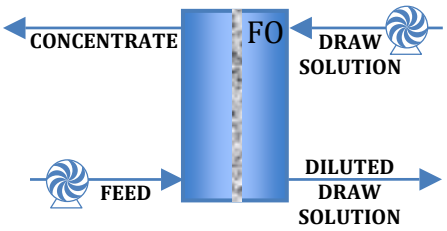
Forward Osmosis

Forward osmosis (FO) is an emerging osmotically driven membrane process. Unlike reverse osmosis (RO) and nanofiltration (NF), FO systems operate without the need for applying hydraulic pressure on the feed stream. During FO, water diffuses spontaneously from a stream of low osmotic pressure (the feed solution) to a hypertonic (draw) solution having a very high osmotic pressure. During this process the feed stream becomes concentrated, while the highly concentrated draw solution is diluted. In most cases, the diluted draw solution will require an additional separation process to produce pure water and the brine stream from the separation process is reused as draw solution in the FO process. Membranes used for this process are dense, non-porous barriers, similar to RO and NF membranes, but they are composed of a hydrophilic, cellulose acetate active layer cast onto either a woven polyester mesh or a micro-porous support structure. FO membranes are less susceptible to irreversible fouling and scaling because of the materials and unique operating conditions of the process; thus, FO may have special merit as a pretreatment technology for feed streams containing high concentrations of sparingly soluble salts or other membrane foulants prior to a pressure driven membrane process. Similar to RO and NF, FO membranes can achieve high removal of many monovalent, divalent, and multi-valent inorganic contaminants, and high removal of organic contaminates. FO processes have been studied for treatment of municipal and industrial waste streams and enhanced water recovery during brackish water desalination. An illustration of the process is shown below.



Summary of technical assessment of FO

Criteria	Description/Rationale
Status of technology	Emerging osmotically driven membrane technology. FO has not been previously employed for produced water treatment.
Feed water quality bins	TDS application range is controlled by the osmotic pressure differential between the feed solution and draw solution. The TDS range is between 500 mg/L to greater than 35,000 mg/L. FO has equivalent solute rejection performance to existing pressure driven processes for monovalent and divalent electrolytes, metals, and organics.
Product water quality	The product of FO is a diluted draw solution (typically composed of NaCl). To obtain pure water from the process, a secondary system is required to extract pure water from the draw solution and to reconcentrate the draw solution. This is typically accomplished with RO. FO membranes have similar solute rejection as NF (>90% TDS, >80% ammonia, low rejection of boron).
Recovery	Product water recoveries have exceeded 96% during testing of the hybrid RO/FO process in the laboratory.
Energy use	FO is an osmotically driven process that occurs spontaneously without the need for substantial energy input. The process requires only enough power to circulate the draw solution and feed solution along the FO membrane.

Summary of technical assessment of FO

Criteria	Description/Rationale
Chemical use	Scale inhibitor and caustic may be required for process control to prevent scaling or fouling. Chemical cleaning rates depend on feed water quality. Membrane cleaning will be triggered when certain operating conditions are exceeded, and may require the use of NaOH, Na_4EDTA, or HCl.
Expected lifetime of critical components	Depending on operating conditions, FO membranes are likely to require replacement within 3 to 7 years.
Infrastructure considerations	FO processes have not experienced the same level of intensive research and development as pressure driven membrane processes. As such, membrane modules are not yet optimized. This results in a larger footprint than an equivalent capacity RO or NF system. Because of its larger footprint, FO systems may have reduced mobility compared to pressure driven membrane processes.
O&M considerations	Monitoring and control required for flow rates, pressures, and membrane integrity. System requires very little oversight, however a skilled technician is required to perform routine system maintenance. Level of flexibility: extremely flexible technology, with sensitivity to low and high pH streams. Level of robustness: FO membranes are highly resistant to fouling and scaling. Level of reliability: FO systems operate semi-continuously with short duration physical or chemical cleanings. Types of energy required: electrical (to power low pressure circulation pumps).
Capital and O&M costs	Capital costs are unknown.
Pretreatment of feed water	A prefilter is required to remove large debris; antiscalent may be required for high recovery operation.
Post-treatment of product water	Diluted draw solution requires further separation to produces pure water and reconcentrate the draw solution for reuse.
Concentrate management or waste disposal	No special concentrate treatment is required. Relatively high recovery rates exceeding 96% (for hybrid RO/FO systems) generate small volume of concentrated brine.
Applicability for produced water treatment	Moderate to good - FO may provide excellent pretreatment for adjacent processes, but FO membranes are not yet available for large commercial installations.
Note: 1 barrel = 42 US gallon	