A Comparative Study of Two Different Forward Osmosis Membranes Tested using Pilot Plant System for Arabian Gulf Seawater Desalination

Dr. Mansour Ahmed

Associate Research Scientist

Water Research Center

Kuwait Institute for Scientific Research

Desalination Challenges at Northern Kuwait

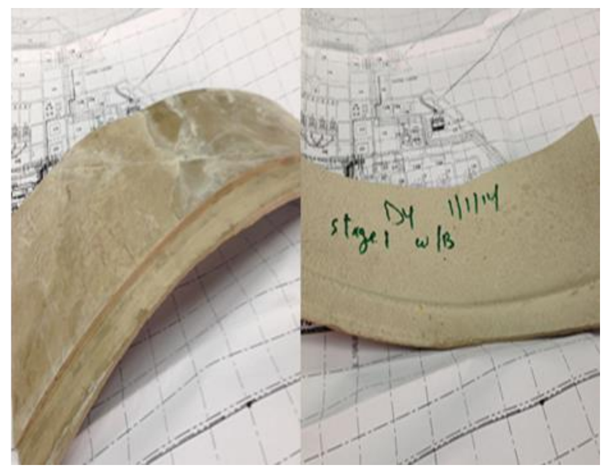
- Sabiya Desalination Plant is facing serious challenge as seawater feed contains high concentrations of silt and sand.
- RO technology is not feasible at Sabiya.
- MSF is the only technology utilized at Sabiya Desalination Plant.

Satellite Image of Sabiya Feed Intake

Desalination Challenges at Northern Kuwait (cont'd)

- MSF at Sabiya encounters scale deposition and fouling problems;
- High energy consumption by MSF;
- Increase in maintenance costs;
- Desalinated water cost at Sabiya is high; and
- Reduction in process performance and availability.

Heat exchanger covered with silt



Scale formation in distiller pipes

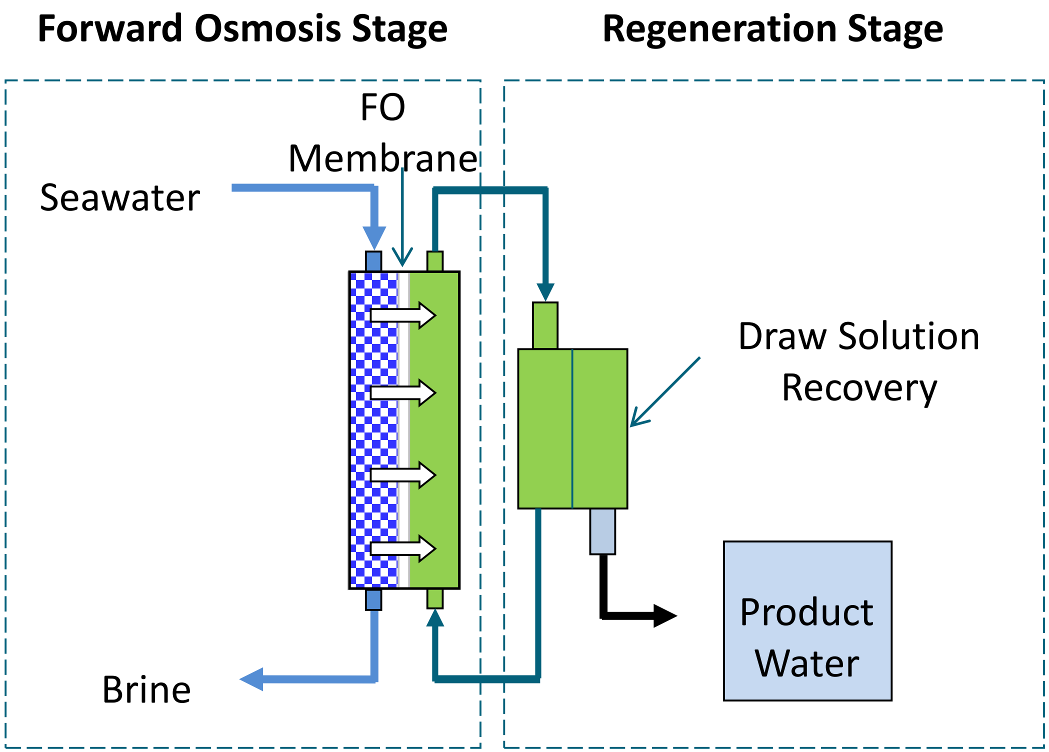
Kuwait Vision 2035

- Kuwait government's 2035 economic vision aimed at weaning the country off its dependence on oil and transform it into a diversified commercial and financial hub for the region.
- Several mega-projects and new urban residential developments coming up to the northern Kuwait such as: Al-Hareer City, North & South Al-Mutlaa City, Boubyan Island, Mubarak Al-Kabeer Port.
- Limited sites are available in southern coastal areas.
- Multiple sites are available in northern coastal areas.
- A substantial need for innovative desalination plants to support the government's 2035 economic vision.

Forward Osmosis (FO) Membrane Desalination Technologies

- Forward Osmosis (FO) is a promising technology to overcome the challenges at northern coastal areas of Kuwait.
  - ✓ FO is less prone to fouling.
  - ✓ Avoids foulant accumulation with absence of hydraulic pressure.
  - ✓ Fouling control and membrane cleaning are more feasible.
  - ✓ Reported Maximum Silt Density Index (SDI) is 8.

Forward Osmosis (FO) Membrane Desalination Technologies (cont'd)



FO Process

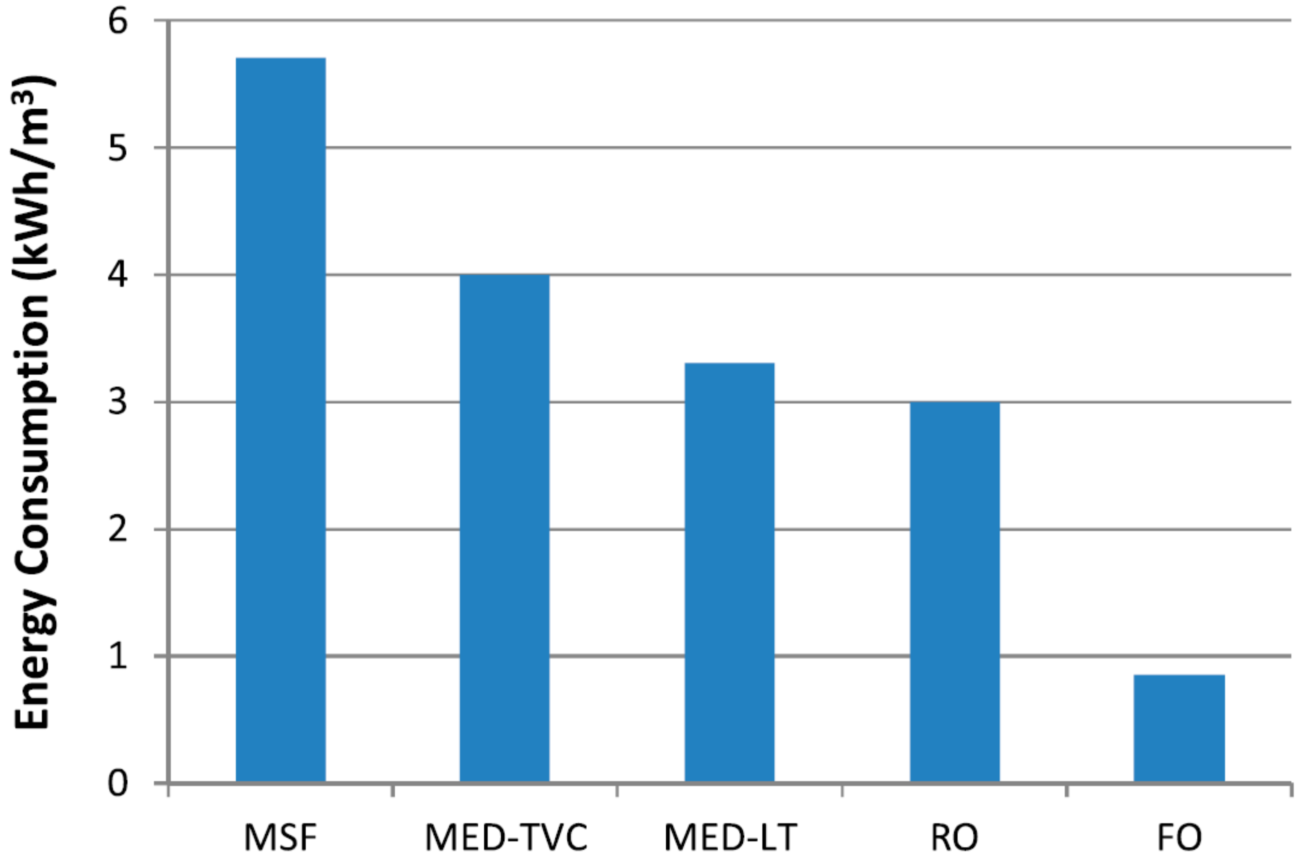
FO Applications:

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

Comparison between RO and FO Membrane Technologies

Sort	Reverse Osmosis (RO)	Forward Osmosis (FO)
Driven Pressure	High hydraulic pressure	Osmosis pressure difference
Water Recovery	30% ~ 50%	At least 75%
Scaling and Fouling	Seriously	Hardly
Energy Consumption	High energy demand	Low energy demand
Equipment [sic]	High-pressure pumps; Energy recovery unit; Resistant high-pressure pipelines; High investment in equipment [sic]	Low investment in equipment
Environment Effect	Harmfully	Friendly
Modules	Compression resistance	Without particular desire
Application	Normal separation system	Temperature-sensitive system; Pressure-sensitive system; Renewable energy; Controlled release of drug

Energy Consumption by Desalination Technologies (Equivalent Work)



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

Waste Heat Utilization

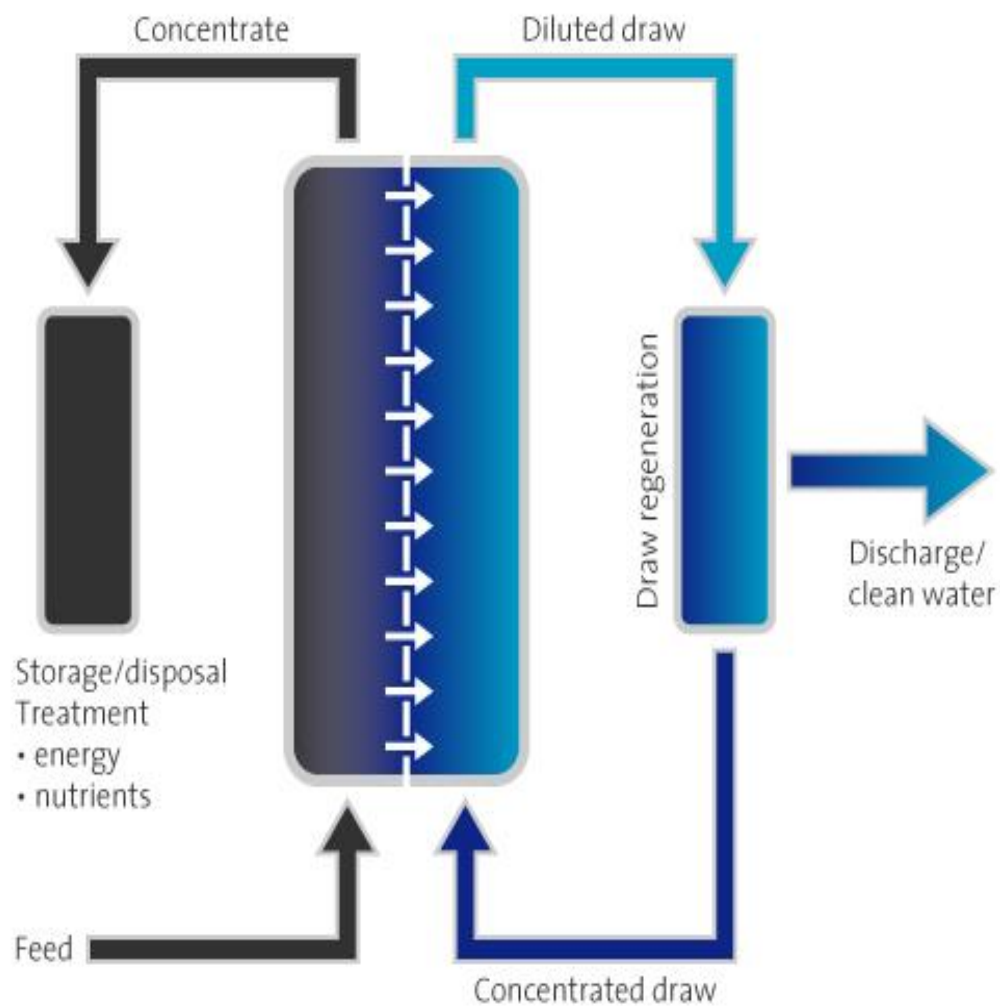
Comparison between Conventional Thermal Desalination Technologies and FO Process on Waste Heat Utilization

Technology	Gain Output Ratio	Waste Heat Utilization (%)	Water Production Rate (tonne/h)
MSF	8 – 12	27.1	64.9 – 97.4
MED	6 – 12	63.8	105.6 – 211.1
FO	10 – 14.8	85.7	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.

FO Challenges

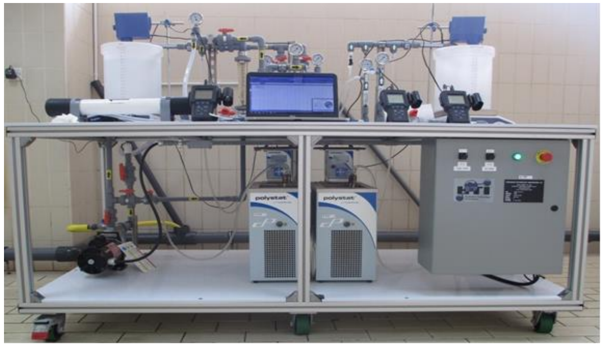
- **Membrane performance**
  - ✓ Material CTA/TFC
  - ✓ ICP/ECP
  - ✓ Thickness
  - ✓ Scaling & Fouling
- **Module Selection**
  - ✓ Flat sheet, Tubular, Hollow Fiber, Spiral Wound
- **Draw Solution**
  - ✓ Organic/Inorganic
- **Draw Solution Recovery**
  - ✓ Membrane Process
    - RO, NF, MD
  - ✓ Thermal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



Principle of FO Technology

Collaborative Projects on Development of Forward Osmosis Technologies in Kuwait

Lab-Scale FO Test Unit

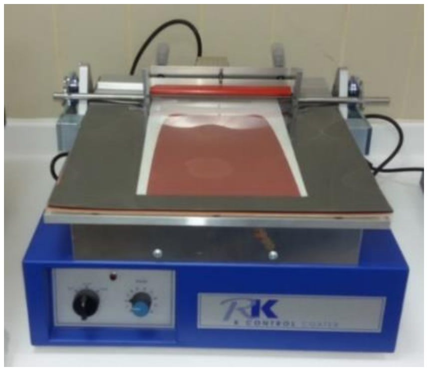


Semi-Pilot FO Test Unit

FO Pilot Test Plant

- Lab and pilot-scale projects involving collaboration with international partners in the areas of development of FO membranes and draw solutions for desalination.
- Efforts involve development of the state of the art of the FO membrane technologies including FO-RO and FO-thermal-based processes, such as absorption and MD.
- Future Vision: development of innovative FO powered by renewable energy and low-grade heat such as waste-heat.

Fabrication of Innovative Membranes for Seawater Desalination



Flat Sheet Membrane Casting Machine

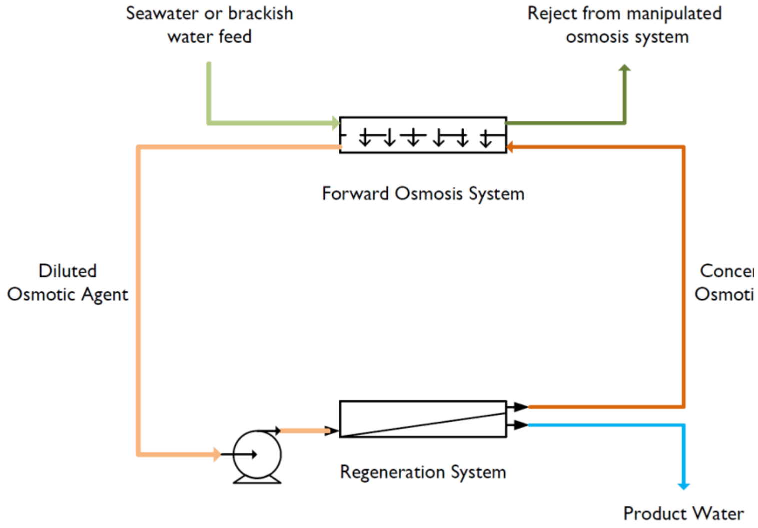
Hollow Fiber Membrane Spinning Machine

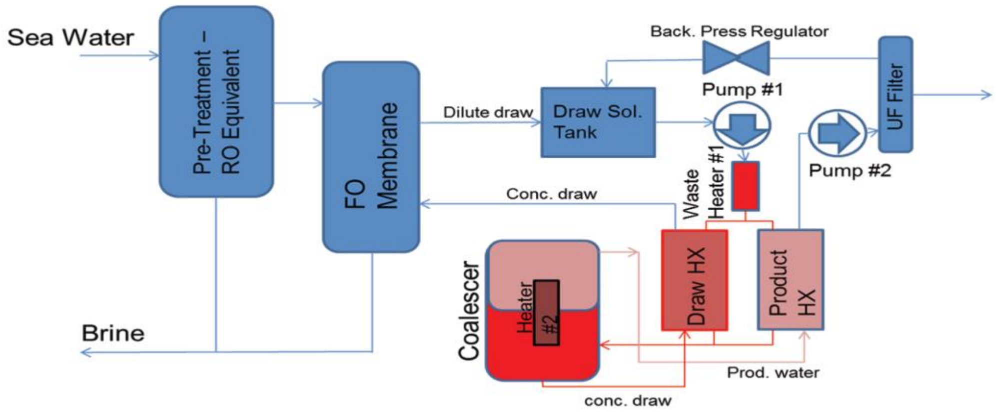
Hydrophobic Membranes Extruder

Membrane Characterization Instruments

- WRC exerted efforts to conduct research on innovative membrane fabrication and characterization for FO, PAO, and PRO processes.

Available FO Technologies on Pilot Scale



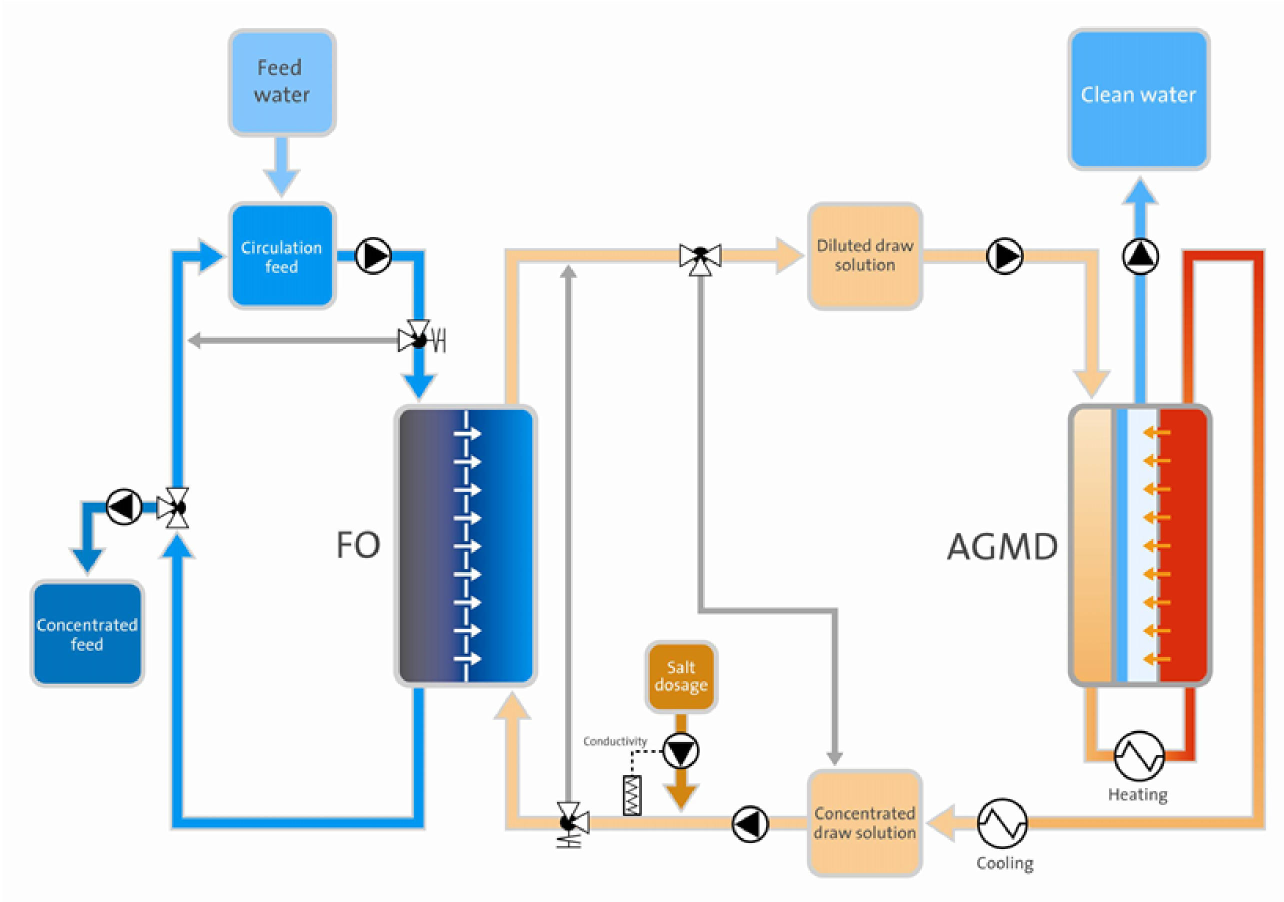


FO-RO

FO-Thermal Separation

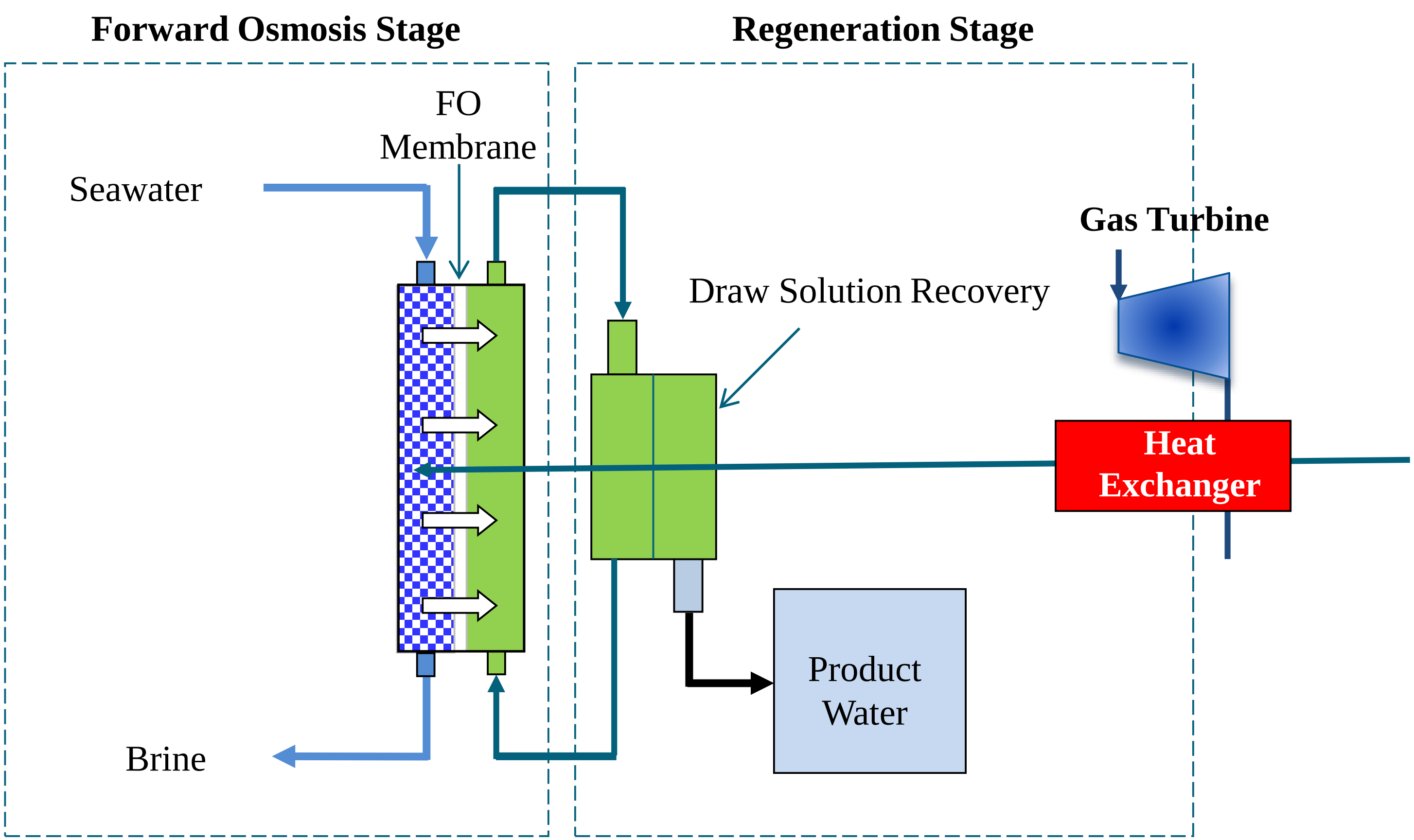
Simplified Diagrams of the Available FO Technologies for Seawater Desalination

Proposed Hybrid FO-MD Technology



A Simplified Flow Process Diagrams of the FO-MD Test Unit

Proposed FO using Waste-Heat Generated by Gas Turbines



Simplified Diagram of FO Technology for Seawater Desalination

Proposed FO using Waste-Heat Generated by Gas Turbines for Northern Coastal Areas

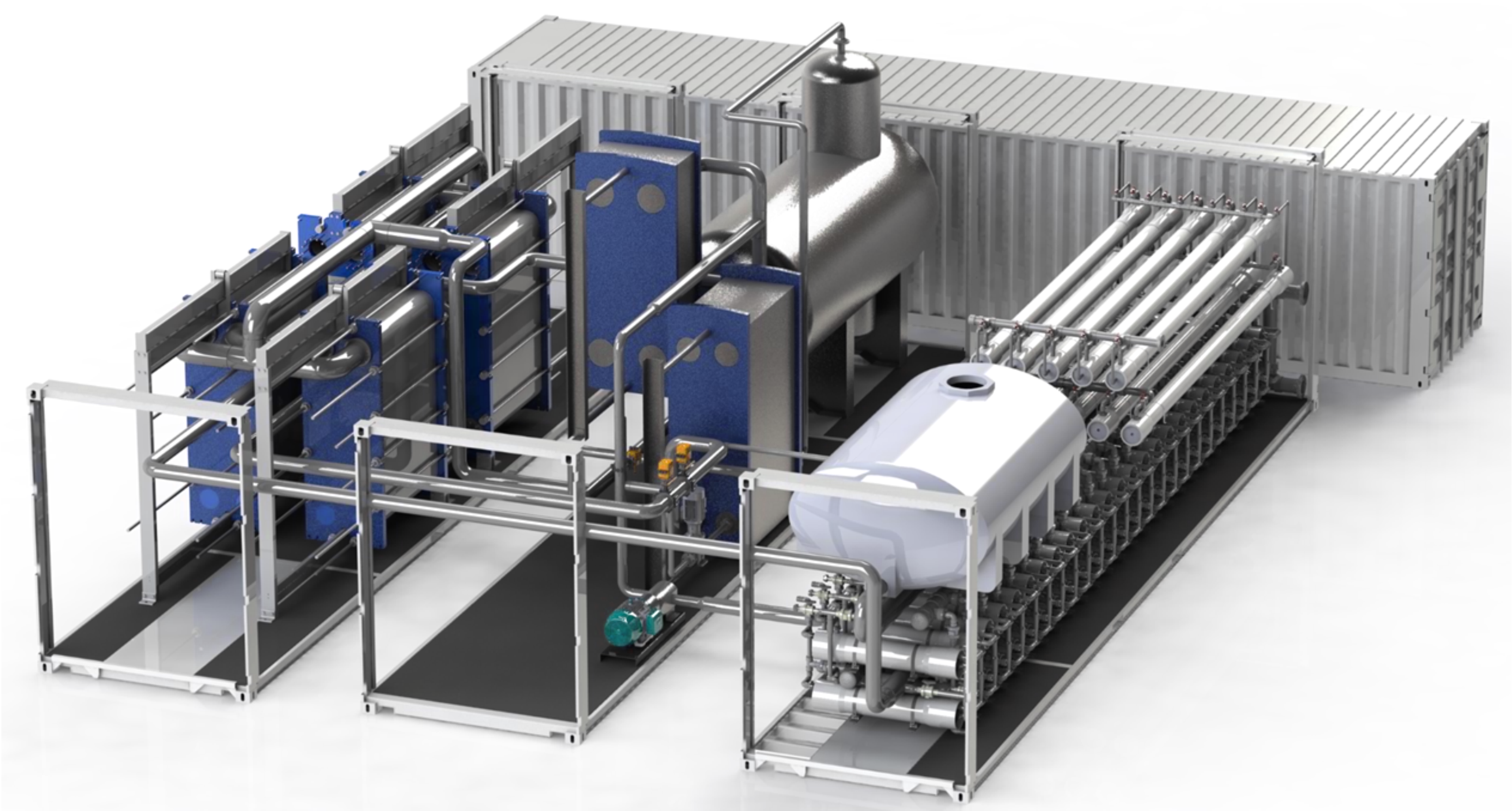


Image of the Proposed FO technology

KISR Project: Pilot-Scale Investigations

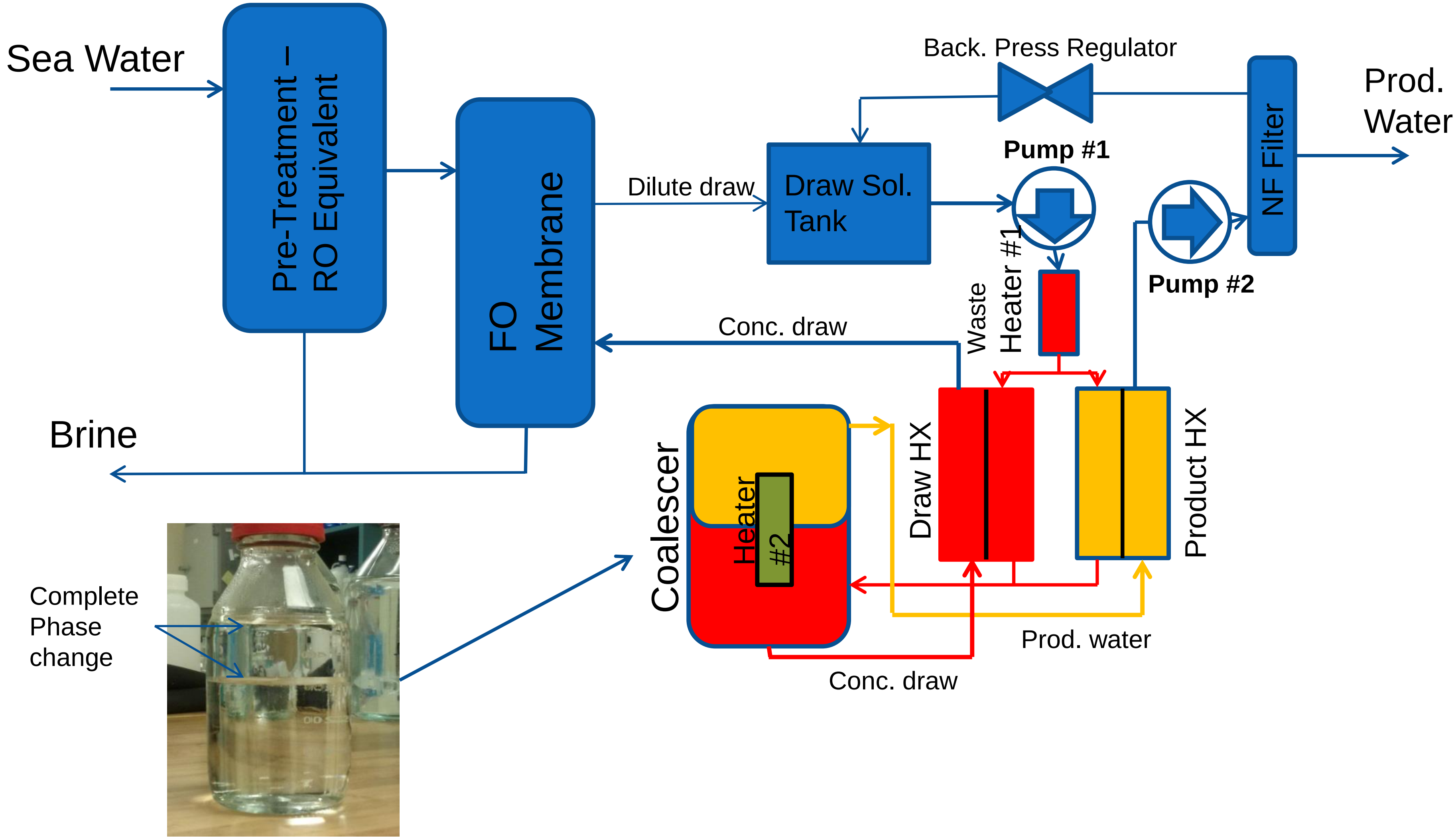
- KISR and Trevi System Inc. had collaborated in developing the FO system, on pilot scale, with the aim of desalinating seawater under the prevailing conditions of Kuwait.

- The capacity of the investigated FO pilot plant test unit is 10 m^3/d using a commercial-scale Toyobo FO membrane.

- Investigated operating conditions:

    - Feed and Draw Solution Flow-Rate;
    - Draw Solution Temperature;
    - Draw Solution Type (Polymeric Grade); and
    - FO Membrane Type (bore size)

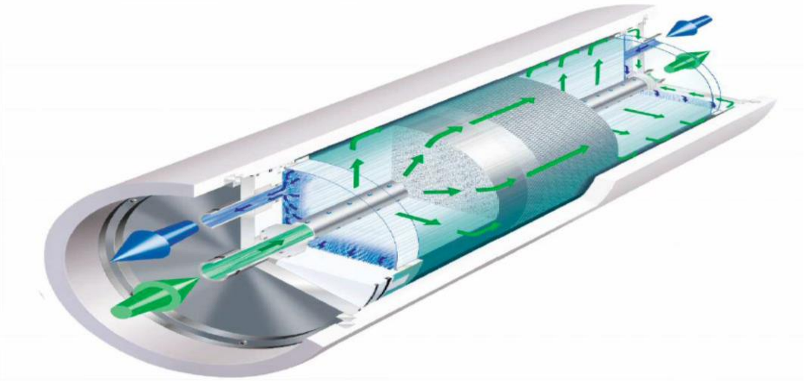
KISR Project: Pilot-Scale Investigations (cont'd)

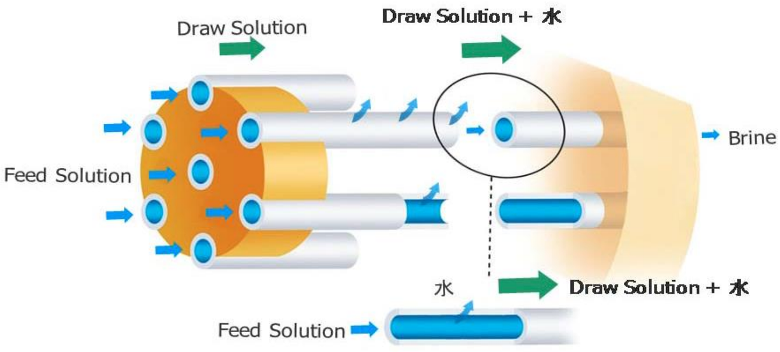


Schematic Diagram of the investigated FO Pilot Plant Test Unit at KISR

KISR Project: Pilot-Scale Investigations (cont'd)

- **TOYOBO** developed Hollow Fiber (HF) FO membrane module with **the outstanding spinning technology**.
- Advantages of Hollow Fiber membrane module:
  - **Larger membrane surface area**
  - **Less membrane thickness** which reduces the osmotic pressure loss inside the membrane.
  - **Improved pressure resistance**.





KISR Project: Pilot-Scale Investigations (cont’d)

FO Pilot Plant Test Unit with a Capacity of 10 m^3/d

KISR Project: Pilot-Scale Investigations (cont'd)

Pre-treatment unit of FO Pilot Plant Test Unit

KISR Project: Pilot-Scale Investigations (cont'd)

Commercial Scale FO module from Toyobo Japan

KISR Project: Pilot-Scale Investigations (cont'd)

Post-treatment unit of FO Pilot Plant Test Unit

KISR Project: Pilot-Scale Investigations (cont'd)

Control and Data Acquisition System

Materials used in Pilot Scale Investigations

- Membrane used was recently developed commercial 10 inch HF FO membrane from TOYOBO, Japan.
- FO HF membranes tested are 135 and 230 micron membranes with approximate thickness of 100 μm and 140 μm, respectively.
- The polymer draw solution used was ethylene oxide-propylene oxide copolymer (TL-1150-1) patented by Trevi systems Inc.
- The feed used was Arabian Gulf seawater (AGS) obtained from beach well located at Desalination Research Plant (DRP) in Doha, Kuwait.

Results and Discussions

FS flow rate, lpm	DS flow rate, lpm	135μ membrane		230μ membrane	
		Capacity, m^3/d	Recovery ratio %	Capacity, m^3/d	Recovery ratio %
16.0	8.1	4.6	22.6	5.5	23.7
	10.1	4.8	27.6	6.3	28.8
	12.1	4.9	28.5	7.0	31.2
	14.1	5.2	27.9	7.2	31.1
	16.1	4.7	26.6	7.1	29.9
	18.1	4.2	25.8	6.5	28.9

Effect of DS Flow Rate upon Production capacity and Water Recovery Ratio

Results and Discussions (cont'd)

Parameter	Unit	135µ membrane			230µ membrane		
		AGS Feed	FO Product	FO Brine	AGS Feed	FO Product	FO Brine
pH		7.5	6.7	7.4	7.5	7.2	7.3
Conductivity	mS/cm	54.8	0.19	78.6	54.8	0.29	75.6
TDS	ppm	39841	78	61266	39841	133	62387
Calcium	mg/L	784	2.64	1144	784	2.16	1176
Magnesium	mg/L	1314	1.17	1720	1314	5.83	1846
Sulfate	mg/L	1980	0	4600	1980	0	2100
Chloride	mg/L	25457	63	40940	25457	69	38780
Sodium	mg/L	13,853	51	20,100	13,853	44	21,515
Alkalinity	mg/L	142	4.3	155.6	142	5.5	232
Boron	mg/L	3.3	0.24	2.9	3.3	0.21	3.2
Nitrate	mg/L	4.6	0.7	4.3	4.6	0.7	4.9
Copper	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Chromium	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Silica	mg/L	103	0.574	20.1	103	0.49	101.5
Phosphate	mg/L	0.52	0.11	0.3	0.52	0.02	0.40
Fluoride	mg/L	5.8	0.13	4.8	5.8	0.02	5.7

Physiochemical Analysis of AGS feed, FO Product and FO Brine using 135 micron and 230 micron membranes

Results and Discussions (cont'd)

- Total energy consumption by the FO pilot plant without the conventional electrical heater, PLC and control was around 1-1.2 kWh/m3.
- The tested FO pilot plant can produce freshwater with an energy requirement less than the conventional desalination processes, provided the energy needed for DS recovery is supplied in the form of low grade industrial waste heat or solar thermal energy.

Conclusion

- The innovative FO technology can be considered as an alternative desalination process for seawater desalination.
- Hollow fiber FO membranes with different bore diameters of 135 and 230 µm are suitable for seawater desalination.
- FO technology can produce water that meets the international standards.
- The FO pilot plant over a continuous stable operation of 30 days was capable to produce product water of TDS ≈ 70 to 150 ppm at water recovery ratio of ≈ 30%.
- FO desalination system is economically beneficial in commercial scale by integration of DS regeneration system with the low energy sources such as waste heat.

Recommendations

- Further applied research are needed to determine the most suitable membrane module and configuration, draw solution, and regeneration system for commercial scale applications.
- Detailed techno-economic analyses are recommended to estimate the actual Capital expenditures (CAPEX) and operating expenses (OPEX) of the investigated FO process and compare the figures obtained to the conventional desalination technologies such as MSF and RO.

Acknowledgements

Thanks to

Director General of KISR,

Director General of KFAS,

Ministry of Electricity and Water,

And

Executive Director of WRC/KISR

for their support towards the related research

thank you
tenki
hvala
takk
спасибо
kam sah hamnida
dank je
дзякуй
dziękuję
bedankt
dhanyavadagalu
tack
gracias
blagodaram
mèsi
xièxie
tanemirt
rahmet
enkosi
mochchakkeram
trugarez
arigatô
danke
kop khun krap
faafetai lava
akun
shukriya
ありがとう
kia ora
dankon
děkuji
manana
diolch
grazzi
mamnun
gràçie
kiitos
spas
ačiū
barka
dhanyavad
gratias ago
tau
शुक्रिया
dankie
sulpay
tapadh leat
chnorakaloutioun
gràcies
teşekkür ederim
bayarlalaa
obrigada
σας ευχαριστώ
mahalo
didi madloba
chokrane
rahmat
sagolun
murakoze
taiku
sukriya
obrigado
dakujem
misaotra
welalin
mercé
najis tuke
terima kasih
謝謝
köszönöm
asante
grazie
nandri
mersi
sobodi
nanni
vinaka
mauruuru
merci
matondo
cảm ơn bạn
go raibh maith agat
paldies
ngiyabonga