# Thermal Desalination of Produced Water in Heavy Oil Assets

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# Outline

- Background
- Thermal Desalination Technologies – Membrane Distillation
- Membrane Distillation - Findings
- Conclusions
- Multiple Effect Distillation : Sylvan Core – Findings ( Optional)

# Thermal Oil Recovery : Heavy Oil Fields

# Produced Water Geochemistry

- Associated with the geology of the reservoir
  - Carbonate Reservoir
  - Sandstone Reservoir
  – High hardness or high silica
  – High temperature

| | California | Canada | Middle East |
|---|---|---|---|
| Hardness ( as $CaCO_3$) | 150-200 | 10-140 | 1000-9000 |
| $HCO_3^-$ ( mg/L) | 500-1500 | 200-400 | 500-1000 |
| $SiO_2$ (mg/L) | 175-350 | 250-350 | 10-40 |
| TDS ( mg/L) | 5000-7500 | 1000-6000 | 7,000-35,000 |
| Temp ( F) | 160 - 180 | 170 - 190 | 170-200 |

# Desalination Drivers

- **Environmental & Regulatory**
  - Reduce reliance on disposal injection
  - Increase reuse of produced water (internal + export) including beneficial reuse
  - Minimize use of freshwater, esp. 3rd party supplies
- **Operations**
  - Reduce CAPEX and OPEX for water plants
  - Consolidate or eliminate treatment stages
  - Improve treatment performance (e.g., efficiency, separation, permeate recovery, reliability, sanding, tolerance to oil upsets, fouling, and scaling)
  - Reduce chemical use and waste generation (esp. liquids/brine)
  - Decrease energy consumption and GHG emissions
  - Replace existing systems at end of life and/or instead of repair
- **Technology Investment**
  - Optimize technology investment budgets and timing
- **Organizational Capability**
  - Optimize BU resources, develop OC in water treatment technologies
- **Asset Development**
  - Meet future production water handling needs (capacity)
  - Extend life of asset by removing reservoir capacity constraints



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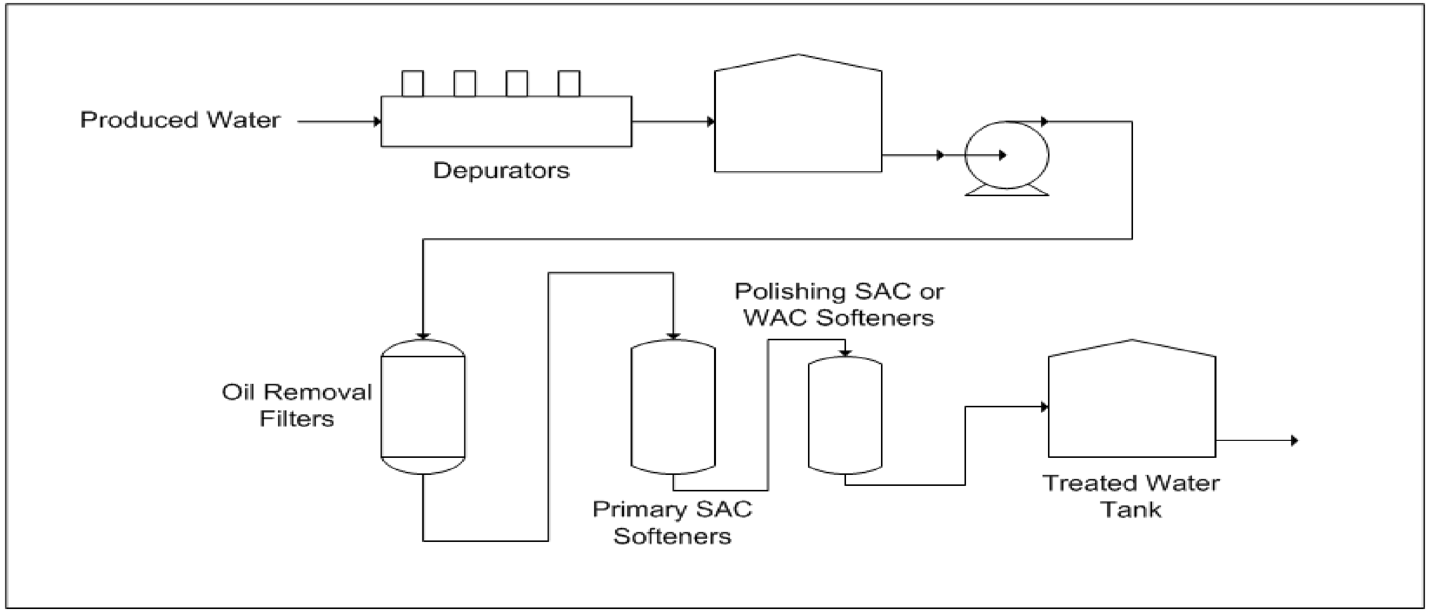
# Steamflood Water Treatment Requirements



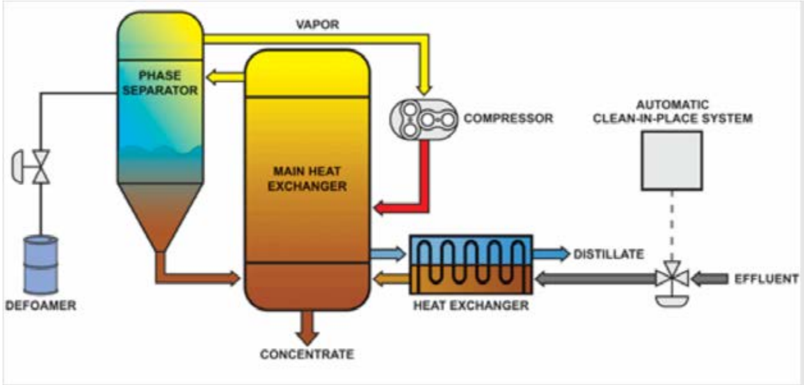

- **Deoiling**
- **Softening**
  - **SAC/SAC Softeners**
  - **SAC/WAC Softeners**
  - **Usually applied to low TDS waters**
  - **Silica is not removed but it does form scales in Once Through Steam Generators**
- **Usually no desalination required**

# Desalination vs Softening for Steamflood : Drivers

- Silica removal is not addressed in softening
- Softening costs may be too high if water has high hardness and TDS
  - Salt consumption during softener regeneration
  - Caustic/acid consumption is high
  - Logistics of bulk chemicals transport
  - Independent studies have shown that OPEX is significantly high
- High temperature of produced water can be of value
  - High temperature RO membranes ( has its own challenges)
  - Thermal Desalination ( subject of this presentation)
    - Normally considered for high TDS waters but may find value in these conditions
- Quality of product water is very high with very low TDS
  - Steam quality can be very high ( only limited by design of the OTSGs)
  - Target Quality : 80% - 85%

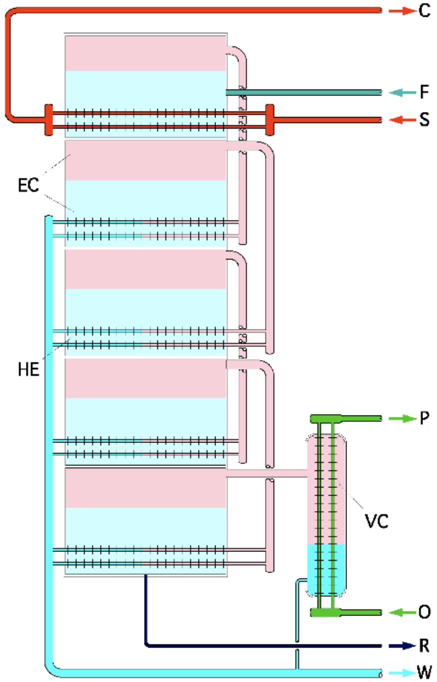
# Thermal Desalination : Technologies

**Mechanical Vapor Compression**

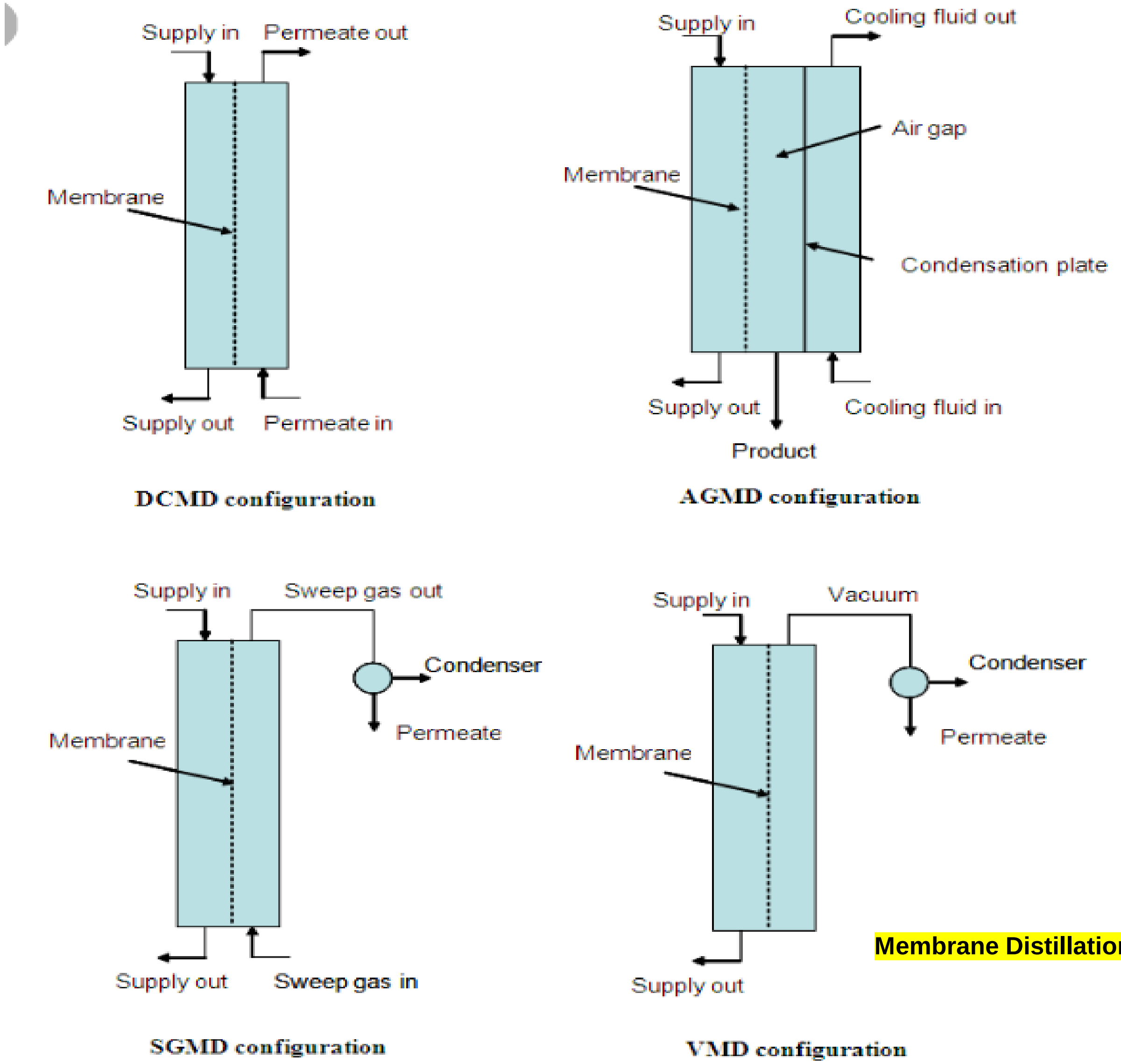



**Multiple Effect Distillation**

Schematic of a multiple effect desalination plant. The first stage is at the top. Pink areas are vapor, lighter blue areas are liquid feed water. Stronger turquoise is condensate. It is not shown how feed water enters other stages than the first. F - feed water in. S - heating steam in. C - heating steam out. W - Fresh water (condensate) out. R - brine out. O - coolant in. P - coolant out. VC is the last-stage cooler.



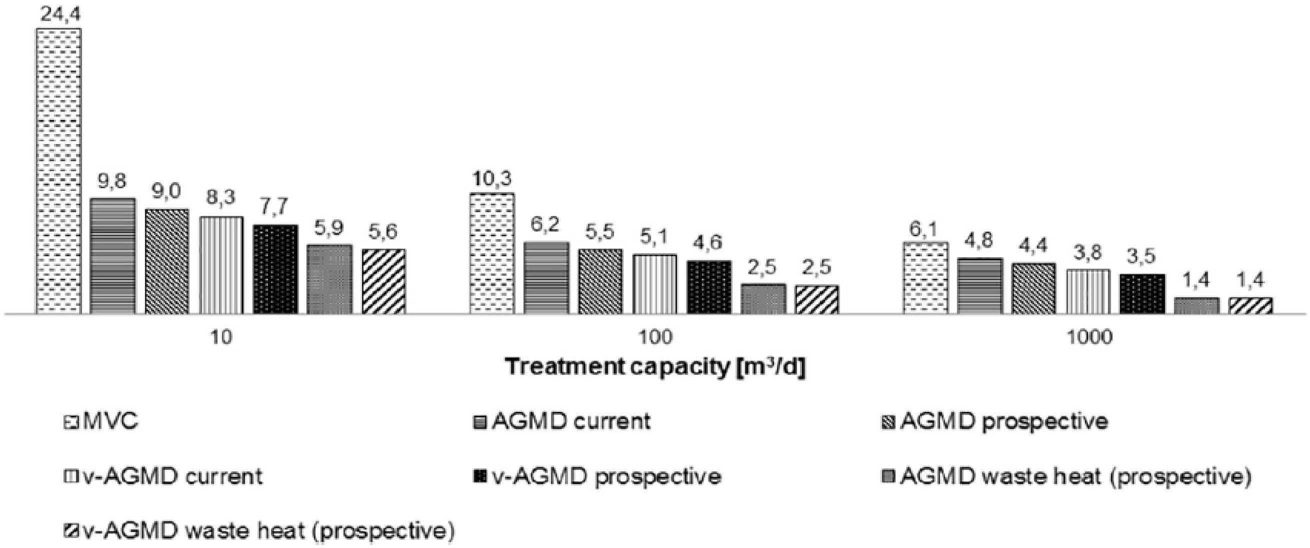

**Membrane Distillation**




**DC – Direct Contact; AG – Air Gap; SG – Sweep Gas; V – Vacuum**

# Membrane Distillation : Advantages

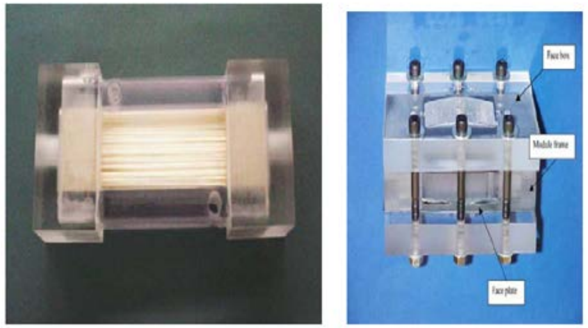
- Lower operating temperature than conventional distillation – improved integrity of equipment
- Lower operating pressure than RO - lower fouling propensity
- Polymeric material of construction – lower Capex
- Limited pretreatment
- Almost 100% rejection of nonvolatile solutes
- No effect of osmotic pressure
- Can remove 99.8% boron & silica without pH adjustment




Schwantes et al : Desalination 428 ( 2018) 50 - 68

# Membrane Distillation : Experimental Work

- Carried out at Professor Kam Sirkar's Lab in NJIT
- Each module picture frame contains porous polypropylene hollow fibers having on their outside surface a highly porous plasma polymerized fluorosilicone coating.
- Hot produced water was pumped on the shell side in cross flow over the hollow fibers and the cold distillate solution was pumped through the lumen side of the hollow fibers by two peristaltic pumps (Masterflex, Cole-Parmer, Vernon Hills, IL).
- The feed produced water was obtained from a 55 gal drum sent by Chevron Inc. (Richmond, CA).
- A sample of this water was heated in a constant temperature bath (A81, HAAKE, Germany).



(a) (b)

Figure 2. Photographs showing (a) rectangular cross flow test module with out face plates etc. (b) rectangular cross flow test module with face boxes, face plates and assembly (Made at NJIT).

Table 1. Characteristics of DCMD modules used in produced water treatment

| Membrane Module | Module#75 | Module#79 |
|---|---|---|
| Fiber O.D., μm | 630 | 630 |
| Fiber I.D., μm | 330 | 330 |
| Membrane porosity | 0.60 | 0.60 |
| No. of fibers | 13x29=377 | 13×29=377 |
| Effective fiber length, cm | 4.3 | 4.5 |
| ** Effective internal membrane surface area, $cm^2$ | 168 | 176 |

*Membrane picture frame supplied by Applied Membrane Technology, Inc, Minnetonka, MN; flow distributors and cover plate fabricated at NJIT.
**Based on fiber internal diameter (I.D.)

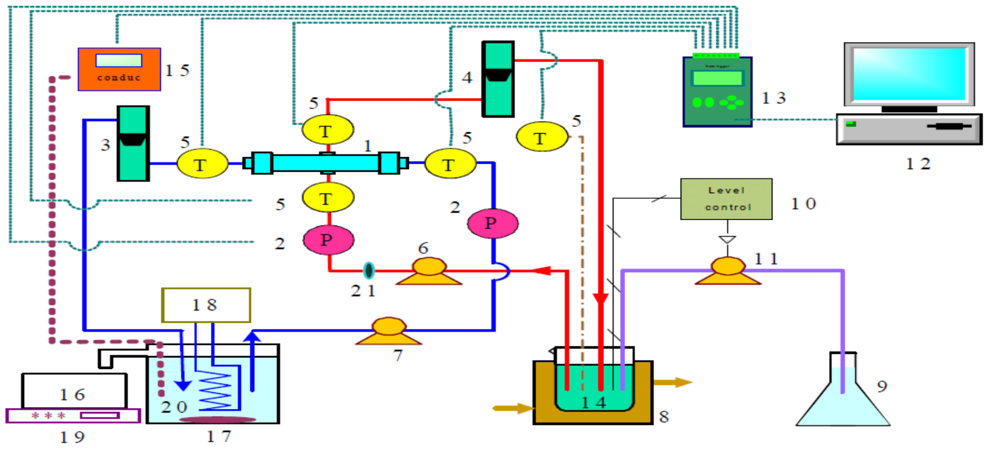



**Figure 1.** Low temperature DCMD setup:
1.Membrane module; 2. Pressure indicator; 3. Distillate flowmeter; 4. Urine flowmeter; 5. Thermocouple; 6. Hot urine pump; 7. Distillate pump; 8. Constant temperature bath; 9. Make-up water reservoir; 10. Level controller; 11. Make-up pump; 12. Computer; 13. Data logger; 14. Hot brine beaker; 15. Conductivity transmitter; 16. Distillate overflow reservoir; 17. Magnetic stirrer; 18. Chiller; 19. Weight balance; 20. Cold distillate beaker; 21. Filter holder.

# DCMD: Results

- **Four different waters were tested. Results of two water samples shown below. One was high silica. The other has both high silica and hardness**

Table 5. Water chemistries for untreated/treated Chevron A (Post-Wemco)

| | **Chevron A (Post WEMCO): Untreated Water Sample** | **Chevron A (Post WEMCO): Treated Water by DCMD** |
|---|---|---|
| Components | (mg/l) | (mg/l) |
| Bicarbonate, $HCO_3^{-1}$ | 678 | 24.2 |
| Carbonate, $CO_3^{-2}$ | 0.0 | 0.0 |
| Chloride, $Cl^-$ | 4010 | 4.49 |
| Hydroxide, $OH^-$ | 0.0 | 0.0 |
| Sulfate, $SO_4^{-2}$ | 67.7 | 2.7 |
| Boron, $B^{+3}$ | 34.5 | 0.541 |
| Calcium, $Ca^{+2}$ | 57.8 | 0.143 |
| Iron, $Fe^{+3}$ | 0.541 | 0.00 |
| Magnesium, $Mg^{+2}$ | 8.34 | 0.022 |
| Potassium, $K^{+1}$ | 54.7 | 0.216 |
| Sodium, $Na^{+1}$ | 2710 | 3.27 |
| Silica, as $SiO_2$ | 159.1 | 0.0 |
| TDS | 7622 | 41.0 |



Ref: DOI: 10.1021/ie4015809

# DCMD: Results Contd.

Table 7. Water chemistries for untreated/treated Chevron B1

| Components | Chevron B1: Untreated Water Sample (mg/l) | Chevron B1: Treated Water by DCMD (mg/l) |
|---|---|---|
| Bicarbonate, $HCO_3^{-1}$ | 1189.1 | 16.8 |
| Carbonate, $CO_3^{-2}$ | 0.0 | 0.0 |
| Chloride, $Cl^-$ | 5885.37 | 0.56 |
| Sulfate, $SO_4^{-2}$ | 1745.27 | 0.50 |
| Boron, $B^{+3}$ | 31.6 | 0.452 |
| Calcium, $Ca^{+2}$ | 1240.09 | 0.106 |
| Iron, $Fe^{+3}$ | 0.097 | 0.00 |
| Magnesium, $Mg^{+2}$ | 330.52 | 0.018 |
| Potassium, $K^{+1}$ | 125.43 | 0.097 |
| Sodium, $Na^{+1}$ | 2902.71 | 3.82 |
| Silica, as $SiO_2$ | 159.1 | 0.0 |
| TDS | 12040 | 22.0 |

Ref: DOI: 10.1021/ie4015809

# DCMD: Results Contd.

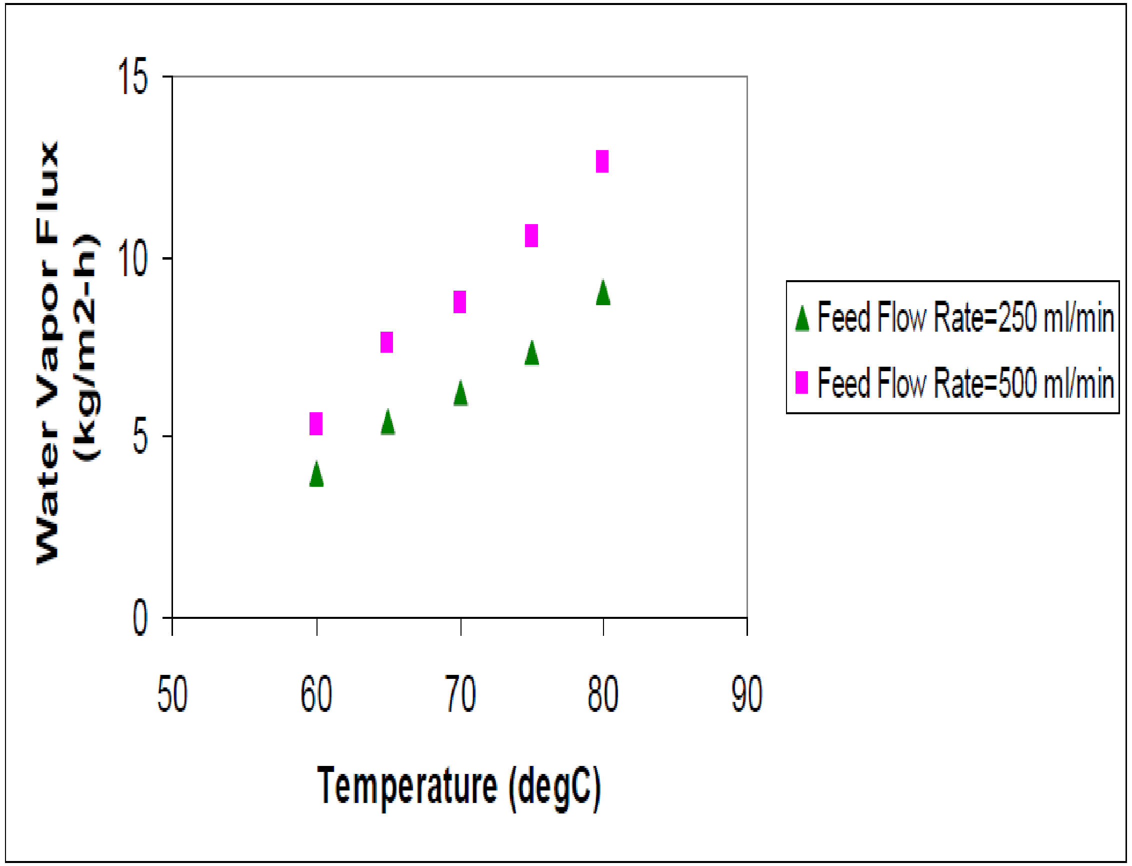



Figure 6. Variation of water vapor flux in DCMD with temperature for Chevron A (Post-Wemco) produced water in rectangular cross flow module #79.

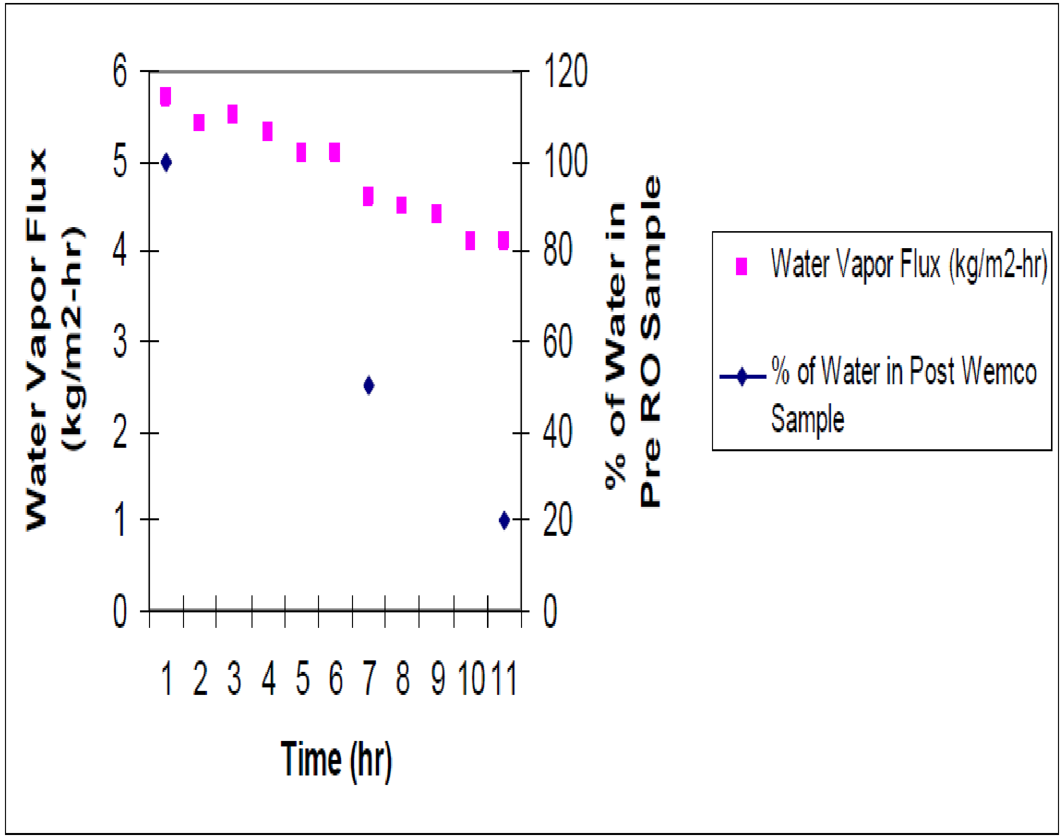



Figure 7. Variation of water vapor flux with time varying concentration of Chevron A (Post-Wemco) produced water at 70° C in rectangular cross flow module #75 during batch recirculation-based feed concentration.



Ref: DOI: 10.1021/ie4015809

# Membrane Distillation : Results Contd.

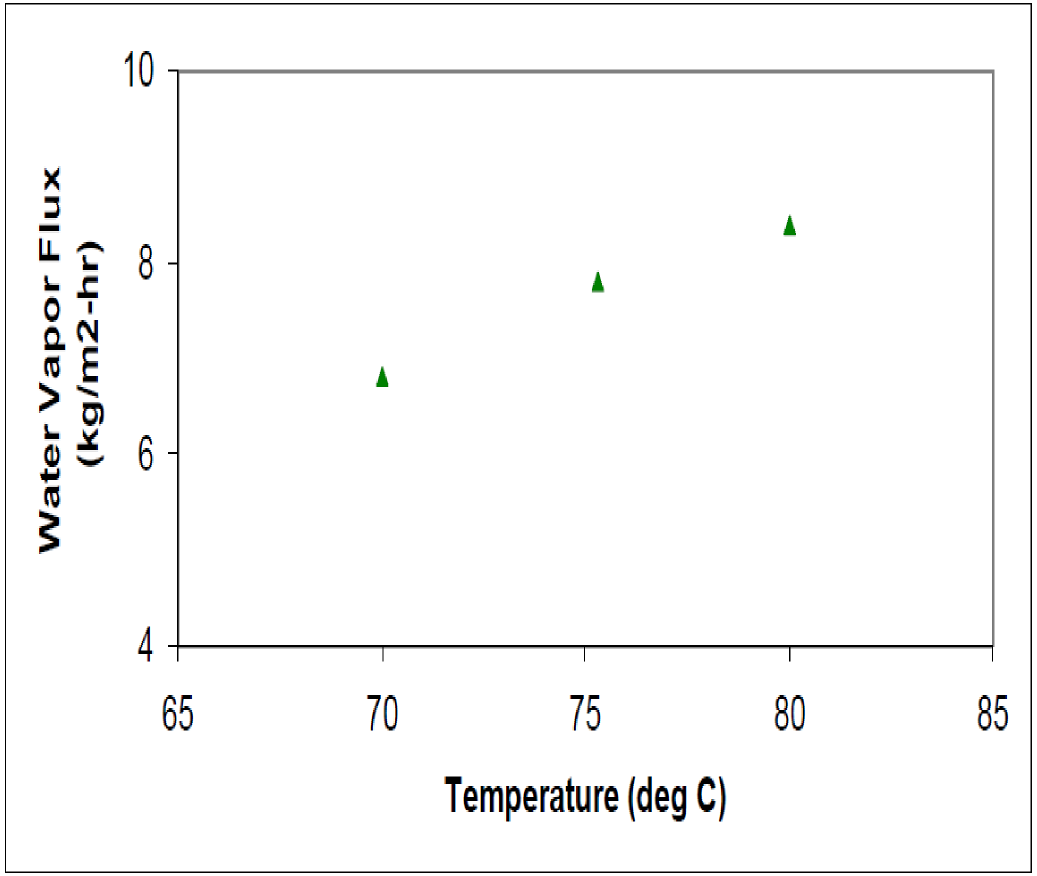



Figure 8. Variation of water vapor flux in DCMD with temperature for Chevron B1 produced water in rectangular cross flow module#75.

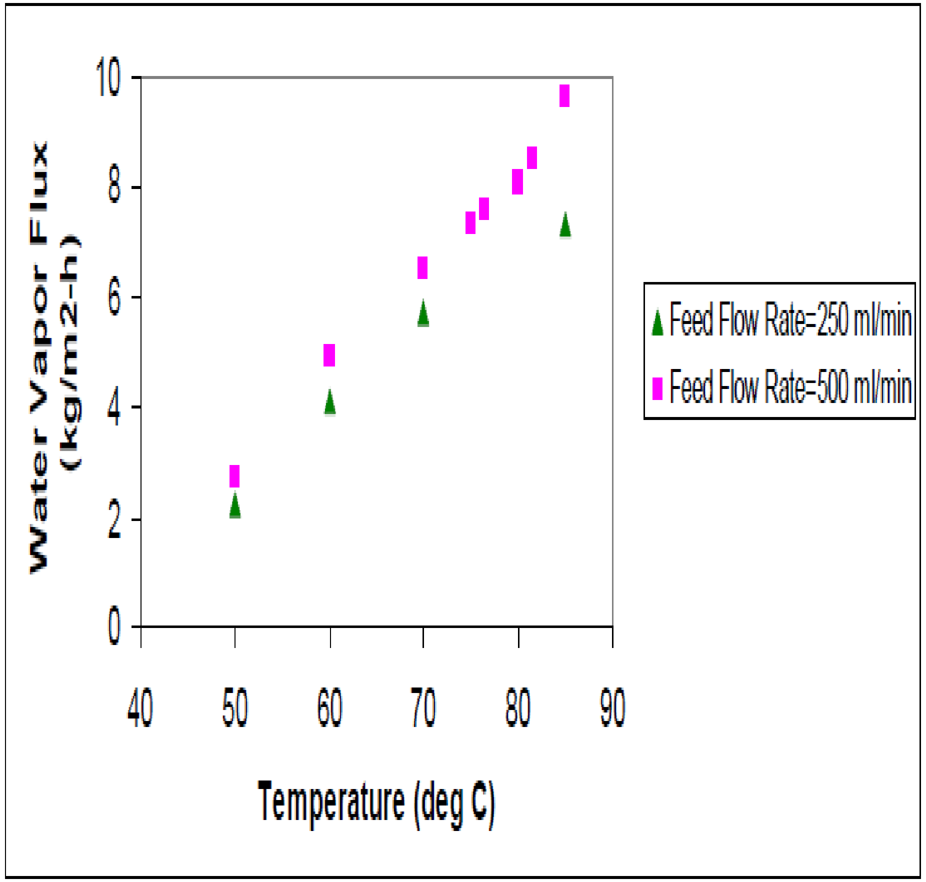



Figure 5. Variation of water vapor flux in DCMD with temperature for Chevron A (Pre-RO) produced water in rectangular cross flow module #75 at two different feed flow rates.

Ref: DOI: 10.1021/ie4015809

# DCMD: Results Contd.

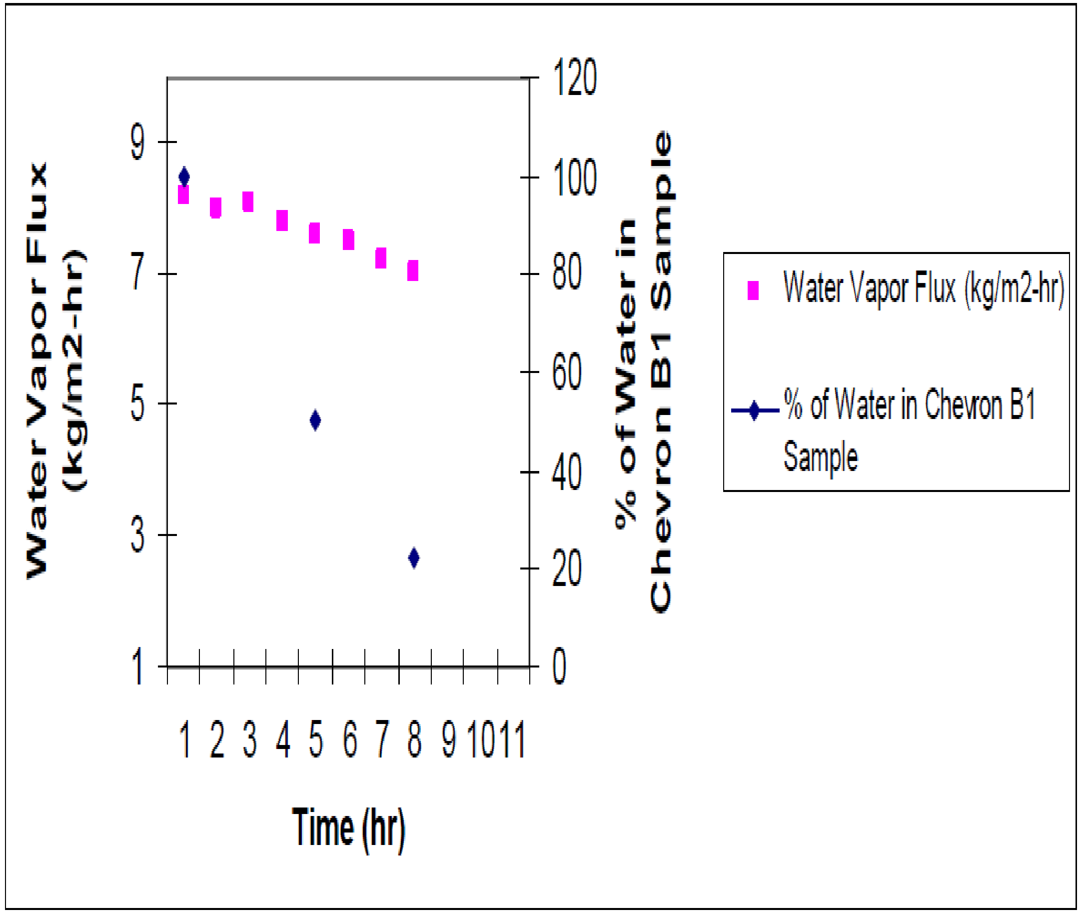



Figure 9. Variation of water vapor flux in DCMD with varying concentration of Chevron B1 at 80°C in rectangular cross flow module #75 during batch recirculation-based feed concentration.

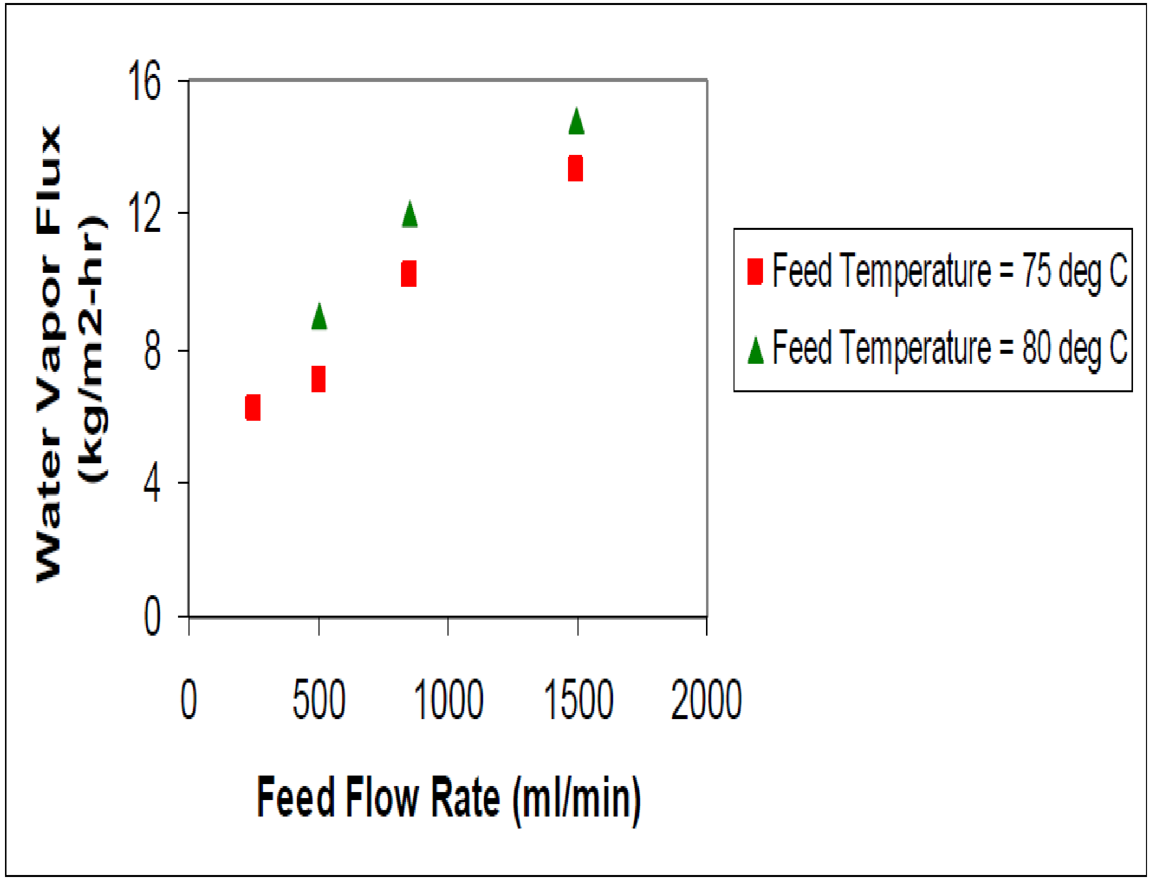



Figure 10. Variation of water vapor flux in DCMD with varying flow rate of Chevron B2 produced water in rectangular cross flow module #75.



Ref: DOI: 10.1021/ie4015809

# Conclusions

- **For DCMD Studies, it was concluded that:**
  - DCMD process could be successfully employed to treat different kinds of produced water. The TDS value was very low in the distilled water
  - Water recovery from different produced waters was ~80% by the DCMD process operated in batch recirculation mode when the process was stopped
  - The amount of scaling salt, sodium chloride and silica was almost negligible in the water recovered by distillation; it may be reused for steam generation and a variety of applications. Probably a minor ion exchange polishing will be needed
  - At a higher feed flow rate, water vapor flux achieved at $80_0$C was 15 kg/m2-hr; at an even higher feed flow rate it may be increased to ~ 20 kg/m2-hr.
  - The novel coated membranes ( plasma polymerized fluorosilicone coating) and the hollow fiber cross flow module design are responsible for the observed performances
  - Previous pilots with this geometry provided a GOR of nearly 6. Therefore more studies with this module will be carried out
  - The heat recovery from the hot distillate using heat recovery heat exchangers will be needed in the pilot design

# Additional Slides

# Comparison of Matured Thermal desalination technologies

- **MVC**
- **Pros**
- Robust
- High recovery
- Wide range feed water quality
- Can handle wide temperature range
- Insensitive to impurities (e.g. oil)
- Minimum pre treatment
- **Cons**
- Exotic materials
- Bulky equipment
- High capex
- High power consumption
- Complex process

- **UF/RO**
- **Pros**
- No exotic materials
- Can be inside a building
- Less capex
- Simple process

- **Cons**
- Extensive pretreatment
- Susceptible to impurities
- Limited feed temperature
- Low recovery
- unproven > 113 F

# Sylvan SSI Core: Advanced MED

| Independent Produced Water Benchmark | | | | |
|---|---|---|---|---|
| 1m gpd (23,810 bbl/d) systems, net | SSI Core | Typical RO | Typical MED | Typical VCE |
| CapEx, Installed $millions | $20.1 | $35.8 - $54.0 | $51.0 | $41.1 |
| OpEx, $/kgals, net | $6.7 | $15.3 - $22.6 | $16.4 | $15.0 |

| Independent Cooling Tower Blowdown Benchmark | | | | |
|---|---|---|---|---|
| 1m gpd (23,810 bbl/d) systems, net | SSI Core | Typical RO | Typical MED | Typical VCE |
| CapEx, Installed $millions | $20.2 | $35.7 | $53.8 | $36.3 |
| OpEx, $/kgals, net | $8.1 | $15.4 | $22.7 | $13.6 |

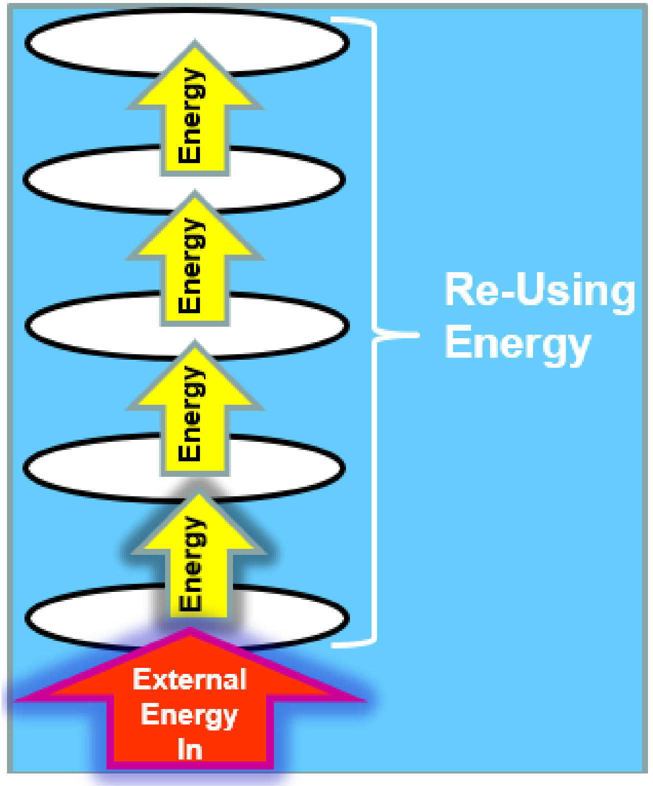
- Independent benchmarks conducted by DiFilippo Consulting with input from customers, vendors and industry groups
- No waste heat was utilized in any competitive benchmark
- Quality of SSI product water not given extra credit

RO = Reverse Osmosis  MED = Multiple-Effect Distillation
VCE = Vapor Compression Evaporator

*Benchmarks by DiFilippo Consulting*

sylvan source

Proprietary Thermal Transfer Art
Physical Process
(patents granted and pending)




more energy efficient than conventional heat exchangers = Lower OpEx
1/3 the surface area requirement = Lower CapEx

# Sylvan Core: Results

- **Lab Scale Testing Set-Up**


- **Two barrels of water tested – 87% recovery**

| Constituents | Feed | Product ( Stage 4) |
|---|---|---|
| Calcium, mg/L | 900 | ND |
| Magnesium, mg/L | 260 | ND |
| TDS, mg/L | 12100 | < 10 |
| Silica, mg/L | 130 | ND |
| Boron, mg/L | 26 | ND |
| Alkalinity, mg/L | 1020 | 10 |
| Sulfate, mg/L | 1500 | ND |

# Conclusions

- **For Sylvan Core MED, we concluded that:**
  - MED process can desalinate water to low TDS : less than 25 ppm
  - Extent of pre-treatment was minimal but more studies needed
  - Witnessed a larger pilot study in Southern California
  - Detailed energy efficiency not studied. More work needed