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Aquaporin Inside® Forward Osmosis Technology

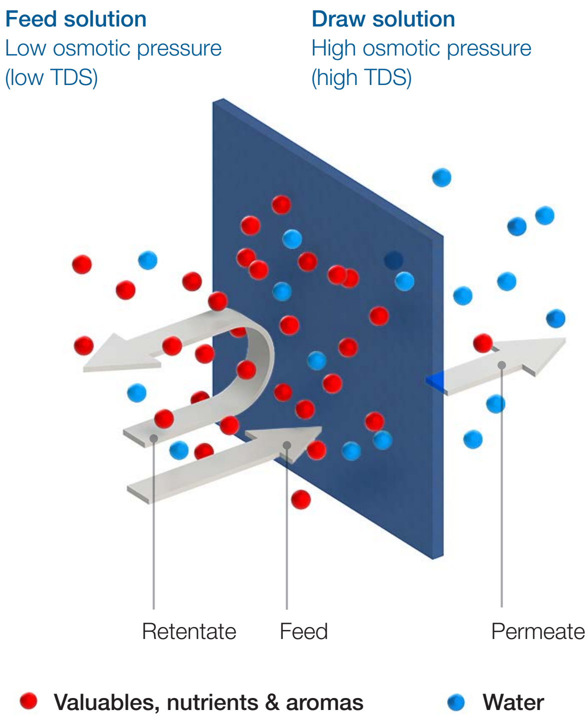
WHAT IS FORWARD OSMOSIS (FO)?

Aquaporin Inside® FO is a gentle process that transports water across a semi-permeable FO membrane while effectively retaining any dissolved solutes on the feed side. The osmotic pressure difference between a solution of higher concentration (draw solution) and a solution of lower concentration (feed solution) drives the FO process as shown in the figure.

FO applications can be broadly categorized into 3 types, depending on the desired outcomes:

- Concentration of valuable products or dewatering of liquid waste stream
- Dilution of the draw solution
- Production of clean water

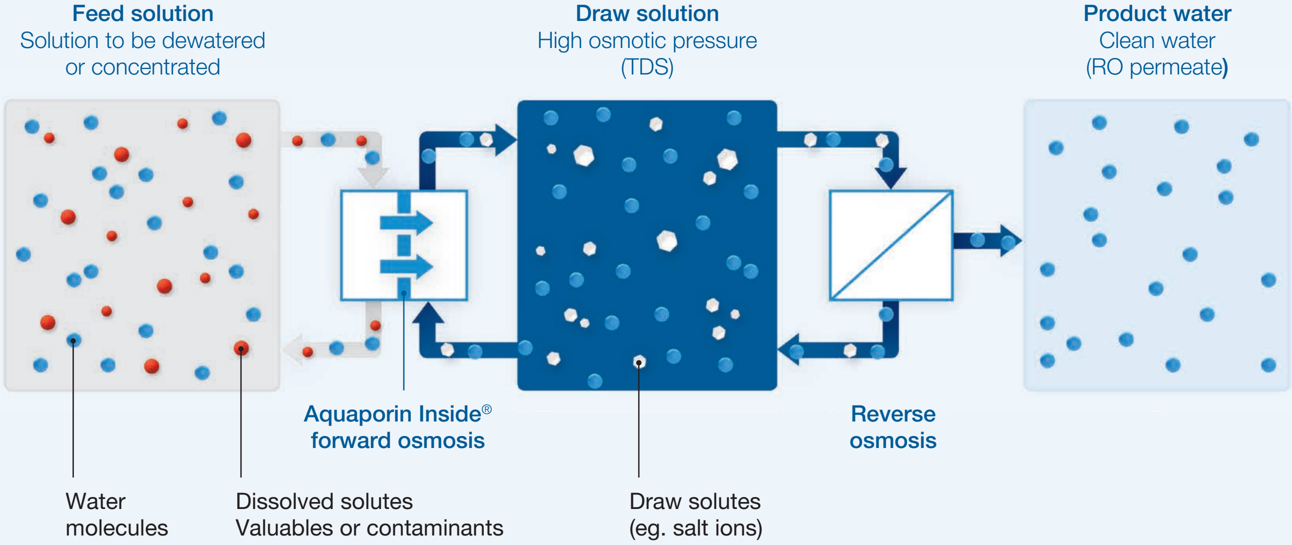
Combining FO with a draw solution recovery system such as reverse osmosis (RO), results in a hybrid system capable of delivering all 3 desired outcomes.



HOW DOES IT WORK?

When water molecules pass through the FO membrane, the feed solution becomes increasingly concentrated while diluting the draw solution in the process. Draw recovery is a necessary step in the FO process to maintain a constant osmotic driving force as well as to “liberate” water trapped in the draw solution.

Aquaporin recommends the use of RO to regenerate the draw solution whenever possible due to its’ long track record and competitive CAPEX & OPEX. Other draw recovery methods such as high brine concentrator or thermal evaporators can be employed when RO is not feasible.



FO APPLICATIONS

VALUABLES CONCENTRATION

Coconut juice & milk concentration

Coffee and tea extract dewatering

Flavors and fragrances concentration

+

Textile dye concentration
Enzymes concentration

WASTEWATER DEWATERING

Textile wastewater dewatering

Dairy wastewater concentration

ZLD in semiconductor wastewater

+

Scrubber wastewater dewatering
Steel pickling

PROCESS OPTIMIZATION

Pre-treatment to multi stage flash thermal desalination

Seawater desalination

Pressure-retarded osmosis (PRO)

+

Fertilizer driven forward osmosis (FDFO)

WHY IS FO RELEVANT?

Challenges with current concentration technology (RO & evaporators)

- Loss of valuables, nutrients and aromas during heating process in evaporators
- Energy intensive operations (high OPEX)
- Frequent cleaning due to fouling and scaling

How can FO solve your problems?

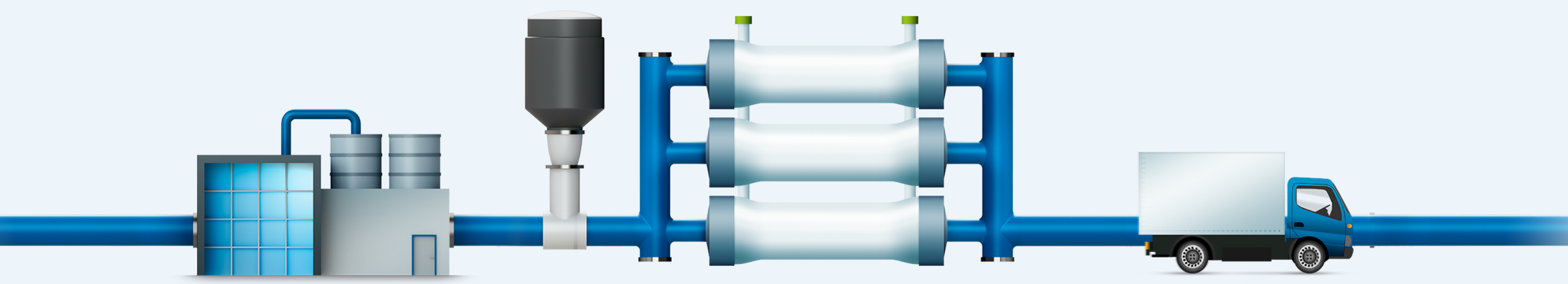
- Protects valuables, nutrients, and aromas during processing by utilizing nature's own water filtration technology to drive water extraction gently without the need for hydraulic pressure and thermal input
- Improved operational stability and product water quality when treating industrial wastewater with high-COD/high-BOD/high-TOC load in applications where traditional membrane technologies fail
- Significantly reduced OPEX/CAPEX cost in zero liquid discharge (ZLD) applications

Valuables concentration

	VALUABLES RETENTION	PRODUCT QUALITY	INITIAL INVESTMENT	ENERGY REQUIREMENTS
FO-RO hybrid system	High levels of valuables retention	Gentle on valuables, High quality concentrate	Mid	Low - RO for draw recovery (3-4 kWh/m³)
Evaporators	Loss of volatiles/aromatic compounds by heating	Degradation of heat-sensitive valuables, Loss of nutritive & sensory quality	High	Extremely high (30-60 kWh/m³)

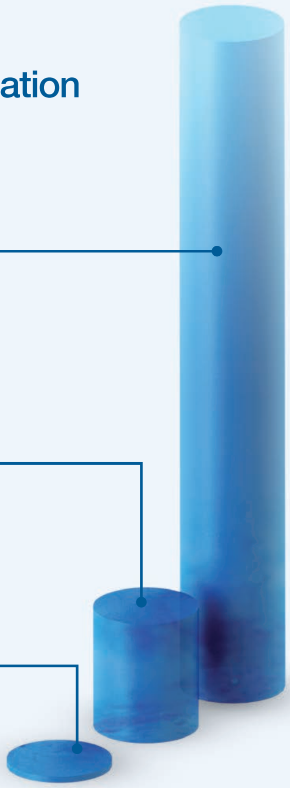
Wastewater dewatering

	CONTAMINANTS REJECTION	PERMEATE QUALITY	INITIAL INVESTMENT	OPERATIONAL STABILITY
FO-RO hybrid system	Highest rejection to contaminants	Higher	Mid	High low fouling propensity
Reverse osmosis	High rejection to contaminants	High	Mid	Medium higher fouling propensity



KICK-STARTING YOUR FO JOURNEY

Road to FO commercialization



Phase 3: Full scale
FO-hybrid system
Capacity: >100 m^3/day

Phase 2: Pilot scale
FO-hybrid system
Capacity: 10-20 m^3/day

Phase 1: Lab scale
Stand-alone test system
Capacity: 1 m^3/day

What is needed in an FO process?

Three steps to design your FO process:

1. Choose a suitable FO membrane form factor
2. Select the type and size of the systems
3. Choose your draw solution and recovery method

For detailed information, please refer to the appendix:
'What is needed in an FO process'.

FO technical support

Aquaporin's expert FO teams will support you technically at every step of the way from lab-scale all the way to full-scale system implementation.

Want to know more? Contact Aquaporin's FO experts at FO@aquaporin.com for more information.

About Aquaporin

Aquaporin A/S is a global water technology company located in Kongens Lyngby, Denmark.

Aquaporin is dedicated to revolutionizing water purification with its' novel membrane technology.

The main goal of Aquaporin is to develop the Aquaporin Inside® technology which is capable of separating and purifying water from all other compounds.

The Aquaporin Inside® platform uses biotechnological principles in a technological context, which is a novel upcoming field with large commercial perspectives. This is a field where Denmark has taken an early global lead.

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WHAT IS NEEDED IN AN FO PROCESS?

Three steps to design your FO process

1. Choose a suitable FO membrane form factor
2. Select the type and size of the systems
3. Choose your draw solution and recovery method

1 FO membrane form factors

Hollow Fiber

- ✓ Ideal for liquids with low viscosity
- ✓ High packing density @ low footprint

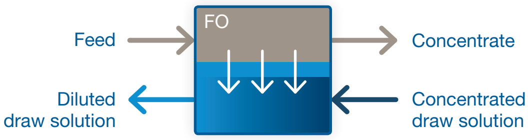
Tubular

- ✓ Very efficient for highly viscous liquids
- ✓ Easy to install and clean

Spiral Wound

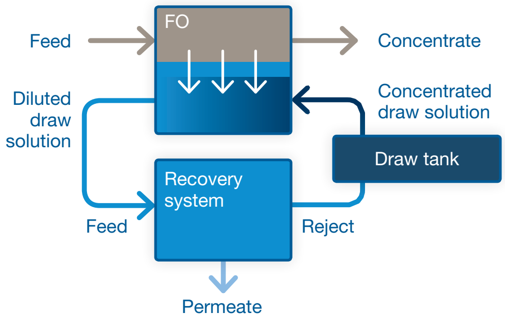
- ✓ Ideal for liquids with medium viscosity
- ✓ Element configuration is industry standard for many membrane types

2 Type & size of FO systems



Stand-alone FO

- ✓ Single pass system
- ✓ Suitable for proof of concept FO applications
- ✓ Ideal for process optimization where concentration of feed can be coupled to dilution of existing draw solution



Hybrid FO

- ✓ Draw regeneration using established water treatment methods

Lab-scale systems

- ✓ Proof of concept studies to assess technical feasibility
- ✓ Initial CAPEX/OPEX estimates to assess economic feasibility

Pilot scale systems

- ✓ Long term testing and process optimisation
- ✓ Fouling & cleaning investigation
- ✓ Full-scale plant feasibility assessment (CAPEX & OPEX)

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3 Draw solutions and draw recovery methods

Draw solutions

- ✓ Select draw solute based on intended application (valuables concentration or wastewater dewatering)
- ✓ Draw solute must exhibit high solubility in water, high osmotic pressure and high diffusion coefficient
- ✓ Solute must be benign to FO membrane
- ✓ Low reverse solute flux and low viscosity

Draw solutions recovery methods

- ✓ Selection of draw recovery methods based on TDS
- ✓ Ensuring that osmotic pressure difference between feed and draw is maintained at a minimum of 10-15 bar
- ✓ Striking a balance between water recovery and draw recovery cost

Draw solute types	Examples	Advantages	Disadvantages
Inorganic salts	NaCl, $MgCl_2$, Na_2SO_4, $(NH_4)_2SO_4$	• High osmotic pressure • NF/RO for draw recovery • Low replenish cost	• High reverse diffusion • Scaling precursor, like Mg^{2+}, SO_4^{2-}
Organic salts	Zwitterions (e.g. glycine) hydroacid complex	• Low reverse diffusion • NF for draw recovery	• High replenish cost
Other organic compounds	Sucrose, fructose	• Suitable for most F&B applications • NF for draw recovery	• High viscosity • Low osmotic pressure
Volatile compounds	$NH_4HCO_3 \rightarrow NH_3 + CO_2$	• High osmotic pressure • Waste heat for draw recovery	• High reverse diffusion • Scaling precursor CO_3^{2-} • High ammonium content in product water
Other responsive solutes	Ionic liquid, glycol ether, nanoparticles, polymer	• Potentially lower energy consumption	• Not commercialized