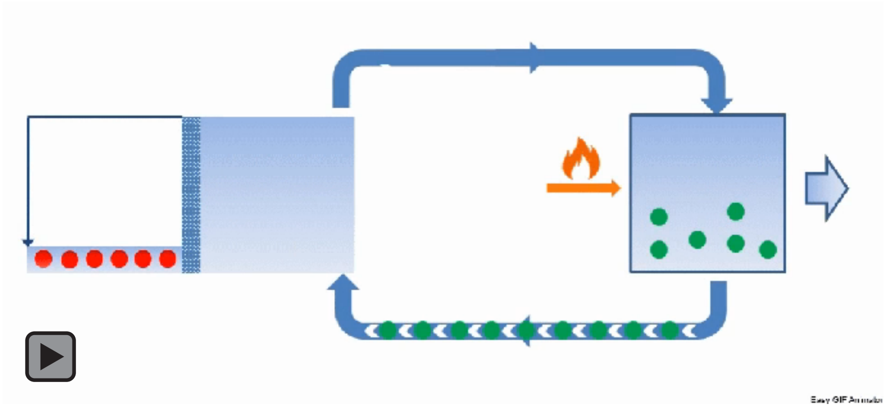

Forward Osmosis

The Brine Solution is separated from a Synthetic Solution by a Semipermeable Membrane that allows only for water molecules to pass. The difference in concentration (Salts -red molecules << Draw Species - green molecules) creates a water flux to the Synthetic Solution. The diluted Synthetic Solution is driven to a regeneration step where the Draw Species are driven back into the process and the water is taken as product.

1) Introduction

Forward Osmosis (FO) is an osmotic membrane process with a semipermeable membrane that unlike Reverse Osmosis (RO) doesn't use applied pressure in order to achieve separation of water from dissolved solutes like ions, molecules and larger particles. That means a lot less of energy for the process in comparison to RO. In general FO uses thermal and electrical energy. Thermal energy can be substituted with low grade waste heat which can be found everywhere in most industrial or nearby areas.

Advantages (+)	Disadvantages (-)
Treating >70,000 ppm	Internal Concentration Polarization
↓Energy	Reverse Salt Flux
Reversible Fouling	Choosing the right Draw Solution
↓↓Chemicals	Choosing the right membrane
↑ Rejection of Boron & TrOCs	-

Energy Consumption; 29. 91 KWh/m^3 = 0.46 KWh/m^3 Electrical + 29.45 KWh/m^3 Thermal

Applications

1) Treatment of >70,000 ppm saline solution (Brine)
2) Oil & Gas Wastewater
3) Heavy Metal Wastewater (Mining & Metallurgy)
4) ↑ Organic WW (e.g. Landfill Leachate)

Energy $_{\text{Forward Osmosis}}$ = Thermal (Waste Heat) + Electrical (<< Electrical $_{\text{Applied Pressure}}$)

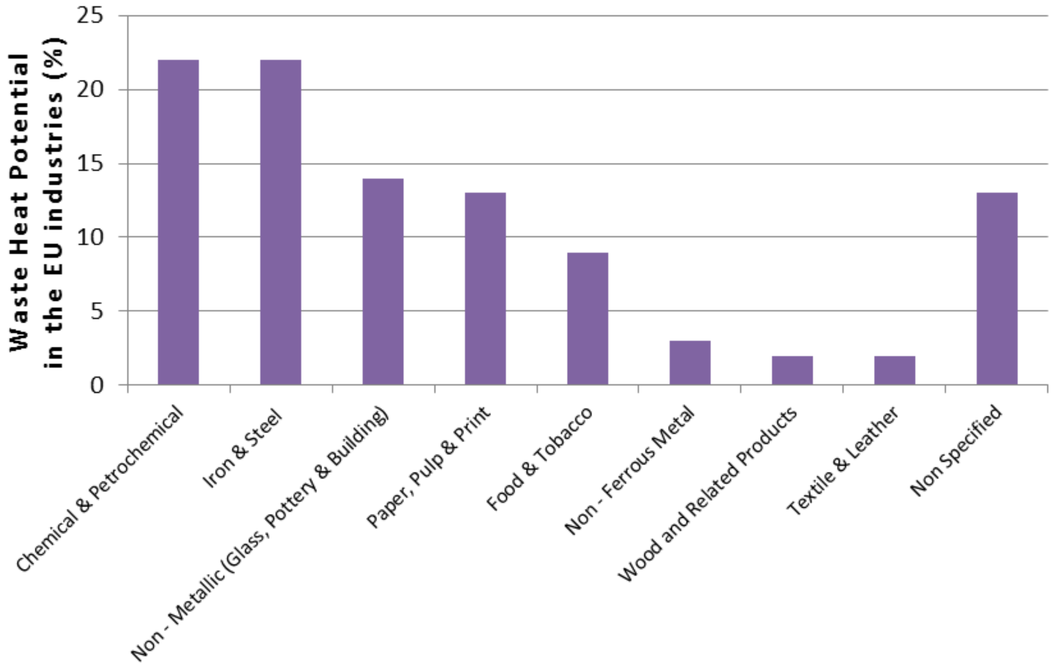

Fig.1, Waste heat potential per industrial sector in the EU (%), ***Preliminary assessment of waste heat potential in major European industries (2107)***

2) Process Function

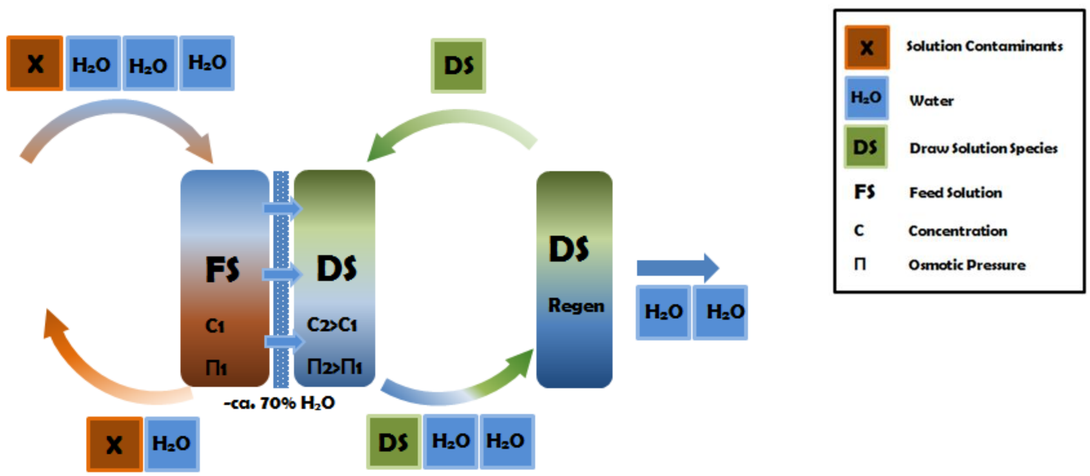

Fig.2, Simplified schematic of the FO process

FO uses the difference of osmotic pressure ($\Delta\pi$) between the feed solution (concentration C_1) and a synthetic draw solution (DS), which we prepare with $C_2 > C_1 \rightarrow \pi_2 > \pi_1 \rightarrow \Delta\pi = \pi_2 - \pi_1$. Due to $\Delta\pi$, the water molecules from the feed will start moving to the draw solution, creating a water flux that removes ca. 70% water from the feed (max 65% recovery (R) for Seawater RO, SWRO and 80% for Brackish Water RO, BWRO). Also due to the fact that FO doesn't use applied pressure to overcome the osmotic pressure, it can deal with much higher TDS levels than RO (ca. 200,000 ppm (mg/L) for FO and 70,000 ppm (mg/L) for RO). That fact makes FO ideal to deal with high salinity brines.

FO → ca. 70 % Water Recovery, up to 200,000 ppm (mg/L) Feed TDS tolerance

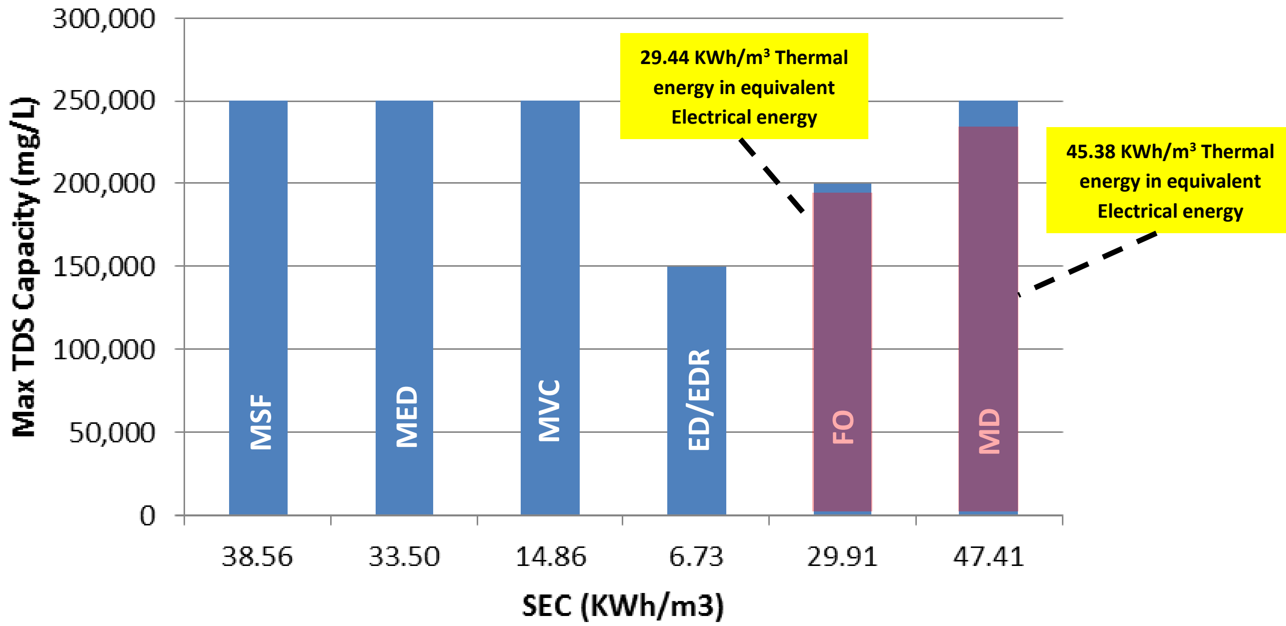

Fig.3, Specific Energy Consumptions (SECs) of Brine Treatment technologies in KWh/m3 versus their Max TDS Capacity in mg/L (ppm). In series we have Multi Stage Flash (MSF), Multiple Effect Distillation (MED), Mechanical Vapor Compression (MVC), Electrodialysis/ Electrodialysis Reversal (ED/EDR), Forward Osmosis (FO), Membrane Distillation (MD). FO and MD can make use of waste heat for up to 90% of their Thermal Energy Demand.

The water flux in FO depends from,

1) The osmotic pressure difference
2) The membrane structure
3) The DS species
4) The fouling properties of the feed

FO membranes are of simple structure (CTA) and composite structure (TFC). TFC membranes have shown better performance in the lab scale worldwide.

The DS species are usually inorganic salts that can be retained in the regeneration loop for a long time before we need to add more in the process.

3) Advantages and Disadvantages

Advantages:

Due to not using applied pressure the fouling layer on the membrane surface is not compact which means that physical cleaning methods can recover the water flux of the membrane (Fig.4). This means less use of chemicals, improved membrane life and less costs overall.

FO → TFC membranes ↑ performance, Inorganic Salts for DS, ↓↓ Fouling than RO (reversible for FO), ↓↓ Chemicals involved

Fig.4, Explanation of the reversible fouling nature of FO. On the right we have a typical RO membrane where we apply pressure in order to push the water through. The applied pressure creates a 'cake layer' of the feedwater contaminants on the membrane surface. On the other hand, on the left we have a FO membrane where no pressure is applied, thus the deposition of the contaminants is very loose and they can be removed by physical methods (e.g. osmotic backwash)

Disadvantages:

Forward Osmosis suffer from two main problems,

1) Concentration Polarization (CP)
2) Reverse Salt Flux

Concentration Polarization in FO membranes is External (ECP) and internal (ICP). ECP is a common phenomenon in the RO processes and can be reduced with improved cross-flow conditions by using spacers on the surface of the membranes.

In ICP DS molecules build up within the pores of the membrane and lower the osmotic pressure gradient, thus lowering the osmotic pressure difference that is the moving force of the FO process. In the last years there has been an extensive effort by the scientific community to battle the ICP effect and there have been some very promising results with physical methods that can improve the already high efficiency of FO.

FO → ↓Water flux by ICP (can be mitigated with physical methods), DS species can contaminate the Feed with Reverse Salt Flux (have to be careful with the DS selection)

4) Process Industry Applications

1. Brine Concentration
2. Oil & Gas
3. Mineral Wastewater (Mining and Metallurgy)
4. Landfill Leachate
5. Cooling Towers Blowdown Treatment
6. Food & Beverages