Micro/Nano-bubble Assisted Direct Spray Method of Low Energy Thermal Seawater Desalination: - An Experimental Study

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Challenges Faced by Conventional Desalination Methods

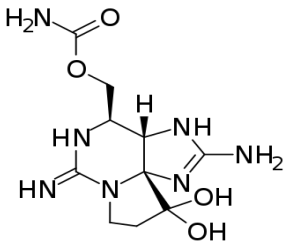
Reverse Osmosis Systems

Thermal Desalination Systems

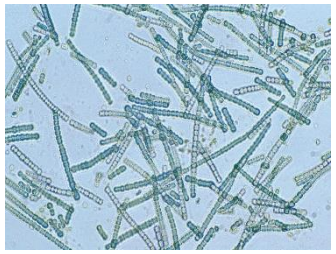
- high capital investment & maintenance costs.
- Susceptible to bio-fouling and scaling,
- High chemical use

GWI 2017	MSF	MED	SWRO	DCSEC
Capital cost	$ 0.42/ m^3	$ 0.35/ m^3	$ 0.29/ m^3	< $ 0.19/ m^3
Operation cost	$ 1.05/ m^3	$ 0.82/ m^3	$ 1.58/ m^3	$ 0.32/ m^3
Total	$ 1.47/ m^3	$ 1.17/ m^3	$ 1.87/ m^3	$ 0.51/ m^3

Some species of Algae, e.g., Saxitoxin is 1000 times more toxic than cyanide and 50 times that of Curare (plant poison), illness such as paralytic shellfish poisoning (PSP), cyanobacteria.



Saxitoxin



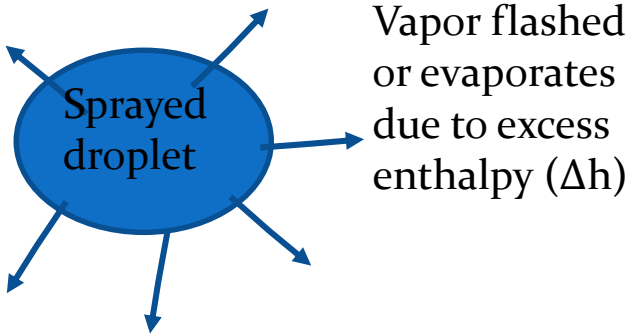
Cyanobacteria

Design Features of DCSEC – emulating evaporation in the Oceans

- Simple hollow chambers, no hard interfaces,
- Spray droplets, micro-bubbles embedded.
- Low CAPEX, OPEX (no chemicals, no fouling or scaling) & low temperature (<70 ºC)
- High salinity operation (> 150,000 ppm)
- Internal heat recovery up to 70% by multi-staging

Hollow chamber (steel or metal-foil lined concrete. For large scale plants)

0.2 to 0.8 mm dia

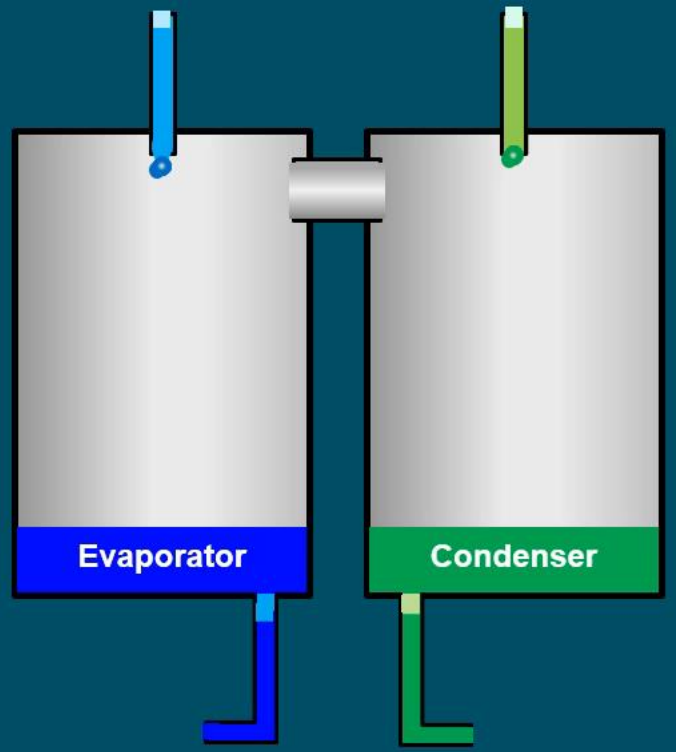


Direct Contact Spray Evaporation and Condensation

(Thermodynamics works at its best)

Externally heated seawater at top-brine stage (> 65°C)

Cooler potable water from stage below, 56-57°C



Rapid evaporation of liquid droplets due to Δh (drop in temperature by 5 to 15K)

Latent heat of condensation (m h_{fg}) from vapor

Seawater to next stage, 60-61° C

Potable water send to the next stage 58-59°C

DCSEC Pilot System with microbubbles (vapor, Tvap< Tliq)

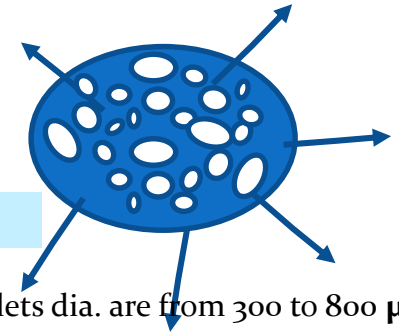
Hollow Chamber Design

Micro Bubble Generator

Droplets at 0.3 to 0.8 mm dia.

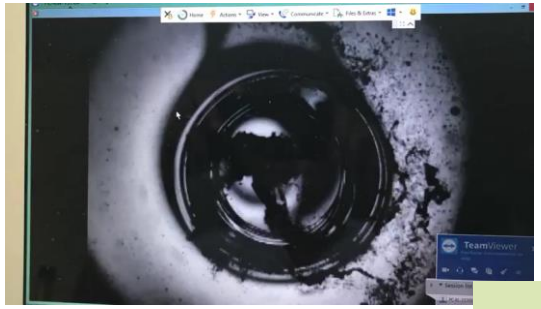
Surface evaporation.

Embedded micro-bubbles (10 to 25µm)



Vapor ($T_{vap} < T_{liq}$)

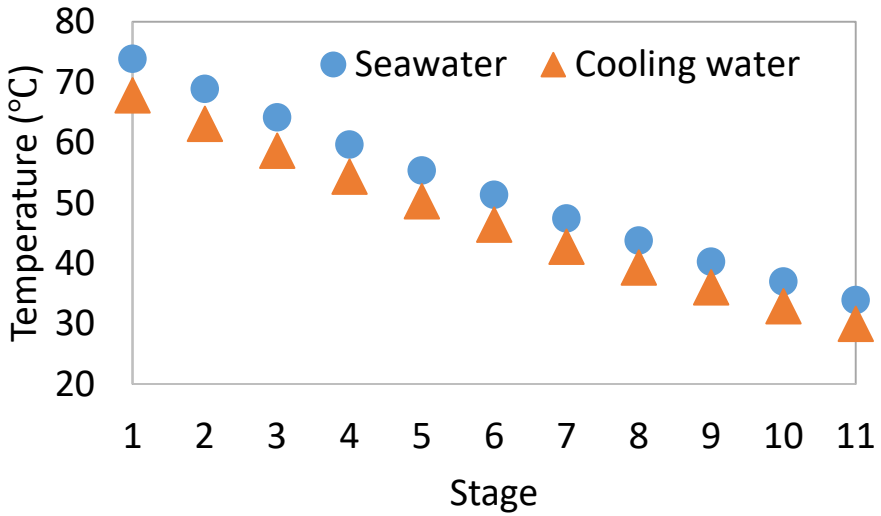
Droplets dia. are from 300 to 800 **µm)**

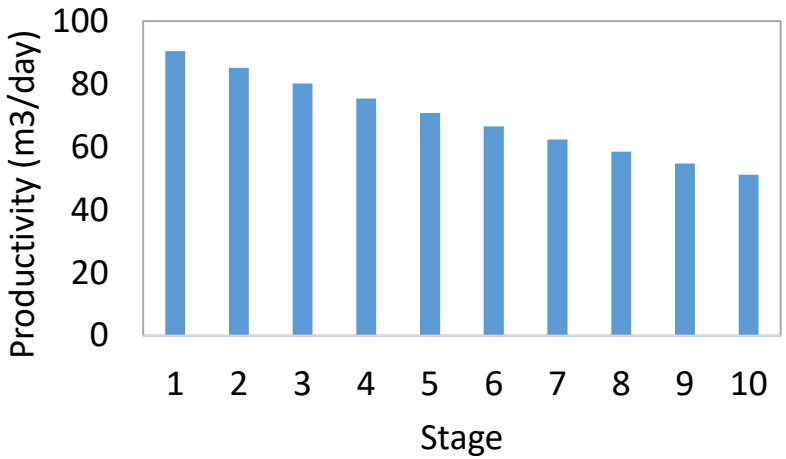


20,000 fps

Results

700 m3/day simulation



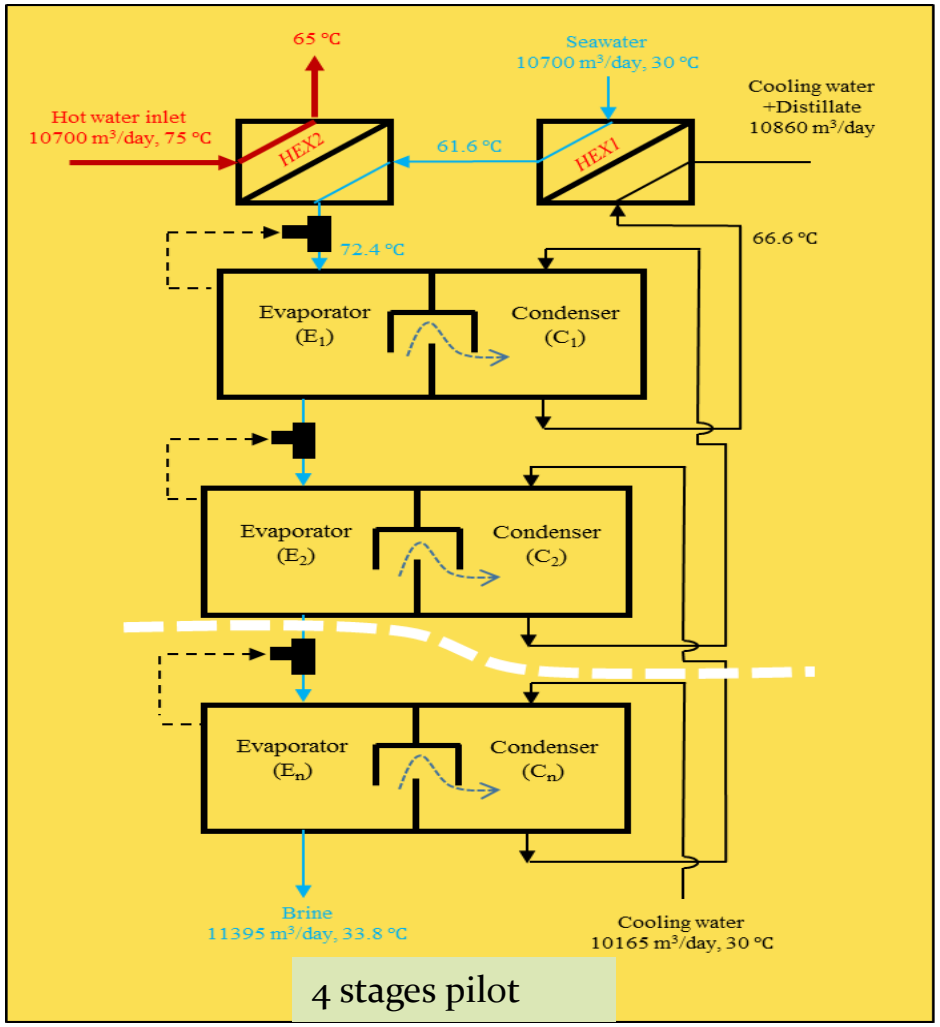


Experimental data

Feed temperature (°C)/ saturation pressure (kPa)	Distillate (l/hr.m³*±0.01) *volume of evaporator	
	DCSEC	DCSEC + MB
38/ 6.62	3.47	4.07
41/ 7.79	7.48	9.09
44 /9.10	10.89	14.6
47/ 10.63	15.31	20.88
50/ 12.33	20.74	28.34
53/ 14.38	25.69	35.15
56/ 16.58	30.01	41.08
60/ 19.92	33.44	45.77

34% improvement

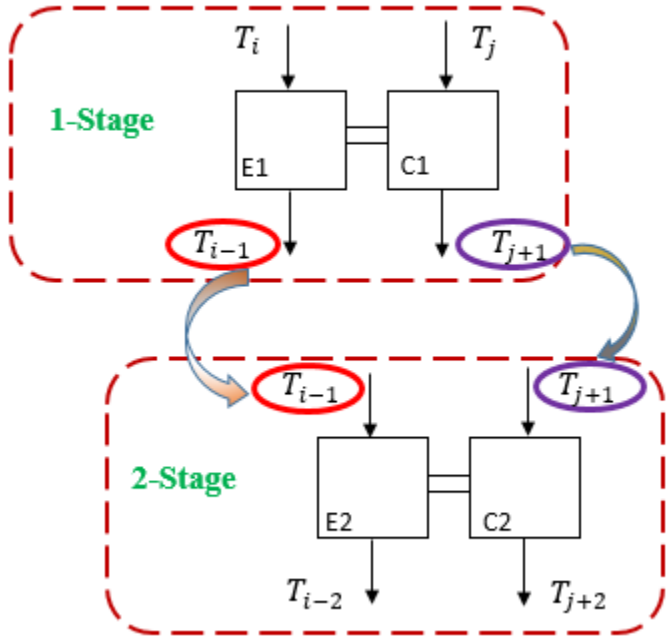
Value Proposition: Energy efficient Multi Stage Design



4 stages pilot

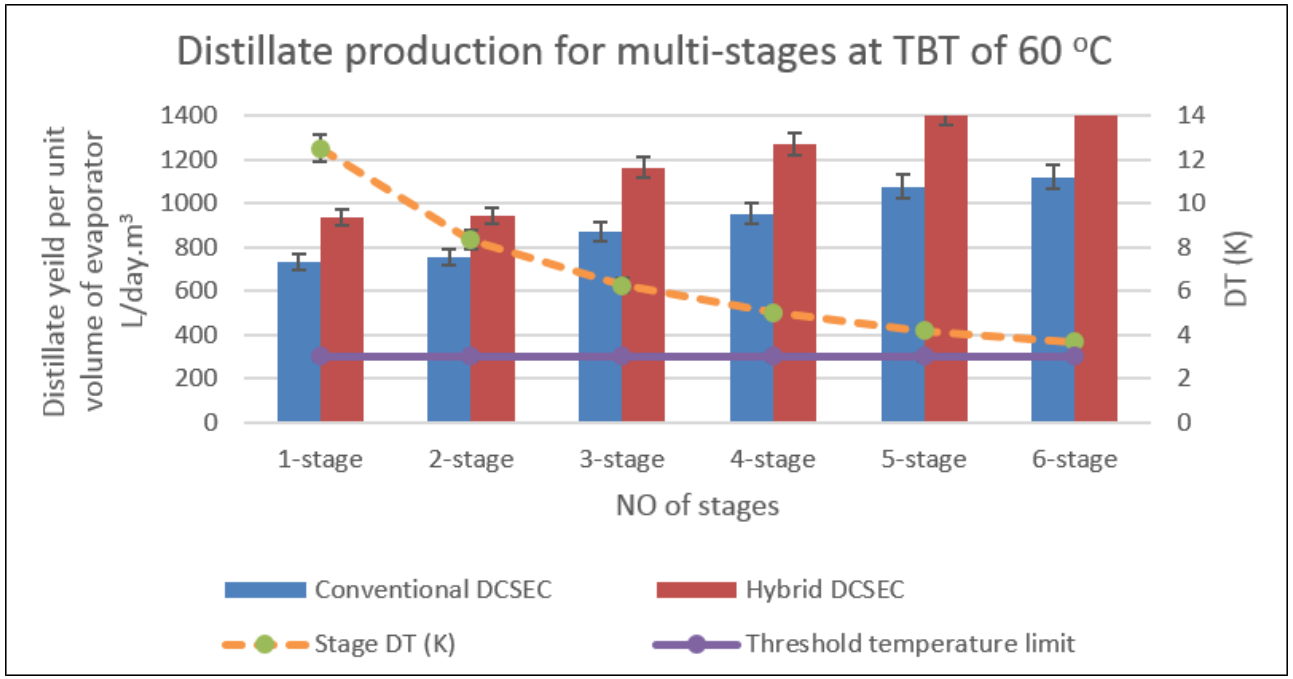
Single-stage

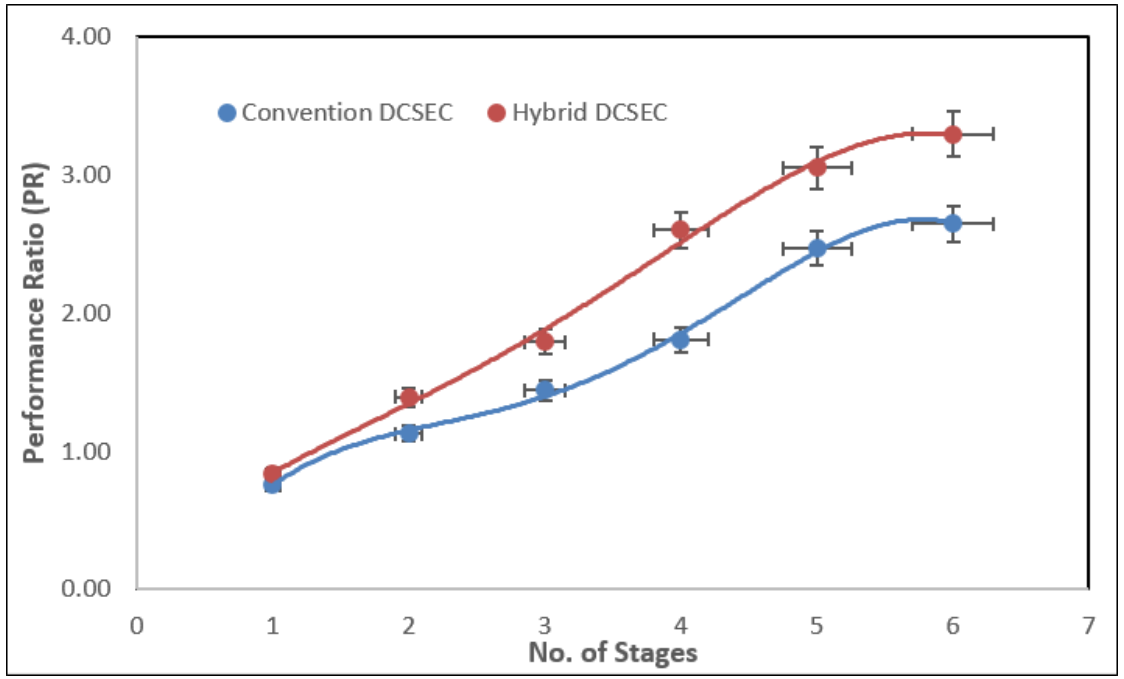
Piece-wise technique



- **Internal heat recovery gives 70% of total heat input at evaporators.**
- **The external heat input to evaporators of DCSEC amounts to 30%.**

Experiments Results (Multi-stage)





- **The distillate production is increasing asymptotically with the number of stages, but the corresponding temperature difference per stage is decreasing.**
- **The flashing phenomena between liquid droplets and vapor chamber can only occur with DT > 3 K;**
  - **The minimum threshold for flashing between liquid and vapor phase is about 1.5 to 2 K.**
  - **The boiling point evaluation effect is about 1 K from salinity of seawater.**

• The performance ratio (PR) shows a maxima at six-stage arrangement for conventional and hybrid cases.
•As compared with MSF or MED of similar six-stages, the PR of DCSEC is comparable to each other at around 3.3.

Conclusions

- **The DCSEC design addresses both challenges of high CAPEX (< 50% of SWRO) and high OPEX (< 60% of MED) of existing desalination methods,**
- **It is simple, robust to high salinity, not susceptible to algae blooms, no fouling nor scalling as there are no internal membranes or tubing. Systems have a multi-stage design (heat recovery up to 75%) to reduce external heat input (8 stages gives a PR > 4.5 to 5),**
- **Suitable for solar thermal and PV_{-elec} driven with almost no chemical use – a totally green seawater desalination for the sustainable future,**

Thank you