CornellEngineering
Civil and Environmental Engineering

CEE 4540

Sustainable municipal drinking water treatment

Topic: Zero Liquid Discharge

Instructor: YuJung Chang
YuJung.Chang@aecom.com

Class #20 11/07/2018 2:55 – 4:10pm

Review: Final BWRO Brine Disposal

- Evaporation Pond is cost-prohibitive for BWRO Brine Disposal due to very high construction costs; particular with the underlined barrier and monitoring for leakage & repair

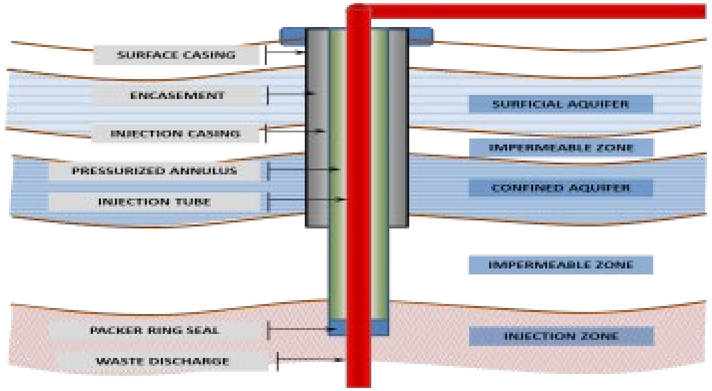
Outline

- RO Waste Brine Disposal Options & Challenges
- Emerging Technologies for Brine Minimization
- Emerging Technologies for ZLD
- Beneficial Uses of BWRO Brine: Brine to Chemical (B-to-C)



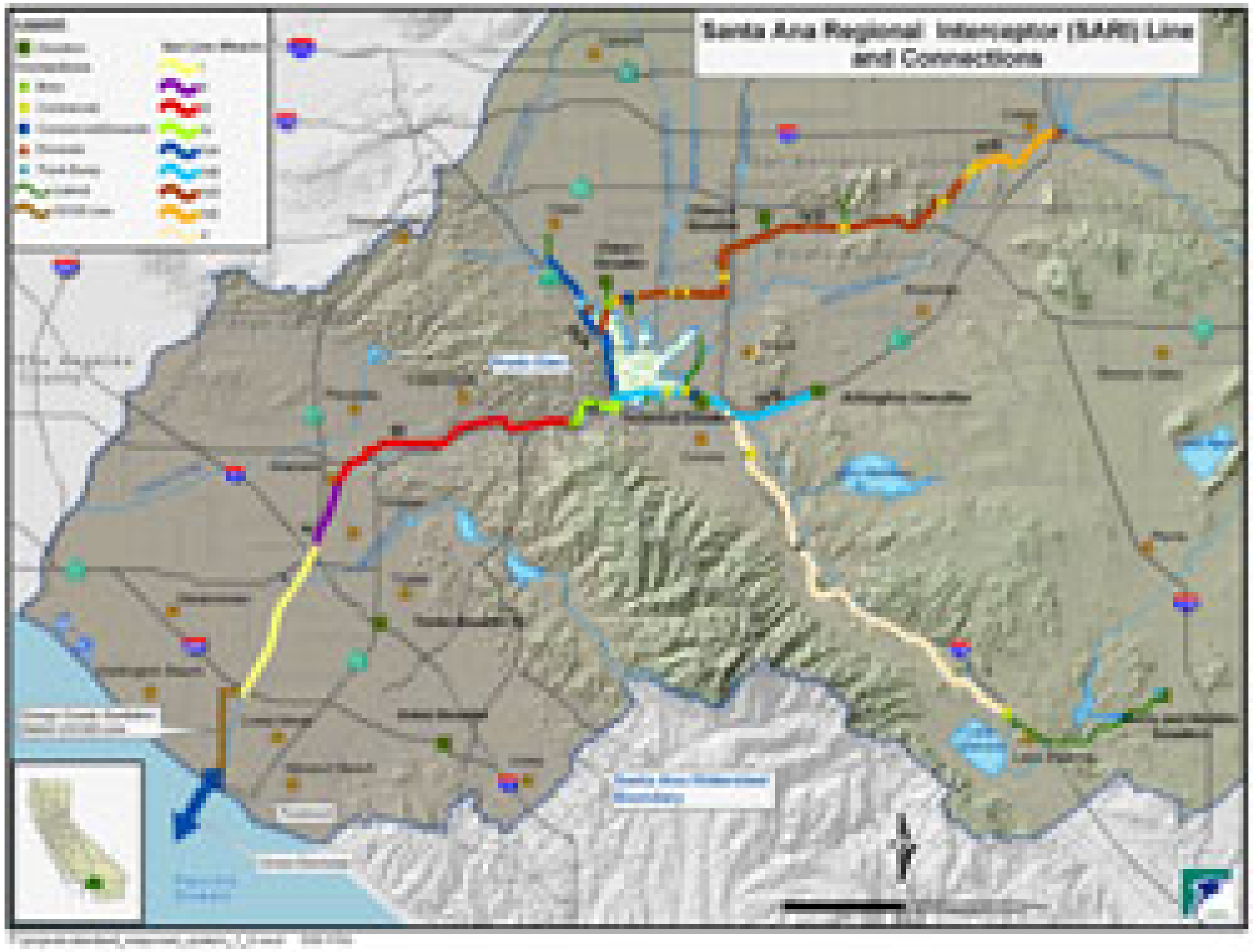
Challenges for Brine Discharge Options

- Sewer line (! ! ! !)
  - Depending on acceptability to WWTP based on brine water quality and impact to WWTP process as well as its discharge permit
- Surface water (! ! ! ! !)
  - Mostly prohibited due to high salinity
- Deep well injection (! ! !)
  - Only available to a few states
  - EPA is tightening up the restrictions
  - Not an option for seismic areas
- Dedicated brine line for ocean discharge (SARI) (! ! ! ! !)
  - Regional effort
  - Close proximity to the ocean
  - High maintenance



Dedicated Brine Line for Collection & Discharge of BWRO Brine

- Inland Empire, CA
- 25 Miles long
- $230 M Capital
- $9M Annual O&M Cost



Beneficial Application of BWRO Brine

- Road salts
  - Most states won't allow due to the presence of other constituents and consistency of quality
- Pellet softening
  - Mostly $CaCO_3$, MgO, with some Fe, Mn
  - Can be used in construction or agriculture applications
- Gypsum ($CaSO4$)
  - Plasterboard
- Feasibility of beneficial application for RO brine is very limited

The Only Option When There is No Discharge Options – Zero Liquid Discharge (ZLD)

- Exotic Treatment Process Involved to further minimize brine volume
  - Advanced RO operation schemes
  - Vibratory Shear Enhanced Process (VSEP)
  - Evaporation Pond
  - Thermal (brine concentrator/crystallizer)
  - Forward Osmosis

Challenges with ZLD Processes

- Extremely high capital costs
  - Unique proprietary technologies
  - High energy consumption
  - Expensive materials

- Operation challenges
  - Sophisticated operations
  - Changes in water quality in the brine
  - Final disposal of salt slurry/solids

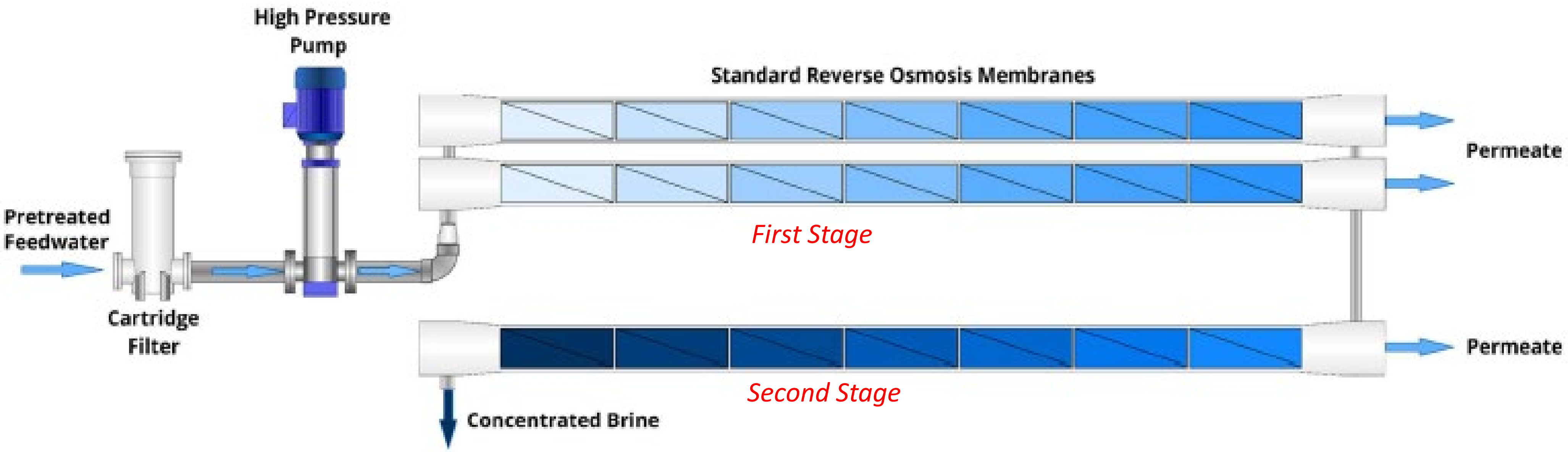
Case Study for a ZLD Application

- Feed water with a TDS of 14,000 mg/L
- Plant capacity 3 MGD (11,356 m^3/day)
- RO recovery target at 70%
- Brine flow rate: 0.9 mgd (625 gpm; 3,406 m^3/day)
- Evaporator (Brine Concentrator): $7M
  - Smaller brine flow results in lower cost for evaporator
- Crystallizer (125 gpm; 681 m^3/day): $7M - $8M
  - Size of crystallizer is fixed based on raw water TDS and flowrate
- Total cost for equipment with installation: $45 - $60M
- Energy: 3 MW for Evaporator and 1.5 MW for Crystallizer

Analyte	Unit	Range
ALUMINUM (AL)	ug/L	ND - 11.7J
BARIUM (BA)	ug/L	9.7 - 10.8
BORON (B)	ug/L	29,100 - 35,900
CALCIUM (CA)	ug/L	501,000 - 536,000
MAGNESIUM (MG)	ug/L	284,000 - 359,000
MANGANESE (MN)	ug/L	8.2 - 11
POTASSIUM (K)	ug/L	3,290 - 3,620
SODIUM (NA)	ug/L	302,000 - 338,000
STRONTIUM (SR)	ug/L	6,930 - 7,610
CHLORIDE	mg/L	1950 - 2250
NITRATE	mg/L	5.9 - 6.5
SULFATE	mg/L	5,950 - 6,840
AMMONIA AS N	mg/L	0.31J - 1.9
AMMONIUM AS N	mg/L	0.30J - 1.9
BICARBONATE AS CACO3	mg/L	280 - 299
SILICA W	mg/L	32.7 - 34.2
TOTAL DISSOLVED SOLID	mg/L	12,300 - 13,300
PHOSPHATE	mg/L	ND - 2.2

RO Recovery Maximization

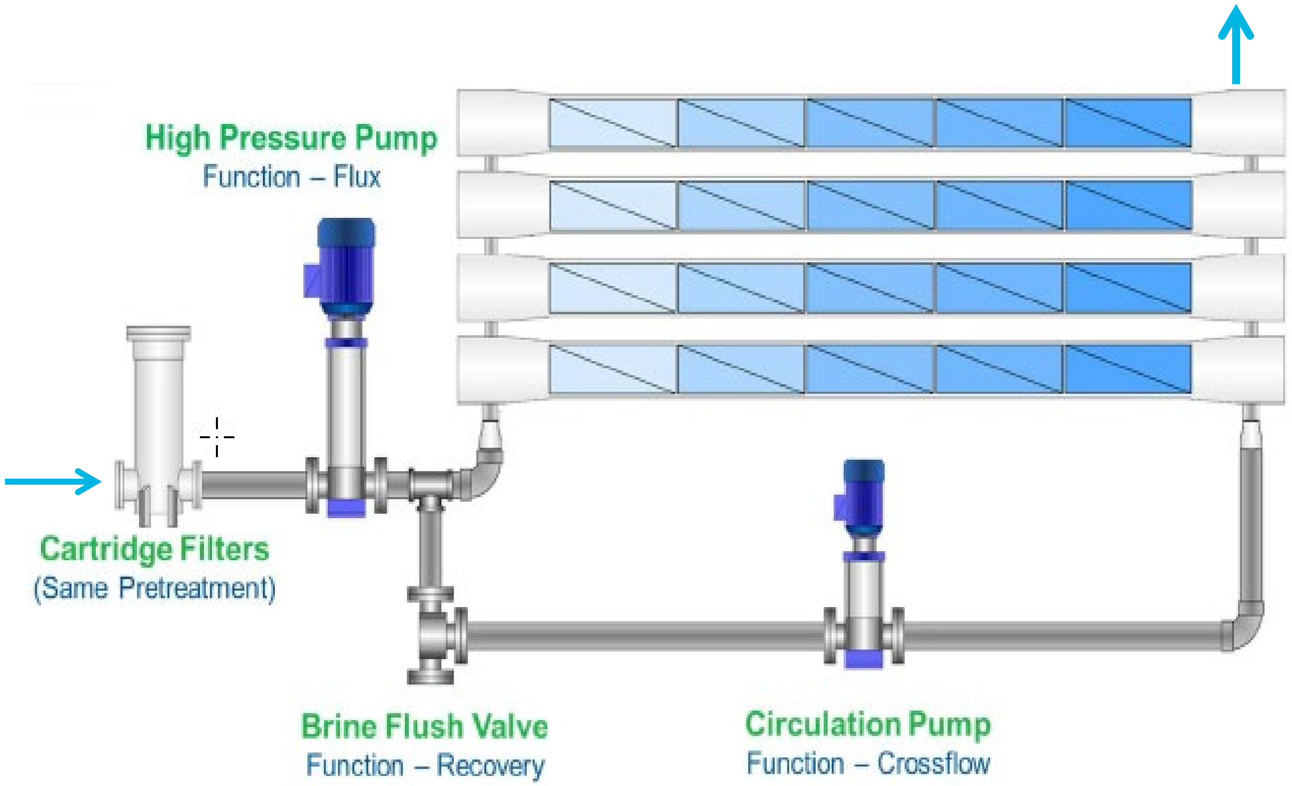
Conventional RO Operation Scheme



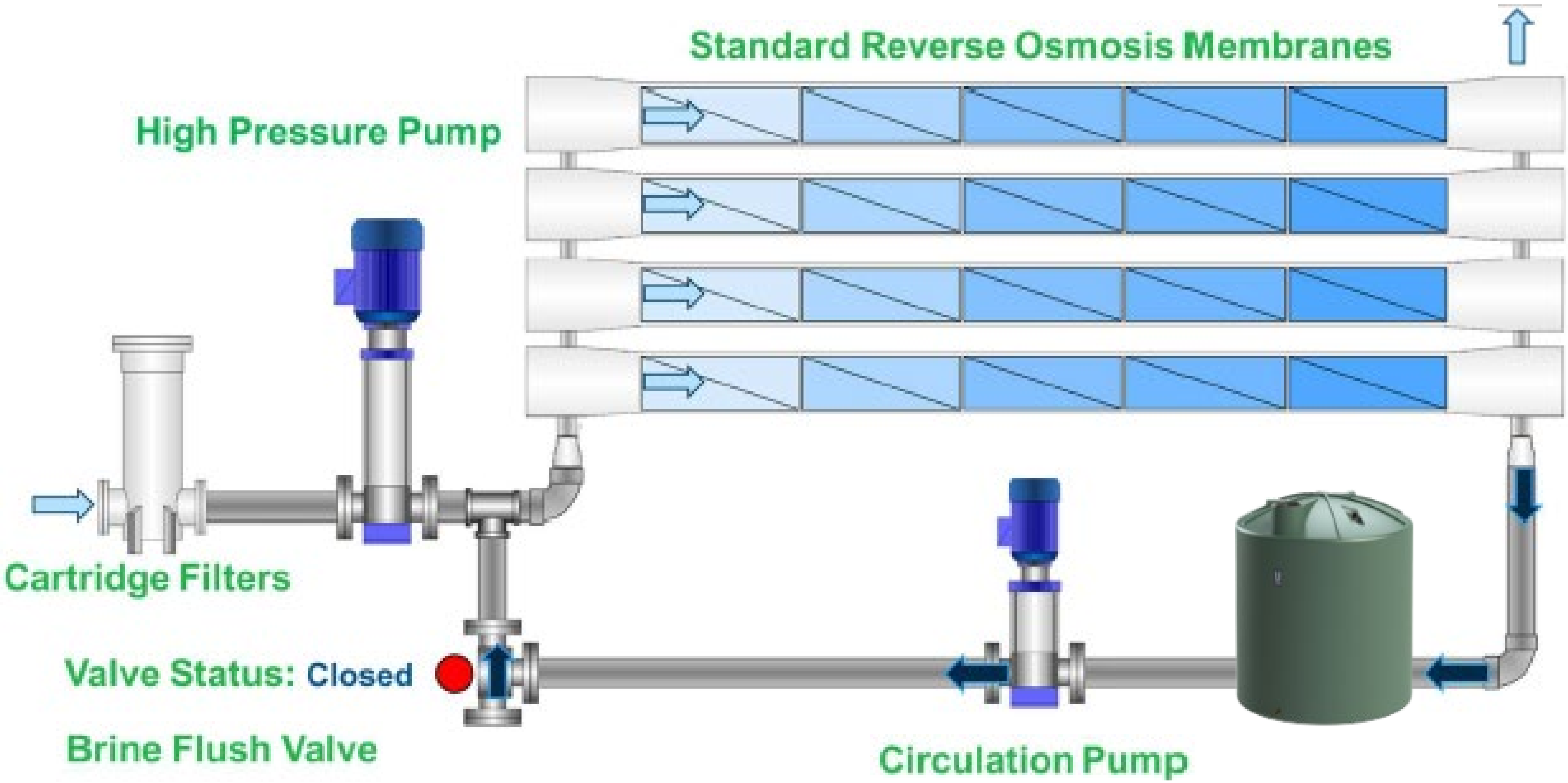
- Multiple stages required if recovery is > 70%
- Increased complexity and is difficult to balance flow
- Fouling on lead elements; scaling on tail elements
- High-pressure pump operates at peak pressure 100% of the time
- Poor flux distribution

Close Circuit Desalination (CCD)

- Concentrating brine inside the loop before reaching the “critical point” of scaling
- RO recovery can be increased > 90%
- Reduced chemical costs
- Energy demand could be similar or lower than conventional, depending on feed water quality
- Permeate water quality degrades along CCD cycle
- More sophisticated control required

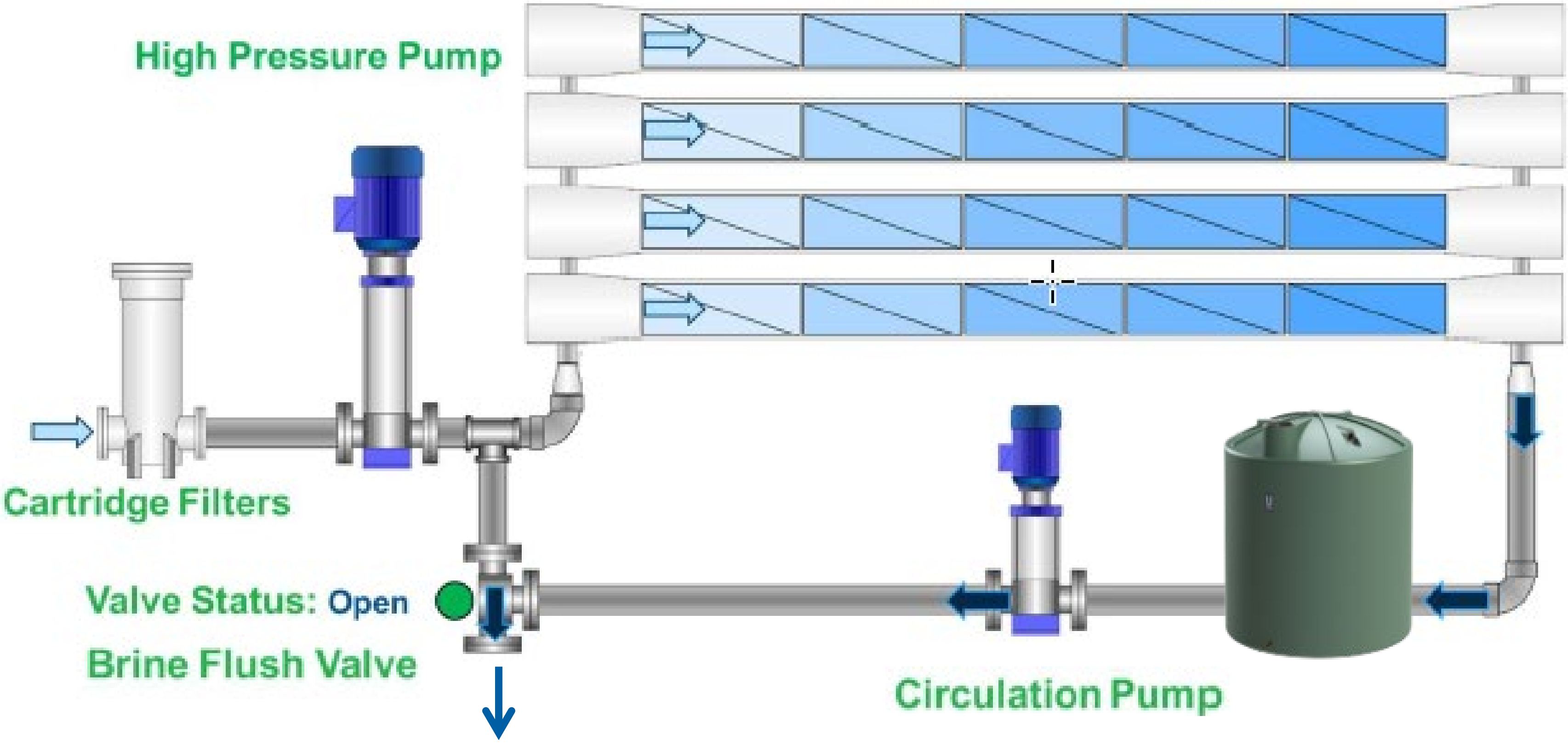


Step 1: Closed Circuit (6 – 60 min)

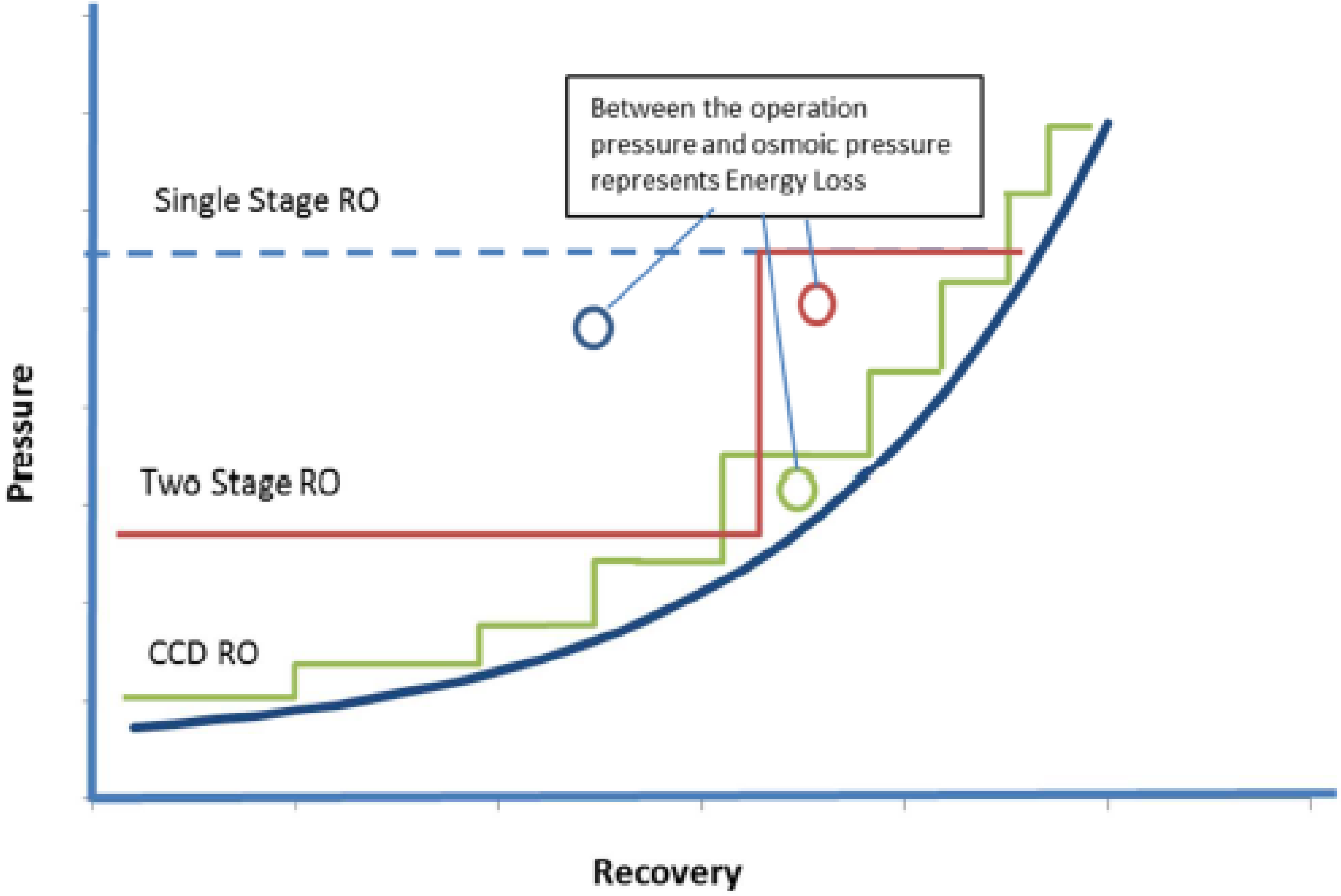


Step 2: Plug Flow (1.5 min)

- Brine is discharged just before scaling is about to occur



Energy Efficiency for CCD Process/CCD



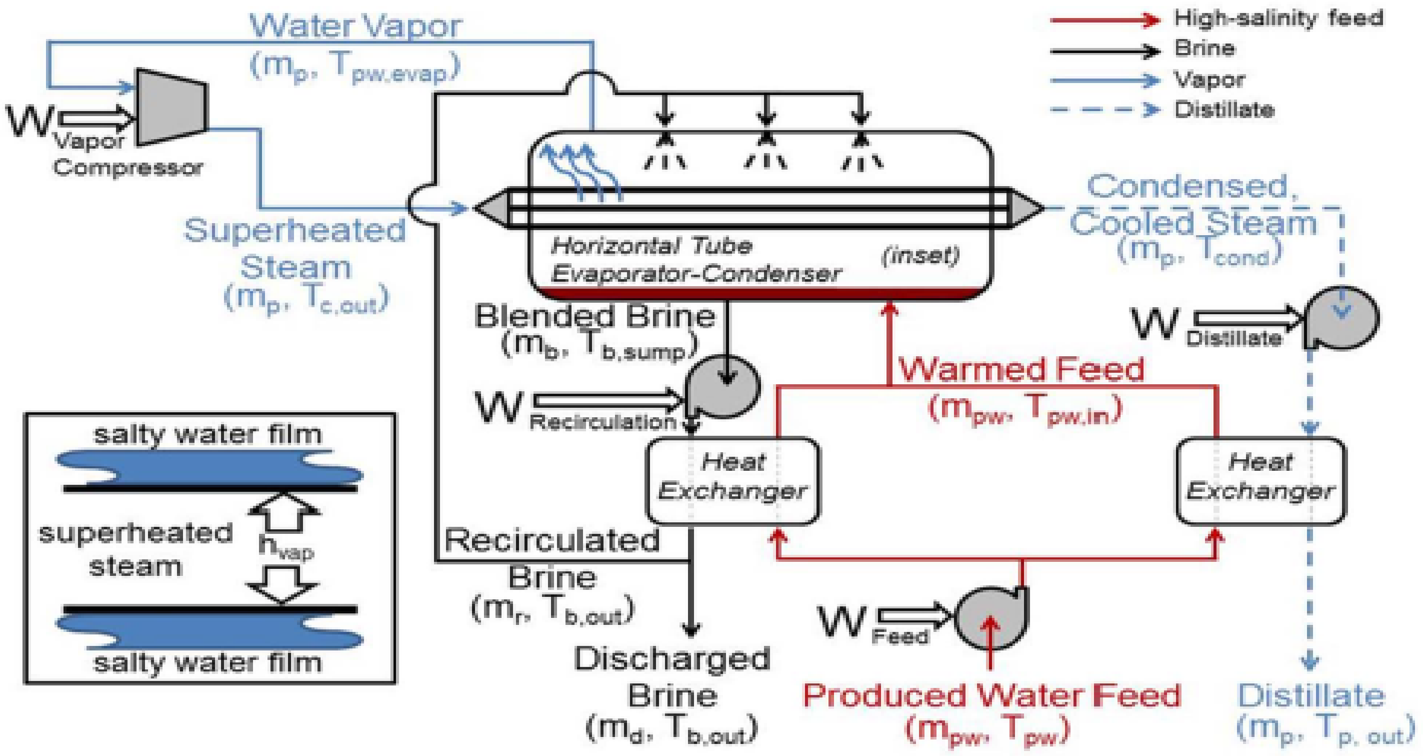
Step 2: Zero Liquid Discharge

AECOM

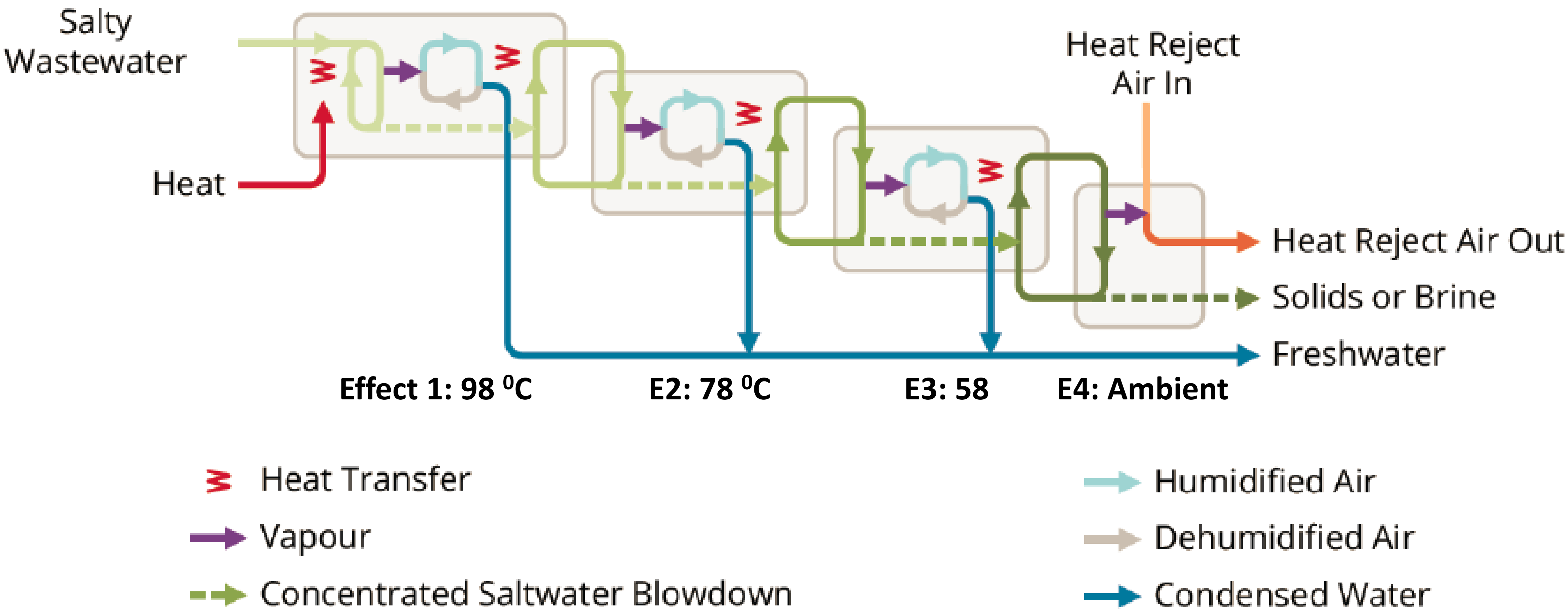
Conventional Thermal ZLD Process for High Salinity Water

- Conventional ZLD (MED or MVC) technologies rely on thermal evaporation and condensation
- Very high energy demand and therefore very high operation costs

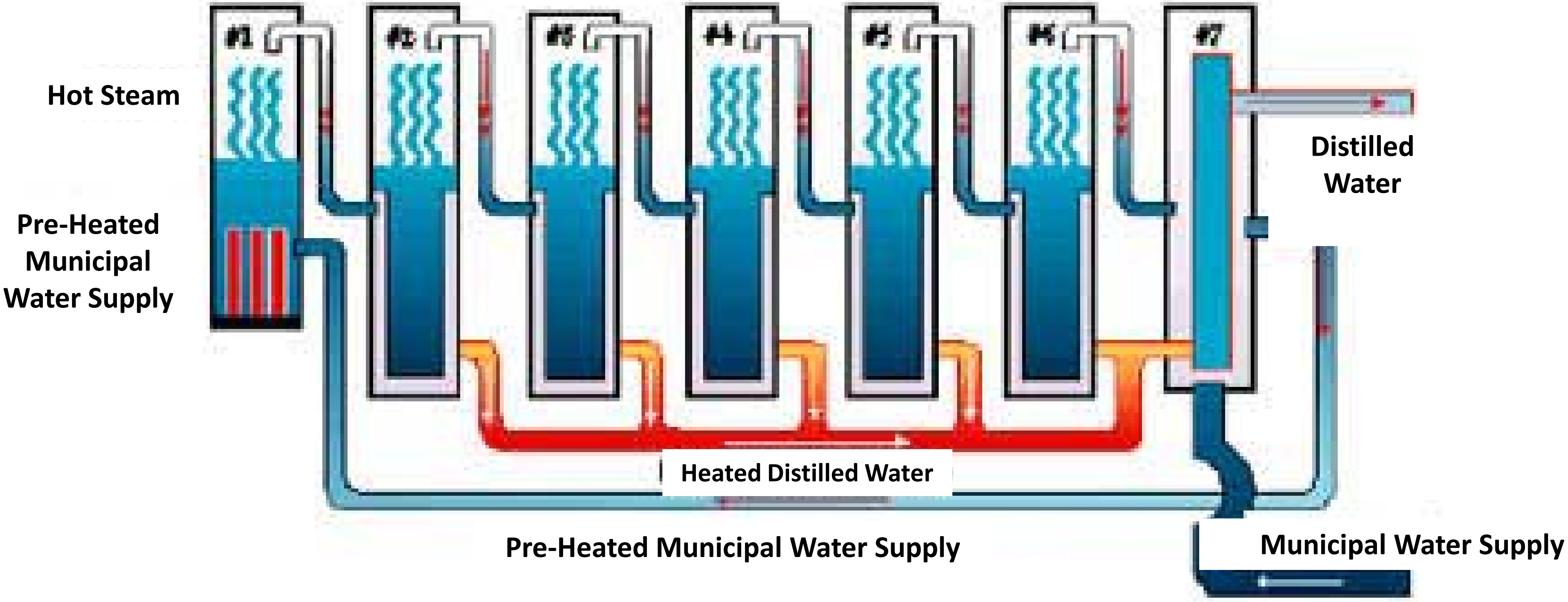
Example: Mechanical Vapor Compression (MVC)



Multi-Effect Low Temperature– Saltworks, Vancouver Canada



Theory of Salt Work is Similar to Multi-Effect Distillation



Single Effect of Saltworks’ ZLD System

Evaporation Module

Fan Module

Radiator Module

An Evaporation-Condensation Process Set

There are Multiple Process Sets in an Effect

Corrosive Resistant, Low Cost Plastic Components

Pipework
UPVC and CPVC

Pumps
Engineered Plastics

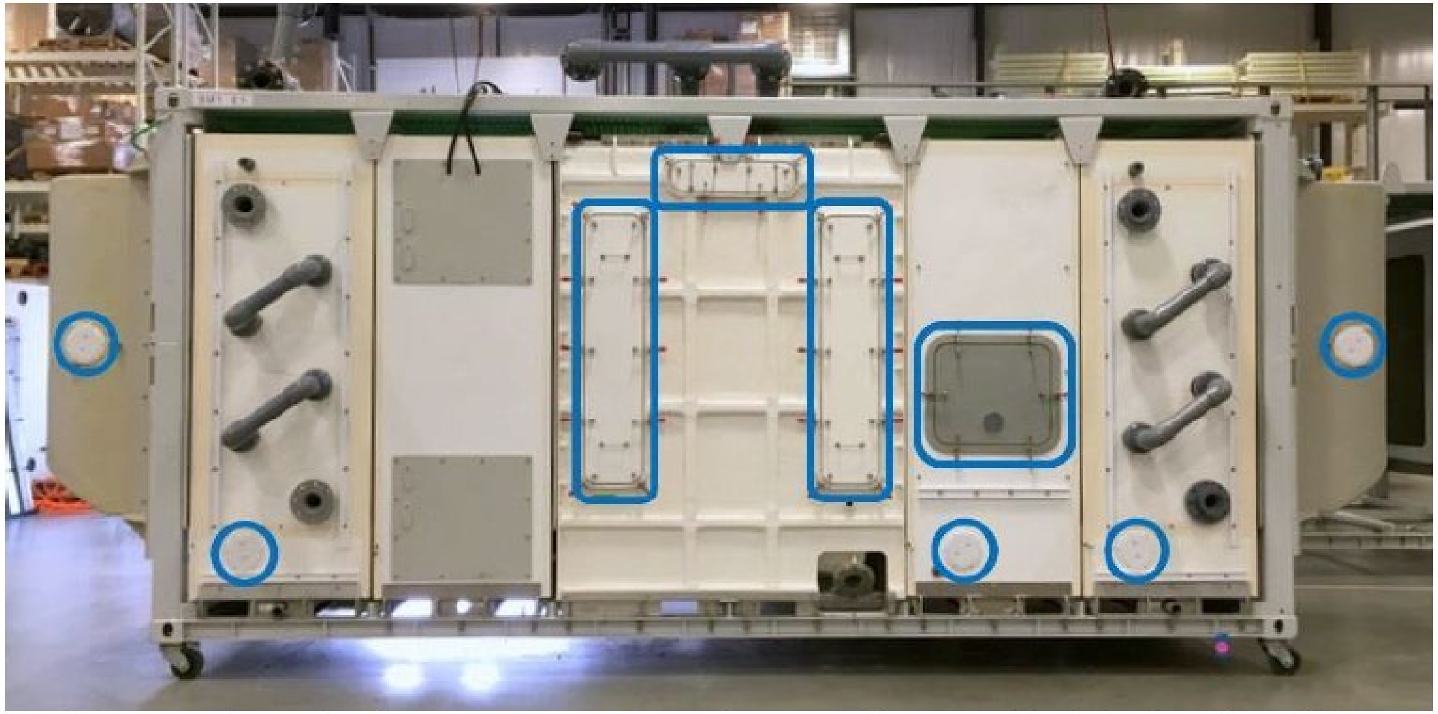
Modules and Tanks
Fiber Reinforced Plastics

Heat Exchanger
Titanium (non-boiling)

- Titanium Crystallization Tube is the only metallic component in contact with concentrated brine

Single Effect Component

An Effect



Effect with Multiple Inspection Hatches and Ports (highlighted in blue)

4-Effect Evaporation System with Solid Collection System

A S100 SaltMaker with Four Effects

Equipment for Solid Collection

Automated Bagging System

Bag Removed by Forklift

Bag of Solids

Landfill leachate

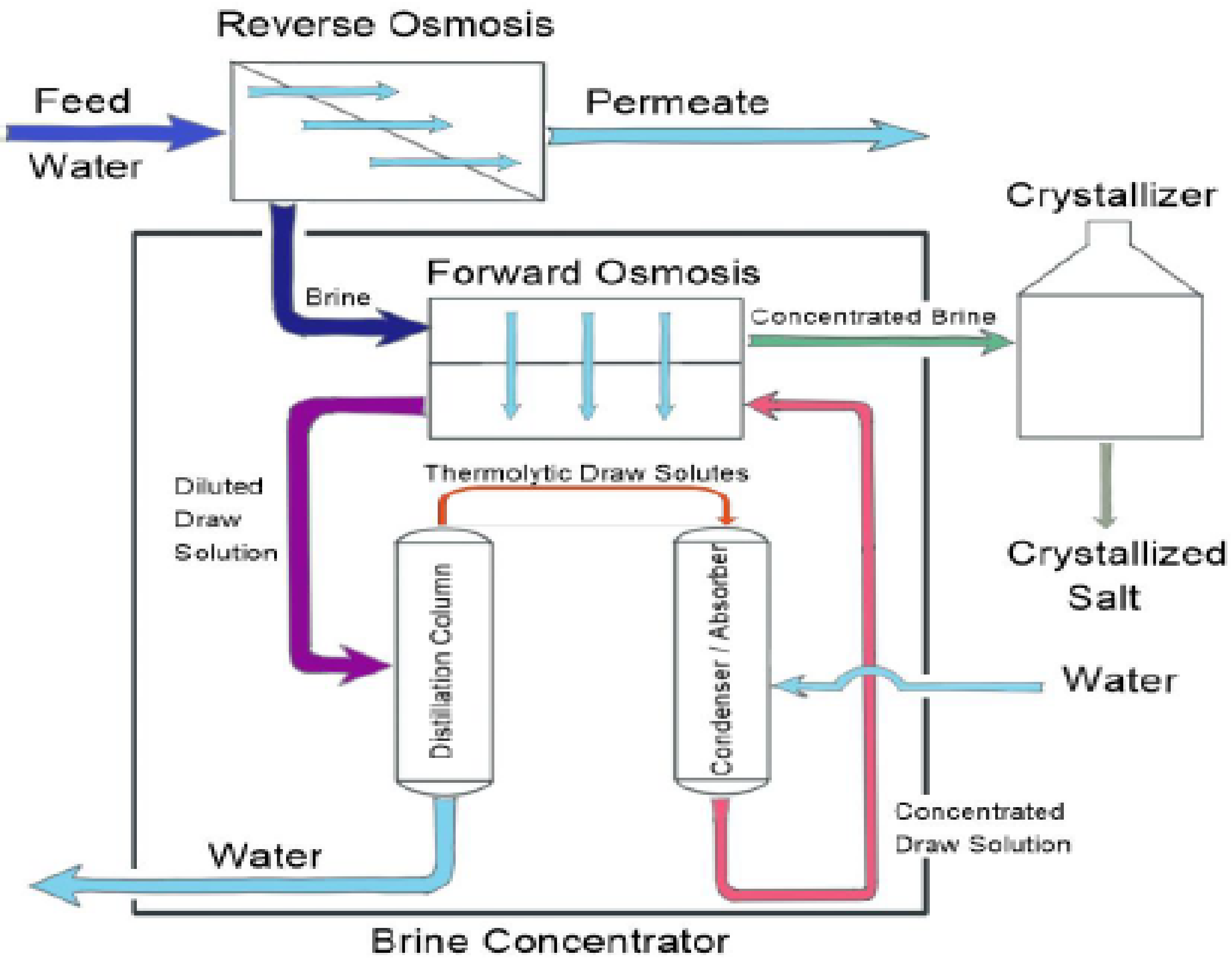
Oil sands evaporator blowdown

Potential 45% Total Cost Savings with Saltworks Technologies

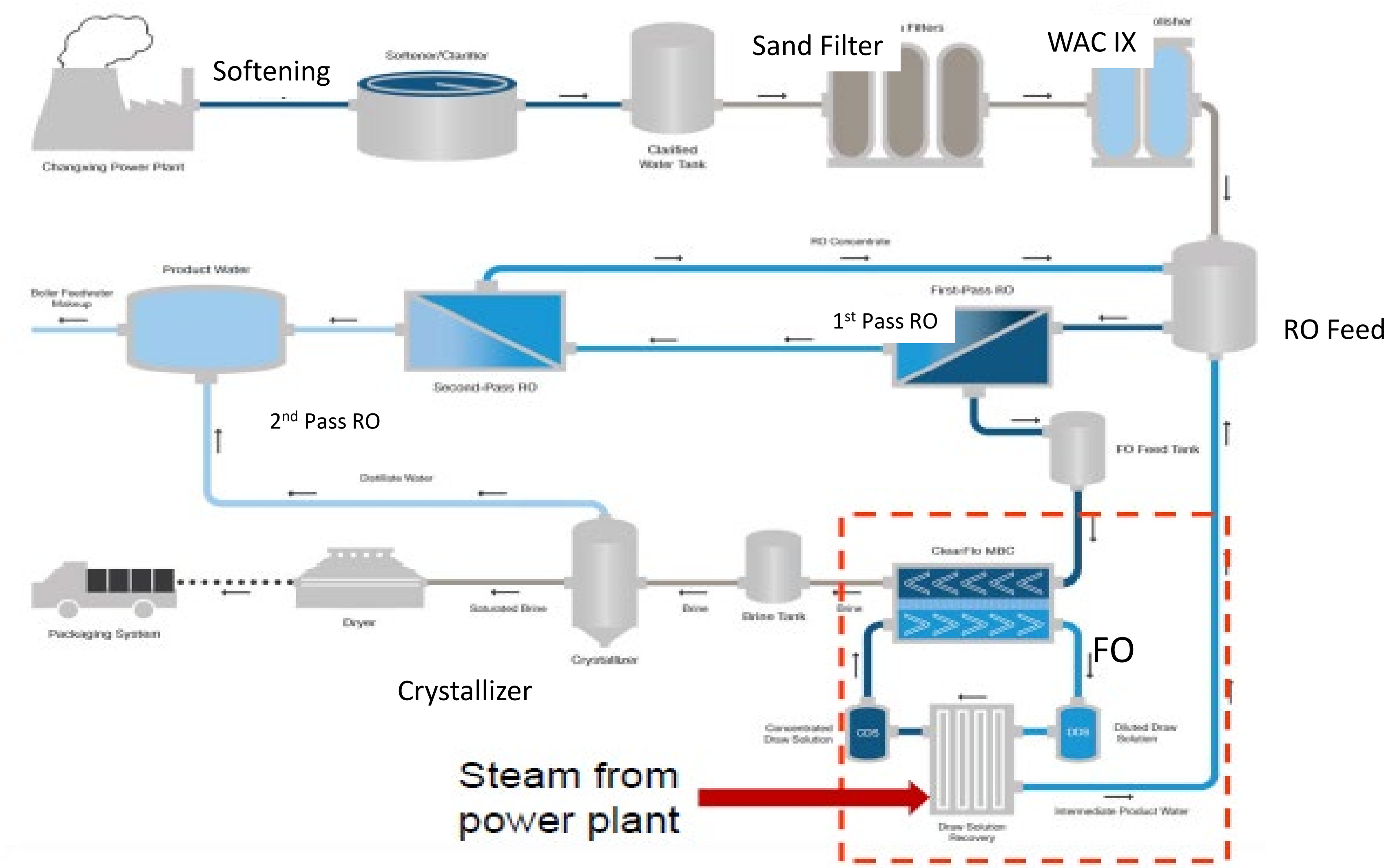
CapEx Savings: 25%; OpEx Savings: 37%

	Soda-RO-Evap-Crys	ED-RO-SaltMaker
Plant Inlet (m3/day)	1,090	1,090
Membrane System Recovery	70%	89%
Size of Evaporation System (m3/day)	327	104
Mass of Solids Re-used (tonnes/day)	-	0.8
Mass of Solids Produced (tonnes/day)	24.6	21.4
Capital Cost	**$8,988,634**	**$6,763,636**
Capital Cost ($/m3)	$3.68	$2.67
Operating Cost ($/yr)	**$1,664,422**	**$670,082**
Operating Cost ($/m3)	$4.40	$1.77
Total Cost ($/m3)	**$8.09**	**$4.44**

Forward Osmosis for ZLD Applications



The World’s First FO-Based ZLD (Oasys USA & China)



Industrial FO Applications

- Treat FGD treats both FGD wastewater & IX regenerant; 22 m^3/hr (528 m^3/day)
- CAPEX: \$60M RMB; OPEX \$23 – 25 RMB/m^3
- Use NH_4HCO_3 based draw solution
- Use drying packing to produce Salt (NaCl and SO_4) for industrial applications
- With significant learning curve

AQUAFORTUS Forward Osmosis ZLD/纽西兰正渗透零排放工艺

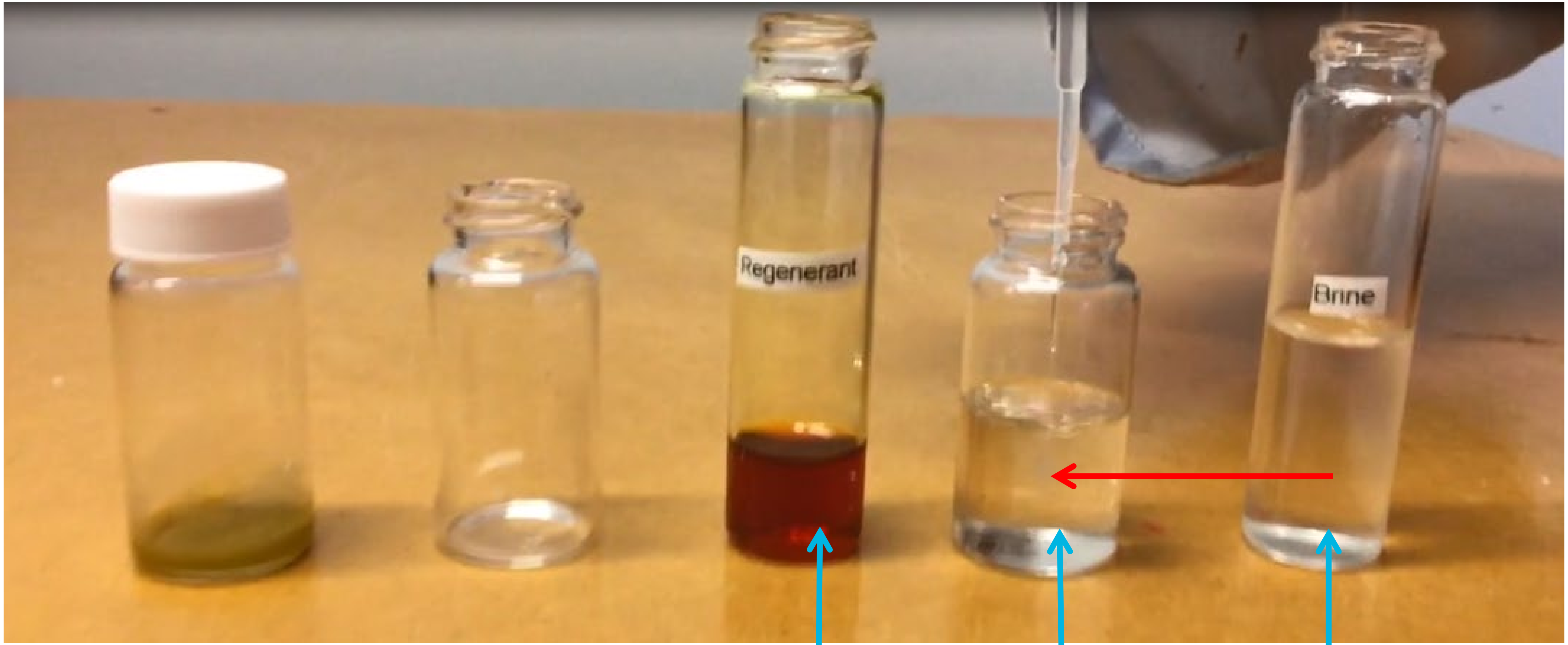
Regenerant

Concentrated Adsorbent

RO Brine

AQUAFORTUS Forward Osmosis ZLD/正渗透零排放

Step 1. Add RO Brine to FO solution

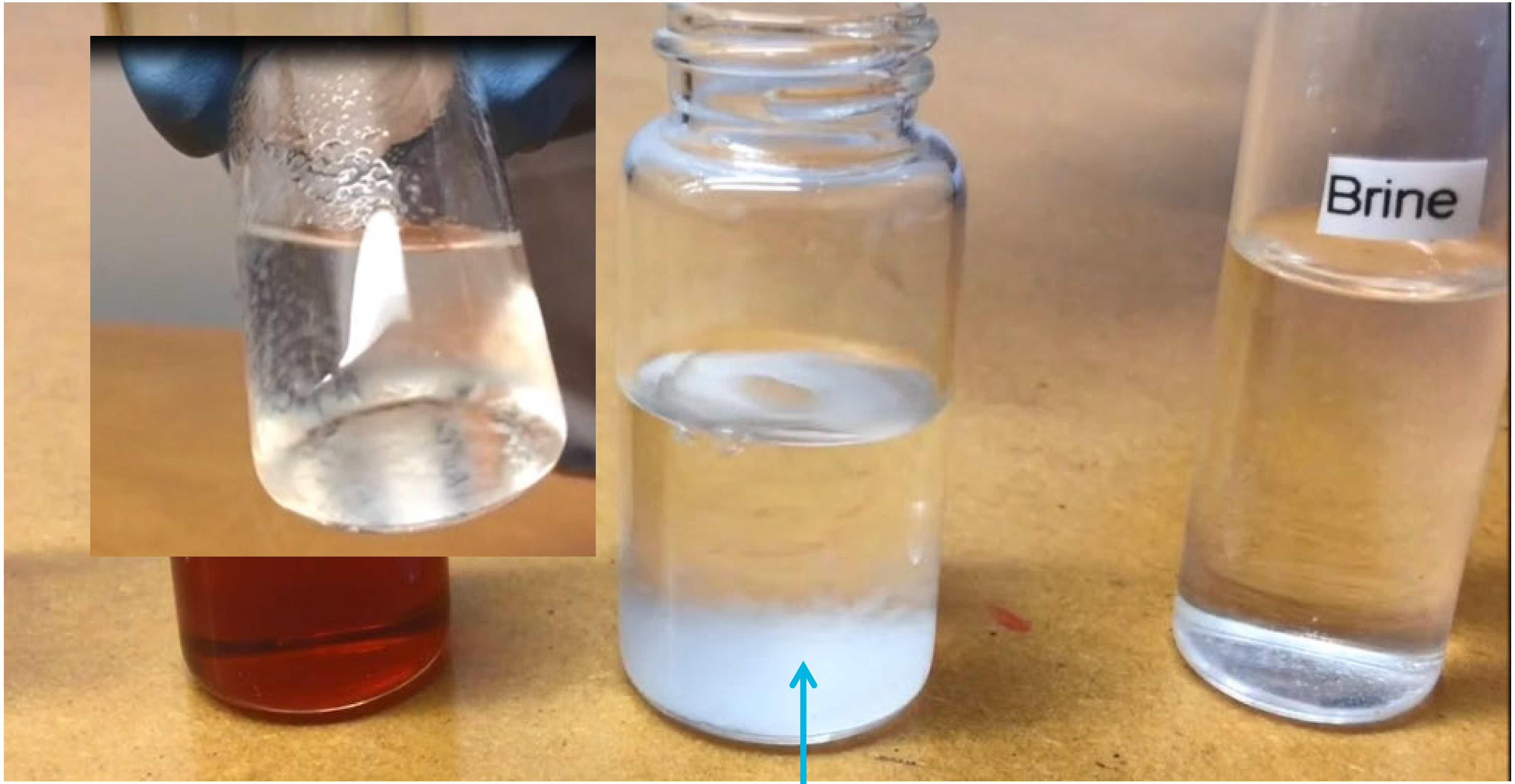


Regenerant

Concentrated Adsorbent

RO Brine

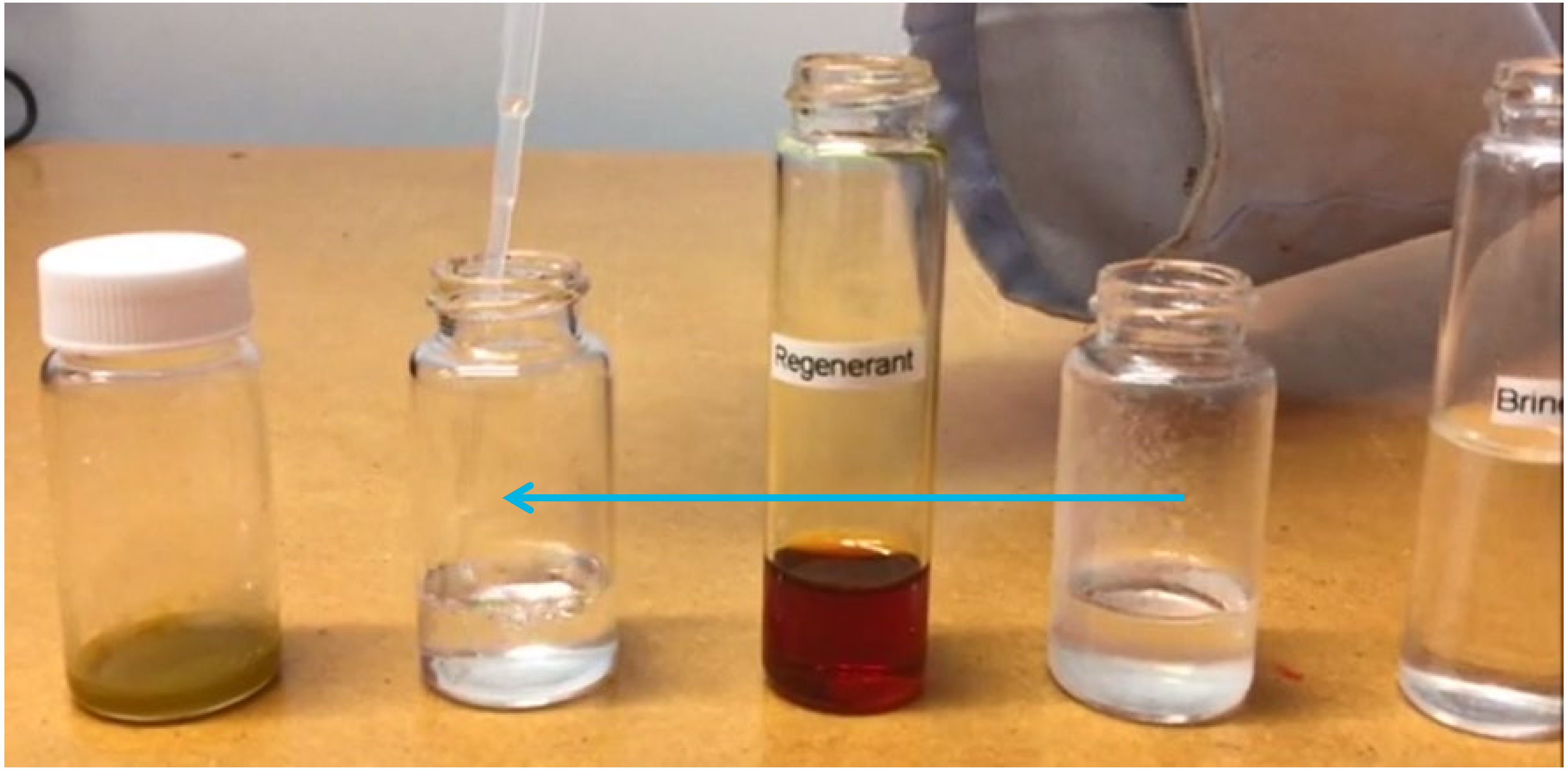
AQUAFORTUS Forward Osmosis ZLD/正渗透零排放



Solid Precipitates Immediately

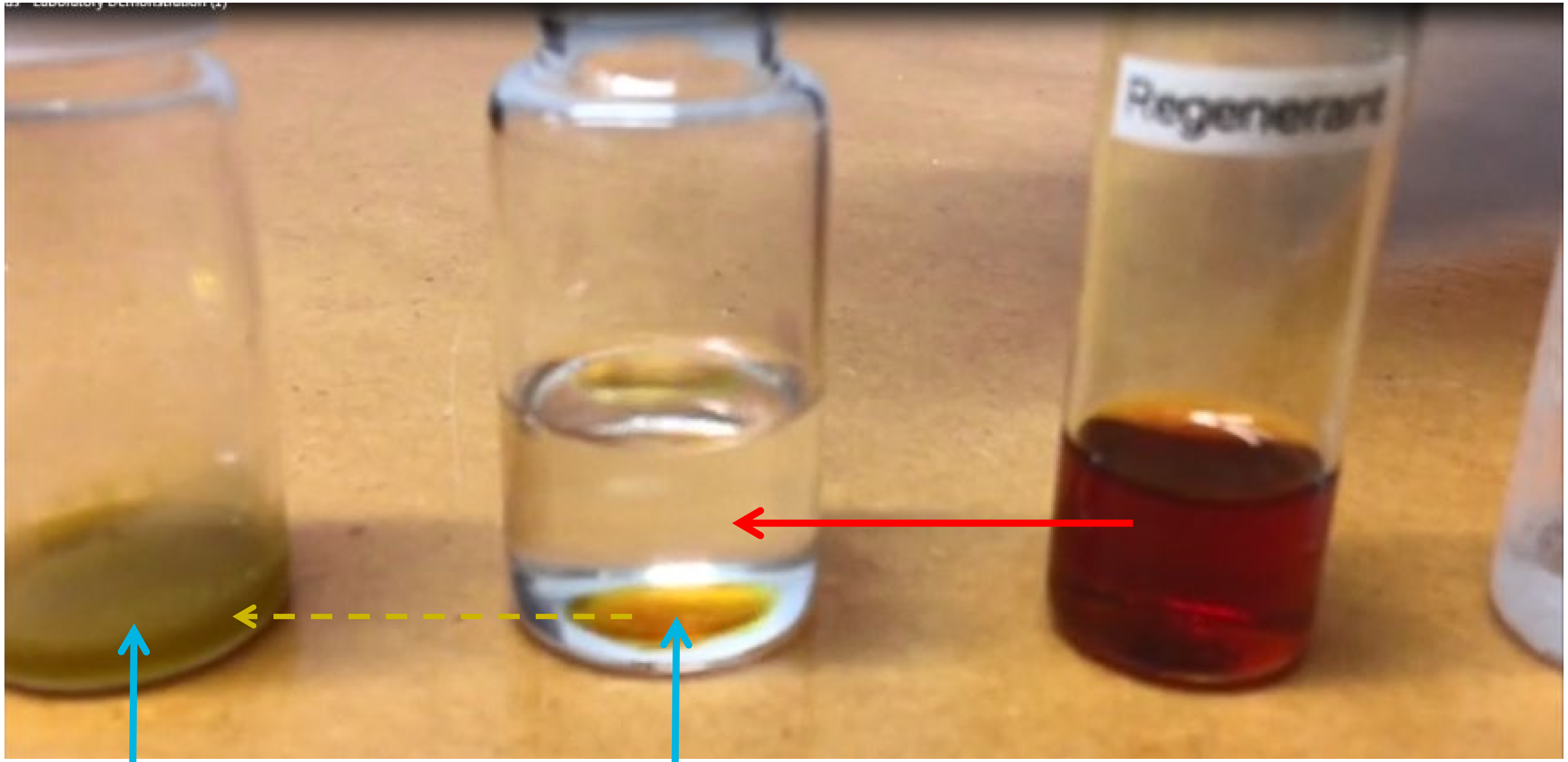
AQUAFORTUS Forward Osmosis ZLD/正渗透零排放

Transfer Water-Enriched FO Solution to Another Vial



AQUAFORTUS Forward Osmosis ZLD/正渗透零排放

Step 2. Add Regenerant to remove water from FO solution

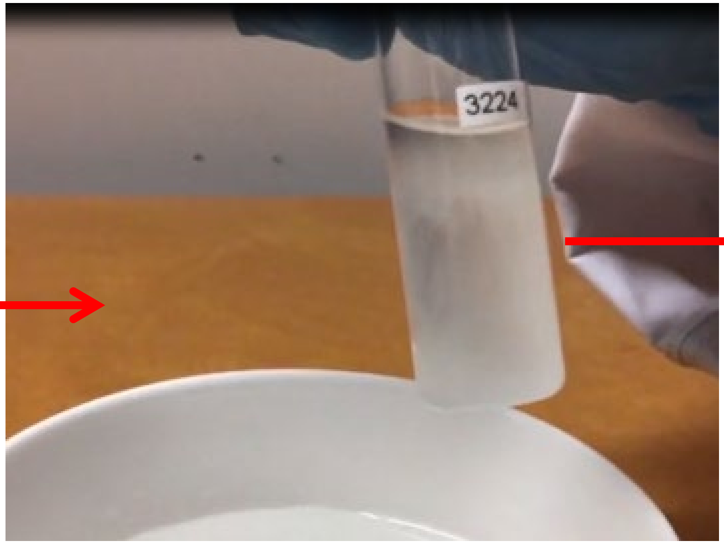


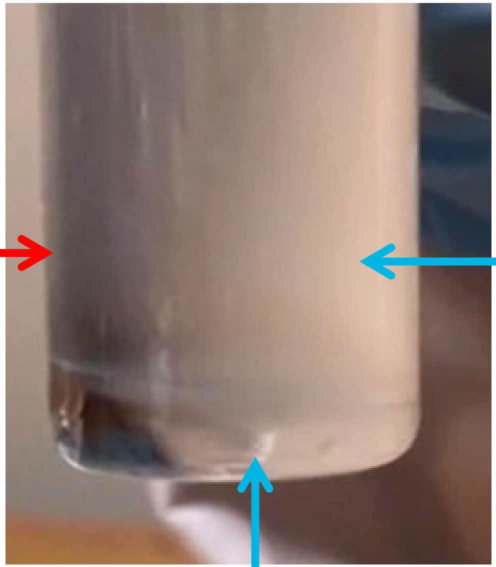
Collected used regenerant

FO solution bound with Regenerant

AQUAFORTUS Forward Osmosis ZLD/正渗透零排放

Step 3. Add Regenerant to remove water from FO solution & Recover FO solution





FO solution

Increase Temperature
by 4 ^{o}C

Water

AQUAFORTUS Forward Osmosis ZLD/正渗透零排放

Experiment with Milk to form Milk Powder