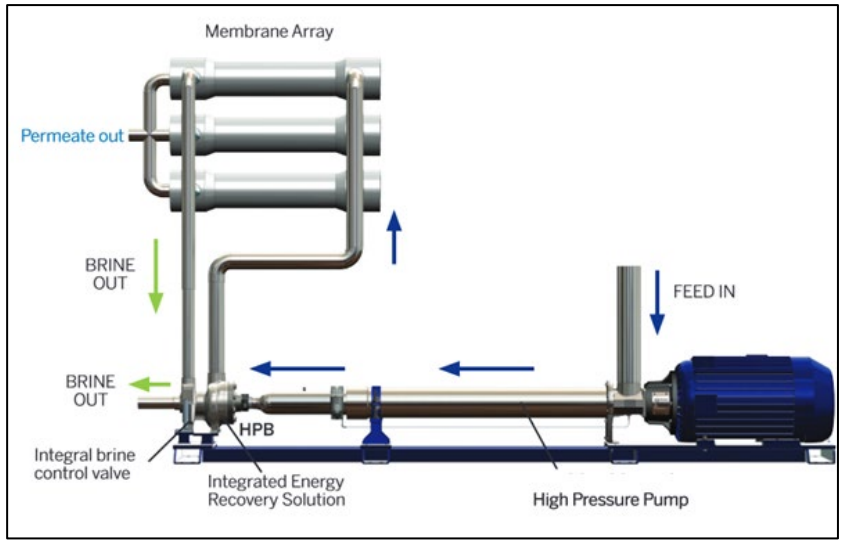
Energy Recovery Devices in Advanced and Emerging Reverse Osmosis Applications

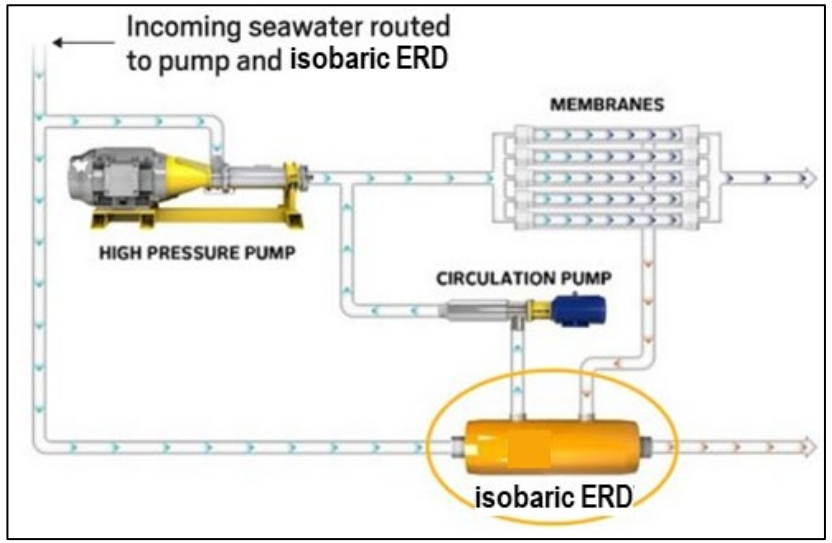
Richard L. Stover, Ph.D.

IDA 2022
WORLD CONGRESS
SYDNEY, OCTOBER 9 -13, 2022
CHARTING RESILIENT
WATER SOLUTIONS

Overview of Energy Recovery Devices



Turbocharger –
- HPP pumps less pressure
- up to 80% efficiency
- no mixing
- not tightly controlled



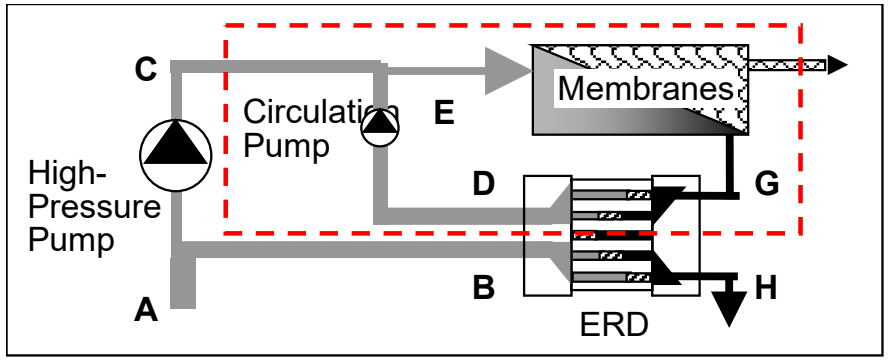
Isobaric Devices –
- HPP pumps less flow
- up to 97% efficiency,
- 0.5 – 2.5% mixing at membrane
- flows externally controlled

- ERDs reduce HP Pump duty
- High suction pressure
- Brine out back pressure
- Pelton turbines
- Reverse-running pumps

IDA International Desalination Association®
IDA 2022 WORLD CONGRESS
SYDNEY, OCTOBER 9 -13, 2022
CHARTING RESILIENT WATER SOLUTIONS

Mixing in Isobaric ERDs

$$M = \frac{C_D - C_B}{C_G - C_B}$$



- Derived by mass balance
- Eqns for bulk salinity
- Compounding affect
- Accurately accounted for in SOME membrane projections

$$S_m = \{S_f*[1-M*(1-R-L)]-S_p*[R*M*(1-R-L)]/(1-R)\}/[1-M*(1-R-L)/(1-R)]$$

Sm = salinity at the membrane feed
Sf = salinity of the feedwater
Sp = salinity of the permeate
R = recovery rate
L = ERD leakage, fraction of membrane feed flow

Salinity increase @ membranes
$SI \approx R*M*1.04$

IDA International Desalination Association
IDA 2022 WORLD CONGRESS
SYDNEY, OCTOBER 9 -13, 2022
CHARTING RESILIENT WATER SOLUTIONS

Energy Recovery Devices in Multi-Stage Systems

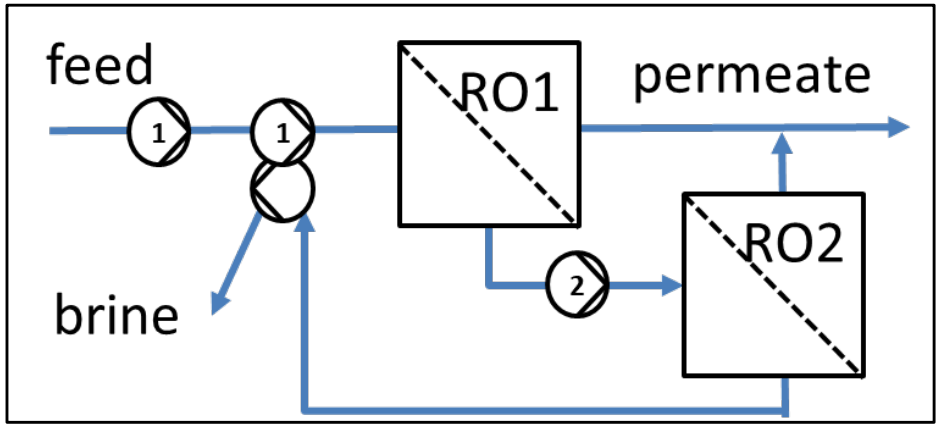


Figure 6. Single Turbo Booster

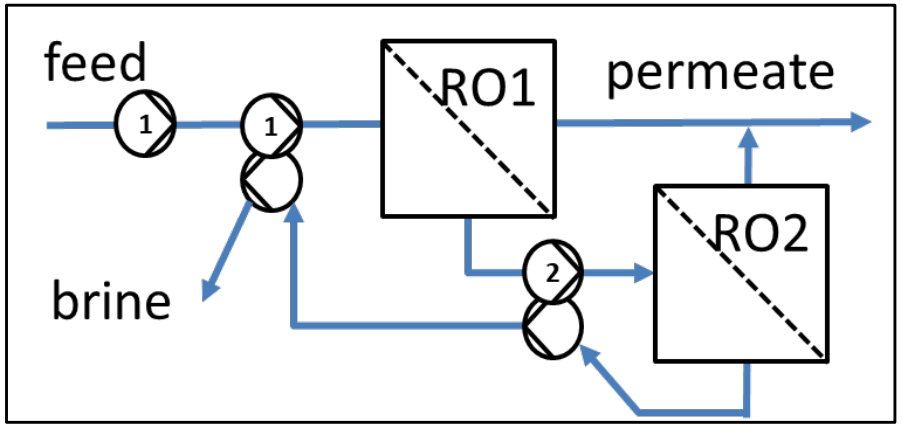


Figure 7. Two Turbo Boosters

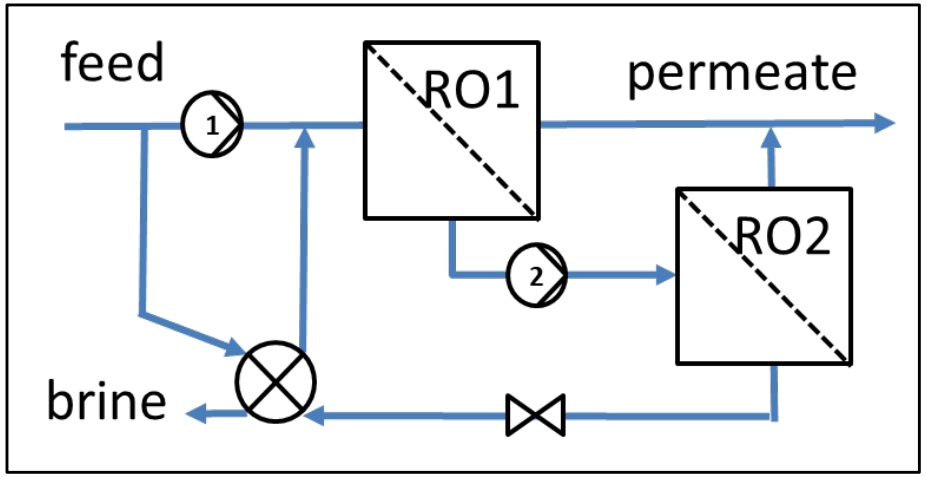


Figure 8. 2 Stages with Isobaric ERD

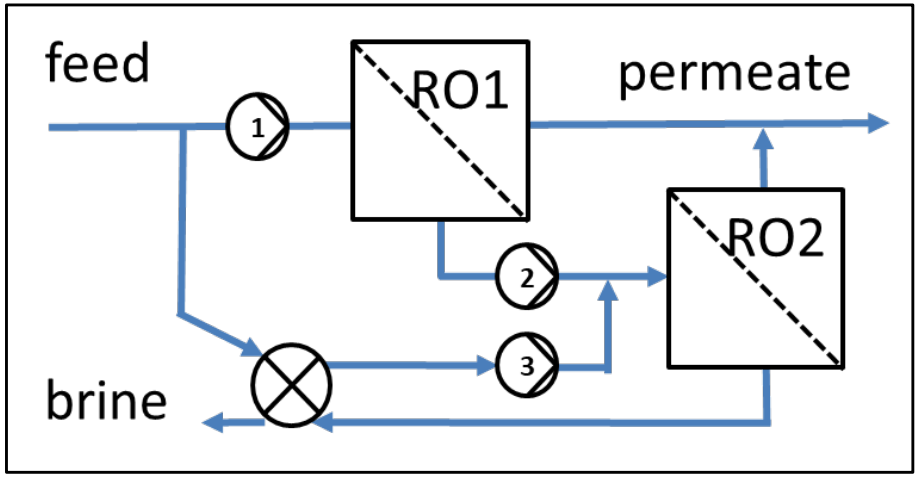


Figure 9. 1-1/2 Stages with Isobaric ERD

Energy Recovery Devices in Multi-Stage Systems

	no ERD	1 turbo	2 turbo	isobaric 2 stg	isobaric 1-1/2 stg
Flow (m3/h)	158.7	158.7	158.7	158.7	158.7
1st stg pressure (bar)	63.0	63.0	63.0	63.0	63.0
2nd stg pressure (bar)	75.7	75.7	75.7	77.8	71.5
total energy (kW)	**394**	**279**	**283**	**274**	**262**
specific energy (kWh/m3)	**3.94**	**2.79**	**2.83**	**2.74**	**2.62**

- 28-33% energy savings vs no ERD
  Compare to 50% savings in SWRO
- 1-1/2 stages w/ isobarics – lowest energy
  Energy min @ equal stage recoveries
- Two-turbo design solves high suction pressure pump problem

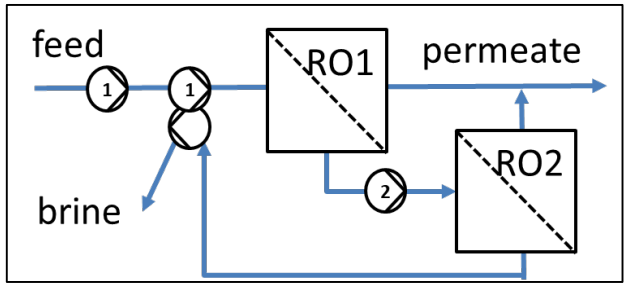


Figure 6. Single Turbo Booster

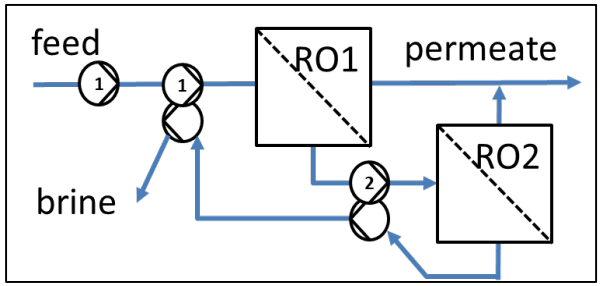


Figure 7. Two Turbo Boosters

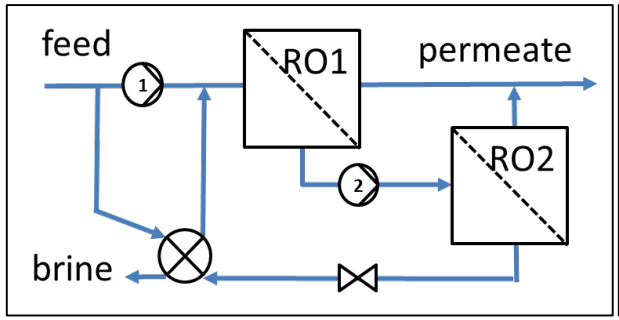


Figure 8. 2 Stages with Isobaric ERD

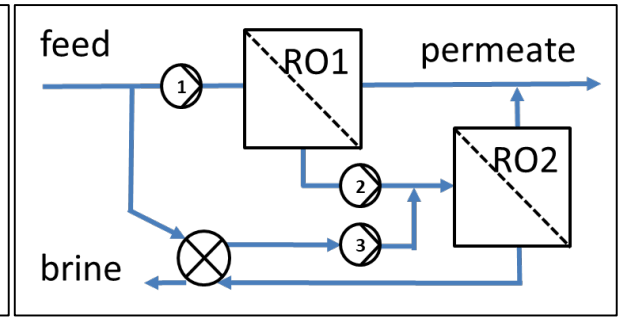
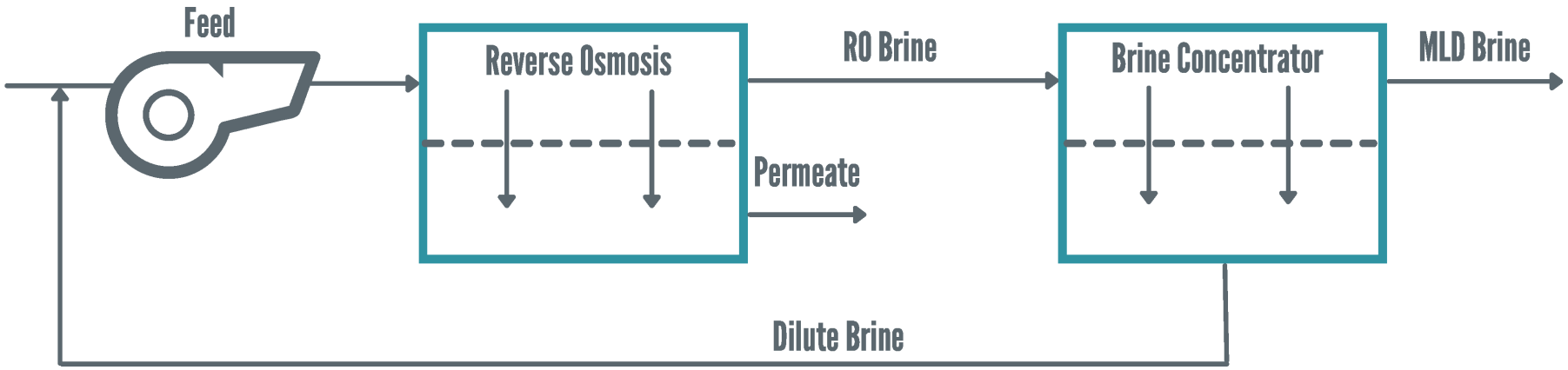


Figure 9. 1-1/2 Stages with Isobaric ERD

IDA International Desalination Association

IDA 2022 WORLD CONGRESS
SYDNEY, OCTOBER 9 -13, 2022
CHARTING RESILIENT WATER SOLUTIONS

Membrane Brine Concentration

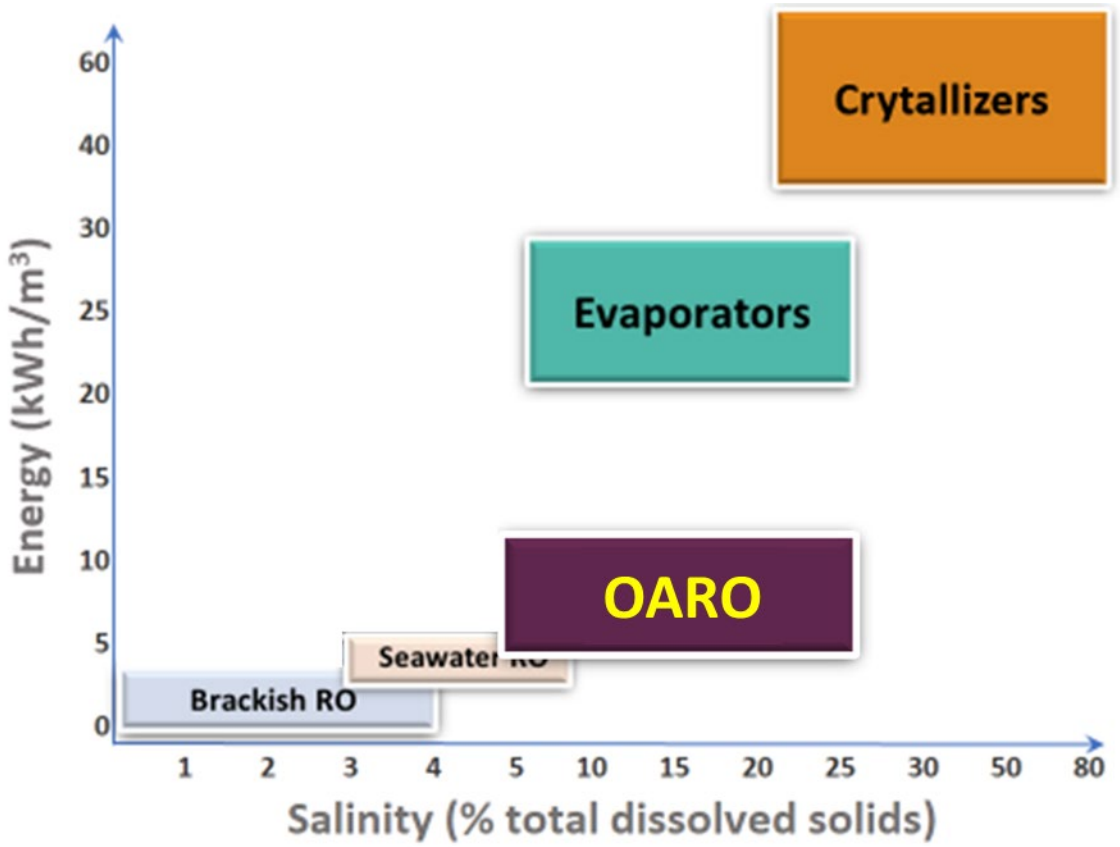


- Osmotically-assisted RO (OARO) - saline permeate lowers feed pressure
- Up to 260,000 mg/l TDS final brine
- Drinking quality permeate, independent of brine TDS
- SWRO components
- **Optimum stage permeability**
- **Thermodynamic balancing**
- **Optimum use of pumps & energy recovery devices**

IDA International Desalination Association®
IDA 2022 WORLD CONGRESS
SYDNEY, OCTOBER 9 -13, 2022
CHARTING RESILIENT WATER SOLUTIONS

Membrane Brine Concentration

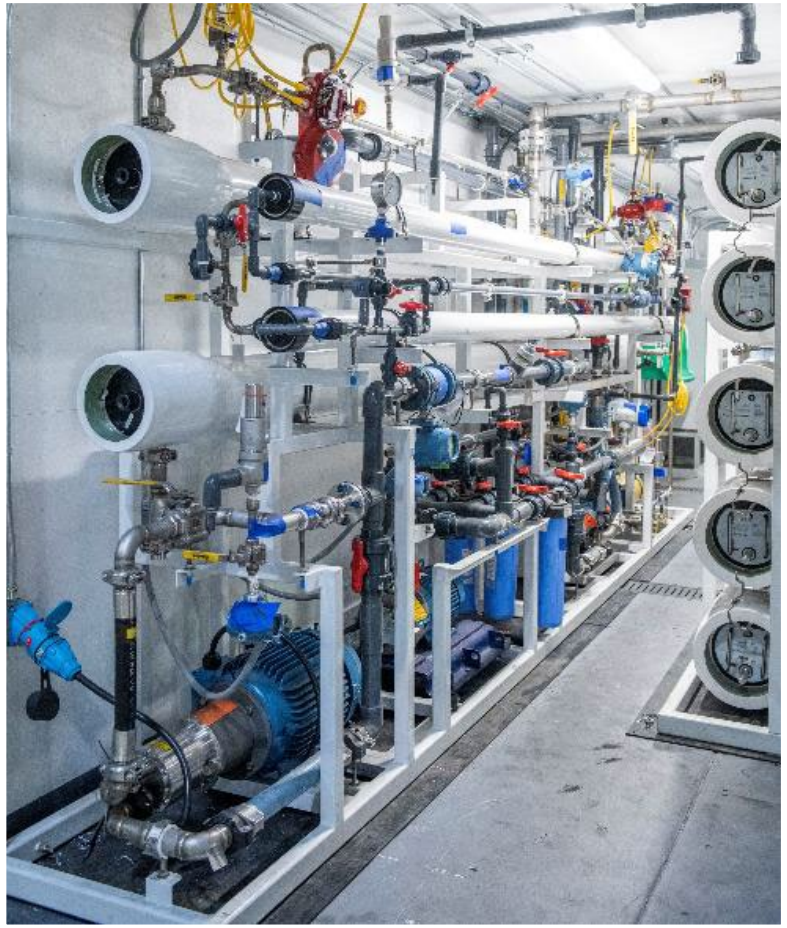
- Brine desalination
- Brine minimization
- Brine valorization
- Lower cost than UHPRO
- Much lower cost than evaporation



IDA International Desalination Association
IDA 2022 WORLD CONGRESS
SYDNEY, OCTOBER 9 -13, 2022
CHARTING RESILIENT WATER SOLUTIONS

Membrane Brine Concentration







IDA
International Desalination Association®

IDA 2022
WORLD CONGRESS
SYDNEY, OCTOBER 9 -13, 2022
CHARTING RESILIENT
WATER SOLUTIONS

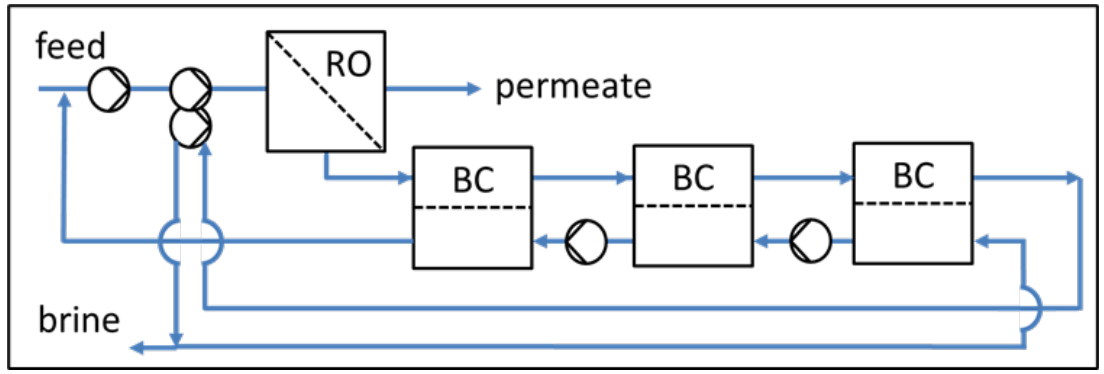
ERDs and Pumps in OARO Systems

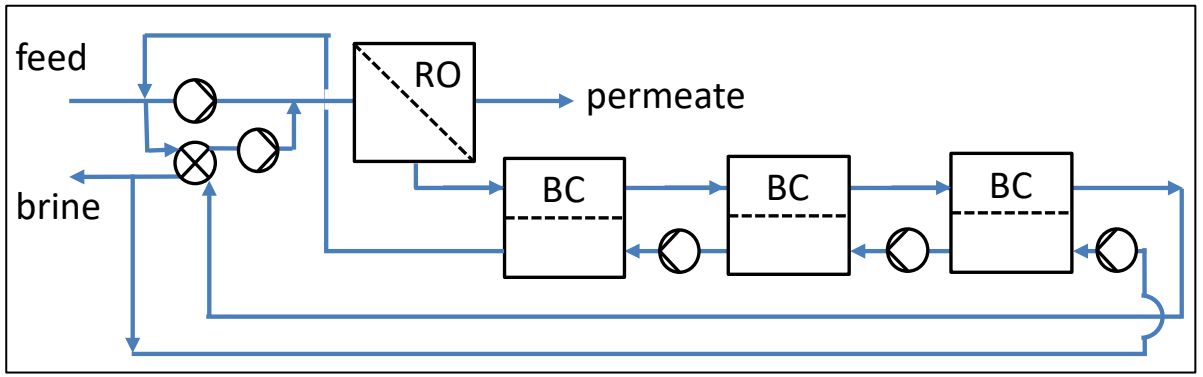
Feed – Brine – Permeate

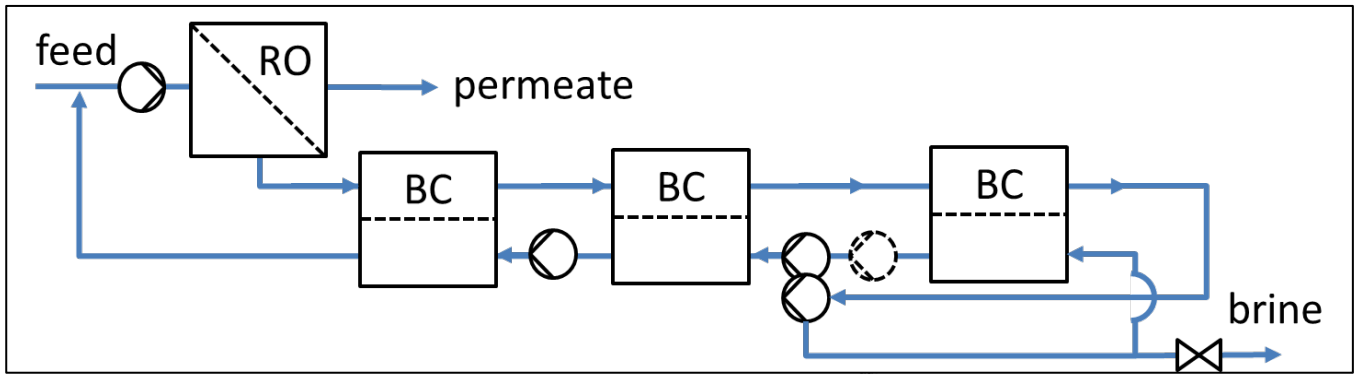
Dilute brine recirculation

Dilute brine injection point
- Feed/brine side, or
- Permeate side

ERD location
- Final brine stream and
- Head of process or
- Interstage







ERDs and Pumps in OARO Systems

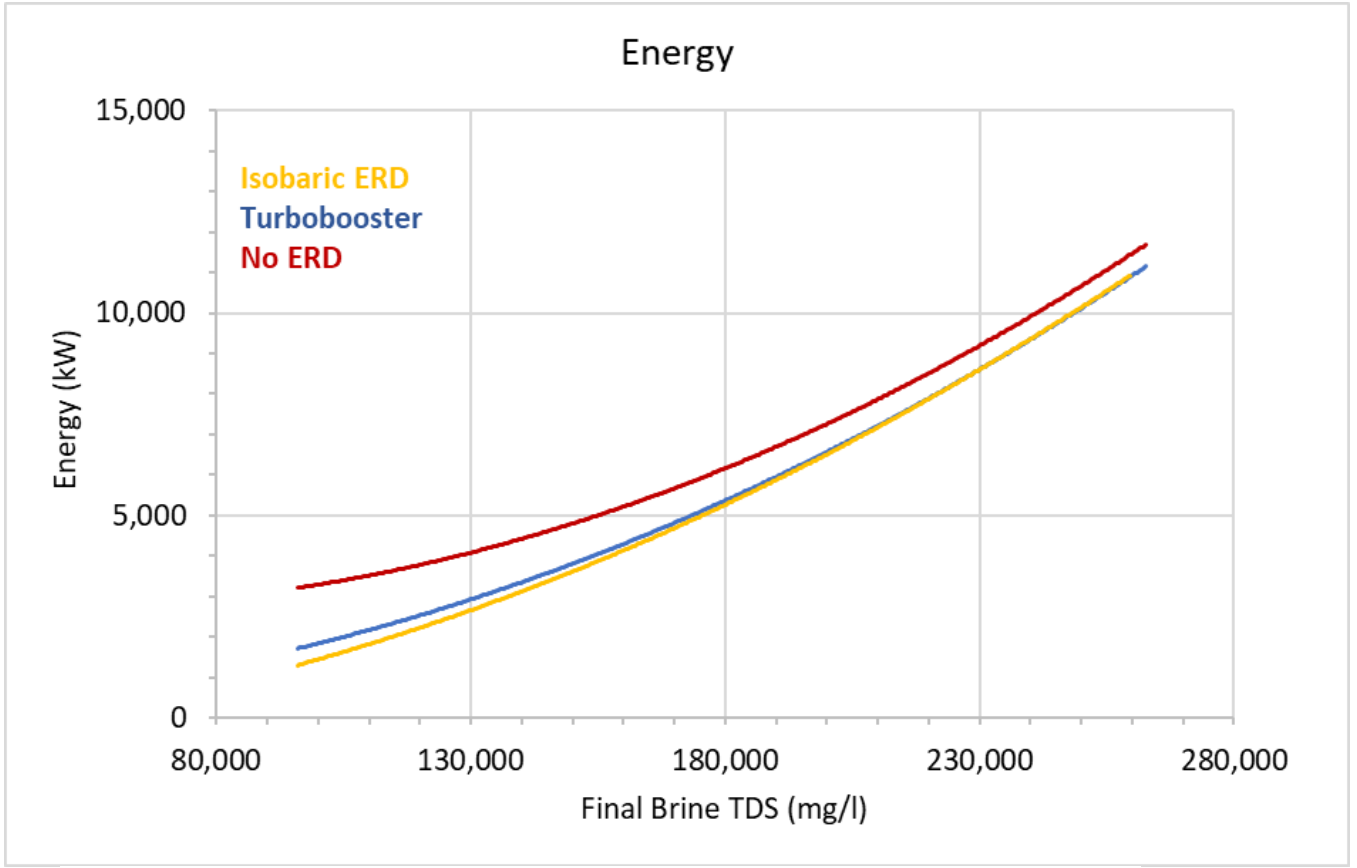
SWRO brine desalination or minimum liquid discharge (MLD)

ERDs save 5-50%

Less savings at high recovery
Similar to multi-stage RO - There is less brine

ERD type matters less at high TDS
Mixing impact greater

Specific energy 3.8 to 13 kWh/m^3 over TDS range
Less than ½ MVC evaporator



70,000 mg/l SWRO brine desalination

IDA
International Desalination Association
IDA 2022 WORLD CONGRESS
SYDNEY, OCTOBER 9 -13, 2022
CHARTING RESILIENT WATER SOLUTIONS

ERDs and Pumps in OARO Systems

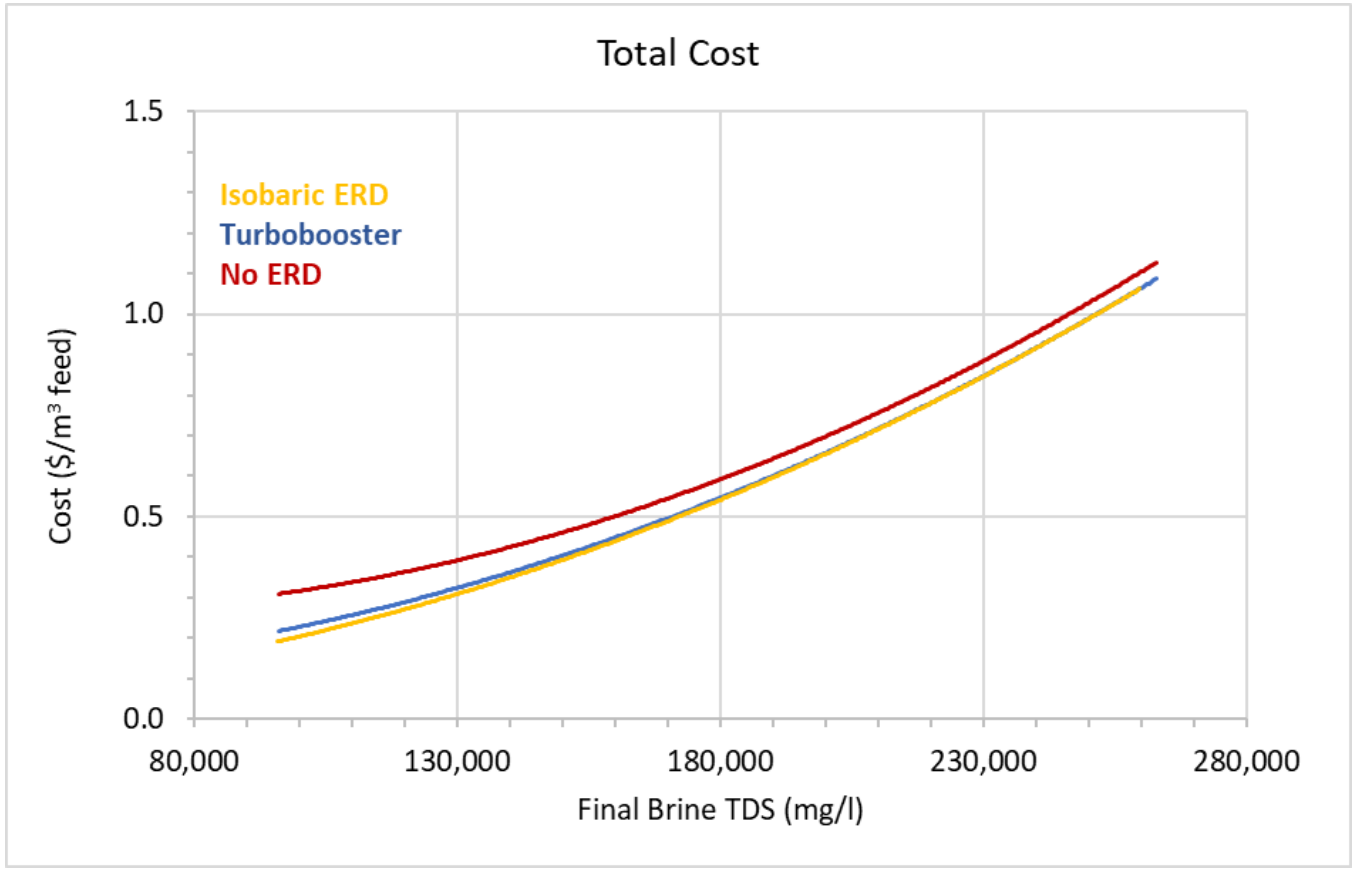
Assumptions

- 20 year amortized CAPEX
- 6% cost of money
- $0.06/kWh power
- OPEX includes spares, chems & power

Total cost reduction of up to 28% with ERDs

ERD choice should consider

- Flexibility
- System complexity
- Availability
- Customer service



70,000 mg/l SWRO brine desalination

IDA International Desalination Association®

IDA 2022 WORLD CONGRESS
SYDNEY, OCTOBER 9 -13, 2022
CHARTING RESILIENT WATER SOLUTIONS

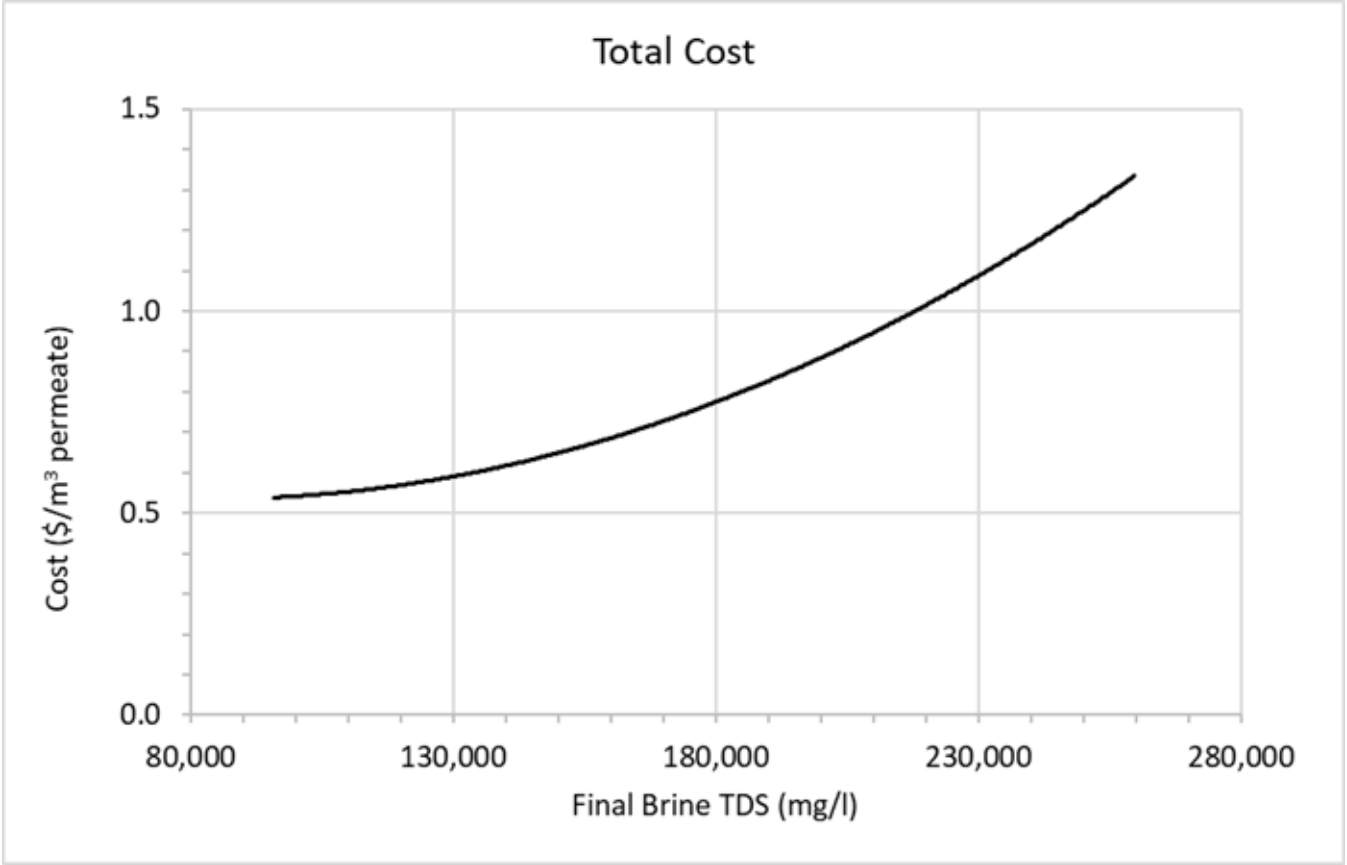
SWRO Brine Desalination with OARO

Same data as previous but now on a permeate basis

Total cost of OARO for 50-75% recovery from SWRO brine
- *Competitive with greenfield SWRO*

OARO stages added between SWRO and ERD
- *Even lower energy and cost*

SWRO expansion with OARO
- *No additional intake or outfall*
- *No additional pretreatment*
- *Brine dispersion effective, safe*



20 year amortized CAPEX
6% cost of money
$0.06/kWh power
OPEX includes spares, chems & power

CONCLUSIONS

- ERDs in multi-stage & advanced desal reduce energy by 5-50% and total cost by 5-25%
- ERDs provide less benefit at high recovery rates, so choice should consider secondary factors like availability & flexibility
- OARO with ERDs in MLD/ZLD: ½ the energy of thermal brine concentration
- OARO retrofit can economically increase SWRO plant production with no additional intake, outfall or pretreatment: < $1/$m^3$ permeate

ACKNOWLEDGEMENTS

The author thanks colleagues at ERI, Fedco and Danfoss for communication supporting this work

Supported by:

NSW GOVERNMENT

BUSINESS EVENTS AUSTRALIA

BUSINESS EVENTS SYDNEY



IDA 2022 WORLD CONGRESS

SYDNEY, OCTOBER 9 - 13, 2022

IDA International Desalination Association®

CHARTING RESILIENT WATER SOLUTIONS

#IDAWC2022