An Overview of Industrial Desalination Technologies

ASME Industrial Demineralization (Desalination): Best Practices & Future Directions Workshop

Washington, D.C.

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January 28-29, 2013

- **The Challenge:**

    Increasing Demand of Water & Energy Resources;

    Decreasing Supplies of Conventional Water & Energy Resources.

Sustainable Management of Water & Energy Resources

- **Eight Major Water Using Industries**
    - **Oil & Gas**
    - **Refining & Petrochemicals**
    - **Power Generation**
    - **Food and Beverage**
    - **Pharmaceutical**
    - **Microelectronics**
    - **Pulp & Paper, and**
    - **Mining**

GWI: Industrial Desalination & Water Reuse: Ultrapure water, challenging waste streams and improved efficiency,

Strategies:

Water Conservation / Water Use Efficiency

Unaccounted / Water Losses

Water Recycling

Desalination - Most Energy Intensive / Expensive Water?

- **Desalination**

An Energy Intensive Process,

An Integral Part of the Future Water Supply Portfolio

Source Waters – Generally Four Types

Brackish Ground Water, Surface Water, Municipal WW, Agricultural Runoff, Industrial Effluents, Sea Water, etc.

Main Processes Categories:

Thermal **4 - 6 kWh / m3 + Steam**

Heating of Contaminated Water under Vacuum Conditions to Create Pure Water Vapors)

Membranes **1 - 6 kWh / m^3**

Energy Requirements - Function of:

Plant Capacity, Feed Water Quality, Pretreatment, Desalination Process/Technology, and Level of Treatment

Desalination Technology of Most Interest Today

Reverse Osmosis

- **Desalination Methods**

Distillation Multi-Stage Flash Distillation (MSF)

Multiple-Effect Distillation (MED / ME)

Vapor-Compression (VC)

Deionization/Demineralization/Ion Exchange

(Typical Example: Home Water Softeners)

Membrane Processes

Electrodialysis & Electrodialysis Reversal (ED/EDR)

Reverse Osmosis (RO)

Nano-Filtration (NF)

Membrane Distillation (MD)

Freezing Desalination

Geothermal Desalination

Solar Desalination – Using Thermal Energy or Electricity

Solar Humidification-Dehumidification (HDH)

Multiple-Effect Humidification (MEH)

- **Electricity Demand for RO Desalination Plants**

A 50 MGD (~ 50,000 AF / year @ 90% uptime)

SW RO Desalination Plant Needs	20 – 35 MW
BW RO Desalination Plant Needs	8 – 20 MW

- **Energy Requirements for RO Desalination Process by Feed Water**

Conventional Surface Water	500 - 700	kWh/AF
Brackish Water	800 - 2,100	
Municipal WW Reclamation	1,000 - 1,200	
Sea Water	3,260 - 4,900	

- **Desalination - Main Issues**

  High Costs

  Direct Costs – Capital, O&M Costs

  (Mainly Financing & Energy Costs)

  Indirect Cost – Permitting (X), PR (X)

  Environmental Considerations

  Impingement & Entrainment (Ocean Desalination) (X)

  Concentrate Management (Inland & Ocean Desalination) (X)

  CO_2 / GHG Emission

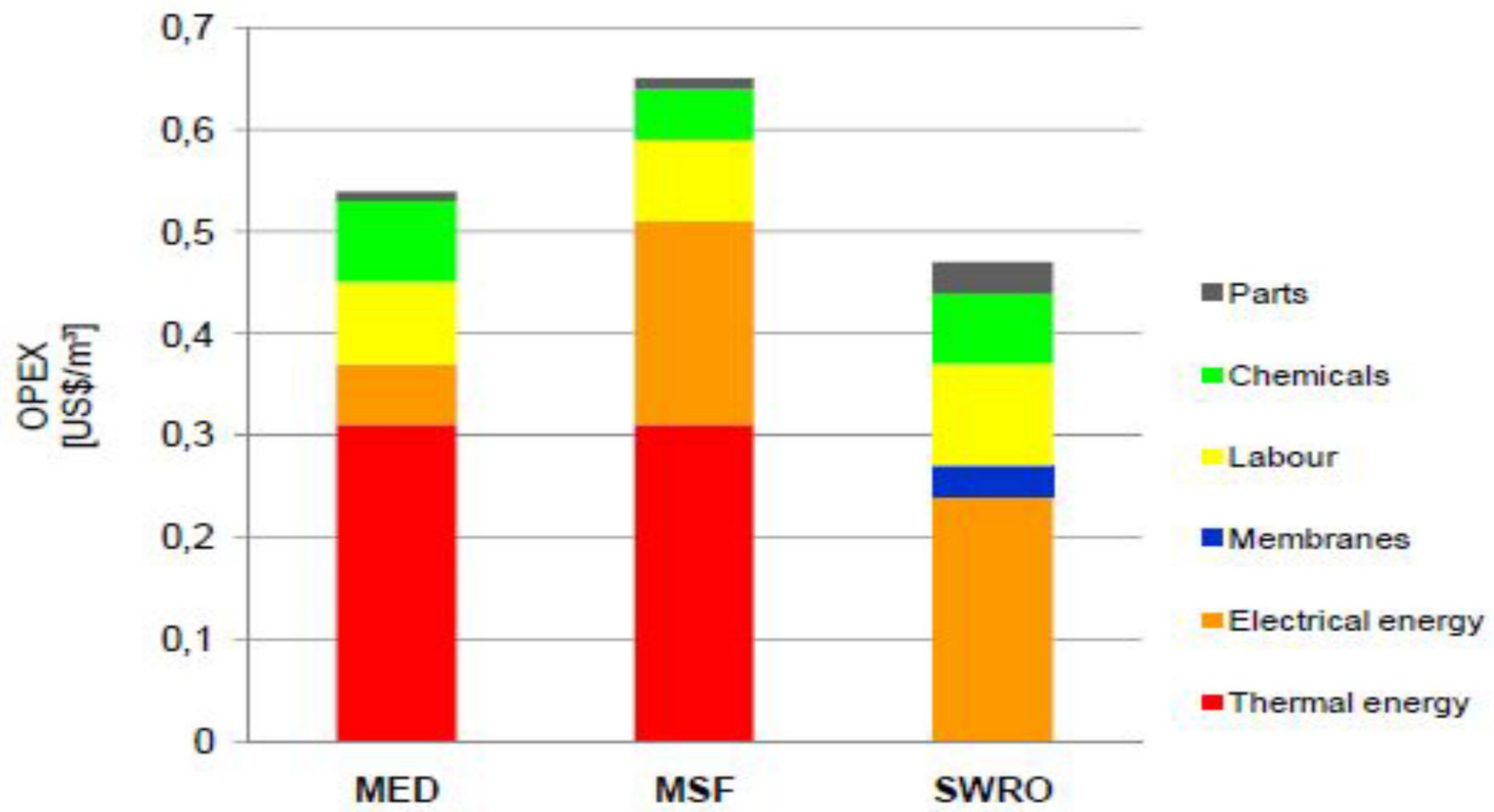
  Regulatory / Permitting Requirements

  Mainly Environmental Considerations (X)

  Growth Concerns (X)

X – Generally Not Applicable for In-house Ind. WW Recycling/Desalination

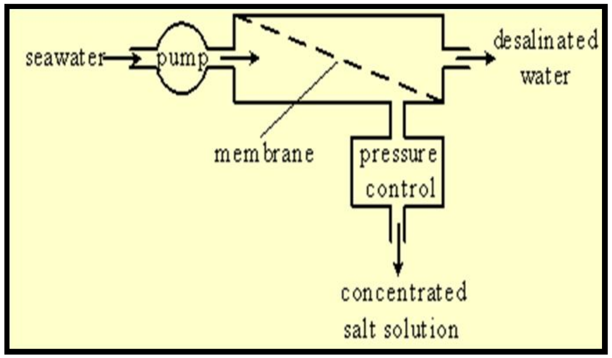
- **Cost Distribution of Desalination Processes**



Courtesy: Nikolay Voutchkov

- **Energy in Desalination**

Basic Concept



Minimum Applied P > 402 psi for RO to Occur

Min. Energy Required for 1L Water

= P*V
= 2.7 MPa * 1L
= 2.7 MPa-L = 0.75 Whr / l
= 0.75 kWh / m³

Assuming SW Salinity = 33,000 mg / l

Minimum Osmotic Pressure to Force Feed Water to Pass though the Membrane:

Using van't Hoff equation:

$$\pi = P_s = c * R * T = 27.75 \text{ bar} = 402 \text{ psi} = 2{,}775 \text{ kilopascals}$$

c = Ionic Molar Conc. = (33 / 58.5) x 2 = 1.128 mole / l

***R* = Gas Constant = 0.082 (liter bar / degree mole)**

***T* = Absolute Temp. (ºK); 27ºC → 300ºK**

The Force Acting on the Membrane is Equal to the Osmotic Pressure Multiplied by the Partition Area.

- **Theoretical Minimum Energy Needs:**

  0.75 kWh / m^3

  (2.84 kWh / 1,000 gal)

  Actual Plants:

  2.7 - 3.8 kWh / m3

  (10 – 14 kWh / 1,000 gal)

→ **3.5 to 5 Times More than Minimum**

In Early Days of Membrane Desalination, Energy Use was in the Order of: 20 kWh / m^3

ADC Accomplished: 1.62 kWh / m^3
6.4 kWh / 1,000 gal
2,100 kWh / AF

This Additional Energy Demand is due to **Factors like:**

Inefficiency of Feed Pump and Motor,

Water Permeating through Membranes (Membrane Resistance),

Energy Lost with Brine,

Recovery (Salinity & Temp. Impacts),

Membrane System Configuration,

Design Flux, &

Pretreatment, etc.

- **Barriers to Desalination**

Technology

Existing Technologies: Mature, Worldwide Applications
Room of Improvement, but Not a Barrier Anymore

Economics

Feasible on Case by Case Bases
Economical in Many Cases

Institutionally

Regulations, Policy, Permits, Financing, Public Perception

Permitting Process is Complex & Long
Number of Permits Needed
Number of Federal/State/Local Agencies Involved
This Increases the Level of Uncertainty →
Results in Longer Time / Higher Costs
(Generally Not Applicable for In-House Water Recycling)

Mindset – Energy Intensive, Expensive, Environmental Impacts

- **Desalination Plants**

Global Installed Capacity*

78.4 million m³/d today,

71.9 million in 2011; & 65.1 million in 2010

Approx. 60% Capacity Treats Seawater; Remainder Treats Brackish Water

Largest Membrane Desalination Plant

Victoria Desalination Plant in Melbourne: 444,000 m³/d (Came on line in Aug. 2012)

Work in Progress on:

Magata Plant (500,000 m³/d) in Algeria
Soreg Plant (510,000 m³/d) in Israel.

USA

Largest SW Plant (189,000 m³/d @ Carlsbad) – Work in Progress (Finally).

Estimated Price of Water: $1.65 – 1.86 / m³
$2,042 - $2,290 / AF (in 2012 $)

* http://www.desalination.biz/news/news_story.asp?src=nl&id=6746

- **Desalination Plants**

Largest Thermal Desalination Plant

Shoaiba 3 Plant in Saudi Arabia: 880,000 m^3/d

Ras Al Khair Plant (Saudi Arabia) with 1,025,000 m^3/d Production Capacity will be Completed in 2014

(Using Both Membrane and Thermal Technology)

- **Zero Liquid Discharge (ZLD)**

Relatively New Approach

Rising Trend

Helps Achieving:

- **Environmental Compliance**
- **High Purity Water to Recycle**
- **+ive Public Perception**
- **Reducing Carbon Footprint?**

Potential Applications:

- **Cooling Water Blowdown**
- **Produced Water**
- **FGD Purge WW**
- **RO Concentrate**
- **Other Complex Industrial WW**

Using a Combination of Treatment Processes

- **Zero Liquid Discharge (ZLD) – Examples**[1,2]

2 New 758 MW NG-CC Power Plants in Texas

Source Water: Treated WW & Lake Water, Respectively

450 gal/min Treatment Capacity for Each Plant

98% Water will be Recycled

Technologies:

i. **Brine Concentrator & ZLD Crystallizer**

ii. **Brine Concentrator**

Steel Mill in India

Main Component - EDR

GE Press Release: Jan. 15, 2013; April 26, 2012

- **Solution Providers**

  A Few Examples:

  Aquatech International

  GE

  Siemens Industry

  Veloia Water Solutions & Technologies

  Eco-Tech Inc.

  Severn Trent Services, Inc.

  DNV KEMA Energy & Sustainability

  H2O Innovation

- **Other Desalination Technologies of Interest**

- **Forward Osmosis**

  A Natural Process for Water Transfer through a Selectively Permeable Membrane Driven by the Osmotic Pressure Gradient Across the Membrane.

  Since, it is Driven by an Osmotic Pressure Gradient, FO Does Not Require Significant Energy Input (only for Stirring or Pumping of Solutions).

  FO Membranes Reject Organics, Minerals and Other Solids - Similar to Traditional Pressure Driven RO; but Resist Typical Fouling Problems.

Technical Barriers in Forward Osmosis:

  Lack of an Ideal Draw Solution that Exhibits High Osmotic Pressure & can be Easily Regenerated to Produce Pure Water

  Lack of an Optimized Membrane to Produce a High Water Flux, Comparable to Commercial RO Membranes

  A Suitable Module Design to Maintain Long-Term System Performance for Specific Applications.

- ## Forward Osmosis

World's First Commercial FO Plant (200 m^3 / day) was built by Modern Water at Al Najdah (Oman) in Sep. 2012.
(Contract Awarded in June 2011)

Propriety Technology Used is Called "Manipulated Osmosis Desalination (MOD)".

→ **Two-Stage Process that Combines FO with RO.**

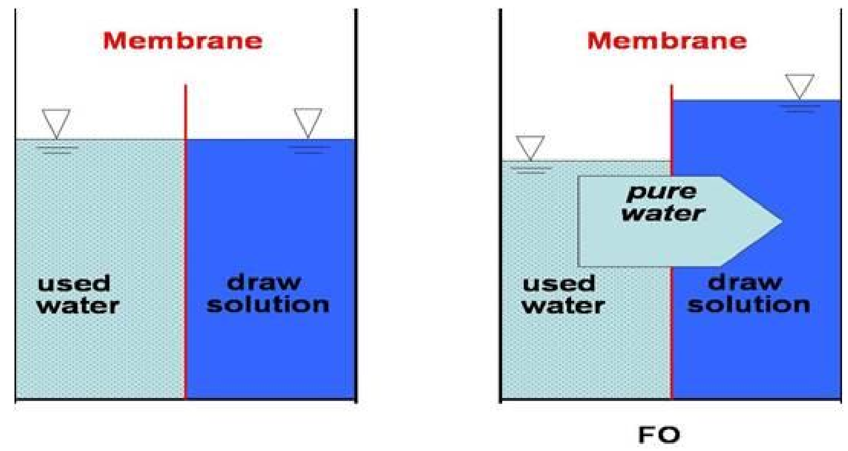
FO, Operating at a 35% Recovery, Dilutes the Draw Solution before it is Desalinated by High-Pressure RO Membranes to Produce Potable Water.

Operational Advantages of MOD:

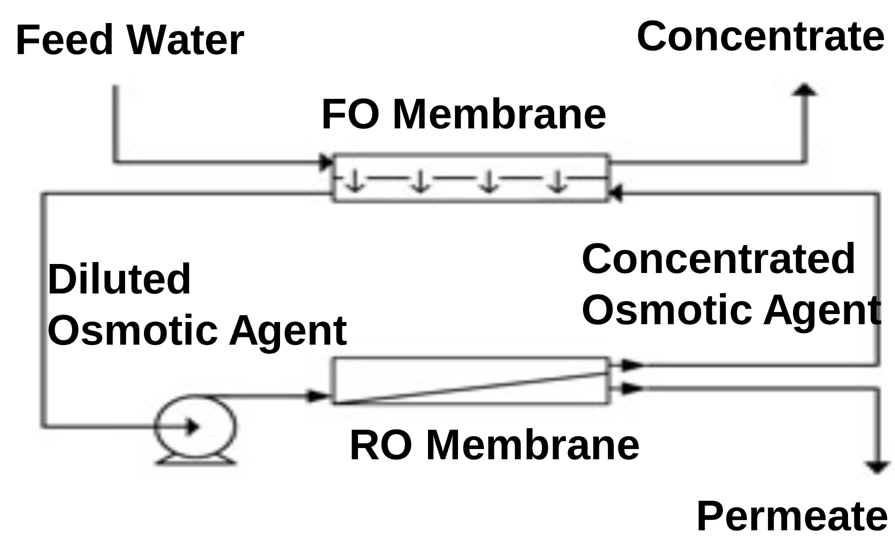
Diluted Feed Reduces RO Process Energy Needs by More than 20%.

The Chlorine-Tolerant, Fouling Resistant FO Membranes Provides Virtually Particulate-Free Feedwater for the High-Pressure RO Membranes.

- **FO Concept**



MOD Concept



- **Membrane Distillation**

  Apparently More Promising for Industrial Applications where Free Waste Heat is Available

  Combining Membrane Technology & Evaporation Processing in One Unit,

  Needs Both Thermal & Electrical Energy,

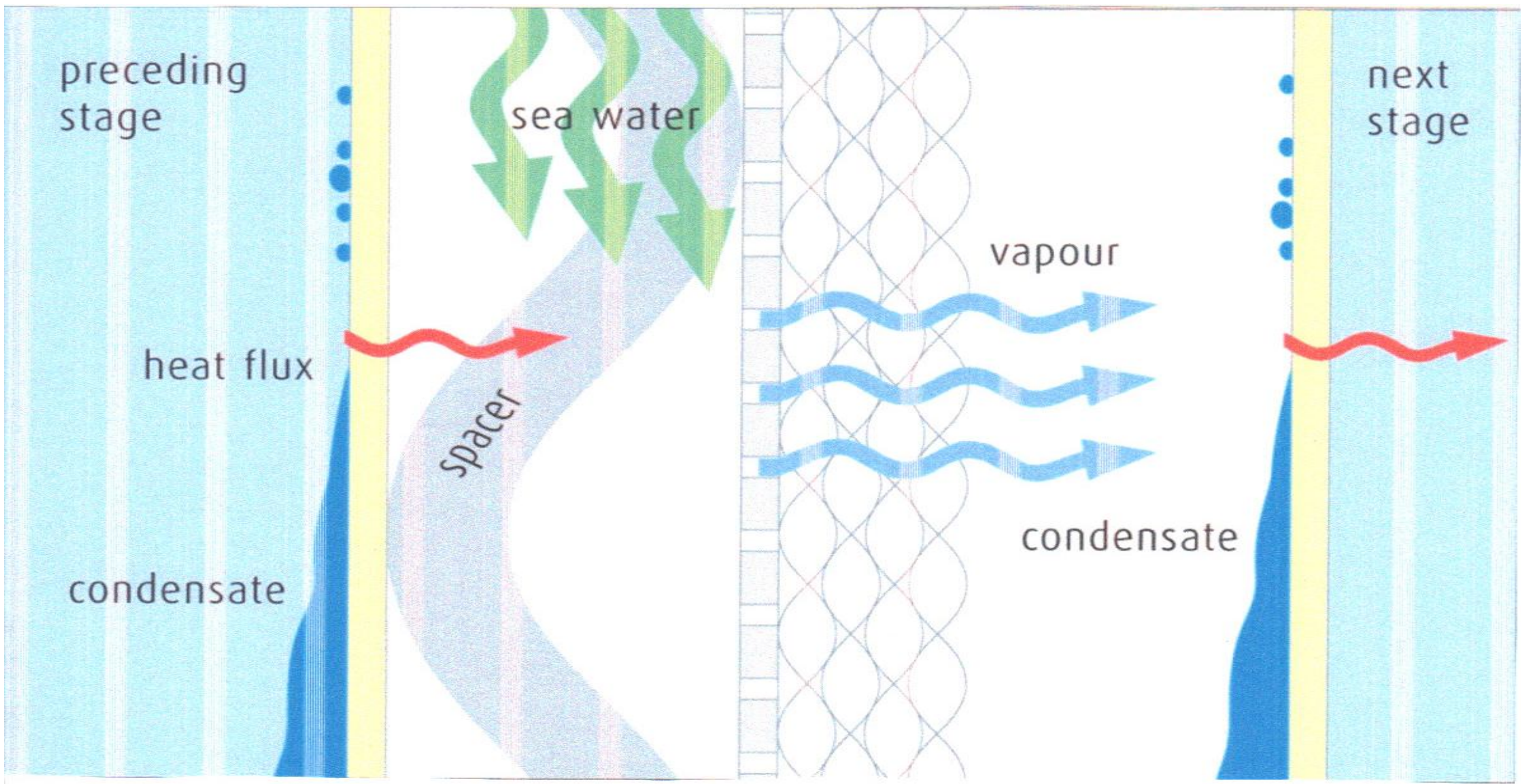
  Water Vapors are Transported through the <u>Hydrophobic Membrane Pores</u> via the Temperature Gradient across the Membrane,

  Offers the Attractiveness of Operation at Atmosphere Pressure and Low Temperatures (30º – 90ºC),

  Has the Theoretical Ability to Achieve 100% Salt Rejection.

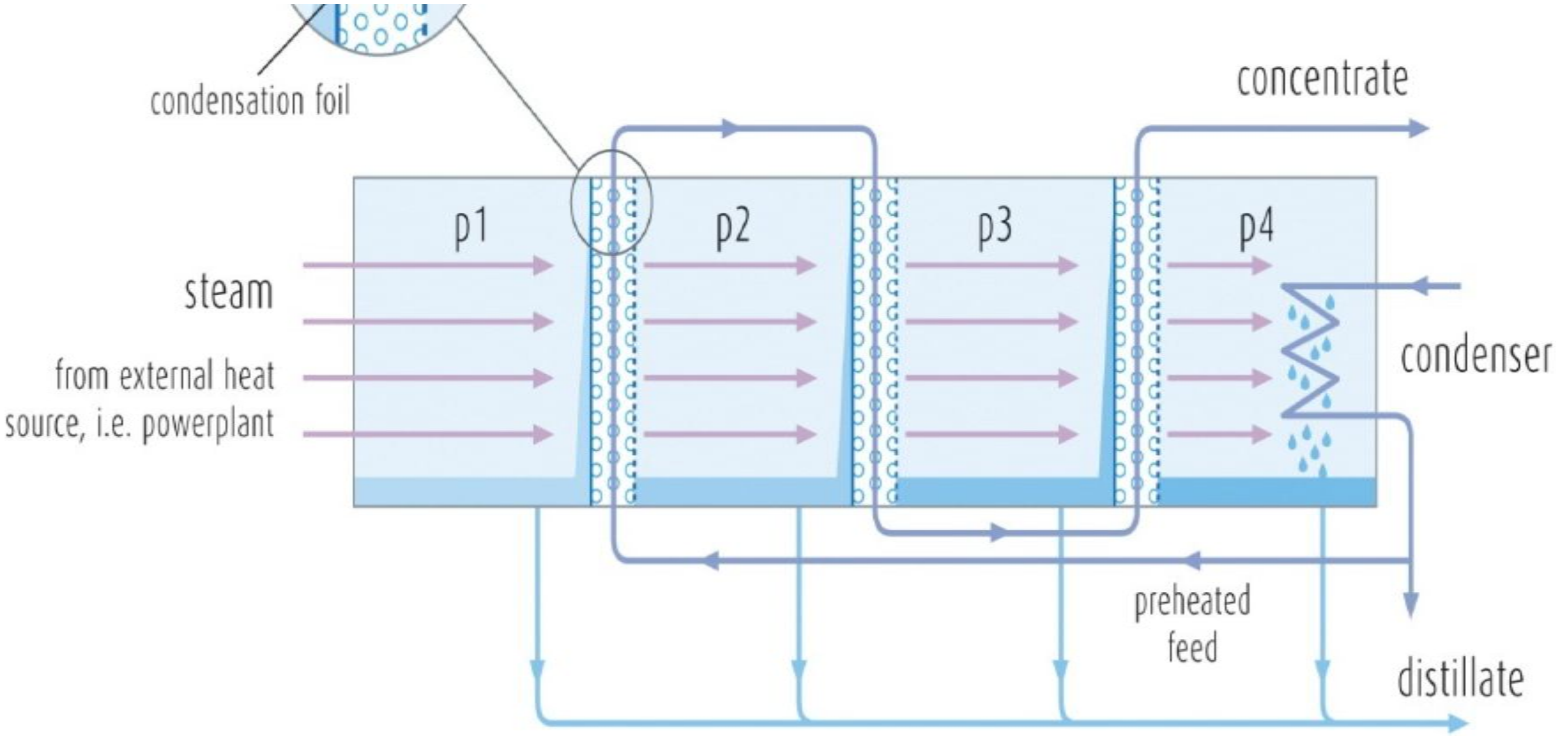
  Promising and Cost Competitive with RO where Thermal Energy (Heat) is Available at Low or No Cost.

- **Membrane Distillation Schematic**



Courtesy Aquaver (The Netherlands)

- **Membrane Distillation Schematic with Four Stages**



Courtesy Aquaver (The Netherlands)

- **Geothermal Desalination**

  RD&D Stage

  First Proof of Concept: 2001

  From 2005 to 2009, Testing with 6th Prototype at Scripps Institute of Oceanography Demonstrated Salt Reduction in Seawater from 35,000 ppm to 51 ppm.

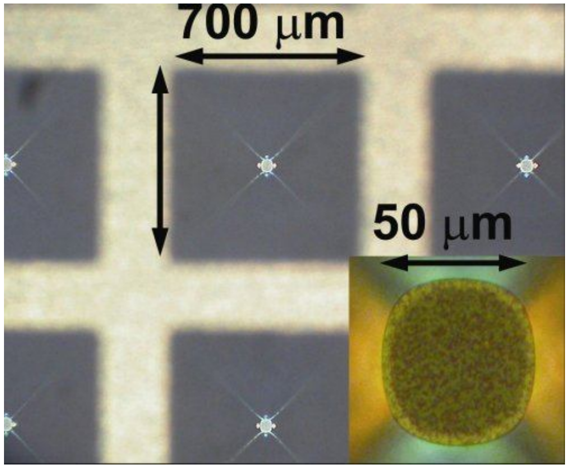
  Claimed Benefits include:

    Relatively Environmental Friendly Geothermal Energy, &
    Less Maintenance than RO Membranes

- **Nano-Desalination**

  Nanotube Membranes are Arranged and Packed like a Pile of Straws;

  Water Molecules can Pass through Membranes, while Bacteria, Biological Material and Other Impurities can Not.

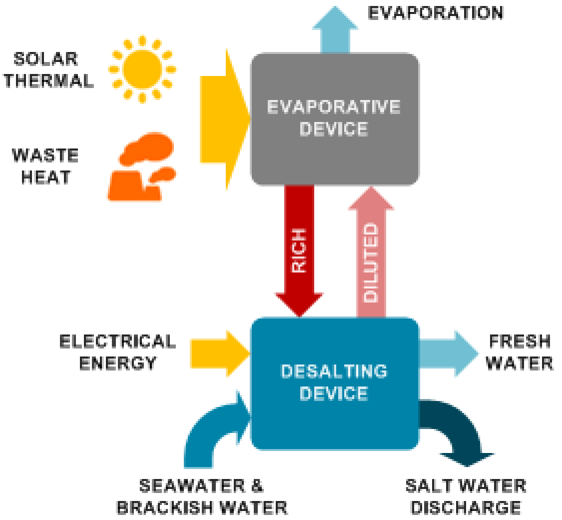


- **Thermo-Ionic Desalination Process**

  Proprietary Technology (Saltwork) – Employs an Innovative Thermo-Ionic Energy Conversion System.

  The Energy Reduction is Achieved by Harnessing Low-Temperature Heat and Atmospheric Dryness to Overcome Desalination Energy Barrier;

  The System Works Best in Dry Regions.

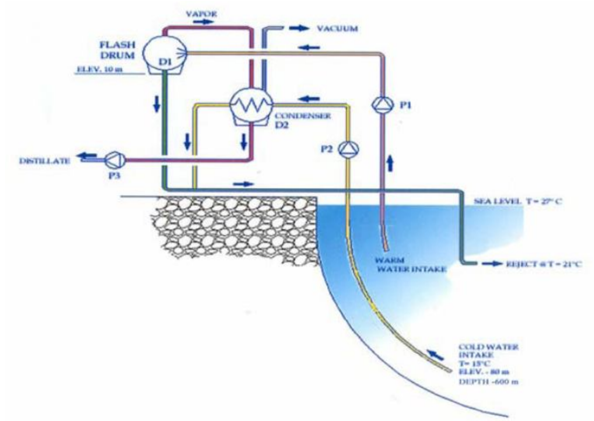


- ## Low Temperature Thermal Desalination

  Involves Flashing Relatively Warm SW (28º – 30ºC) Inside a Vacuum Flash Chamber and Condensing the Resultant Vapor using Deep Sea Cold Water (7º – 15ºC);

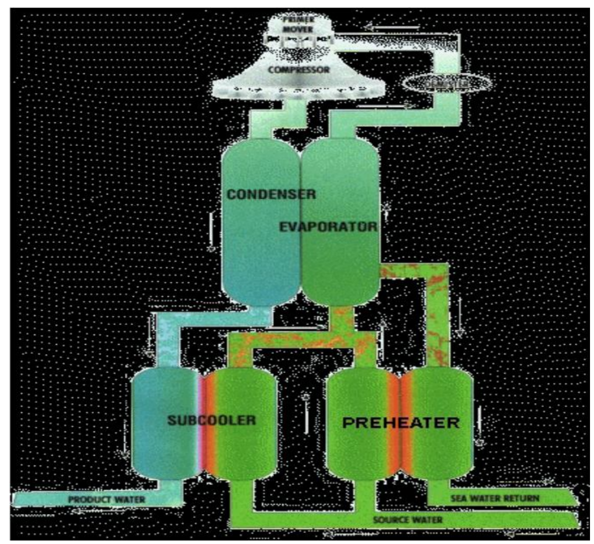
  Technology Was Developed in Italy, but First LTTD Plant was Built in India;

  The Process can be Used to Produce Drinking Water as well as for Power Generation and Air-Conditioning.

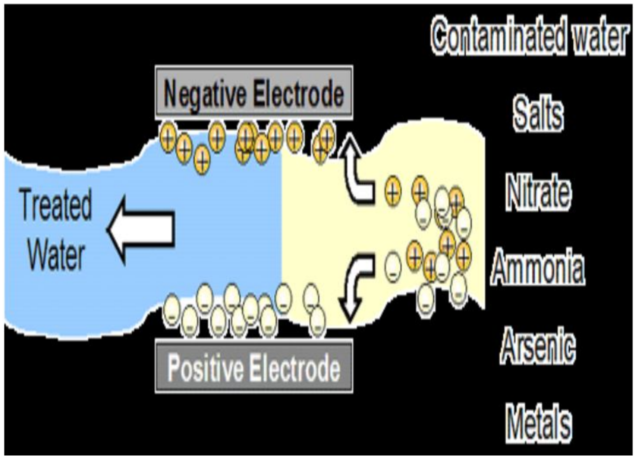


- ## Passarell Process

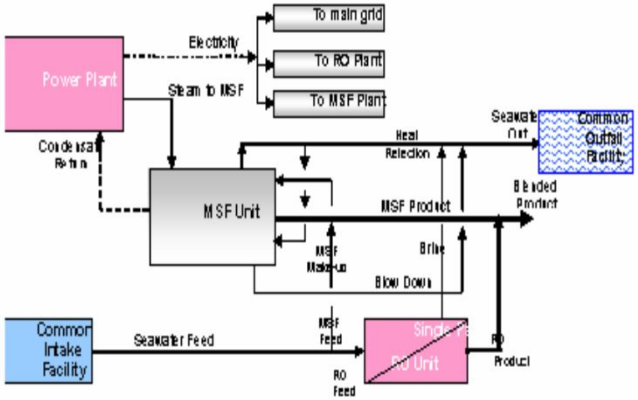
  Combines Accelerated Distillation with Advance Vapor Compression System (AD-AVCS) Resulting in Process Efficiency and Economy which is Unobtainable from Other Desalination Technologies.



- **Capacitive Deionization (CDI)**
  (aka Flow Through Capacitor - FTC)
  Works by Adsorption of Ions in the Electric Double Layer of Porous Carbon Electrodes;
  Accordingly, the FTC Removes Minerals & Salts from Aqueous Solutions by Charging Electrodes.

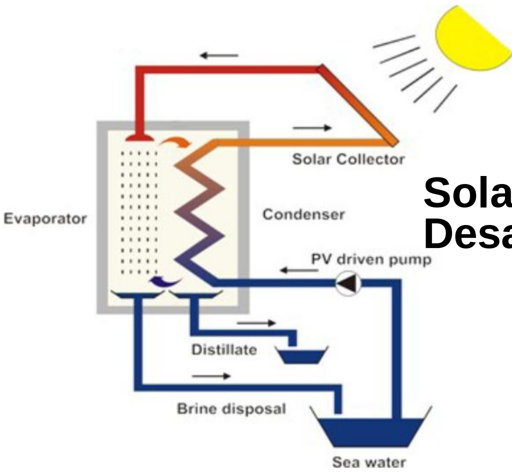


- **Hybrid Configurations**
  Hybrid Desalination Systems Combine Thermal and Membrane Desalination Processes;
  Power / Membrane / Thermal Configurations are Characterized:
  - **More Operationally Flexible,**
  - **Less Specific Energy Consumption,**
  - **Low Construction Cost,**
  - **High Plant Availability, and**
  - **Better Power and Water Matching.**

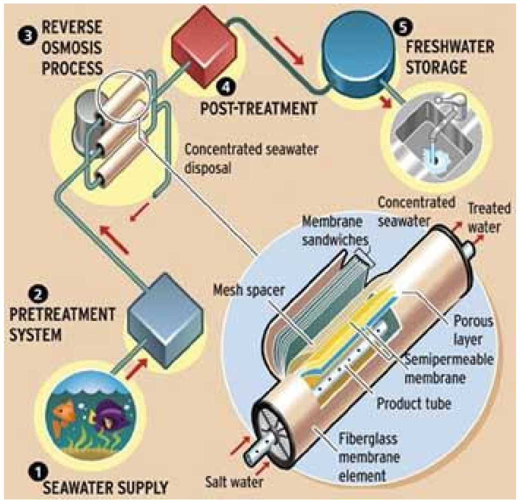


- **Solar Desalination**
  Desalination Using Solar Power

- **Geothermal Desalination**
  Desalination Using Geothermal Heat



Solar Desalination



Geothermal Desalination

- **Summary**

  Desalination May be Relatively Expensive for Municipal Water Supplies, but Makes Lot More Sense for Industrial Sector;

  Thermal Desalination & Emerging Technologies like Membrane Distillation Appears to be More Attractive to Recycle Strong Industrial Wastewaters;

  Industrial WW Recycling Helps Making Water & Energy Resources Sustainable; Reduces Carbon Footprint; and Demonstrates Corporate Social Responsibility (CSR).