Forward Osmosis Energy Use

Comparisons to RO, MSF, MED

R. McGinnis, J. McCutcheon M. Elimelech
Dept. of Chemical Engineering
Environmental Engineering Program
Yale University

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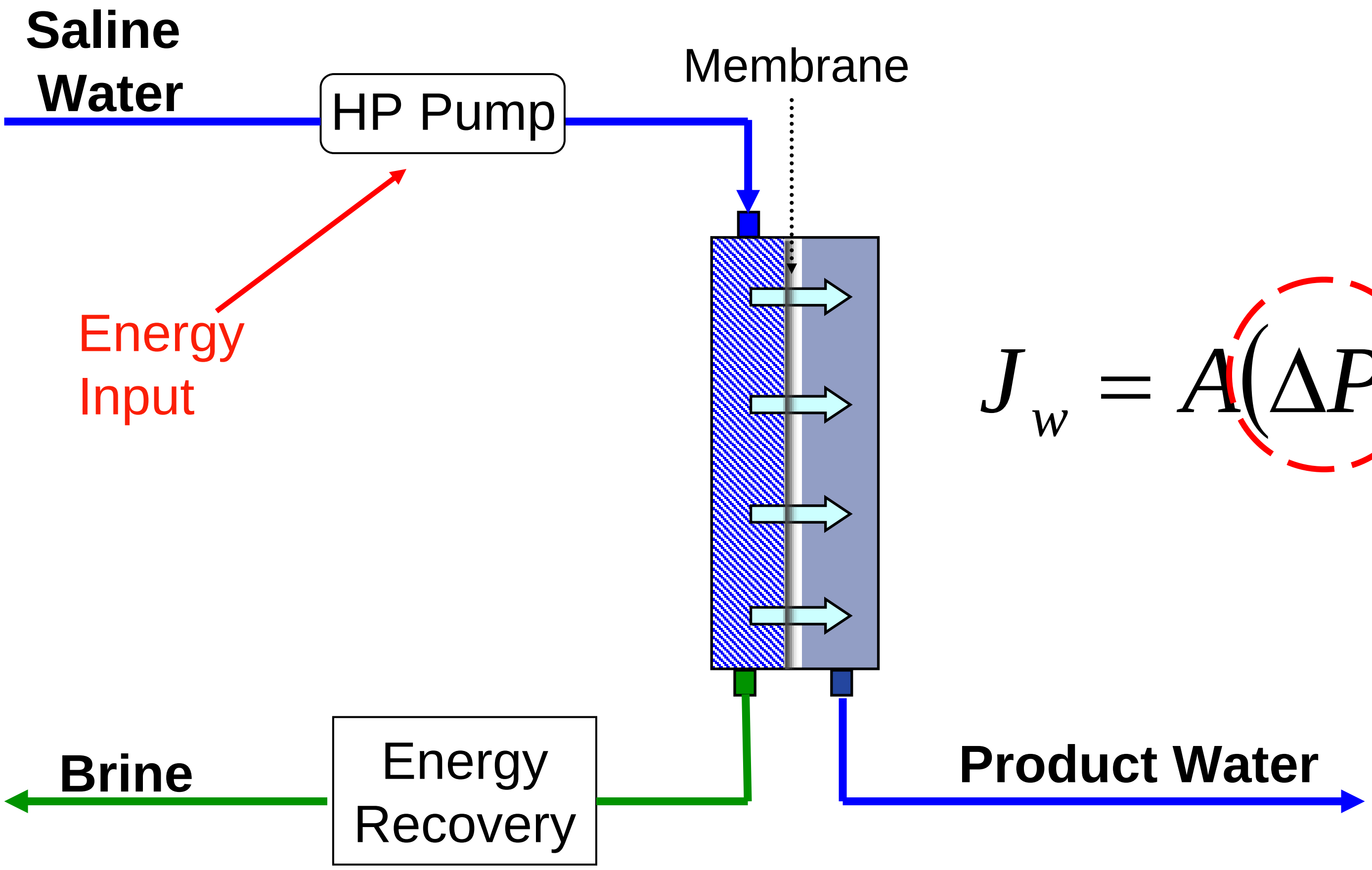
Outline

- Overview of NH_3/CO_2 FO
- Solute Removal / Recycle Methods
- Modeling Methods
- FO Energy Estimates
- Comparison to RO, MSF, MED
- Impact of Membrane Efficiency on Heat Use

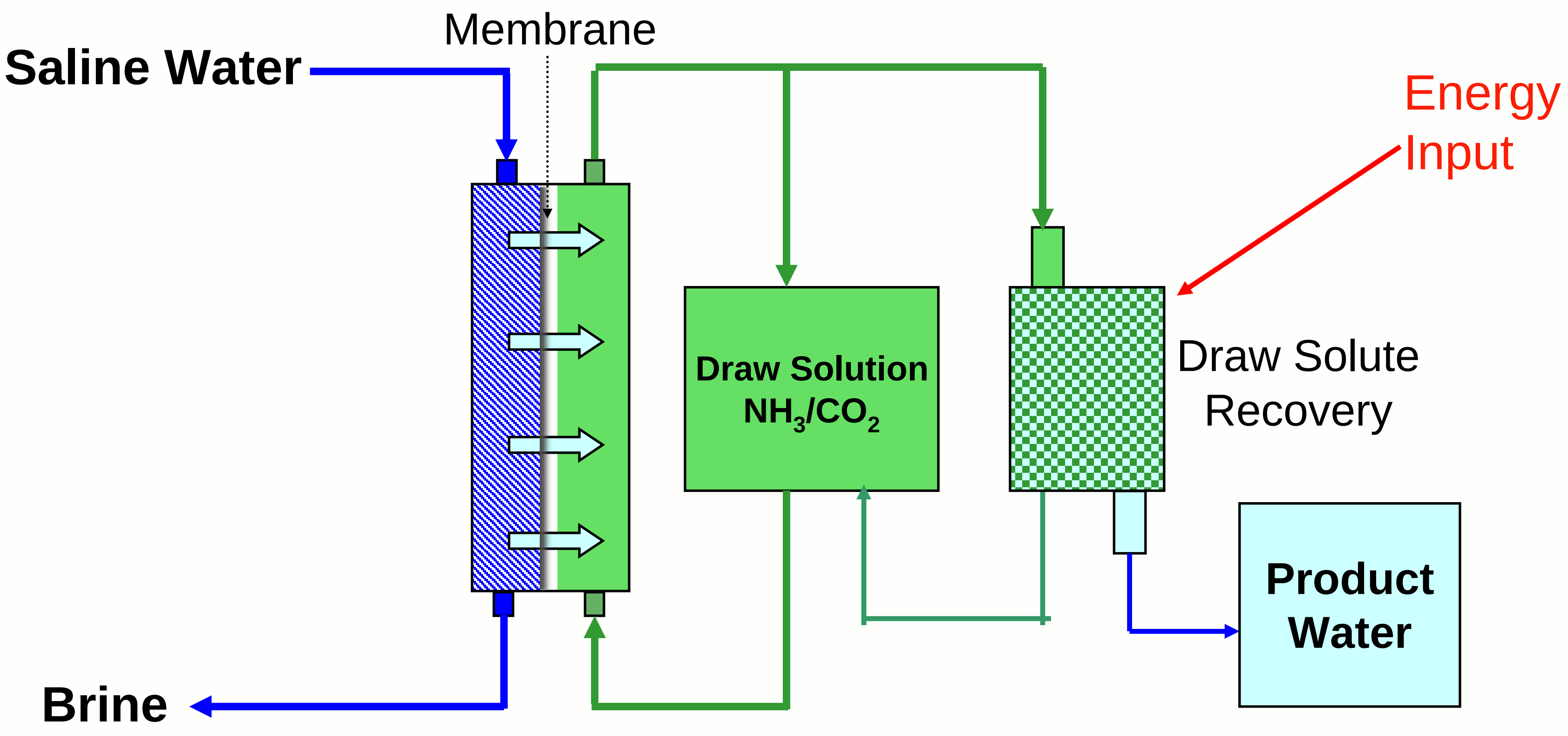
The Ammonia-Carbon Dioxide FO Process

Reverse Osmosis



$$J_w = A\left(\Delta P - \sigma \Delta \pi\right)$$

Forward Osmosis Process



$$J_w = A\left(\sigma\Delta\pi - \Delta P\right)$$

Potential Benefits

- Low Energy Costs
  - Can use low temperature heat
  - Low cost of heat favors low total water costs
- Lower Energy Use than Other Thermal Methods
  - Phase change of solute, not solvent
- High Feedwater Recovery
  - No osmotic pressure limitation to recovery
  - Pretreatment to prevent scaling will be limiting factor
- Reduced Brine Discharge
- May be Effective for Difficult Feedwaters
  - FO uses so far: food concentration, landfill leachate treatment, anaerobic sludge centrate treatment

Solute Removal / Recycle Methods

Seawater Distillation

$$GOR = \frac{Kg_{water}}{Kg_{steam}} \approx 1$$

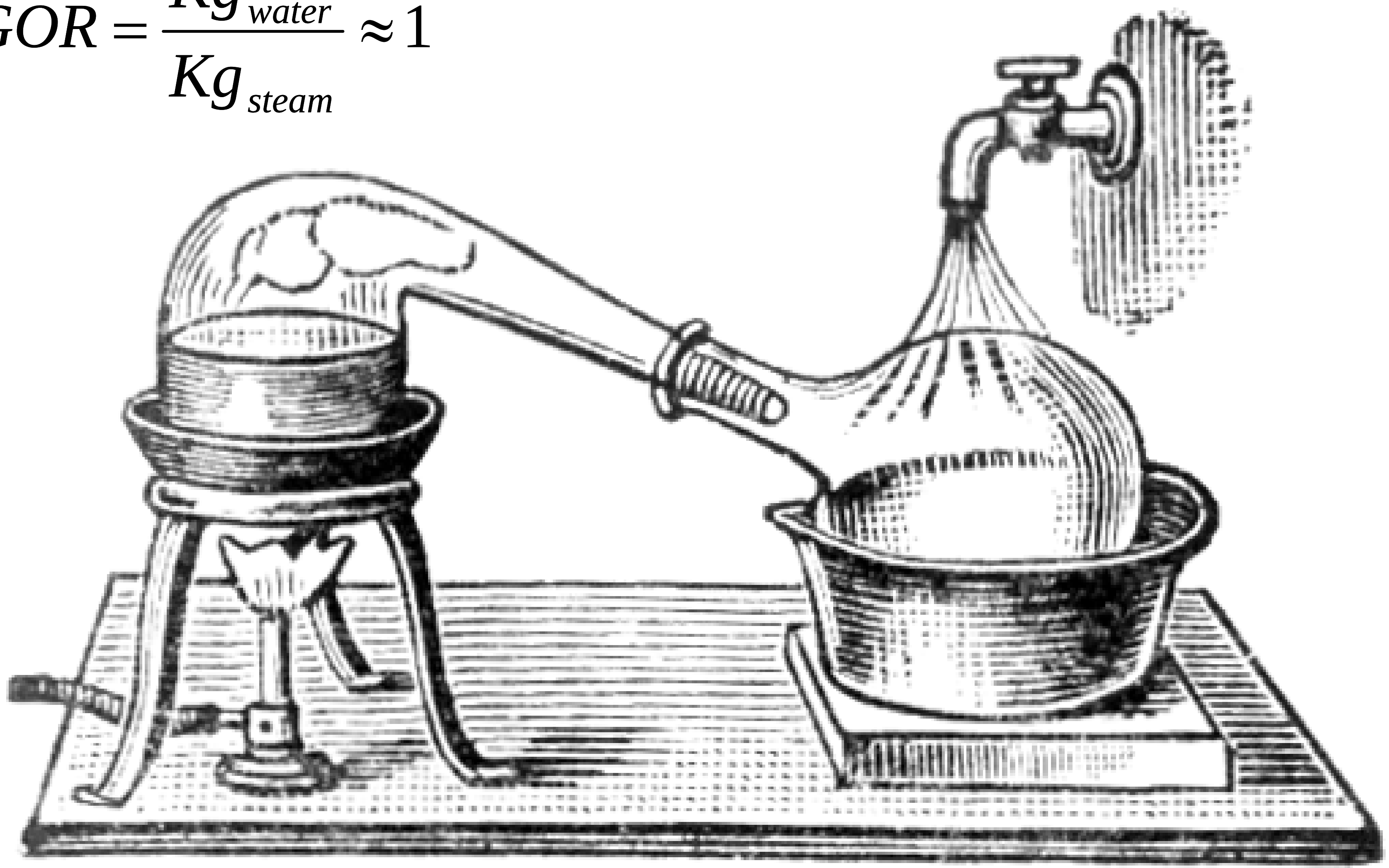
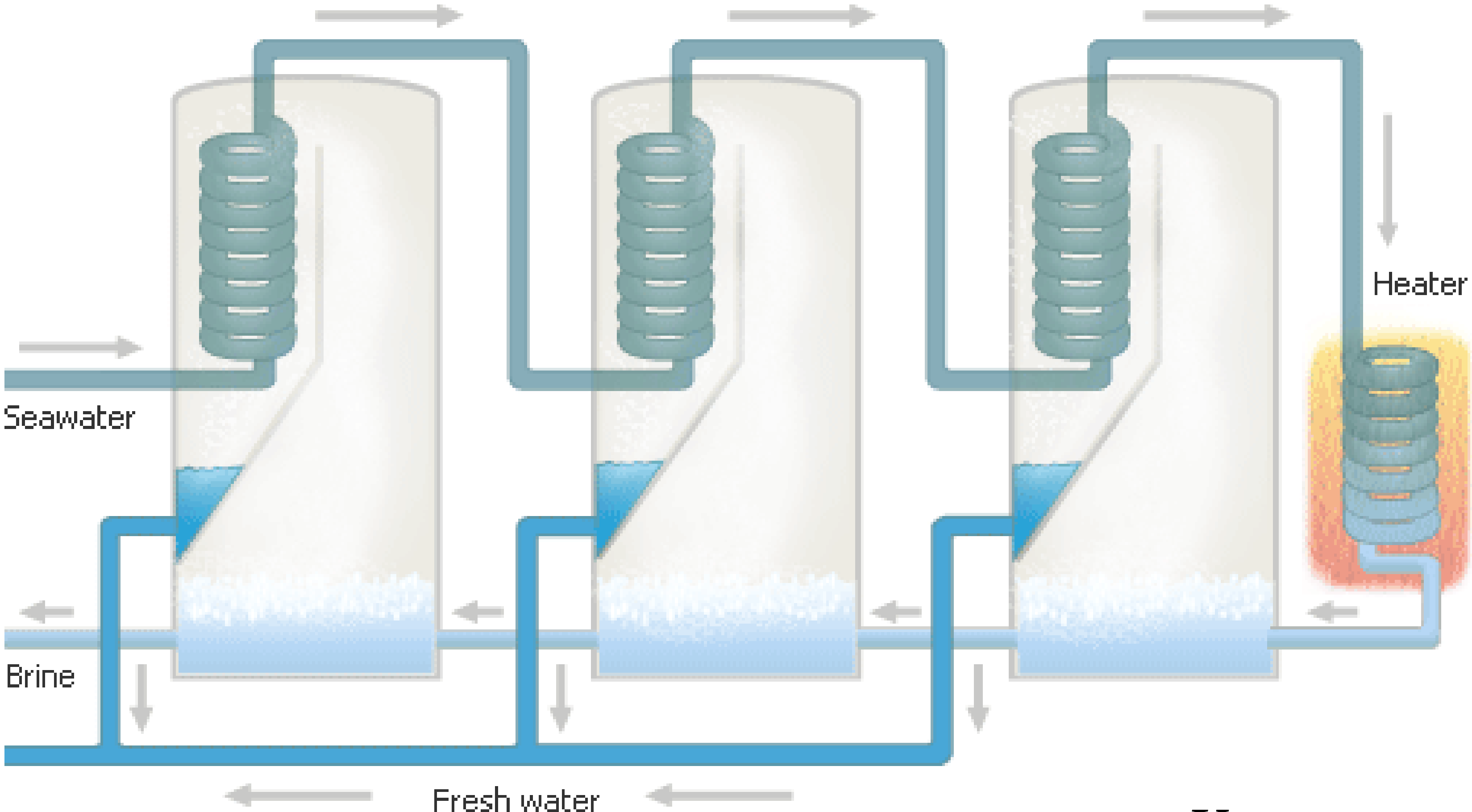


Image from Wikipedia

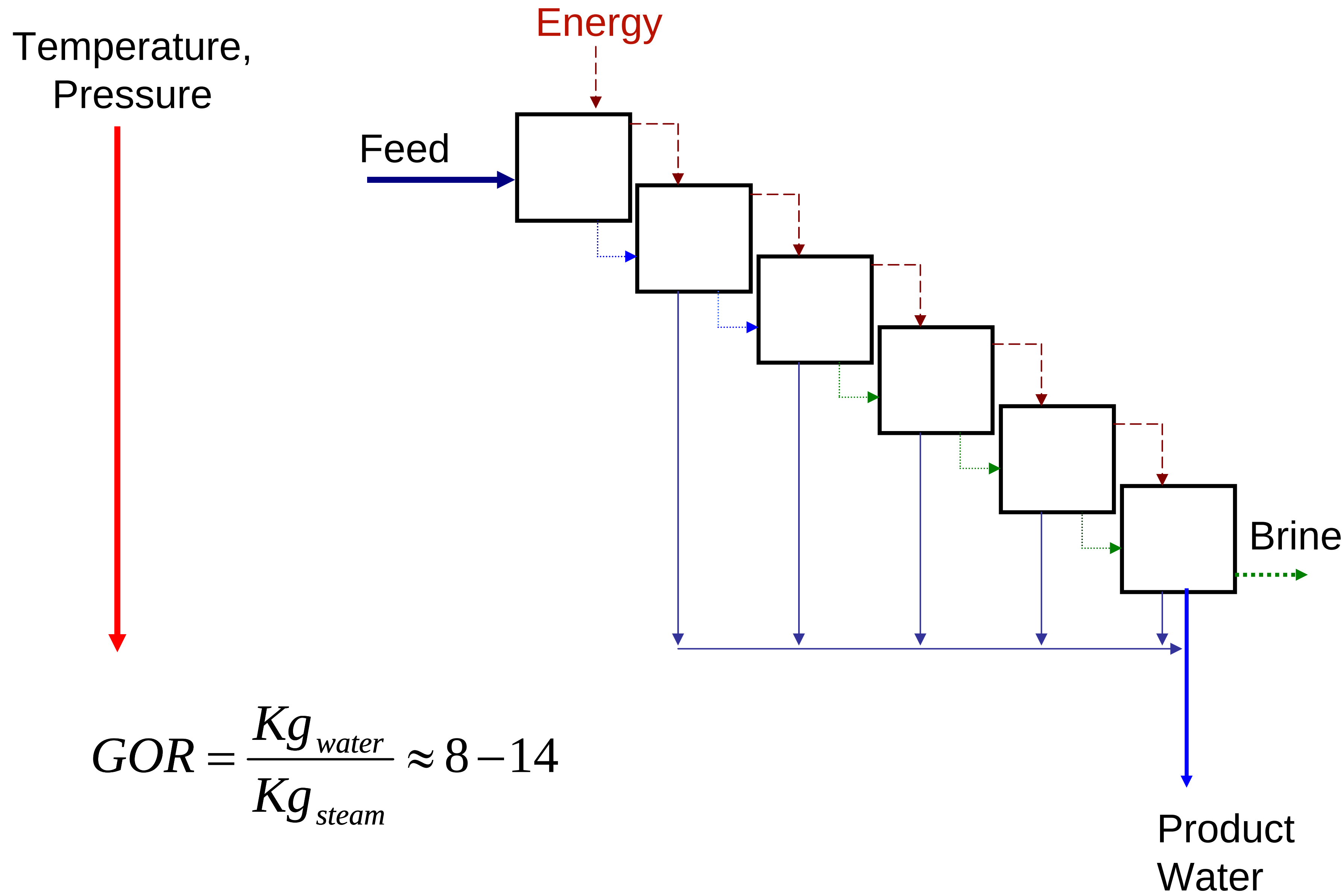
Multi-Stage Distillation



$$GOR = \frac{Kg_{water}}{Kg_{steam}} \approx 8-12$$

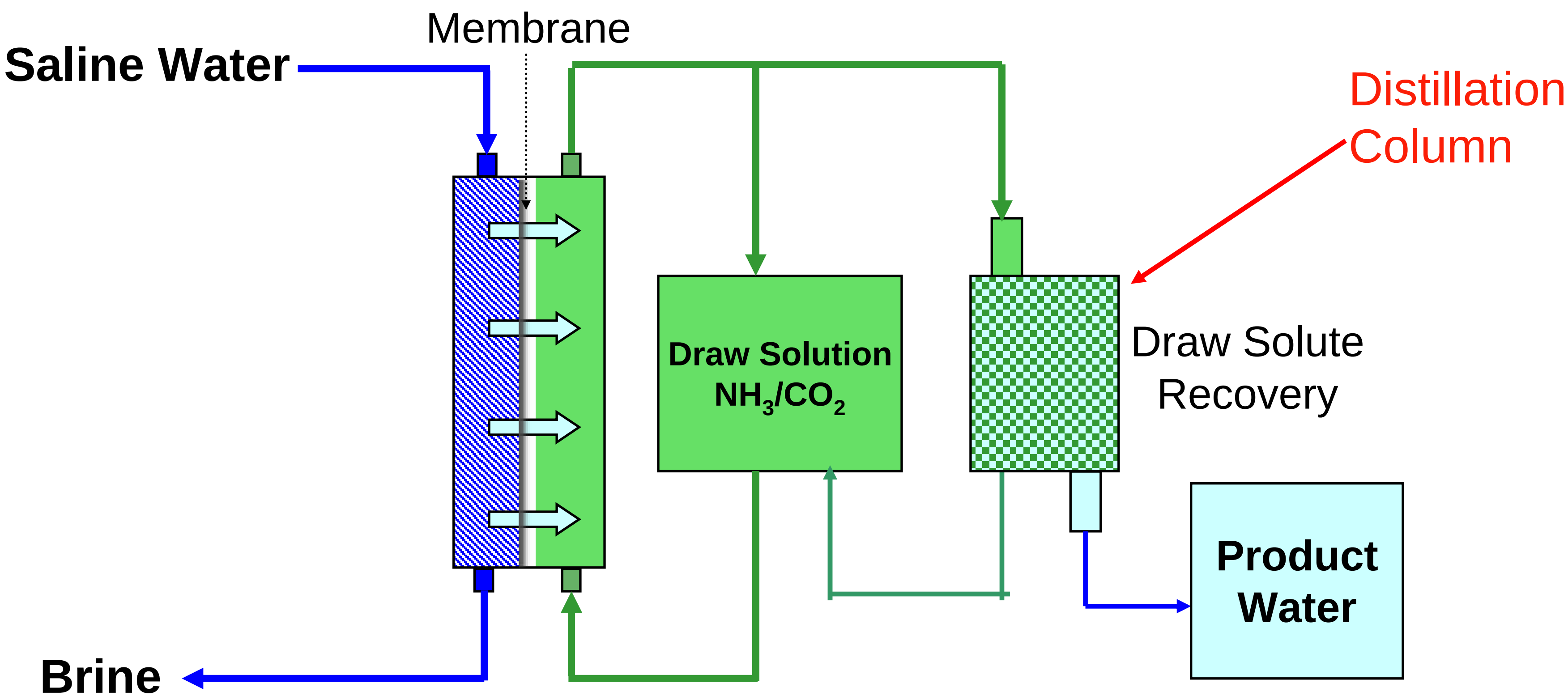
Image from Encarta Encyclopedia Online

MED Desalination

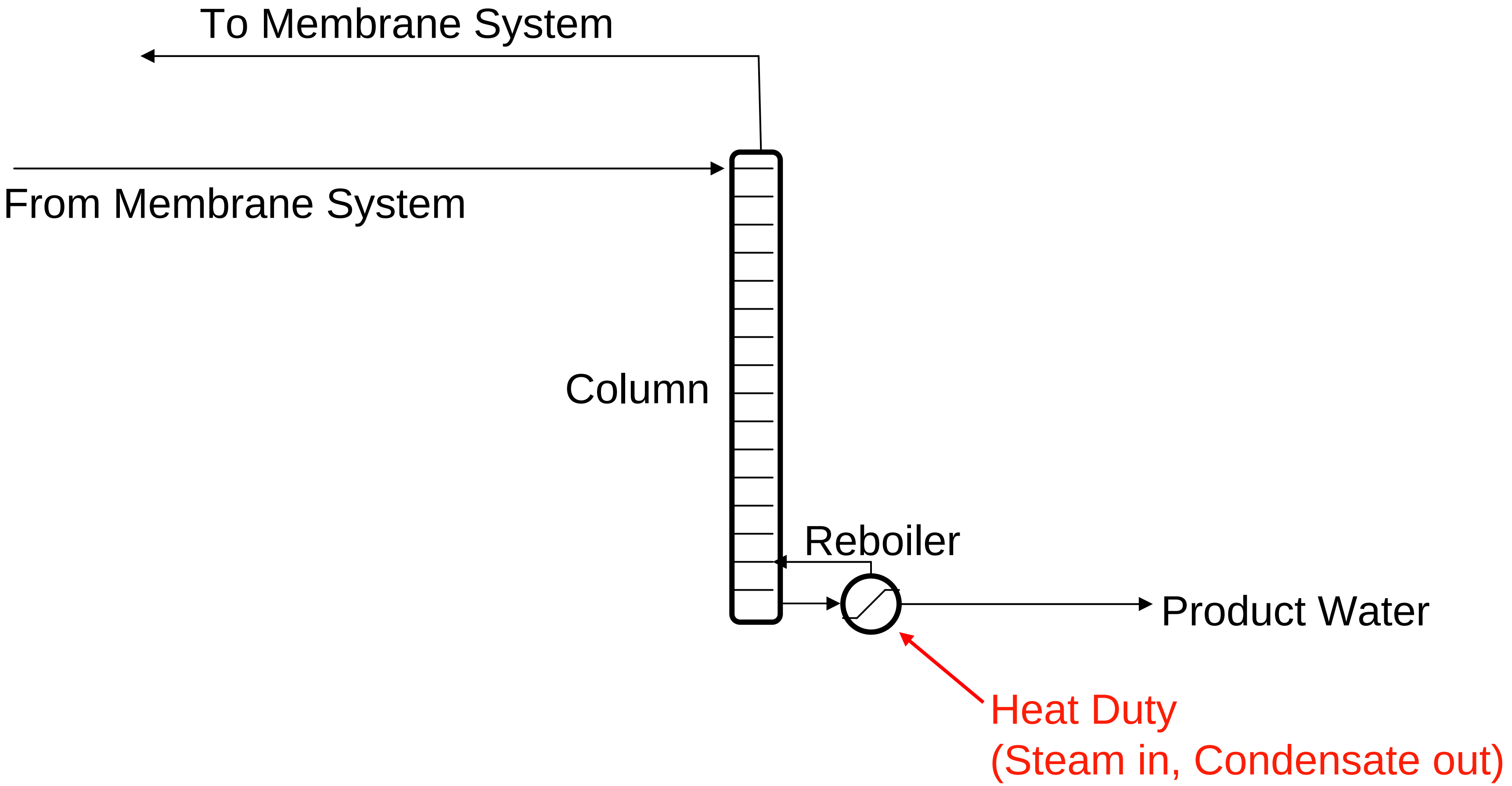


$$GOR = \frac{Kg_{water}}{Kg_{steam}} \approx 8-14$$

Forward Osmosis Process



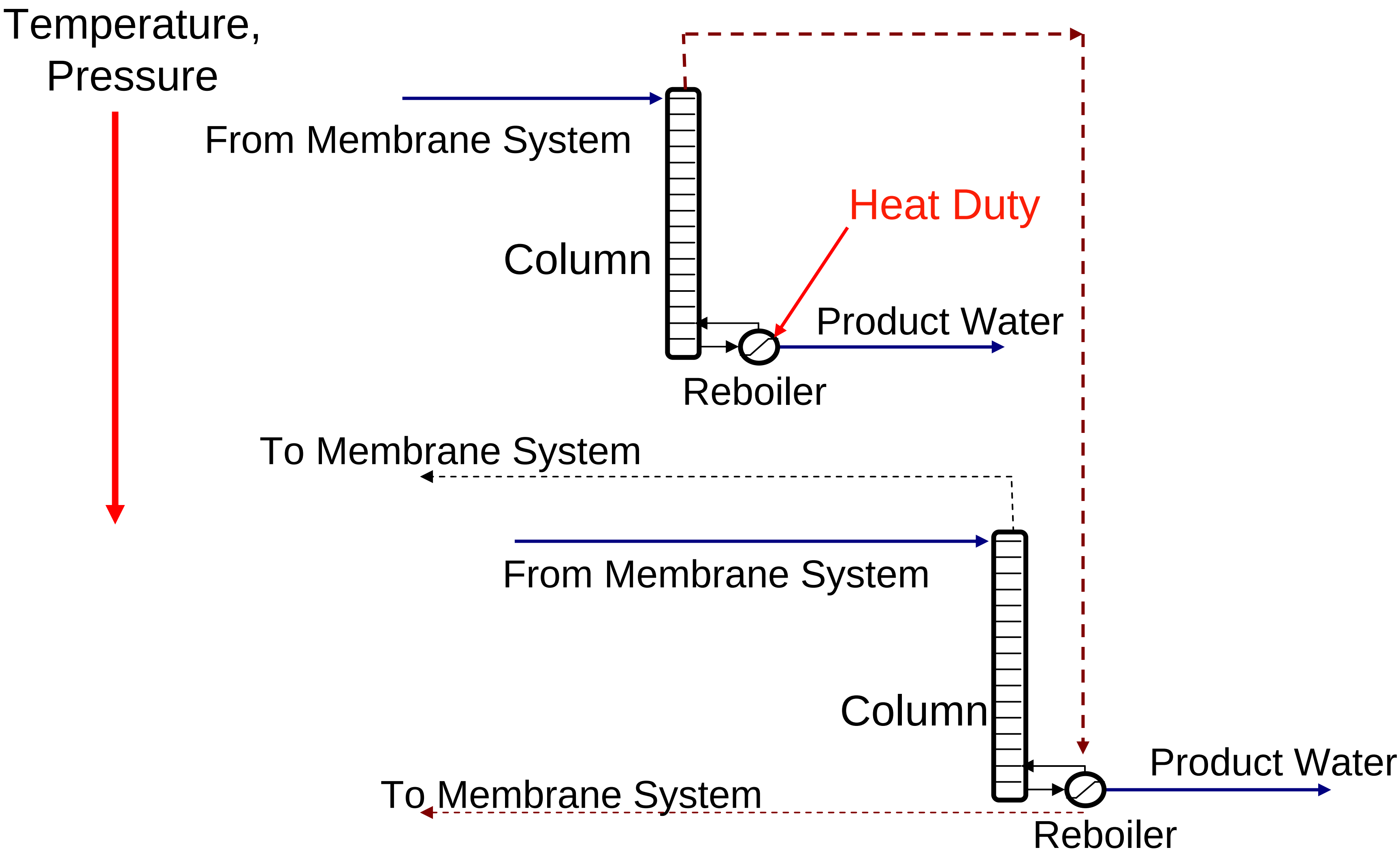
Single Distillation Column



Multi-Stage Column Distillation

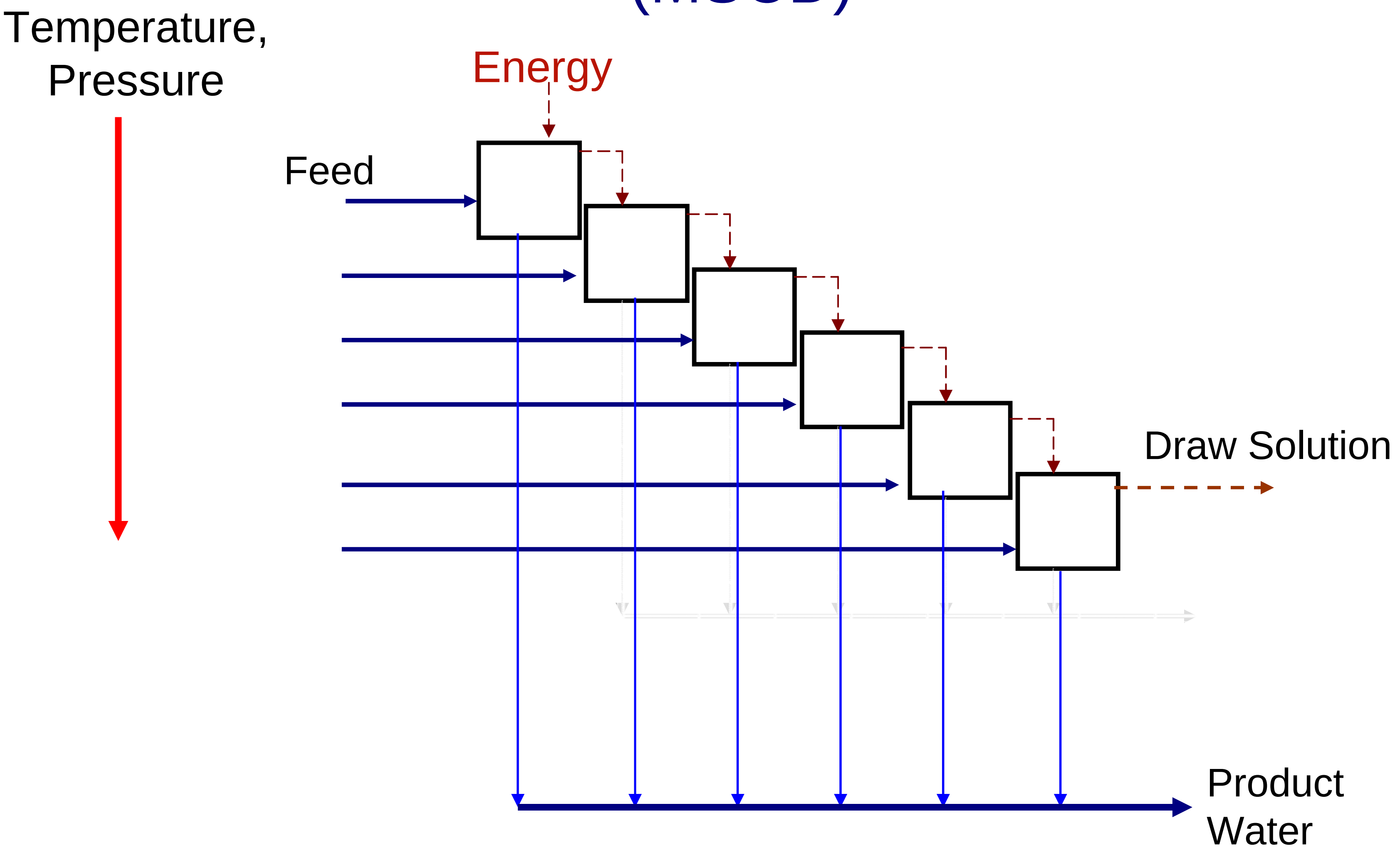
- Benefits from Heat Reuse Efficiencies of MSF / MED
- Reduces Quantity of Energy Required by 60-70%
- May use Higher Temperatures than MSF or MED (to increase range of increased efficiency)

Multiple Column Operation



Multi-Stage Column Distillation

(MSCD)

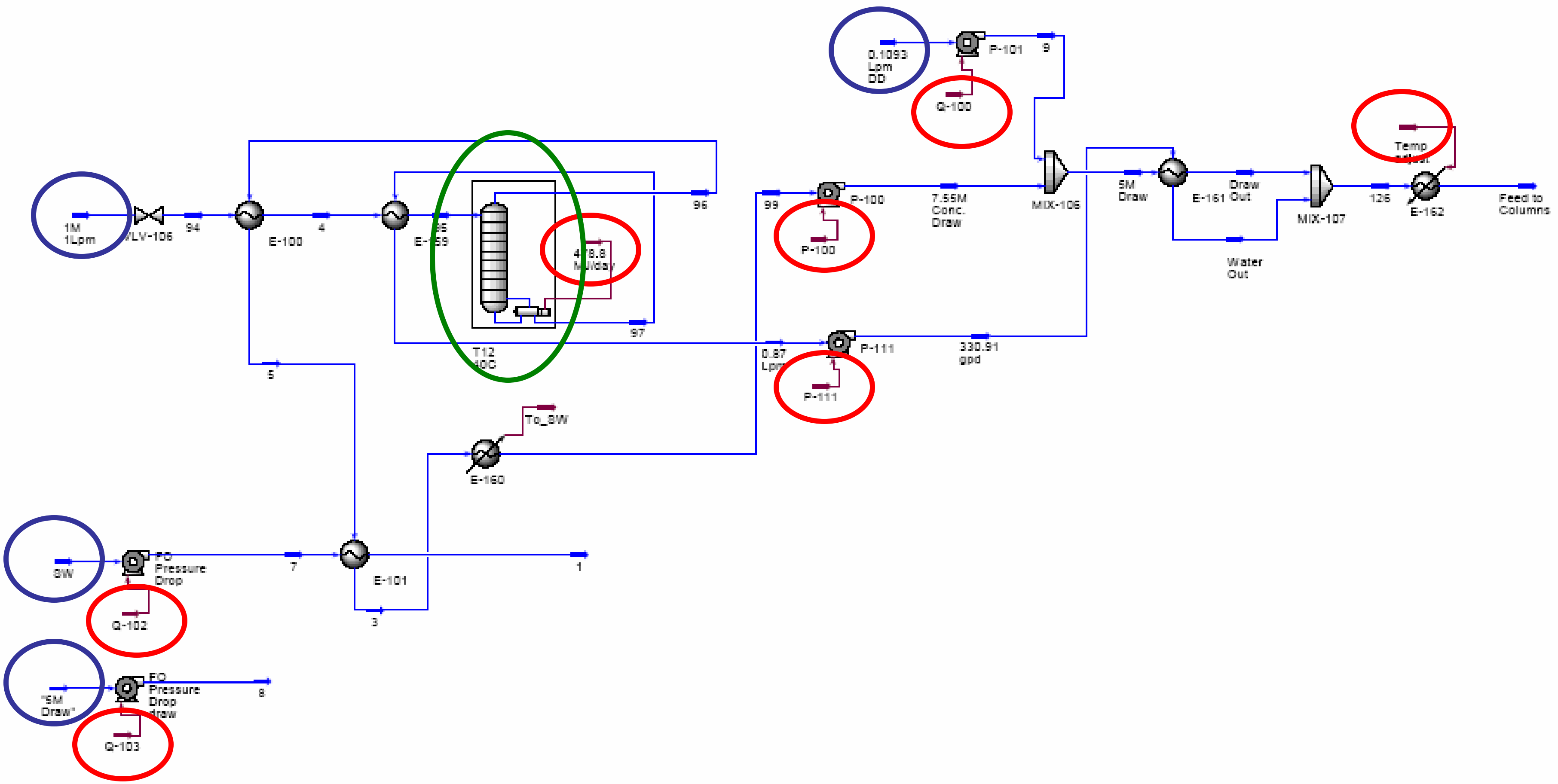


McGinnis, Elimelech, “Energy Requirements of Ammonia–Carbon Dioxide Forward Osmosis Desalination”, *Desalination*, 207 (2007) 370-382.

Modeling Methods

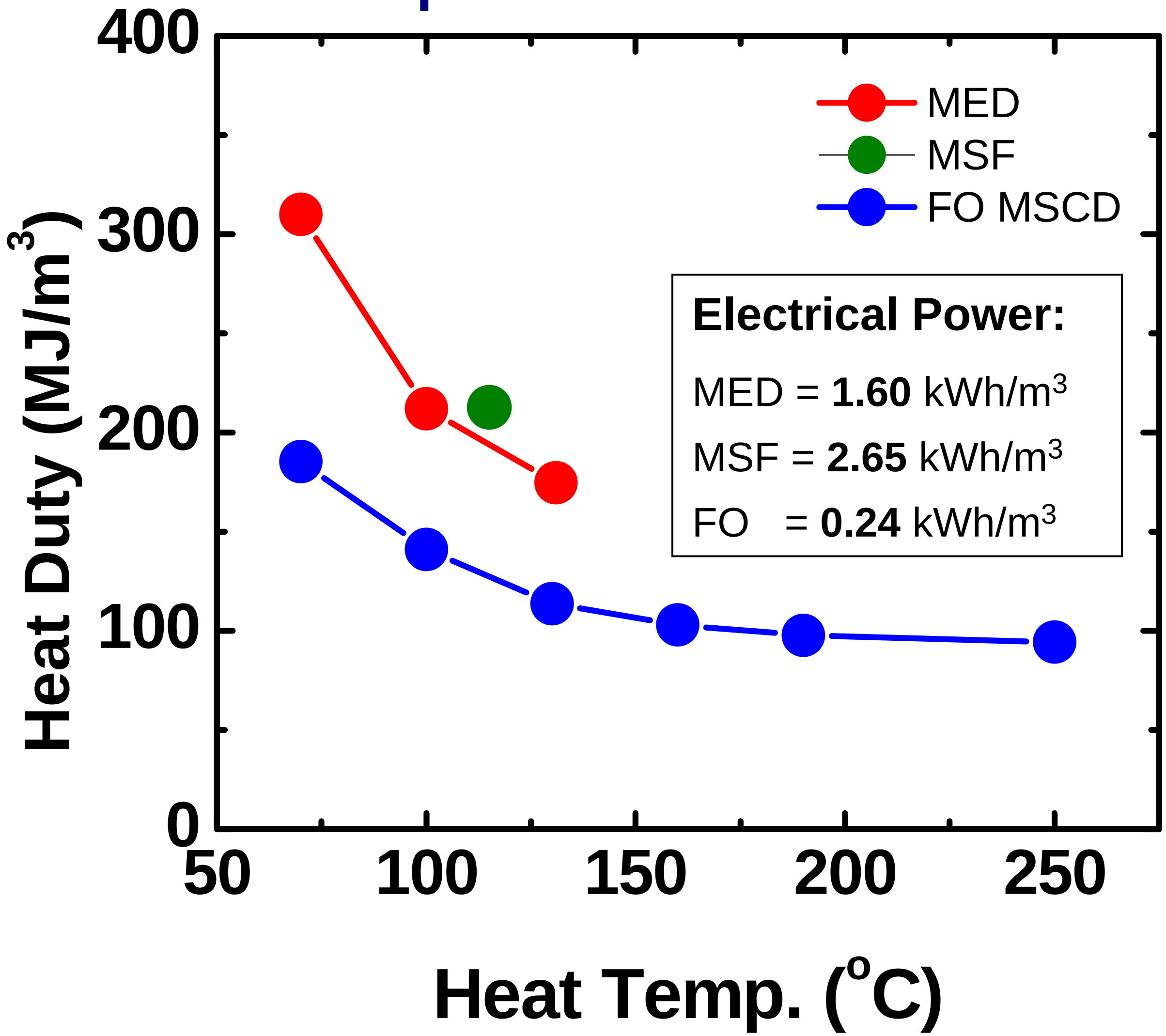
- AspenTech Hysys Chemical Process Modeling Software
- OLI Electrolyte Property Database (high ionic strength)
- Draw Solution Concentrations Based on Experimental Flux Data

Hysys / OLI



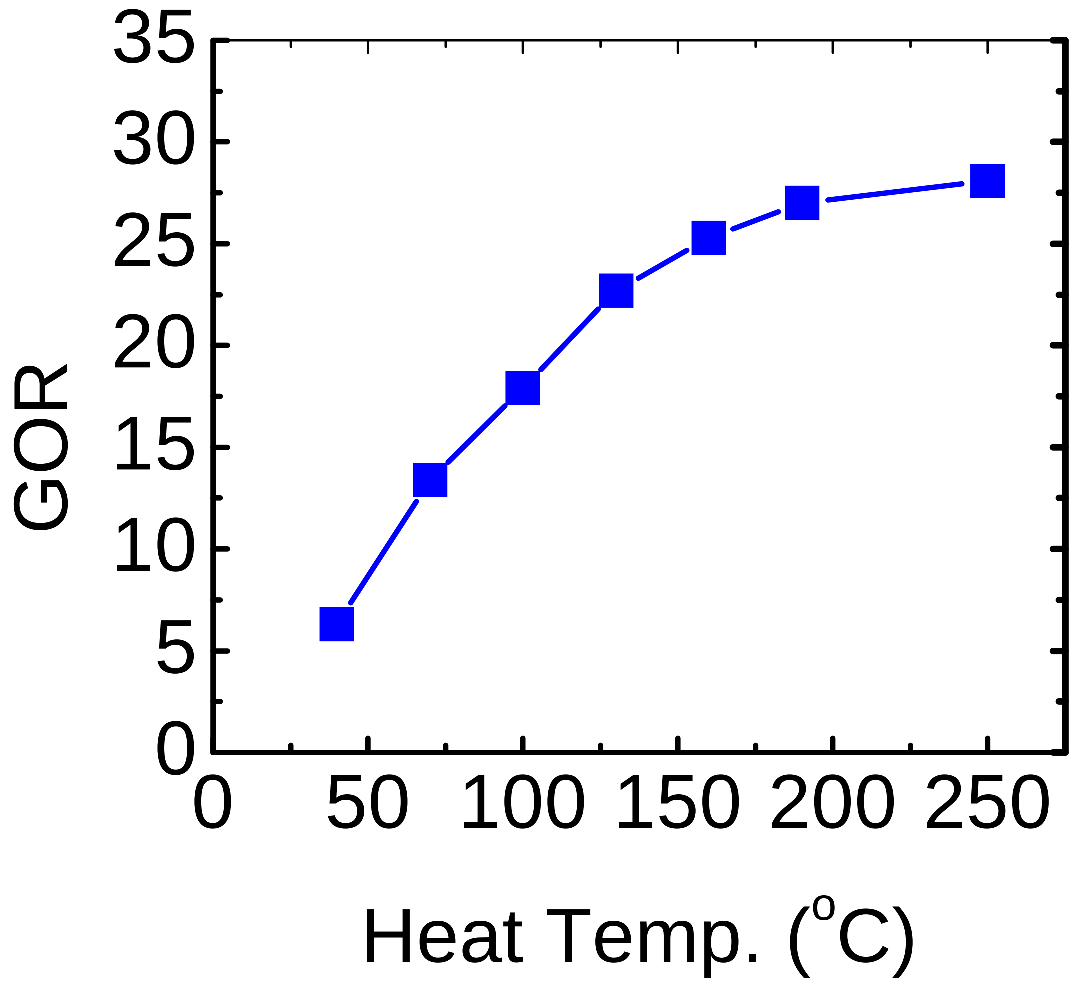
0.1093
Lpm
DD
P-101
9
Q-100
Temp
adjust
1M
1Lpm
VLV-106
94
E-100
4
E-159
95
T12
40C
478.8
MJ/day
96
97
99
P-100
P-100
7.55M
Conc.
Draw
MIX-106
5M
Draw
E-161
Draw
Out
Water
Out
MIX-107
126
E-162
Feed to
Columns
0.87
Lpm
P-111
330.91
gpd
P-111
5
To_SW
E-160
SW
FO
Pressure
Drop
7
E-101
1
Q-102
3
"5M
Draw"
FO
Pressure
Drop
draw
8
Q-103

Heat Duty versus Temperature of Heat



MED plot based on Performance Ratios (lbs water / 1000 BTU) of 8 - 14.73 for heat temperatures of 70-131 °C; MSF for GOR of 12 for 115 °C (from Morin, O.J., *Design and Operating Comparison of MSF and MED Systems.* Desalination,**93**(1-3) (1993) 69-109)

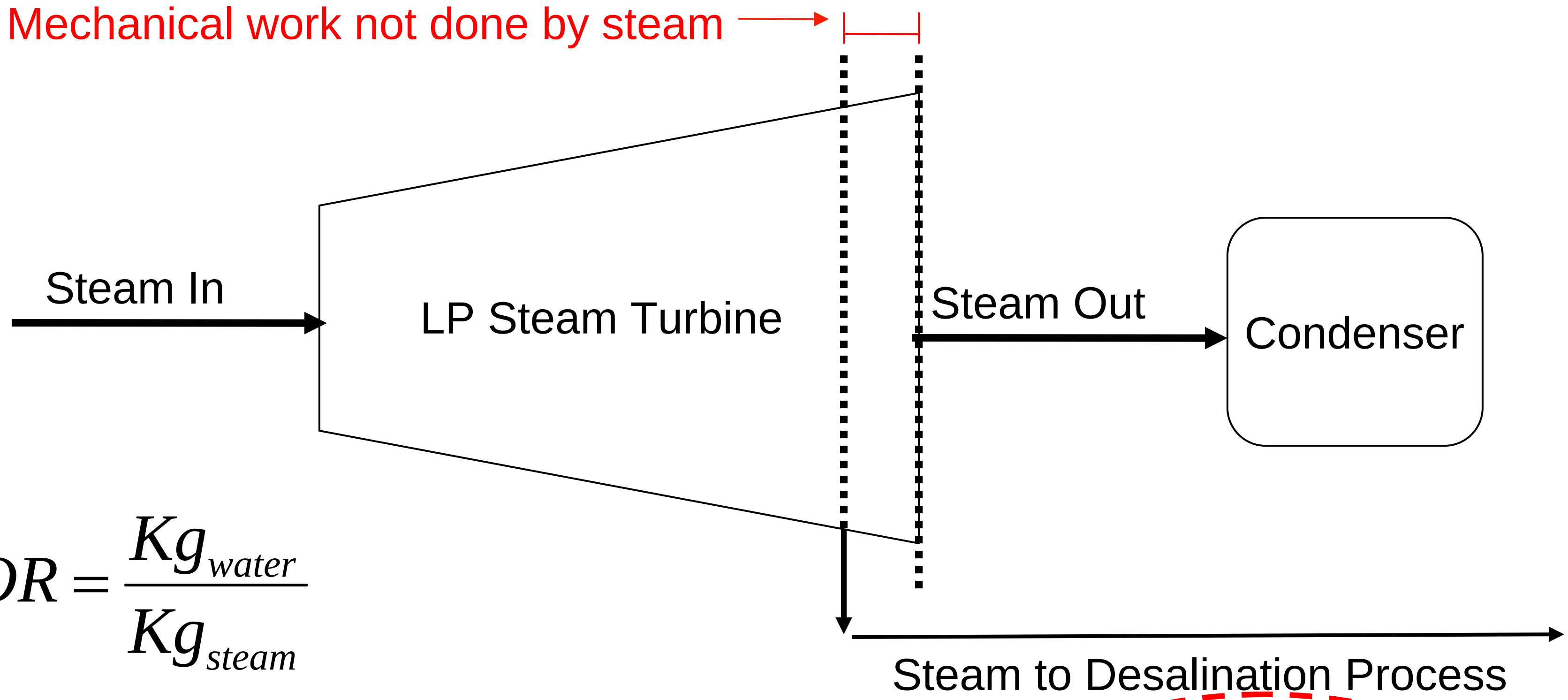
Heat Duty vs. Temp. of Heat



$$GOR = \frac{\left[\left(H\,steam\right) - \left(H\ water\ @\ 35^{0}C\right)\right](kJ/kg)}{Heat\ Duty\ FO\ (kJ/kg)} \longrightarrow GOR = \frac{Kg_{water}}{Kg_{steam}}$$

Equivalent Work

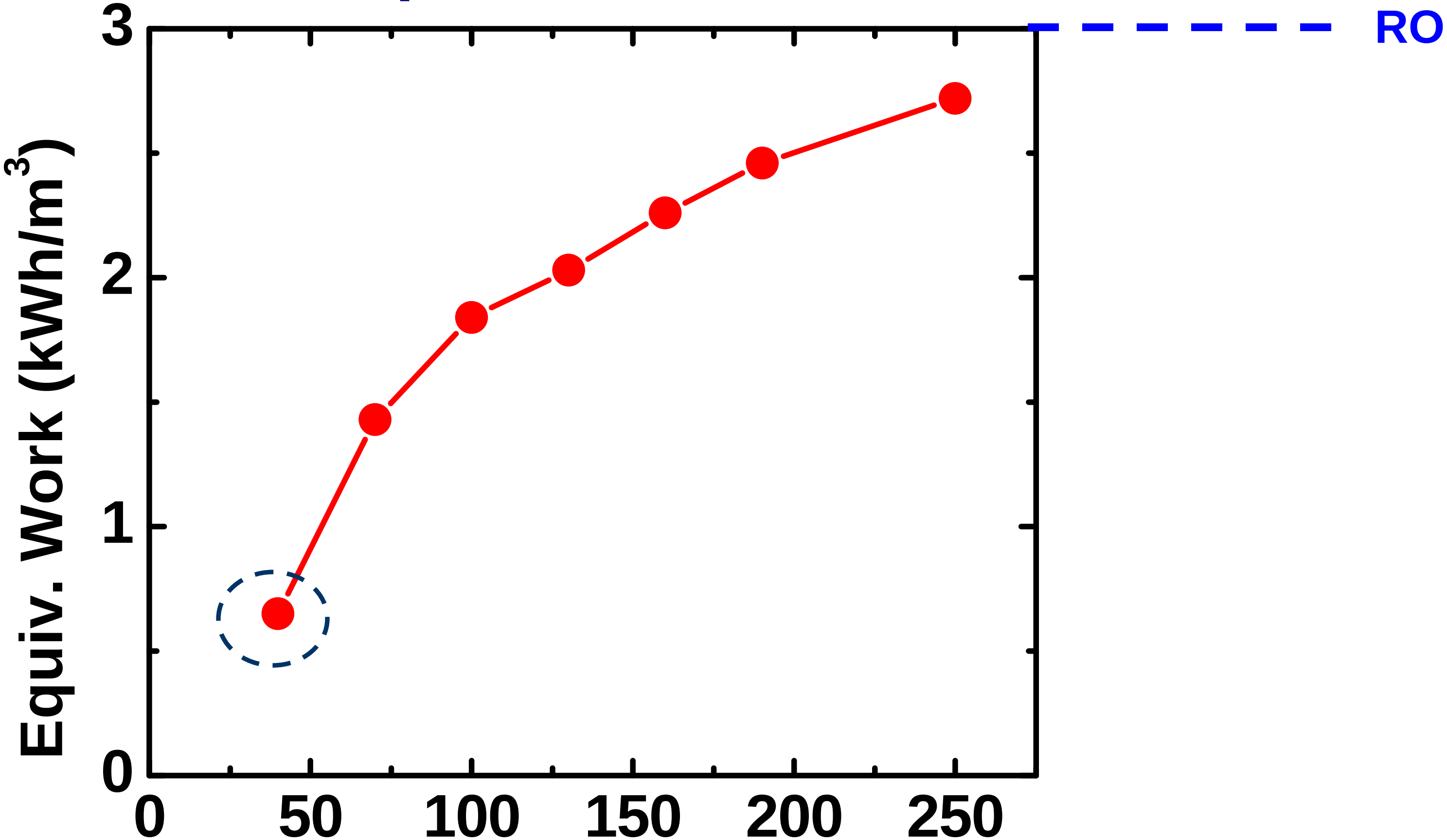
Decreasing Steam Pressure, Decreasing Ability to do Work



$$GOR = \frac{Kg_{water}}{Kg_{steam}}$$

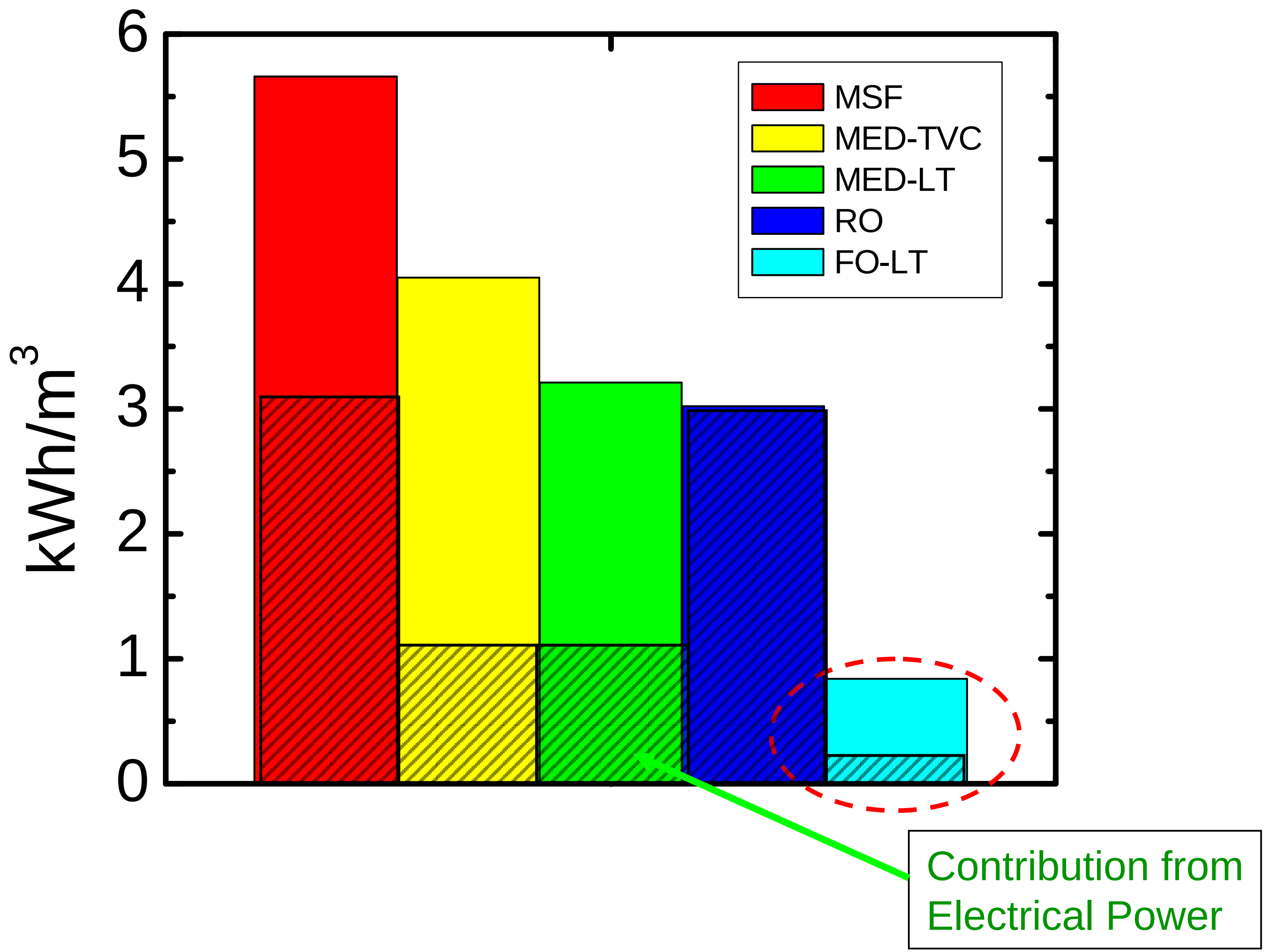
$$W_{equiv} = \left(\frac{m^3{}_{water}}{GOR_{35^0 C}} \right) \left[(H_{in} - H_{out}) \times E_{turbine} \right] \times \left(2.77 \times 10^{-6} \frac{kWh}{MJ} \right) + W_{elec}$$

Equivalent Work vs Heat Temperature (FO MSCD)

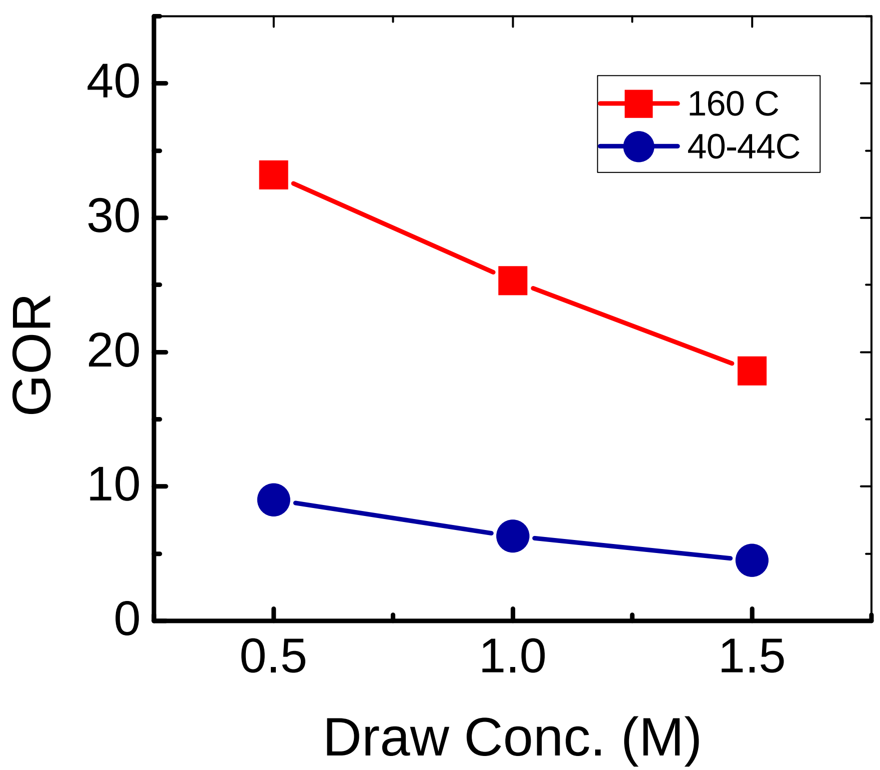


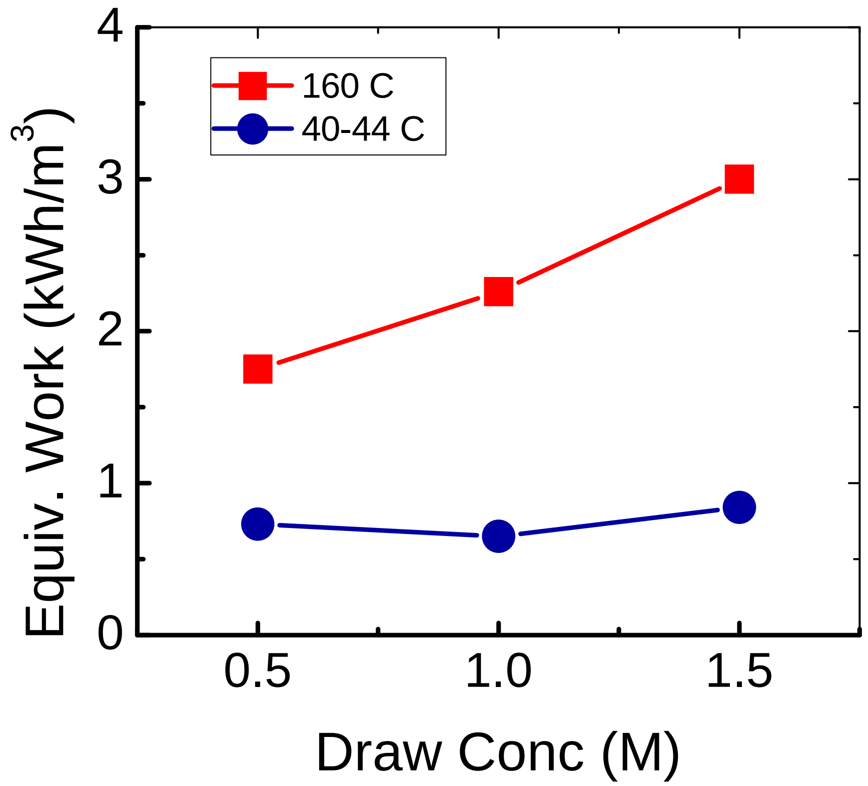
$$W_{equiv} = \left(\frac{m^3{}_{water}}{GOR_{35^0 C}}\right)\left[\left(H_{in} - H_{out}\right)\times E_{turbine}\right]\times\left(2.77\times 10^{-6}\,\frac{kWh}{MJ}\right)+W_{elec}$$

Comparison of Desalination Technologies Based on Equivalent Work



Draw Concentration vs. Energy Use





Adapted from: McGinnis, Elimelech, “Energy Requirements of Ammonia–Carbon Dioxide Forward Osmosis Desalination”, *Desalination*, 207 (2007) 370-382.

Concluding Remarks

- Availability of heat determines best desalination method
  - If heat is available for cogeneration, FO is likely preferable to RO in energy cost
  - If only electricity or fuel is available, RO is best
- Multiple columns useful to produce the most water yield for a given heat source
- FO membrane performance drives energy use of FO

Acknowledgements

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