Water Reclamation with Reverse Osmosis – Staging and Energy Recovery

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Overview

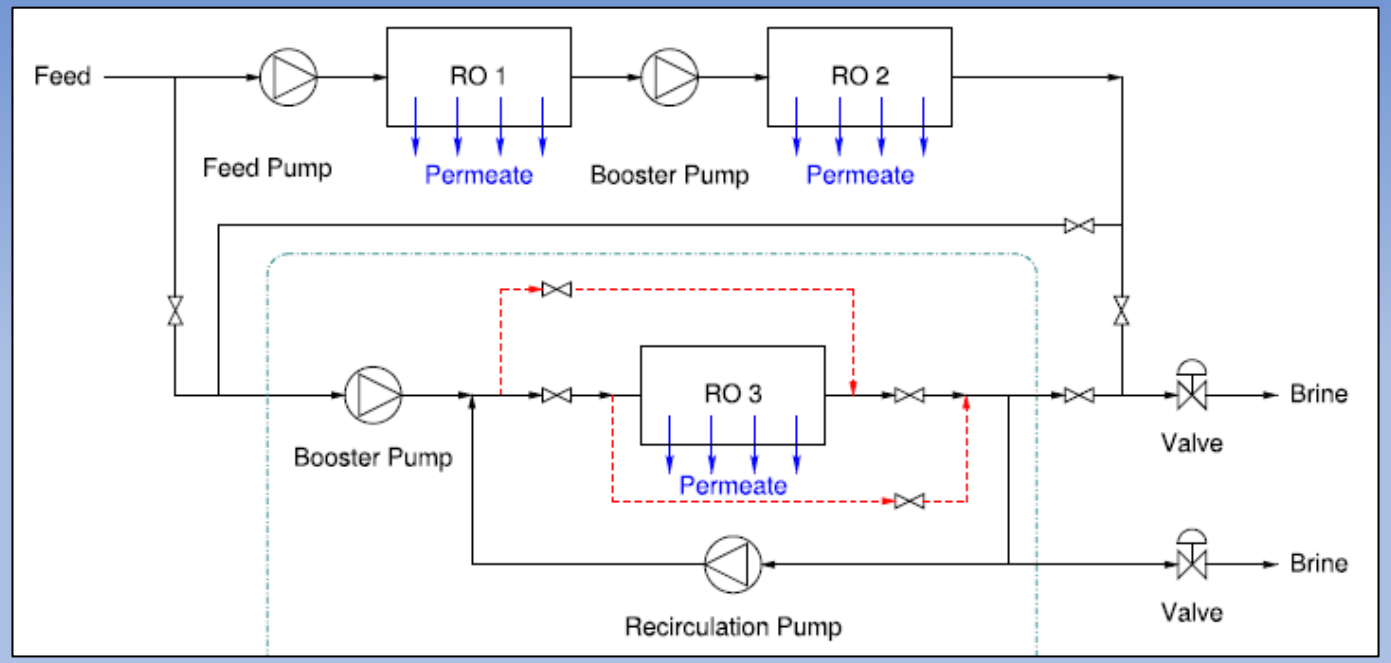
- Reverse osmosis (RO) is required in potable reuse
- Staging design affects water efficiency & fouling/scaling management
- Energy recovery devices save cost & enable innovative staging designs

This paper assesses RO process design options to increase energy efficiency and/or permeate recovery rate in water reclamation.

RO Staging

- Muni reuse: 75-90% recovery, balancing water efficiency & scaling avoidance.
- 3+ stages required for >80% recovery.
- Interstage boosting and/or permeate throttling applied to achieve even flux distribution – important for minimizing fouling.
- Novel processes like batch, semi-batch, and flow reversal can elevate recovery, reduce fouling, and benefit flux distribution, but can add capital cost, energy consumption, and process complexity.
- Detached 3rd stage can provide many of the benefits of novel processes while increasing uptime compared to conventional 3 stage.

Detached Third Stage

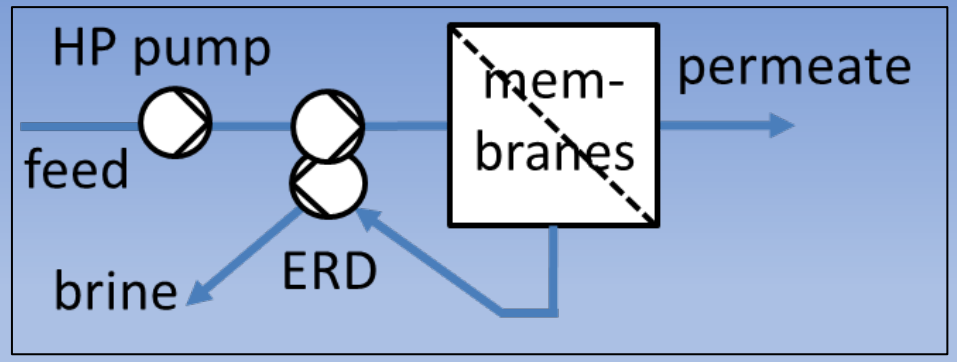


(Li, 2024)

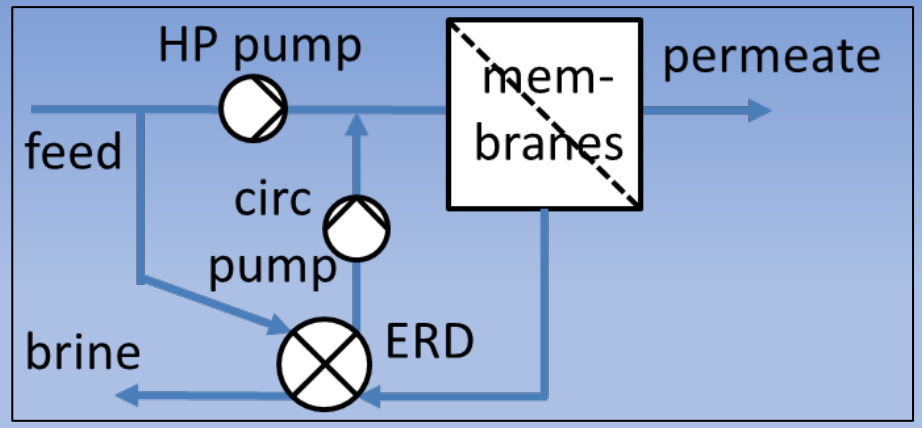
- Stages 1 and 2 operated gently and continuously.
- Stage 3 operated aggressively, intermittently, and creatively.
- Greater reliability than conventional 3 stage.

Energy Recovery Devices (ERDs)

Turbo Booster ERD



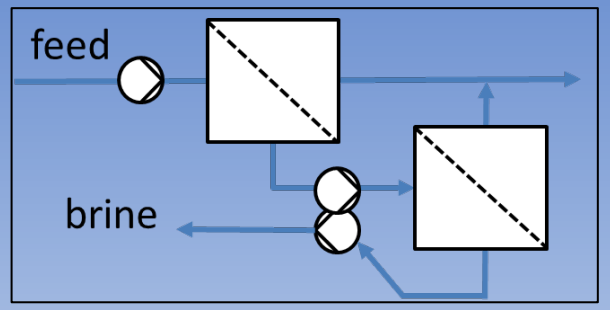
Isobaric ERD



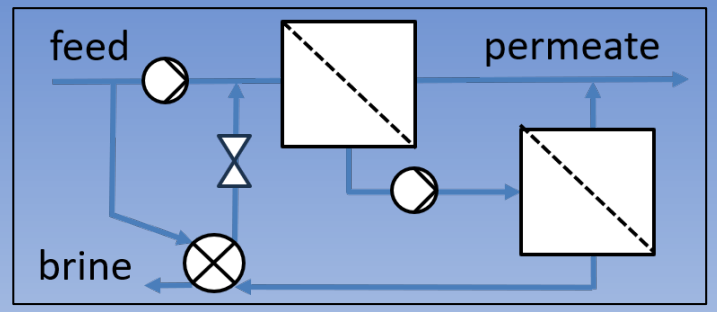
- ERDs recycle brine energy and reduce high pressure pump duty.
- ERDs are used universally in seawater desalination.
- ERDs now available for low pressure (< 400 psi) RO, including reuse.

Case 1 – Isobaric ERD vs Interstage Turbo

Interstage Turbo



Isobaric ERD with Interstage Booster Pump



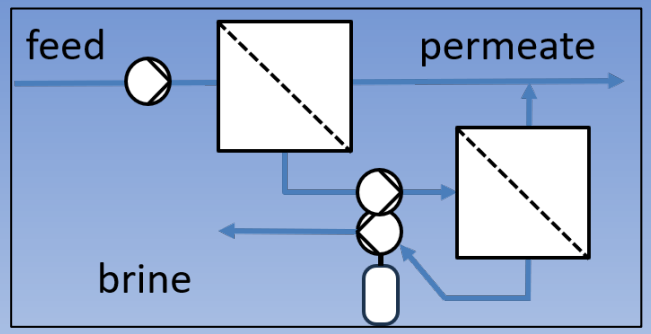
System Design	Power ($/y)	Capital Cost ($)	ROI (y)
Interstage Turbo	234,000	972,000	baseline
Isobaric ERD	220,000	1,012,000	2.7

- Both ERD options reduce system pump costs. Payback instantaneous.
- <3 year payback with isobaric ERD vs turbo. Continued savings for 20+ yrs.

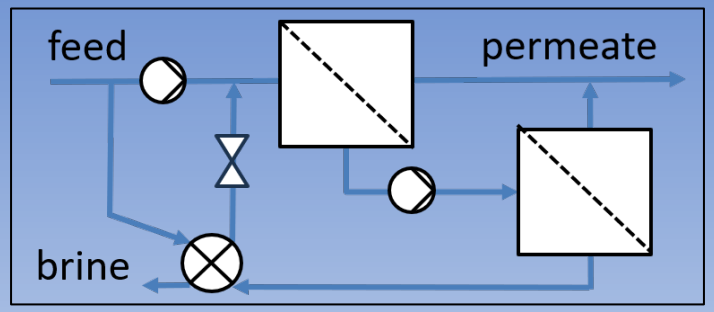
1,600gpm permeate, 210psi 1st stage, 230-240psi 2nd stage

Case 2 – ERD Process Options

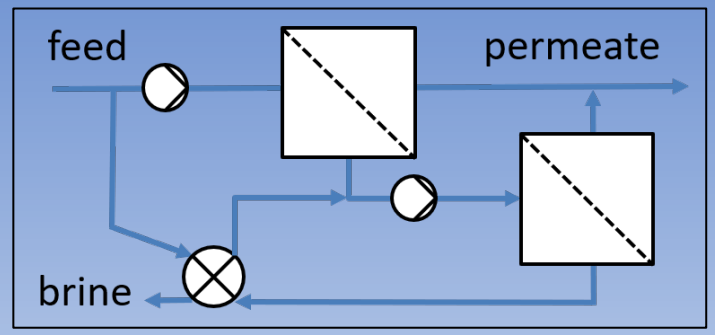
Two Stages w Motor-Driven Turbo



Two Stage System with Isobaric ERD



1.5 Stage System with Isobaric ERD

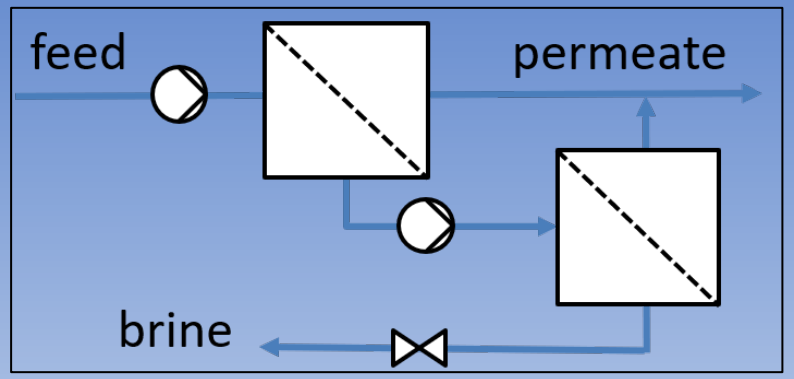


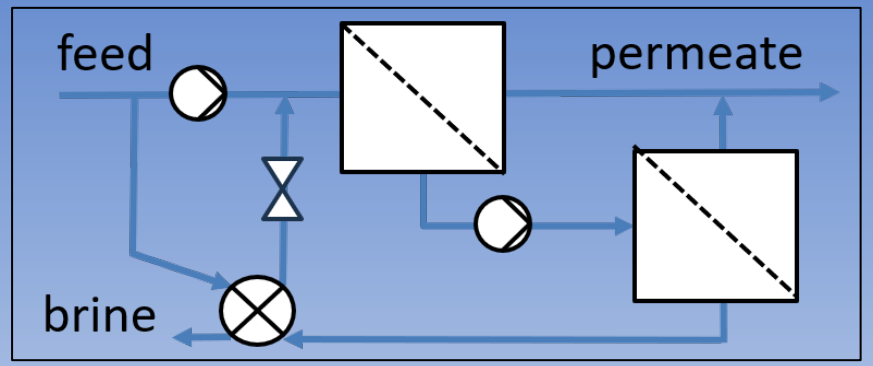
System Design	SEC (kWh/kgal)
No ERD	5.6
Two Stage with Isobaric ERD	5.0
1.5 Stage with Isobaric ERD	4.8
Two Stage with Motor Driven Turbo Booster	5.4

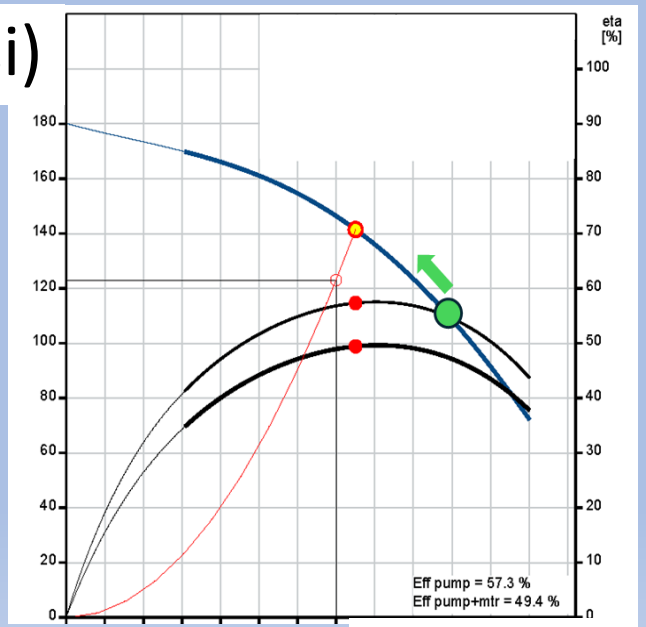
- Motor driven turbo efficiency low due to low rpm.
- Isobaric ERD requires throttle valve.
- <3-year payback w/ 1.5-stage design

3,500 gpm (5 MGD) permeate @ 85% recovery

Case 3 – Retrofit to Improve Pump Performance



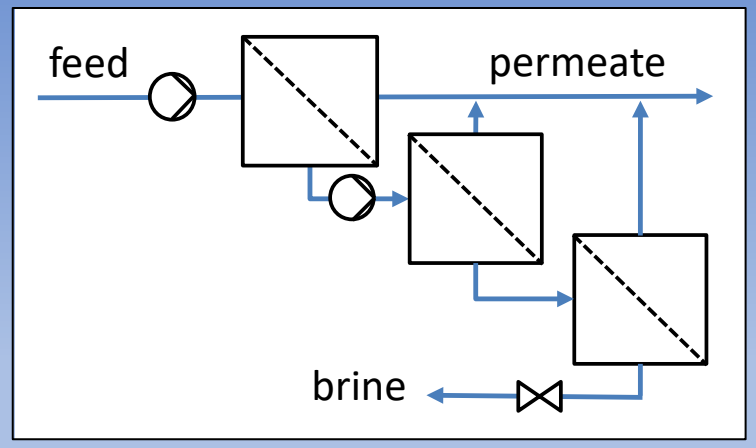




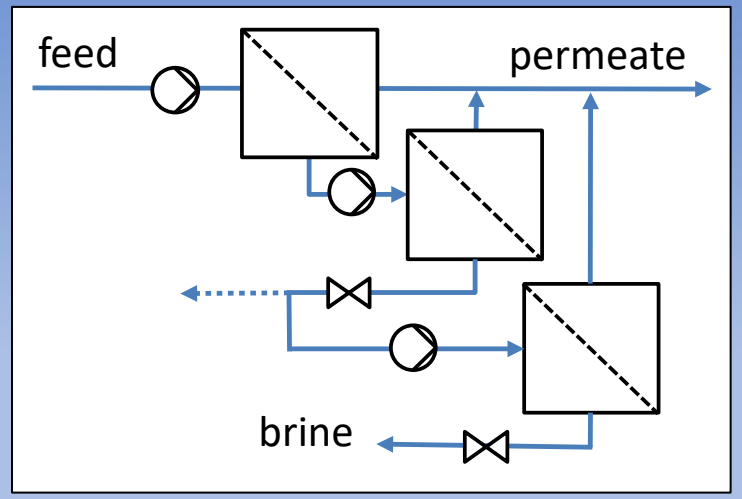
- Pump had moved off design efficiency point.
  - Feed salinity increase, or
  - Membrane compaction/fouling/scaling/aging
- ERD reduced HPP flow = elevated pressure.
- 17% permeate production increase.
- 13% specific energy consumption reduction.

Case 4 – Detached 3rd Stage with ERDs

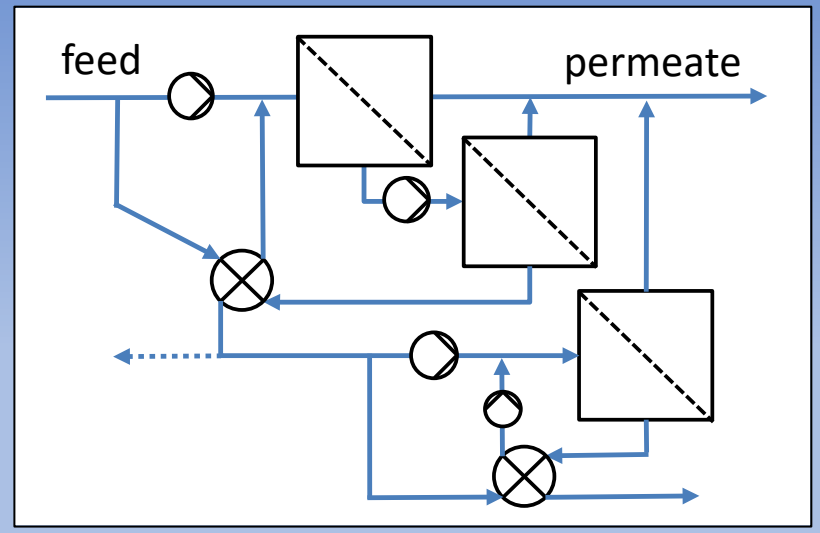
Non-Detached Third Stage



Detached Third Stage



Detached Third Stage with Isobaric ERDs



- Non-detached: Low energy, but entire train stops for cleaning.
- Detached 3rd stage: 2nd stage brine pressure broken, re-pumped to 3rd stage.
- Detached 3rd stage w isobaric ERDs on 2nd and 3rd stages:
  - Same energy as non-detached 3rd stage
  - More reliable than non-detached 3rd stage

CONCLUSIONS

- Proper multi-stage reverse osmosis designs for water reclamation and other low pressure applications can reduce fouling/scaling risk and increase productivity.
- Low pressure energy recovery devices save substantial cost and enable innovative staging designs.
- Detached 3rd stage with ERDs: more reliable with no energy penalty.

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