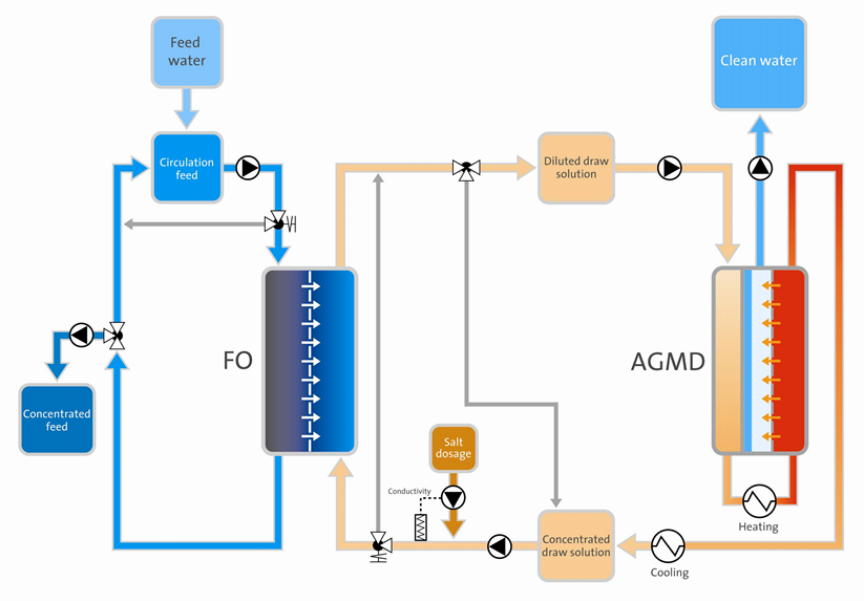
FO-RO Pilot-Scale Results:

Main Findings & Overall Experimental Results

- **Main Findings:**
  - High water recovery ratio (55%) and high purity water production using a single FO membrane in a single-stage operation.
  - The total energy consumption was 12 kWh/m^3 without use of energy recovery system.
  - Techno-economical study showed that the proposed systems is feasible for commercial-scale applications for high turbid seawater (1 MIGD).
- **Overall Experimental Results:**
  - Feed TDS = 45,400 ppm, Product TDS = 420 ppm, Salt Rejection = 99%, and Water recovery = 55%

FO-Membrane Distillation Pilot-Scale Investigations at KISR

Integration FO-MD Systems for Desalination Applications



Schematic Diagram of FO-MD for Desalination

Image of the FO-MD Pilot Test Unit at KISR

FO-MD Pilot-Scale Results:

Main Findings & Overall Experimental Results

- **Main Findings:**
  - High purity water production using a single FO membrane in a single-stage operation.
  - The total energy consumption was 12 kWh/m^3.
  - Techno-economical study showed that the proposed systems is feasible for commercial-scale applications for high turbid seawater (1 MIGD) with a use of low-grade heat sources.
- **Overall Experimental Results:**
  - Feed TDS = 45,400 ppm, Product TDS = 15 ppm, Salt Rejection = 99.9%, and Water recovery = 30%

Multi Effect Desalination (MED) Pilot-Scale Investigations at KISR

MED System for Seawater Desalination Applications

Image of the MED Pilot Test Unit at KISR

- **Overall Objectives:**
  - To develop a mathematical model for the seawater desalination process with MED using a horizontal tubes bundle.
  - To Improve the efficiency of desalination plants;
  - To reduce its capital and operating costs; and
  - To reduce environmental impact.

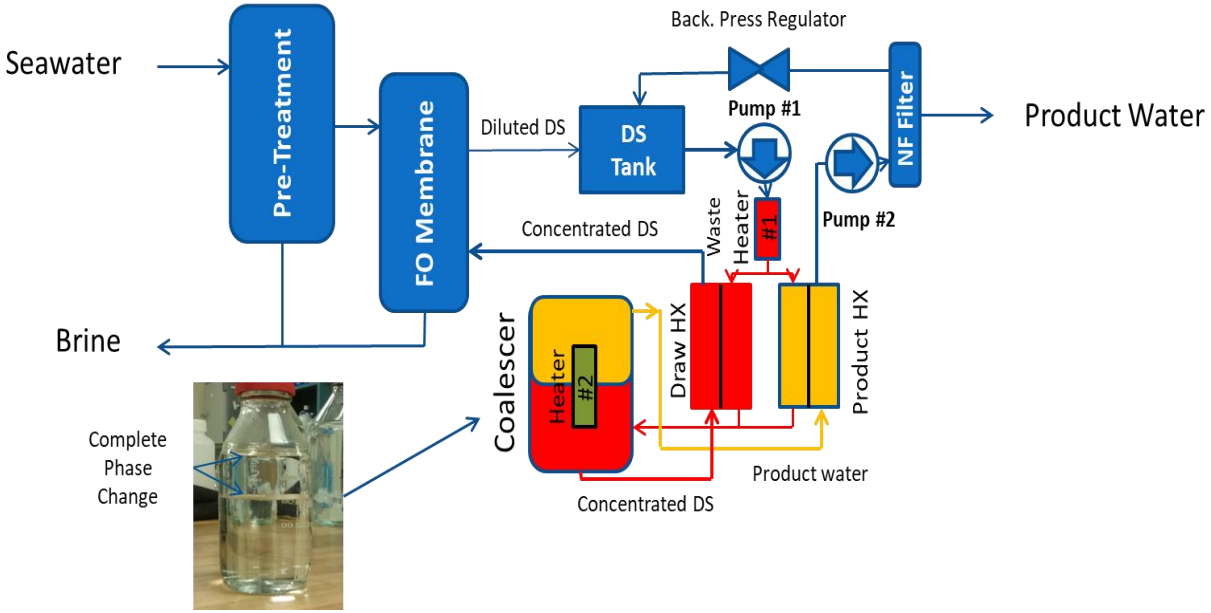
KISR
معهد الكويت للأبحاث العلمية
KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH

Solution Area

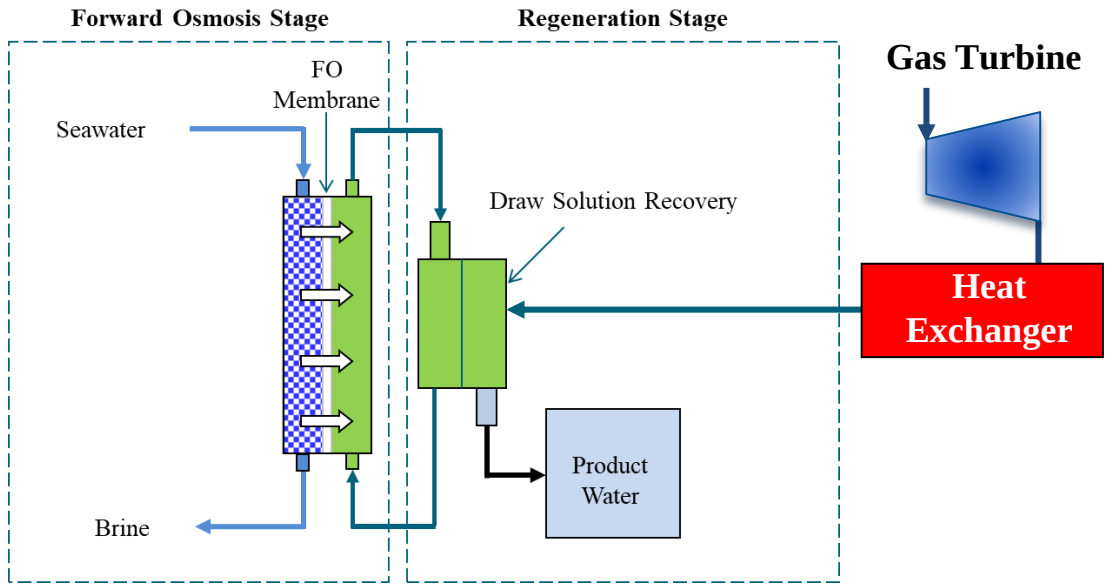
Innovative Desalting Processes using Waste Heat

FO Demonstration Pilot Investigations at KISR

Integration FO-TS Systems using Waste-Heat Generated by Open Cycle Gas Turbines (GT) for Desalination Applications



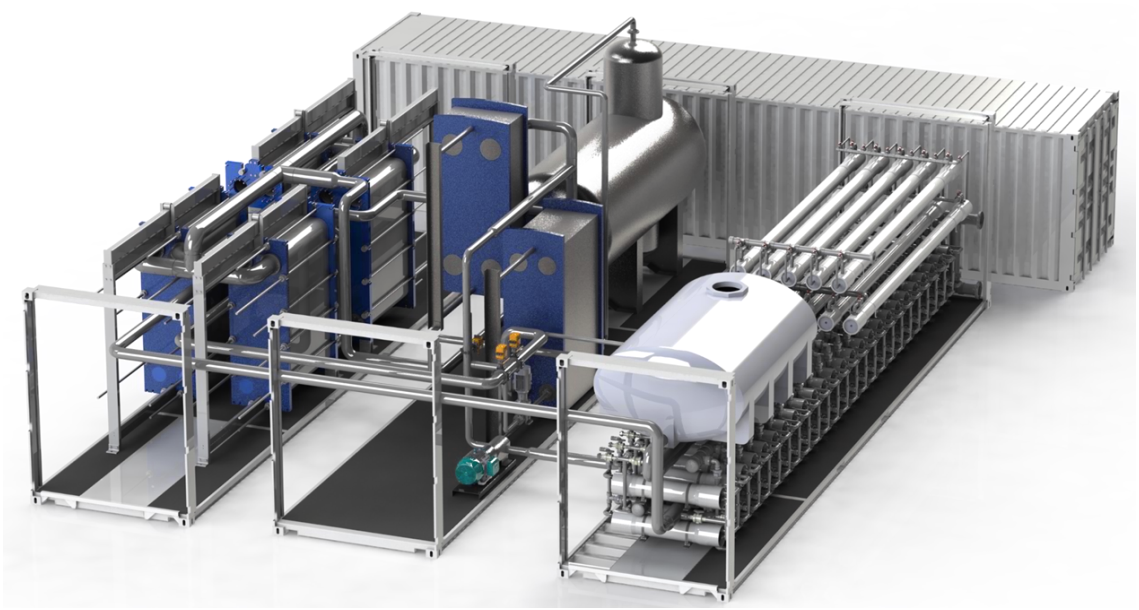
Schematic Diagram of Proposed FO-TS for Desalination



Schematic Diagram of Proposed FO-TS-GT Demonstration Plant

FO Demonstration Pilot Investigations at KISR (cont'd)

Integration FO-TS Systems using Waste-Heat Generated by Open Cycle Gas Turbines (GT) for Desalination Applications



Schematic Diagram of Proposed FO-TS-GT Demonstration Plant

Image of Proposed FO-TS-GT Demonstration Plant

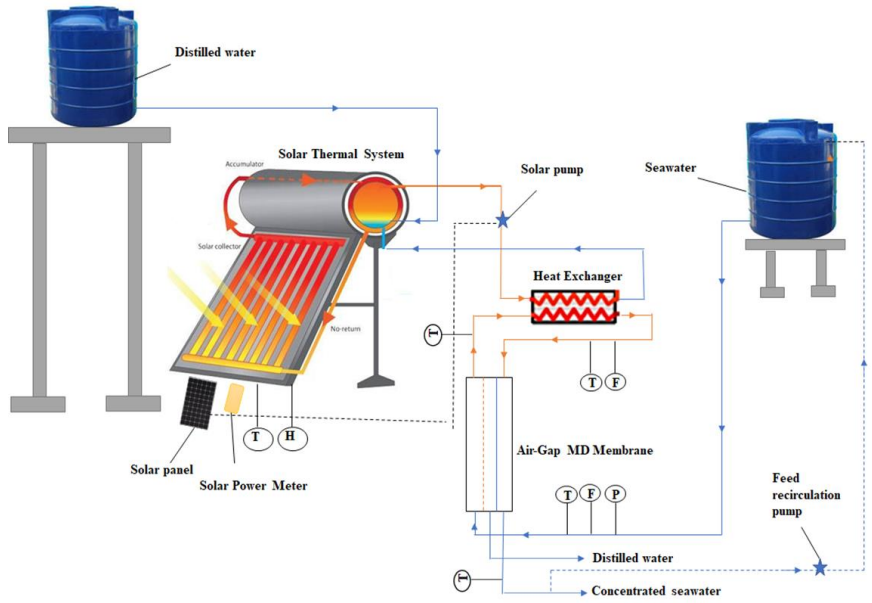
KISR
معهد الكويت للأبحاث العلمية
KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH

Solution Area

Desalination Technologies using Renewable Energy for large and small scale applications and Emergency

Solar MD Pilot-Scale Investigations at KISR

MD System using Solar Pannel for Desalination Applications



Schematic Diagram of Solar MD System for Desalination

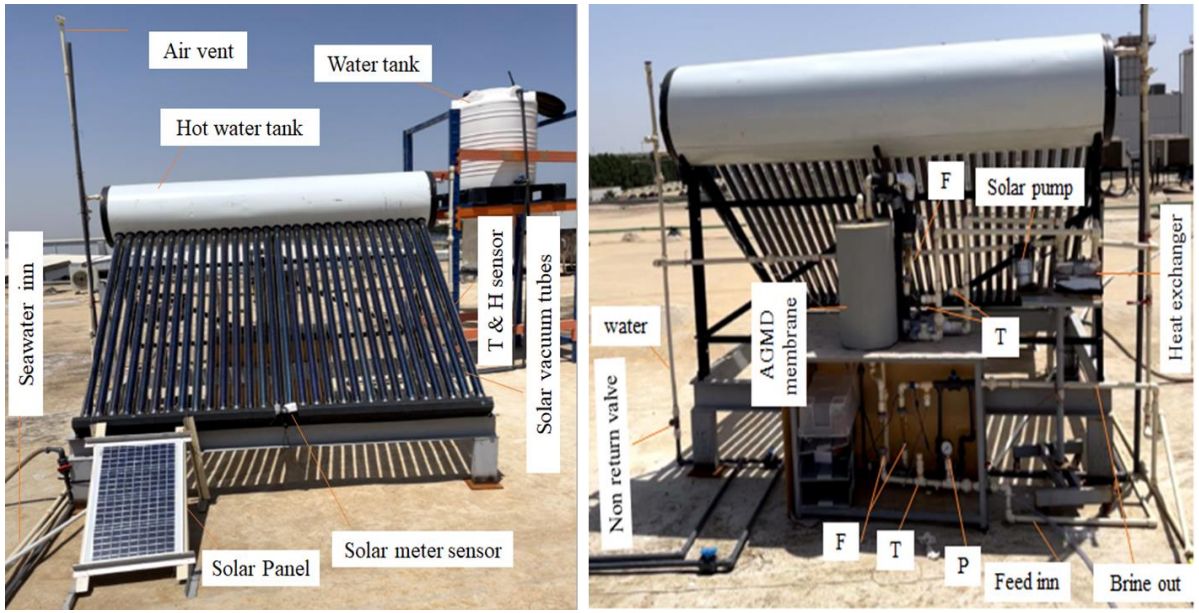


Image of Solar MD Pilot Test Unit at KISR

Solar MD Pilot-Scale Results:

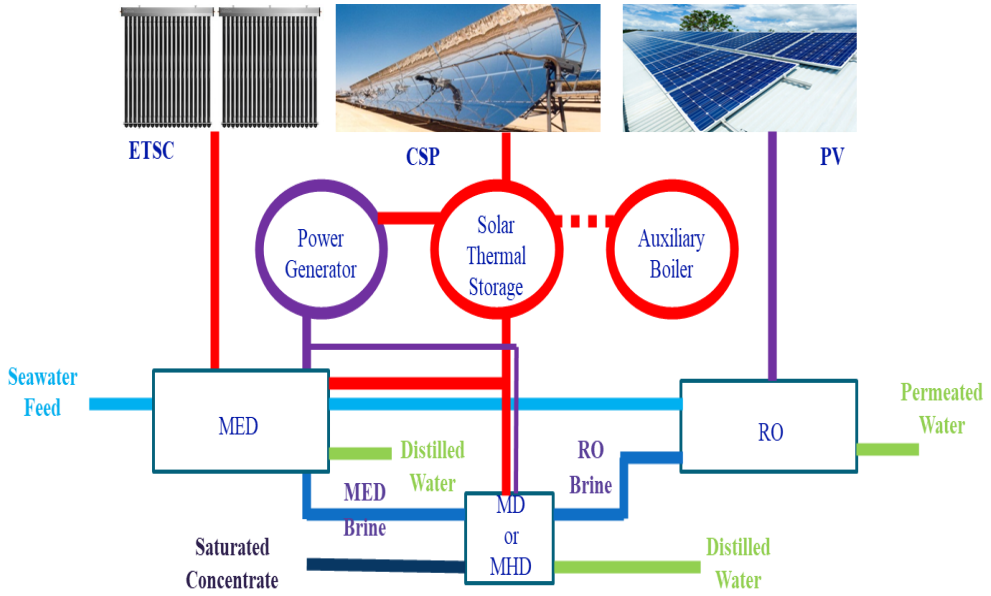
Main Findings & Overall Experimental Results

- **Main Findings:**
  - High purity water production using a single MD in a single-stage operation.
  - Techno-economical study showed that the proposed systems is feasible for small and large-scale applications with a use of low-grade heat sources.

- **Overall Experimental Results:**
  - Feed TDS = 45,400 ppm, Product TDS = 10 ppm, Salt Rejection = 99.9%, and Water recovery = 30%

Solar Desalination Approach

Integration of Advanced Desalination Technologies using Renewable Energy Resources



Schematic Diagram of Proposed Integration of Advanced Desalination Technologies using Renewable Energy Resources

- Pilot project involving collaboration with international partners in the areas of solar thermal energy conversion and storage, and advanced desalination systems.
- Desalination systems under consideration include RO, MED, MD and MHD systems.
- Efforts involve development of the state of the art of the solar-based water desalination and offer incubation and adaptation of new technologies leading to establishment of competitive

FO using Renewable Energy at KISR

FO-TS System utilising a wind turbine and High Vacuum Thermal Solar Collectors for Emergency and Small-Scale Applications

Image of Test Unit with a Plant Capacity of 50 m^3 per day

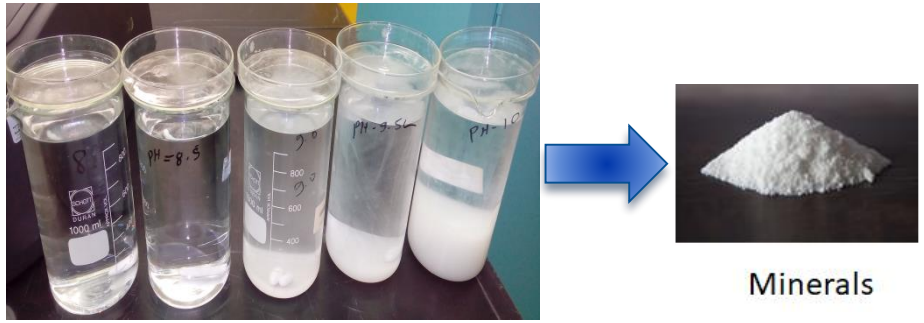
Image of Commercial-Scale FO Membrane Modules

Solution Area

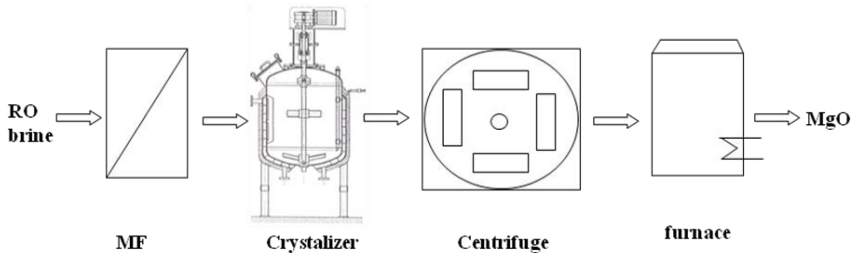
Salts and Minerals Extraction Technologies

Salts and Minerals Recovery from High Saline Waters

Development of Salts and Minerals Extraction Technologies



Precipitated minerals from RO brine



Schematic Diagram of extraction of MgO from RO brine

- Lab and pilot-scale projects involving collaboration with international partners in the areas of developing mineral extraction processes.
- Target salts: sodium (Na+), magnesium (Mg2+), potassium (K+), calcium (Ca2+), chlorine (Cl2), sulfate (SO42-), iodine (I2), bromine (Br2), boron (B3+), strontium (Sr2+) and lithium (Li+).
- Demineralizing these minerals offer economic and environmental benefits.
- Future vision is to establish new local chemical industries to increase the gross domestic product (GDP) and diversify the single major income to Kuwait, i.e.,

Pilot-Scale Investigations on Magnesium Oxide Recovery at KISR

Innovative Magnesium Oxide Extraction Technologies

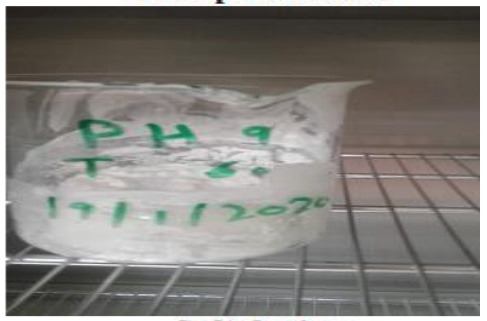
Image of Pilot crystallization test unit installed at KISR site

- Source of Saline Water: RO Brine
- Operating Temperature: 50 °C
- pH: 11
- MgO Production: 10 Kg per day
- Power Consumption: 10 kW/h

Draining precipitated salt.

Precipitated salt.

Centrifuge: Salt separation.



Salt drying.

Salt grinding.

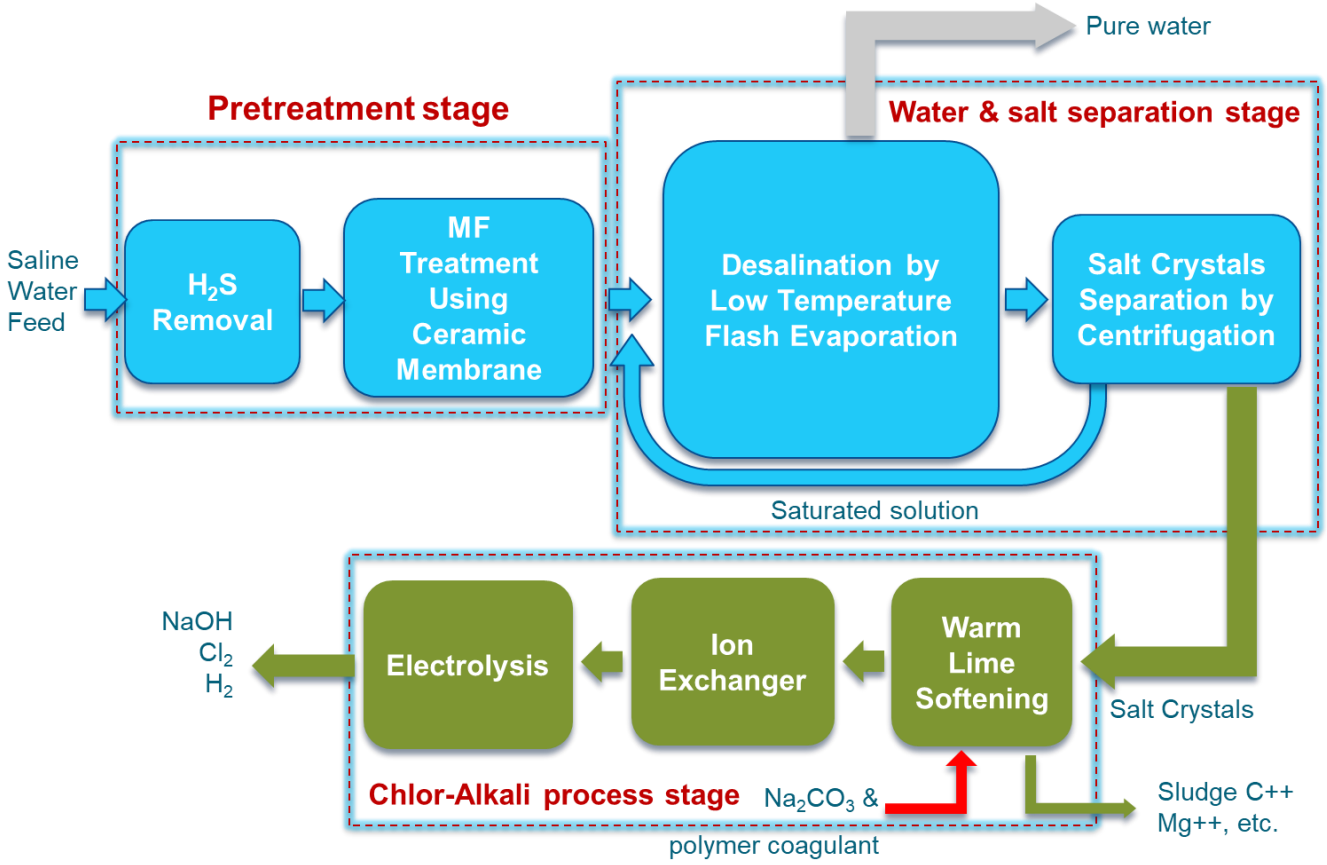
Salt after calcination.

Solution Area

Zero Liquid Discharge (ZLD) Processes

Pilot Investigations on ZLD for Produced Water at KISR

ZLD Model based on Collaboration between KISR and Japan Cooperation Center Petroleum (JCCP)



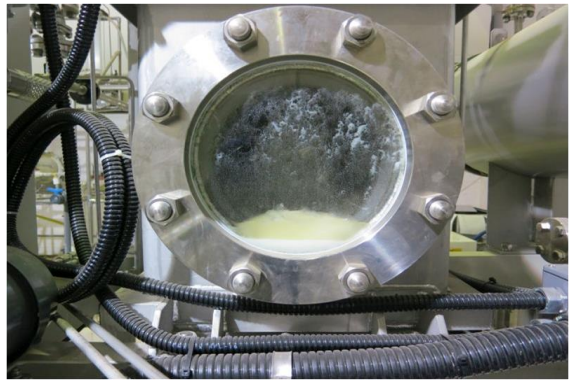
ZLD Model for Produced Water (Collaboration with Japan Cooperation Center Petroleum)

- Ceramic membrane microfiltration combined with H2S stripping can be used effectively as pretreatment of high salinity oilfield water feeding into ZLD desalination processes.
- Low temperature flash evaporation (LTFE) process is capable of desalting high salinity oilfield produced waters (> 250,000 ppm) and produce distillate.
- ZLD treatment and desalination model offers practical and powerful solution for Effective Management of Oilfield Produced Water, especially where high salinity is encountered.

Produced Water

Ceramic MF unit

Crystallization Unit

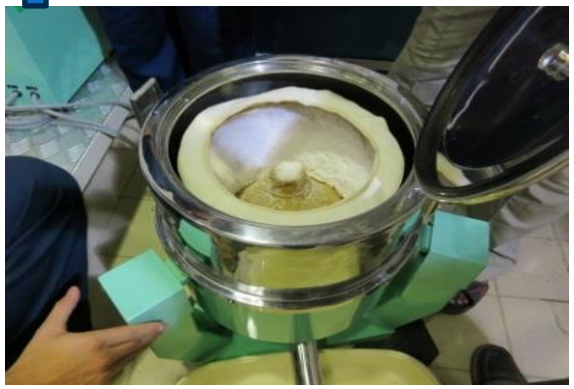


Precipitation of Salts

Pure Water

Salts and Minerals

Reject of Centrifuge Unit



Centrifuge Unit

Intellectual Property (IP) Developments by KISR

Patents

Intellectual Property (IP) Developments by KISR

Patent on Innovative Technology for Desalination & Air Conditioning using HDH-AB

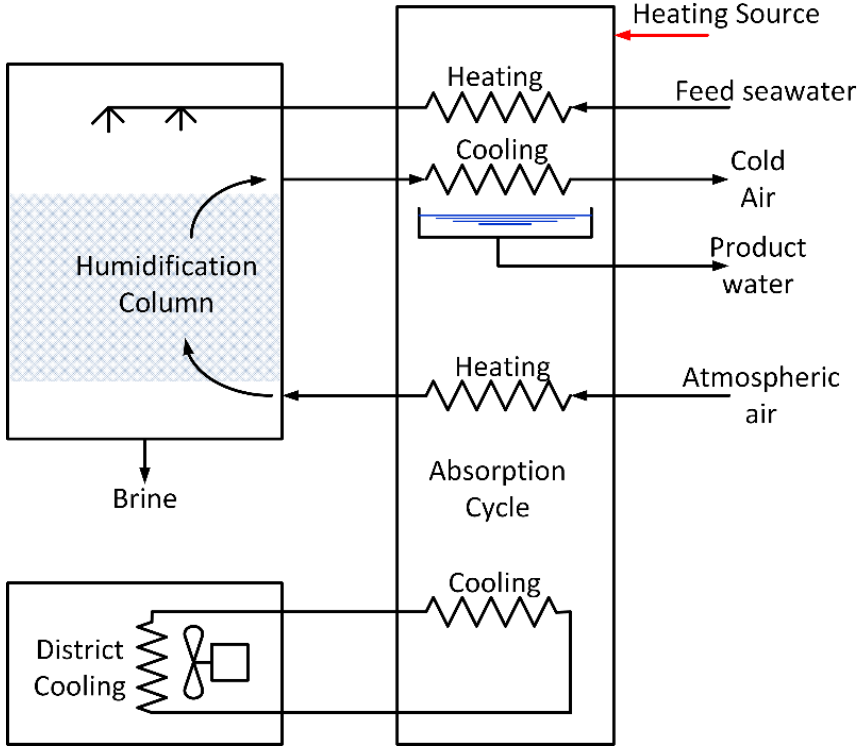
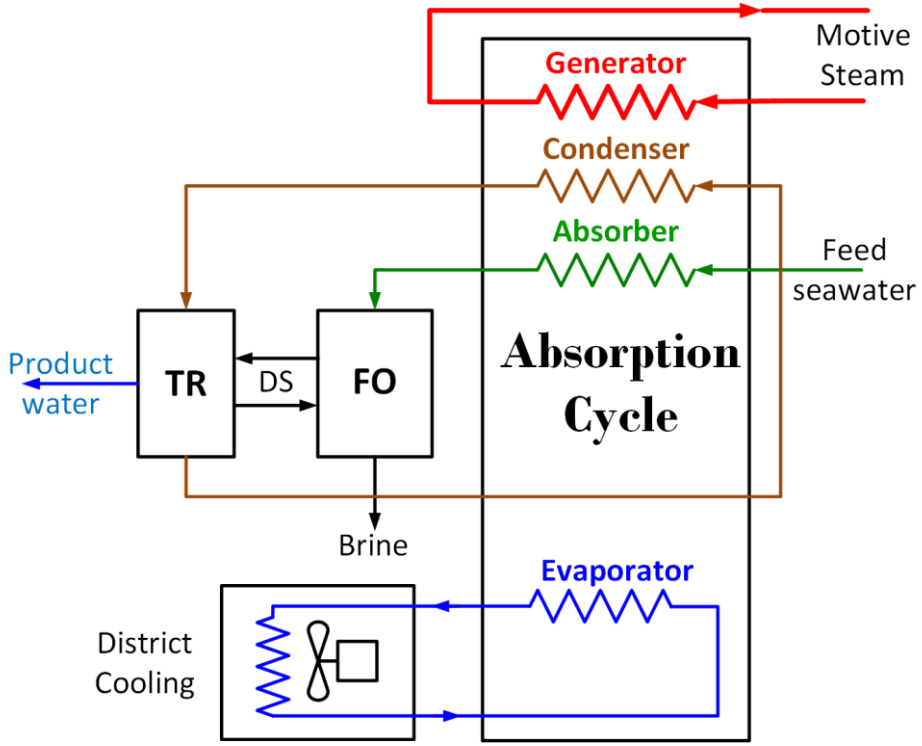


Illustration of the integrated system of humidification and drying technologies with the cooling cycle, which works by the method of absorbing steam

- Innovative desalination and air conditioning technology that addresses the problems of fresh water scarcity and high temperatures during the summer.
- It is based on the integration of humidification and drying technologies with the cooling cycle that works in a steam absorption way.

Intellectual Property (IP) Developments by KISR (cont'd)

Patent on Innovative Technology for Desalination & Air Conditioning using FO-AB

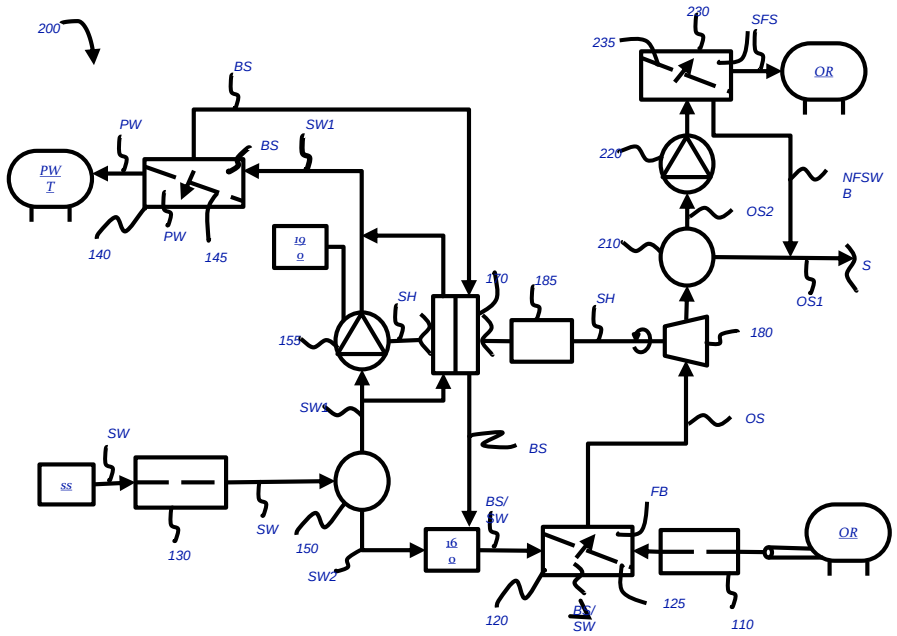


- The innovative process is based on the integration of FO technology with the cooling cycle that works in a steam absorption way.
- The innovative approach can be implemented in different capacities of desalination and cooling.

Illustration of the FO technology with the cooling cycle, which works by the method of absorbing steam

Intellectual Property (IP) Developments by KISR (cont'd)

Patent on Innovative MSF-MED Technologies

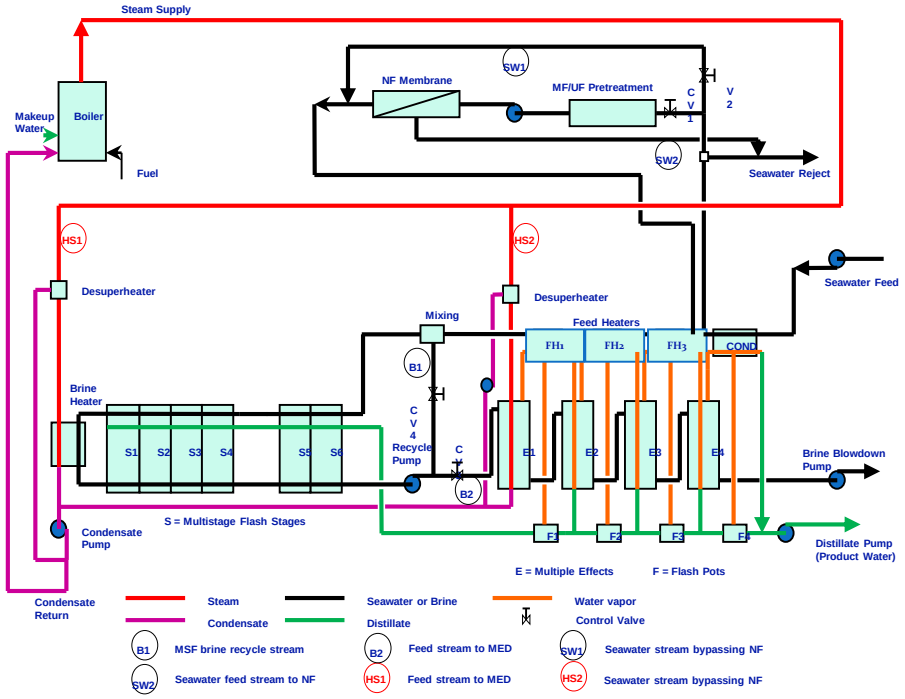


Integrated of MSF-MED Technologies

- Significant increase in the MSF product water recovery to more than 30% compared with the existing 10%, which also means significant reductions in the seawater intake facility, hence, significant savings in both capital and operating costs.
- Significant reduction in energy consumption by 20-30%

Intellectual Property (IP) Developments by KISR (cont'd)

Patent on Innovative RO-PRO Membranes Technologies

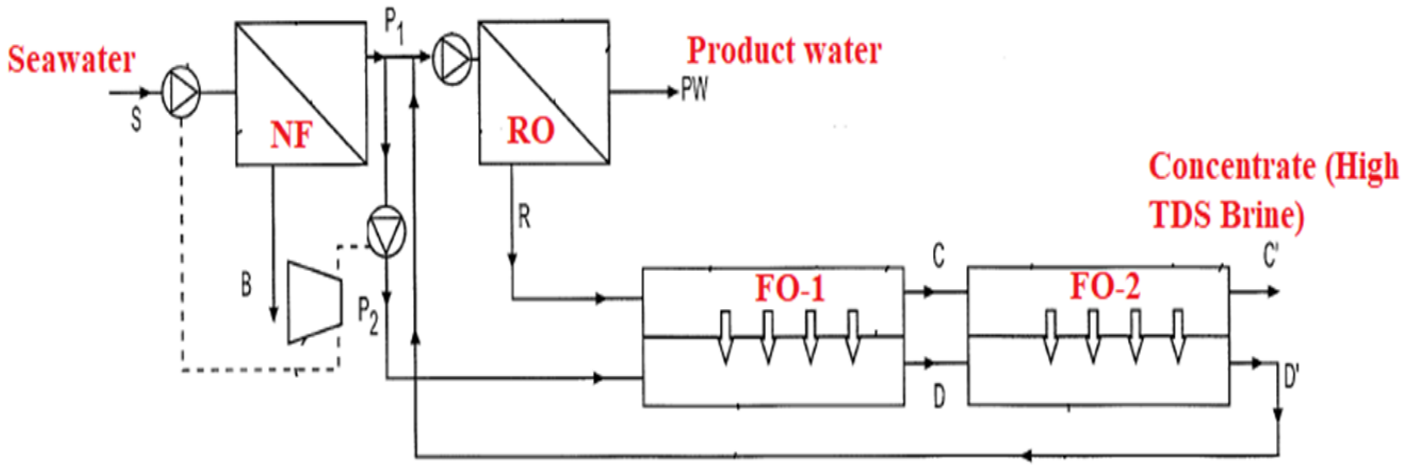


Integrated of RO-PRO Membranes Technologies

- The patented technology can be easily designed to produce potable water of similar quantity to the brine waste stream
- The patented technology provides means for safe disposal of the brine waste stream to the sea
- The patented technology performs with minimum or no energy consumption

Intellectual Property (IP) Developments by KISR (cont'd)

Patent on High-Water Recovery Hybrid Membrane Desalination System



Innovative Hybrid Membrane Desalination System

- Seawater Desalination Applications: Hybrid System achieved an overall water recovery of 60% based experimental investigations.
- Brackish Water Desalination Applications: Hybrid System achieved an overall water recovery of 90% based mathematical modelling investigations.

Exploring Future Initiatives: Potential Projects Under Consideration

- **Innovation on ZLD Technologies:** Innovative approaches and advancement in ZLD technologies will offer great opportunities in eliminating the challenges of desalination. Innovative desalination technologies (such as ED/EDR, MD, FO) can be considered as attractive systems for ZLD approach.
- **Innovation on Desalination Technologies using Renewable Energy:** The integration of renewable energy into desalination processes holds immense promise across various scales, from large industrial operations to small-scale applications, including desalination systems that can work efficiently in remote areas and emergency situations.
- **Innovation on Desalination Technologies using Waste Heat:** Development of innovative desalination processes using waste heat from power and nuclear plants to address both water scarcity and energy efficiency.
- **Nuclear Desalination:** Potential collaborative initiatives on nuclear desalination signify a forward-looking approach. The surplus of waste heat from nuclear plants can be used to produce fresh water by integrating with MED and MSF desalination plants, whereas, electricity from nuclear plants can be used to operate RO systems.
- **National Industries in Water Fields:** Establishment of National Industries with clear vision of transforming GCC countries into a leading industrial powerhouse by focusing on water,

Acknowledgements

- The author would like to acknowledge all the members and representatives of the Conference Board of WSTA 15 Gulf Water Conference for organizing the conference.
- The author is thankful to the Kuwait Foundation for the Advancement of Sciences (KFAS), Ministry of Electricity and Water and Renewable Energy (MEWRE), the management of Kuwait Institute for Scientific Research (KISR) and Water Research Centre (WRC) for their continued support and encouragement towards the research and development activities.

KISR
معهد الكويت للأبحاث العلمية
KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH

Email Address:
mahmed@kisr.edu.kw

Contact Number:
(+965) 24989570
(+965) 99912501

Affiliation:
Water Research Center, Kuwait Institute for Scientific Research, PO Box 24885, 13109 Safat, Kuwait.

THANK YOU for your time